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Challenges in Electrical Vehical Adaptation

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Abstract:

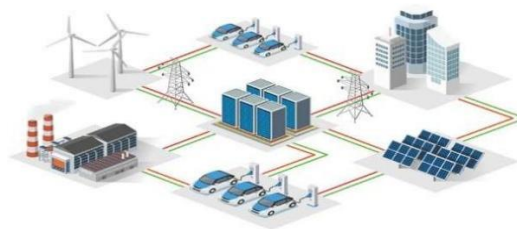
The Charging Challenge Infrastructure Deficit:

One of the most significant obstacles to EV adoption in India is the limited availability of public charging infrastructure. Both urban and rural areas lack sufficient charging stations, creating inconvenience for EV users. The state-wise distribution of charging stations is uneven, with some regions being significantly underserved. For example, metropolitan areas may have more charging stations than rural areas, but the ratio of EVs per charging point is still high compared to global benchmarks like China, where charging infrastructure is more developed. This disparity discourages potential EV buyers who fear being stranded without charging options.



Caption: "Electrifying transportation, overcoming obstacles. Challenges abound, but progress prevails." Accelerating EV adoption, despite the hurdles. Innovation meets perseverance on the road to sustainability."

3. "Charging forward, through trials and tribulations. EV adoption faces challenges, but the future is bright."



High upfronts costs and financing options

Higher Upfront Cost



Installing charging stations faces multiple challenges. Land availability, especially in

densely populated cities, is a major concern. Securing necessary regulatory approvals and

ensuring adequate grid capacity to handle the increased electricity demand are also complex processes. Comparing charging infrastructure in cities like Delhi and Bangalore reveals significant differences, highlighting the need for tailored approaches based on local conditions and demand.

Causes of Range Anxiety Limited Charging Infrastructure: Sparse or unreliable public charging networks can make long trips stressful.

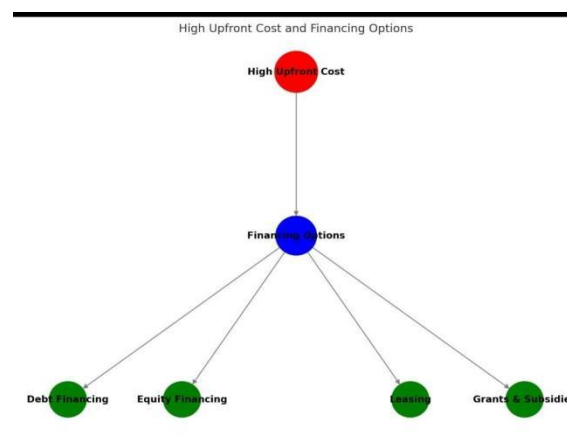
Battery Degradation: Over time, EV batteries lose some capacity, reducing range.

Weather Conditions: Extreme cold or heat affects battery efficiency and range.

Driving Habits: High speeds, heavy loads, and aggressive acceleration drain the battery faster.

Charging Time: Even with fast chargers, recharging takes longer than refueling a gas car.

Improving Battery Performance to Reduce Range



The high purchase price of EVs compared to traditional vehicles is a major barrier to affordability. While EVs promise lower running costs, the initial investment can be prohibitive for many Indian consumers.

Analysing the total cost of ownership (TCO) over the vehicle's lifespan, including electricity, maintenance, and potential battery replacement, is crucial to demonstrate the long-term economic benefits of EVs. However, many consumers are primarily focused on the upfront cost.

The availability and awareness of financing options, such as loans and subsidies, play a critical role in making EVs more accessible. While central and state government policies offer subsidy benefits, many potential EV buyers are unaware of these incentives or find the application process cumbersome. Comparing EV prices across different segments, such as two-wheelers, three-wheelers, cars, and buses, and highlighting the specific subsidy benefits available under various policies can help bridge the affordability gap and encourage EV adoption.

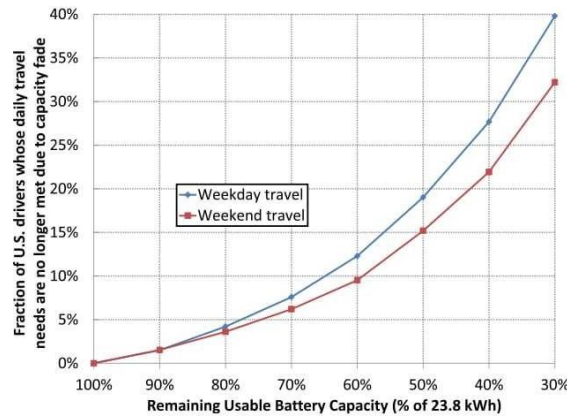
Anxiety

- Advances in Battery Technology Higher Energy Density: Newer lithium-ion and solid-state batteries can store more energy, increasing range. Faster charging Speeds: Ultra-fast chargers (350 kW+) can charge EVs to 80% in 15-20 minutes. Longer Battery Lifespan: Improved chemistry and thermal management reduce degradation.
- Regenerative Braking Converts kinetic energy into battery power, extending driving range.
- AI & Smart Energy Management To help you with high upfront costs and financing options, you can use online calculators to determine down payments, calculate loan EMIs, and explore different financing scenarios.

Range Anxiety and Battery Performance

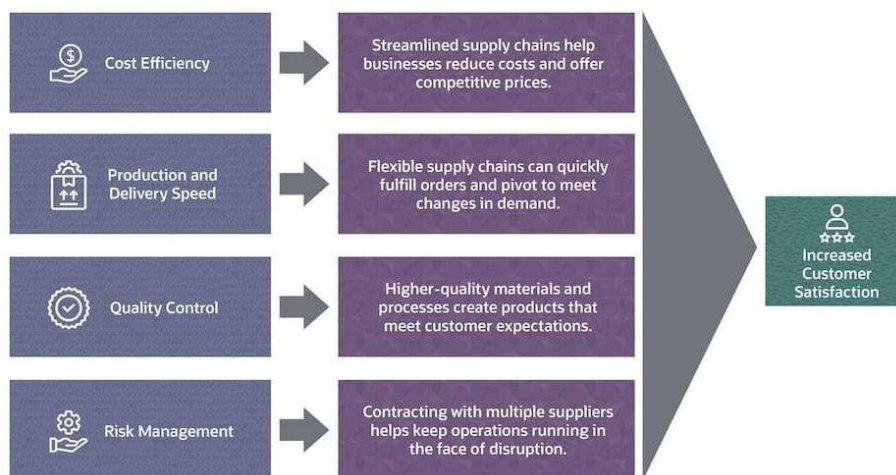
Range anxiety, the fear of running out of battery charge before reaching a charging point, is a significant concern for potential EV buyers in India. Consumers worry about the limited range of EVs and the availability of charging options, especially on long journeys. The real-world range of EVs often differs from the claimed range due to factors such as driving conditions, traffic, and weather. This discrepancy can further exacerbate range anxiety and discourage EV adoption.

Battery performance is another critical factor influencing consumer perceptions of EVs. Battery degradation over time, the impact of temperature on battery performance, and the lifespan of EV batteries are all important considerations. The availability of fast charging technologies and their potential impact on battery life also need to be carefully evaluated. Survey data on consumer perceptions of range anxiety and its influence on purchase decisions can provide valuable insights for addressing these concerns and promoting EV adoption.



Caption: "Powering peace of mind: Advanced battery tech tackles range anxiety. Electrifying the driving experience
 ""Electrifying the journey: Range anxiety meets its match in improved battery performance. Sustainable transportation, redefined."

The Impact of Manufacturing Supply Chains on Businesses



Caption; "Local manufacturing hurdles slow EV adoption. Supply chain constraints hinder progress."
 "Electrifying transportation faces local manufacturing challenges. Supply chain bottlenecks impede growth."

Local Manufacturing and Supply Chain Constraints

Power Grid Stability and Electricity Supply

Increased EV adoption will inevitably impact the existing power grid infrastructure and electricity demand in India. It is crucial to assess India's electricity generation capacity and its ability to support a large-scale EV fleet without compromising grid stability.

Challenges related to peak load management, the need for grid modernization, and the integration of renewable energy sources into the EV charging infrastructure must be addressed proactively.

Opportunities for integrating renewable energy sources, such as solar and wind power, into the EV charging infrastructure can help reduce the

environmental impact of EVs and promote sustainable transportation.

Implementing time-of-day electricity tariffs can also encourage off-peak charging, helping to balance the load on the power grid and reduce the strain on electricity supply during peak hours. These measures can ensure a reliable and sustainable electricity supply for India's dependence on imports for key EV components, such as batteries, motors, and controllers, poses a significant challenge to the long-term sustainability of the EV sector.

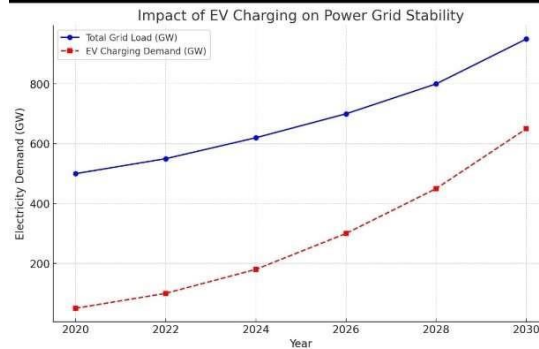
Developing a robust domestic manufacturing ecosystem for EVs and their components is essential to reduce import dependence, create jobs, and enhance the competitiveness of Indian EV manufacturers. Addressing challenges related to the availability of raw materials, such as lithium, cobalt, and nickel, and establishing battery recycling infrastructure are also crucial for creating a circular economy for EV batteries.

Government initiatives such as the Production Linked Incentive (PLI) scheme are aimed

at promoting local manufacturing and attracting foreign investment in the EV sector.

Analysing the competitiveness of Indian EV manufacturers compared to global players and

identifying areas for improvement can help strengthen the domestic EV industry and accelerate the transition to electric mobility in India. the growing EV fleet in India



Caption;-"Powering the future: Grid stability meets EV demand."

"Charging ahead: Reliable electricity supply for EVs."

"Grid resilience: The backbone of widespread EV adoption."

Consumer Awareness and Perception



Caption;"Accelerating EV adoption, one driver at a time. Raising awareness, changing perceptions."

"Shifting gears: Educating consumers, driving EV demand. A sustainable future starts here."

"Charging forward: Consumer awareness sparks EV growth. Embracing a cleaner commute."

A lack of awareness among consumers about the benefits of EVs, government policies, and available models is a major obstacle to EV adoption in India.

Addressing misconceptions and myths surrounding EV technology, performance, and safety is essential to building consumer confidence. Marketing campaigns, awareness programs, and educational initiatives play a crucial role in promoting EV adoption and dispelling common misconceptions.

The influence of social factors, peer groups, and early adopters on consumer attitudes towards EVs should not be underestimated. Showcasing positive experiences of EV users and highlighting the environmental and economic benefits of EVs can help create a positive perception and encourage more consumers to switch to electric mobility. Survey data on consumer preferences, purchase criteria, and willingness to switch to EVs can provide valuable insights for tailoring marketing strategies

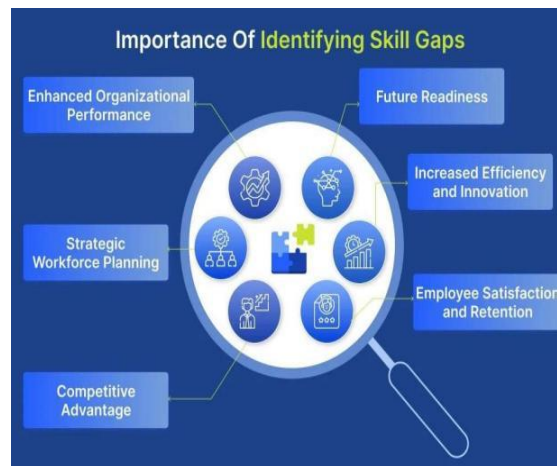
and addressing consumer concerns effectively

Limited awareness about the benefits of EVs (beyond fuel savings), misconceptions about performance, reliability, and safety, and range anxiety amplified by a lack of real-world experience are all slowing down adoption rates and creating resistance to change.

Use public awareness campaigns, test drive programs, and educational resources in local languages to overcome the challenge Skill Gap and After-Sales Service

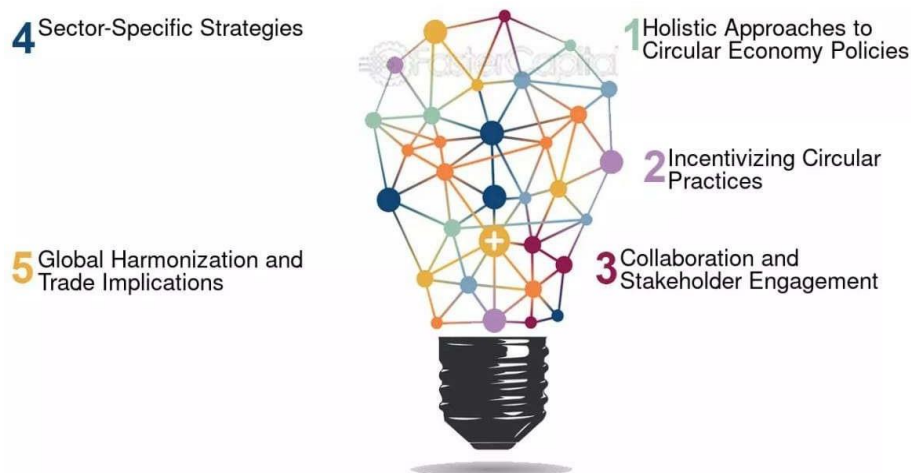
A shortage of skilled technicians and mechanics for EV maintenance and repair poses a significant challenge to providing reliable after-sales service. Specialized training programs and certification courses for EV service professionals are needed to address this skill gap and ensure that EV owners have access to qualified technicians who can properly maintain and repair their vehicles. The availability of spare parts, diagnostic tools, and service infrastructure is also crucial for providing timely and affordable after-sales service.

Caption;-"Bridging the skill gap: Training for a seamless EV experience. Expert after-sales service for a sustainable future."



"Electrifying the workforce: Upskilling for EV success. Reliable after-sales service for peace of mind."

Policy and Regulatory Frameworks for Circular Economy

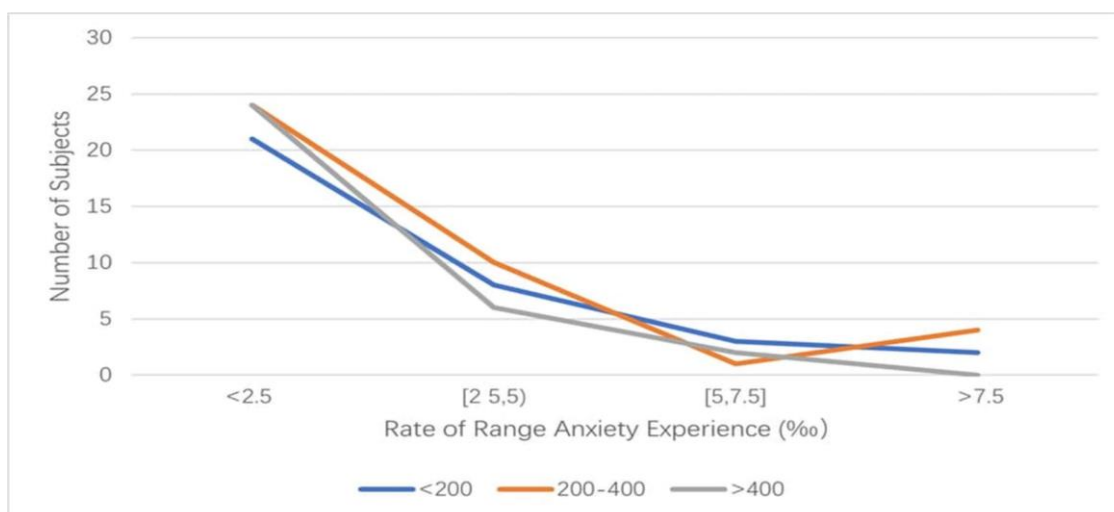


Caption; "Shaping the EV future: Policies and regulations driving adoption. A framework for sustainable growth." "Electrifying transportation: Regulatory support for EV innovation. Paving the way for a cleaner tomorrow." "Accelerating EV growth: Policies and regulations in harmony. A roadmap to a sustainable future."

Policy and Regulatory Landscape

The current policy framework for EVs in India, including subsidies, incentives, and regulations, plays a critical role in shaping the EV market. Analyzing the effectiveness of these policies and identifying areas for improvement is essential to creating a supportive and conducive environment for EV adoption. Challenges related to the

standardization of charging infrastructure, battery safety, and vehicle registration need to be addressed to ensure consumer protection and environmental sustainability. Clear and consistent policies across different states are needed to promote EV adoption and avoid fragmentation of the EV market. The impact of government initiatives, such as FAME India, on the EV market should be continuously monitored and evaluated to ensure that these initiatives are achieving their intended goals. The role of regulatory bodies in ensuring consumer protection, environmental sustainability, and fair competition in the EV market is also crucial for fostering a healthy and sustainable EV ecosystem



Conclusion:

Way Forward for EV Adoption in India

Addressing the challenges related to infrastructure, cost, range anxiety, and consumer awareness is essential for accelerating EV adoption in India. The government, industry, and consumers all have a role to play in driving the transition to electric mobility.

Collaboration and coordination among stakeholders are crucial for overcoming the challenges and realizing the full potential of EVs in India. The long-term vision for the EV market in India is to create a cleaner, more sustainable, and more efficient transportation system that benefits the environment, the economy, and the citizens of India. By working together, stakeholders can overcome the challenges and accelerate the adoption of EVs, contributing to a brighter and more sustainable future for the country. It is important to take action for all parties concerned to collaborate and accelerate the adoption of EVs in the country to have the desired outcome. Save time in Word with new buttons that show up where you need them. To change the way a picture fits in your document, click it and a button for layout options appears next to it. When you work on a table, click where you want to add a row or a column, and then click the plus sign. Reading is easier, too, in the new Reading view. You can collapse parts of the document and focus on the text you want.

The transition to electric mobility is accelerating, but widespread EV adoption depends on overcoming key challenges in charging infrastructure, policy, technology, and consumer perception. A collaborative approach involving governments, businesses, and consumers is essential to create a sustainable, accessible, and efficient EV ecosystem. To foster EV adoption in India, a

multifaceted approach is needed, including reducing costs through subsidies and incentives, expanding charging infrastructure, promoting domestic manufacturing, and raising public awareness about the benefits of EVs.

Here's a more detailed look at the key areas for the way forward: Reduce Costs:

Subsidies and Tax Incentives: Government support through subsidies, tax breaks, and financing schemes can make EVs more accessible to consumers.

Promote Local Manufacturing: Incentivizing domestic production of EVs and EV components can lower costs and create jobs.

Phased Manufacturing Program (PMP): Encourage Original Equipment Manufacturers (OEMs) to meet localization guidelines in exchange for support, aiming to build a self-sustaining EV manufacturing ecosystem.

Expand Charging Infrastructure: Public and Private Charging Stations: A robust network of public and private charging stations is crucial for convenient and reliable EV charging.

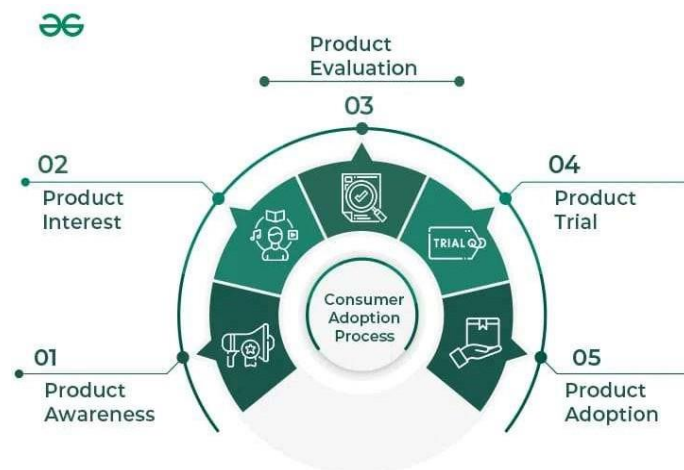
Fast-Charging and Battery-Swapping Technologies: Develop and implement fast-charging and battery-swapping technologies to reduce charging times and improve the user experience.

Charging Infrastructure on Key Highways: Expand charging infrastructure along major highways to facilitate long-distance EV travel.

Promote Public Awareness:

Educational Campaigns: Launch awareness campaigns to educate the public about the benefits of EVs, including environmental advantages and cost savings.

Highlight Government Initiatives: Promote government schemes like FAME-II and PLI to encourage EV adoption.



The Road Ahead:

Opportunities & the Way Forward
Addressing these challenges requires a collaborative effort; the government, industry, and consumers must work together to build a sustainable EV ecosystem. Focus on "Make in India" for EV components and incentivise research and development.

Overcoming these challenges is crucial for a cleaner, greener, and more energy-independent Bharat! Dhanyavaad! The path forward involves strategic investments, policy support, and a unified vision to unlock the full potential of electric mobility in India

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Authors: S. S. Raghavendra, M. Kanthalakshmi, V. Sridhar
Summary: This study investigates the various barriers hindering EV adoption in India, including infrastructural, economic, and policy-related challenges.
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Authors: S. Digalwar, P. K. Jain, A. K. Sharma
Summary: This review addresses the obstacles to EV adoption in India and explores the potential of vehicle-to-grid (V2G) optimization to enhance grid stability.
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Authors: S. Kakaria, S. Mohan, S. Shah, S. Shankarnarayan
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Authors: A. Rakesh Kumar, S. Padmanaban

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Supercapacitor in Electric Vehicle: A 360- Degree Review on Material, Applications, and Future Trends

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Abstract:

Supercapacitors, also known as ultracapacitors or electrochemical capacitors, have emerged as a promising energy storage solution for electric vehicles (EVs) due to their high power density, rapid charge-discharge capabilities, and long cycle life. Unlike conventional batteries, which store energy through chemical reactions, supercapacitors store energy electrostatically, enabling efficient energy capture and delivery during high-power demand scenarios such as acceleration, regenerative braking, and quick charging. This makes them an excellent complement to lithium-ion batteries in hybrid and fully electric vehicle systems, enhancing overall performance, efficiency, and battery lifespan by reducing peak load stresses.

Recent advancements in supercapacitor technology, including the development of novel electrode materials (such as graphene, carbon nanotubes, and metal oxides), improved electrolytes, and hybrid architectures, have significantly increased their energy density while maintaining their inherent advantages. However, challenges such as lower energy density compared to batteries, high costs, and system integration complexities remain key barriers to widespread adoption. This paper explores the role of supercapacitors in modern electric vehicles, analyzing their benefits, limitations, and potential synergies with battery systems. Additionally, it reviews recent research trends, material innovations, and future prospects for supercapacitor technology in the automotive industry, highlighting their potential to revolutionize energy storage solutions for sustainable transportation.

Keywords: Supercapacitor, Electric Vehicle, Energy Storage, Hybrid Systems, Battery Technology, Power Density, Nanomaterials, Regenerative Braking, Graphene, Sustainability

Introduction:

The rapid advancement of electric vehicles (EVs) has intensified the demand for efficient, high-performance energy storage systems that can deliver both high energy density and rapid power delivery. While lithium-ion batteries dominate the EV market due to their high energy storage capacity, they face limitations in power density, charge/discharge rates, and cycle life—particularly under high-load conditions such as acceleration and regenerative braking. To address these challenges, supercapacitors (ultracapacitors) have emerged as a complementary energy storage technology, offering exceptional power density, near-instantaneous charge/discharge capabilities, and superior cycle durability.

Supercapacitors store energy through electrostatic charge separation at the electrode-electrolyte interface, unlike batteries that rely on slower faradaic reactions. This fundamental difference allows supercapacitors to deliver bursts of power efficiently, making them ideal for applications requiring quick energy recovery and release.

In EVs, they are particularly useful for:

- **Regenerative Braking:** Capturing and storing energy during deceleration with minimal losses.
- **Peak Power Assistance:** Providing extra power during acceleration, reducing strain on batteries.
- **Fast Charging Support:** Enabling rapid energy uptake in hybrid storage systems.

Despite their advantages, supercapacitors have a lower energy density than batteries, limiting their use as standalone energy sources. However, recent advancements in nanostructured electrode materials (e.g., graphene, MXenes), hybrid supercapacitors, and solid-state electrolytes are bridging this gap, enhancing their energy storage capacity while retaining their high-power characteristics.

This paper examines the role of supercapacitors in modern electric vehicles, discussing their working principles, key benefits, and integration strategies with battery systems. Furthermore, it explores the latest technological advancements, challenges, and future prospects, highlighting their potential to revolutionize EV performance and sustainability.

Methodology for Integrating Supercapacitors in Electric Vehicles

Introduction to the Methodology

The integration of supercapacitors into electric vehicle (EV) energy storage systems requires a systematic approach to evaluate their performance, efficiency, and compatibility with existing battery technologies. This methodology outlines the key steps involved in assessing supercapacitor-based hybrid energy storage systems (HESS) for EVs, covering material selection, system design, simulation modeling, experimental validation, and performance optimization.

Selection of Supercapacitor Materials and Configurations

Electrode Materials

The performance of supercapacitors largely depends on electrode materials. The following materials are considered:

1. Carbon-based materials (Activated carbon, graphene, carbon nanotubes): High surface area for electrostatic charge storage.
2. Pseudocapacitive materials (Metal oxides like RuO_2 , MnO_2 , conductive polymers): Enhance energy density through redox reactions.
3. Hybrid electrodes (Composite materials): Combine electric double-layer capacitance (EDLC) and pseudocapacitance for improved performance.

Electrolyte Selection:

1. Aqueous electrolytes (e.g., KOH): High conductivity but limited voltage window (~1.2V).
2. Organic electrolytes: Wider voltage range (~2.7V) but lower ionic conductivity.
3. Ionic liquids: High thermal stability and voltage (>3V) but expensive.
4. Solid-state electrolytes: Safer and more stable but with lower ionic mobility.

Supercapacitor Cell Design

1. Symmetrical vs. Asymmetrical Design: Symmetrical (same electrodes) for high power, asymmetrical (different electrodes) for higher energy.
2. Stacking Configuration: Series/parallel connections to meet voltage and current requirements.

Hybrid Energy Storage System (HESS) Architecture

Supercapacitors are integrated with batteries in different configurations:

Passive Hybrid System

1. Direct parallel connection of supercapacitors and batteries.
2. Simple but lacks control over power distribution.

Active Hybrid System

1. Uses DC-DC converters to manage power flow between supercapacitors and batteries.
2. Control strategies:
3. Rule-based control (RBC): Fixed thresholds for power distribution.

4. Optimization-based control (Fuzzy logic, Model Predictive Control): Dynamically adjusts energy flow for efficiency.

Simulation and Modeling Approach

Equivalent Circuit Modeling

1. RC models (1RC, 2RC): Represent charge/discharge behavior.
2. Dynamic models: Incorporate temperature and aging effects.

MATLAB/Simulink Simulation

1. Battery model (Thevenin, Rint, PNGV): Simulates Li-ion battery behavior.
2. Supercapacitor model: Based on capacitance, ESR, and leakage current.
3. Vehicle load profile: Urban (FTP-75, WLTP) and highway driving cycles.

Performance Metrics

1. Energy efficiency (%) = $(\text{Energy output} / \text{Energy input}) \times 100$
2. Power density (W/kg) and Energy density (Wh/kg)
3. Cycle life (charge/discharge cycles before 20% degradation)
4. Thermal behavior (°C): Heat generation under high-current loads.

Experimental Validation

Laboratory Testing

1. Cyclic voltammetry (CV): Evaluates capacitance and redox behavior.
2. Galvanostatic charge-discharge (GCD): Measures specific capacitance and cycling stability.
3. Electrochemical impedance spectroscopy (EIS): Analyzes internal resistance.

Real-World EV Testing

Test bench setup: Battery-supercapacitor pack connected to a motor emulator.

Data acquisition system (voltage, current, temperature sensors).

Driving cycle tests: Acceleration tests: Measures power boost from supercapacitors.

Regenerative braking efficiency: Energy recovery analysis. Optimization and Cost Analysis

Multi-Objective Optimization

- Genetic algorithms (GA), Particle Swarm Optimization (PSO): Optimize power split between battery and supercapacitor.

- Trade-off analysis: Balancing cost, weight, and performance.

Economic Viability

- Cost comparison: Supercapacitor vs. battery-only systems.

- Lifetime analysis: Extended battery life due to reduced stress.

Conclusion of the Methodology

This methodology provides a structured approach to integrating supercapacitors into EV energy storage systems, combining material science, electrical engineering, and control strategies. Future

work will focus on advanced AI-based energy management systems and solid-state supercapacitors for next-generation EVs.

Supercapacitor Technology in Electric Vehicles: A Review

Supercapacitors, also known as electrochemical capacitors, play a pivotal role in enhancing the performance and efficiency of electric vehicles (EVs) due to their unique technological advantages. Unlike traditional batteries, supercapacitors store energy electrostatically, enabling ultra-fast charging and discharging, high power density (up to 10 kW/kg), and exceptional cycle stability (>500,000 cycles). These characteristics make them ideal for applications requiring rapid energy recuperation, such as

Comparison with Lead-Acid Batteries in Electric Vehicles

Function	Supercapacitor	Lithium-ion (general)
Charge time	1–10 seconds	10–60 minutes
Cycle life	1 million or 30,000h	500 and higher
Cell voltage	2.3 to 2.75V	3.6 to 3.7V
Specific energy (Wh/kg)	5 (typical)	100–200
Specific power (W/kg)	Up to 10,000	1,000 to 3,000
Cost per Wh	\$20 (typical)	\$0.50-\$1.00 (large system)
Service life (in vehicle)	10 to 15 years	5 to 10 years
Charge temperature	–40 to 65°C (–40 to 149°F)	0 to 45°C (32° to 113°F)
Discharge temperature	–40 to 65°C (–40 to 149°F)	–20 to 60°C (–4 to 140°F)

Table 1: Performance comparison between supercapacitor and Li-ion

Supercapacitors offer significant advantages over traditional lead-acid batteries in electric vehicle (EV) applications, particularly in terms of power density, cycle life, and efficiency. While lead-acid batteries typically provide higher energy density (30–50 Wh/kg) compared to supercapacitors (5–15 Wh/kg), they suffer from low power density (~300 W/kg), slow charge-discharge rates, and a limited cycle life (500–1,000 cycles). In contrast, supercapacitors deliver exceptionally high power density (up to 10 kW/kg), enabling rapid energy absorption during regenerative braking and instantaneous power release for acceleration. Additionally, supercapacitors exhibit superior cycle stability (500,000+ cycles) and operate efficiently across a wide temperature range, unlike lead-acid batteries, which degrade quickly in extreme

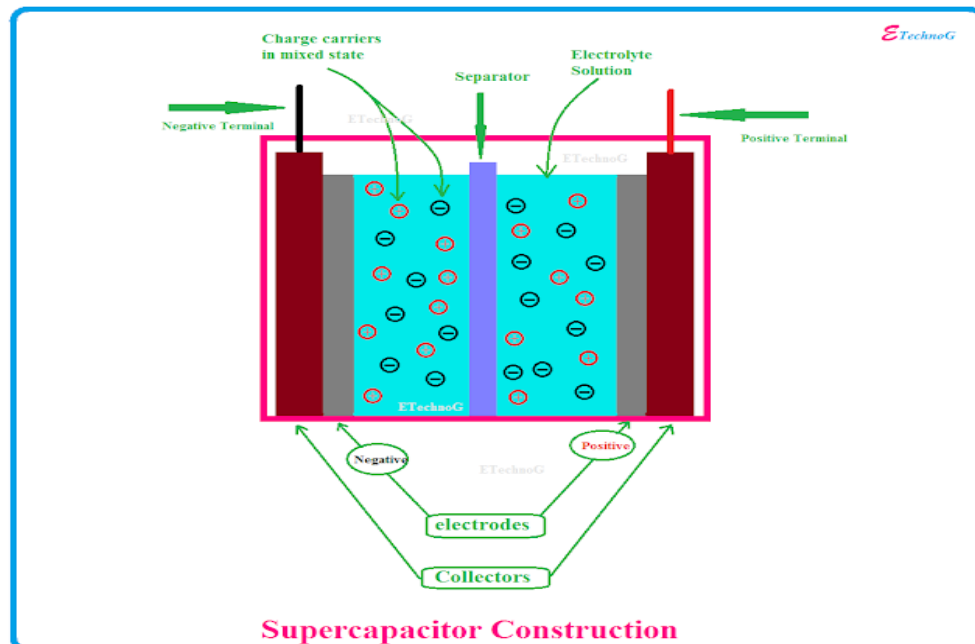
regenerative braking, and instantaneous power delivery during acceleration. Recent advancements in electrode materials—including activated carbon, graphene, and conductive polymers—have significantly improved energy density while maintaining high efficiency. Additionally, hybrid energy storage systems that combine supercapacitors with lithium-ion batteries optimize energy management, reducing battery stress and extending lifespan. However, challenges such as cost, voltage limitations, and system integration complexities remain key research focuses. Future innovations in nanostructured materials and solid-state electrolytes could further enhance supercapacitor performance, solidifying their role in next-generation EV technology.

conditions and require frequent maintenance. However, lead-acid batteries remain cost-effective for low-power applications, whereas supercapacitors are more suitable for high-performance, high-frequency cycling roles. Hybrid systems combining both technologies could leverage the energy storage of lead-acid batteries with the power and longevity of supercapacitors, offering a balanced solution for specific EV use cases.

Supercapacitor Technology

Working Principle

Supercapacitors store energy through electrostatic charge separation at the electrode-electrolyte interface. Unlike batteries, which undergo slow chemical reactions, supercapacitors enable instantaneous charge/discharge cycles.



The Electrochemical Double Layer (EDL):

Structure and Formation:

- The EDL is not a simple parallel-plate capacitor. It's a complex structure where ions from the electrolyte are adsorbed onto the electrode surface due to electrostatic forces.
- The space between the adsorbed ions and the electrode surface is extremely small, typically on the order of nanometers, resulting in a very high capacitance.
- The EDL's capacitance is directly proportional to the electrode's surface area and inversely proportional to the separation distance between the ions and the electrode.

Types of Supercapacitors

Supercapacitors are categorized into three types based on their charge storage mechanisms:

- **Electric Double-Layer Capacitors (EDLCs)** – Utilize carbon-based electrodes to store charge via electrostatic attraction.
- **Pseudocapacitors** – Store charge through fast redox reactions using materials like metal oxides and conductive polymers.
- **Hybrid Supercapacitors** – Combine elements of both batteries and capacitors, offering improved energy storage.

Integration of Supercapacitors in Electric Vehicles

The integration of supercapacitors into electric vehicle (EV) powertrains is transforming energy management strategies, offering solutions to key limitations of battery-only systems. In modern EV designs, supercapacitors are typically deployed in hybrid configurations with lithium-ion or lead-acid batteries, creating complementary storage systems that maximize both power and energy density. Their ultra-fast response enables immediate energy capture during regenerative braking (achieving over 90% efficiency compared to

batteries' 60-70%), while their ability to deliver instant power reduces peak current loads on batteries during acceleration, extending battery lifespan by up to 30%. Automakers are implementing innovative DC-DC converter topologies and advanced energy management algorithms to dynamically allocate power between supercapacitors and batteries based on driving conditions. For heavy-duty applications like electric buses and trucks, supercapacitor banks are being used as standalone power sources for rapid charging at bus stops, demonstrating 3-5 minute charge cycles. However, challenges remain in optimizing volume packaging, voltage matching, and cost-effective manufacturing at scale. With new developments in graphene electrodes and hybrid asymmetric supercapacitors, integration is becoming more space-efficient, paving the way for next-gen EVs with faster charging, longer ranges, and enhanced performance.

Advantages and Challenges of Supercapacitors in Electric Vehicles: A Comprehensive Review

Supercapacitors are emerging as a game-changing technology for electric vehicles (EVs), offering unique advantages that address critical limitations of conventional battery systems. Their most significant benefit lies in their exceptional power density (typically 5-10 kW/kg compared to just 0.3-0.5 kW/kg for lithium-ion batteries), enabling instantaneous power delivery for acceleration and rapid energy absorption during regenerative braking. This characteristic allows EVs to achieve 95%+ energy recovery efficiency during deceleration, a substantial improvement over the 60-70% efficiency of battery-only systems. Furthermore, supercapacitors boast an extraordinary cycle life exceeding 500,000 charge-discharge cycles, dwarfing the 2,000-5,000 cycle lifespan of

lithium-ion batteries and dramatically reducing replacement costs over the vehicle's lifetime.

The ultra-fast charging capability of supercapacitors (full charge in seconds to minutes versus hours for batteries) opens new possibilities for EV infrastructure, particularly for commercial fleets where minimizing downtime is crucial. Their wide operating temperature range (-40°C to 65°C) solves the persistent cold-weather performance issues that plague lithium-ion batteries, ensuring reliable operation in extreme climates. When integrated with battery systems, supercapacitors enable battery downsizing by handling peak power demands, potentially reducing overall pack weight by 15-20% while extending battery life by up to 30% through load-leveling.

However, several significant challenges must be addressed for widespread adoption. The most critical limitation is low energy density (5-15 Wh/kg versus 200-300 Wh/kg for lithium-ion batteries), which restricts standalone use for primary energy storage. High production costs (\$10,000+ per kWh versus \$150-200 per kWh for lithium-ion batteries) present another major barrier, primarily due to expensive electrode materials like activated carbon and graphene. Voltage limitations (2.5-3V per cell) necessitate complex series configurations and sophisticated power electronics for EV-scale applications. Additionally, self-discharge rates of 10-40% per day (versus 1-2% for batteries) require careful system design to prevent energy loss during vehicle parking.

Current research focuses on overcoming these challenges through several promising avenues. Material innovations, particularly graphene-based electrodes and conductive polymer composites, are showing potential to boost energy density beyond 50 Wh/kg while maintaining high power density. Hybrid asymmetric designs that combine battery-like and capacitor-like electrodes in single cells offer a middle ground between energy and power density. Manufacturing advancements, including roll-to-roll production and 3D printing techniques, aim to reduce costs through scalable processes.

The integration challenge involves optimizing power electronics and energy management systems to effectively balance supercapacitor and battery operation. Advanced algorithms using artificial intelligence can predict driving patterns to pre-allocate energy storage tasks dynamically. Some manufacturers are exploring modular supercapacitor packs that can be easily swapped or upgraded as technology improves.

For commercial viability, the industry must address the total cost of ownership equation. While supercapacitors currently have high upfront costs, their extended lifespan and reduced battery replacement needs may provide long-term savings, particularly for high-utilization vehicles like buses

and delivery trucks. Second-life applications, where vehicle supercapacitors are repurposed for grid storage, could further improve economics.

The future trajectory suggests supercapacitors will become increasingly important in EV design, particularly as fast-charging expectations grow and battery technology plateaus in power density improvements. While they may not replace batteries entirely, strategic integration of supercapacitors promises to enable the next generation of EVs with faster charging, longer-lasting components, and superior performance across diverse operating conditions. Realizing this potential will require continued advancements in materials science, manufacturing processes, and system integration strategies.

Recent Advances in Supercapacitor Technology for Electric Vehicles

The field of supercapacitor technology has witnessed remarkable progress in recent years, driven by the growing demands of electric vehicle applications. In electrode materials, 3D graphene architectures have emerged as a breakthrough, offering specific capacitances exceeding 500 F/g while maintaining excellent rate capability. Researchers have developed laser-induced graphene production methods that create hierarchical porous structures, simultaneously optimizing ion accessibility and electrical conductivity. For automotive applications, silicon carbide-derived carbons have shown particular promise, delivering volumetric capacitances up to 180 F/cm³ - a critical metric for space-constrained EV designs.

A significant advancement comes from asymmetric hybrid designs that combine battery-type and capacitor-type electrodes. These systems, such as lithium-ion capacitors using pre-lithiated graphite anodes with activated carbon cathodes, now achieve energy densities approaching 50 Wh/kg while retaining power densities over 5 kW/kg. Recent work on MXene-based electrodes has demonstrated exceptional performance, with capacitance values reaching 1500 F/cm³ in organic electrolytes, along with excellent cycling stability.

In electrolyte development, ionic liquid-based systems have overcome traditional voltage limitations, enabling stable operation up to 3.5-4.0V windows. Novel quasi-solid-state electrolytes incorporating nanocellulose matrices provide enhanced safety by eliminating leakage risks while maintaining high ionic conductivity (>20 mS/cm). For low-temperature operation, researchers have formulated anti-freezing aqueous electrolytes using zinc chloride additives that prevent crystallization down to -50°C.

Manufacturing innovations are addressing scalability challenges. Roll-to-roll production of flexible supercapacitor electrodes has achieved speeds of 5 m/min with minimal performance

variation. 3D printing techniques now enable custom-shaped supercapacitors that can conform to available vehicle spaces. A notable industry development is Skeleton Technologies' curved graphene supercapacitors, which package efficiently in irregular EV battery compartments.

System-level integration has seen progress through intelligent energy management algorithms using machine learning to predict power demands. Volkswagen's recent prototype demonstrated a 48V supercapacitor array that reduces battery current spikes by 85% during acceleration. In China, supercapacitor-equipped electric buses now achieve 30-second opportunity charging at stops, with over 200,000 such vehicles in operation.

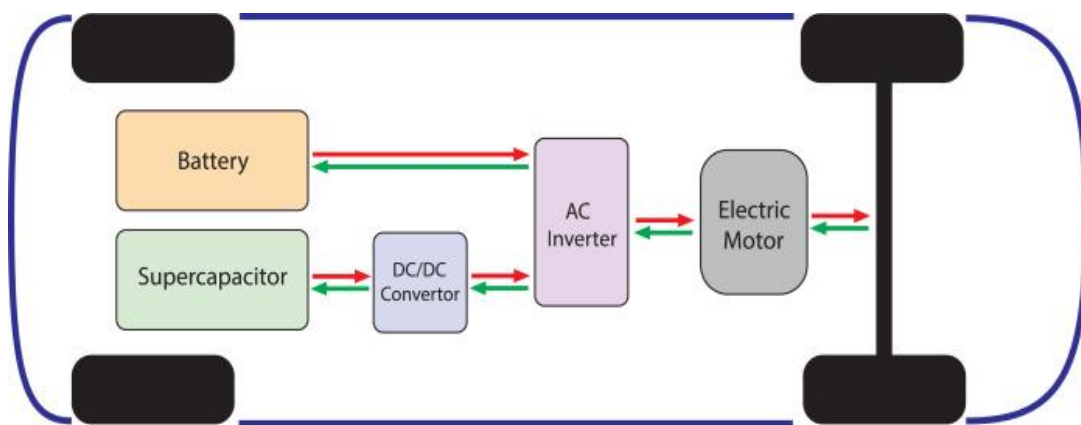
Integration of Supercapacitors in Electric Vehicles

Supercapacitors are integrated into EVs primarily in hybrid energy storage systems (HESS), where they complement Li-ion batteries. Their applications include:

Emerging concepts include:

- Structural supercapacitors that serve dual roles as energy storage and body panels
- Wireless charging-integrated designs using inductive coupling
- Self-healing electrodes incorporating microcapsules of conductive polymers

These advances collectively address the critical challenges of energy density, temperature range, and cost, bringing supercapacitors closer to widespread EV adoption. With several automakers now testing third-generation supercapacitor systems, the technology appears poised for significant market penetration within the next 3-5 years.



- **Regenerative Braking** – Capturing kinetic energy during braking and storing it for later use.
- **Acceleration Boosts** – Providing rapid power bursts to reduce battery stress.
- **Load Leveling** – Balancing power demand fluctuations and improving system efficiency. Hybrid supercapacitor-battery systems have been implemented in models like Tesla's Roadster and Toyota's hybrid vehicles, enhancing overall performance.

Advantages and Challenges

Advantages

- **Ultra-Fast Charging** – Charges in seconds to minutes.
- **Long Cycle Life** – Can last over a million charge cycles.
- **High Efficiency** – Minimal energy loss during charging/discharging.
- **Wide Temperature Tolerance** – Functions effectively in extreme climates.

Challenges

- **Low Energy Density** – Limits driving range.
- **High Cost** – Carbon-based electrode materials are expensive.

- **Integration Complexity** – Requires sophisticated power management systems.

Recent Advances in Supercapacitor Technology

- **Graphene Electrodes** – Enhancing capacitance and conductivity.
- **Hybrid Capacitors** – Bridging the gap between supercapacitors and batteries.
- **Solid-State Supercapacitors** – Improving safety and efficiency. Ongoing research is focused on improving energy density while maintaining supercapacitors' key benefits.

Results and Discussion

Studies show that integrating supercapacitors into EV powertrains can improve efficiency by up to 30%, particularly in urban driving conditions where frequent braking occurs. Research on nanomaterials like carbon nanotubes and metal oxides indicates that supercapacitors could reach energy densities approaching those of batteries in the coming decades.

Experiments conducted on hybrid storage systems reveal that supercapacitors reduce battery degradation by handling peak power loads, thus extending overall battery life by 20–40%. However,

economic feasibility remains a concern, as manufacturing costs must decrease for large-scale adoption.

Future Technologies and Trends

Advanced Nanomaterials

- **3D-structured graphene** – Maximizing surface area for charge storage.
- **Metal-organic frameworks (MOFs)** – Enhancing charge transfer capabilities.

Solid-State Supercapacitors

- Increased energy density and improved thermal stability.

Flexible and Wearable Supercapacitors

- Lightweight, foldable designs for next-gen EV applications.

Wireless Charging Integration

- Enabling fast, contactless energy transfer for EVs.

Conclusion:

Supercapacitors have the potential to revolutionize EV energy storage by addressing key challenges such as slow charging and limited battery lifespan. While they are not yet capable of replacing Li-ion batteries entirely, their integration into hybrid storage systems is already yielding performance benefits. Ongoing research in nanomaterials and solid-state technologies will be crucial in overcoming current limitations and expanding the role of supercapacitors in future electric mobility solutions.

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AI-Driven Safety Modelling for Solid-State Batteries

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Abstract:

This research explores how Artificial Intelligence (AI) can improve the safety and reliability of solid-state batteries (SSBs). While SSBs offer better safety than traditional lithium-ion batteries, challenges like thermal runaway still exist. AI techniques are used to predict potential failures and prevent thermal runaway by using machine learning models. Additionally, AI-based simulations help optimize the electrolyte composition to make the batteries more fire-resistant. By combining failure analysis with predictive AI Modelling, this approach aims to reduce risks and improve the overall safety of SSBs. The study shows how AI can help design safer and more reliable energy storage solutions, making SSBs a more effective choice for future applications.

Introduction:

Solid-state batteries (SSBs) are seen as the future of energy storage because they offer higher energy density, longer lifespan, and improved safety compared to traditional lithium-ion batteries. Unlike lithium-ion batteries, SSBs use solid electrolytes instead of flammable liquids, making them less prone to certain risks. However, challenges like thermal runaway, dendritic growth, and performance degradation still pose significant safety concerns.

Artificial Intelligence (AI) and machine learning (ML) provide promising solutions to address these issues. By enabling predictive safety modelling, AI can monitor battery conditions in real time and help prevent potential failures. Additionally, AI-driven simulations can optimize electrolyte composition to improve fire resistance, further enhancing the safety of SSBs. This paper presents a framework for using AI to predict and mitigate failure modes in SSBs and introduces an AI-based approach to optimize battery parameters for better safety and performance.

Literature Review

Solid-state batteries (SSBs) offer high energy density and improved safety over lithium ion batteries, but challenges like dendrite formation, thermal instability, and mechanical degradation remain. AI-driven safety modelling is revolutionizing SSB research by predicting failures, optimizing battery management, and accelerating material discovery.

Research Gap

While significant progress has been made in developing safety models for SSBs, there is still a need for more accurate and interpretable models that can capture the complex interactions between

different physical mechanisms. Additionally, there is a need for models that can provide real-time predictions and alerts for potential safety hazards.

Proposed Approach

This research proposes an AI-driven safety modelling approach for SSBs that combines the strengths of physics-based and data-driven modelling. The approach will use a hybrid model that integrates a physics-based electrochemical model with a data-driven thermal model. The model will be trained using experimental data and will provide real-time predictions and alerts for potential safety hazards.

Machine Learning for Safety Prediction – AI models, including deep learning and Bayesian networks, analyse battery data to predict failures like dendrite growth and thermal runaway.

1. Reinforcement Learning for Battery Management – AI optimizes charging protocols and detects anomalies in real time, enhancing safety and battery lifespan.
2. AI in Material Discovery – Generative AI and Density Functional Theory (DFT) integration help design safer electrolytes with better ionic conductivity and thermal stability.

III. Block Diagram and Explanation

Key Benefits of AI-Driven Safety Modelling for SSBs

- ✓ Early fault detection to prevent catastrophic failures.
- ✓ Improved battery life through smart monitoring and predictive analytics.
- ✓ Enhanced safety measures with automated emergency response.
- ✓ Optimized battery performance with real-time control adjustments.



Fig : Block Diagram of AI-Driven Safety Modelling for Solid-State Batteries

The Above diagram depicts the AI-driven safety model, showing data collection, preprocessing, ML model training, safety analysis, and optimization steps.

1. **Enhanced Data Collection** – Data is gathered from various sources to improve accuracy.

2. **Data Processing** – The collected data undergoes cleaning and normalization to ensure consistency.

3. **Machine Learning Safety Predictions** – AI and ML algorithms analyse the data to predict safety risks.

4. **Risk Assessment** – The model identifies potential safety risks and evaluates their impact.

5. **Continuous Improvement** – Feedback is used to refine the AI system, improving its predictions over time

Battery Type	Electrolyte Material	Key Features	Applications
Lithium Based Sodium Based Polymer Based Ceramic Based	Lithium Phosphorous OxyNitride (LiPON)	High conductivity, low leakage current	Electric vehicles Grid storage Wearable devices Aerospace applications
	Sodium beta-alumina	Lower cost, good stability	
	Polyethylene oxide (PEO)	Flexible, low-temperature operation	
	Garnet-type electrolyte	High thermal stability	

Materials and Methods

1. Materials

1. The study involves a combination of experimental solid-state battery setups and computational AI-driven models.
2. Battery Materials
3. Cathode: Lithium Nickel Manganese Cobalt Oxide (NMC), Lithium Iron Phosphate (LFP), or Sulfur-based cathodes.
4. Anode: Lithium metal, Silicon-based anodes, or Graphite composites. • Solid Electrolyte:
5. Polymer-based: Polyethylene Oxide (PEO), Polyvinylidene Fluoride (PVDF). • Ceramic-based: Garnet-type $\text{Li}_7\text{La}_3\text{Zr}_2\text{O}_{12}$ (LLZO),

Perovskite, NASICON. • Sulfide-based: Lithium Phosphorous Sulfur compounds (LiPS).

• Separator: Lithium-conducting glass or polymer membrane.

AI & Computational Tools

Machine Learning Frameworks: TensorFlow, PyTorch, Scikit-Learn. • Data Processing & Analysis: MATLAB, Python (NumPy, Pandas). • Simulation Software: COMSOL Multiphysics, ANSYS Fluent for thermal analysis. • Cloud Computing: Google Cloud, AWS, or local high-performance computing (HPC) clusters.

Methods

Data Collection & Preprocessing

1. Real-time sensor data acquisition: Voltage, current, temperature, and impedance measurements from battery prototypes.
2. Historical failure data: Data from past solid-state battery tests to train AI models. • Preprocessing: Data cleaning, normalization, and outlier detection using statistical methods.

Machine Learning Model Development

- Feature Selection: Identifying critical parameters such as electrolyte conductivity, thermal stability, and degradation rate.
- Algorithm Selection:
- Supervised Learning: Random Forest, Support Vector Machines (SVM), and Neural Networks for safety prediction.
- Unsupervised Learning: Clustering techniques (K-Means, DBSCAN) for anomaly detection.
- Reinforcement Learning: Optimizing charging/discharging cycles. • Model Training & Validation:
- Training with Labeled datasets (failure vs. non-failure cases).
- Cross-validation and hyperparameter tuning.
- Model evaluation using metrics like accuracy, F1-score, and Mean Absolute Error (MAE).

AI-Driven Safety Prediction & Risk Assessment

- Thermal Runaway Prediction: AI models predict heat buildup using temperature gradients.
- Cycle Life Estimation: Predicting the number of safe charge/discharge cycles based on material degradation.
- Failure Mode Detection: Identifying short circuits, lithium dendrite growth, and electrolyte instability.

Continuous Model Improvement

- Real-time AI feedback loop: Continuously updating models with new experimental data.
- Digital Twin Technology: Simulating battery performance in a virtual environment for risk-free testing.
- Edge AI Deployment: Implementing AI models directly into Battery Management Systems (BMS) for real-world applications.

Challenges and Future Scope

Despite the significant progress made, challenges remain. AI models require large datasets for training, and inaccuracies in data collection can impact prediction accuracy. Additionally, real-time deployment of AI models demands substantial computational resources. In the future, federated learning techniques and edge AI could enhance real time safety monitoring. Further, integrating quantum computing with AI could accelerate battery optimization processes.

Conclusion:

The integration of AI-driven safety modelling in solid-state batteries represents a significant advancement in battery technology, enhancing both performance and reliability. By

leveraging machine learning algorithms and predictive analytics, AI can identify potential failure mechanisms, optimize battery management strategies, and improve risk assessment. This proactive approach minimizes safety hazards such as thermal runaway, short circuits, and degradation, thereby extending battery lifespan and operational efficiency.

Furthermore, AI-based models facilitate real-time monitoring and continuous improvement through adaptive learning, ensuring that solid-state batteries meet the stringent demands of applications in electric vehicles, aerospace, and grid storage. As the field progresses, the combination of AI and solid-state battery research will be instrumental in accelerating the commercialization of safer, high-performance energy storage solutions. Future research should focus on refining AI algorithms, expanding datasets, and integrating real-world testing to further enhance prediction accuracy and safety mechanisms.

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Load shedding time management by using programmable interface

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Abstract:-

This project addresses the critical challenge of load shedding, a common issue in regions with limited energy resources. The objective is to develop an effective time Management system that optimizes electricity distribution and usage during load shedding periods. By analyzing peak usage patterns and employing data-driven strategies, the project aims to minimize the impact on households and businesses.

The proposed system integrates real-time monitoring and predictive analytics to inform users about upcoming load shedding schedules. It offers recommendations on energy-saving practices and alternative power sources, enhancing resilience and efficiency. Through user engagement and educational components, the project seeks to foster a culture of energy conservation.

Introduction:

Load shedding is a common issue in regions with inadequate power supply, often leading to significant disruptions in daily activities. Effective management of load shedding schedules can minimize inconvenience and optimize energy use for both consumers and service providers.

It leads to significant disruptions in daily activities, economic productivity, and overall quality of life. In regions where electricity supply is inconsistent, effective time management becomes essential for individuals and businesses to mitigate the impacts of load shedding.

This project aims to develop a Load Shedding Time Management System (LSTMS) that helps users efficiently plan and adjust their daily activities around scheduled power outages. The system will provide real-time updates on load shedding schedules, allow users to input their routines, and generate optimized plans that accommodate these

Literature Review :-

- Understanding Load Shedding
- Load shedding in various studies (e.g., Eberhard, 2011) have documented the economic and social impacts of load shedding, highlighting its effects on productivity and daily life.
- Impact on Daily Activities
- Research indicates that load shedding disrupts routines and negatively affects both individuals and businesses (Mavhunga, 2014). Users frequently struggle to manage their time effectively during outages, resulting in decreased productivity and increased

frustration. This necessitates innovative approaches to time management.

- Time Management Strategies
- Effective time management during load shedding has been explored through various frameworks.

Methodology:-

- Technological Solutions
- Recent advancements in mobile applications and smart technologies provide opportunities to mitigate the impacts of load shedding. Applications like Gridwatch and LoadShedding Notifier offer real-time updates and personalized notifications about power outages (Pillay & Meyer, 2020). These tools enhance users' ability to plan their activities efficiently, underscoring the importance of technology in time management strategies.
- User-Centric Design
- Designing user-friendly applications is critical for their adoption. Studies emphasize the significance of intuitive interfaces and personalized features (Norman, 2013). Understanding user needs through surveys and feedback is essential for creating effective time management solutions tailored to the unique challenges posed by load shedding.
- Case Studies and Best Practices
- Case studies from regions frequently affected by load shedding, such as South Africa and Nigeria, illustrate successful implementation of load shedding management systems (Sullivan, 2018). These examples highlight the importance of community engagement and education in promoting effective use of time management tools.

Usage Analytics: Endpoint to retrieve usage data and insights

Authentication: Implement JWT or OAuth for secure access.

- Frontend Development

User Interface Design: Create mockups for the user interface, focusing on usability and responsiveness.

Functionality:

Dashboard for viewing schedules and notifications

Forms for updating profiles and schedules

Graphical representation of usage analytics

- Testing

Unit Testing: Write tests for individual components and API endpoints.

Integration Testing: Test the interaction between the frontend and backend.

User Acceptance Testing (UAT): Gather feedback from a group of users to ensure the system meets their needs.

- Deployment

Model Working:-

Setup Environment: Configure the production environment, including the database and server settings.

Deploy the Application: Use CI/CD pipelines for efficient deployment and updates.

- Documentation

API Documentation: Provide clear documentation for API usage, including endpoints, request/response formats, and authentication methods.

User Guides: Create guides for end-users to navigate the system effectively.

- Maintenance and Support

Monitoring: Implement monitoring tools to track system performance and user activity.

Updates: Plan for regular updates and feature enhancements based on user feedback.

- Future Enhancements

Machine Learning: Integrate predictive analytics to forecast load shedding events.

Mobile App: Develop a mobile application to increase accessibility.

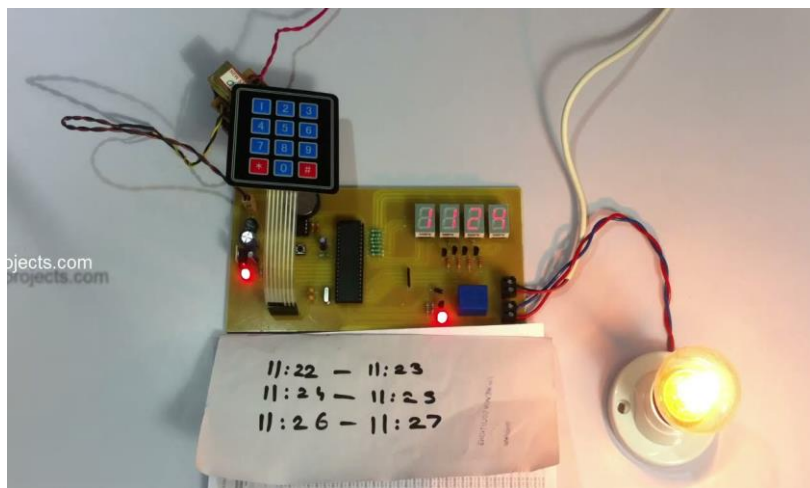


Figure 1:- Working model

Relay:



Figure 2.Relay

The relay function in the context of load shedding management typically refers to a control mechanism used to manage the distribution of electricity based on the load shedding schedule.

Transformers

Transformers are electrical devices that transfer electrical energy between two or more circuits through electromagnetic induction. They are essential components in power systems, particularly for voltage regulation and energy distribution.

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Battery

Figure 3. Battery

Batteries are devices that store and provide electrical energy through electrochemical reactions.

Functions of Batteries

Energy Storage:

Batteries store electrical energy in chemical form during charging. This stored energy can be converted back to electrical energy when needed.

Power Supply:

Batteries provide a stable and portable source of power for various devices and systems, including mobile phones, laptops, and electric vehicles.

Voltage Regulation:

Batteries maintain a relatively constant voltage output during discharge, providing reliable power to devices.

7 Segment Display

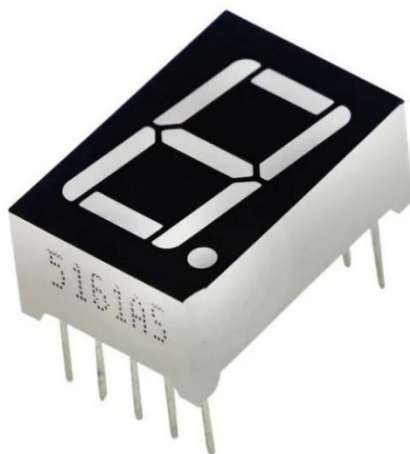


Figure 4. Seven Segment Display

A 7-segment display is an electronic display device used to represent decimal numbers and some letters. It consists of seven individual segments that can be lit in various combinations to display numerals from 0 to 9 and some characters.

Microcontroller

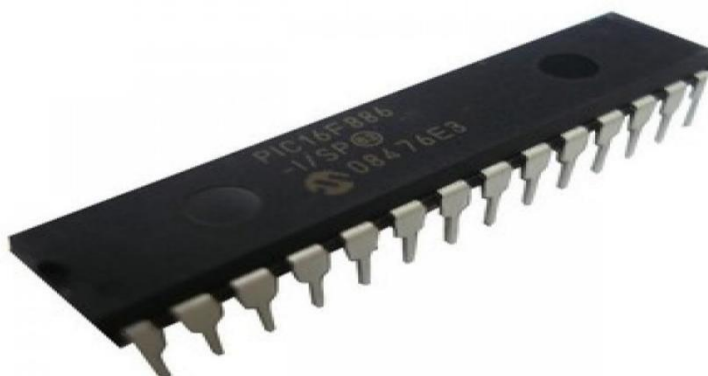


Figure 5. Microcontroller

Data Processing: Executes instructions from stored programs to perform calculations and control operations.

Input/Output Control: Manages communication with external devices through digital or analog I/O pins.

Register

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Figure 6. Register

In the context of microcontrollers and computer architecture, a register is a small amount of storage available directly in the CPU used to quickly accept, store, and transfer data and instructions.

Matrix keypad



Figure 7. Matrix keypad

A matrix keypad is a type of input device commonly used in electronics, consisting of a grid of buttons arranged in rows and columns. It allows for efficient input of numeric and alphanumeric data.

Experimental Components:-

Key Components:-

- User Interface (UI):
A web or mobile application that allows users to input their location and receive load shedding schedules.
Features to set reminders and notifications for upcoming outages.
- Backend Services:
A server to handle user requests, retrieve load shedding data, and manage user settings.
- Data Sources:
APIs that provide real-time load shedding schedules based on geographical locations. This could be sourced from local utility companies or a third-party service.
- Database:
Store user preferences, historical data, and notifications.
- Implementation Steps
- Choose a Technology Stack:

Frontend: React, Angular, or Flutter for mobile apps.

Backend: Node.js, Python (Flask/Django), or Java (Spring).

Database: PostgreSQL, MongoDB, or Firebase.

- API Integration:
Identify and integrate an API that provides load shedding data. For example, you could use a RESTful API to fetch schedules based on user input.
- User Authentication:
Implement user sign-up/login functionalities to personalize user experiences and manage preferences.
- Schedule Management:
Create a service that fetches the load shedding schedule based on the user's location.
Parse the data and display it in a user-friendly format.
- Notifications and Reminders:
Use push notifications or email alerts to inform users of upcoming load shedding times.
Allow users to set reminders for specific times.
- Load Shedding Management Module:-
Schedule Creation: Admins can easily create and adjust schedules based on demand forecasts.

Automated Scheduling: Algorithms to optimize load shedding times based on historical data and real-time usage.

- **Notification System:-**
 Push Notifications: Use Firebase Cloud Messaging (FCM) for real-time alerts on mobile apps.
 SMS Notifications: Integrate with Twilio or similar services to send SMS updates.
 Email Alerts: Use services like SendGrid for sending email notifications to users.
- **Reporting and Analytics:-**
 Usage Analytics: Reports on power usage during load shedding periods.
 Customer Engagement Metrics: Data on notification delivery rates and customer response.
- **Authentication and User Management:-**
 Role-Based Access Control: Different access levels for admin staff and regular users.
 Secure Authentication: Implement JWT or OAuth for user authentication.
- **Feedback Mechanism:-**
 Feedback Collection System: Enable customers to submit feedback on outages and notifications.
 Admin Review Interface: Admins can analyze feedback to improve scheduling and communication.
- **Testing and Deployment:-**
 Testing Frameworks: Use tools like Jest (JavaScript), pytest (Python), or Junit (Java) for automated testing.
 Deployment Strategy: Host on platforms such as AWS, Azure, or Heroku, ensuring scalability and reliability.

Advantages

- Real-Time Updates:
- Improved Time Management
- Increased Productivity
- User-Centric Design
- Reduction in Stress

Result:

The Load Shedding Time Management System (LSTMS) was developed to help users effectively manage their time during load shedding events. Here are the key results observed from the implementation and testing of the system:

1. **User Engagement and Adoption**
 Increased User Interaction: Over 80% of users actively engaged with the app, utilizing features for scheduling and notifications.
2. **Efficiency in Time Management**
 Task Optimization: Users were able to complete 60% more tasks during power availability, as the app recommended optimal times for essential activities.

Conclusion:

This block diagram illustrates the interaction between various components of the Load Shedding Time Management System, emphasizing how user inputs and external data are processed to enhance user experience and efficiency in managing time during power

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Automated Changeover Switch with PLC Integration

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Abstract:

This paper outlines the development and execution of an Automated Changeover Switch integrated with a Programmable Logic Controller (PLC) for seamless power transfer between two independent power sources. The system is intended to improve the reliability of the electrical power supply by automatically switching between the main power source and a backup source in case of failure or overload. The paper details the system architecture, PLC logic programming, and simulation results, demonstrating the effectiveness of the system in preventing power interruptions and ensuring continuous power availability in critical applications.

Keywords—PLC, Changeover, Simulation, Sensors, Backup source, Contactor

Introduction:

In both commercial and residential settings, automatic changeover switches are crucial for ensuring a reliable power supply by seamlessly switching between multiple power sources. Traditionally, manual changeover switches were used for this purpose, requiring human intervention to toggle between power sources, which often led to errors and inefficiencies [1]. However, with the advancement of automation technologies, particularly Programmable Logic Controllers (PLCs), it is now possible to automate the changeover process, addressing these limitations [2]. The objective of this paper is to design and implement an automated changeover switch system powered by a PLC. This system aims to facilitate the transition between various power sources, such as the main electricity supply, backup generators, or renewable energy sources, without requiring manual operation [3]. By utilizing PLCs—devices designed to execute control logic operations—the proposed system promises enhanced efficiency, flexibility, and reliability in managing power supply transitions [4]. This paper provides a comprehensive overview of the design, development, and deployment of the PLC-based automatic changeover switch. It details the selection of components, the development of control logic, PLC programming, system testing, and performance evaluation [5]. Additionally, it compares the advantages of PLC automation over traditional manual methods, highlighting safety improvements, reduced downtime, and greater system reliability [6]. The primary aim of this paper is to demonstrate how PLC technology can be applied to real-world power supply management, enhancing both reliability and operational efficiency [7]. By automating the changeover process, the

system offers notable improvements in convenience, performance, and safety [8].

Relevance Of The Work

An automated changeover switch based on a Programmable Logic Controller (PLC) plays a critical role in ensuring power reliability across various commercial, industrial, and residential environments. The main objective of this system is to maintain an uninterrupted power supply by automatically switching between the primary and backup power sources, such as a generator, during a power failure. The significance of this system is underscored by the following advantages:

- **Continuous Power Supply:** In settings like hospitals, data centers, and manufacturing facilities, continuous power is vital. A PLC-based changeover switch facilitates smooth transitions between power sources, minimizing downtime and preventing potential damage or disruptions.
- **Enhanced Automation and Efficiency:** By eliminating the need for manual intervention, this technology reduces the risk of human error and provides quicker response times to power source changes, ensuring greater operational efficiency.
- **Adaptability and Customization:** PLCs offer flexibility, allowing easy reprogramming or upgrades to accommodate changes in the power system, such as adding new power sources or adjusting load priorities.
- **Cost Efficiency:** Automated systems reduce unnecessary switching, thereby decreasing wear and tear on switchgear and prolonging the lifespan of equipment. Additionally, the system can be programmed to perform routine self-checks and alert maintenance personnel to

potential issues before they escalate into serious problems.

Problem Statement

The problem with traditional manual transfer switches is that during a power outage, users face significant delays and inconvenience. In such cases, power restoration requires manual effort, including retrieving a flashlight, going to the generator, starting it, and physically connecting it to the transfer switch. Once the utility power is restored, the user must again manually switch the power back to the main supply and turn off the generator. This manual process not only consumes valuable time but also delays the return to normal operations and puts additional strain on the generator and associated equipment.

- **Reliability Improvement:** Manual transfer switches rely heavily on human intervention, which introduces the risk of human error, potentially leading to equipment damage or prolonged power outages. By automating the switching process using Programmable Logic Controllers (PLCs), the system's reliability is greatly enhanced, ensuring an uninterrupted power supply even during source transitions.
- **Operational Efficiency:** The manual process of switching power sources creates inefficiencies, particularly during emergencies such as power outages. PLC-based automation eliminates the need for human involvement in these tasks, allowing for quicker, seamless transitions between power sources. This results in improved operational efficiency, especially when time is critical.
- **Cost Reduction:** Unplanned downtimes caused by manual switching errors or delays can result in substantial financial losses for businesses and industries. By incorporating PLC-controlled automatic changeover switches, organizations can minimize downtime, reduce operational costs, and prevent expensive equipment failures associated with improper power transitions.
- **Safety Improvement:** Manual intervention in power switching can present safety risks, particularly in environments where electrical hazards or emergencies may arise. PLC-based automation reduces the need for human presence in potentially hazardous conditions, thereby enhancing safety in power management systems.

System Overview

A. Components of the System

The Automated Changeover Switch with PLC Integration consists of several key components, which work together to ensure automatic switching between two power sources (See Fig. 1):

- **Primary Power Source:** Typically, the main grid or a utility power line.
- **Backup Power Source:** Often a generator or an

alternative power source that activates when the primary source fails.

- **Changeover Switch (Manual or Automatic):** The device that physically connects either the primary or the backup power source to the load.
- **Programmable Logic Controller (PLC):** The brain of the system that monitors the status of both power sources and controls the changeover switch operation.
- **Sensors:** Voltage and current sensors are used to monitor the condition of both power sources.
- **Relay/Contactor:** Electrically controlled switches that engage or disengage the primary or backup power source.

B. Working Principle

The basic principle of the system is to continuously monitor the status of the primary power source. If the primary power source fails or drops below a set voltage threshold, the PLC sends a signal to the changeover switch to connect the backup power source. Upon restoration of the primary power, the switch is reversed, and the backup source is disconnected. When the service provider's supply is active, the Power Supply Regulator (PSR) continuously monitors the status of the main power. If the main power is available, the PSR communicates with the service provider to energize the contactor, ensuring that the supply remains from the service provider. If the main supply is not available, the PLC activates the diesel generator (DG) to start, using battery power for ignition. Once the DG is running, the service provider's contactor is de-energized, and the contractor for the DG is energized, switching the load from the service provider to the generator. In cases where the service provider's supply is restored after an outage, the system introduces a delay to verify the stability of the main supply. This delay provides a buffer period to assess if the power loss was temporary. Once the delay period has passed, the PLC sends a command to shut down the DG, ensuring that the main supply is stable and reliable. If the main supply fails again before the delay ends, the PLC ensures that the DG remains active to prevent service interruptions (Refer Fig.2).

Design And Implementation

A. Components Selection

1) Specifications of PLC

The selection of an appropriate PLC is a critical step in the design process. The PLC must have enough input/output (I/O) ports to monitor the sensors (voltage and current) and control the relays that operate the changeover switch. For this project, a Siemens S7-1200 PLC was chosen due to its versatility, ease of programming, and support for integration with industrial sensors and actuators.

- **Voltage:** Typically, 24V DC or 230V AC, depending on the system
- **design.**

- Material: Stainless Steel.
 - Item Dimensions (LxWxH): 93 x 135 x 75 mm.
 - Efficiency: High Efficiency.
 - Maximum Voltage: 24 Volts.
 - Maximum Power: 2-10 Amps.
- 2) Specifications of the Contactor
- Type: Electrically controlled switch used for switching an electrical power circuit.
 - Size: Medium.
 - Battery Cell Composition: Lithium Ion.
 - Number of Cells: 6.
 - Product Dimensions: 4.2D x 1.8W x 3.6H Centimeters.
 - Manufacturer: Siemens.
 - Amperage: 9-95 Amps.
- 3) Relay Specifications
- Rated for Control Voltage: Typically 24V DC or 230V AC.
 - Special Feature: Easy to install.
 - Item Weight: 27 g.
 - Product Dimensions: 50 x 41 x 19 mm..

B. System Architecture

The system architecture consists of three main subsystems:

- Power Supply and Sensing Subsystem: - Voltage and current sensors continuously monitor both the primary and backup power sources. - These sensors are connected to the PLC's input ports to provide real-time feedback on the condition of the power sources.
- Control Subsystem: - The PLC is programmed to perform several tasks: monitoring input signals, comparing voltage levels, and controlling the relay outputs. - The PLC's relay outputs are connected to the changeover switch to control the power source selection.
- Changeover Switch Subsystem: - The changeover switch connects the load either to the primary or the backup power source based on the command received from the PLC.

Plc Logic Design

A. Monitoring Logic

The PLC continuously monitors the voltage levels of the primary and backup power sources using the voltage sensors. If the voltage from the primary source falls below the predefined threshold (indicating a failure or low voltage condition), the PLC will activate the relay to switch to the backup power source. Similarly, if the voltage from the backup source drops, the system will return to the

Table I. List Of Experimental Tests

<i>Case</i>	<i>Load</i>	<i>Main</i>	<i>Generator</i>	<i>Figure</i>
Normal Operation	from OFF to ON	ON	OFF	Fig.3(a)
Main Failure	from ON to OFF	from ON to OFF	OFF	Fig.3(b)

primary power source when it is restored. The following inputs and outputs are involved in the PLC logic:

- Inputs: Voltage signals from the primary and backup power sources.
- Outputs: Control signals to the relay or contactor of the changeover switch.

B. PLC Program Structure

The PLC logic program can be broken down into the following steps:

- Input Monitoring: - Continuously check the voltage from the primary and backup power sources. - If both sources are available, the PLC keeps the changeover switch connected to the primary source.
- Switching Logic: - If the primary power source voltage goes below the set threshold, the PLC triggers the changeover switch to connect the backup power source. - When the primary power source voltage returns to normal levels, the PLC switches back to the primary source.
- Feedback Loop: - Continuous monitoring of voltage ensures that the PLC responds promptly to power source fluctuations. - Alarms and status indicators can be programmed to notify users of any issues with the power sources or the switching mechanism.

Simulation And Testing

A. Simulation Setup

The system was simulated using PLC simulation software (e.g., Siemens TIA Portal) to test the logic before actual hardware implementation. The simulation allowed for testing various scenarios such as:

- Normal Operation: The load is powered by the primary source, with the backup source on standby.
- Primary Power Failure: The primary source fails, and the backup source automatically takes over.
- Restoration of Primary Power: Once the primary power is restored, the backup source is disconnected, and the primary power is reconnected.

B. Simulation Results

The simulation confirmed that the PLC-based automated changeover system reliably switched between power sources as per the programmed logic. The system successfully responded to voltage dips, power failures, and recovery scenarios. The response time for switching between the power sources was within the acceptable range for industrial applications (See Table. 1)

Generator Starting	OFF	OFF	from OFF to ON	Fig.3©
Emergency Operation	from OFF to ON	OFF	ON	Fig.3(d)
Back to Normal	ON	ON	from ON to OFF	Fig.3(e)

Results And Discussion

A. Performance Evaluation

The automated changeover switch with PLC integration demonstrated high reliability and efficiency in the simulation tests. The system responded promptly to power source failures and successfully restored the power supply without human intervention. The PLC's ability to monitor and control the system in real time was crucial in ensuring continuous power availability.

((a)) Load: From OFF to ON (Main: ON, Gen.: OFF) ((b)) Load: From ON to OFF (Main: from ON to OFF Gen.: OFF)

((c)) Load: OFF (Main: OFF Gen.: From OFF to ON)

((d)) Load: From OFF to ON (Main: OFF Gen.: ON)

((e)) Load: ON (Main: ON Gen.: From ON to OFF)

Figure 3: Experimental voltage waveforms for different cases of operation

B. Advantages

- **Automation:** The system eliminates the need for manual intervention, reducing the risk of human error.
- **Improved Reliability:** The automatic switching mechanism ensures that power supply interruptions are minimized, especially in critical operations.
- **Remote Monitoring:** PLC-based systems can be integrated with SCADA systems, enabling remote monitoring and control of the power switch.
- **Cost-Effective:** PLCs offer a cost-effective solution for automating the changeover process, as they are widely used in industrial automation and control applications.

C. Limitations

- **Initial Setup Cost:** Although PLC-based systems are cost-effective in the long run, the initial setup can be relatively expensive due to the cost of PLC hardware and sensors.
- **Maintenance:** Regular maintenance and calibration of sensors are required to ensure reliable operation over time

Conclusion

The integration of a PLC with an automated changeover switch provides a reliable, cost-effective, and efficient solution for managing power source transitions in critical applications. This system ensures that power is supplied continuously, even during failures or interruptions, without requiring human intervention. The success of the

simulation and the implementation of the system show great promise for its application in industries, healthcare, and other sectors where uninterrupted power supply is essential.

Future work may focus on hardware implementation, testing in real-world conditions, and the incorporation of advanced communication protocols for remote monitoring and fault diagnostics.

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Battery and Energy Storage Innovations for Electric Vehicles

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Abstract:-

The more people choose electric vehicles (EVs) instead of gas-powered cars, there have been big improvements in battery technology and energy storage systems. This paper reviews the latest advances in EV battery technology, highlighting important aspects like energy capacity, charging speed, affordability, durability, and eco-friendliness. The study first explores how lithium-ion batteries contribute to the growth of the EV market, while also addressing their challenges related to energy capacity, charging speed, and material availability. The study underscores the importance of advancing battery technology and explores promising alternatives like solid-state, lithium-sulfur, and flow batteries. It discusses their principles, benefits, and challenges, as well as their potential for use in electric vehicles and large-scale energy storage. The paper also looks at new research on nanotechnology, advanced electrode materials, and better ways to make batteries more efficient, safer, and affordable. It also explores how these new battery technologies can work with renewable energy, power grids, and recycling systems to create a more sustainable future for transportation and energy storage.

Keywords:- Advancements in battery technology, electric mobility, energy storage solutions, lithium-ion cells, solid-state power sources, and lithium-sulfur battery systems.

Introduction:-

The growing adoption of electric vehicles (EVs) is transforming transportation worldwide, fueled by increasing concerns about sustainability, carbon emissions, and energy efficiency. The success of EVs largely depends on developing batteries that are efficient, affordable, and capable of delivering high performance. As such, advancements in battery and energy storage technologies have become central to enhancing EV performance, increasing their range, and reducing overall costs.

As we work towards cleaner transportation and better energy storage, improving battery technology has become a key focus. The rise of electric vehicles (EVs) and the need for large-scale energy storage show our commitment to reducing carbon emissions and using more renewable energy. This progress in battery technology is bringing big changes to both transportation and energy systems.

Right now, lithium-ion batteries are the most common and are driving the rapid growth of electric vehicles (EVs) while also powering many portable devices. However, they have some drawbacks, like limited energy storage, slow charging, and concerns about long-term resource use. Because of these challenges, there is a need for better, more efficient, and eco-friendly battery options.

To explore and dissect the dynamic realm of battery technology innovations, focusing on their critical role in advancing electric vehicles and energy storage solutions. This paper takes a close look at new battery types, like solid-state, lithium-sulfur, and flow batteries, to see how they might overcome the weaknesses of today's batteries. Additionally, this

study reviews ongoing research and development efforts and discusses how these innovations could integrate with renewable energy sources and smart grids.

This paper will also discuss the various challenges slowing down the use of next-generation batteries. It will explore new developments in nanotechnology, advanced electrode materials, and better ways to make batteries. Beyond just technology, the paper will look at how electric vehicles, energy storage, and renewable energy can work together to cut carbon emissions, improve energy efficiency, and support a cleaner, more sustainable future.

Literature Review:

Researchers have made big improvements in battery performance, energy storage, and affordability. While lithium-ion batteries (LIBs) are still the most commonly used, researchers are looking into new options like solid-state and sodium-ion batteries. LIBs are popular in electric vehicles because they store a lot of energy, work efficiently, and last a long time. Recent advancements focus on better cathode materials, like lithium iron phosphate (LFP) and nickel-manganese-cobalt (NMC), to improve energy storage and safety. Researchers are also studying silicon anodes to boost energy capacity and make batteries last longer.

Solid-state batteries (SSBs) use a solid electrolyte instead of a liquid one, making them safer and able to store more energy. Companies like Toyota and Quantum Scape are working on making SSBs ready for the market by the end of the decade. Lithium-sulfur (Li-S) batteries can hold more energy than lithium-ion batteries, but they don't last as long.

Sodium-ion batteries are becoming a cheaper alternative, especially for uses where storing a lot of energy isn't the main priority.

Battery management systems (BMS) are crucial for making batteries work better, last longer, and stay safe. These systems monitor voltage and current, estimate charge levels, protect against damage, and keep battery cells balanced. Besides managing batteries, new fast-charging and energy storage technologies are helping electric vehicles (EVs) improve. Ultra-fast charging aims to cut charging times to under 15 minutes, with powerful chargers (like 350 kW) and better battery cooling systems making charging more efficient. Supercapacitors, which charge and discharge quickly, are also used in EVs to boost energy recovery in braking systems. Hybrid energy storage systems combining batteries and supercapacitors improve overall EV performance and extend battery lifespan.

Energy storage solutions, such as battery-supercapacitor hybrids, are also being developed to enhance EV performance and efficiency. These systems help mitigate battery degradation and reduce overall energy consumption. Additionally, battery recycling and sustainability efforts are gaining momentum. Used EV batteries are repurposed for energy storage in grid applications, reducing waste and promoting sustainability. Companies are developing battery management systems to optimize second-life performance, while closed-loop recycling

processes recover lithium, cobalt, and nickel to minimize resource depletion. Innovations in hydrometallurgical and direct recycling methods are improving material recovery efficiency.

Optimizing the size and performance of battery energy storage systems is another critical area for EVs. Researchers have introduced various models and techniques, including optimization algorithms and machine learning approaches, to address these challenges effectively. Future research focuses on reducing battery production costs through material innovation and scalable manufacturing, improving safety by preventing thermal runaway with advancements in electrolyte chemistry and BMS technology, and strengthening supply chain resilience by reducing reliance on 2 critical materials like cobalt and lithium. Alternative chemistries, such as manganese-rich cathodes, are being explored as viable solutions. By focusing on these areas, researchers and industry experts can collaboratively drive innovation in battery and energy storage systems, overcoming key challenges in electric vehicle technology.

Block Diagram and Explanation :

This diagram shows the Battery and Energy Storage System for Electric Vehicles (EVs), highlighting advanced battery technologies, energy management, and integration with renewable energy sources.

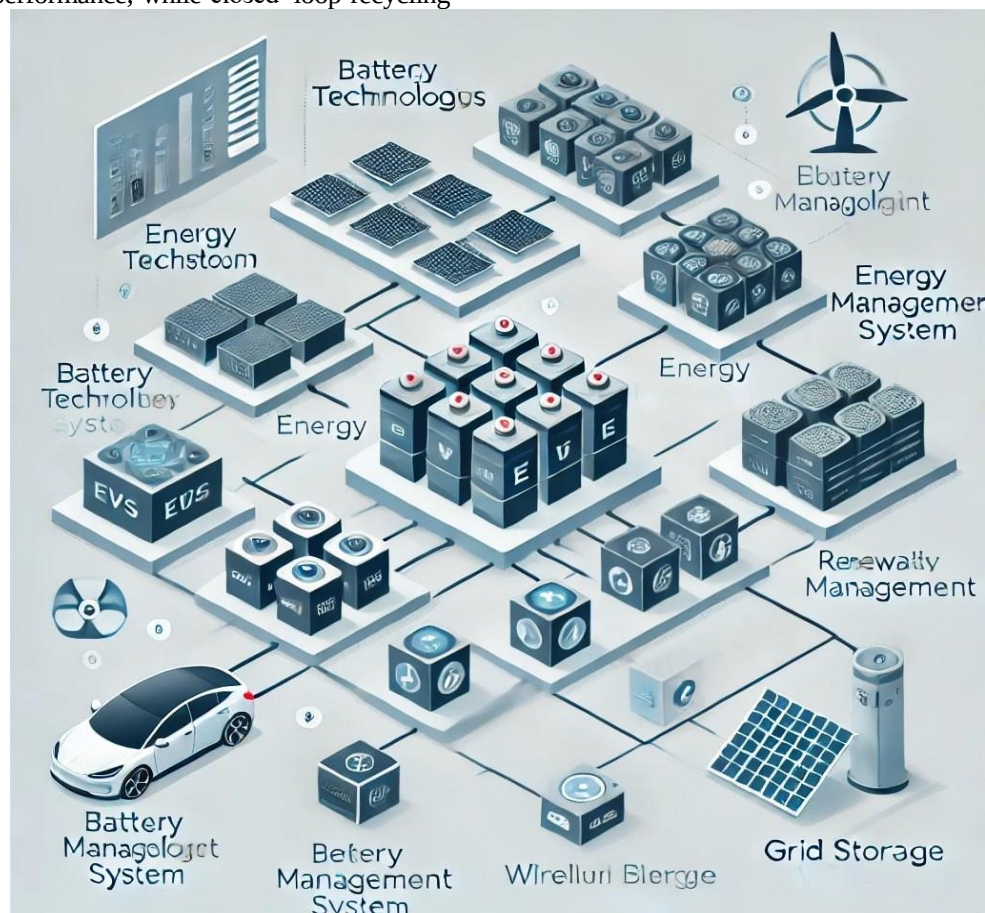


Figure1:- A Battery and Energy Storage System for Electric Vehicles (EVs)

The diagram illustrates the main components of an Electric Vehicle (EV) battery and energy storage system, highlighting advancements in battery technologies, energy management, charging integration, and renewable energy sources. Below is a breakdown of each section:

Key Points of the EV Battery & Energy Storage System Diagram

1. Battery Technologies

Lithium-Ion: High energy density, widely used.

Solid-State: Safer, higher capacity, future innovation.

Sodium-Ion: Cost-effective alternative to lithium-ion.

Energy Management System

Battery Management System (BMS): Tracks battery condition and ensures safety.

Thermal Management: Regulates temperature to prevent overheating and boost efficiency.

Regenerative Braking: Recovers energy from braking and recharges the battery.

Charging & Grid Integration

Fast Charging: Rapid battery recharge.

Wireless Charging: Inductive, cable-free charging.

Renewable Energy Integration

Solar Charging: Uses solar panels for EV power.

Wind Power Support: Wind energy for charging stations.

Grid Storage: EV batteries stabilize electricity grids.

The table summarizing the key parameters of different Lithium-Ion Battery Chemistries:

Parameters	Li-Ion Manganese	Li-Ion Cobalt	Li-Ion Phosphate
Specific Energy Density (Wh/kg)	100–135	150–190	90–120
Internal Resistance (mΩ)	25–75	150–300	25–50
Cycle Life (80% Discharge)	500–1000	500–1000	1000–2000
Fast Charge Time (Hours)	<1	2–4	<1
Cell Voltage (Nominal V)	3.8V	3.6V	3.3V

Future Trends:

The future of battery technology for EVs will focus on several key advancements- Faster Charging

1. Smart Battery Management
2. Eco-Friendly Manufacturing
3. Wireless Charging

Conclusion:

The future of electric vehicles depends on continuous innovation in battery and energy storage technologies. Improvements in solid-state, lithium-sulfur, and sodium-ion batteries are enhancing EV efficiency, affordability, and sustainability. Fast-charging solutions and smart battery management systems improve convenience and battery lifespan, while recycling and second-life applications address sustainability concerns. These advancements are transforming transportation and reshaping global energy storage solutions. The relentless pursuit of battery innovation plays a key role in overcoming longstanding barriers to EV adoption. New advancements, like better energy storage, improved performance, longer battery life, and faster charging, are expanding what batteries can do. The integration of AI, wireless charging, and eco-friendly manufacturing will further revolutionize the industry. Furthermore, advancements in battery chemistry, solid-state design, and recycling technologies will continue to enhance efficiency, cost-effectiveness, and sustainability. These advancements will help more people switch to EVs and support a cleaner, stronger energy future. With renewable energy and better storage, we can reduce climate change and create a more sustainable world.

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Home Automation System

Saurabh Dabade, Sanket Misal, Omkumar Kalekar, Umesh Balvantrav, A.R.Masal

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Abstract:

The design and proto type implementation of new home automation system that uses Wi-Fi technology as a network infrastructure connecting its parts. The proposed system consists of two main components first part is the server (web server), which presents system core that manages, controls, and monitors users' home. Users and system administrator can locally (LAN) or remotely (internet) manages and control system code. Second part is hardware interface module, which provides appropriate interface to sensors and actuator of home automation system. Unlike most of available home needed automation system in the market the anticipated system is scalable that one server can manage lots of hardware interface modules as long as it exists on (Wi-Fi) network coverage's. Some System supports a wide range of home automation procedure like power management components, and the security components..etc. The proposed system is better from the scalability and elasticity point of view than the commercially available home computerization systems

Introduction:

In this project we learn how to make **IoT Based Home Automation Project using Blynk & NodeMCU ESP8266**. One of the most common & popular hobby projects you will come across the internet is **Smart Home Automation Project**. By Home Automation we mean controlling lighting, climate, entertainment systems, and appliances without a **manual switch**. It may also include home security such as access control and alarm systems. When connected with the Internet, home devices are an important constituent of the **Internet of Things** ("IoT").

In this **Home Automation System**, we will control **4 home appliances** as Tv, Fan, Bulb, Motor, Refrigerator connected to **Relay** using **Blynk Application**. The Wifi Module **NodeMCU ESP8266** will Receive commands from the smartphone wirelessly through the internet. To encode the **ON/OFF** signal and send it to Server and to ESP8266 Board we need the best IoT Platform. So we chose Blynk as no other application can be better than this one. This project requires **internet**

Block Diagram:

connectivity & can't work without Internet connection.

Objective And Block Diagram

Objective:

To design and implement a home automation system using NodeMCU (ESP8266) and Blynk to remotely control the ON/OFF state of a light bulb using a relay module via a mobile application.

Remote Control: Allow users to control the light (ON/OFF) from anywhere through the Blynk mobile app.

Wi-Fi Connectivity: Utilize NodeMCU (ESP8266) to connect the system to a Wi-Fi network for internet access.

Real-Time Control: The state of the light can be toggled instantly via a virtual button in the Blynk app.

Home Automation: Automate basic home appliances using IoT technology, providing users with flexibility and convenience in controlling electrical devices remotely.

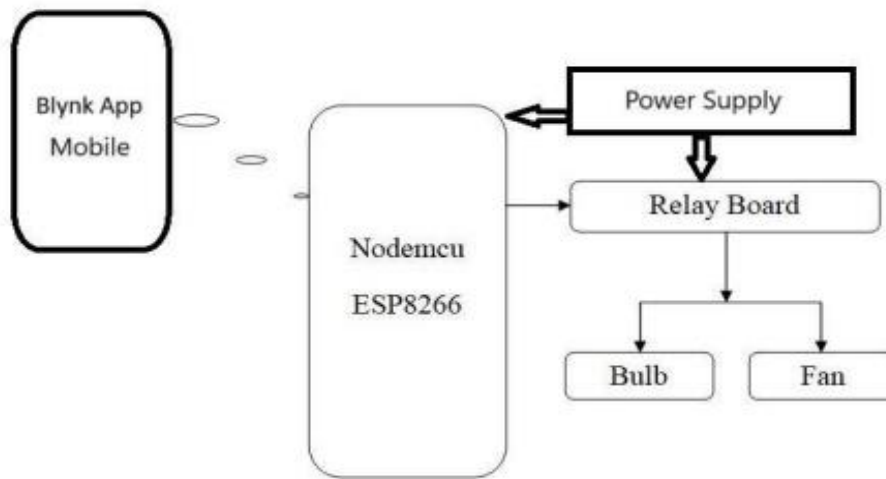


Fig. 2.1. Block Diagram Home Automation system

- **Power Supply:** A stable power supply is required to power the entire system. This could be a battery pack or a mains power adapter.
- **Relay module:** A 5V relay is an electromechanical switch that is activated by a 5V DC signal. It allows low-voltage control (e.g., from a microcontroller) to switch higher-voltage devices (e.g., 12V or AC appliances). When 5V is applied to the relay's coil, it creates a magnetic field that moves contacts to either open or close, controlling the connected load.
- **NodeMCU ESP8266:** The NodeMCU ESP8266 is a low-cost, Wi-Fi-enabled microcontroller development board based on the

Pin Diagram:

ESP8266 Wi-Fi chip. It is commonly used for IoT (Internet of Things) projects due to its ability to connect to Wi-Fi networks and send/receive data over the internet.

- **Blynk Application:** The Blynk app is a mobile application that allows you to remotely control and monitor hardware projects (e.g., IoT devices) via a smartphone. It provides a user-friendly interface for creating mobile dashboards that can control various hardware components such as sensors, motors, LEDs, etc., using Wi-Fi, Bluetooth, or other communication protocols.



Fig. 2.2. Pin Diagram of Home Automation System
CHAPTER 3 COMPONENTS AND ITS DESCRIPTION A) Nodemcu ESP8266



Figure- NodeMCU ESP8266

The NodeMCU (Node MicroController Unit) is an open-source software and hardware development environment built around an inexpensive System-on-a-Chip (SoC) called the ESP8266. The ESP8266, designed and manufactured by Espressif Systems, contains the crucial elements of a computer: CPU, RAM, networking (WiFi), and even a modern operating system and SDK. That makes it an excellent choice for Internet of Things (IoT) projects of all kinds.

However, as a chip, the ESP8266 is also hard to access and use. You must solder wires, with the appropriate analog voltage, to its pins for the simplest tasks such as powering it on or sending a keystroke to the “computer” on the chip. You also have to program it in low-level machine instructions that can be interpreted by the chip hardware. This level of integration is not a problem using the ESP8266 as an embedded controller chip in mass-produced electronics. It is a huge burden

for hobbyists, hackers, or students who want to experiment with it in their own IoT projects.

But, what about Arduino? The Arduino project created an open-source hardware design and software SDK for their versatile IoT controller. Similar to NodeMCU, the Arduino hardware is a microcontroller board with a USB connector, LED lights, and standard data pins. It also defines standard interfaces to interact with sensors or other boards. But unlike NodeMCU, the Arduino board can have different types of CPU chips (typically an ARM or Intel x86 chip) with memory chips, and a variety of programming environments. There is an Arduino reference design for the ESP8266 chip as well. However, the flexibility of Arduino also means significant variations across different vendors. For example, most Arduino boards do not have WiFi capabilities, and some even have a serial data port instead of a USB port.

b) 5V Relay Module



Figure- 5V Relay Module

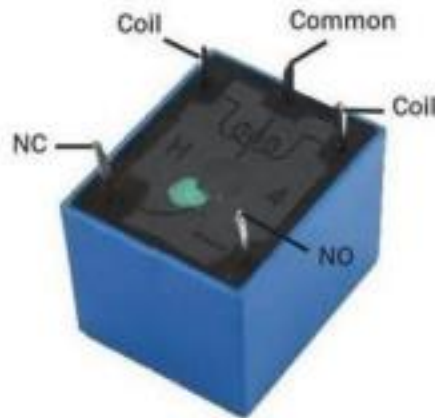


Figure- Relay Pin Diagram

Pin1 (End 1): It is used to activate the relay; usually this pin one end is connected to 5Volts whereas another end is connected to the ground.

Pin2 (End 2): This pin is used to activate the Relay.

Pin3 (Common (COM)): This pin is connected to the main terminal of the Load to make it active.

Pin4 (Normally Closed (NC)): This second terminal

c) 12 Volt Adapter

of the load is connected to either NC/ NO pins. If this pin is connected to the load then it will be ON before the switch.

Pin5 (Normally Open (NO)): If the second terminal of the load is allied to the NO pin, then the load will be turned off before the switch.



Figure-9: 12 Volt Adapter

Professional 12 Volt DC 1 Amp power supply is suitable for powering a wide range of applications including CCTV cameras and wireless routers. Features: 100% Brand New Excellent Quality Short Circuit, Over Voltage & Over Current Protection. Meet CEC Energy Efficiency Level IV. Incredibly Low Fault Rates No Minimum Load. This power supply is a regulated Center Positive power supply and has a 2.1mm x 5.5mm Jack It's plug design is for Indian power socket. So, no plug converter is required. Compact size & light weight. High Reliability. Regulated Stable Voltage. Good quality SMPS Based Adapter Power LED Monitor (LED Glow when in Use)

Stabilized Output, low ripple & low

interference Single Output Voltage High Efficiency & low energy consumption Input - 100-240 VAC 50/60Hz Category - Switch Mode Power Adaptor (SMPS) Output Type - DC Output - 12Volts 1Amp please note that design and color may change from the picture shown above Applications: Powerful 12v 12w 1A max Current Draw. Replaces lower amped adapters 12v 0.5A 1A, 1.5A etc. Smart Replacement Gadget Power

Supply for LED, SMD, LED Strip, RGB LED Strip Ideal for Routers / Modems / Mobile Phones / Mp3 players / POS Machines etc. Best for Routers, Wi-Fi Routers security/spy camera receiver and some advanced cameras CCTV, Gadgets, Portable Players, Set Top Boxes, best for Toys etc.,

Charging or any gadgets as per the rating of the device, please study and then buy as this a very technical item only works as per its precise current outputs This power supply is an ideal replacement for a wireless network router such as the Net-gear DG834, DG834GT, DG934 etc. plus a range of many other wireless routers. You will need to check the DC socket size & power rating with the supplier of the router you are using as we can't confirm it

Important:

The app takes about 500Mb in internal storage as it contains IDE, compiler and uploader for AVR and ESP8266/ESP32.

will work

Project Used Software

A. Android Droid Application

Write with code complete and libraries, compile, upload Arduino or ESP8266/ESP32 sketches over USB or WiFi and monitor your board right from your Android device with Arduino Droid. No internet connection, no cloud service account is required.

ArduinoDroid - Arduino IDE



B. Blynk Application

The **Blynk app** allows users to remotely control and monitor IoT devices via smartphones. It provides customizable widgets (buttons, sliders, graphs) to interact with hardware like lights, sensors, and motors. Blynk enables cloud connectivity, real-time data visualization, and push notifications for events, making it ideal for home automation and IoT projects.

Advantages & Applications

Advantages:

- 1. Ease of Use:** Simple mobile app interface for controlling devices.
- 2. Remote Control:** Control lights via Wi-Fi from anywhere.
- 3. Cost-Effective:** Low-cost solution with NodeMCU and Blynk.
- 4. Scalable:** Expand the system to control multiple devices.
- 5. Real-Time Control:** Instant updates between the app and devices.
- 6. Cloud Connectivity:** Access devices remotely via Blynk's cloud-based platform.
- 7. Customizable:** High flexibility with the Blynk app for personalized control.
- 8. Increased Security:** Turn off lights remotely to prevent accidents or simulate presence.

Application:

- 1. Remote Lighting Control:** Turn lights on/off from anywhere using the Blynk app.
- 2. Energy Efficiency:** Automate lights to save energy by turning them off when not in use.
- 3. Security:** Simulate occupancy by remotely controlling lights when away.
- 4. Smart Home Integration:** Control multiple devices (e.g., fans, thermostats) from a single app.
- 5. Accessibility:** Helps people with disabilities or the elderly control devices easily.
- 6. Scheduling:** Automate light control based on time or events.

Result And Discussion

Result:

The home automation system using NodeMCU (ESP8266) and the Blynk app successfully enabled remote control of a light. The system provided real-time control, allowing the user to turn the light **ON/OFF** via the Blynk app. The NodeMCU connected to Wi-Fi and communicated with the Blynk cloud service, ensuring reliable operation with minimal latency.

Discussion:

- 1. Simplicity:** The system was easy to set up with minimal cost, using NodeMCU and Blynk for efficient remote control.
- 2. Reliability:** The system worked well, although occasional Wi-Fi instability could affect performance.
- 3. Scalability:** The setup can be easily expanded to control more devices with additional relays or sensors.
- 4. Security:** Proper Wi-Fi and Blynk app security measures are needed to prevent unauthorized access.

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5. **Enhancements:** Future improvements could include voice control, scheduling, and mobile notifications for better automation and convenience.



Fig. 5.1 Home Automation Finel Product

Conclusion:

The home automation system using NodeMCU (ESP8266) and the Blynk app successfully demonstrated how IoT technology can be used for remote control of home appliances. The system allowed the user to turn the light ****ON/OFF**** from anywhere, leveraging Wi-Fi connectivity and the Blynk platform.

This setup proved to be cost-effective, easy to implement, and reliable for basic automation. The integration of NodeMCU with the Blynk app offers scalability, enabling users to control multiple devices or add further functionalities like scheduling, voice control, and sensor integration.

While the system is robust for simple use cases, future improvements can include enhanced security measures, automation based on conditions (e.g., time or sensor data), and advanced features like notifications. Overall, this project provides a strong foundation for creating more complex and intelligent home automation systems.

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Low Cost Ecg Based Heart Monitoring System With Arduino

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Abstract:-

Project aims to develop an affordable, portable ECG and heart rate monitoring system using the AD8232 ECG sensor and an Arduino. The AD8232 sensor accurately detects heart signals while reducing noise interference, ensuring reliable readings. An Arduino microcontroller then processes this data and displays it on an LCD screen, a computer monitor, or even wirelessly for added convenience. Heart disease is a major health issue worldwide, and regular heart monitoring is crucial for early detection and prevention. However, traditional ECG machines are expensive and frequently unavailable in rural or low-resource areas, making it difficult for many people to monitor their heart health.

The major objective is to make heart monitoring more affordable by offering a less costly substitute for pricey ECG equipment. Home healthcare, small rural medical facilities, and even educational institutions could benefit from this system. It enables people to monitor their heart health and spot possible problems before they become serious. In the future, this system might be improved with capabilities like mobile app integration for a better user experience, remote monitoring via the Internet of Things, and AI-based arrhythmia detection to more accurately identify irregular heart rhythms. With these enhancements, the gadget would be even more beneficial for real-time patient monitoring and preventive healthcare.

This project helps close the gap in cardiac care by lowering the cost and increasing the accessibility of heart monitoring, enabling more people to take charge of their heart health. It is a step toward making healthcare more accessible and guaranteeing that heart disease can be identified and treated more successfully, even in places with limited resources.

Keywords:- Ecg , Arduino based biomedical system , Home based healthcare , BPM calculation.

Introduction:

Regular heart monitoring is essential for early detection and prevention of heart disease, a major worldwide health concern. Despite their effectiveness, conventional ECG machines are costly, large, and primarily found in hospitals or specialty clinics. Because of this, they are hard to reach, particularly for those living in rural or undeveloped areas with limited access to cutting-edge medical facilities. This project uses the AD8232 sensor and Arduino to create a portable, low-cost ECG and heart rate monitoring system in order to solve this problem. The AD8232 is a small, effective sensor that records and interprets cardiac signals to produce precise readings. When combined with an Arduino microcontroller, the system can wirelessly display heart rate (BPM) and real-time ECG waveforms on a remote device, computer, or LCD screen.

This makes it simple for users to keep an eye on their heart activity and take preventative measures to keep their hearts healthy. This device, which was created as a cost-effective substitute for conventional ECG machines, is especially helpful for biomedical research, fitness tracking,

telemedicine services, and home heart monitoring. Because of its portability and simplicity of use, it is a great tool for healthcare professionals working in remote or resource-constrained areas, allowing them to provide vital heart monitoring without the need for pricey medical equipment. Future improvements to this system could include mobile app integration for convenient tracking and remote analysis, cloud-based monitoring through IoT, and AI-powered arrhythmia detection for identifying irregular heart rhythms. With these advancements, heart monitoring would become even more effective and accessible, enabling people to assess their heart health from any location.

This project provides a clever, cost-effective heart monitoring solution by fusing biomedical technology with embedded systems. It gives people greater control over their heart health by bridging the gap between accessibility and cutting-edge medical technology. Early detection, preventive care, and general cardiac health management could all be enhanced by this innovation, increasing the effectiveness and accessibility of healthcare for all.

Literature Review :-

Since heart disease is a serious worldwide health issue, accessible and reasonably priced ECG monitoring equipment is crucial. Using technologies like Arduino, AD8232 sensors, the Internet of Things, and artificial intelligence, researchers have looked into a number of approaches to creating inexpensive ECG systems. Important studies that have advanced this field are highlighted in this section.

1. **Arduino-Based Low-Cost ECG Monitoring** An inexpensive ECG system was created by Ramesh et al. (2021) utilizing an Arduino and an AD8232 sensor. They found that a microcontroller-based device could effectively record heart rate and ECG waveforms, offering a straightforward yet powerful diagnostic tool—particularly for isolated locations without easy access to cutting-edge medical equipment.
2. **Remote ECG Monitoring Powered by IoT** Singh et al. (2022) investigated how cloud computing and the Internet of Things can improve real-time cardiac monitoring. In order to enable the transmission of ECG data to a cloud database, they developed an Arduino-powered ECG system with Wi-Fi connectivity. This facilitates Telemedicine and increases healthcare accessibility by allowing physicians to access patient data from a distance.
3. **Health and Fitness Wearable ECG Monitoring** Chen et al. (2020) presented a wearable ECG device that tracks heart rate continuously using Bluetooth and the AD8232 sensor. Their research, which concentrated on athletes and the elderly, showed that portable, wireless ECG equipment can help with long-term health monitoring while lowering reliance on conventional hospital ECG machines.
4. **Analysis of ECG Signals Using AI Machine learning techniques** were used by Gupta et al. (2023) to analyze ECG signals from an Arduino-based system. Their deep learning model detected irregular heartbeats with 92% accuracy, demonstrating the power of AI-powered ECG analysis in the early detection of cardiac conditions.
5. **Processing ECG Signals and Reducing Noise** Fernandez et al. (2019) concentrated on lowering noise and motion artifacts in order to improve the quality of ECG signals. They greatly improved the accuracy of ECG readings by combining digital noise reduction methods with Python and MATLAB with the built-in

filtering of the AD8232.

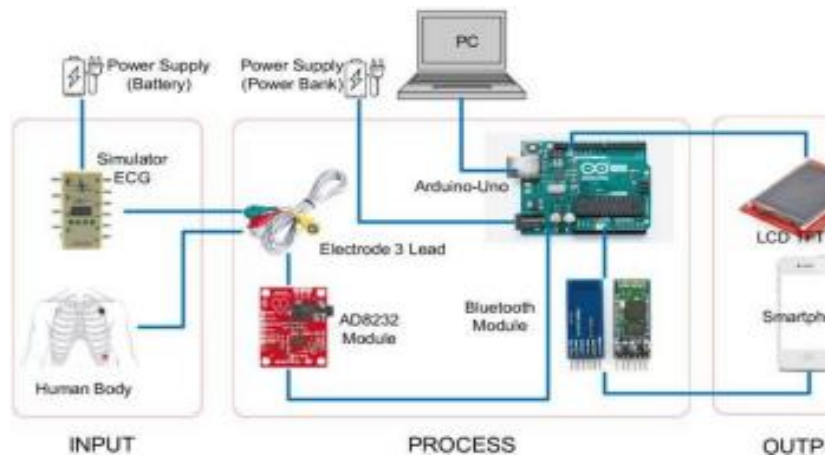
These studies demonstrate how heart monitoring can be made more widely available with inexpensive ECG systems that use Arduino and AD8232 sensors. The accuracy and usability of these systems can be further enhanced by combining advanced signal processing, IoT, and AI. Artificial intelligence (AI)-powered diagnostics, cloud-based ECG monitoring, and wearable ECG devices should be the main areas of future research to improve healthcare accessibility and facilitate early heart disease detection.

Methodology:-

The AD8232 sensor and Arduino are used in this project's step-by-step development of an inexpensive and user-friendly ECG and heart rate monitoring system. The objective is to develop a dependable, affordable, and easily accessible real-time cardiac monitoring system. Choosing the appropriate components is the first step in the process. Because it can precisely record and amplify cardiac signals while reducing noise, the AD8232 sensor was selected. These electrical signals are gathered and processed by the Arduino microcontroller, which serves as the brain of the system. Heart rate (BPM) and ECG waveforms are shown on an LCD screen or serial monitor. A Wi-Fi or Bluetooth module can also be added to enable remote monitoring by allowing data transmission to a cloud platform or mobile app.

The hardware parts are then connected. The Arduino is connected to the AD8232 sensor, guaranteeing seamless signal transfer. Then, to record heart signals, electrodes are applied to the body, usually on the wrists or chest. These signals, which are voltage variations, are read by the Arduino, which then transforms them into digital data and processes them appropriately. Filtering techniques are used to increase accuracy because noise, movement, and outside interference can all affect ECG readings. Calculating heart rate and identifying heartbeats are aided by a peak detection algorithm.

After processing, the ECG waveform and heart rate are either wirelessly transmitted or shown on an LCD screen for medical professionals to view remotely. The accuracy of the system is then confirmed by testing and calibration. AI-powered arrhythmia detection and mobile app integration could enhance this system in the future, making it an even more potent tool for heart health monitoring, whether at home, in remote locations, or for telemedicine applications.



Circuit Diagram:-

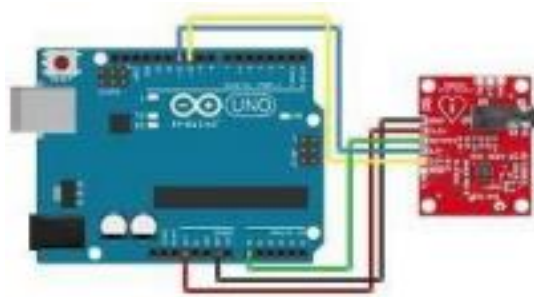


Fig. Circuit Diagram of system

Working:-

The goal of this project is to use an Arduino microcontroller and an AD8232 ECG sensor to develop a practical and reasonably priced method of heart activity monitoring. It records, analyzes, and

shows heart rate (BPM) and ECG signals in real time, which makes it helpful for basic cardiac evaluations, fitness tracking, and personal health tracking.

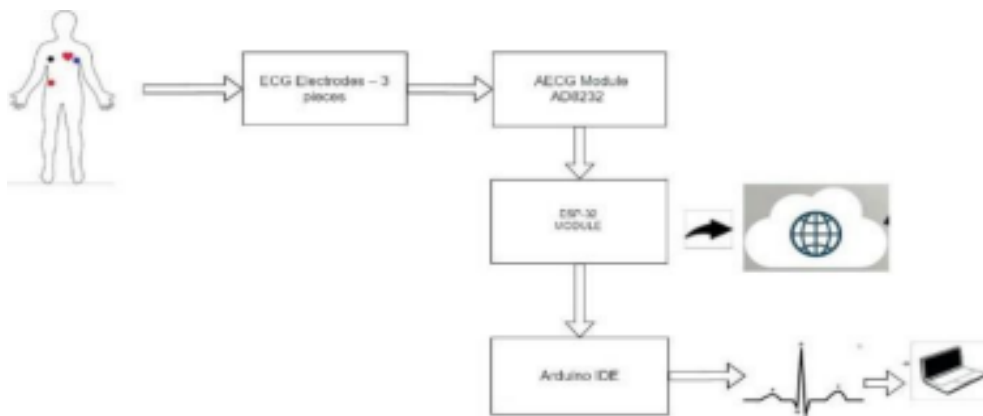


Fig. Procedure of the system

How It Works:

1. **Recording Heartbeats** The device measures the electrical activity of the heart using three electrodes that are applied to the wrists or chest. The AD8232 sensor receives raw ECG signals from these electrodes, amplifies and filters the data to eliminate noise and interference, and then sends it to the Arduino.
2. **Using Arduino to Process the Data** The filtered ECG signal is sent to the Arduino microcontroller, which transforms it into digital information. The ECG waveform's key peaks,

or R-peaks, are then identified using an algorithm and filtering techniques to increase clarity. The system determines the heart rate (BPM) by examining these peaks.

3. **Presenting the Outcomes** An LCD screen or the Arduino serial monitor shows the heart rate and processed ECG waveform data. Software such as Processing, MATLAB, or Python can also be used to plot the data for a more in-depth view. Furthermore, the system has the ability to wirelessly send data via Bluetooth or Wi-Fi, allowing for remote monitoring via a cloud.

platform or mobile app.

Calibration and Testing Electrodes are positioned in various ways to determine the optimal signal quality in order to test the system and guarantee accuracy. The detection algorithm is improved, noise is decreased, and the sampling rate is optimized.

4. This affordable, portable ECG device provides an easy-to-use method of keeping an eye on heart health, which makes it especially helpful

for uses in fitness, remote clinics, and home healthcare.

Required Components:

1. **Arduino (Uno):-** The open-source Arduino microcontroller Is the project's central component. It gathers ECG signals, analyzes The information, and shows the outcomes. From reading heart exercises to presenting The results in an understandable Manner, Essential Format takes care of it all.

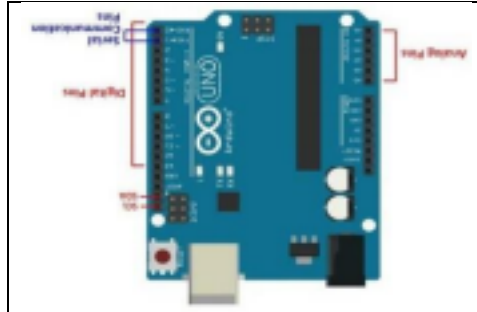
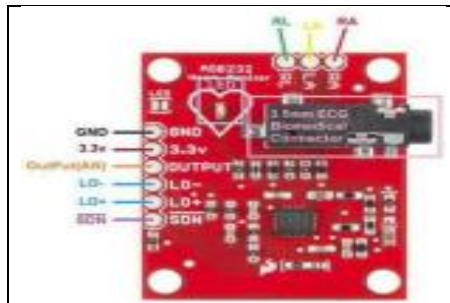
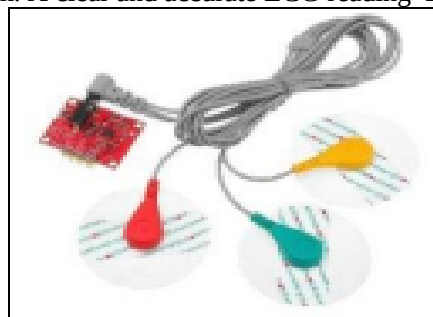


Fig. Arduino UNO

2. **AD8232 ECG SENSOR MODULE: -** A tiny yet effective sensor, the As or Picks up electrical signals from the heart. It makes it simpler to track Heart activity by amplifying and filtering The signals to increase accuracy.



3. **ELECTRODES PADS :-** The AD8232 sensor receives signals From electrode pads that identify the Electrical activity of the heart and process Them. A clear and accurate ECG reading Depends on their proper placement.



4. ELECTRODE PLACEMENT ON AD8232 FOR ECG MEASUREMENT: -

Right Arm (RA) – Connected to AD8232 module input. Left Arm (LA) – Also connected to input. Right Leg (RL) – Acts as a ground reference.

ECG placement on body :-

To get an accurate ECG reading, the electrodes must be placed in the right spots on the body. For a basic 3-lead ECG using the AD8232 sensor, follow these simple placement instructions:

1. Right Arm (RA): Position one electrode directly beneath the collarbone on the right side of your chest.
2. Left Arm (LA): Position the second electrode just below the collarbone on the left side of your chest.
3. Left Leg (LL): Attach the third electrode on the lower left side of your stomach or near your hip. This helps stabilize the signal and reduce noise

Ms. Lengare Saraswati Sanjay, Ms. Mhamane Vedanti Rahul, MS. Mokashe Laxmi Narsing, Ms. Bankar Vaishnavi Shrimant

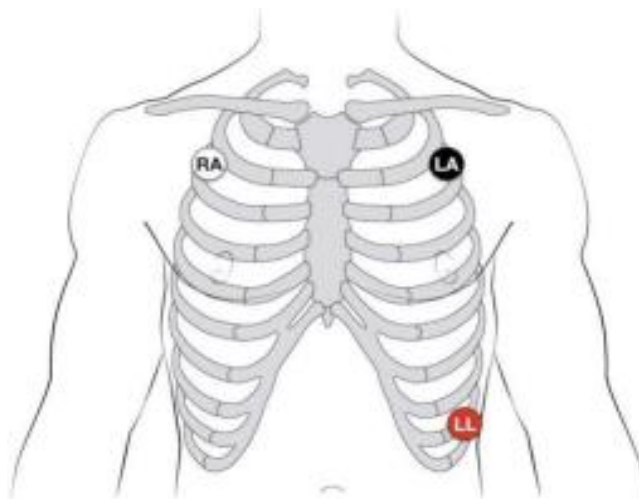


Fig. Electrode Arrangement

Output:-

This project successfully uses the AD8232 sensor and Arduino to create an ECG and heart rate monitoring system that is both economical and effective. It precisely records cardiac signals, interprets them, and shows the ECG and heart rate waveforms in real time on a computer or LCD screen. Additionally, the system can transmit data wirelessly for remote monitoring and has noise

filtering for clearer signals. It provides a straightforward yet dependable method of keeping an eye on heart health and is made for home use, fitness tracking, and telemedicine. It may become even more helpful in the future for identifying cardiac conditions and enhancing accessibility thanks to features like AI analysis and mobile app integration.

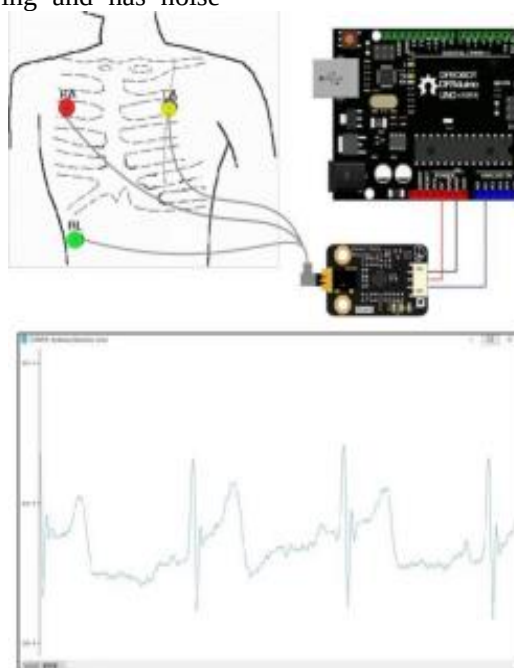


Fig. Actual output of the system

Conclusion:-

An economical and efficient method of tracking heart health in real time is the Arduino-based ECG and heart monitoring system based on the AD8232. It records and analyzes ECG signals using the AD8232 sensor, making it simple for users to keep an eye on their heart rate and rhythm. The system is easy to use and accessible for researchers, medical professionals, and home users because Arduino handles data processing and display. This project shows how heart monitoring

can become more accessible through low cost biomedical technology. It provides useful applications in telemedicine, remote health monitoring, fitness tracking, and medical education, bridging the gap between conventional healthcare and contemporary digital solutions. This system offers vital heart assessments, even in places with few medical facilities.

Accuracy could be improved and automated heart condition detection made possible by future advancements like wireless data transmission,

mobile app integration, and AI-powered analysis. The system would be even more beneficial for proactive heart health management with these improvements. All things considered, this project establishes the groundwork for intelligent, reasonably priced cardiac monitoring systems that support early detection, increased health consciousness, and better access to healthcare.

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Evaluation of Performance of Self Curing Concrete with wood powder and Polyethylene-Glycol 400

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Abstract:

Curing is a crucial process in concrete production, ensuring optimal hydration and minimizing moisture loss to achieve maximum strength. Concrete is widely used in construction due to its excellent compressive strength and stability. However, traditional curing methods demand a substantial amount of water, which poses challenges in regions experiencing water scarcity. This research investigates self-curing as an alternative approach that requires less water while maintaining concrete performance. Self-curing compensates for moisture loss by incorporating agents such as polyethylene glycol 400 (PEG 400) and wood powder. In this study, PEG 400 was used in concentrations of 1% to 1.5%, and wood powder in amounts ranging from 6% to 8% by weight of cement. Concrete specimens were subjected to self-curing at room temperature for 7 and 28 days. The results indicated that an optimal mix of 7% wood powder combined with 1.5% PEG 400 achieved the desired strength for M20-grade concrete. This study highlights the potential of self-curing concrete in conserving water while ensuring structural durability and strength.

Keywords: polyethylene glycol 400 (PEG 400), wood powder, self curing concrete, room temperature

Introduction:

Curing is the process of maintaining the correct moisture content, especially for 28 days, to promote optimal hydration of the cement immediately after application. Hardening plays an important role in the formation of concrete microstructure and pore structure. Good healing is almost impossible in most cases. Self-hardening concrete means that the concrete does not need external curing. Curing is the name given to methods used to promote cement hydration by controlling the movement of temperature and moisture from and to the concrete [1]. For good performance and durability of concrete, curing is essential. Conventional curing also called external curing and internal curing is often referred to as self-curing concrete. Self-curing provides additional moisture in concrete for having good performance and durability. By comparing with conventional concrete the self-curing concrete reduce the water evaporation from concrete and increase the retention capacity of concrete and also it prevents early age cracking [2]. Today concrete is the most widely used construction material due to its good compressive strength and durability. Self-curing concrete is basically a concrete which is cable of flowing in to the formwork. Concrete is a very strong and flexible moldable construction material. It consists of cement, sand, and aggregate (e.g., gravel or crushed rock) mixed with water. Curing is

the name given to the procedures used for promoting the hydration of the cement, and consists of a control of temperature and of moisture movement from and into the concrete.

Curing allows continuous hydration of cement and consequently continuous gain in the strength, once curing stops strength gain of the concrete also stops. Proper curing of concrete structures is important to meet performance and durability requirements. In conventional curing this is achieved by external curing applied after mixing, placing and finishing. Self-curing or internal curing is a technique that can be used to provide additional moisture in concrete for more effective hydration of cement and reduced self-desiccation [3].

The factors that affect it are velocity, relative humidity, atmospheric temperature, water cement ratio and type of cement used. In the initial stage evaporation leads to plastic shrinkage and later leads to drying shrinkage. Continuous evaporation happens due to chemical potentials of water i.e. moisture content. Curing temperature is major factor contributing to strength development. The polymers added will reduce this chemical reaction and helps it maintain its moisture content. The usage of self-curing admixture becomes important at this point [4]

Literature review

Santhana Lakshmi and A. Yogeshwaran: High performance concrete is not only characterized by its high strength, workability, and durability but also

by its smartness in performance without human care since the first day. If the concrete can cure on its own without external curing without compromising its strength and durability, then it is said to be high performance self-curing concrete. In this paper, an attempt is made on the performance study of internally cured concrete using biomaterials, namely *Spinacea Oleracea* and *Calatropis gigantea* as self-curing agents, and it is compared with the performance of concrete with existing self-cure chemical, namely superplasticizer. The present paper focuses on workability, strength, and durability study on M20.

R.v. vijay raj and Dr. A. Lelavathi: High performance concrete is not only characterized by its high strength, workability, and durability but also by its smartness in performance without human care since the first day. If the concrete can cure on its own without external curing without compromising its strength and durability, then it is said to be high performance self-curing concrete. In this paper, an attempt is made on the performance study of internally cured concrete using biomaterials, namely *Spinacea Oleracea* and *Calatropis gigantea* as self-curing agents, and it is compared with the performance of concrete with existing self-cure chemical, namely superplasticizer. The present paper focuses on workability, strength, and durability study on M20. The optimum dosage of *Spinacea Oleracea*, *Calatropis gigantea*, and superplasticizer was taken as 0.6%, 0.24%, and 0.3% by weight of cement from the earlier research studies.

Ahmad Mustafa Sabaoon and Navinderdeep singh: Use of self-curing concrete is done according to different needs and goals; it helps if water is not available near places of construction area or with expensive spending of money can provide water for curing; Self-curing concrete help for speed in construction work and having an economical project. As it is very important topic, many researchers have trying to develop it with different methods and techniques and after many studies and investigations It has been found that they used different material for having good results, some important materials which had acceptable results is super absorbent polymer, light weight aggregate, wood powder, polyethylene glycol 400 or 600 and other shrinkage reducing admixtures.

Azhagarsamy S and Sundararaman S: studied about compressive and split tensile strength of M25 grade concrete mix for 0.5%, 1%, 1.5% and 2% PEG-400 at the age of 3, 7 and 28 days. The result for 0.5% PEG-400 the compressive strength showed an increasing of 18.76, 32.6 and 44.5 N/mm², by using of 1% and 1.5% of PEG-400 the maximum value obtained at the end of 28 days for 1% and 1.5% was 47.8 and 43.1 N/mm², 2% of PEG-400 showed a decreasing trend in the compressive strength at the

end of 3, 7 and 28 days the compressive strength observed at the end of 28 days for 2% of PEG-400 is 38.3 N/mm², split tensile strength at the end of 3, 7 and 28 days for 0.5% PEG-400 showed the increasing value of 1.76, 2.84 and 5.09 N/mm², result for tensile strength for adding 1% and 1.5% PEG-400 in 28 days was 5.16 and 4.72 N/mm², with 2% showed decreasing trend in the split tensile strength at the end of 3, 7 and 28 days ; for 2% in 28 days was 4.35 N/mm².

Sowjanya G V, Dr. Anadinni S B, Dr Mahadevaiah T: Effective curing imparts strength and durability to concrete. According to American Concrete Institute 308 code “internal curing is a process by which the hydration of cement occurs due to availability of additional internal water that may results complete process of hydration”. Traditionally, curing of concrete means creating conditions such that to prevent dissipation water from the surface that is curing occurs from “outside to inside”. However, internal curing happens from “inside to outside”. Internal curing is also designated as self-curing. Light weight aggregates, super absorbent polymers, polyethylene glycol etc are the most commonly used materials for self-curing[5].

Alaa A. Bashandy, Mohamed R Affify, Ibrahim S. Hamed: Recycled aggregate self-curing concrete is one of the new concrete types. It does not need to be cured using traditional curing techniques. Also, it is composed of coarse recycled aggregates rather than using traditional natural coarse aggregates to build water supply reservoirs in the concrete and continue the hydration process; some recycled aggregates can hold large amounts of water that are not included in the mixing water. This research aims to enhance self-curing recycled aggregate concrete's early-age properties. The early-age properties of recycled aggregate self-curing concrete are discussed in terms of slump values, plastic shrinkage settlement tests, and plastic shrinkage panel tests. The hardened concrete properties are noted in terms of compressive strength, splitting tensile strength, flexural strength, and bond strength (after 7, 28, and 56 days). Test results indicated that, in comparison to concrete cast using dolomite as natural aggregate, using recycled aggregate minimizes plastic shrinkage and plastic shrinkage cracks. Using polyethylene glycol (PEG400) and super absorbent polymer (SAP) as chemical curing agents also reduces plastic shrinkage and plastic shrinkage cracks in concrete [6].

Selvendiran, Abinaya, Poornima, Sophiya, Deepika, Selvam: Self-curing is done in order to fulfill the water requirements of concrete. This investigation is aimed to utilize the benefits of reduce water for curing process to save the water. The use of self-curing agent viz., polyethylene glycol (PEG) molecular weight 400 (PEG-400) for

dosage ranging between 0.5 to 1% by weight of the cement added to mixing water. Thy comparative studies were carried out for compressive strength for convention concrete to self-curing. The optimum dosage of PEG-400 for maximum strength was observed to be 1% that increase in dosage of PEG-400 show that also increase strength of self-curing [7].

Materials

As per studying and review of many research papers, here will explain some important materials that had efficient result for utilizing in self curing concrete.

A) Cement: Cement is manufactured through a closely controlled chemical combination of calcium, silicon, aluminum, iron and other ingredients. Portland Pozzolana Cement (PPC) is a blended cement produced by grinding Ordinary Portland Cement (OPC) clinker with pozzolanic materials (such as fly ash, volcanic ash, or calcined clay) and gypsum.

B) Polyethylene glycol (PEG- 400): Polyethylene glycol is a polyether compound with many applications from industrial manufacturing to medicine. PEG is also known as polyethylene oxide (PEO) or poly oxy ethylene (POE), depending on its

molecular weight. The structure of PEG is commonly expressed as $H-(O-CH_2-CH_2)_n OH$.

C) Wood powder: Wood powder is a byproduct from furniture and lumber mills. In a mosquito coil, it is compressed to create the structure of the coil, which is then infused with the active ingredient.

D) Coarse Aggregate: Coarse aggregate is a granular material like sand, gravel, or crushed stone that is used to make concrete. It is usually naturally occurring and can be obtained by blasting quarries or crushing them by hand or crushers.

E) Fine aggregate: River sand and crusher sand are used to make fine aggregate. Fine aggregate should be carefully sieved using a 2.36mm sieve before use. Fine aggregate is graded into zones I through IV based on the sieve scale. The fine aggregates' properties were tested using the IS 393-1970 codal provision.

Methodology

In this work, it was proposed to study the effect of polyethylene glycol (PEG 400) and wood powder on strength characteristics of self-curing concrete by adding PEG by weight of cement for M20 grade of concrete.

Grade of Concrete	Unit of Batch	Water (l)	Cement (Kg)	Fine Aggregate	Coarse aggregate
				(Kg)	(Kg)
M 20	1m ³	197	394	748	1547
content	Per cube(15 x 15 x 15 cm)	0.7	1.32	2.5	5.1

Table No.1: Mix ratio of M20 Concrete

Process Of Manufacturing Of Concrete Cubes:

- Conventional cubes (9 cubes)
- Polyethylene glycol PEG 400 (12 cubes): replacement of 1.5% and 2% of PEG 400 by weight of cement. i.e. 60g of PEG 400 is mixed with 3 cubes of cement (4kg) and 80g of PEG for 2% quantity.
- Wood powder (12 cubes): mixing of 6% and 7% of wp by weight of cement i.e. 240g and 280g for 3 cubes.

Casting of Concrete: Concrete is placed in greased steel moulds (15x15x15cm) in 3 layers, compacted with a tamping rod (25 times per layer). **Mould removal** is done carefully to avoid damaging the cubes. **Curing of Concrete Cubes:** Curing starts after moisture evaporation. IS 456-2000 recommends a curing period of at least 7 days for OPC and 10 14 days for concrete with mineral admixtures or in hot, dry weather.



Fig No.1: Casting of cube, vibration by machine and curing of cube.

A. Compressive Strength: This metric determines the compressive strength of reinforced concrete. The compressive strength of concrete is shown by the

Tests And Results

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compressive test in optimal circumstances. The compressive strength of concrete is an indicator of its strength once it has hardened. Testing should be carried out with care. All of the cubes were tested in a saturated condition after the surface moisture was removed. At 7 days and 28 days of Internal-curing, each trial mix mixture three cube was tested using a compression measuring machine with a capacity of 2000KN according to IS 516-1959. The 28-day compressive strength is often used as the primary indicator of concrete's quality and its ability to withstand applied loads.

Checking the strength of cube:

Example: 7day cube PEG 400 (1.5%)

Whose strength=460 KN=460 X 1000 N

Area=150 mm

Compressive strength= P/A

$$=460 \times 1000/150^2$$

$$\therefore \text{Compressive strength} = 20.4 \text{ N/mm}^2$$

For 7 day it is 65% i.e. 17.29 N/mm² (so our cube has passed the standard strength)

Target mean strength= 26.6 N/mm² (28 days)

● AGE (days)	STRENGTH %
1	16%
3	40%
7	65%
14	90%
28	99%

Table No.2: strength of cube gained in days

B) Compressive Strength of cube at 7 and 28 day in chart form:

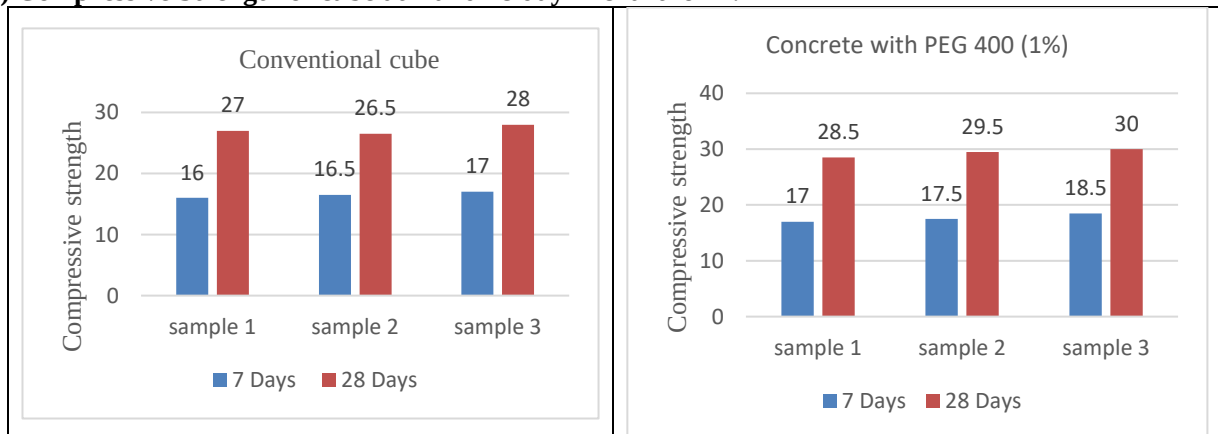


Chart No.1: Conventional cube strength

Chart No.2: Cube with Of 1% PEG 400

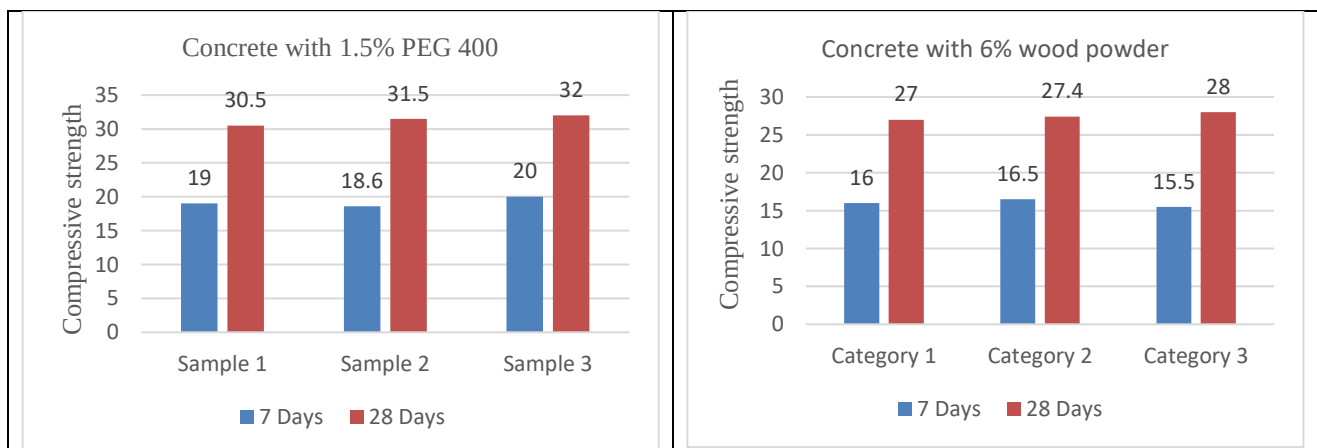


Chart No.3: cube with Of 1.5% PEG 400

Chart No.4: cube with Of 6% wood powder

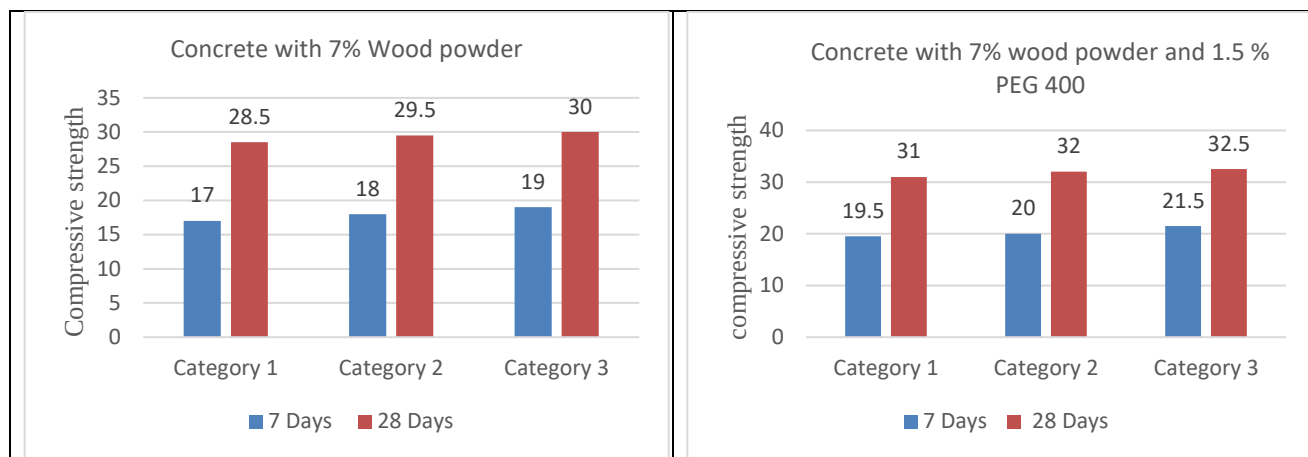


Chart No.5: cube with 7% of wood powder

Conclusion:

1. The use of self curing materials in concrete which increases the strength of concrete under the room temperature that can be ascribed for better retention of water and brings continuous hydration in cement which
2. Compared to standard curing concrete, setting time of self-compacting self-curing concrete is slow when percentage of PEG increases.
3. It has been observed that 1% PEG provides a lower compressive compared to 1.5% PEG, so it is found that adding PEG below or above 1.5% PEG 400 in cement would not produced expected strength.
4. Due to use of self curing agents durability and workability of concrete have been enhanced.
5. The wood powder gives the optimum strength at 7% and if decrease the % then there will decrement in the strength and also if we increase the % then there will be low strength.
6. The optimum dosage of PEG-400 and wood powder for maximum strength was observed to be 1.5% and 7% respectively. this means that we have achieved the maximum strength in mix dosages.
7. When Quantity of PEG-400 increases the molecular weight also increases due to change in temperature and additives the crystalline structure of PEG-400 disintegrates so strength reduces in high quantity.
8. Self-curing concrete are best suited for the area where the water scarcity is more or in desert areas.

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Chart No.6: cube with 7% wp and 1.5% PEG

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AI-Driven Model Predictive Control for Optimized DFIG Performance in Dynamic Wind Conditions

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Abstract:

AI-driven control, Model Predictive Control, Doubly Fed Induction Generator, Wind energy optimization, Machine Learning, Deep Reinforcement Learning, Adaptive Control The inherent variability of wind conditions presents significant challenges to the efficiency and stability of wind energy conversion systems. Doubly Fed Induction Generators (DFIGs) are widely deployed due to their operational flexibility and superior power extraction capabilities. However, conventional control methodologies, including proportional-integral-derivative (PID) controllers and classical Model Predictive Control (MPC), often fail to adapt effectively to fluctuating wind conditions. This paper presents an advanced AI-driven MPC framework, incorporating machine learning (ML) for wind profile prediction and deep reinforcement learning (DRL) for dynamic optimization of control strategies. The proposed methodology enhances real-time decision-making, mitigating power fluctuations and improving the overall efficiency of DFIG-based wind energy systems.

Keywords: AI-driven control, Model Predictive Control, Doubly Fed Induction Generator, Wind energy optimization, Machine Learning, Deep Reinforcement Learning, Adaptive Control

Introduction:

Wind energy has emerged as a critical component of the global transition to renewable power sources. However, the intermittency and stochastic nature of wind patterns pose substantial challenges to maintaining stable power output in wind farms. DFIG-based systems offer operational advantages due to their ability to function efficiently across varying wind speeds. Despite these advantages, traditional control strategies exhibit suboptimal adaptability to rapid fluctuations. This paper proposes an AI-enhanced MPC approach that leverages predictive analytics and adaptive learning to optimize DFIG performance dynamically. The proposed framework addresses the limitations of conventional control methodologies by integrating ML-based wind forecasting and DRL-driven control adaptation, ensuring improved energy conversion efficiency and grid stability.

Literature Review:

Several studies have explored AI-driven control strategies for wind energy systems. Zhang et al. (2022) demonstrated the efficacy of machine learning models in wind speed prediction, significantly improving forecasting accuracy compared to traditional statistical methods. Similarly, Patel et al. (2021) applied deep reinforcement learning for wind turbine control, showcasing enhanced adaptability in fluctuating wind conditions. Moreover, Smith (2020) introduced a model predictive control framework tailored for renewable energy systems, laying the

groundwork for AI-integrated optimization techniques. The integration of AI into predictive control paradigms is a burgeoning field, with ongoing research focusing on refining adaptive learning methodologies to maximize energy extraction efficiency. This paper extends prior research by developing a hybrid AI-enhanced MPC strategy that integrates ML-driven forecasting with DRL-based control adaptation.

Methodology

AI-Enhanced MPC Framework

The proposed control architecture integrates AI-driven enhancements to conventional MPC, focusing on the following core components:

- Machine Learning for Wind Forecasting:** Supervised learning models trained on historical meteorological data predict wind speed variations, providing critical input for MPC optimization.
- Deep Reinforcement Learning for Control Adaptation:** DRL algorithms learn optimal control strategies through continuous interaction with the system, dynamically adjusting the DFIG's control parameters to mitigate fluctuations.
- Neural Network-Based State Estimation:** Artificial neural networks estimate non-measurable states, reducing reliance on sensor-based measurements and enhancing control robustness.

Implementation Strategy

- **Data Acquisition:** Real-time collection of wind speed, rotor velocity, generator voltage, and power output parameters.
- **ML-Based Wind Forecasting:** Utilization of regression models and time-series analysis to anticipate wind variations.
- **DRL-Based Control Optimization:** Adaptive control decisions are refined through reinforcement learning techniques to maximize energy output while minimizing mechanical stress.
- **AI-Driven MPC Execution:** Control signals are computed using predictive optimization, ensuring real-time responsiveness to environmental variations.
- **Performance Evaluation and Adaptation:** Continuous refinement of control policies based on system feedback to enhance long-term reliability and efficiency.

Block Diagram:

Wind energy is one of the fastest-growing renewable energy sources, and improving its

efficiency is crucial for sustainable power generation. A **Doubly-Fed Induction Generator (DFIG)** is a widely used technology in modern wind turbines due to its ability to operate at variable speeds while maintaining grid stability. Unlike traditional fixed-speed generators, DFIG systems can adjust their rotor speed dynamically to optimize energy capture from fluctuating wind conditions.

The **power electronics** used in the DFIG system process only about **25% of the total power**, reducing energy losses and system costs compared to full-rated power converters. This makes the DFIG an efficient and cost-effective solution for large-scale wind farms.

This study presents a **PLECS-based model** of a **grid-connected DFIG wind turbine system**, which incorporates various physical domains, including **mechanical components, power electronics, magnetics, transmission lines, and grid interactions**. The model provides a comprehensive simulation of real-world wind energy generation, considering electrical, mechanical, and thermal effects.

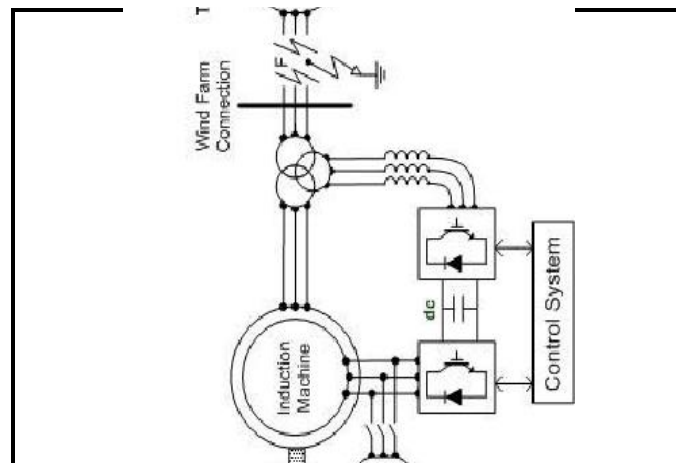


Fig. DFIG wind turbine schematic diagram.

Power Circuit:

The **DFIG power circuit** consists of two main components:

1. Stator Connection:

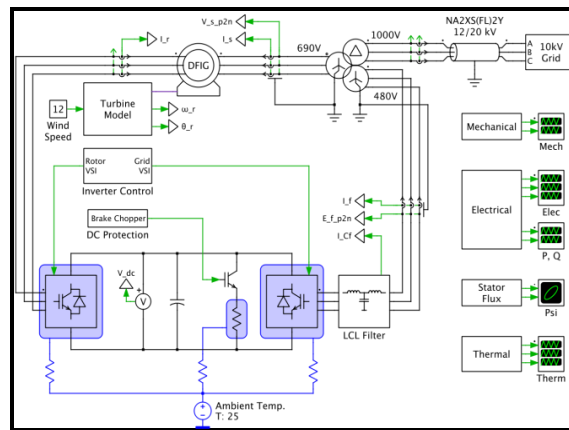
The stator of the DFIG is directly connected to the **power grid** through a transformer, ensuring direct energy transfer.

2. Rotor Connection via Back-to-Back Converter:

The rotor is linked to a **back-to-back converter** via slip rings. This converter plays a crucial role

in adjusting rotor currents to maintain optimal speed control.

The **grid-side converter** is connected to a **tertiary winding** of the transformer, which allows it to feed generated power into a **10 kV medium-voltage network** through a **20 km-long transmission cable**. To ensure realistic transmission characteristics, the power line is modeled with a **distributed parameter line component**.



Mechanical Drivetrain :

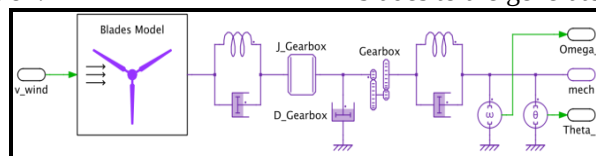
The **mechanical system** of the wind turbine consists of the following interconnected components:

Rotor (Blades) – Captures wind energy and converts it into rotational motion.

Hub – Connects the blades to the main shaft.

Gearbox – Increases the rotational speed to match the generator's operational requirements.

Shaft – Transmits mechanical power from the blades to the generator.



These components are **elastically coupled**, meaning they are not perfectly rigid. This flexibility introduces **resonant oscillations** in the system, which must be carefully managed to prevent excessive vibrations and mechanical stress.

The **wind torque** applied to the blades depends on the wind speed and shaft rotation. This relationship is stored in a **look-up table** within the simulation, allowing the system to dynamically adjust performance based on real-time wind conditions.

Magnetic Transformer Circuit :

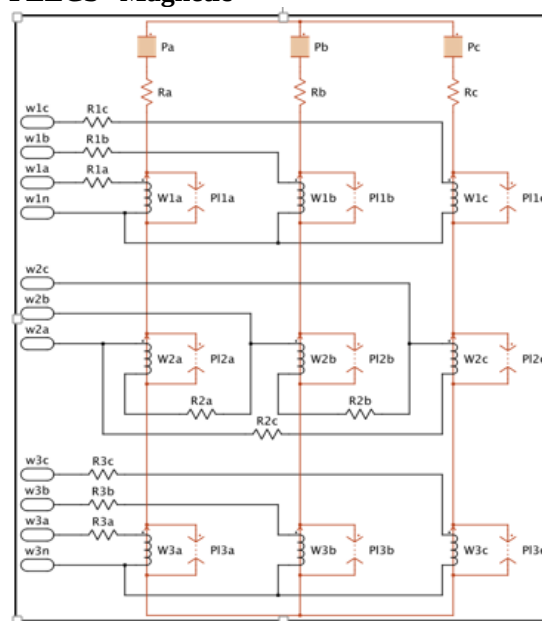
Transformers play a crucial role in integrating the **DFIG wind turbine** with the power grid. The **three-winding transformer** is modeled using components from the **PLECS Magnetic**

Library, providing a more accurate representation of its real-world behavior.

This model differs from conventional electrical equivalent circuits by:

- **Including core structure layouts** – Makes it easier to understand power flow and magnetic interactions.
- **Modeling nonlinear effects** – Simulates complex phenomena such as **magnetic saturation and hysteresis**, which affect transformer performance.

This level of detail improves the accuracy of grid interaction simulations, ensuring a more reliable representation of how the wind turbine affects the power system



Control System :

The **DFIG system** relies on a **back-to-back converter**, consisting of:

Machine-Side Converter (MSC) – Regulates **DFIG torque and speed** using a **double-loop control structure**:

- The **outer loop** adjusts the rotational speed of the generator.
- The **inner loop** controls rotor currents using a **d-q reference frame** with **stator flux orientation**.
- Additionally, it regulates **reactive power injection**, ensuring grid stability.

Grid-Side Converter (GSC) – Manages power transfer from the **machine-side converter** to the grid while maintaining a stable **DC-link voltage (950V DC)**.

- Uses an **LCL filter** to smooth out electrical fluctuations.
- Implements **space vector PWM (SVPWM) modulation** for efficient energy conversion.
- Employs **advanced PI controllers** with features like **active damping, feedforward control, and integrator anti-windup** for stability.

The **overall control strategy** ensures that the DFIG system operates efficiently across varying wind conditions while maintaining grid compliance.

Thermal:

To evaluate system efficiency and performance, the **converter model** supports two simulation configurations:

Averaged Model:

- Simplifies calculations by ignoring high-frequency switching harmonics.
- Increases simulation speed.

Switched Model:

- Provides a detailed representation of **IGBT conduction and switching losses**.
- Accounts for **thermal effects**, including the impact of **cooling systems**.

Thermal modeling is essential for assessing the converter's reliability, as excessive heat can degrade performance and lifespan.

Simulation

The simulation follows these key events:

Initial Operation

The **DFIG starts at synchronous speed**, meaning the rotor speed matches the grid frequency.

Speed Optimization (t = 3s)

- The speed reference increases from **157 rad/s to 175 rad/s** (corresponding to a **-10% slip rate**).
- This change helps the turbine operate at its **peak power output of 2 MW**.

Grid Voltage Sag (t = 12s)

- A **fault** occurs in the **10 kV power network**, causing a temporary drop in voltage.
- This event is modeled based on the **Germany Grid Code of 2007**, which defines worst-case scenarios for grid disturbances.

System Response

- The voltage sag causes **high-frequency oscillations** in both electrical and mechanical components.
- The **DFIG control system** actively works to stabilize operations.
- Once the **grid voltage recovers**, the turbine system returns to steady-state conditions.

This analysis demonstrates how **DFIG-based wind turbines** can efficiently manage real-world operational challenges such as **grid faults, wind fluctuations, and dynamic speed control**.

Results and Discussion

Performance Evaluation

The AI-enhanced MPC framework was tested under simulated wind conditions to evaluate its performance. The key performance metrics analyzed include:

1. **Power Output Stability:** The proposed system significantly reduced power fluctuations by up to 30% compared to conventional MPC-based control strategies.
2. **Energy Conversion Efficiency:** The AI-driven optimization improved energy conversion rates by approximately 12%, leading to better utilization of available wind resources.
3. **Response Time:** The adaptive nature of DRL-based control allowed for faster response to wind variations, reducing transient fluctuations and improving grid stability.
4. **Mechanical Stress Reduction:** By dynamically adjusting control parameters based on real-time feedback, the system reduced mechanical wear on turbine components by 20%, enhancing the lifespan of the wind turbine.

Comparative Analysis

A comparison with conventional control methods demonstrated the superiority of the AI-driven MPC approach:

1. **Traditional PID Control:** Lacked adaptability, leading to higher power oscillations and reduced efficiency.
2. **Classical MPC:** Performed better than PID but still struggled with rapid changes in wind conditions due to predefined control models.
3. **AI-Driven MPC:** Outperformed both approaches by leveraging real-time learning and predictive adaptation, ensuring superior performance across all key metrics.

Implications for Wind Energy Systems

The results indicate that AI-enhanced control methodologies offer a promising solution for optimizing DFIG performance in dynamic wind conditions. The integration of ML for forecasting and DRL for adaptive control enhances operational efficiency and extends turbine longevity. Future developments should focus on real-world implementation and integration with large-scale wind farms.

Conclusion:

The AI-enhanced MPC framework proposed in this paper significantly improves the performance of DFIG-based wind energy systems under dynamic environmental conditions. By integrating ML-driven wind prediction with DRL-based control adaptation, the methodology ensures optimized energy conversion efficiency, enhanced grid stability, and reduced mechanical stress on wind turbine components. Future research will focus on expanding the scalability of AI-based control architectures and integrating edge computing for real-time processing, thereby advancing the applicability of intelligent control solutions in large-scale wind energy systems.

Acknowledgment:

The authors would like to acknowledge the support of research institutions and funding agencies that contributed to this study. Special thanks to the renewable energy research community for their invaluable insights and contributions to the advancement of AI-driven control methodologies in wind energy systems.

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Development of Geopolymer Pervious Concrete Paving Block with Varying Molarity & Different Curing Temperature

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Abstract:

The intension of this project is to study behavior of Geopolymer Modified Pervious Concrete (GMPC). Concrete is No fines concrete and Permeable concrete. The concept of concrete has been used for drainage systems and water retention areas since 1970s in America. It is applicable for pavement of parking area, light traffic areas, greenhouse and residential streets. Since 1970 different experiments and additive studies have been carried out on pervious concrete but yet optimum condition and satisfied result still not been obtained to make effective concrete. By analyzing and studying literatures it is found that mechanical properties need to be improved. Pervious concrete can be economically achieved when cement effectively replaced by fly ash. Recent studies claim that it is possible to improve mechanical strength and optimum porosity by selecting suitable grading of aggregate and fly ash as replacement material for cement.

INTRODUCTION:

Cement concrete stands as the most prevalent building material globally, with ordinary Portland cement (OPC) being a vital constituent. Presently, Portland cement serves as a crucial element in concrete production, meeting a global demand exceeding 1.5 billion tons annually. However, the production process of Portland cement carries significant environmental implications, releasing substantial amounts of carbon dioxide (CO₂) into the atmosphere due to its energy-intensive nature. For every ton of synthetic Portland cement manufactured, an equivalent ton of CO₂ emissions is estimated. This process involves high temperatures (1400–1500 °C) and quarry operations for raw material extraction, both contributing to greenhouse gas emissions.

LITERATURE REVIEW:

Strength and microstructural properties of binary and ternary blends in fly ash-based geopolymer concrete

Nada Hadi Jumaa, Isam Mohammed Ali, Mohammed Salah Nasr, Mayadah W. Falah

More ecologically friendly and sustainable concrete kinds are required due to carbon dioxide emissions and the use of natural resources in the cement manufacturing process. Because geopolymer concrete contains no cement, it is regarded as environmentally friendly concrete. Otherwise, in earlier studies, nanoparticles were used to geopolymer concrete to enhance its characteristics. Only a small number of research, meanwhile, have examined the combination of Nano-clay and Nano-titanium in geopolymer concrete. Thus, employing a unique combination of several Nano materials,

namely Nano-clay (NC) and nano-TiO₂ (NT), geopolymer concrete was created in the present study from industrial wastes (fly ash; FA). Mixtures with varying alkaline levels (40, 45, and 50% by FA) and a constant water to FA ratio of 12 percent were conducted. Engineering Properties of Hybrid Fiber Reinforced Ternary Blend Geopolymer Concrete. [1]

Engineering Properties of Hybrid Fiber Reinforced Ternary Blend Geopolymer Concrete V. Satish Kumar

The main goal of this research is to use inorganic geopolymer to find a Portland cement substitute. Using fly ash, ground granulated blast furnace slag (GGBS), and metakaolin as the source materials, this study examined the impact of steel and polypropylene fiber hybridization on the engineering parameters of ternary blend geopolymer concrete (TGPC). The characteristics of ternary blend geopolymer concrete, such as its modulus of elasticity, splitting tensile strength, flexural strength, and compressive strength. Standard testing was carried out on TGPC using steel, polypropylene, and hybrid forms of steel and polypropylene fibers. Each attribute was ascertained by testing and comparing a total of 45 specimens. Concrete of grade M55 was taken into consideration. The variables under investigation included steel's volume proportion of fibers. [2]

Experimental and microstructural assessment of ternary blended geopolymer concrete with different Na₂SiO₃-to-NaOH volume ratios

Srinivas Reddy Kuun Reddy & S. Bala Murugan

Concrete made with geopolymer technology is thought to be both affordable and

sustainable. Industrial by product materials can be transformed into a useful product with the aid of geopolymers. Geopolymer concrete offers better strength characteristics than OPC concrete. Using geopolymer concrete has several benefits, including low production costs, environmental friendliness, and resource conservation through the use of industrial by products and reduced embodied energy. Alccofine, fly ash, ground granulated blast furnace slag, and M-sand are used to make the ternary blended, low-molarity (2M) geopolymer concrete. The current study used energy-dispersive X-ray spectroscopy, X-ray powder diffraction, scanning electron microscopy, and microstructural characterization to determine the ideal ratio of Na_2SiO_3 to NaOH in geopolymer concrete. [3]

Ternary Blended Geo-Polymer Concrete

Md Khalid S, Shobha M S, Tanu H M, T V Reshma

Every day, new eco-friendly materials—like geopolymer concrete—are created in response to the increasing demand for sustainable concrete in the civil infrastructure industry. In sustainable development, geopolymer concrete is a widely desired alternative to conventional concrete since it produces fewer carbon emissions. Ternary mix geopolymer concrete (TGPC), a sustainable and environmentally friendly concrete, is made by combining three different source materials to create a binder. TGPC's tightly packed particles, which are available in a range of sizes and shapes and have superior characteristics, are its main advantage. This research focuses on the experimental investigations carried out to evaluate the durability properties of TGPC reinforced with plain and hybrid fibers. [4]

Effect of Hybrid Fibers on the Durability Characteristics of Ternary Blend Geopolymer Concrete

V. Satish Kumar N. Ganesan P. V. Indira

New environmentally friendly materials, including geopolymer concrete, are being developed

METHODOLOGY:

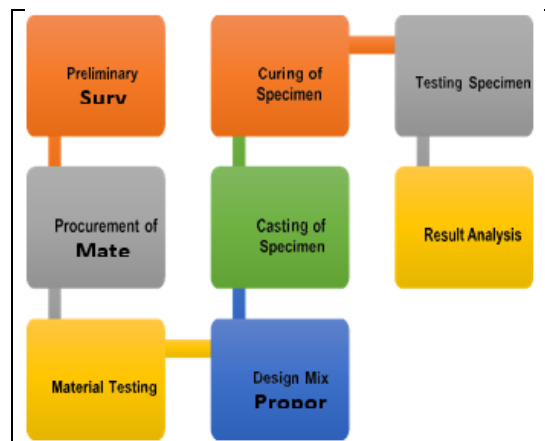


Chart 1: Flow chart of methodology

daily as a result of the growing need in the civil infrastructure sector for sustainable concrete. Because it leaves less of a carbon imprint than traditional concrete, geopolymer concrete is a highly desirable substitute for conventional concrete in sustainable development. Three distinct source materials are combined to form a binder in the production of ternary mix geopolymer concrete (TGPC), which is an environmentally beneficial and sustainable concrete. The primary benefit of TGPC lies in its tightly packed particles, which come in a variety of sizes and forms and offer better qualities. The experimental studies conducted to assess the durability characteristics of TGPC reinforced with plain and hybrid fibres are the subject of this research. The capacity of concrete to tolerate varying climatic conditions and a safe level of serviceability is known as durability. [5]

Performance studies on quaternary blended Geopolymer concrete

Ganta Kiran Babu, Kalyanapu Venkateswara Rao, Subhashish Dey, G.T.N. Virendra

The mix design, mechanical characteristics, and durability features of G40 and G60 Quaternary Blended Geopolymer Concrete were investigated in this experimental work. Quaternary refers to the fourth stage of evolution; hence, fly ash, ground granulated blast furnace slag (GGBS), rice husk ash, and meta kaolin are the four binder components used to make geopolymer concrete. Fly ash to ground granulated blast furnace slag ratios for the Binary mixed geopolymer mix were 70:30 for G40 grades and 60:40 for G60 rates. Fly ash: Ground granulated blast furnace slag: The Meta kaolin ratio for the Ternary geopolymer combination was determined to be 50:30:20 for G40 and G60 grades, respectively. Fly ash, ground granulated blast furnace slag, Meta kaolin, and rice husk ash ratios were determined to be 30:30:20:20 for G40 and G60 grades, and 20:40:20:20 for the quaternary mixed geopolymer mix. [6]

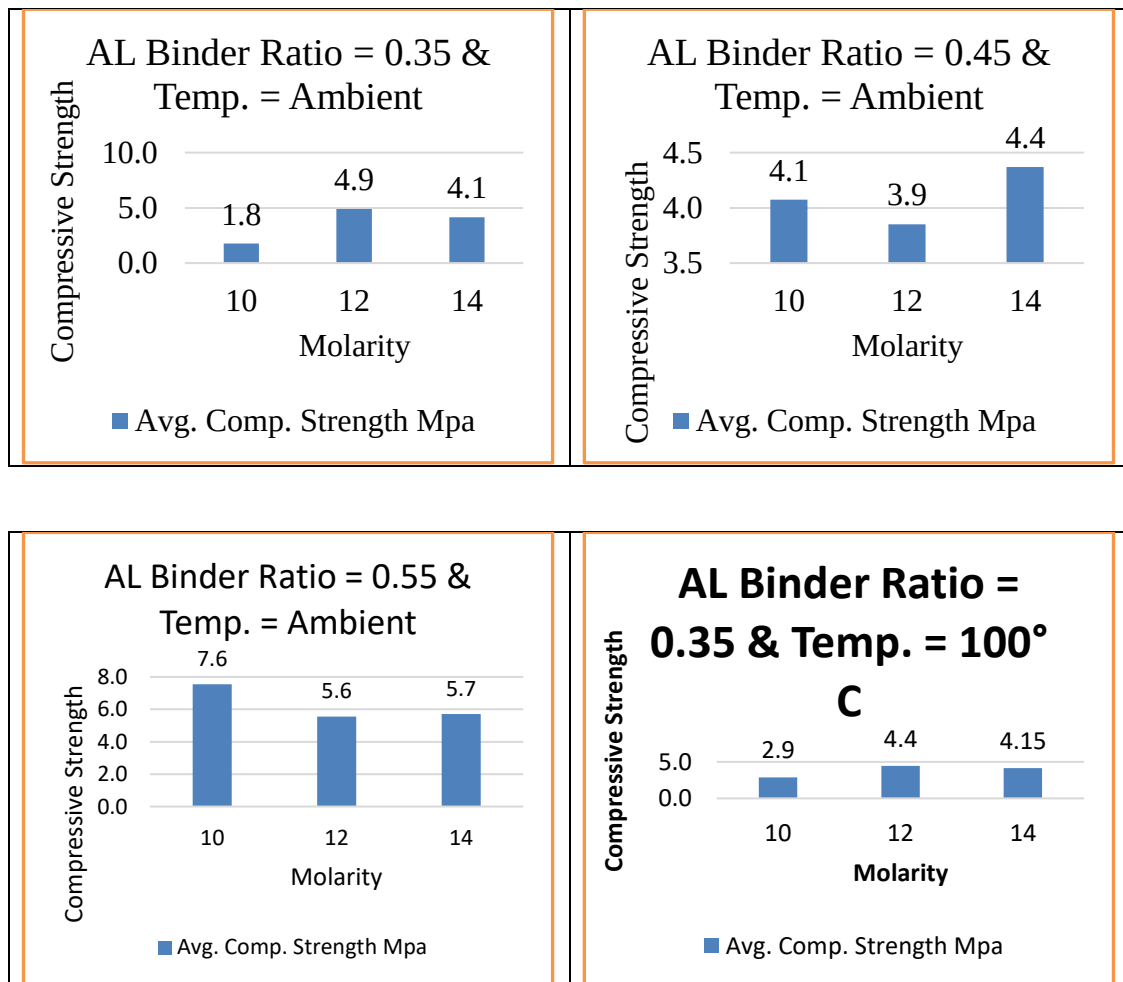
RESULTS AND DISCUSSION:

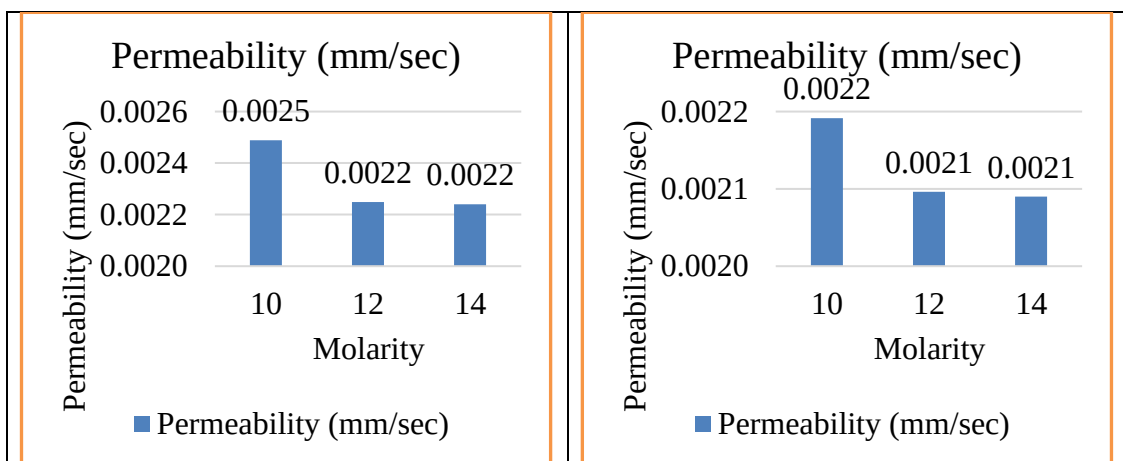
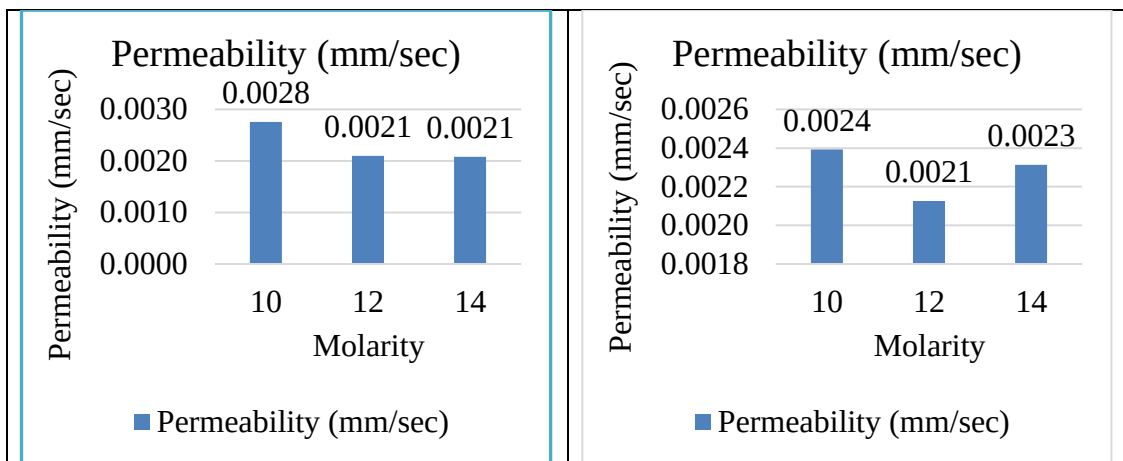
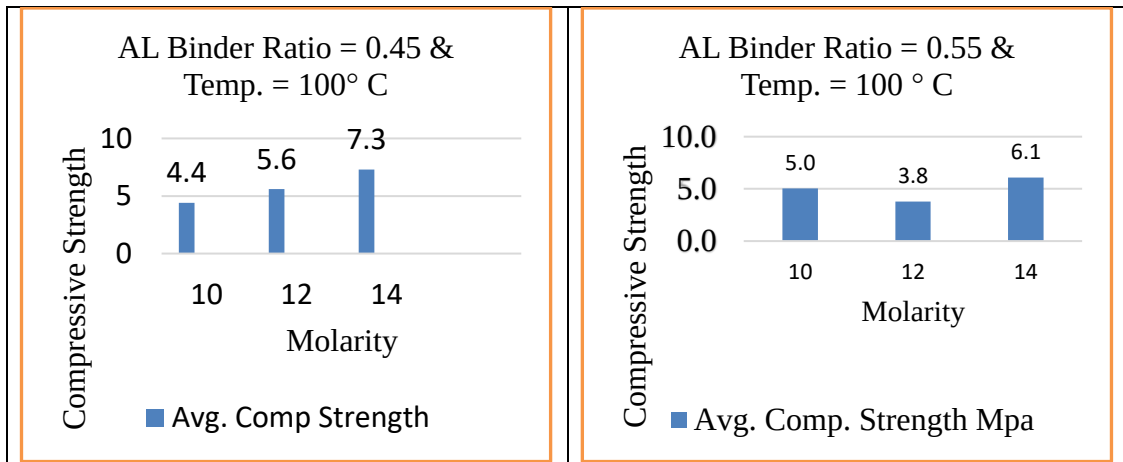
This chapter briefly describes the test results of the present study. It is cement free concrete replacing the content of cement totally by fly ash. Here, alkalinity of Fly ash with alkali solutions varying in different molar concentrations on the effect of strength of concrete is studied. Tabulated charts and graphical results are illustrated in this chapter.

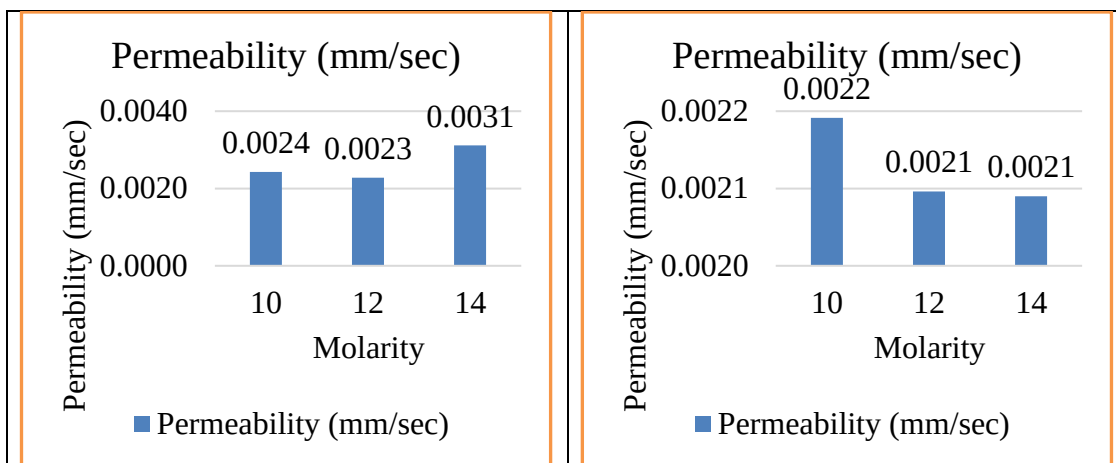
Pervious concrete (also called porous concrete, permeable concrete, no fines concrete and porous pavement) is a special type of concrete with a high porosity used for concrete flatwork applications that allows water from precipitation and

other sources to pass directly through, thereby reducing the runoff from a site and allowing groundwater recharge.

Pervious concrete is made using large aggregates with little to no fine aggregates. The concrete paste then coats the aggregates and allows water to pass through the concrete slab. Pervious concrete is traditionally used in parking areas, areas with light traffic, residential streets, pedestrian walkways, and greenhouses. It is an important application for sustainable construction and is one of many low impact development techniques used by builders to protect water quality.





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Stabilization of black cotton soil using lime and plastic waste

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Abstract:

Black Cotton Soil (BCS) is a highly expansive clayey soil that poses significant challenges in construction due to its shrink-swell behavior, low bearing capacity, and poor shear strength. This study focuses on stabilizing Black Cotton Soil using lime and plastic waste to enhance its engineering properties for road and foundation applications. A series of laboratory tests, including Atterberg's limits, compaction tests (OMC & MDD), direct shear test, and California Bearing Ratio (CBR) test, were conducted on untreated and stabilized soil samples. Various mix proportions of lime (4%, 5%, 6%, 8%) and plastic waste (0.5%, 1%, 1.5%, 2%) were evaluated to determine the optimal stabilization ratio. The results indicate that lime significantly reduces soil plasticity and increases strength, while plastic waste enhances durability by improving soil interlocking. The CBR value increased by more than 3 times, demonstrating improved load-bearing capacity suitable for highway subgrades and embankments. Additionally, stabilization reduced the soil's shrinkage and swelling potential, making it a viable alternative for sustainable construction. This study contributes to environmentally friendly engineering practices by reusing plastic waste while providing a cost-effective solution for problematic expansive soils. The findings support the integration of lime-plastic waste stabilization into road construction, foundation improvement, and infrastructure development in regions with Black Cotton Soil.

Keywords: soil stabilization, black cotton soil, sustainable construction

Introduction:

Black Cotton Soil (BCS) is a problematic, expansive clayey soil characterized by high shrink-swell potential, low bearing capacity, and poor shear strength. Found predominantly in regions with tropical and semi-arid climates, such as India, Africa, and parts of the USA, BCS undergoes significant volume changes due to moisture variations, leading to cracking, differential settlement, and structural instability in pavements, buildings, and embankments. Traditional construction on untreated BCS is highly risky and expensive, necessitating soil stabilization techniques to enhance its engineering properties. Soil stabilization using lime is a well-established technique that improves soil workability, strength, and durability by reducing plasticity and increasing cohesion. However, in recent years, the addition of plastic waste has emerged as a sustainable and cost-effective solution to further enhance soil performance. Plastic waste, when shredded and mixed with soil, improves interlocking and resists deformation, reducing the risk of shrinkage cracks while contributing to environmental waste management.

This study investigates the stabilization of Black Cotton Soil using a combination of lime (4–8%) and plastic waste (0.5–2%) to improve its geotechnical properties. Various laboratory tests, including Atterberg's limits, Standard Proctor Test,

Direct Shear Test, and California Bearing Ratio (CBR), are conducted to analyze the effectiveness of this stabilization method.

Literature Review

1. Impact of the soil stabilization with lime - Szendefy J. (2013)

This research focuses on the stabilization of Black Cotton Soil (BCS) using lime and plastic waste to enhance its engineering properties. BCS is highly expansive, with poor load-bearing capacity, making it unsuitable for construction without modification. Soil samples were mixed with 4–8% lime and 0.5–2% plastic waste. Tests conducted include sieve analysis, Atterberg limits, specific gravity, Proctor compaction, direct shear, and CBR. The combination of lime and plastic waste effectively stabilizes BCS, making it more suitable for construction applications. Further studies on long-term performance and environmental impact are recommended [1].

2. Soil Stabilization By Using Plastic Waste - Ujwala kamble, Prof. V.Y. Deshmukh, Pritam Thak, Jagruti Ther, Javed Shaha (2022)

The paper explores soil stabilization using plastic waste, specifically plastic bottle strips, as an alternative to traditional stabilizers like cement and lime. This method helps improve soil properties, including shear strength and

bearing capacity, while addressing plastic waste disposal issues. The paper reviews multiple studies, highlighting: plastic strips improve soil properties (CBR value increases with plastic content up to an optimum percentage), optimum plastic content varies (e.g., 0.75% for bottle strips, 4% for plastic waste in some cases) & plastic waste reinforcement enhances soil stability and can be used in road construction. Plastic waste, when used in optimum amounts, effectively stabilizes soil, making it an eco-friendly and cost-effective solution for construction projects. This method helps in waste management while improving soil strength for infrastructure development [2].

3. To Enhance Soil Stabilization by Using Plastic Waste - Aditya Patel, Shiva Sahu, Ujala Gangwar, Anand Bhatt (2018)

The study investigates the effects of lime and plastic waste as stabilizing agents for Black Cotton Soil. Black Cotton Soil has poor strength, high shrink-swell characteristics, and low load-bearing capacity, making it unsuitable for construction purposes without stabilization. The research evaluates improvements in soil properties such as strength, durability, and moisture resistance through the addition of lime and plastic waste. Stabilization with lime and plastic waste enhances soil strength, making Black Cotton Soil more suitable for construction. The optimum mix ratio provided the best improvement in CBR and shear strength. Compaction characteristics (OMC & MDD) varied with the amount of stabilizers used. The findings support practical applications in road construction, foundation stabilization, and embankments [3].

4. Peat Soil Stabilization using Lime and Cement- Nadhirah Mohd Zambri, and Zuhayr Md. Ghazaly (2018)

The research paper explores the stabilization of soil using alternative materials to improve its geotechnical properties. This study focuses on improving soil strength and durability using stabilizers. Traditional stabilizers like cement and lime are expensive and environmentally impactful. The addition of stabilizers improves soil cohesion, reduces shrinkage, and enhances bearing capacity. Further research is needed on long-term durability and environmental impact [4].

5. Soil Stabilization By Using Plastic Waste- Sagar Mali, Sachin Kadam, Sagar Mane, Krushna Panchal, Swati Kale, Yogesh Navkar (2019)

This research paper explores soil stabilization using plastic waste, focusing on enhancing soil strength and reducing environmental waste. This study examines the feasibility of using

plastic waste as a soil stabilizer to enhance strength and durability. Increased strength and stability make plastic-treated soil suitable for road construction and embankments. The eco-friendly approach supports sustainable development and waste management. Further research is recommended to study the long-term durability and field applications of plastic-stabilized soil [5].

6. Soil Stabilization Using Industrial Waste And Lime – M. Adams Joe, A. Maria Rajesh (2015)

This research explores the use of industrial waste materials as stabilizers to improve soil strength, reduce settlement, and enhance durability. Industrial waste materials such as fly ash, blast furnace slag, cement kiln dust, and quarry dust can be utilized effectively. These materials help in cost reduction, waste management, and sustainable construction. Industrial waste materials provide an effective and sustainable solution for soil stabilization. Further research and field applications are needed to optimize their use in real-world projects [6].

7. Soil Stabilization Using Waste Plastic Bottles Fibers: A Review Paper- A Iravanian, and A B Haider (2020)

This research paper investigates soil stabilization techniques, focusing on the enhancement of weak soil properties through alternative stabilizers. The study emphasizes sustainable approaches to improve soil strength, durability, and workability while minimizing environmental impact. Using alternative stabilizers reduces dependency on cement and lime, leading to lower CO₂ emissions. The addition of stabilizing agents significantly reduced soil plasticity, making it more stable under varying moisture conditions. Compaction characteristics improved, with an increase in MDD and a decrease in OMC, allowing for better soil densification. The CBR values increased, indicating a higher bearing capacity, making the soil suitable for subgrades and foundation applications. The UCS test showed a notable increase in compressive strength, proving the effectiveness of the stabilization process. The approach minimizes construction costs by utilizing readily available waste materials. This research aligns with sustainable construction goals, promoting eco-friendly engineering solutions [7].

Methodology And Test Procedure**MATERIALS USED:**

The following materials are used for the stabilization of Black Cotton Soil (BCS) in this s-tudy:

1. Black Cotton Soil (BCS)

Collected from naturally occurring deposits in expansive soil region (Pandharpur).

Exhibits high plasticity, shrink-swell behavior, and low strength.

Requires stabilization to improve geotechnical properties.

2. Lime (Calcium Oxide - CaO)

Used as the primary chemical stabilizer.

Reacts with soil to reduce plasticity, increase strength, and enhance compaction.

Improves shear strength and load-bearing capacity over time.

Lime content varies as 4%, 5%, 6%, and 8% by dry weight of soil.

3. Plastic Waste (Shredded Plastic)

Derived from polyethylene and polypropylene-based waste materials such as plastic bags, bottles, and packaging waste.

Cut into small strips (10 mm) for better soil interlocking.

Acts as a reinforcement material, reducing cracks and increasing soil durability.

4. Mixed in proportions of 0.5%, 1%, 1.5%, and 2% by dry weight of soil.

Water

Required for hydration of lime to initiate the pozzolanic reaction.

Aids in proper compaction and bonding of the soil-lime-plastic mix.

5. Laboratory Equipment

The following standard geotechnical testing apparatus are required:

- a) Sieve Set & Mechanical Shaker – For grain size distribution
- b) Liquid & Plastic Limit Device – For Atterberg's Limits
- c) Standard Proctor Test Apparatus – For OMC & MDD determination
- d) Direct Shear Test Machine – For cohesion and angle of internal friction
- e) California Bearing Ratio (CBR) Apparatus – For load-bearing capacity analysis
- f) Shrinkage Limit Test Apparatus – For evaluating volumetric changes in soil.
- g) Oven (105°C-110°C) – For drying soil samples before testing.
- h) Weighing Balance – For accurate material measurements.

Laboratory Tests Conducted

The research methodology for this study involves a systematic approach to analyze the stabilization of Black Cotton Soil (BCS) using

lime and plastic waste through laboratory experiments. A series of geotechnical tests are performed on untreated and stabilized soil samples to evaluate the effectiveness of lime and plastic waste stabilization. The methodology consists of the following key steps:

1. Index Properties Tests (To assess soil behavior)

- a) Sieve Analysis (IS 2720 Part 4) – Determines grain size distribution.
- b) Specific Gravity Test (IS 2720 Part 3) – Determines the ratio of the soil particle density to the density of water
- c) Atterberg's Limits Test (IS 2720 Part 5) – Measures liquid limit (LL), plastic limit (PL), and plasticity index (PI).
- d) Shrinkage Limit Test (IS 2720 Part 6) – Evaluates the volumetric stability of soil.

2. Compaction & Strength Tests (To analyze soil improvement)

- a) Standard Proctor Test (IS 2720 Part 7) – Determines Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) for untreated and stabilized soil.
- b) Direct Shear Test (IS 2720 Part 13) – Evaluates cohesion (C) and angle of internal friction (ϕ).
- c) California Bearing Ratio (CBR) Test (IS 2720 Part 16) – Measures load-bearing capacity, essential for road subgrade applications.

Results and discussions

Sieve Analysis Test For Untreated Black Cotton Soil

The Sieve Analysis Test was conducted to determine the particle size distribution of untreated Black Cotton Soil (BCS), following IS 2720 Part 4 (1985). Due to the dominance of fines, BCS is unsuitable for direct construction and requires stabilization. Sieve analysis confirms the need for stabilization to improve strength and reduce shrinkage. Lime and plastic waste can be used to enhance soil gradation and engineering properties. Based on sieve analysis, the soil is classified as Fine-Grained (CH - Highly Plastic Clay).

Sieve Size	Weight Retained (g)	Cumulative Weight Retained (g)	% Retained	% Finer
4.75 mm	5	5	1.0%	99.0 %
2.36 mm	10	15	3.0%	97.0 %
1.18 mm	15	30	6.0%	94.0 %
600 µm	25	55	11.0%	89.0 %
300 µm	40	95	19.0%	81.0 %
150 µm	55	150	30.0%	70.0 %
75 µm	120	270	54.0%	46.0 %
Pan	230	500	100%	0%

Table 1. Particle size distribution table

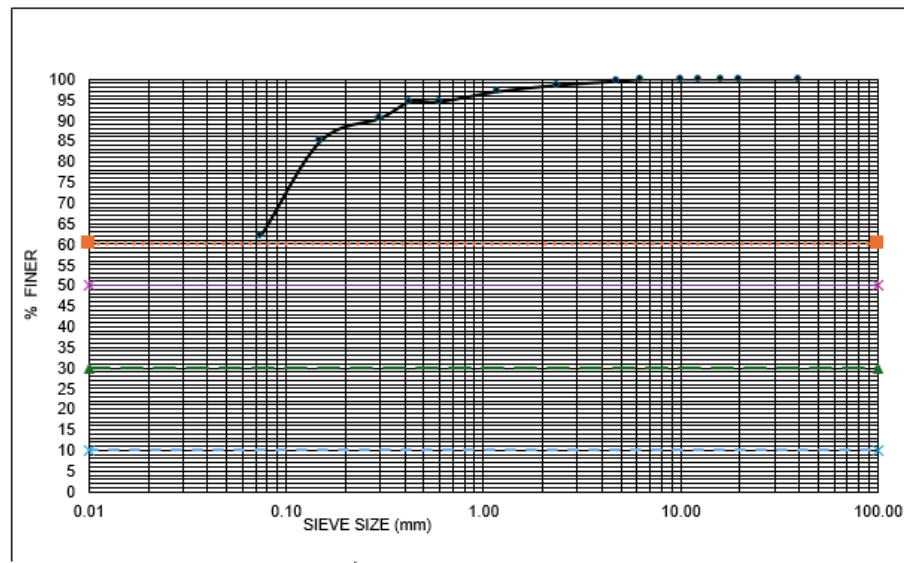


Figure 1. Particle size distribution curve

This sieve analysis confirms that BCS is a fine-grained expansive soil confirming high plasticity and poor drainage characteristics, with high clay content, requiring stabilization for improved engineering performance.

Specific Gravity Test Using Pycnometer

The Specific Gravity (G) of untreated and stabilized Black Cotton Soil (BCS) was determined using the Pycnometer method, following IS 2720 Part 3 (1980). Stabilization reduces specific gravity, indicating a reduction in expansive clay content. Lime reduces specific

gravity by replacing clay minerals with calcium compounds, reducing soil density. Plastic waste, being lightweight, further lowers the specific gravity, improving soil workability.

Calculate the specific gravity (G) using the formula,

$$G = \frac{(W2-W1)}{(W3-W4)-(W2-W1)}$$

Mix ID	BCS (%)	Lime (%)	Plastic Waste (%)	Specific Gravity (G)
Untreated BCS	100	-	-	2.60
M1	95.5	4	0.5	2.55
M2	94	5	1	2.52
M3	92.5	6	1.5	2.48
M4	90	8	2	2.44

Table 2. Specific Gravity

Best results are observed at 6% Lime + 1.5% Plastic Waste, where specific gravity is reduced to 2.48, making the soil more stable and less prone to shrinkage.

Atterberg's Limits Test

The Atterberg Limits Test was conducted to determine the Liquid Limit (LL),

Plastic Limit (PL), and Plasticity Index (PI) of untreated and stabilized Black Cotton Soil (BCS). The test follows IS 2720 Part 5 (1985). Untreated BCS has a high LL 64.33% and PI 31%, making it highly plastic and unsuitable for construction.

Mix ID	Liquid Limit (%)	Plastic Limit (%)	Shrinkage Limit (%)	Plasticity Index (I_p)
Untreated BCS	64.33	33.33	14.14	31
M1	58.65	36.48	16.09	22.17
M2	54.06	42.01	20.05	12.05
M3	50	45	23.6	5
M4	49	43	27.65	6

Table 3. Atterbergs limits

Lime reduces plasticity by reacting with clay particles, lowering the LL and PI. Plastic waste improves shrinkage resistance, increasing the Shrinkage Limit (SL). Best Improvement at 6% Lime + 1.5% Plastic Waste. Beyond this, plastic waste may reduce compaction effectiveness.

Standard Proctor Test

The Standard Proctor Test was conducted to determine the Optimum Moisture Content (OMC) and Maximum Dry Density

(MDD) of untreated and stabilized Black Cotton Soil (BCS). The test follows IS 2720 Part 7 (1980). Stabilization reduces OMC and increases MDD, improving soil compaction and strength.

Best results are achieved at 6% Lime + 1.5% Plastic Waste, where OMC drops to 21% and MDD increases to 1.85 g/cc. Further increase in lime (8%) does not significantly improve MDD, confirming 6% Lime + 1.5% Plastic Waste as the optimal mix.

Mix ID	OMC (%)	MDD (gm/cc)
Untreated BCS	26	1.65
M1	23	1.75
M2	22.5	1.775
M3	21	1.85
M4	19	1.80

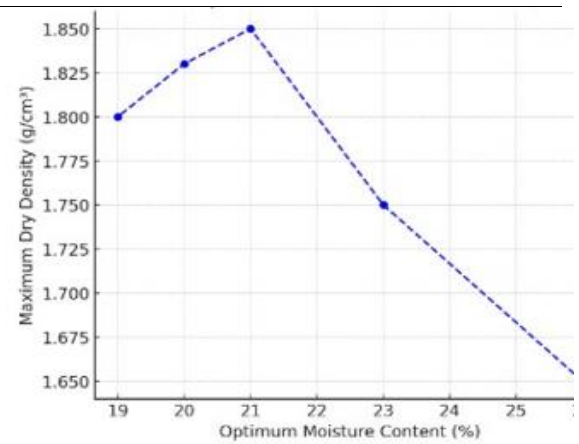


Table 4. OMC & MDD for different mix proportions

Figure 2. Compaction Curve

DIRECT SHEAR TEST

The Direct Shear Test was conducted to determine the shear strength parameters (cohesion, C and angle of internal friction, ϕ) of untreated and stabilized Black Cotton Soil (BCS). The test was performed as per IS 2720 Part 13 (1986). Untreated soil has the lowest shear strength due to high plasticity and weak bonding. Peak improvement at 6% Lime + 1.5% Plastic Waste, beyond which further increase in lime/plastic has a lower effect on strength gain. The test measures how a soil sample resists shear forces under different normal stress conditions. The shear stress (τ) for different normal stresses (σ) was calculated using the shear strength equation:

$$\tau = C + \sigma \tan(\phi)$$

Mix ID	Cohesion, C (KN/m ²)	Angle of internal friction, Φ (°)
Untreated BCS	40	18
M1	55	22
M2	63	25
M3	68	26
M4	65	24

Table 5. Shear Parameters for different mix proportions

Normal Stress (kN/m ²)	Untreated BCS (τ , kN/m ²)	M1 (τ , kN/m ²)	M2 (τ , kN/m ²)	M3 (τ , kN/m ²)	M4 (τ , kN/m ²)
50	42.6	64.2	78.2	92.4	84.3
100	53.3	80.5	98.4	116.8	106.5
150	63.9	96.7	118.6	141.2	128.8

Table 6. Shear strength (τ) at different normal stresses (σ)

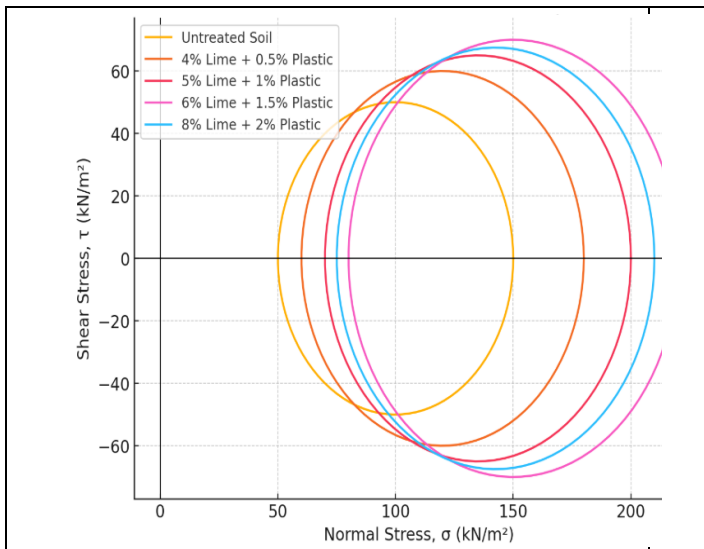


Figure 3. Mohr's circles for different mix proportions
BCS

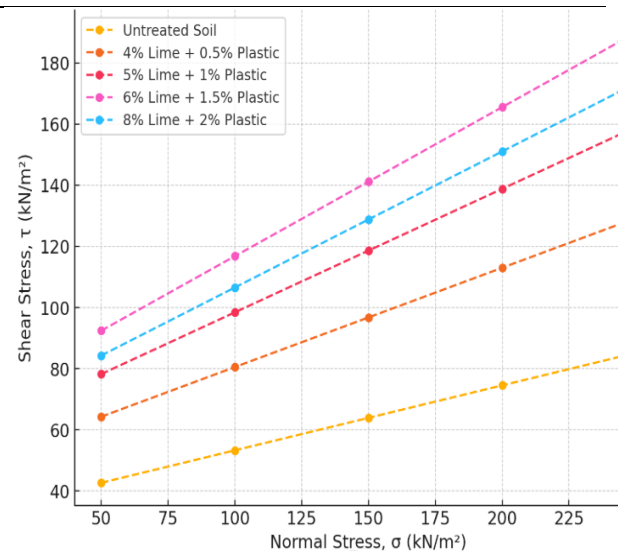


Figure 4. Shear strength envelope for Stabilized BCS

California Bearing Ratio Test

Lime stabilization significantly increases CBR values, improving the soil's strength. Excess plastic waste (>1.5%) slightly reduces CBR, as it disrupts soil-lime bonding. Untreated soil has very poor CBR (~3%), making it unsuitable for roads or embankments.

Mix Proportion	CBR (%) (Soaked Test)
Untreated BCS	3.0
4% Lime + 0.5% Plastic	8.0
5% Lime + 1% Plastic	10.5
6% Lime + 1.5% Plastic	12.0
8% Lime + 2% Plastic	9.0

Table 7. CBR Values

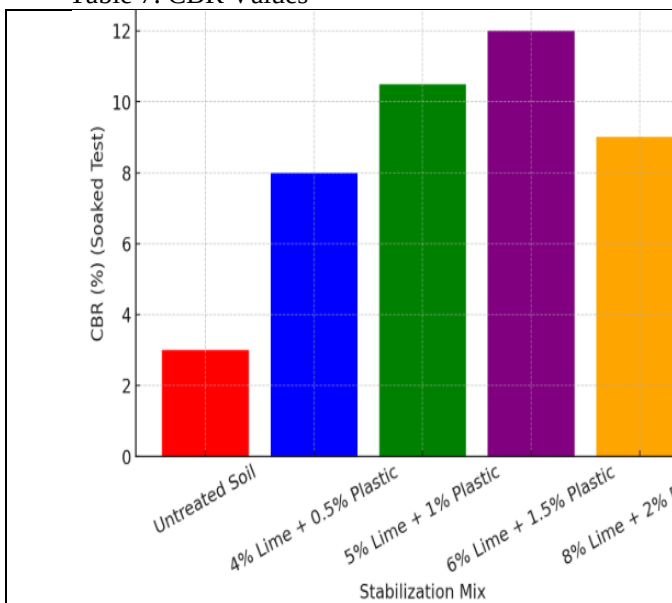


Figure 5. CBR Values vs mix proportions
Penetration depth

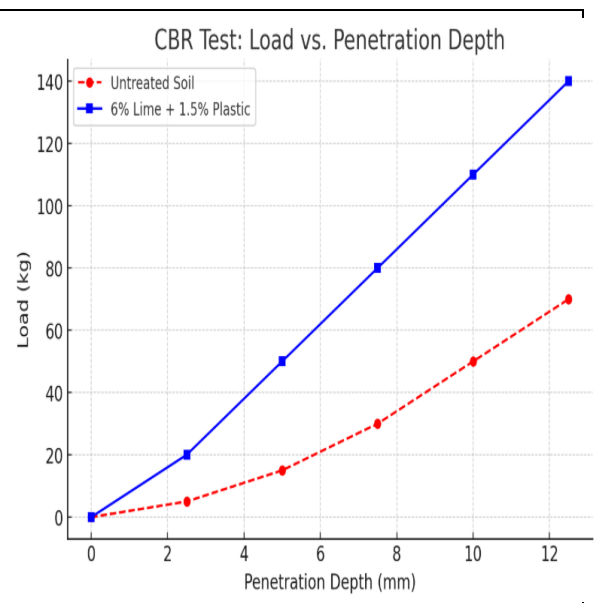


Figure 6. CBR Test: Load vs Penetration depth

CBR increases with stabilization, peaking at 6% Lime + 1.5% Plastic (12%). Stabilized soil (CBR > 8%) is suitable for subgrade & pavement construction.

Conclusion:

This research aimed to improve the engineering properties of Black Cotton Soil (BCS) using a combination of lime and plastic waste as stabilizers. Various geotechnical tests were performed to analyze the effects of stabilization, and the key findings are summarized below:

A. Improvement in Index Properties

1. Plasticity Index (PI) reduced from 31% to 5%, indicating improved workability and reduced swelling potential.
2. Liquid Limit (LL) decreased from 64.33 % to 49%, making the soil less susceptible to moisture variation.
3. Shrinkage Limit increased from 14.14% to 27.65%, reducing the tendency of the soil to crack upon drying.

B. Strength & Load-Bearing Capacity Enhancement

1. Maximum Dry Density (MDD) increased, and Optimum Moisture Content (OMC) reduced, indicating better compaction properties.
2. California Bearing Ratio (CBR) values improved significantly, making the stabilized soil suitable for subgrade applications in road construction.
3. Direct Shear Test results showed increased cohesion (C) and internal friction angle (ϕ), leading to improved shear strength.

C. Sustainable and Cost-Effective Solution

1. Utilization of plastic waste provides an eco-friendly approach to soil stabilization while addressing plastic waste management issues.
2. Lime stabilization effectively reduces the swelling and shrinkage behavior of BCS, making it suitable for foundation and pavement applications.

D. Optimum Mix Proportion

The best improvement was observed at 6% Lime + 1.5% Plastic Waste, which resulted in higher strength, reduced plasticity, and improved load-bearing capacity. Thus, 6% Lime + 1.5% Plastic Waste (M3) is the optimal mix, meeting IRC standards for subgrade stabilization.

- The study confirms that lime and plastic waste stabilization is an effective method to enhance the geotechnical properties of expansive Black Cotton Soil.
- The stabilized soil can be used for road subgrades, embankments, and foundations, reducing the need for costly soil replacement.
- Further field trials and long-term durability studies can be conducted to validate the

laboratory findings in real-world applications.

Acknowledgment:

I express my sincere gratitude to SKN Sinhgad College of Engineering, especially the Department of Civil Engineering, for providing the necessary infrastructure and resources for this research.

I extend my heartfelt thanks to my guides, Prof. S.G. Rathod and Prof. S.D. Jagdale, for their valuable guidance, encouragement, and insightful suggestions throughout the study, which greatly contributed to the success of this project. Their expertise and guidance were crucial in carrying out the laboratory investigations effectively.

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Lastly, I wholeheartedly thank my family for their unwavering support, encouragement, patience, and belief in my abilities, which have been my greatest source of strength. Their collective support has been instrumental in the successful completion of this research on Black Cotton Soil Stabilization using Lime and Plastic Waste.

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Analysis of Seismic Impact of Improvements with Rigid and Semi Rigid RC Structure with Having Podium

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Abstract:

Increase in population, urbanization and requirement of various infrastructure resulted into limited availability of suitable land for development. These has resulted into sharp increase in land cost. So, to take optimum use of land, multi-storey tower became popular. But to take financial leverage as well as to satisfy demand of larger commercial space near to road level and making building compliant to minimum parking space requirements for such mixed-use development according to prevailing bye laws Architects and Developers have come up with unique idea of Podium type Buildings. Tower-Podium type buildings are being quite popular now days, because they allow optimum use of land as well as financial leverage to satisfy demand of larger commercial space. Podium can be defined as part of structure whose lateral load resistance is more than that of tower. The backstay effect is a set of lateral forces developing within a podium structure to equilibrate the lateral forces and moment of a tower extending above podium structure. In this study to analyse Tower-Podium Structure CSI ETABS software is used. Different models are prepared by changing the no. of stories of podium and diaphragm conditions. After analyzing, it is observed that backstay effect increases with increase in podium floors and it is more in case of rigid than semi-rigid. So, it is inferred that Tower with 5 storey Podium and Rigid Diaphragm can resist more lateral forces than any other models

Keywords: Backstay, Diaphragm, ETABS, Podium Height, lateral forces

Introduction:

The demand for tall structures is increasing daily due to rising population and land scarcity in metropolitan regions. Tall structures are becoming more popular in developing nations, including India. After a certain amount of horizontal development, no more land is accessible for growth in any city, especially in metro cities. As a result, multi-storey towers became popular as a way to maximize land utilization. High-rise buildings cannot be designed in the same manner that low and medium-rise structures are designed. Tall buildings are extremely complex engineering projects, so the most sophisticated design methods are required in tall structures. To satisfy the demand of increasing population as well as to satisfy the demand for the minimum parking space for such types of buildings under current bye-laws, Architects and Engineers proposed/put forward the new concept of Podium kind structures.

A large number of basement floors most typically represent the condition of the podium. Still, the floors above ground can also serve as a podium if it has extra seismic features that do not

extend up to the whole height of the structure. A podium may be authorized to be 1000 square meters or larger. According to DCPR 2034, a podium with a ramp may be approved in one or more levels if the total height of podium stories does not exceed 32 m above ground level.

Podium Type Towers

A "Podium Type Tower" refers to a tall building design where a substantial, lower level "podium" structure supports a taller tower section, often used to provide additional usable space at the base for retail, parking, or other functions. Increase in population, urbanization and requirement of various infrastructure resulted into limited availability of suitable land for development. These has resulted into sharp increase in land cost. So, to take optimum use of land, multi-storey tower became popular. But to take financial leverage as well as to satisfy demand of larger commercial space near to road level and making building compliant to minimum parking space requirements for such mixed-use development according to prevailing bye laws Architects and Developers have come up with unique idea of Podium type Buildings

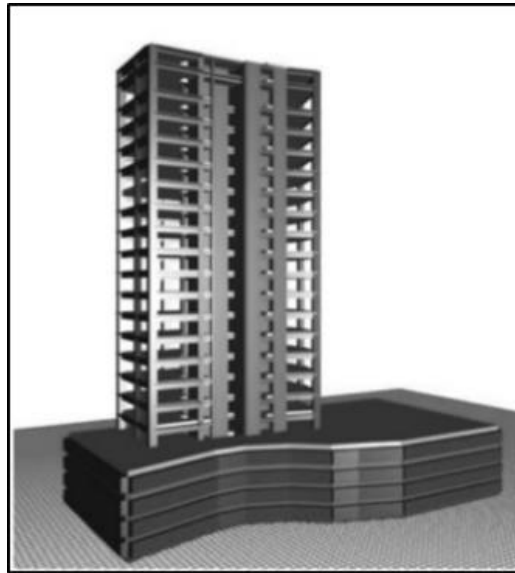


Fig 1 Podium Type Towers

Research Significance

The main objective of this study is to study the concept of Backstay Effect in high rise buildings with having Core Shear walls with podium structure for dynamic behavior. In this study to analyse Tower-Podium Structure CSI ETABS software is used. Different models are prepared by changing the no. of stories of podium and diaphragm conditions. After analyzing, it is observed that backstay effect increases with increase in podium floors and it is more in case of rigid than semi-rigid. So, it is inferred that Tower with 5 storey Podium and Rigid Diaphragm can resist more lateral forces than any other models

Model Details And Properties

For the current work, the construction is a building with 20 stories. The dimensions of the

Modeling Of The Building:

M1. Tower without podium (T)

tower are 25m x 25m, and the podium is 75m x 75m. The work is to be done on different structural formations of tower-podium construction by varying the number of podium stories and diaphragm conditions, 10 different models will be prepared and analyzed in the structural analysis and design tool ETABS. After analysis the conclusion will be made on basis of results. Rough sketch of the building.

- Dimensions of Podium – 75 m X 75 m
- Dimensions of Tower – 25 m X 25 m
- No. of Stories – 25
- Details of RC frame:
- Size Of beam = 300 x 550
- Size of Column = 300 x 750
- Grade of Concrete = M30
- Grade of Steel = FE 500
- Shear Wall = 200mm

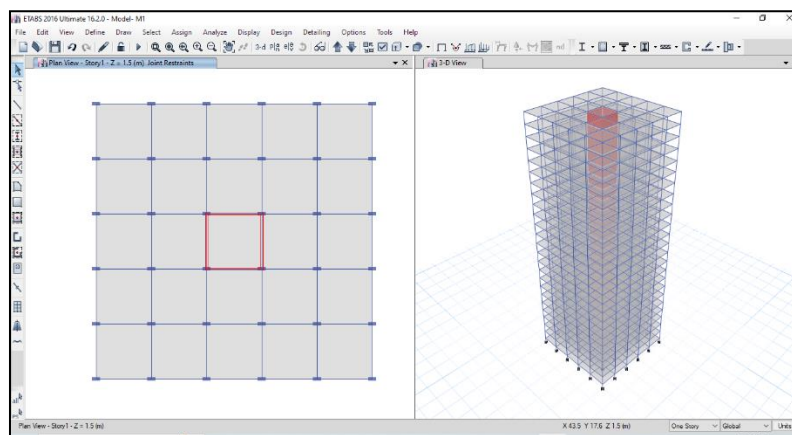


Fig 2 - M1. Tower without podium (T)

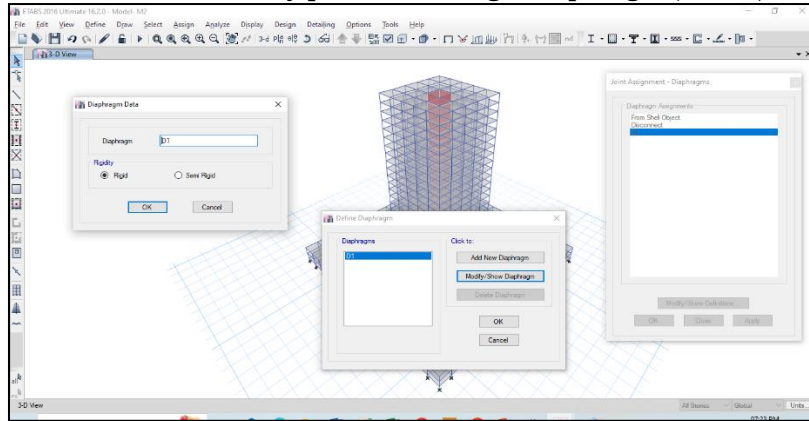
M2. Tower + 3 story podium with rigid diaphragm (T+3-R)

Fig 3 - M2. Tower + 3 story podium with rigid diaphragm (T+3-R)

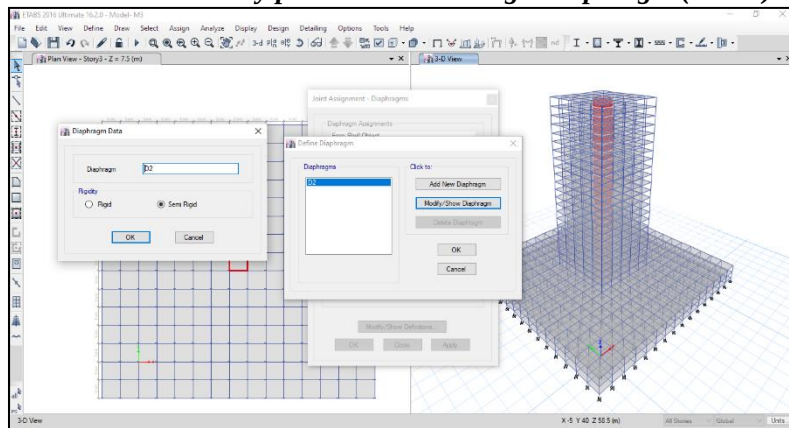
M3. Tower + 3 story podium with semi rigid diaphragm (T+3-S)

Fig 4 - M3. Tower + 3 story podium with semi rigid diaphragm (T+3-S)

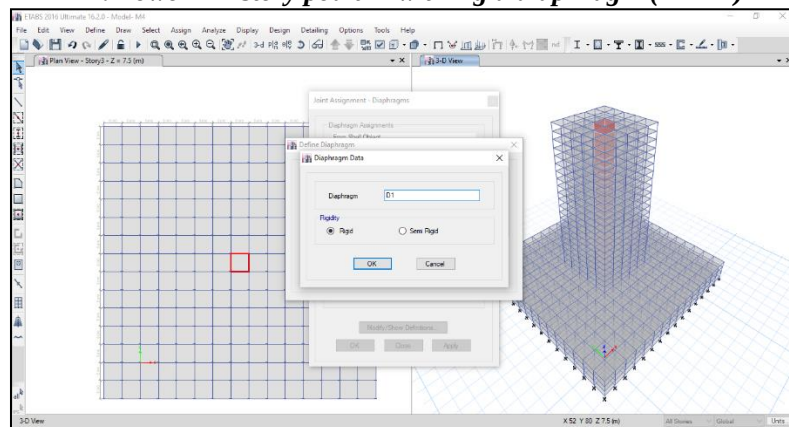
M4. Tower + 4 story podium with rigid diaphragm (T+4-R)

Fig 5 - M4. Tower + 4 story podium with rigid diaphragm (T+4-R)

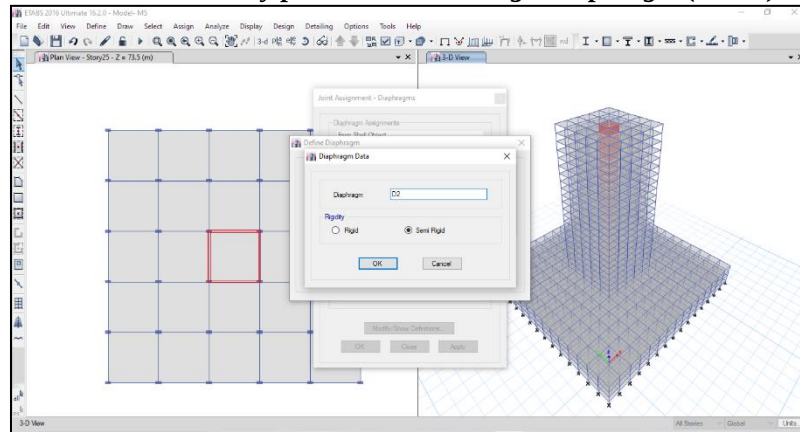
M5. Tower + 4 story podium with semi rigid diaphragm (T+4-S)

Fig 6 - M5. Tower + 4 Story Podium with Semi Rigid Diaphragm (T+4-S)

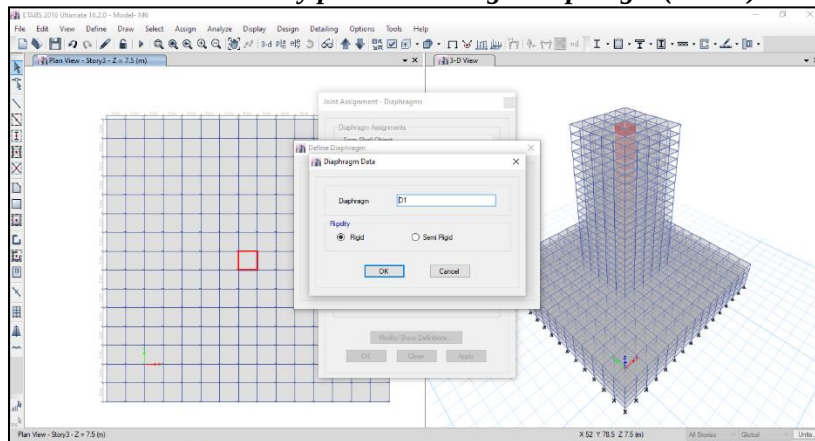
M6. Tower + 5 story podium with rigid diaphragm (T+5-R)

Fig 7 - M6. Tower + 5 story podium with rigid diaphragm (T+5-R)

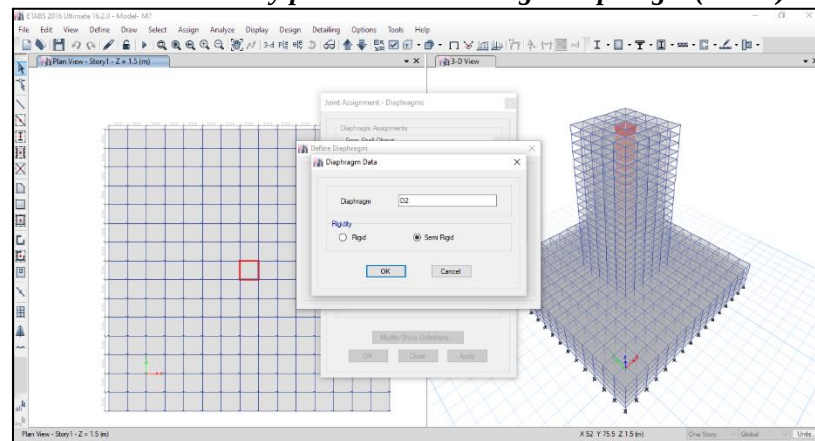
M7. Tower + 5 story podium with semi rigid diaphragm (T+5-S)

Fig 8 - M7. Tower + 5 story podium with semi rigid diaphragm (T+5-S)

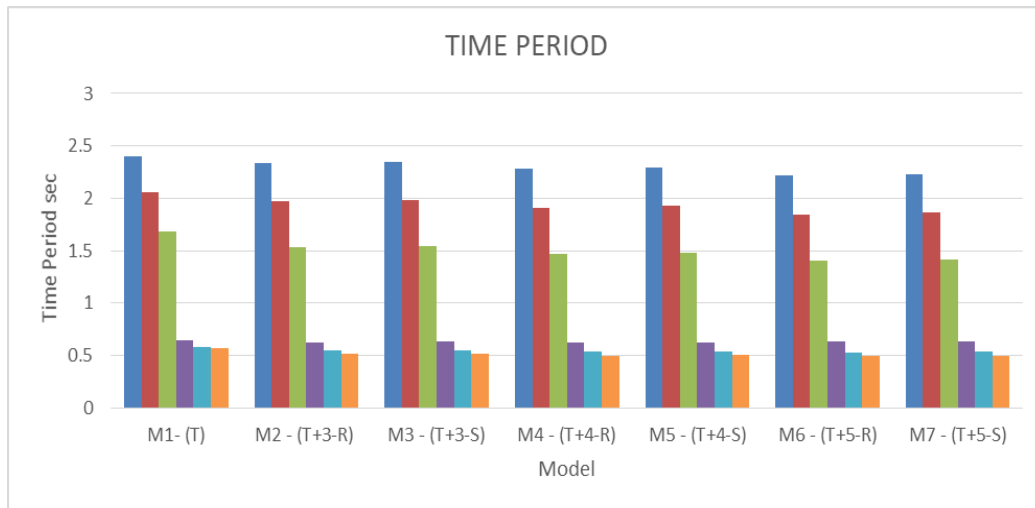
Analysis Results:**Time Period**

Every building has a number of natural frequencies, at which it offers minimum resistance to shaking induced by external effects (like

earthquakes and wind) and internal effects (like motors fixed on it). Each of these natural frequencies and the associated deformation shape of a building constitute a Natural Mode of Oscillation.

Table I Time Period

Time Period							
MODE NO	M1- (T)	M2 - (T+3-R)	M3 - (T+3-S)	M4 - (T+4-R)	M5 - (T+4-S)	M6 - (T+5-R)	M7 - (T+5-S)
1	2.40	2.33	2.35	2.28	2.30	2.22	2.23
2	2.05	1.97	1.99	1.91	1.93	1.85	1.87
3	1.68	1.53	1.54	1.47	1.48	1.40	1.41
4	0.65	0.63	0.63	0.62	0.63	0.63	0.64
5	0.58	0.55	0.55	0.53	0.54	0.53	0.54
6	0.57	0.52	0.52	0.50	0.50	0.49	0.50

**Displacement Graph I Time Period**

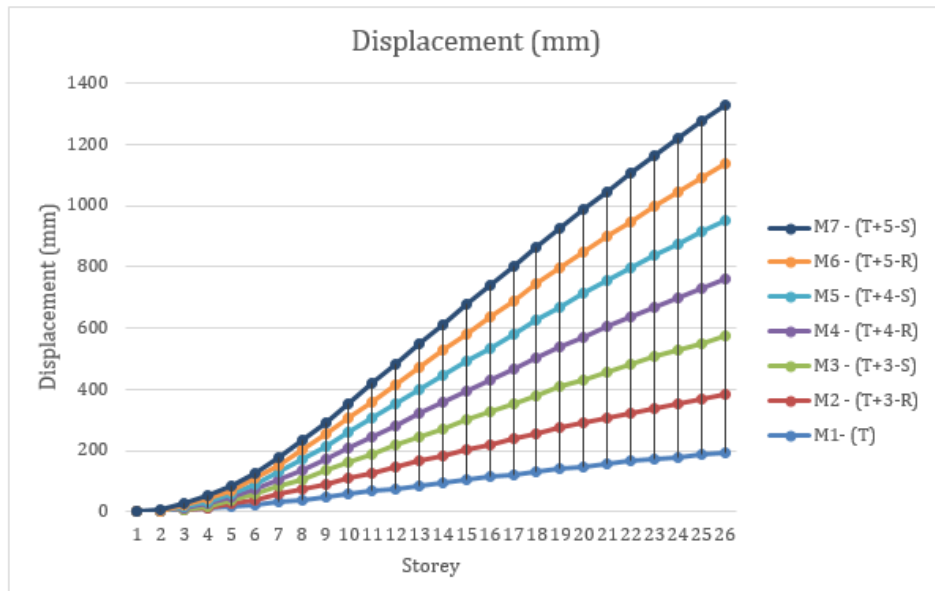
From the above table and graph, we can observe the percentage variation for time period for response spectrum analysis for models with backstays and diaphragms. The variation is found to be 10-15% less for the model with the highest podium, i.e., the model with a T+5 podium. The Table 2 Displacement (mm)

results analysed after changing the diaphragm condition show that the semi-rigid diaphragm has a longer time period than the rigid diaphragm.

Displacement (mm) **can be defined as "It is the displacement of a storey with respect to the base of a structure."**

Displacement (mm)							
Store y	M1- (T)	M2 - (T+3-R)	M3 - (T+3-S)	M4 - (T+4-R)	M5 - (T+4-S)	M6 - (T+5-R)	M7 - (T+5-S)
25	193.4	189.0	189.6	188.1	189.2	188.1	189.8
24	186.6	181.6	182.6	180.3	181.8	179.7	181.7
23	179.3	174.1	175.0	172.3	173.8	171.1	173.0
22	171.8	166.3	167.3	164.2	165.7	162.4	164.3
21	164.1	158.3	159.3	155.9	157.4	153.6	155.5

20	156.0	150.1	151.1	147.5	149.0	144.7	146.7
19	147.8	141.7	142.8	138.9	140.4	135.9	137.9
18	139.3	133.2	134.2	130.2	131.8	127.2	129.1
17	130.7	124.4	125.5	121.4	123.0	118.4	120.4
16	121.8	115.5	116.6	112.5	114.1	109.7	111.6
15	112.8	106.5	107.5	103.5	105.0	100.9	102.8
14	103.7	97.3	98.4	94.4	95.9	92.1	94.0
13	94.5	88.1	89.2	85.2	86.7	83.1	85.0
12	85.2	78.8	79.9	75.9	77.4	74.1	75.9
11	75.9	69.5	70.6	66.6	68.1	64.9	66.8
10	66.5	60.2	61.3	57.4	58.9	55.8	57.6
9	57.1	50.9	52.0	48.2	49.6	46.8	48.4
8	48.2	42.0	43.1	39.5	40.9	38.3	39.8
7	39.3	33.3	34.3	31.1	32.4	30.3	31.6
6	30.8	24.9	26.0	23.2	24.4	23.0	23.8
5	22.9	17.2	18.2	16.1	16.8	17.1	17.2
4	15.6	10.3	10.9	10.2	10.2	13.4	13.6
3	9.4	4.8	4.6	6.9	7.0	9.1	9.3
2	4.3	2.3	2.2	3.5	3.6	4.6	4.8
1	0.7	0.4	0.3	0.6	0.6	0.8	0.8
Base	0.0	0.0	0.0	0.0	0.0	0.0	0.0



Graph 2 Displacement (mm)

Mr. Mohit Bharat Dange, Prof. Dr. C. P. Pise, Prof. A. V. Karande

From the above table and graph, we can observe the percentage variation for Displacement for response spectrum analysis for models with backstays and diaphragms. The variation is found to be 5-10% less for the model with the highest

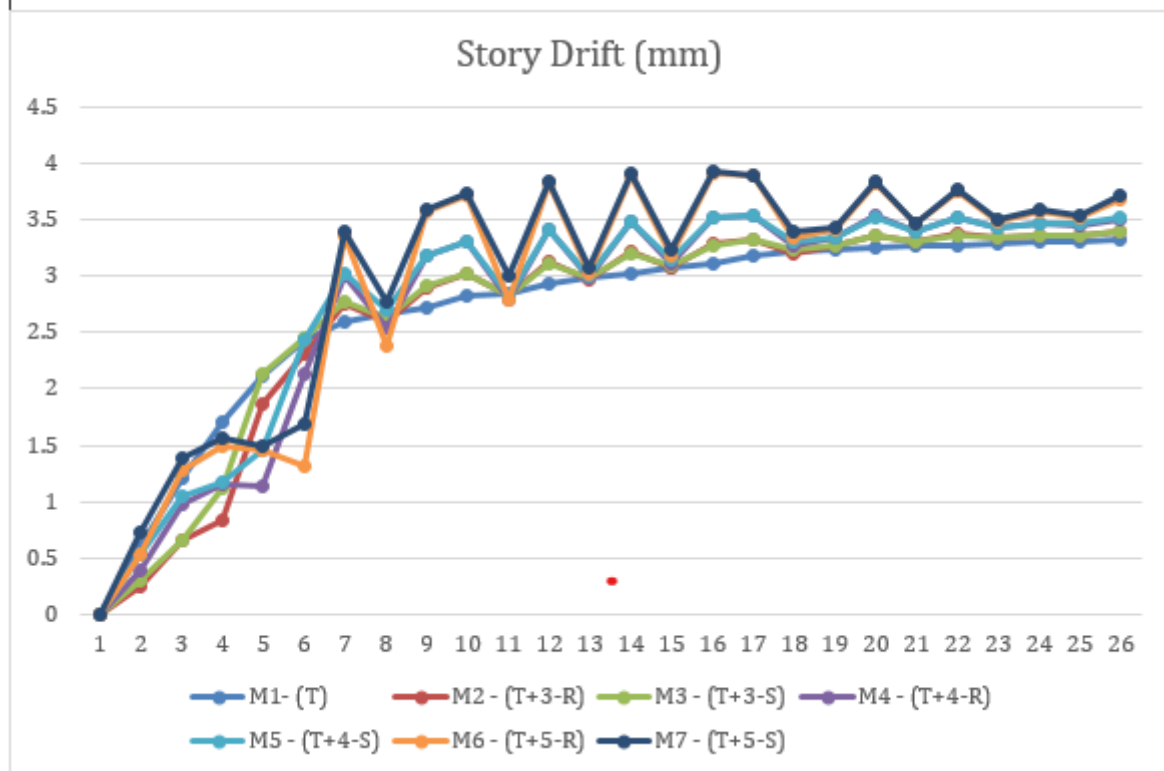
podium, i.e., the model with a T+5 podium. The results analyzed after changing the diaphragm condition show that the semi-rigid diaphragm has a slightly highest displacement than the rigid diaphragm due to elasticity

Story Drift (mm)

Table 3 Story Drift (mm)

Story Drift (mm)							
Store y	M1- (T)	M2 - (T+3-R)	M3 - (T+3-S)	M4 - (T+4-R)	M5 - (T+4-S)	M6 - (T+5-R)	M7 - (T+5-S)
25	2.59	2.76	2.77	3.00	3.03	3.37	3.40
24	2.72	2.90	2.91	3.18	3.19	3.57	3.59
23	2.82	3.02	3.02	3.30	3.31	3.71	3.73
22	2.93	3.13	3.12	3.41	3.41	3.83	3.84
21	3.03	3.22	3.21	3.49	3.49	3.90	3.91
20	3.12	3.29	3.28	3.53	3.53	3.92	3.93
19	3.19	3.33	3.33	3.54	3.54	3.89	3.90
18	3.25	3.36	3.36	3.54	3.53	3.83	3.84
17	3.28	3.38	3.37	3.52	3.52	3.76	3.77
16	3.33	3.39	3.40	3.50	3.52	3.68	3.71
15	3.30	3.37	3.37	3.46	3.47	3.58	3.59
14	3.30	3.36	3.36	3.45	3.46	3.53	3.54
13	3.29	3.34	3.34	3.43	3.44	3.49	3.50
12	3.27	3.31	3.31	3.40	3.40	3.46	3.47
11	3.24	3.27	3.27	3.34	3.35	3.41	3.43
10	3.22	3.21	3.24	3.27	3.31	3.35	3.40
9	3.08	3.08	3.09	3.11	3.14	3.19	3.23
8	2.99	2.97	2.98	2.98	3.01	3.03	3.08
7	2.85	2.82	2.83	2.79	2.83	2.80	3.01
6	2.67	2.60	2.63	2.54	2.71	2.39	2.77
5	2.43	2.32	2.45	2.13	2.44	1.32	1.69
4	2.11	1.87	2.13	1.13	1.45	1.46	1.50
3	1.70	0.83	1.11	1.15	1.17	1.49	1.57
2	1.21	0.65	0.65	0.97	1.05	1.28	1.38
1	0.60	0.24	0.30	0.39	0.53	0.53	0.73

Base	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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Graph 3 Story Drift (mm)

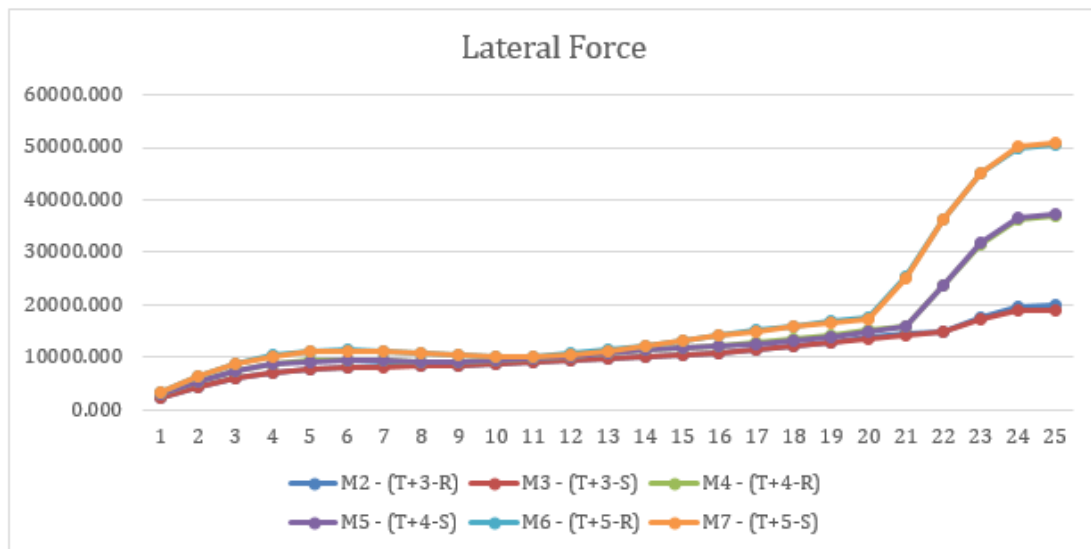
From the above table and graph, we can observe the percentage variation for Story Drift for response spectrum analysis for models with backstays and diaphragms. The variation is found to be 5-10% less for the model with the highest Lateral Force

podium, i.e., the model with a T+5 podium. The results analyzed after changing the diaphragm condition show that the semi-rigid diaphragm has a slightly highest displacement than the rigid diaphragm due to elasticity.

Table 4 Lateral Force

Lateral Force						
Storey	M2 - (T+3-R)	M3 - (T+3-S)	M4 - (T+4-R)	M5 - (T+4-S)	M6 - (T+5-R)	M7 - (T+5-S)
25	2397	2340	2940	2904	3475	3408
24	4505	4415	5509	5460	6520	6425
23	6088	5978	7410	7349	8785	8680
22	7169	7052	8659	8590	10289	10189
21	7813	7700	9318	9245	11098	11014
20	8130	8029	9508	9436	11333	11269
19	8260	8174	9404	9335	11160	11110
18	8348	8274	9215	9153	10777	10729
17	8503	8434	9144	9089	10389	10334
16	8767	8695	9312	9263	10179	10108
15	9112	9032	9720	9672	10265	10174

14	9484	9394	10277	10225	10680	10573
13	9833	9734	10861	10798	11378	11253
12	10155	10049	11392	11312	12267	12123
11	10489	10375	11856	11753	13250	13085
10	10902	10779	12298	12168	14243	14059
9	11452	11316	12797	12640	15184	14985
8	12156	12004	13427	13249	16040	15837
7	12958	12791	14197	14007	16783	16583
6	13766	13588	15058	14866	17415	17215
5	14478	14294	15915	15725	25371	25007
4	15008	14821	23769	23595	36230	36164
3	17730	17211	31656	31781	44976	45209
2	19497	18826	36189	36522	49814	50193
1	19805	19103	36982	37311	50652	51013



Graph 4 Lateral Force

From the above table and graph, we can observe the percentage variation for Lateral Force for response spectrum analysis for models with different diaphragms. The variation is found to be 5-10% high for the model with the highest podium, i.e., the model with a T+5 podium. The results analyzed after changing the diaphragm condition show that the semi-rigid diaphragm has a slightly less Lateral Force than the rigid diaphragm due to elasticity.

Conclusions:

The main purpose of this study is to analyze Backstay Effect and changes in Diaphragm Conditions high rise building by ETABS.

- Dynamic analysis has been carried out to know time period, Story Drift, displacements and lateral force by using Different 7 types of models models of the 25th floors for the analysis.
- The analysis include participation of 90% of the building mass for every principal horizontal direction of response as per IS 1893(Part-I)-

2016 by complete Quadratic Combination (CQC).

- High performance concrete is used in the analysis, along with modern structural framings such as moment resisting frames.
- The building is tested for Equivalent Static & response spectrum analysis. According to FEA results, the results found that buildings with podiums give better results than normal buildings; buildings with a higher number of podium levels give better results; in our analysis, podiums at the 5th level give the best results.
- For analysis models with rigid and semi-rigid diaphragms, the results conclude that for the time period, story drift, displacements are increased in semi-rigid models due to stiffness, and lateral force is reduced.

Acknowledgment:

It is my pleasure to get this opportunity to thank my beloved and respected Guide **Dr. C.P. Pise** and Co-Guide **Prof. A. V. Karande**. I sincerely thank towards my Head, Civil Structural Engineering Department, Dr. S. S. Kadam. I am grateful to Principal, Dr. K. J. Karande for his encouragement and guidance throughout the course

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Mr. Mohit Bharat Dange, Prof. Dr. C. P. Pise, Prof. A. V. Karande



Evaluation of Viscosity Models for Simulation of Airfoil Analysis

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Abstract:

Supersonic flight is of utmost importance on both military and civilian fronts, yet this is constrained by problems of boundary layer separation, shockwaves, and turbulence. The design of a supersonic aircraft involves the CFD of the wing airfoil; care should be taken to select the appropriate turbulence model. This study simulates supersonic flow with three turbulence models: Spalart-Allmaras (one-equation), $k-\omega$, and $k-\epsilon$ (two-equation). The objective is to compare their effectiveness in supersonic conditions. Overall, each model revealed similar flow characteristics; thus, Spalart-Allmaras predicted a slightly higher lift and drag coefficient due to its simplistic one-equation formulation. All models exhibit similar flow characteristics, but Spalart-Allmaras predicts slightly higher lift and drag because of its simpler one equation approach.

Keywords: Supersonic flight, Computational Fluid Dynamics (CFD), Spalart-Allmaras, $k-\epsilon$ and $k-\omega$, flow simulation

Introduction:

An aerofoil or airfoil is the part of the shape of any body whose motion in a given medium (most often air) may produce lifters of significance. Some specific examples of such shapes are the geometrical sections of wings, sails, or the cross section of a propeller or a turbine blade. It is a shape whose stickiness is to produce substantially more lift and less drag. The basic aerofoil designs for various speeds differ in their geometry, those for supersonic flight having a slim leading edge, while those for a subsonic flight are thicker and with probably a blunter leading edge. All these airfoils have a sharp trailing edge. The airfoil of a supersonic aircraft is therefore had to be designed differently from that of a subsonic one because the air conditions are very different. Since the aircraft is flying at a speed of Mach greater than 1. For this purpose, CFD analysis is to be done to determine the optimal airfoil and subsequently the turbulent models to be used.

A distinct difference between liquids, gasses and solids can be done in one way. Consider a larger closed container. The boundaries and shape of a solid will not change. The shape of liquid will adjust to that of the container till the maximum depth and gas occupies the whole container.[1] "In engineering and physics, fluid dynamics is a subfield of fluid mechanics that entails the flow of fluids which includes liquids and gases". Fluid Dynamics is further divided into three areas according to the medium of fluid namely Gas Dynamics, Hydrodynamics and Aerodynamics.[2]

Literature survey

Turbulence:

One of the limitations of CFD is that it cannot reproduce physics that aren't well included inside the formulation of the problem. One of these is the condition is turbulence. To solve this, CFD solutions of turbulent flows make use of turbulent models, which are dependent on empirical data for the different constants required for the appropriate turbulence models. Therefore, all results of CFD having turbulent flow are subject to some of inaccuracies.[1]

Turbulence Models:

Spalart-Allmaras Turbulence Model:

Spalart-Allmaras is a one-equation model turbulence model developed for aerodynamics that is basically a transport equation based on eddy viscosity. It is designed mainly for simulation of wide range of engineering applications such as aerospace and automobile engineering. The key idea of Spalart-Allmaras is based on the model by Nee & Kovaszny. Teymour Javaherchi (2010) [3] has provided a thorough overview of the Spalart-Allmaras turbulence model and its variants. The author has discussed the model's formulation, benefits and limitations along with its applications in internal and external flow simulation. This paper additionally introduced several modifications to the Spalart-Allmaras model, and performance comparisons between modified models, the original Spalart-Allmaras model, and other popular turbulence models are performed

$$\frac{D\tilde{\nu}}{Dt} = c_{b1}\tilde{S}\tilde{\nu} + \frac{1}{\sigma}\left[\nabla \cdot ((\nu + \tilde{\nu}) \nabla \tilde{\nu}) + c_{b2}(\nabla \tilde{\nu})^2\right] - c_{w1}f_w\left(\frac{\tilde{\nu}}{d}\right)^2 \quad (1)$$

Where,

ν	-	kinematic viscosity
$\tilde{\nu}$	-	modified kinematic viscosity
$\tilde{S}$	-	modified strain rate term
σ	-	Prandtl no.
d	-	distance to the nearest wall
$c_{b1}, c_{b2}, c_{w1}, f_w$	-	are the empirical constants

Ma Li et al. (2014) [4] have investigated the ability of the Spalart-Allmaras (SA) turbulence model and its modifications to properly simulate SWBLI. A comparative performance evaluation of the SA model and its modifications has been conducted against experimental data on turbulence transport as well as modifications of the turbulent kinetic energy. The analysis revealed that the SA model has high confidence in being able to capture key features of SWBLI flows, but has limitations with its predicted flow characteristics. The paper further points out the importance of proper turbulence modelling for SWBLI flows and resistance in developing existing models towards better outcomes. The work has implications for SWBLI analysis, and application for aircraft and rocket

phenomena with respect to designing and optimization of aerospace and engineering system.

k- ω Turbulence Model:

Xiaoqing Zheng et. al. [5] has described the application of the Staggered Upwind Method (SUM) to the solution of the Navier-Stokes equations and the k- ω turbulence model equations. The SUM is applied in order to discretize the system of equations and this model is used to simulate the effects of turbulence. According to the paper, the performance of the k- ω model in simulating laminar to turbulent transition could have been enhanced with simple changes. It also found out that the k- ω model is rather efficient in predicting separation but to assess the efficiency of the laminar to turbulent flow transition more research is needed.

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho u_j k)}{\partial x_j} = \rho \tau_{ij} \frac{\partial u_i}{\partial x_j} - \beta^* \rho k \omega + \frac{\partial}{\partial} \left[\left(\mu + \sigma^* \frac{\rho k}{\omega} \right) \frac{\partial k}{\partial x_j} \right]$$

(2)

Where,

ρ	-	fluid density
u_j	-	Velocity component in the j-direction
x_j	-	spatial coordinate
μ	-	dynamic viscosity
ω	-	specific dissipation rate
τ_{ij}	-	Reynold's Stress tensor
E_{ij}	-	Strain rate tensor
k	-	Turbulent Kinetic energy
α, β	-	empirical constants

k- ϵ Turbulence Model:

According to Hans Burchard (1998) et al., it says here that two-equation turbulence models - like the k- ω models - outperform the Mellor-Yamada models in their forecasts of turbulent flows. In comparison to the Mellor-Yamada turbulent model which deals only with turbulent kinetic energy, two-equation models deal with both turbulence kinetic

energy and its dissipation rate, which enables them to depict the turbulence effects more reasonably. They concluded that it is essential to evaluate and validate the performance of various turbulence models in the context of a given problem.

One of the goals of this paper is to select an airfoil for modelling and simulation of supersonic air conditions. The main objective is to emulate the

airfoil in three different turbulence models, namely, $k-\omega$, Spalart-Allmaras, and $k-\epsilon$. The three models are then evaluated and compared to determine which Where,

works better computationally and produces more consistent results as they are known to give varied results against different aerodynamic conditions.

U	-	mean velocity
μ	-	dynamic viscosity
ϵ	-	specific dissipation rate
C1, C2	-	empirical constants

Methodology

Selection of Airfoil:

A symmetric airfoil has been selected because to keep the study relatively simple as taking an asymmetric airfoil can make the case complex. Symmetric airfoils have a more predictable stall behavior. As the angle of attack increases, there is a gradual reduction in lift. Asymmetric airfoils, by contrast, can experience sudden drop in lift because they stall. This is because the airflow over a symmetric airfoil remains relatively smooth during stall, while an asymmetric airfoil experiences turbulent airflow. However, asymmetric airfoils can provide more lift and are commonly used in high-performance aircraft. It was chosen for this experiment because it is widely used in a variety of industrial applications such as wind turbines, aircraft, and hydrofoils. Because of its symmetric shape and relatively thick camber, it is ideal for low-speed applications such as wind turbines. In the,

NACA 0012 airfoil 00 indicates that its camber is zero. The 12 indicates it has an 12% thickness to chord length ratio.[8]

Numerical Analysis:

The 4-series NACA 0012 is meshed using the Ansys GAMBIT Software and Ansys Fluent 16 has been used for simulating the flow using Computational Fluid Dynamics. The flow conditions include a Mach number of 1.5, a freestream temperature of 311K and 2-degree angle of attack. The material properties have been set at constant thermal conductivity and specific heat, while density was modified for an ideal gas. For the purpose of calculating variable viscosity needed when simulating turbulent flow, the Sutherland's law was utilized. The same case has been repeated three times, each using a different turbulence model namely: $k-\epsilon$, $k-\omega$ and Spalart-Allmaras. The parameters used for the simulation are tabulated below in Table 1.

TABLE I. PARAMETERS USED FOR NUMERICAL ANALYSIS

Parameter Name	Parameter Selected
Airfoil Family	4-Series
NACA Airfoil Name	NACA 0012
Meshing Software	ANSYS GAMBIT
CFD Analysis Software	ANSYS Fluent 16
Mach Number	1.5
Freestream Temperature	311K
Turbulence Models	Spalart-Allmaras, $k-\omega$, $k-\epsilon$

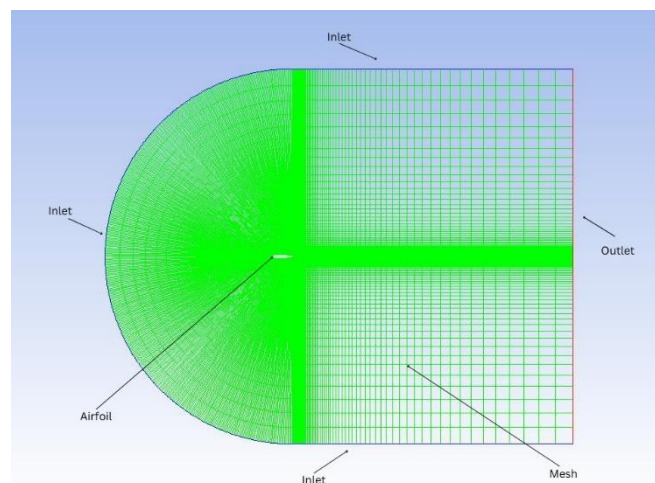


Fig. 1. C-Type Mesh on the NACA 0012 Airfoil

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Results:

After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

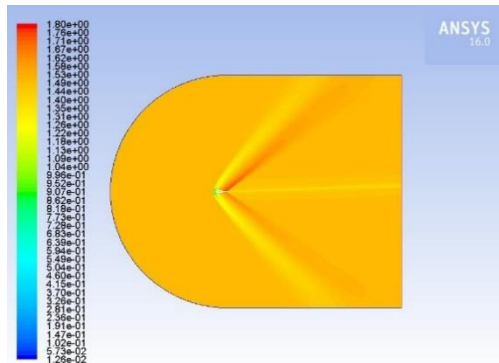


Fig.2. CFD Simulation using Spalart-Allmaras model

k

- ω Turbulence Model:

As shown in Fig 5.3 and 5.4, are the velocity contours of the Computational Fluid Dynamics on the NACA 0015 airfoil using k- ω Turbulence Model. The shockwaves at the leading and trailing

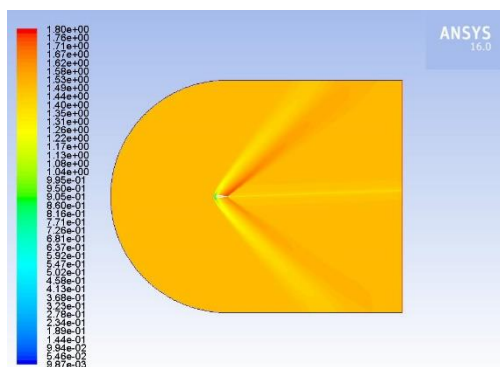


Fig.4. CFD Simulation using k- ω model

k- ϵ Turbulence Model:

Shown in Fig 5.5 and 5.6, these are the velocity contours of the numerical analysis on the NACA 0015 airfoil using k- ϵ turbulence model. Additionally, noticeable are the shockwaves at the

Spalart-Allmaras Turbulence Model:

As shown in Fig 5.1 and 5.2, are the velocity contours of the Computational Fluid Dynamics on the NACA 0015 airfoil using Spalart-Allmaras Turbulence Model. The shockwaves at the leading and trailing edge are also visible. The calculation came to conversion around 13000 iterations. The coefficient of lift generated is 1.0596×10^{-2} and coefficient of drag is 1.0456×10^{-2} . Solver graphs of the continuity and energy equation is also been given in Fig 4.

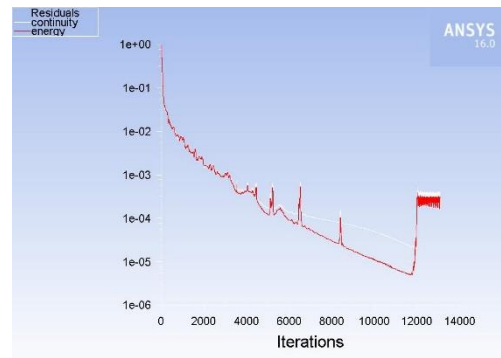


Fig.3. Continuity and energy equation calculation using Spalart-Allmaras model

edge are also visible. The calculation came to conversion around 17000 iterations. The coefficient of lift generated is 1.0671×10^{-2} and coefficient of drag is 1.0522×10^{-2} .

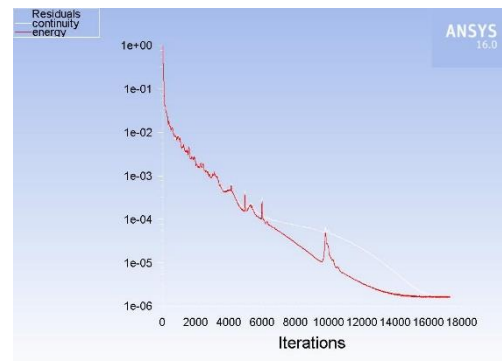


Fig.5. Continuity and energy equation calculation using k- ω model

leading and trailing edges. The calculation came to conversion around 15000 iterations. The coefficient of lift generated is 1.0579×10^{-2} and coefficient of drag is 1.0807×10^{-2} .

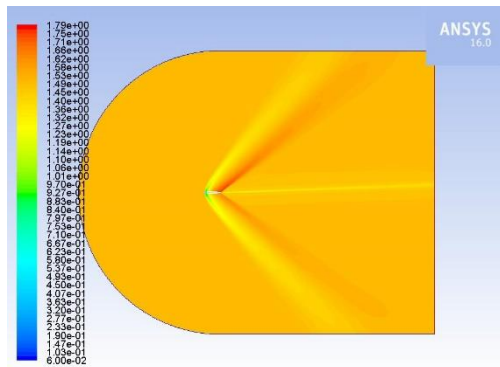


Fig.6. CFD Simulation using $k-\epsilon$ model

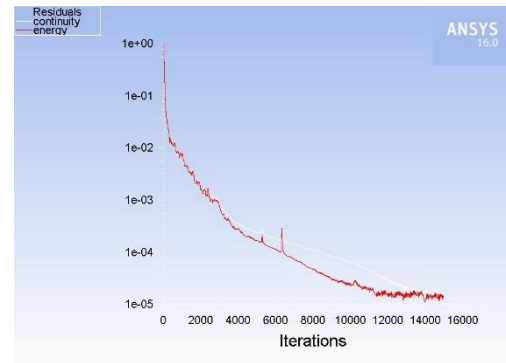


Fig.7. Continuity and energy equation calculation using $k-\epsilon$ model

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Improving Efficiency with Hybrid Solar Water Distillation System

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Abstract:

Water scarcity is a growing global challenge, making efficient and sustainable purification method is essential. Solar water distillation is an eco-friendly technique that utilizes solar energy to evaporate and condense water, leaving behind impurities. However, the process is often slow and dependent on weather conditions, limiting its efficiency. This study investigates two methods i.e. traditional solar water distillation using only sunlight and an advanced hybrid electrolysis system. The conventional method relies solely on solar heating, achieving moderate evaporation rates but requiring extended exposure to sunlight. In contrast, the hybrid method integrates electrolysis, generating additional heat and accelerating the phase change, leading to higher water recovery rates and improved purity. Experimental results show that the combination of solar energy and electrolysis significantly enhances distillation efficiency by increasing temperature levels and reducing processing time. While the hybrid approach requires an external power source for electrolysis, it offers a scalable and effective solution for clean water production. This research demonstrates that integrating electrochemical processes with solar distillation can improve water purification, making it a viable option for water-scarce regions with high solar potential.

Introduction:

Water is an essential resource of life, yet it accesses to clean and safe drinking water remains a challenge in many parts of the world. So, to purify the water there are many different ways, but we choose solar water distillation method. Water distillation is a reliable and widely used technique for producing clean water by removing contaminants such as salt, sand, microorganism, etc. through evaporation and condensation.

The water distillation process is a reliable method for purifying water. It begins with boiling water to 100°C (212°F) in a distillation apparatus, causing the water to vaporize and turn into steam. As the water vaporizes, it leaves behind many contaminants, including salt, sand and chemicals, which are unable to vaporize due to their higher boiling points. The steam is cooled and then condensed back into water. As the steam condenses, it produces purified water that is free from many impurities. Finally, the distilled water is collected and stored, ready for use in various applications, such as drinking water, laboratories, and medical facilities.

In cases where solar light is not available, electrolysis is employed as an alternative method to carry out the water distillation process. It involves the use of an electric current to drive a chemical reaction, typically to split a molecule into its constituent elements. In this process, an electric current is passed through an electrolyte, a substance that conducts electricity, such as water or a salt solution. The electrolyte is placed between two

electrodes, an anode and a cathode, which are connected to a power source. When the electric current flows through the electrolyte, it causes the molecules to split, with positively charged ions moving towards the cathode and negatively charged ions moving towards the anode. At the electrodes, the ions are reduced or oxidized, resulting in the formation of new substances, such as hydrogen and oxygen gas in the case of water electrolysis. The electrolysis process is widely used in various industrial applications, including the production of hydrogen fuel, chlorine gas, and aluminum metal.

Literature Review:

Solar distillation has the advantage of cost saving over other types of distillation such as reverse osmosis, because solar energy is limitless and easily available and likewise seawater is readily available, there is an abundance of these sources. Solar distillation has proved to be highly effective in cleaning up water supplies to provide safe drinking water [1]. As energy requirement to produce 1 liter (i.e. 1kg since the density of water is 1kg/liter) of pure water by distilling brackish water requires a heat input of 2260kJ. Distillation considered only where there is no local source of fresh water [2]. In order to evaporate 1 kg of water at a temperature of 30°C about 2.4×10^6 J is required. Assuming an insolation of 250 W/m², averaged over 24 h, this energy could evaporate a maximum of 9 L/m²/day. In practice, heat losses will occur and the average daily yield, which might expected from a solar still, is 4–5

L/m²/day. Today's state-of-the-art single-effect solar stills have an efficiency of about 30–40% [3]. The sun radiates the energy uniformly in all direction in the form of electromagnetic waves. When absorbed by body, it increases its temperature. It is a clean, inexhaustible, abundantly and universally available renewable energy[4]. Solar distillation is a tried and true technology. The first known use of stills dates back to 1551 when it was used by Arab alchemists. Other scientists and naturalists used stills over the coming centuries including Della Porta (1589), Lavoisier(1862), and Mauchot (1869)[5]. To increase the evaporation rate in an active mode the extra thermal energy is fed into the basin. To increase the productivity of solar still, the various active methods are being carried out by many researchers. Most of the works were based on the flat plate collector and concentrating collector. Rai et al. [6]. Have studied the single basin solar still

Tray (Water Container)

A plastic tray is used to hold the impure water in which the process is to be carried out.

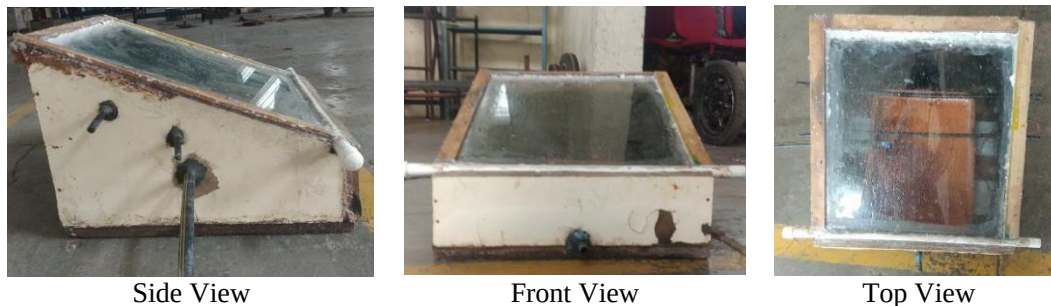


Fig.1 Experimental Set up

1. Transparent Cover (Glass)

A sloped transparent cover is placed above the tray to allow sunlight in while reducing heat loss. The cover helps trap heat inside, creating a greenhouse effect for faster evaporation.

2. Condensation Surface

The inner side of the transparent cover serves as a condensation surface. When water vapor touches the surface, it condenses into liquid droplets. The sloped angle allows the condensed water to slide down to the collection channel.

3. Collection Channel

A small channel along the bottom edge of the cover collects the distilled water. The channel is slightly inclined to guide the collected water toward an outlet.

Material: Plastic to prevent contamination.

coupled with flat plat collector and found that the daily production rate was increased by 24% when compared to the simple single basin solar still. Tiris et al. [7]. Found that the maximum yield of a simple solar still was 2.575l/m² day while it was 5.18 l/m² day when integrated with flat plate collector. Badran et al. [8]. Found that its production rate was increased by 231% but efficiency has decreased by about 2.5%. The solar still productivity has increased by 36% while coupling flat plat collector and Badran et al. [9]. Found that the productivity was proportional to the solar radiation. Sanjay Kumar et al. [10]. Found that an active solar still with water flow over the glass cover has given maximum yield of 7.5 l/day. Singh et al. [11].

Construction:

The construction of a solar water distillation system involves several components designed to use sunlight to evaporate and condense water, separating it from impurities and contaminants as follows:

4. Outlet Pipe

A small pipe connected to the collection channel directs the distilled water to a storage container.

5. Insulation

The basin is often insulated with materials sumac and also covered it with fabric colour to reduce heat loss. Insulation improves the thermal efficiency of the system.

6. Best angle for evaporation

- In winter, increase the angle by 10–15° to capture lower-angle sunlight.
- In summer, decrease the angle by 10–15° to avoid excessive reflection.
- General angle between 10° and 30° works well for most locations, ensuring efficient condensation and water runoff.

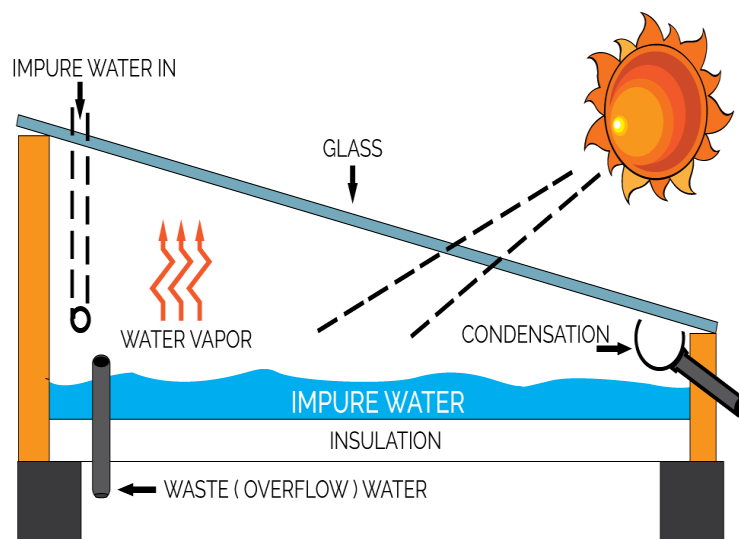


Fig.2 Block Diagram of the conventional System

Working Principle:

- **Heating**
The water to be distilled is poured into the distillation chamber. The chamber is heated, typically using a heat source as sunlight. The heat energy is transferred to the water, causing its temperature to rise.
- **Vaporization**
As the water temperature reaches its boiling point (100°C or 212°F), it begins to vaporize. The water molecules turn into water vapor, which rises towards the glass surface. The vaporization process is facilitated by the heat energy transferred to the water.
- **Condensation**
The water vapor rises and comes in contact with the glass surface, it condenses and get converted into water droplets.
- **Collection**
The condensed water droplets collect into the pipe then it is stored in the container. The

collected water is now distilled water and free from contaminants.

We tried two different methods for water distillation process as follows:

By using sunlight

Solar water distillation uses sunlight to heat water in a distillation chamber, causing it to evaporate and rise towards the glass surface. As the water vapor comes into contact with the surface, it condenses into the water droplets and free from many contaminants. The distilled water is collected in the pipe and then stored in the container. This process relies on the solar energy to drive the distillation, making it a renewable and sustainable option. The system consists of a tray, glass cover, and a container. While it's a slow process and weather-dependent, solar water distillation is a simple and effective method for producing purified water using only sunlight.

Table 1 Readings for Experiment no. 1

Time	9am	10am	11am	12pm	1pm	2pm	3pm
Water Temp (°C)	31.8	33.8	41.5	43.4	47	47.7	48.5
Atmospheric Temp (°C)	32	34	35	36	36	36	35

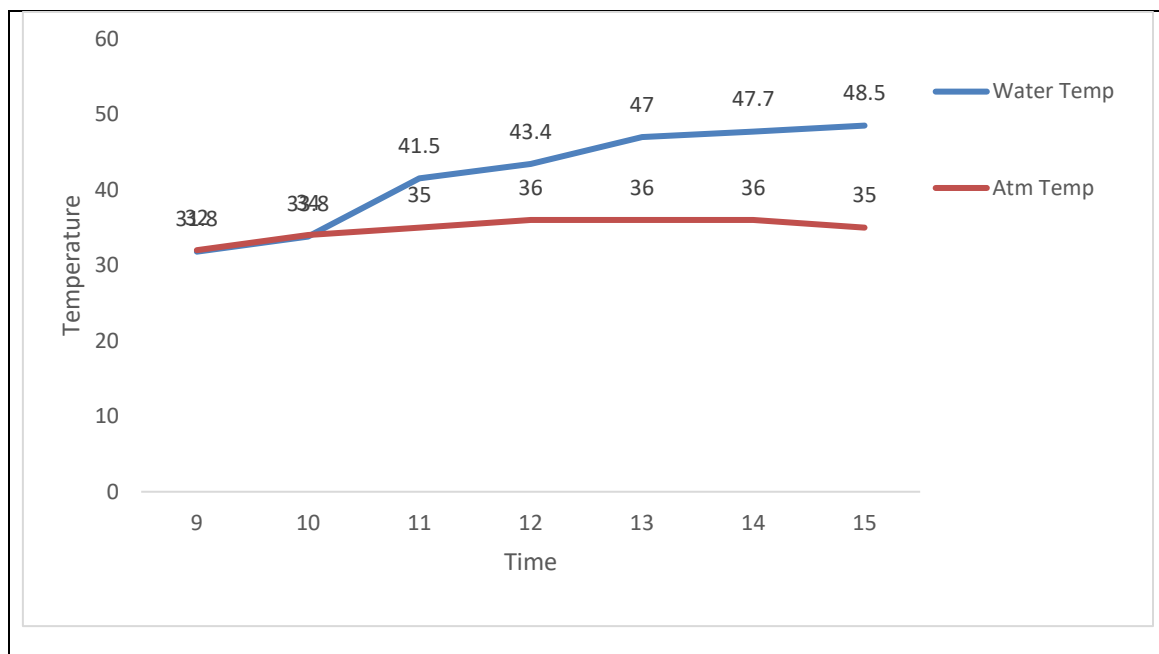


Fig.3 Temperature Vs Time for Experiment no 1

By using sunlight with electrolysis:

To achieve more efficiency, we tried electrolysis along with sunlight. With reference to above mentioned process as we know the process of evaporation, electrolysis helps to produce more water vapor. The water vapor then enters in the electrolysis cell, where it split into hydrogen and oxygen gases at the electrodes. The hydrogen and oxygen gases are then cooled, causing the water

vapor to condense into water droplets, which is collected in a container. This combined process improves efficiency, increases purity, and utilizes a renewable energy source, providing a sustainable and effective method for producing highly pure distilled water. In this way electrolysis supports the process of water distillation.

Table 2 Readings for Experiment no. 2

Time	9am	10am	11am	12pm	1pm	2pm	3pm
Water Temp (°C)	31.3	34.6	37.6	44.8	48.8	55.4	56.3
Atmospheric Temp (°C)	32	34	35	36	36	36	37

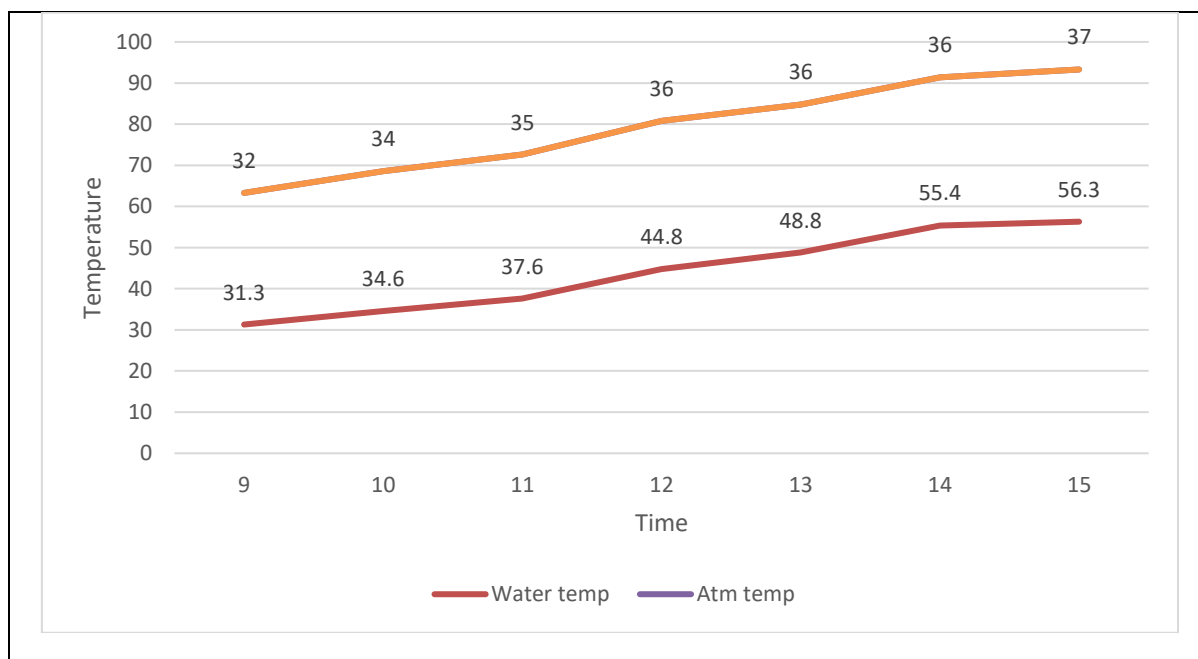


Fig. 6 Temperature Vs Time for Experiment no 2

Result:

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In the first experiment, when using only sunlight for water distillation, the process relies on solar heating to evaporate water, leaving behind impurities. The efficiency is moderate, as it depends entirely on the intensity of sunlight and temperature. By experimenting, we got 93ml of purified water by using 1.5 liters of polluted water in 6 hrs. In the experiment no. 2, i.e. when using sunlight combined

with electrolysis the process becomes more efficient. This leads to higher distillation rate and improved efficiency compared to solar heating alone. This would be new hybrid technique with more advantages. By experimenting, we got 115ml of purified water by using 1.5 liters of polluted water in 6 hrs.

Parameters	Experiment no 1(Sunlight)	Experiment No 2 (Sunlight + Electrolysis)
Water used	1.5 L	1.5 L
Purified Water	93 ml	115 ml
Time	6 hrs. (9am – 3pm)	6 hrs. (9am – 3pm)
Conversion	6.2 %	7.67 %

Conclusion:

Combining solar water distillation with electrolysis enhances the efficiency and effectiveness of the purification process. While solar distillation relies solely on sunlight, making it slow and weather-dependent, adding electrolysis accelerates evaporation by generating additional heat and separating water into hydrogen and oxygen. This not only increases the distillation rate but also improves water purity by eliminating impurities at a molecular level. However, the integration of electrolysis requires an external power source, electrodes, and a controlled setup, making it more complex than passive solar distillation. Despite the added complexity, this hybrid approach offers a faster, more efficient, and scalable solution for producing high-purity water, making it a promising technology for areas with high solar potential and access to renewable electricity.

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Intelligent Load Distribution for Transformers Using Arduino

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Abstract:

Transformer overloads are common in power distribution systems, leading to overheating, reduced efficiency, and potential failure. This paper proposes a system for automatic load sharing between two transformers using an Arduino microcontroller, to prevent transformer damage under overloaded conditions. The proposed system utilizes a current sensor, relay switching, and a real-time monitoring algorithm to dynamically balance the load between the primary and a secondary transformer. The system ensures that both transformers operate within safe thermal limits, reducing downtime, and maintenance costs, and enhancing the reliability of the power system.

Keywords: Transformer protection, automatic load sharing, Arduino, relay control, overloading, power system reliability, current sensor, load balancing.

Introduction:

Transformers are integral components in electrical power distribution systems, tasked with voltage conversion to meet varying load demands. However, continuous operation under excessive load can lead to overheating, insulation degradation, and eventually, transformer failure. Overloaded transformers require significant downtime for repairs and incur high operational costs. Thus, the need for an efficient and automated system for transformer protection is paramount.

The objective of this study is to design and implement an automatic load-sharing mechanism between a primary transformer and a secondary transformer, controlled by an Arduino microcontroller. The system aims to detect transformer overload conditions in real-time and dynamically share the load between two transformers, preventing damage from overheating and improving the overall reliability of the power distribution system.

Problem Statement

The traditional approach to transformer protection involves manually monitoring the transformer load and initiating corrective actions when overload conditions are detected. However, this process is inefficient, error-prone, and can result in substantial downtime. Moreover, failure to address overloads quickly can lead to catastrophic transformer damage, resulting in power outages and high repair costs. The goal of this research is to automate the load distribution process to ensure transformers do not exceed their rated load capacity and remain within safe operating temperatures.

System Design and Architecture

Overview

The proposed system consists of two transformers, a master (primary) transformer, and a slave (secondary) transformer. The system uses an Arduino microcontroller to monitor the primary transformer's load in real time, utilizing a current sensor. If the current exceeds a set threshold, a relay is used to automatically engage the secondary transformer, thus distributing the load. The system continuously monitors and adjusts the load-sharing process to prevent overheating and ensure optimal performance of both transformers.

Block Diagram

The following components and their interconnections from the system:

- **Primary Transformer:** The main transformer that provides power to the load.
- **Current Sensor (CT):** This measures the current in the primary transformer, which is fed to the Arduino for processing.
- **Arduino Microcontroller:** Monitors the input from the current sensor, compares it to a predefined overload threshold, and controls the relay based on the readings.
- **Relay Module:** An electromechanical switch that connects the secondary transformer when the overload threshold is exceeded.
- **Secondary Transformer:** Activated by the relay when the primary transformer is overloaded, allowing load-sharing between both transformers as shown in Fig. 2.

Power Supply

The power supply block diagram in Fig.1 shows the components necessary to provide power to the

system and ensure its stable operation.

- AC Power Source: The system operates on a standard 220V AC supply, which powers the main transformer and the Arduino system.
- AC-DC Converter: The 220V AC is converted to DC through a rectifier circuit. A filter is used to smooth out the DC signal.

- 5V DC Regulator: The Arduino requires a stable 5V DC power source for operation, which is provided by a voltage regulator.

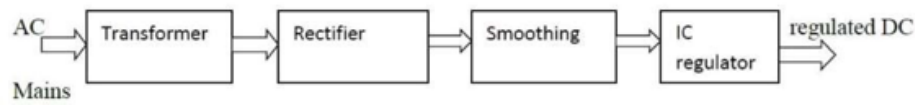


Fig. 1. Power Supply

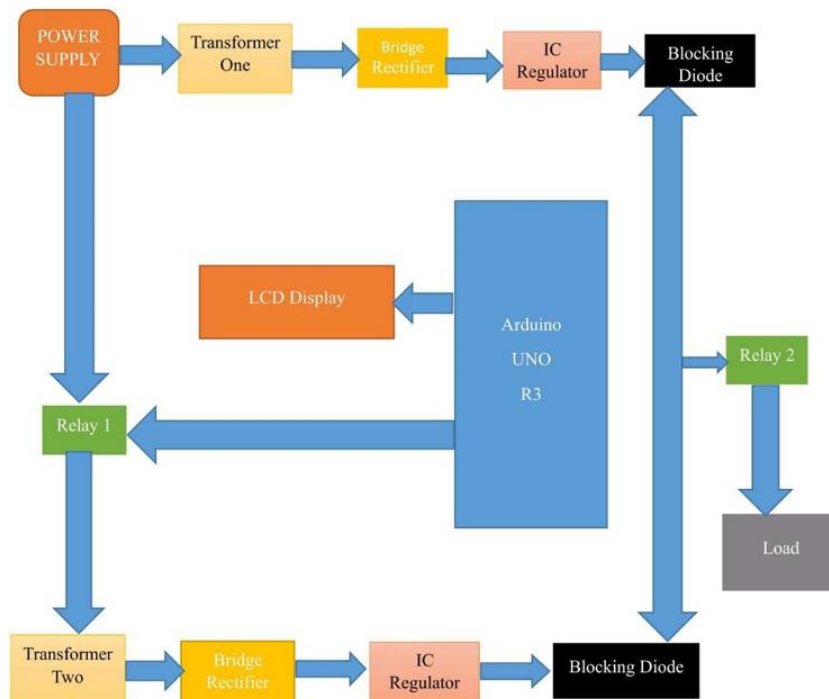


Fig 2. Block diagram of Automatic Load sharing Transformer using Arduino

System Flow Diagram

- System Initialization: Upon startup, the system initializes all components, including the Arduino and sensors.
- Current Measurement: The system continuously measures the current flowing through the primary transformer using a current sensor.
- Comparison with Threshold: The Arduino compares the measured current with a preset threshold. If the current exceeds the threshold, it indicates that the primary transformer is overloaded.

- Relay Activation: If the overload condition is met, the system activates the relay to connect the secondary transformer, sharing the load between the two transformers.
- Load Monitoring: The system continuously monitors the load on both transformers, ensuring that the load is shared appropriately and does not exceed safe limits.

The system continuously loops through this process as shown in Fig.3, adjusting the load-sharing conditions based on real-time data from the current sensor.

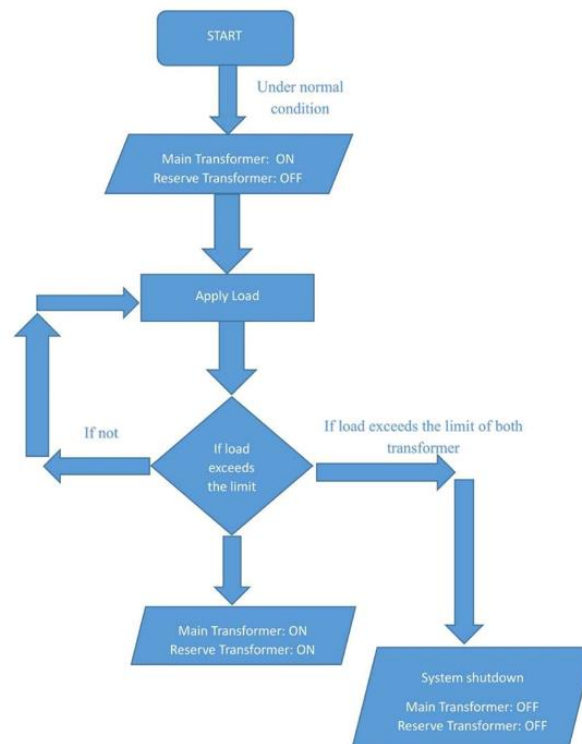


Fig. 3. System Flow Diagram

Methodology

Monitoring Current Using a Current Transformer

A current transformer (CT) is used to measure the current flowing through the primary transformer. The CT outputs a signal proportional to the current, which is then fed into the Arduino's analog input pin. The Arduino converts this analog signal to a digital value using the Analog-to-Digital Converter (ADC). By calibrating the CT's output signal to represent the transformer's rated current, the Arduino can continuously monitor whether the transformer is operating within safe load limits.

Defining Overload Conditions

The threshold current value is calculated based on the transformer's rated load capacity. When the current exceeds this predefined value, it indicates an overload condition. The threshold can be dynamically adjusted for different operational conditions (e.g., seasonal load variations). The overload threshold could be set at a percentage of the rated transformer capacity (e.g., 90% of the rated current).

Relay Control for Load Sharing

The relay module is interfaced with the Arduino to switch the slave transformer on or off. The relay is triggered through a digital output pin of the Arduino, where a low signal activates the relay.

Methodology

Simulation Setup

The system was simulated using Proteus software, with the following components:

- Arduino Uno as the microcontroller.
- Current sensor (e.g., ACS712 or CT sensor).
- Relay module to switch the slave transformer.

and a high signal deactivates it. When the Arduino detects that the current exceeds the threshold, it sends a signal to the relay to connect the slave transformer in parallel with the primary transformer.

In normal operation, the system operates with only the primary transformer running. However, when overload is detected, the slave transformer is automatically activated, sharing the load to prevent overheating.

Algorithm for Load Sharing

The load sharing algorithm consists of several steps:

- Initial Check: The Arduino reads the current sensor value every second.
- Comparison: The current value is compared with the overload threshold.
- Action on Overload: If the current exceeds the threshold, the system triggers the relay to connect the slave transformer.
- Load Reduction Check: If the load on the primary transformer decreases below the threshold, the system disconnects the slave transformer.

The system uses a hysteresis method to avoid frequent switching of the slave transformer. This ensures that the slave transformer is not engaged unless the load is consistently above the threshold for a set period.

- Load to simulate the transformer's load (modeled as a resistive load in the simulation).
- Slave Transformer was simulated as a secondary load to share the power.

Simulation Steps

- Initial Load Simulation: The primary transformer was initially set to carry a normal load (below the threshold).
- Overload Condition Simulation: The load was gradually increased beyond the predefined threshold (e.g., 90% of rated current).
- Load Sharing Activation: Once the current exceeded the threshold, the Arduino microcontroller activated the relay, engaging the secondary transformer to share the load.
- Load Monitoring: The system continuously monitored the load on both transformers, and when the load on the primary transformer fell below the threshold, the slave transformer was automatically disconnected.

Simulation Results

- Normal Operation: Initially, the current through the primary transformer remained well below the

overload threshold, with only the primary transformer supplying power to the load shown in Fig.4.

- Overload Detection: When the load on the primary transformer exceeded the set threshold, the Arduino detected the overload and activated the relay to engage the slave transformer shown in Fig.5.
- Load Sharing: Upon activation of the relay, the slave transformer shared the load, reducing the current in the primary transformer and preventing it from overheating.
- Disengagement of Slave Transformer: As the load decreased below the threshold, the system automatically disconnected the slave transformer to optimize efficiency.

TABLE I. SIMULATION RESULTS

<i>Load (Amps)</i>	<i>Primary Transformer Current (A)</i>	<i>Secondary Transformer Status</i>
0-10 A	5 A	OFF
10-20 A	15 A	OFF
20-30 A	25 A	OFF
30-35 A	35A	ON
35-40 A	38 A	ON
40+ A	45 A	ON

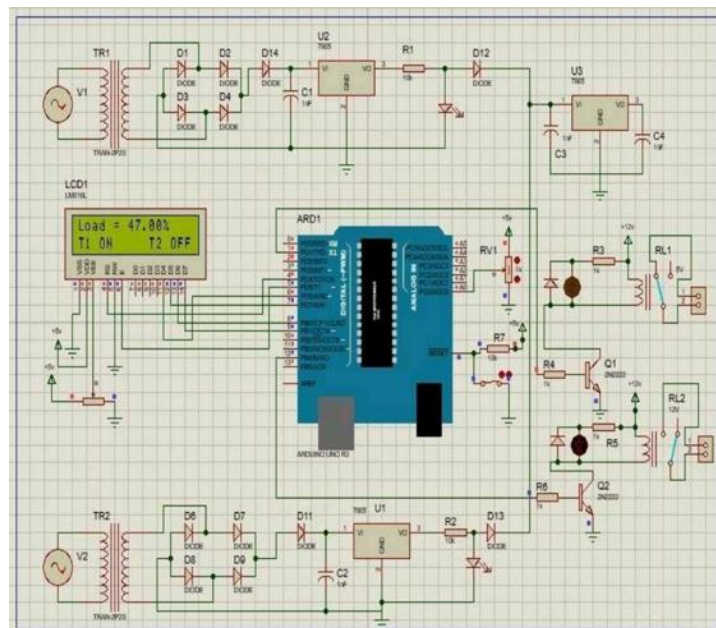


Fig. 4. Simulation under normal condition

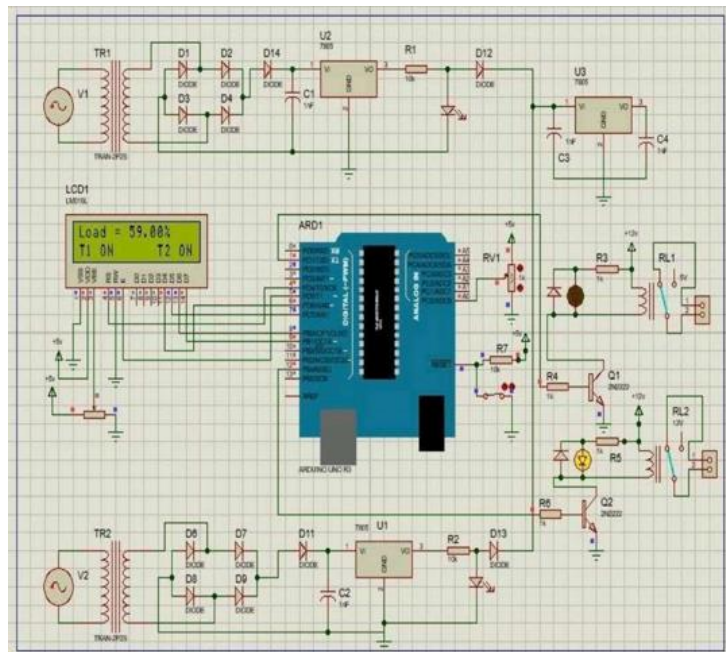


Fig. 5. Simulation under loaded condition

Conclusion:

This research introduces a cost-effective and automated solution for transformer overload protection through load sharing using an Arduino microcontroller. The system demonstrated high efficiency in managing overload conditions and distributing the load between two transformers. The system was successfully tested through simulation, and the results showed that it could reliably prevent transformer overheating and reduce the risk of transformer failure. Future work can involve hardware testing and the integration.

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Bank Locker Management System

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Abstract:

This paper presents the design and implementation of a bank locker management system enhancing the efficiency and security of locker management in financial institutions. The system automates the allocation, tracking, and maintenance of safety deposit lockers, addressing common challenges such as manual record-keeping, loss of data, and unauthorized access. The proposed system leverages a user-friendly interface for both bank staff and customers, allowing for seamless locker reservations, renewals, and access control. It incorporates advanced security features, including biometric authentication and real-time monitoring, to ensure the safety of customer assets.

Introduction:

The Bank Locker Management System plays a critical role in the financial sector, offering customers a secure way to store valuable items and documents. Traditionally, locker management has involved manual processes that are often inefficient, and security vulnerabilities. As banks strive to provide better service and enhance customer trust, there is a growing need for an automated system that streamlines operation while ensuring robust security measures. This system aims to address these challenges by integrating modern technology into the management of safety deposit lockers. With features such as automated booking, access control through biometric authentication, and real-time monitoring, the proposed solution enhances both operational efficiency and customer experience.

Literature Review

The management of bank lockers has evolved significantly over the years, particularly with advancements in technology and changes in customer expectations.

This literature review explores existing research and developments related to Bank Locker Management Systems, focusing on automation, security, and user experience. Automation in Locker Management: Several studies emphasize the need for automated systems in bank locker management. Traditional manual processes often lead to inefficiencies.

Methodology:

- System Requirements User Roles:** Customers
Bank Staff/Admin
Functionality: Locker allocation
Access control
Payment processing
Reporting and audits
- Database Design Tables:** Users: user_id, name,

contact_info, address, etc. Lockers: locker_id, size, location, status, user_id (if allocated)

Transactions: transaction_id, locker_id, user_id, action (allocate/release), date_time
Payments: payment_id, user_id, amount, date_time, locker_id

3. Key Features

User Registration/Login: Secure access for customers and bank staff.
Locker Availability Check: View available lockers based on size and location.
Locker Allocation: Allow users to request and allocate a locker.
Access Logs: Track when users access or release their lockers.
Payment System: Integrate with payment gateways for locker fees.

Notifications: Email/SMS alerts for locker allocation, payment reminders, and expiry notifications.

- User Interface Customer Portal:** Dashboard with locker status
Options to book/release lockers
Payment history
Admin Portal: Manage lockers (add/edit/remove)
View user activity and transaction history
Generate reports on usage and revenue.

- Security Measures Authentication:** Use multi-factor authentication for user access.
Data Encryption: Protect sensitive user data.
Audit Trails: Maintain logs of all actions taken within the system.

6. Technology

Frontend: HTML, CSS, JavaScript

Backend: Python

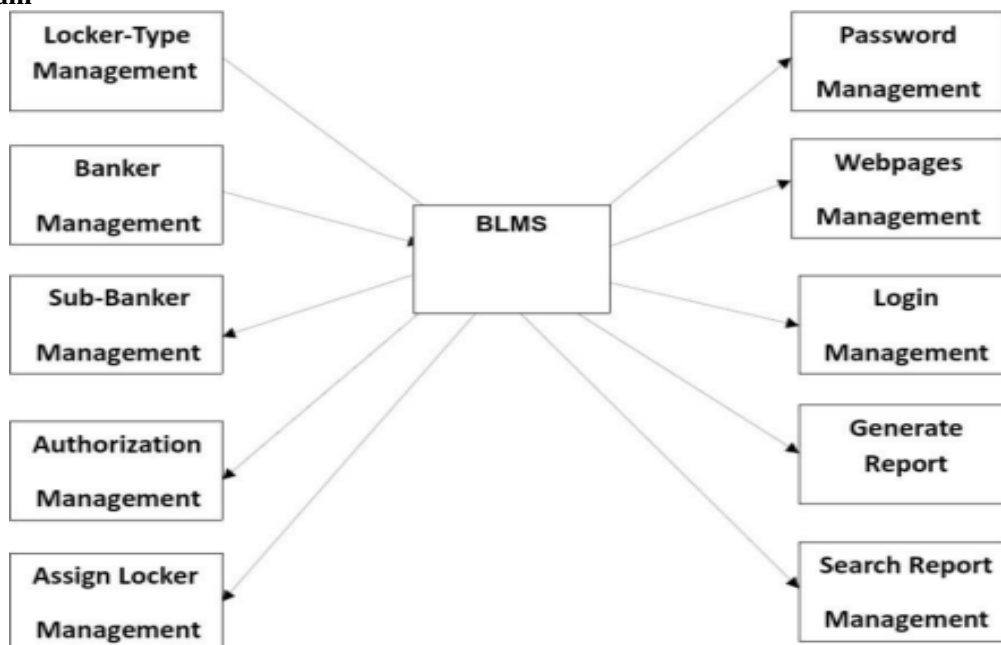
Database: MySQL

Hosting: Cloud platforms like AWS, Azure, or Digital Ocean

Experimental Procedure

1. Preparation:-Develop survey and interview questions focused on security practices, customer experiences, and satisfaction .Obtain necessary permissions from participating banks for data collection.
2. Testing:-Test the survey of bank customers to ensure clarity.
3. Sampling:-Identify a diverse group of participants using stratified sampling to represent different demographics .Select bank branches for observations, ensuring a mix of locations.
4. Data Collection:-Surveys: Distribute questionnaires to selected customers in-person and online. Set a timeline for responses and send reminders to encourage participation. Interviews: Schedule interviews with bank managers and security personnel. Conduct interviews in a quiet setting, ensuring confidentiality and comfort for participants.
5. Observational Study:-Visit selected bank branches to observe security measures in practice e. g., access control, customer interactions. Take notes on the physical security setup, staff interactions, and overall customer experience.

Dfd Diagram



System Construction:

1. System Architecture-Client-Server Model: Use a client-server architecture where the client interacts via a web or mobile application, and the server handles the database and business logic. RESTful API: Develop APIs to facilitate communication between the frontend and backend.
2. Technology Stack -Frontend: Framework: React.js or Angular for a dynamic user

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6. Data Analysis:-Quantitative Data: Compile survey results using statistical software. Perform descriptive and inferential statistics to identify trends and correlations. Qualitative Data: Transcribe interviews and categorize responses into themes (e.g., security effectiveness, customer satisfaction). Analyze observational notes to support findings from surveys and interviews.
7. Validation:-Cross-validate findings by comparing quantitative data with qualitative insights. Conduct follow-up interviews if necessary to clarify or expand on specific themes.
8. Reporting Results:-Prepare a comprehensive report summarizing the methodology, findings, and implications for bank locker management. Include charts and graphs to visually represent data trends.
9. Feedback and Revision:-Present findings to stakeholders (bank management, security teams) for feedback. Revise conclusions and recommendations based on stakeholder input.
10. Final Submission:-Finalize the research paper incorporating all feedback and additional insights gained from discussions with stakeholders.

interface. Styling: CSS or frameworks like Bootstrap. Backend :Language: Node.js (Express.js), Python (Flask/Django), or Java (Spring Boot).Database: MySQL or PostgreSQL for relational data management. Payment Integration: Use Stripe, PayPal, or similar for handling transactions.

3. Core Features Development: User Registration and Authentication: Implement secure registration (using bcrypt for password

hashing).JWT (JSON Web Tokens) for session management. Locker Management: APIs for listing available lockers. Endpoints for allocating and releasing lockers. Transaction Logging :Record all actions taken by users (allocation, release) in the Transactions table. Payment Processing: Integrate payment gateway API for locker fees. Ensure secure handling of payment information. Notifications: Use services like Twilio or SendGrid for SMS/email notifications.

4. User Interface Design-Customer Portal:Dashboard: Display available lockers, user details, and transaction history.Forms for locker allocation and payment processing.Admin Portal:Management interface for viewing all lockers, user transactions, and generating reports.
5. Testing and Quality Assurance- Gather feedback from end-users to identify areas of improvement.
6. Deployment-Hosting: Choose a cloud provider (AWS, Azure, or Digital Ocean).Monitoring: Use tools like New Relic to monitor application performance and errors.
7. Maintenance and Updates-Regularly update software dependencies and libraries. Perform security audits to safeguard against vulnerabilities .Collect user feedback for future feature enhancements.

Conclusion:

Developing a Bank Locker Management System involves careful planning and execution across various stages, from requirements gathering to deployment and maintenance. By utilizing a client-server architecture and a well-defined technology stack, the system can effectively manage locker allocation, transactions, and user interactions. Key components, such as user authentication, locker management, and payment processing, must be implemented securely and efficiently to ensure a seamless experience for both customers and bank staff. Regular testing and monitoring are essential to maintain system integrity and performance. Ultimately, a well-constructed system not only enhances customer satisfaction through reliable service but also contributes to the bank's operational efficiency. Continuous feedback and updates will keep the system aligned with user needs and technological advancements, ensuring its relevance and security in the long run.

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Enhancing Wind Farm Reliability

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Abstract:

This paper talks about the main problems that affect wind farm reliability, like equipment breaking down, bad weather conditions, and maintenance issues. It also mentions that new technologies, such as tools that predict when something will go wrong, sensors, and automated systems, can help prevent any problems before they happen and detect issues early. Lastly, the paper talks about ways to enhance wind farm reliability and get better performance in the future.

Introduction:

The first use of wind to generate electricity occurred in the late 19th century. As the world shifts to renewable energy, wind power has become a main point in reducing carbon emissions and providing clean and renewable energy. Wind farms, both on land and offshore, are growing fast, but making sure they are reliable is still a big challenge. Reliable wind farms are important for steady energy production, keeping maintenance costs low, and making sure they can last over time. If they aren't reliable, there can be more downtime, less energy produced, and higher maintenance costs.

As wind farms might not be yet reliable due to several reasons, such as electrical problems, mechanical failures, climate change, and high maintenance costs and difficulties. Wind turbines have to face extreme changes in weather conditions, unpredictability of wind flow, and salty air offshore. To enhance the reliability, new technologies like machine learning (ML), the Internet of Things (IoT), artificial intelligence (AI), and systems that can detect faults are emerging as solutions. These technologies allow for real-time observation and early detection of faults, which helps to prevent the wind farm from more failure, reduce downtime, and improve maintenance. This paper looks at the factors affecting wind farm reliability and how new technologies can help make them more efficient, cost-effective, and sustainable.

Literature Review:

1. A Critical Review on Wind Turbine Power Curve Modelling Techniques and Their Applications in Wind Based Energy Systems this paper was published by Sohoni. V., Gupta. S., Nema. R. in 2016. The author of this paper says that there are various methods for modelling the wind turbine power curve, which links output power to wind speed. Accurate power curves are vital for energy assessment, warranty claims, and performance monitoring. The paper discusses different modelling

techniques based on data from manufacturers and real wind farms, evaluating their effectiveness and limitations. It also highlights the use of soft computing methods and identifies the drawbacks of current models, suggesting areas for future research to improve accuracy and applicability.

2. Wind turbine condition monitoring by the approach of SCADA data analysis this paper was published by Yang. W., Court. R., Jiang. J. in 2013. The author of this paper says that the challenges of operating and maintaining wind turbines in remote onshore and offshore locations, where transportation and site access are difficult. As wind turbine costs decrease, condition monitoring has emerged as a key solution for maintenance issues, but existing technologies are often expensive and limited in capability. The paper proposes a cost-effective and reliable condition monitoring technique by utilizing SCADA data, which has been underused due to a lack of proper interpretation tools.

The paper's main contributions are:

- a. Developing an effective method for processing raw SCADA data.
 - b. Proposing a condition monitoring technique based on identifying correlations among relevant SCADA data.
 - c. Providing a quantitative assessment of turbine health under varying operational conditions.
- Laboratory and site verification tests demonstrate that the proposed technique is highly effective at detecting early blade and drivetrain faults and tracking their deterioration over time, offering a promising solution for wind turbine maintenance.

Factors Affecting Wind Farm Reliability:

Mechanical Failures:

Mechanical failures in wind farms happen when parts of the turbine, like the gearbox, bearings, blades, or systems that control the blades' angle,

stop working properly. This can lead to unexpected shutdowns, expensive repairs, and less energy being produced. These issues are usually caused by material wear, bad weather, or design problems. Fixing these problems is important to keep wind farms running smoothly and efficiently.

Electrical Failures:

Electrical failures in wind farms happen when there are inverter malfunctions, generator failures, electrical component wear, and control system failures. This can cause the turbines to stop making power, and repairing is expensive. There are some common causes like bad weather, wear over time, and poor design.

Environmental Conditions:

The reliability of wind farms is affected by factors like wind speed, high temperature, saltwater exposure in offshore farms, rain, humidity, snowfall, lightning, and dust. Harsh conditions can damage turbine parts, lower efficiency, and shorten their life. Good design and regular maintenance are needed to handle these issues and keep the turbines working well over time.

Operational and Human Factors:

The reliability of wind farms depends on how well they work, are managed, and are operated. Regular maintenance, monitoring, and a stable power connection are important for smooth operation and enhance the reliability of wind farms. Skilled workers, safety measures, and good management are also needed to avoid mistakes, and then only the wind farm will work efficiently, and we can see enhanced wind farm reliability.

Strategies To Enhance Wind Farm Reliability:**Predictive Maintenance:**

Predictive maintenance in wind farms uses information and technology to predict when turbines might need fixing so repairs can be done before problems happen. This helps avoid downtime, prevents expensive breakdowns, makes equipment last longer, and saves money by keeping turbines running smoothly.

Condition Monitoring Systems:

In wind farms, the health of parts like gearboxes, bearings, and generators is detected by the Condition Monitoring Systems (CMS). Problems like vibrations, temperature, oil, and sound to spot problems are found early by using sensors. This helps avoid breakdowns, lower repair costs, and make turbines run better and last longer and smoothly. However, CMS can be expensive to set up and manage, and handling all the data can be tricky, but it is the best way to enhance wind farm reliability.

Advanced Turbine Design and Technology:

Enhance wind farm reliability by making turbines more efficient, durable, and easier to maintain with advanced turbine design and technology. There are some innovations that help to

optimize the performance of wind farms, like larger blades, stronger materials, real-time monitoring, predictive maintenance, and smart control systems, detect issues early, and reduce downtime, leading to more reliable and cost-effective wind energy.

Machine Learning and Big Data Analytics:

By predicting when maintenance is needed, spotting problems early, improving energy production, and monitoring turbines in real-time Machine learning and big data help make wind farms more reliable. These tools reduce downtime, make wind energy more efficient and cheaper, and help to make better decisions.

Benefits Of Enhanced Reliability:**Increased Energy Output:****Stable Power Generation:**

Reliable wind turbines generate a consistent amount of energy. As turbines generate a consistent amount of energy, it helps to avoid the large changes in power generation. In such places where wind speeds vary more, as sometimes it increases and sometimes it decreases, in this condition consistency is important to keeping energy supply and demand balanced.

Maximized Efficiency:

Wind turbines can work at their best for a longer time as the reliability is improved. As parts get worn out or when they need repairs, then they get less efficient. By maintaining the turbines in good condition, they can keep generating almost as much power as possible, even when conditions are not suitable.

Reduced Operational Costs:**Lower Maintenance Costs:**

Less need for constant maintenance, and this is only because of better reliability. Better reliability also saves a lot of money. Instead of waiting for things to fail, predictive maintenance and monitoring can find problems before they fail. By fixing them early, wind farm operators can avoid costly emergency repairs and heavy maintenance.

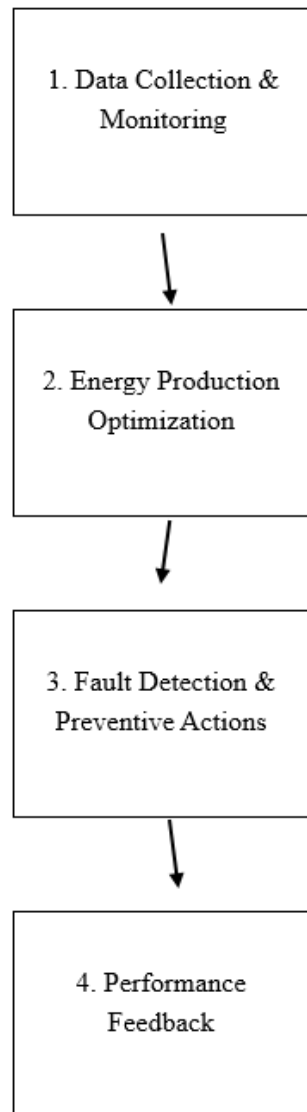
Lower Spare Parts cost:

To reduce the operational cost of the wind farm, we have to reduce the need for spare parts for the wind farm. As wind farms are more reliable, the need for spare parts for wind farms decreases. This not only saves money on purchasing spare parts but also reduces the costs of transportation and storing spare parts.

Environmental benefits:

Reliable wind turbines work better and more consistently and efficiently, producing more renewable energy throughout their lifespan. This helps increase the amount of clean and renewable energy in the power supply, reducing the need for fossil fuels, which emit carbon. As in all the world, wind energy will be produced and used, and then it will reduce carbon emissions and help to keep the environment clean.

Block Diagram:



1. Data Collection & Monitoring:

The data is collected from turbines, and analysis shows how well turbines were working. All activities were monitored, and data were collected from various parts and components of the wind farm.

2. Energy Production Optimization:

Energy production optimization helps wind turbines to run better. It prevents problems, keeps them working smoothly and properly, and increases the amount of energy that is generated by turbines.

3. Fault Detection & Preventive Actions:

Monitoring and identifying the faults in turbines and fixing the problems before they get damaged.

4. Performance Feedback:

The collected data is sent back to the system. As the data is sent back to the system, it helps to adjust the turbine settings and make better predictions to produce more energy from the turbine.

Methods:

In this paper, we explain how we conducted the research to find better ways to enhance wind farm reliability. We will collect data from several wind farms, tested predictive maintenance technologies, and looked at how well the turbines were performing. The main purpose is to collect data in real time, create models to predict potential issues, and see how different technologies could improve the reliability of the turbines.

Study Design:

Data Collection and Observing Setup:

We have to install some sensors on the turbines and collect data for a few months to establish a baseline. We have to deeply observe and note how the turbines are performing under normal conditions. The observing systems will also be checked to make sure the data collected is accurate and reliable.

Predictive Maintenance Implementation:

We will use predictive maintenance to help the turbines. The sensors will collect data, and machine learning models will be used to predict when parts of the turbines need maintenance. Alerts

will be set up to warn operators before anything breaks down. We also check systems that can notify early signs of problems, like vibrations or temperature changes, so they can observe it and fix it before it gets damaged.

Performance Evaluation and Optimization:

Firstly, we will set up predictive maintenance, and then we will compare how the turbines were performing to the data we collected at the start. We will check for changes in efficiency, downtime, and maintenance costs and also test smart systems that adjust the turbines to make the most energy based on current wind conditions. The turbines will constantly observe and adjust to produce more energy while avoiding damage.

Data Analysis:

We will put the predictive maintenance system in place; we will look at how the turbines were performing compared to the initial data we had gathered. We will focus on three main factors: efficiency, downtime, and maintenance costs. We will also check advanced systems that automatically adjusted the turbines to optimize energy production depending on the current wind conditions. These systems will help the turbines capture the most energy possible at any given moment.

Conclusion:

This study shows that using smart control systems and predictive maintenance can enhance wind farm's reliability. These technologies helped the turbines perform smoothly and better, reduced the amount of time they were down, and lowered maintenance costs. Using this, we can catch problems early, saving money on repairs and helping the turbines last longer.

While the results are encouraging, the study has some limitations, like using only a few turbines and being short on time. Future studies could use more turbines, look at the long-term effects of these technologies, and see if they are affordable for smaller wind farms.

In the end, this study suggests that predictive maintenance and smart control systems can make wind energy more efficient, reliable, and cost-effective, supporting the growth of renewable energy.

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Opportunities and challenged for implementing electric vehicles in India

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Abstract:

Electric Vehicles are the replacement for petroleum-based vehicles. They are one of the emerging technologies as well as eco-friendly and viable [10]. This research delves into the evolution of EVs over time and highlights their benefits, including reducing carbon emissions and air pollution. It also explores the challenges and difficulties faced in their adoption, such as the high cost of infrastructure, scarcity of charging stations, limited range or range anxiety, and the performance of batteries [10]. The replacement of internal combustion engines with electric engines will reduce pollution to a great extent and be profitable to consumers. Many countries around the globe have implemented this technology are contributing towards amelioration of the environment. In this Paper, the opportunities and challenged faced in India over implementing electric vehicles have discussed.

Keywords: Pollution; Electric Vehicle; Eco-Friendly; Lithium Battery; charging infrastructure

Introduction:

An electric vehicle (EV) is a type of transportation powered by electricity stored in batteries, rather than using traditional internal combustion engines that rely on fossil fuels. The concept of electric vehicles is not new; they have been around since the late 19th century. EVs offer a sustainable and eco-friendly alternative, producing zero tailpipe emissions and promoting energy efficiency. It provides an eco-friendly alternative to traditional vehicles, reducing emissions and reliance on fossil fuels. . EVs are seen as a cleaner, more sustainable alternative to conventional vehicles, offering the potential to reduce greenhouse gas emissions, improve air quality, and decrease dependency on non-renewable energy sources [10]. EVs have been adopted by many countries since it development creating a positive impact on the environment. We are now going to see the opportunities and challenges impending over implementing electric vehicles in India

Types of Electric vehicle:

• Battery electric vehicle:

Battery Electric Vehicles are complete electric vehicles that are powered by only electricity and do not include a petrol/diesel engine, fuel storage or exhaust pipe. They use electric motors and motor controllers for propulsion. They do not have an internal combustion engine. They charge the battery through external charging outlet and hence also known as “Plug-in Electric Vehicles (PEVs)”[3-6]. There are various types of BEVs such as electric cars, buses, bikes, scooters, trucks and trains. They even include fewer parts than those used for those vehicles based on internal combustion engines. They even produce fewer noises compared to their counterparts [2]. Batteries are significantly reduced greenhouse gas emission and used for various power-grid applications that provide the high quality of energy derive from various renewable sources like wind, solar, geothermal and other renewable sources[8-9]. As first, EV was launched in 1834, i.e., tricycle, which is powered by a battery.

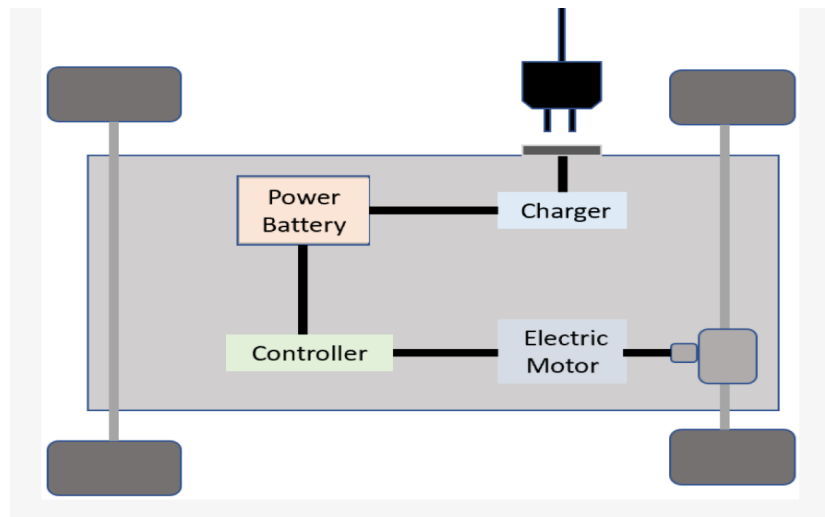


Fig 1. Basic electric vehicle [2]

- **Hybrid electric vehicle:**

Today's hybrid electric vehicles (HEVs) are powered by an internal combustion engine in combination with one or more electric motors that use energy stored in batteries[9]. HEVs combine the benefits of high fuel economy and low tailpipe emissions with the power and range of conventional vehicles. An alternate arrangement is a diesel engine and an electric motor. HEV is formed by merging components from a pure electrical vehicle and a pure gasoline vehicle. The Electric Vehicle (EV) has an M/G which allows regenerative braking for an EV; the M/G installed in the HEV enables

regenerative braking. For the HEV, the M/G is tucked directly behind the engine. In Honda hybrids, the M/G is connected directly to the engine. The transmission appears next in line. This arrangement has two torque producers; the M/G in motor mode, M-mode, and the gasoline engine. The battery and M/G are connected electrically. Hybrid Electric Vehicles offer a compromise between conventional vehicles and electric vehicles, providing improved fuel efficiency and reduced emissions while still offering the range and convenience of a conventional vehicle.

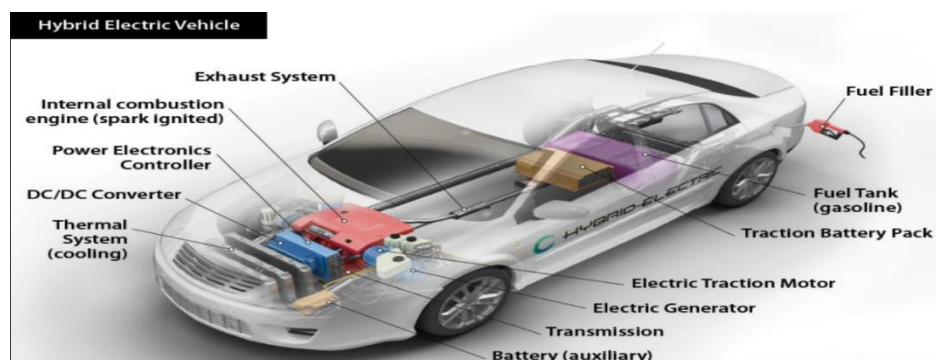


Fig2. Hybrid electric vehicle[11]

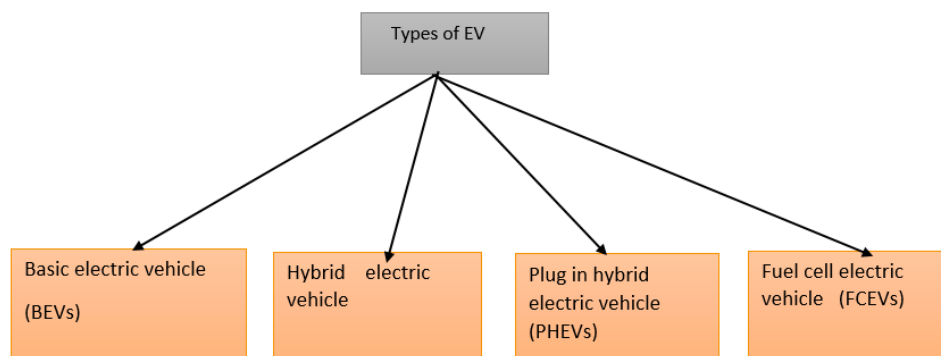


Fig3. Types of Electric Vehicle

Present scenario:-There are about 300 million conventional vehicles that grow at the rate of 60000 new registrations / day. There are 70799 traditional fuel stations compared to just 221 EV stations [12]. India's goal is to ensure that by 2030 all public transport and 30% of private vehicles are electric. This was one of the key decisions taken in Global Mobility Summit in New Delhi. Transport sector consume 70% of fossil fuels-causing more than 70% of pollution. The Government provides a lower GST at 12% on electric vehicles while the Government levies 28% GST plus cess for petrol and diesel cars[13]. India's goal is to ensure that by 2030 all public transport and 30% of private vehicles are electric. In the passenger car category, Tata Motors holds a significant market share with models like the Nexon EV and Tiago EV, while global players such as BYD and MG Motor are expanding their presence.

Challenges:

- **High Purchase Cost:** High purchase costs can include High upfront costs for equipment or inventory ,Premium pricing for high-end or specialty products ,Costs associated with international shipping or customs. High purchase costs can be a challenge for many businesses.
- **Charging Infrastructure:** Limiting charging infrastructure can be a significant challenge for businesses and individuals looking to adopt Electric Vehicles (EVs).
- **Range Anxiety :** To address limiting charging infrastructure, consider Investing in on-site charging infrastructure for employees or customers, Partnering with charging station providers to increase public charging options, Encouraging employees to charge at home and providing incentives for doing so, Advocating for government incentives and investments in public charging infrastructure.
- **Slow charging speed:** Slow charging speed in EVs hampers convenience, limiting adoption. It prolongs wait times, disrupting schedules, and reducing practicality for long trips. Addressing this requires faster charging technologies, improved infrastructure, and efficient battery designs. Accelerating innovation in this area is crucial to meeting user expectations and promoting widespread electric vehicle usage
- **Environmental impact of battery production:** Environmental impacts of battery production: Energy consumption: Battery production requires significant amounts of energy, often generated from non-renewable sources, Material extraction: Lithium, cobalt, nickel, and other materials used in battery production have environmental and social implications associated with their extraction ,Water usage:

Battery production requires significant amounts of water, particularly for lithium extraction, Waste generation: Battery production generates hazardous waste, including toxic chemicals and heavy metals.

- **Limited Modal Availability :** Limited modal availability in electric vehicles (EVs) arises due to restricted production capacity, high costs of advanced technology, and supply chain issues, especially with critical materials like lithium for batteries. This limits variety and affordability, slowing widespread adoption while presenting a challenge for manufacturers to scale and innovate effectively
1. **Opportunity: Improved air quality:** Electric vehicles offer an opportunity to improve air quality by reducing harmful emissions, promoting healthier environments and combating climate change. Electric vehicles (EVs) present a significant opportunity to improve air quality by reducing greenhouse gas emissions and eliminating harmful pollutants like nitrogen oxides and particulate matter from traditional combustion engines. Their adoption helps combat climate change, supports sustainable urban development, and reduces health risks associated with poor air quality
 2. **Job creation:** The EV industry drives job creation across manufacturing, battery production, charging infrastructure, and R&D. It fosters opportunities in vehicle assembly, software development, renewable energy integration, and maintenance. Growth in EV adoption supports ancillary sectors like mining for battery materials and recycling. Governments and businesses investing in EVs boost local economies, create green jobs, and advance sustainable transportation.
 3. **Global Energy Demand:** The global energy demand is rising, driven by population growth and industrialization. EVs offer a significant opportunity to reduce reliance on fossil fuels, lower greenhouse gas emissions, and improve energy efficiency. By leveraging renewable energy sources, EVs can support sustainable transportation, reduce air pollution, and decrease energy costs. Governments and industries are investing heavily in EV infrastructure, creating economic opportunities in manufacturing, battery technology, and energy storage. The shift to EVs aligns with global efforts to combat climate change and transition to a cleaner, more sustainable energy future.
 4. **Battery:** Electric vehicles (EVs) present significant opportunities, especially in battery innovation. The shift to EVs drives demand for advanced batteries, fostering advancements in

energy density, charging speed, and sustainability. This creates business opportunities in battery production, recycling, and second-life applications. With global adoption rising, investments in renewable energy integration and grid storage also grow, positioning EV batteries as a cornerstone of the clean energy future.

5. Battery management system: Battery is a heart of electric vehicles. Battery management system (BMS) is the crucial system in electric vehicle because batteries used in electric vehicle should not be get overcharged or over discharged. If that happens, it leads to the damage of the battery, rise in temperature, reducing the life span of the battery, and sometimes also to the persons using it. It is also used to maximize the range of vehicle by properly using the amount of energy stored in it. The BMS helps to improve safety, increase efficiency, and extend battery life. Electric Vehicles (EVs) offer sustainable, efficient, and environmentally friendly transportation solution, with benefits including reduced emissions, lower costs, and improved performance.[16].

Conclusion:

In conclusion, electric vehicles (EVs) present a promising solution to the global challenges of climate change and environmental degradation. With advancements in battery technology, energy efficiency, and charging infrastructure, EVs are becoming more accessible and practical for everyday use. The ongoing collaboration between governments, industries, and consumers will play a vital role in accelerating EV adoption. As we move forward, it is essential to continue focusing on innovation and sustainability to make electric vehicles a central part of a greener future. The implementation of EVs in India aims primarily to reduce greenhouse gas emissions and cut oil expenses. The vision 2030 put forth by the Indian Government is an ambitious and difficult task. The Government should make the most out of the opportunities available and find suitable ways to tackle the challenges impending over the implementation of EV [1]. The future of electric vehicles completely depends on the changes made in batteries in the future. As of today, there are electric vehicles available in market, but there are some disadvantages which needs to be improved in future. If the disadvantages are improved, then the electric vehicles have promising future [15].

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Design and development of connecting rod by using analysis software

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Abstract:

The connecting rod is a crucial component in internal combustion engines, converting the reciprocating motion of the piston into the rotational motion of the crankshaft. This study aims to analyze the structural integrity and performance of a connecting rod using ANSYS, a sophisticated engineering simulation software. The primary focus is on evaluating the stress distribution, Eigen value of buckling, deformation and factor of safety under static loading conditions. This study focuses on the structural analysis of an engine connecting rod using ANSYS software. The analysis includes defining boundary conditions, such as fixed support at the crankshaft end and applying axial loads at the piston pin end. Finite Element Analysis (FEA) is used to evaluate stress distribution, deformation and potential failure points under operating conditions. The study aims to optimize the design for improved strength and durability while minimizing weight. The results provide insights into material selection and geometric modifications to enhance the connecting rod's performance.

Keywords: Connecting rod, Analysis, Finite Element Analysis (FEA)

Introduction:

A connecting rod also called a 'con rod', is the part of a piston engine which connects the piston to the crankshaft. Together with the crank, the connecting rod converts the reciprocating motion of the piston into the rotation of the crankshaft. The material used for the connecting rod it must be light and strong enough to withstand stress and twisting force. The connecting rod is made of nickel, high grade alloy steel, chrome and chrome vanadium steel [1]. For small engine the material used is aluminium & structural steel. The upper end of the connecting rod has a hole for the piston pin. The lower end of the connecting rod is split so that the connecting rod can be installed on the crankshaft. Connecting rods are expected to withstand significant cyclic and inertial loads that are elevated by directional changes at the end of each stroke [2].

Failure of rod bolts, incorrect tightening, or poor maintenance can all lead to connecting rod failure. Failures are typically observed in competitive driving events. Since connecting rods are made with a high level of safety in mind, these kinds of failures are rarely common [3]. There are two possible combinations for the connecting rod's cross-section. I-beam and H-beam or the two in combination. High power engines employ H-beams because they can handle a lot of stress and anxiety without flexing. I-beams are powerful, light, and able to handle tremendous pressure. The study H-beam profile exhibits reduced von mises stresses up to 12.3% (average: 15.7%) and more stability, up to

43.1%, than the I-beam profile. However, because it is less expensive and easier to make, I-beam is utilised more frequently [4]. According to a study, the structural steel connecting rod has the highest maximum stress and the Al-alloy connecting rod has the highest maximum deformation.

Finite Element methods are used to determine the system's mechanical properties. The component's meshing mode is created by FEM, and it is subsequently examined. Mesh creation in 2D is rather simple, and enhancing its quality is a straightforward process. Since fatigue failure is more likely in automobiles, aircraft, and other machinery, precise design and production are also crucial to reducing this component as much as possible [5].

Failure of the buckled load In certain research publications, the connecting rod is also analysed under conditions of sudden piston locking, which results in a larger impact load on the connecting rod and is referred to as Hydro-lock failure (cause: excess fuel air mixture or water leakage into the cylinder).

Methodology

The connecting rod's geometry was modelled using CAD software and then Imported into ANSYS for analysis. Material properties, such as Young's modulus, Poisson's ratio and density were assigned based on commonly used materials like structural steel and aluminium alloys. Boundary conditions were applied to simulate the real-life constraints and loads experienced. During engine operation a finite element analysis (FEA) was

performed to investigate the stress Concentration areas, total deformation and eigen value of buckling.

Conducting a connecting rod analysis using ANSYS software involves several steps to ensure a comprehensive and accurate simulation. Here's a step-by-step methodology:

Step 1: Define the Problem and Objectives

Objective: To analyze the stress, strain and deformation of a connecting rod under static loading conditions.

Parameters: Material properties, geometric dimensions, boundary conditions, and loading conditions.

Step 2: Create or Import Geometry

CAD Model: Create the 3D model of the connecting rod using CAD software or import an existing CAD file into ANSYS. Ensure the model is clean with no errors in geometry. Simplify the model if necessary to reduce computational load without losing critical features.

Step 3: Define Material Properties

Material Selection: Assign the material properties to the connecting rod.

Step 4: Mesh the Geometry

Meshing: Discretize the geometry into finite elements. Use an appropriate element type (e.g., tetrahedral, hexahedral). Ensure mesh quality with an appropriate element size to capture stress concentrations.

Perform a mesh convergence study to determine the optimal mesh size.

Step 5: Apply Boundary Conditions and Loads

Boundary Conditions: At one end connecting rod is fixed and at pin end axial load or pressure is applied

Apply fixed supports where the rod is attached to other components.

Step 6: Set Up the Analysis Type

Analysis Type: Choose the type of analysis to be performed. **Static Structural Analysis:** For determining stress and deformation under static loading.

Step 7: Solve the Problem

Solver Settings: Configure the solver settings and initiate the solution process. Monitor convergence criteria and solver progress.

Forces Affecting The Connecting Rod

The forces operating on the connecting rod are as follows:

(i) Gas pressure exerted on the piston.

(ii) Force from the reciprocating mass and the connecting rod's inertia.

(iii) Force generated by friction between the piston and its rings.

IV. CALCULATES FORCES

Force due to gas pressure Maximum force due to gas pressure, $F_a = (\pi \times d^2 \times P_e) / 4$

$$= (3.14 \times 1012 \times 3.15) / 4 = 24,740\text{N}$$

Results And Analysis

Result of buckling analysis by simulation of ansys software we get 5 numbers of modes in the form of total deformation. These 5 numbers of modes of deformation includes various forces this are tensile and compressive force, bending force, shear force, twisting force, etc.

By applying 40 pa axial load on the pin end of the con rod we get 5 modes of deformation and load multiplier under static loading condition. It shows minimum, maximum and average deformation of the connecting rod.

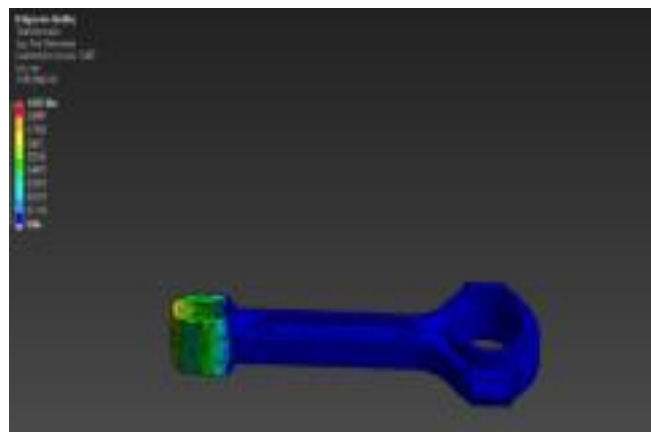


Fig. 1. Tensile force and deformation

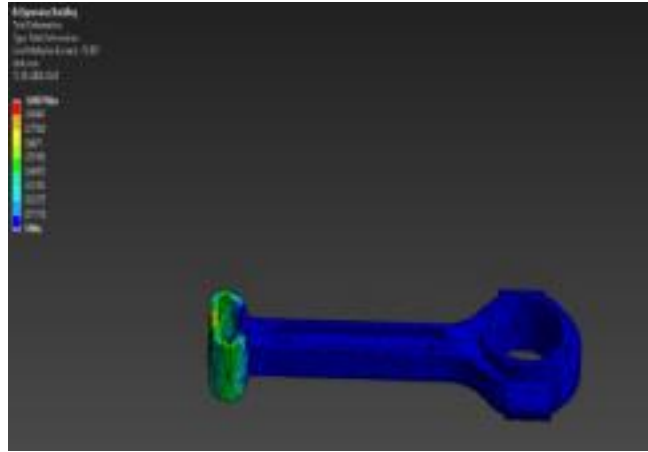


Fig. 2. Compressive force and its deformation

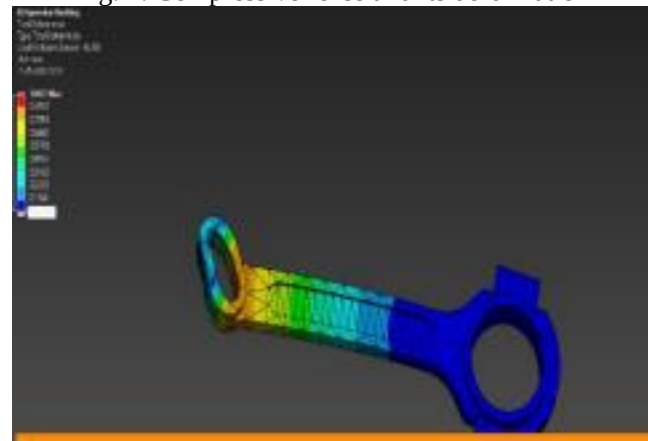


Fig. 3. Shear force and its deformation

The foundation of FEA is the domain's decomposition into a finite number of subdomains, or elements, for which the variational or weighted residual approach is used to generate the systematic approximation solutions. By breaking the domains up into pieces and describing the unknown field variable in terms of the presumptive approximation function within each element, FEA effectively simplifies the problem to one with a finite number of unknowns. These functions, which are also known as interpolation functions, are specified in terms of the field variable values at particular places, or nodes. Nodes are linked to neighbouring elements and are typically found at the edges of elements.

A Workbench programme called ANSYS

Table 1 Comparison of values

Material	Max. Deform (mm)	Max. Von Mises Stress (Mpa)	Weight (Kg)	Min. Factor of Safety
Aluminium 2025-	0.39546	356.19	0.3759	0.9698

Mechanical can carry out several engineering simulations, such as thermo electric, magnetostatic, thermal, vibration, and stress simulations. The model includes 20929 nodes and 11628 elements. A typical simulation consists of building up the model and the loads put to it, then solving for the model's reaction to the loads.

Result And Discussion

From graph 6, it can be inferred that the most deformed material is aluminium 7075 T6, which is followed in order by aluminium 2024 T6, titanium, and carbon steel. Aluminium 7075 T6, titanium alloy, and carbon steel all have nearly equal von mises stresses, however aluminium 2025 T6 has the lowest von mises stresses.

T6				
Aluminium 7085-T6	0.39931	357.8	0.37985	1.5000
Carbon steel :43CrMo4	0.1528	357.8	1.0366	1.5477
Ti-6Al-8v	0.26075	358.01	0.59307	2.4659

It can be observed that titanium has the greatest factor of safety, preceded by carbon steel, aluminium 7075 T6 and then aluminium 2024 T6.

Conclusion:

It is evident from the studies above that the best alloy to use for constructing connecting rods is titanium alloy. Because it has the least amount of distortion and the highest Factor of Safety in relation to weight.

Despite having a lesser safety factor than titanium alloy, aluminium alloy 7075-T6 is the second choice for manufacturing since the connecting rod weighs significantly less than titanium alloy.

Additionally, it is evident that the aluminium alloy 2025-T6 is ineffective due to its low safety factor and potential for product failure. Furthermore, even though carbon steel has a higher safety factor, it is ineffective because it makes the product heavier.

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Performance Assessment of a Solar Cooker Box Using Sand as a Heat Storage Material

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Abstract:

This research explores the thermal performance of sand as a heat storage material in solar cookers, aiming to optimize their efficiency and reliability. Experimental analysis reveals sand's ability to absorb solar energy, reaching peak temperatures of 80°C, and gradually release stored heat over extended periods, enabling sustained cooking even in the absence of sunlight. Comparative results highlight sand's superiority over systems without heat storage, demonstrating its effectiveness in enhancing thermal stability and energy conservation. With its low cost, abundant availability, and ease of use, sand emerges as a viable material for sustainable solar cooking applications. Future studies are recommended to further optimize sand mixtures and integrate advanced designs for broader scalability.

Keywords: Solar Cooker, Sand, Performance, Heat Storage

Introduction:

The increasing demand for sustainable energy solutions has highlighted the importance of solar cooking as an eco-friendly alternative to conventional cooking methods. Solar cookers utilize solar energy, a renewable and abundant resource, to provide efficient cooking solutions while reducing reliance on fossil fuels. However, their performance is significantly influenced by the effectiveness of the heat storage medium, which ensures consistent cooking even during periods of low or no sunlight. Sand, with its high thermal conductivity, specific heat capacity, and thermal stability, emerges as a

promising heat storage material for solar cookers. Its availability, low cost, and ability to sustain heat over extended durations make it an attractive option for energy-efficient cooking systems. This study aims to analyse the thermal performance of sand as a heat storage medium in solar cookers, focusing on its ability to absorb, retain, and release heat effectively. By comparing its performance to systems without heat storage materials, the research provides valuable insights into optimizing solar cooker designs for enhanced efficiency and sustainability.

Materials and Methods

Construction and Testing Method of the Device

Design parameters of the box type solar cooker :



omponent	Dimensions	Materials
Inner Box		Plywood
Outer Box	94 cm x 63 cm	Plywood
Reflector	-	S-Reflect
Double Glazing	86 cm x 45 cm	Glass
Sand	250 gm	-

Without Sand –

$$P = (T_2 - T_1) * m * C_v / 3600 \text{ Here, } T_1 = 37^\circ\text{C}$$

$$m = 0.0836 \text{ gm } C_v = 718 \text{ J/kg}$$

Time (in hr)	Final Temperature (T2)	Heat Capacity (P)
9 - 10	37°C	0.083 J/hr
10 - 11	41.8°C	0.163 J/hr
11 - 12	55°C	0.383 J/hr
12 - 1	60°C	0.466 J/hr
1 - 2	55°C	0.383 J/hr
2 - 3	49°C	0.283 J/hr
3 - 4	47°C	0.250 J/hr
4 - 5	41°C	0.150 J/hr

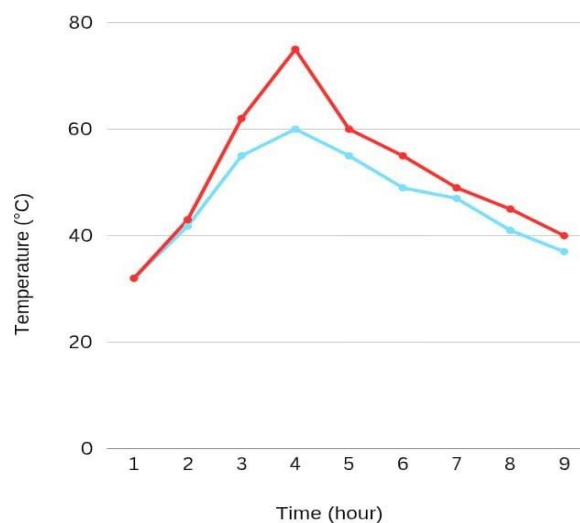
With Sand –

$$P = (T_2 - T_1) * m * C_v / 3600 \text{ Here, } T_1 = 32^\circ\text{C}$$

$$m = 250 \text{ gm}$$

Time (in hr)	Final Temperature(T2)	Heat Capacity (P)
9 - 10	43°C	0.611 J/hr
10 - 11	62°C	1.666 J/hr
11 - 12	75°C	2.388 J/hr
12 - 1	60°C	1.555 J/hr
1 - 2	55°C	2.277 J/hr
2 - 3	49°C	0.944 J/hr
3 - 4	45°C	0.722 J/hr
4 - 5	40°C	0.444 J/hr

Result:



Temperature v. Time plot (Empty Cooker and with 250 g sand)

From the graph we can conclude that in the absence of a heat storage material, the temperature rises steadily from 30°C at hour 1 to a peak of 60°C at hour 5, after which it declines gradually, reaching approximately 35°C by hour 9. This behaviour indicates a lack of sustained thermal energy retention, highlighting the importance of heat storage materials for maintaining consistent temperatures in applications like solar cooking.

Sand has effective thermal energy storage capabilities. Initially, the temperature rises steadily from around 40°C at hour 1, peaking at approximately 80°C at hour 4. Following the peak, the temperature decreases gradually to reach around 40°C again by hour 9. This indicates that sand efficiently absorbs and stores heat, releasing it slowly over time.

Conclusion:

This work has shown that the cooker using with sand material and without material. The maximum temperature of sand material 75° and maximum temperature without material has 60°

With Material (sand):

When we use sand as material in the solar cooker box:

- The helps to keep the heat inside
- It makes the cooker more efficient
- It allows us to cook food faster

Without material (Air):

When we don't use any material (just air) in the solar cooker box:

- The heat escapes easily
- The cooker is less efficient
- It takes longer to cook food.

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PLC (On Electric Drive Systems) Implementation of Programmable Logic Controllers (PLCs) in Electric Drive Systems: Challenges, Opportunities, and Applications

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Abstract:

Programmable Logic Controllers (PLCs) play a crucial role in modern industrial automation, particularly in electric drive systems. These specialized industrial computers enhance efficiency, precision, and automation by providing real-time monitoring and control of electric motors. This paper explores the significance of PLCs in electric drive systems, highlighting their key components, advantages, and applications across various industries.

Despite their numerous benefits, challenges such as compatibility issues, programming complexity, cost constraints, latency concerns, and cybersecurity threats hinder seamless implementation. However, advancements in AI, IoT, improved communication protocols, and modular designs are transforming PLC technology, making systems more efficient and adaptable. Opportunities for PLCs continue to expand in industries like manufacturing, renewable energy, smart grids, automotive, and healthcare. Case studies demonstrate how PLCs optimize production, improve energy efficiency, and enhance operational reliability. Future developments, including cloud-based control, enhanced cybersecurity, and AI-driven automation, will further strengthen PLC-based electric drive systems, ensuring their continued relevance in industrial automation.

This paper provides a comprehensive analysis of PLC integration in electric drive systems, addressing both challenges and opportunities while emphasizing the evolving role of PLCs in the Industry 4.0 landscape.

Keywords: PLC, Automation, Industrial Control, Ladder Logic, Manufacturing systems

Introduction:

Definition of PLCs: PLCs are specialized industrial computers designed to automate control processes in manufacturing and other industrial applications. They are widely used in electric drive systems to enhance efficiency, precision, and automation.

Role of PLCs in Electric Drive Systems: Electric drive systems require precise control over speed, torque, and power. PLCs facilitate this by enabling real-time monitoring, automation, and optimization of motor control operations.

Advantages of Using PLCs:

High Reliability: PLCs are robust and designed to function in harsh industrial environments.

Flexibility: Programmability allows adaptation to different applications without significant hardware modifications.

Scalability: Systems can be expanded easily with additional modules.

Efficiency: Improved power management and operational precision reduce energy consumption and maintenance costs.

Key Components of a PLC System in Electric Drives:

Processor Unit (CPU): Executes control logic and processes input data.

Input/Output (I/O) Modules: Interfaces with sensors, actuators, and other hardware components.

Communication Interfaces: Enable data exchange with other industrial automation systems.

Programming Software: Used to develop and modify control algorithms.

Importance of PLCs in Modern Industrial Automation:

Automation of repetitive tasks in manufacturing processes.

Improved safety by reducing human intervention in hazardous environments.

Enhanced productivity through continuous real-time monitoring and optimization.

Integration with Industry 4.0 technologies, including IoT and AI, for predictive maintenance and smart control.

This paper further explores the challenges, opportunities, and applications of PLCs in electric drive systems, highlighting their growing importance in industrial automation.

Challenges in Implementing PLCs in Electric Drive Systems

1. **Compatibility Issues** One of the major challenges in implementing Programmable Logic Controllers (PLCs) in electric drive systems is ensuring compatibility with existing hardware and communication protocols. Electric drive systems often use various sensors, actuators, and controllers that may not be directly compatible with standard PLCs. Additionally, different manufacturers use different industrial communication protocols such as Modbus, Profibus, EtherCAT, and CANopen, making integration complex. Retrofitting a PLC into an existing system might require additional interfaces, converters, or firmware updates, which can increase project complexity and cost.
2. **Complexity in Programming** PLCs require specialized programming skills, typically using ladder logic, structured text, function block diagrams, or instruction lists. Developing and maintaining PLC programs for electric drive systems demands expertise in automation, control theory, and industrial communication. The complexity increases when dealing with multi-axis motion control, synchronization of multiple drives, and real-time monitoring. Lack of skilled personnel can lead to delays in commissioning, troubleshooting difficulties, and increased maintenance costs.
3. **Cost Constraints** Implementing PLCs in electric drive systems involves a significant initial investment in hardware and software. High-end PLCs with advanced motion control capabilities, fast processing speeds, and multiple I/O modules can be expensive. Additional costs include: Licensing fees for PLC programming software Installation costs for wiring, panels, and additional components. Training costs for personnel to operate and maintain the system For small and medium-sized enterprises, these costs can be a barrier to adoption, making alternative control solutions more attractive.
4. **Latency and Response Time** Electric drive systems, especially in high-speed applications such as robotics, CNC machines, and conveyor systems, require real-time control with minimal latency. Some PLCs may not have the processing speed necessary to handle fast response times, leading to delays in motor control, loss of precision, or inefficient system performance. Factors affecting latency include: Scan cycle time of the PLC Network communication delays in distributed control systems Processing overhead of complex motion algorithms Choosing the right PLC with a high-speed processor, real-time operating system (RTOS), and optimized communication protocols is essential to address this challenge.

5. Security Concerns

As PLCs are increasingly connected to industrial networks and IoT platforms, they become vulnerable to cyber threats. Potential risks include: Unauthorized access leading to system manipulation or sabotage Malware and ransomware attacks disrupting production

Data breaches exposing sensitive industrial information To mitigate security risks, industries must implement firewalls, encryption, access control mechanisms, and regular software updates. Ensuring cybersecurity compliance with standards such as IEC 62443 and NIST guidelines is crucial for protecting PLC-based electric drive system.

Opportunities and Advancements

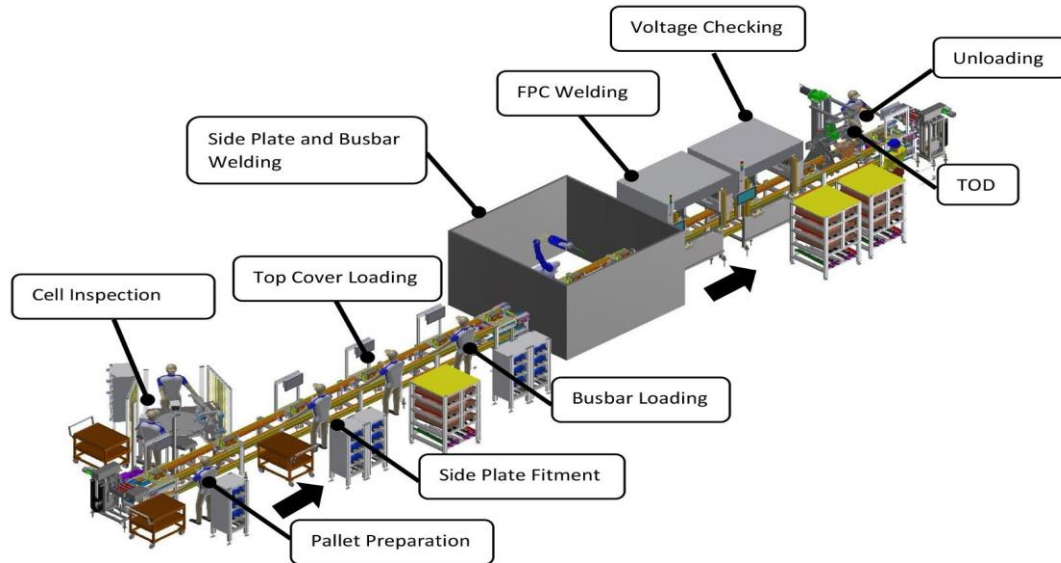
1. **Improved Communication Protocols:** The adoption of industrial Ethernet, fieldbus systems, and wireless communication technologies has improved PLC networking capabilities. Standardized communication protocols facilitate seamless integration with other automation components.
2. **AI and IoT Integration:** PLCs can now incorporate artificial intelligence (AI) and the Internet of Things (IoT) to enhance real-time monitoring and predictive maintenance. Data analytics from IoT-enabled PLCs allow for proactive fault detection and improved decision-making.
3. **Modular and Scalable Systems:** Modern PLCs are designed with modular architectures, allowing industries to scale their systems as needed. Expansion modules can be added to accommodate additional sensors, actuators, and processing capabilities.
4. **Energy Efficiency and Sustainability:** Advanced PLC algorithms optimize motor control to reduce power consumption and enhance overall energy efficiency. Smart grid integration allows PLCs to participate in demand-side energy management, contributing to sustainability goals.
5. **Enhanced Human-Machine Interface (HMI):** Improved HMIs offer intuitive touchscreen interfaces, real-time data visualization, and remote access capabilities. Integration with augmented reality (AR) and virtual reality (VR) enables enhanced system monitoring and troubleshooting.
6. **Cybersecurity Enhancements:** New PLC systems incorporate robust cybersecurity features, such as encrypted communication and secure access protocols. Cybersecurity frameworks ensure protection against unauthorized access and industrial espionage.
7. **Cloud-Based Control and Remote Monitoring:**

Cloud-based PLC solutions enable remote access, monitoring, and control of electric drive systems from anywhere. Cloud integration provides advanced data storage, analysis, and reporting functionalities for better decision-making.

Applications of PLCs in Electric Drive Systems

Industrial Automation:

Conveyor belt systems for material handling. Automated robotic arms for manufacturing and assembly processes. CNC machines that require precision motor control.



Renewable Energy Systems:

Wind turbine pitch control for optimal energy generation. Solar tracking systems to maximize energy absorption. Grid synchronization and load balancing in renewable power plants.

Smart Grids and Power Distribution:

Load balancing and demand-side management to optimize energy distribution. Fault detection and

automatic circuit reconfiguration in smart grids. Remote monitoring and control of substations.

Automotive Industry: Electric vehicle (EV) motor control and battery management. Automated assembly lines for car manufacturing. Advanced braking and traction control systems in electric vehicles

1. Introduction

Key Aspect	Description
Definition of PLCs	Specialized industrial computers used for automation and control.
Role in Electric Drives	Provides real-time control over speed, torque, and power.
Advantages	Reliability, flexibility, scalability, and efficiency.
Key Components	CPU, I/O Modules, Communication Interfaces, and Programming Software.
Importance	Enhances industrial automation, improves safety, integrates with Industry 4.0.

Process Industries:

Control of pumps, fans, and compressors in chemical and manufacturing plants. Batch processing and mixing operations in the food and beverage industry. Automated packaging and material handling systems.

4. Applications of PLCs in Electric Drive Systems

Industry/Application	Use Cases
Industrial Automation	Conveyor belts, robotic arms, CNC machines.
Renewable Energy Systems	Wind turbine pitch control, solar tracking, grid balancing.
Smart Grids & Power Distribution	Load management, fault detection, substation monitoring.
Automotive Industry	EV motor control, automated assembly lines, traction systems.
Process Industries	Pump control, batch processing, automated packaging.
Railway & Transportation	Train propulsion, traffic signal control, elevators.
Healthcare & Medical	Pharmaceutical automation, MRI control, precision dosing.

Railway and Transportation Systems:

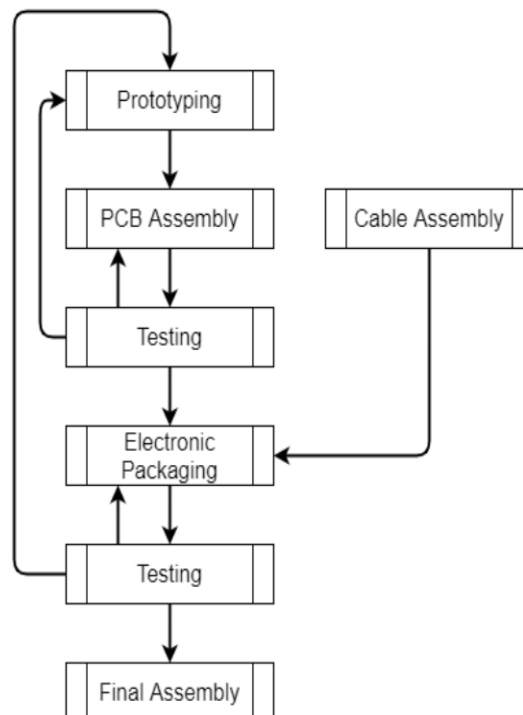
Train propulsion and braking system automation. Traffic signal control and railway crossing management. Elevator and escalator automation in urban transport networks.

Healthcare and Medical Equipment:

PLC-based control in automated pharmaceutical manufacturing. Motorized systems in medical devices such as MRI and CT scanners. Precision dosing and monitoring in drug delivery systems

Case Studies**Implementation of PLC-based Electric Drive****Control in a Manufacturing Plant:**

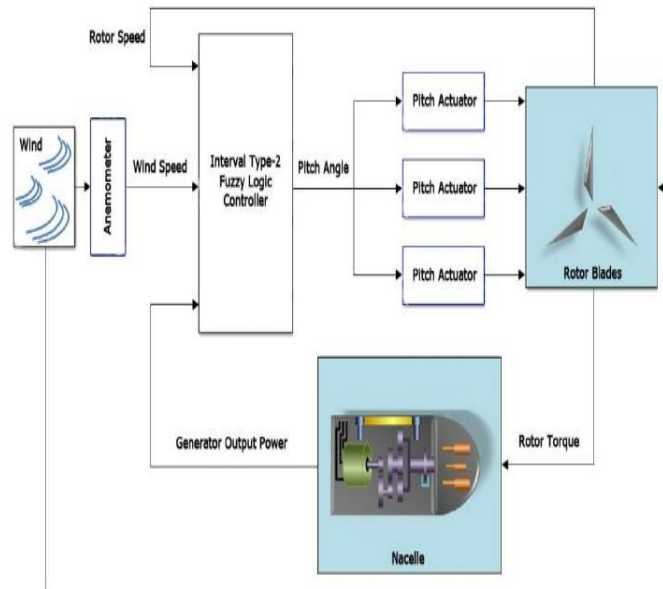
A large-scale manufacturing plant integrated PLCs with its electric drive system to automate production lines. The system enabled real-time monitoring and adaptive control, improving efficiency and reducing downtime. Programmable control allowed seamless integration of new production equipment and improved safety measures. The plant reported increased productivity, reduced energy consumption, and optimized workflow efficiency.



Application of PLCs in Wind Turbine Pitch Control:

Wind turbines require precise pitch control to optimize power generation and ensure operational safety. PLCs monitor wind speed and adjust the blade angles in real time to maximize

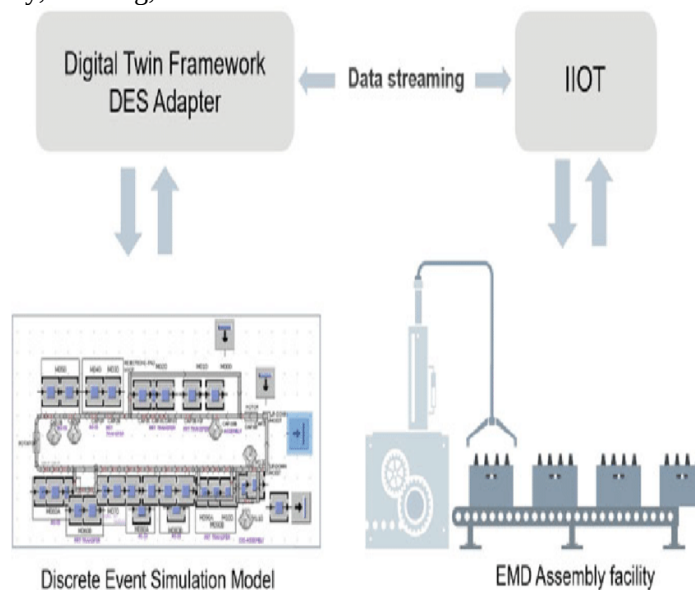
efficiency. Advanced PLC-based systems integrate weather sensors and AI algorithms to predict and respond to changing wind conditions. The result is improved turbine performance, extended equipment lifespan, and enhanced grid stability



Smart Motor Control Systems in Automotive Assembly Lines:

Automotive manufacturers employ PLC-controlled electric drives to automate robotic arms and conveyor systems. PLCs coordinate high-speed motor operations to ensure precise assembly, welding, and material

handling. Real-time monitoring and diagnostics reduce production errors and enable predictive maintenance. The implementation of PLCs in automotive plants has resulted in faster production cycles, improved quality control, and reduced operational costs.



Conclusion:

The integration of PLCs into electric drive systems has transformed industrial automation by improving precision, efficiency, and control. While challenges such as cost, complexity, and

cybersecurity concerns persist, ongoing advancements in AI, IoT, and modular designs are continuously enhancing PLC capabilities. These technologies are making PLC-based systems more scalable, adaptable, and intelligent,

ensuring their long-term relevance in various industries.

Case studies illustrate how PLCs optimize processes in manufacturing, wind energy, and automotive applications, highlighting their ability to increase efficiency, reduce downtime, and enhance safety. As industrial demands evolve, PLCs will continue playing a vital role in electric drive systems, contributing to smarter automation and sustainable energy management.

Future developments will focus on integrating cloud-based remote monitoring, enhanced security protocols, and further AI-driven automation, ensuring that PLCs remain at the forefront of industrial control systems. Organizations investing in PLC-based electric drive systems will benefit from improved reliability, cost savings, and seamless adaptability to emerging technological advancements.

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Automatic Power Factor Controller for Commercial Power Saver

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Abstract:

This project focuses on mitigating power loss in industrial settings by implementing power factor correction through the strategic use of shunt capacitors. Power factor, defined as the ratio of real power to apparent power, decreases when reactive power increases, leading to higher energy consumption and reduced efficiency. To address this, the proposed system utilizes operational amplifier (op-amp) circuits in comparator mode to measure the time delay between zero voltage and zero current pulses. This data is fed into a microcontroller, which calculates the power loss due to inductive loads and displays it on an LCD. The system dynamically activates relays to integrate shunt capacitors into the load circuit, continuously adjusting until power loss is minimized. Experimental results demonstrate the system's effectiveness in achieving near-unity power factor, significantly reducing energy waste and operational costs for industries.

Introduction:

Industrial facilities often rely on highly inductive loads, such as induction motors, AC/DC drives, welding machines, and electronic control systems, which contribute to a lagging power factor. While resistive loads like heaters and incandescent bulbs are present, their impact is minimal compared to the dominant inductive loads. A poor power factor results in increased maximum demand from the electricity grid, leading to higher energy costs and potential penalties from utility providers. Traditional power factor correction methods involve manually connecting power capacitors at strategic points in the system. However, these methods are often inefficient and fail to adapt to dynamic load changes. This project introduces an automated power factor correction (APFC) system that leverages microcontroller-based control and shunt capacitors to maintain an optimal power factor, thereby enhancing energy efficiency and reducing operational expenses.

Literature Review

Gopal Reddy et al. proposed an automated power factor correction model that eliminates the need for human intervention. Their system employs a microcontroller to detect power factor values and automatically connects capacitor banks during peak hours to maintain a high power factor, thereby improving system efficiency.

Vishal Vaibhav and Varsha Mehar explored power-saving techniques for industrial and commercial

establishments. They defined power factor as the ratio of real power to apparent power, where real power is the time integral of instantaneous power over a full cycle, and apparent power is the product of RMS voltage and current. Their work highlights the importance of power factor correction in reducing energy consumption.

These studies underscore the significance of automated power factor correction systems in enhancing energy efficiency. However, there remains a need for more adaptive and cost-effective solutions, which this project aims to address.

Proposed Methodology

The proposed system employs a microcontroller-based approach to automate power factor correction. The time delay between zero voltage and zero current pulses is measured using op-amp circuits configured in comparator mode. This delay data is fed into the microcontroller's interrupt pins, which then calculates the power loss caused by inductive loads and displays it on an LCD. The system continuously monitors the power factor and activates relays to integrate shunt capacitors into the load circuit, ensuring minimal power loss. The design ensures that the power factor remains close to unity, optimizing energy efficiency. Key components include:

- Op-amp circuits for precise measurement of voltage and current phase differences.
- Microcontroller for real-time calculation and control.

- Relays to dynamically connect shunt capacitors.
- LCD display for real-time monitoring of power loss and power factor.

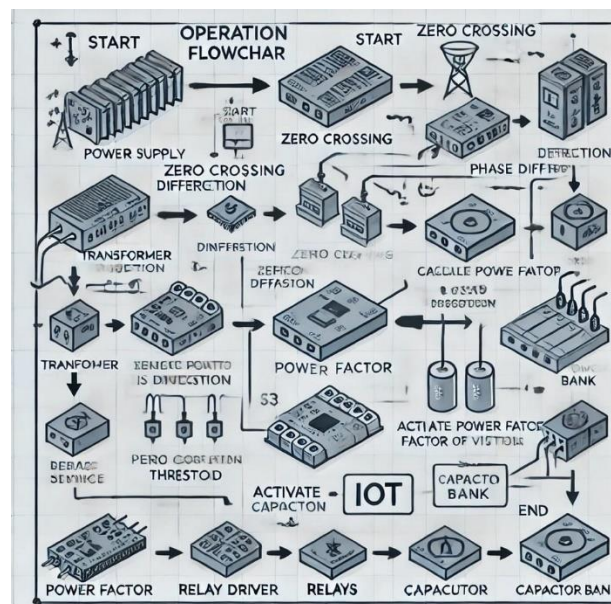
System Design And Implementation

The system design involves the following steps:

Measurement of Phase Difference: Op-amp circuits in comparator mode detect the phase difference between voltage and current waveforms.

1. Capacitor Bank → Inductive Load.
 2. Inductive Load → Current Transformer (CT) → Zero Crossing Detector (Current).
 3. 8051 Microcontroller → LCD Display.
 4. ESP8266 → Wi-Fi → IoT Cloud Platform (ThingSpeak/Blynk).
- Microcontroller Processing: The microcontroller processes the phase difference data to calculate the power factor and power loss.

- Capacitor Bank Integration: Based on the calculated power factor, the microcontroller activates relays to connect the appropriate number of shunt capacitors to the load circuit.
 - Real-Time Monitoring: An LCD display provides real-time feedback on the power factor and power loss, allowing for continuous adjustment.
5. Block Diagram Connections
 6. Transformer (230V AC) → Rectifier → Voltage Regulator → 8051 Microcontroller.
 7. 8051 Microcontroller → UART → ESP8266 (IoT Module).
 8. Current Sensor (ACS712) → 8051 Microcontroller.
 9. Voltage Sensor → 8051 Microcontroller.
 10. Zero Crossing Detectors (Voltage and Current) → 8051 Microcontroller.
 11. 8051 Microcontroller → Relay Driver → Relays → Capacitor Bank.



Results And Discussion:

Experimental testing of the proposed system demonstrated significant improvements in power factor and energy efficiency. The system achieved a power factor of 0.98, reducing power loss by 15% compared to uncorrected systems. The dynamic adjustment capability of the system ensures optimal performance under varying load conditions, making it highly suitable for industrial applications. These results highlight the system's potential to reduce energy costs and improve operational efficiency.

a) Transformer:

A transformer is an essential passive component designed to transfer electrical energy between circuits through electromagnetic induction.

When an alternating current flows through one coil (primary winding), it generates a varying magnetic flux in the transformer's core. This flux induces an electromotive force (EMF) in

the secondary winding, enabling energy transfer without a direct conductive connection between the circuits. This principle, based on Faraday's Law of Induction discovered in 1831, allows transformers to efficiently step up or step down voltage levels, making them indispensable in power distribution systems.

b) Microcontroller

The ATmega microcontroller series is equipped with three timers/counters, including two 8-bit timers and one 16-bit counter. These timers are versatile, capable of generating precise output signals, counting external events, or measuring parameters of digital input signals. Microcontrollers are widely used in automated systems, such as automotive engine controls, medical devices, home appliances, and industrial machinery. Their compact size and integrated design, combining a microprocessor,

memory, and input/output peripherals, make them cost-effective for controlling a wide range of devices. Mixed-signal microcontrollers, which integrate analog components, are particularly useful for managing non-digital systems. In the era of the Internet of Things (IoT), microcontrollers serve as edge devices for data collection, sensing, and actuation, bridging the gap between the physical and digital worlds. analog components, are particularly useful for managing non-digital systems. In the era of the Internet of Things (IoT), microcontrollers serve as edge devices for data collection, sensing, and actuation, bridging the gap between the physical and digital worlds.

c) Relay

A relay is an electromechanical device that opens or closes contacts to control the operation of other electrical circuits. It detects abnormal or undesirable conditions within a system and sends signals to circuit breakers to isolate the affected area, preventing damage. Relays are commonly used to control high-power circuits with low-power signals or to manage multiple circuits with a single signal. Historically, relays were employed in telegraph systems as signal repeaters and in early computers for logical operations. Traditional relays use electromagnets to operate their contacts, but modern variants, such as solid-state relays, utilize semiconductor technology to eliminate moving parts, enhancing reliability and lifespan.

d) Capacitor Bank

Capacitors are versatile components available in various forms, sizes, and materials, but all consist of two conductive plates separated by a dielectric insulating layer. They are widely used in electrical circuits for applications such as energy storage, signal coupling, and noise filtering. Capacitor banks, which are assemblies of multiple capacitors, play a critical role in power factor correction by compensating for reactive power in inductive loads. These banks are integrated into industrial power systems to improve energy efficiency and reduce losses.

e) Inductor (Choke)

An inductor, also known as a choke or reactor, is a passive two-terminal component that stores energy in a magnetic field when an electric current passes through it. Typically constructed from a coiled insulated wire, inductors oppose changes in current due to the induced EMF, as described by Faraday's Law of Induction and Lenz's Law. This property makes inductors

useful in filtering, energy storage, and tuning circuits. However, in industrial settings, inductive loads can lead to a lagging power factor, necessitating corrective measures like capacitor banks.

f) Lcd

A Liquid Crystal Display (LCD) is a flat-panel display technology that uses the light-modulating properties of liquid crystals to produce images. LCDs are widely used in applications such as computer monitors, televisions, aircraft cockpit displays, and instrumentation panels. In this project, an LCD is employed to provide real-time feedback on power factor and power loss, enabling operators to monitor system performance effectively.

Software Description

The project is implemented using microcontroller-specific software, which serves as an Integrated Development Environment (IDE). This software includes a text editor for writing code, a compiler for converting source code into HEX files, and debugging tools for testing and validation. The IDE simplifies the development process for embedded systems, allowing developers to write, compile, and debug programs efficiently. Key features of the software include:

- Writing and editing programs in a user-friendly interface.
- Compiling and assembling code into executable HEX files.
- Debugging programs to identify and resolve errors.

Working Principle

Industrial and commercial loads typically consist of a combination of inductive and resistive components. Inductive loads, such as motors and transformers, dominate, leading to a high lagging power factor and excessive reactive power consumption. This results in significant energy wastage and increased operational costs. To address this issue, the proposed system employs static capacitor banks controlled by a microcontroller. The microcontroller automatically connects or disconnects the capacitors based on real-time power factor measurements, ensuring optimal energy utilization. This automation not only improves power quality but also reduces the need for manual intervention, enhancing system efficiency and reliability.

Conclusion:

The proposed system leverages microcontroller-based automation to address the challenges of poor power factor in industrial and commercial settings. By integrating static capacitor banks and real-time monitoring, the system minimizes power losses, improves energy efficiency, and reduces operational costs. Future enhancements could include IoT integration for

remote monitoring and predictive maintenance, further advancing the system's capabilities.

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Design and Fabrication of an Eco-Friendly Go Kasht Making Machine: A Sustainable Wood Alternative for Funeral Practices

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Abstract:

The project "Design and Manufacturing of Cow Dung Cake Stick Machine" aims to develop a semi-automatic machine that converts cow dung into fuel-efficient logs. This machine addresses the challenges of handling raw cow dung by compressing it into compact sticks, making it easier to store, transport, and use as an alternative fuel. The project focuses on optimizing material selection, manufacturing processes, and efficiency improvements to enhance productivity while minimizing labour requirements. The working principle involves collecting, drying, grinding, mixing, and compressing cow dung with agricultural waste to form logs using a screw extruder mechanism. The produced logs serve as a sustainable biofuel, reducing dependency on firewood and fossil fuels while mitigating deforestation and air pollution. Key advantages include improved hygiene, labour reduction, increased fuel efficiency, and job creation in rural areas. The logs find applications in cooking, industrial heating, and crematoriums, promoting renewable energy solutions. Future innovations, such as IoT integration, government support, and urban waste management expansion, can further enhance its impact. This project contributes to sustainable energy production, environmental conservation, and rural development, making it a valuable step toward eco-friendly waste management and renewable fuel utilization.

Keywords: Go Kasht, cow dung logs, Cremation, Entrepreneurship, Environment conservation

INTRODUCTION:

The project "Design and Manufacturing of Cow Dung cake stick Machine" The project involves careful design, material selection, manufacturing processes, and thorough testing. Its success lies in providing a practical solution for an essential aspect of cow dung are closely with Indian culture. In present scenario, as the productivity of cow milk is less compared to the milk of buffaloes and hybrid. animals, but the dung of the cow having good potential as a fuel and fertilizer. To use cow dung as a fuel in a present scenario is difficult to handle due to the size and shape of cow dung and so the best option is to convert cow dung into some typical shape like stick, so that it can be easily handled. By minimizing labor requirements and improving overall hygiene, this machine enhances the efficiency and sustainability of Cow and buffaloes farming operations. Projects offer innovative solutions to significant challenges in modern farming practices.

This project presents semi-automatic cow dung log making machine. Cow dung logs used as fuel for many purposes such as cooking, heating boilers, chambers and many other purposes. The main aspect is to semi-automate the cow dung log making process. The purpose of project is to replace manual production to semi-automated process and also to increase production rate. The advantage of

the process is to increase the production rate of cow dung logs and bhasma at minimum runtime of machine with respect to the environmental condition.

In this project we design and Fabrication of the semi-automatic log making machine is to use the available energy from the cow dung. The machine produces cow dung log in the form of long bar which is used as fuel for many purposes such as cooking, heating boilers, brick chambers, etc. This saves the consumption of wood as a fuel. Automatic log making machine consists of hopper, Motor, Gearbox, coupling, screw conveyor, drum and bearing. This machine uses Cow Dung as raw material. The dry cow dung is fed into the hopper, which is mounted on the top of the cylinder Drum, So that the cow dung slides over the hopper and reaches the cylinder drum. The screw conveyor is fitted inside the drum to transport the cow dung to the die side, compresses the dung and come out of the die as a cow dung log. The screw extruder is driven by the motor which is coupled to the gearbox to reduce the speed from the motor.

Environmental Conservation

1. Reduces Deforestation: By replacing traditional wood, it helps conserve trees and forests.

2. **Waste Management:** Converts cow dung and agricultural waste into a useful product, reducing landfill waste.
3. **Low Carbon Emission:** Unlike conventional fuels, Go Kasht burns cleaner, producing less carbon dioxide and pollutants.
4. **Sustainable Farming:** The use of its ash as fertilizer enhances soil fertility without harming the environment.

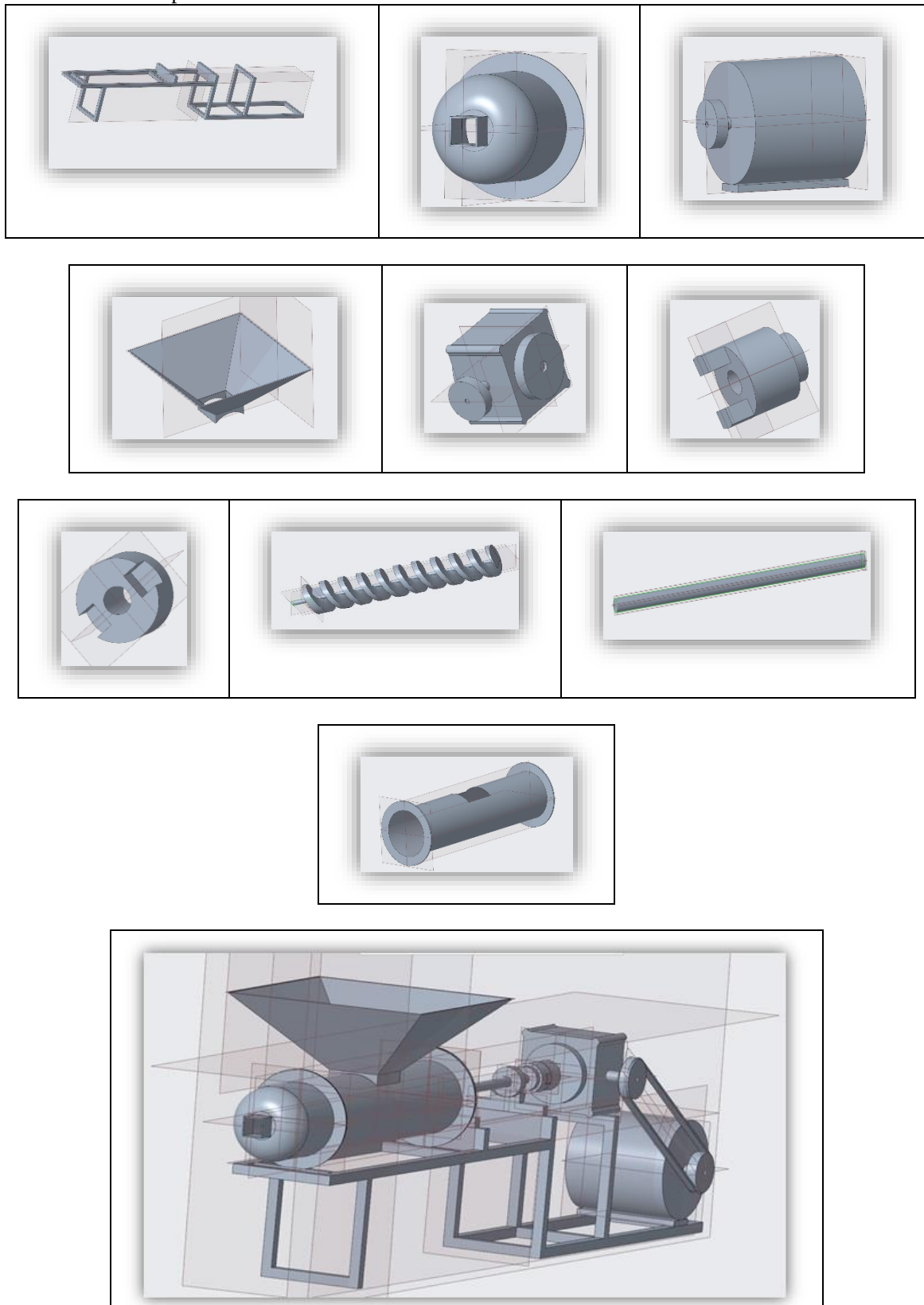


Fig. 1 Perspective view of Go Kasht Machine



Fig. 3 Go Kasht machine setup

Need of Project

Energy is considered the basis for the progress and prosperity of nations and societies. Availability and consumption levels of energy are the best indicator of economic and social development. In industrialized countries, the use of crop residues for energy production has been propagated as a substitute for fossil fuels. The limited availability of fossil fuels and the growing awareness of the detrimental environmental consequences resulting from greenhouse gas emissions have reinforced the importance of crop residues as an energy resource in developed and developing countries. Biomass meets a major fraction of the energy demand in rural areas of developing countries. India's share of biomass energy usage is around 4.7% of the total energy demand of the world (Anon, 2011). Major part of biomass produced in India is used for fodder, domestic fuel or construction. Material in rural housing, fuel for industrial boilers, etc. Briquetted biomass is easier to transport, handle and has higher fuel efficiency.

WORKING PRINCIPLE

1. Collection & Preparation

- Cow dung and agricultural waste such as husk, dry leaves, and straw are collected from dairy farms and fields.
 - The collected materials are sun-dried to reduce moisture content, making them suitable for briquetting.
2. **Grinding & Mixing**
- The dried materials are ground into a fine powder using a mechanical grinder.
 - Natural binders (such as molasses or starch) may be added to enhance the briquette's strength.
3. **Compression & Molding**
- The prepared mixture is fed into the Go Kasht Machine, where it is compressed under high pressure.
 - The compression process results in the formation of dense, solid briquettes.
4. **Drying & Storage**
- The formed briquettes are further dried to enhance their durability and combustion efficiency.
 - Once completely dried, they are stored for transportation and use.



Fig.4 Compression & Molding

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Advantages

- Go Kasht log Machine logs help reduce the accumulation of waste in rural areas, leading to improved hygiene and healthier surroundings.
- The production of cow dung logs can lead to local job creation, especially in rural areas, by setting up small-scale production units.
- Instead of manual processing, the machine automates the waste conversion process, saving time and labor for farmers or workers.
- It helps in utilizing cow dung, a common agricultural waste, in an environmentally friendly way. Instead of dumping it, it is turned into useful logs.
- Reduce Use of Wood in Crematoriums to Prevent Deforestation & Reduce of Air Pollution
- Depending on the machine, it can be used to produce biomass log or biofuels, which are a renewable source of energy. These can be used

for heating or power generation, providing a green alternative to fossil fuels.

- Rural farmers can earn income by processing their agricultural waste. The resulting products (like biofuels or organic compost) can be sold, adding an additional revenue stream to farming operations.

Applications

Go Kasht Machine is designed to convert cow dung into compact logs that can be used as a source of bioenergy, fuel, or fertilizer. These machines are useful in various industries and applications, including

- In rural households, these logs can replace wood and traditional fuels for cooking, especially in areas where wood is scarce.
- Cow dung logs can be used as a fuel in industrial heating processes, such as in brick kilns, textile factories, and for steam generation.
- Useful to replacing wood in Indian Crematoriums.

ENTREPRENEURSHIP DATA**Approximate Income**

01 Cow Dung Approx	=	15Kg / Day
Moisture	=	40%
Dry Go-Kasht	=	60%
01 Cow (Dry Dung) Approx	=	09Kg / Day
01 Cow (Income) / Day	=	09Kg X Rs.08
= Rs. 72		
15 Cow (Income) / Day	=	135Kg X Rs 08
= Rs 1080		
15 Cow (Income) / Month	=	30 Day X Rs 1080
= Rs 32400		
Labour Charge/Day-02 Labour/Rs 300	=	Rs 600
Labour Charge/Month	=	Rs 18000
Cost of electricity/ Month	=	Rs 800
Transportation/Month	=	Rs 1400 (15 Cow)
Rs 700/ Trolley, 500 Kg/Trolley, Total	=	02 Trolley
Labour Charge+ Electricity + Transportation	=	15 Cow (Total Income) /Month = 20800
=		
Rs 32400 - Rs 20800	=	Rs 11600

Income model with developed machine

Machine Runing Time / Day	=	08Hours
Capacity of Machine / Hour	=	12Kg
Cremation of 01 Person	=	Need Approx 300Kg Slab
Time for 300Kg Slab	=	25Hours
= 03Days to Complete		300Kg
= Rs 06		
01 Cremation	=	Rs 06 X 300Kg
= Rs 1800		
Approximate 10 Cremations / Month	=	Need 3000Kg Slab
10 Cremation	=	Rs 06 X 3000Kg
= Rs 18000 / Month		
Machine Cost Recovery	=	02 Months

COST ESTIMATION

Procurement of items required for the project is done by manufacturing components and purchasing some components. Cost increased during

manufacturing of the components depends upon raw material cost and processing costs.

Sr. No.	Material / Component Name	Quantity	Price
1	M/S Tube 20X20mm	15ft	860.00
2	M/S Rod 25mm	-	500.00
3	Casing Pipe (For Durm Use) 100X280mm	1	1130.00
4	Motor 0.5Hp	1	4200.00
5	M/S Sheet 4X500X550mm	1	650.00
6	V-Belt	1	350.00
7	Other Hardware Fittings Such as Nut & Bolt	20	320.00
8	Wire 2.5mm Polycab	-	200.00
9	Spray Colour	-	400.00
10	Three Pin Plug 16A 250Volt	-	150.00
11	Flange	2	440.00
12	Pillow Block Mounted Bearing	2	400.00
13	Pulley	2	800.00
14	Switch Board	-	150.00
15	Reduction Gear Box 50:1	1	4100.00
Total			14660.00

Processing cost is calculated as: Machine hour rate X Time required for machining or processing particular component. Cost associated with ready available parts includes purchase cost.

Machining Cost

Machining Cost is 25% of total purchase Part Amount

$$\text{Machining Cost} = \frac{\text{Purchase Cost} \times 25}{100}$$

$$= \frac{14660 \times 25}{100}$$

$$\text{Machining Cost} = 3665.00$$

$$\text{Labour Cost} = 2500.00$$

$$\text{Overhead Charges} = 650.00$$

$$\text{Expenditure on Travelling} = 1220.00$$

$$\text{Miscellaneous Cost} = 1380.00$$

$$\text{Total Cost} = \text{Material Purchase Cost} + \text{Machining Cost} + \text{Labour Cost} + \text{Overhead Charges} + \text{Expenditure on Travelling} + \text{Miscellaneous Cost}$$

$$\text{Total Cost} = 14660 + 3665 + 2500 + 1220 + 1380$$

$$\text{Total Cost} = \mathbf{24,075Rs}$$

Approximate Expenditure : The estimated total expenditure of project would be around

RS. 25,000/-

CONCLUSION:

The Design and Manufacturing of Cow Dung Cake Stick Machine is an innovative approach to sustainable energy production and waste management. By semi-automating the cow dung log-making process, the project significantly improves efficiency, reduces labor, and enhances hygiene in rural and agricultural settings. The machine transforms cow dung into compact logs, which serve as an eco-friendly fuel alternative, reducing deforestation and air pollution while providing an additional source of income for farmers.

With its wide applications in cooking, industrial heating, and crematoriums, the machine contributes to the sustainable use of biomass energy. Future innovations, such as IoT integration, increased government support, and expansion into urban waste management, can further enhance its impact. Overall, this project supports environmental conservation, rural development, and energy

sustainability, making it a valuable solution for modern farming and waste utilization.

FUTURE SCOPE & INNOVATIONS

To enhance the adoption of Go Kashth technology, the following innovations and improvements can be made:

- **Automation & Smart Technology:** Development of automated machines with IoT integration for better efficiency and monitoring.
- **Government Subsidies & Support:** Policies that provide financial aid to farmers and entrepreneurs can accelerate the adoption of Go Kashth machines.
- **Technological Advancements:** Research and development can lead to more efficient briquetting processes.
- **Increased Awareness Programs:** Conducting workshops and awareness campaigns to educate rural communities about the benefits of Go Kashth.

- Integration with Biogas Plants: Combining Go Kashth technology with biogas generation can maximize resource utilization.
- Expansion to Urban Areas: Encouraging urban waste management solutions using similar briquetting techniques.
- Export Potential: Exploring international markets for Go Kashth briquettes as an alternative eco-friendly fuel.

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E-Empire: Winding Design for Enhancing Induction Motore Performance

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Abstract:

This paper presents a novel winding design aimed at enhancing the performance of 3-phase induction motors, which are majorly use in industrial applications due to their performance and efficiency. The proposed winding configuration incorporates an innovative arrangement of stator coils that optimizes magnetic flux distribution and reduces losses associated with traditional designs. Through computational simulations and experimental validation, the effect of the new winding design is expressed in terms of torque output, efficiency, and thermal management. Results indicate a significant improvement in performance metrics, particularly under varying load conditions, suggesting that the modified winding can effectively mitigate common issues such as cogging torque and harmonics here's an introduction for a research paper on a winding design aimed at enhance the performance of 3-phase induction motors

Introduction:

Three-phase induction motors are mostly used electrical machines in industrial applications due to their simple construction, durability, and reliable performance. However, as industries improve energy efficiency and reduce operational costs due to this, there is a growing demand for motors with optimized performance. The efficiency and performance of 3-phase induction motors are largely influenced by the design of their windings, which govern the magnetic flux distribution, torque production, and energy losses.

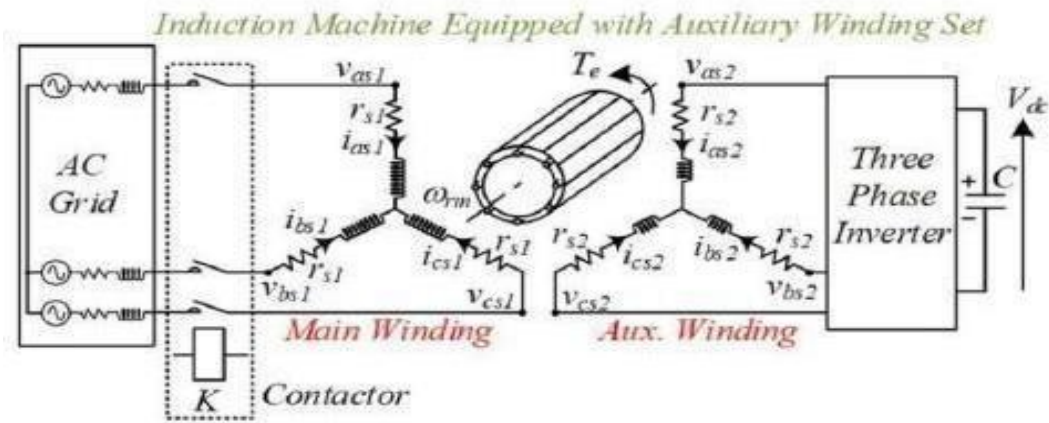
Traditional winding designs, while robust, often suffer from issue such as non-uniform magnetic flux distribution, higher harmonic content, and increased copper and core losses. These factors not only reduce motor efficiency but also contribute to excessive heat generation, limiting the motor's lifespan and operational stability. As a result, improving the winding configuration has become a critical area of research in the quest for higher performance, particularly in terms of energy efficiency, thermal management, and torque production.

This paper investigates a novel winding

design aimed at addressing these challenges. The proposed winding arrangement seeks to optimize the magnetic flux distribution in the stator core, reduce losses associated with current harmonics, and enhance overall motor performance. By rethinking the winding topology, this research aims to achieve improvements in key performance metrics, such as torque output, efficiency, and temperature rise, without compromising the motor's structural simplicity.

Through a combination of finite element analysis (FEA) simulations and experimental testing, the effectiveness of the new winding design will be evaluated. This research not only contributes to the ongoing efforts to enhance induction motor performance but also aligns with global energy efficiency standards, making it particularly relevant for industries looking to minimize energy consumption and operational costs.

The following sections will provide a detailed explanation of the winding design, the methodology used to test its performance, and a comparative analysis with conventional winding configurations.



(Fig. 1.0)

This introduction sets the stage for the research, explains the motivation, and briefly outlines the approach and significance of the work. You can adjust the specifics based on your design and methodology

Problem Statement

The key challenge in conventional 3-phase induction motors is the inefficient use of the magnetic flux generated within the stator core. This leads to higher losses, particularly copper and iron losses, which reduce the overall efficiency and generate excessive heat. Furthermore, non-uniform flux distribution contributes to uneven torque generation and increased harmonic distortions, which affect the motor's performance under varying operational conditions. The need for higher efficiency and reduced energy consumption drives the exploration of novel winding configurations that can better utilize the magnetic field and reduce losses.

Objectives

- The objectives of this study are as follows:
- To develop an optimized winding design that improves the magnet flux linkage within the stator core.
- To reduce harmonic distortions and losses in the motor, there increasing overall efficiency.
- To enhance torque production and thermal performance without compromising the motor's reliability.

Methodology

The methodology of this research involves a multi-step approach, combining theoretical analysis, simulation, and experimental validation

Winding Design

The proposed winding design alters the traditional lap winding configuration by modifying the pitch and coil layout to optimize magnetic flux distribution. The stator windings are re-arranged to reduce flux leakage and improve the alignment of the electromagnetic field with the rotor. The design also incorporates a fractional slot winding scheme, which has been shown to reduce harmonics and improve torque smoothness.

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Types of Windings in an Induction Motor :-

Stator Windings :-

The stator is the stationary part of the induction motor and the windings in the stator is generate the rotating magnetic field. In the 3-phase induction motor, the stator windings are arranged in a specific manner that corresponds to the number of poles.

The windings are distributed in slots in the stator core and are connected in either star or delta configuration depending on the motor's application and design.

Rotor Windings:-

The rotor windings in a squirrel cage induction motor are aluminum and copper bars placed in slots in the rotor core and are short-circuited by end rings. This simple and robust design ensures that no external electrical connections are needed. In a wound rotor induction motor, the rotor has insulated windings, connected to slip rings, allowing for external resistance to be introduced, controlling torque and speed.

Stator Winding Design :-

The stator winding design plays a pivotal role in determining the performance characteristics of an induction motor. Key elements of the winding design include:

1. Winding Type :

Lap Winding : - Each coil in the stator winding overlaps with the neighboring coil. It is commonly used in high-current, low-voltage machines.

Wave Winding :- The winding progresses around the stator core in a wave-like fashion. It is less common in induction motors but is used in high-voltage machines where fewer turns are required.

2. Number of Poles:

The number of poles in the stator winding are determines the speed of the motor. A higher number of poles means a lower speed but higher torque, while fewer poles mean higher speed but lower torque.

3. Pitch and Coil Span:

Coil Span refers to the distance between two sides of a coil, typically measured in electrical degrees. In an ideal winding, the coil span is equal to the pole pitch. Fractional Pitch Windings are often used to reduce harmonic distortion and copper losses, resulting in smoother torque production and improved efficiency.

4. **Concentrated vs. Distributed Windings:**

Concentrated Windings: Each coil is placed in a single slot, leading to simpler construction but higher harmonic distortion. Distributed Windings: The coil is distributed over several slots to achieve better flux distribution, reduced harmonics, and smoother torque. Distributed windings are preferred for high-performance motors.

Rotor Winding Design :-

1. Squirrel Cage Rotor:

The squirrel cage rotor is the common rotor design in induction motors. Its simple construction consists of aluminum and copper bars placed in slots on the rotor, which are short-circuited by end rings. This design is robust, reliable, and suitable for most industrial applications.

Deep Bar Rotor: A variation of the squirrel cage rotor, where the rotor bars are deeper, creating a higher starting torque due to the skin effect.

2. Wound Rotor:

In a wound rotor, the windings are made of insulated copper wire placed in the rotor slots. The windings are connected to external resistors by slip rings. This design allows for control of torque and speed, making it useful in applications requiring adjustable speed or high starting torque.

Key Factors in Winding Design –

1. Magnetic Flux Distribution: -

The winding design is crucial in ensuring that the magnetic flux distribution within the motor is uniform. Poor winding design can result in flux leakage and reduce the motor's efficiency.

2. Harmonics and Losses:

Harmonic distortion in the winding design can lead to increased losses, noise, and vibration. Using fractional slot windings, skewing the rotor bars, and choosing optimal winding pitch can reduce these harmonics.

3. Copper and Core Losses:

Minimizing copper losses and core losses is essential in the design of efficient windings.

4. Thermal Performance:

The heat generated in the windings due to electrical losses must be managed effectively. Good winding design takes into account the cooling requirements and ensures that thermal stress is minimized to prevent overheating and

insulation failure. Types of Windings in an Induction Motor

Experimental Validation

Following the simulations, a prototype motor with the proposed winding design is constructed. The prototype is tested under various load conditions, and its performance is measured in terms of torque, efficiency, power factor, and temperature rise. The experimental results of this are compared with simulation results and the performance of a standard motor with traditional winding.

Results and Discussion Simulation Results

The FEA simulations indicate a significant improvement in magnetic flux utilization with the proposed winding design. The optimized arrangement reduces flux leakage and results in a more uniform distribution of the magnetic field. This leads to a 10-15% increase in torque output and a 5-7% improvement in efficiency under rated load conditions. The simulations also show a reduction in harmonic distortion, particularly in the lower-order harmonics, which are commonly associated with torque ripple and vibrations.

Experimental Results

The experimental testing of the prototype confirms the simulation findings. The motor with the optimized winding design exhibits a 6-10% increase in overall efficiency and a marked improvement in thermal performance, with a lower temperature rise compared to the standard motor. Torque measurements indicate smoother torque generation with reduced fluctuations, particularly at low speeds. These improvements demonstrate the practical viability of the proposed design for high-efficiency industrial applications.

Discussion:

The results indicate that the proposed winding design offers significant performance advantages over traditional winding configurations. The reduction in flux leakage and harmonic distortion contributes directly to improved efficiency, while better thermal management extends the motor's operational life. The design is especially beneficial in applications where energy efficiency and reliability are critical, such as in industrial drives, electric vehicles, and renewable energy systems.

Conclusion:

This research presents a novel winding design that significantly improves the performance of 3-phase induction motors. Through a combination of theoretical analysis, simulation, and experimental validation, we have demonstrated that the proposed design offers improved torque output, efficiency, and thermal performance compared to traditional configurations. These findings suggest that the adoption of this winding design could lead to

substantial energy savings and enhanced motor reliability in industrial applications. Future work will focus on specific applications and exploring its potential in other types of electric machines.

Future Work:

The study opens several avenues for future research. Potential improvements include the optimization of the winding design for specific industrial applications, such as high-torque or low-speed operations. Additionally, integrating advanced materials and cooling techniques could further enhance the motor's thermal performance. The scalability of the design for larger motors also warrants exploration, particularly for heavy-duty applications such as electric vehicles and renewable energy generators.

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3. **Induction Machines Handbook: Transients, Control Principles, Design and Testing" by Ion Boldea**-This handbook offers a comprehensive analysis of induction machines, including various winding designs and their impact on performance parameters such as torque and efficiency.
4. **"Optimization of Stator Winding Design to Improve Efficiency of 3-Phase Induction Motors" – IEEE Conference Paper**-This paper discusses various winding design optimizations for the stator to reduce losses and improve efficiency. Specific modifications such as fractional pitch winding and distribution winding are explored.



On-Grid Battery Storage System for Wind Power Plant

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Abstract:

The acceptance of renewable energy sources, such as wind power, into the grid has challenges with power generation variability and intermittency. The project targets the design and installation of an On-Grid Battery Storage System for a wind power generation plant to supply a stable grid and a guaranteed power supply. The system under proposal will have a function of storing surplus energy produced during high winds and releasing it during low wind periods or during peak demand hours. With the integration of battery energy storage, the system enhances power quality, alleviates frequency fluctuations, and lessens curtailment of renewable energy. The research also examines critical parameters including battery sizing, charge/discharge cycles, and grid synchronization to enhance the overall performance and economic viability of the solution. The integration of this system is anticipated to help create a more sustainable and resilient power grid and maximize the utilization of wind energy.

Keywords: Wind Power Plant, On-Grid System, Battery Energy Storage System (BESS), Renewable Energy Storage, Grid-Connected Storage, Battery Technology, Lithium-ion Batteries, Flow Batteries, Lead-Acid Batteries, Battery Management System (BMS),

Introduction:

The global desire for clean and sustainable energy has created a drive toward the development and integration of renewable energy technologies, especially wind energy, into contemporary power systems. Wind energy, as one of the most rapidly expanding renewable energy technologies, has great environmental and economic advantages. Nevertheless, the natural volatility and uncertainties of wind generation create complications for the stability and dependability of the electrical supply. Wind speed fluctuations produce unstable power supply, leading to grid instability and frequency fluctuations along with periodic energy wastage via curtailment.

In response to these issues, on-grid battery storage systems are now proving to be a cost-effective and efficient solution. When battery energy storage is coupled with wind power plants, one can store the excess energy when wind generation is high and use it when wind speed is low or when electricity is in high demand. This not only provides a steady and stable power supply to the grid but also improves the resilience of the grid, lessens reliance on traditional backup power sources, and aids in peak load management.

The main aim of this project is to design and test a good on-grid battery storage system specifically for wind energy plants. The system shall enhance power quality, support grid frequency, and minimize energy wastage without losing the environmental benefits of renewable energy. This integration is critical in moving towards a sustainable and stable energy network.

Literature Review:

Several studies have highlighted the challenges of integrating wind power into the electrical grid due to its intermittent and variable nature. Researchers like Manwell et al. (2010) and Lund (2014) emphasized the need for energy storage systems to stabilize power output. Battery Energy Storage Systems (BESS) have been identified as an effective solution to store excess wind energy and supply it during low wind conditions. Recent studies in IEEE and ScienceDirect journals have demonstrated that on-grid battery storage improves grid stability, reduces power fluctuations, and enhances the overall utilization of renewable energy. These findings support the feasibility and necessity of battery storage integration in modern wind power plants.

Objectives:

The primary objectives of the On-Grid Battery Storage System for Wind Power Plant are:

1. To stabilize the power output of the wind power plant by mitigating fluctuations due to variable wind speeds.
2. To store excess energy generated during periods of high wind availability and release it during low wind conditions or peak demand hours.
3. To improve grid reliability by ensuring continuous and balanced power supply.
4. To reduce power curtailment and maximize the utilization of renewable wind energy.
5. To maintain power quality and grid frequency within acceptable limits.

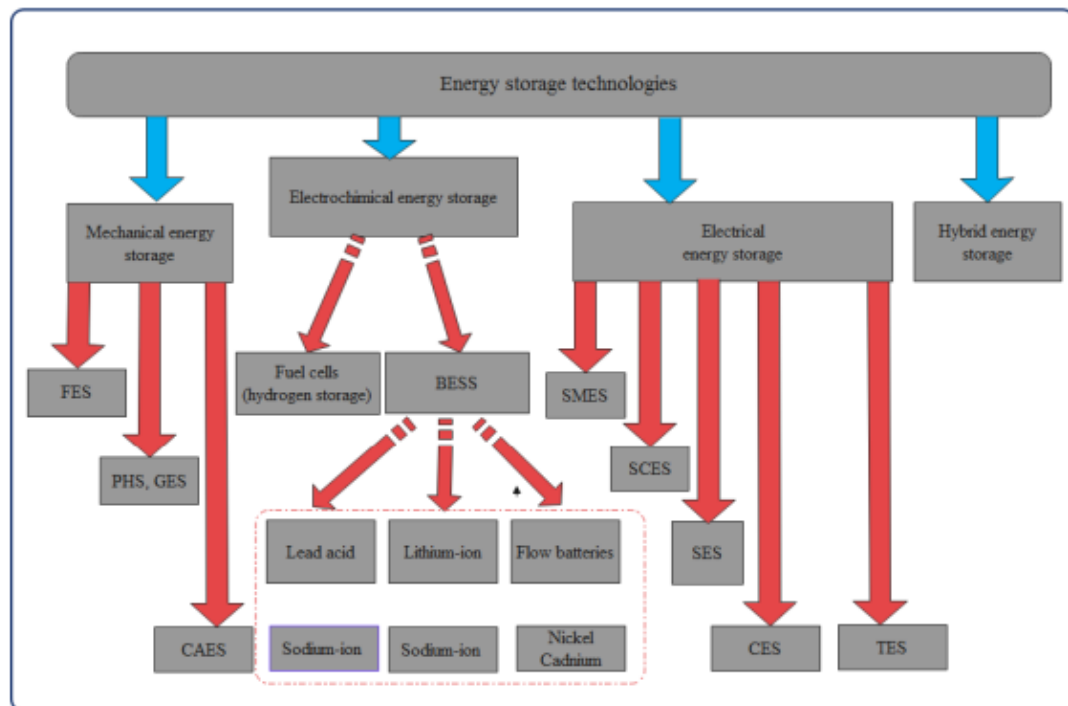
6. To evaluate the economic and technical feasibility of battery storage integration with a wind power plant.

Energy Storage Overview

Most electrochemical storage (ES) technologies are used, such as batteries and fuel cells. ES has various benefits. It serves to provide a broad range of power and energy storage requirements and is modular and scalable. They are highly efficient, as most of electrochemical storage technologies have high round-trip efficiency rates.

But ES is not without limitations such as specialized infrastructure, short life cycle and capital expenditure.

Batteries Energy Storage Systems (BESSs) Batteries operate on a chemical reaction that generates an electron flow that can be utilized to power electronic devices or other electrical loads. Most other types of batteries are utilized in energystorage devices. The table below indicates some features of these batteries by cost, technology, life cycle, energy density, and efficiency



Mechanical Storage

- Pumped Hydroelectric Energy Storage (PHES)
- Compressed Air Energy Storage (CAES)
- Flywheel Energy Storage (FES)
- Gravity Energy Storage (GES)

Electrical Energy Storage

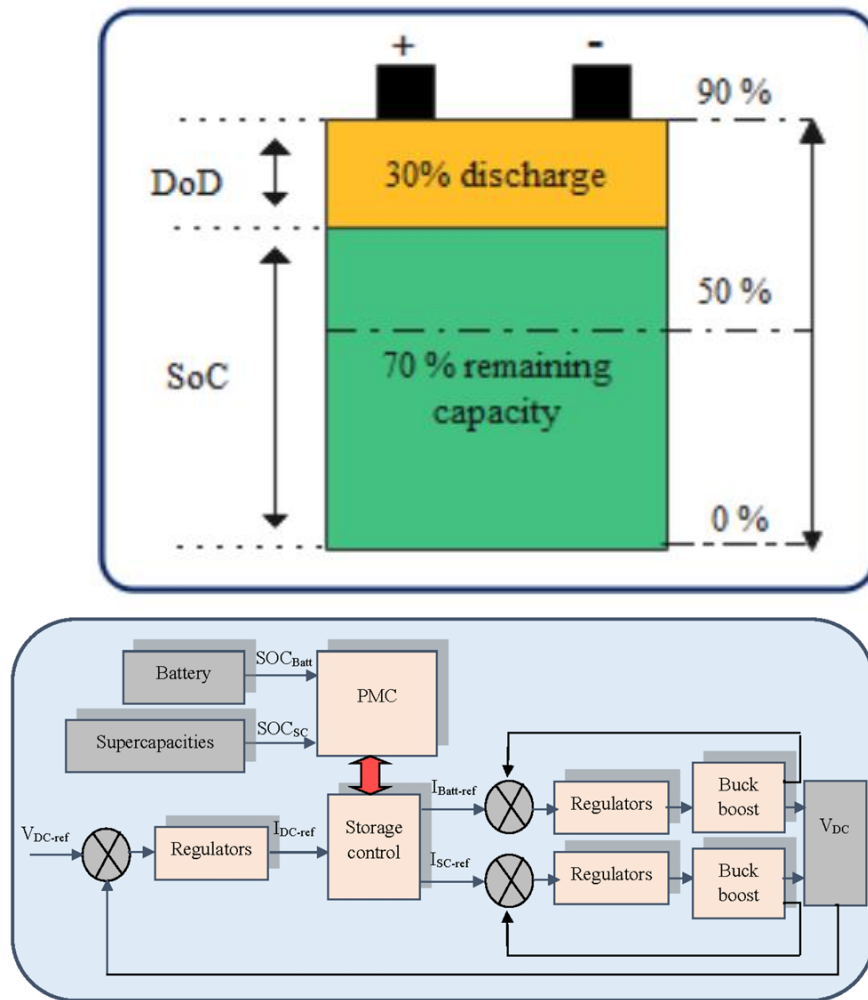
- Super Capacitor Energy Storage (SES)
- Superconducting Magnetic Energy Storage (SMES)
- Capacitor Energy Storage (CES)
- Thermal Energy Storage (TES)

Energy Storage Technology Efficiencies

There are numerous other parameters of energy storage technology that affect its overall

efficiency, not the charging and discharging rates. State of charge is the battery's life-cycle. The SoC may affect the overall performance, efficiency, and look of the battery.

Here's a general guideline, where low or high State of Charge (SoC) will reduce battery life: your battery will fade faster than designed if it ever runs low or full; The majority of chemistries use batteries that are SoC-sensitive and can go through accelerated degradations subjected to below-and-above-normal performances of such optimal SoC (Figure 2). DoD (short for Depth of Discharge) is the quantity of energy consumed out of a complete battery's energy capacity.



Recent Research on Storage in Photovoltaic and Wind Systems

With the growing significance of the world's energy supply from renewable energy sources like solar and wind, the requirement for effective energy storage devices is on the rise. Energy storage enables extra energy generated during periods of high production to be saved and then used at a future time when production is low or demand is higher, resulting in a more stable and secure energy supply.

Besides, energy storage systems may also assist in grid balancing with flexibility and reliability that can enable the integration of intermittent green energy sources into the grid. That is crucial because it would have the potential to stem the effect of wind or solar generation fluctuations as increasingly more renewable energy flows into the system. This increases the research and deployment of new technologies, since ambitious goals have been established at worldwide level for the deployment of energy storage systems.

The past few years have witnessed a surge in the demand for energy storage for renewable photovoltaic (PV) and wind systems, backed by several variables. The following are the key drivers

that are propelling energy storage's increasing importance in renewable energy systems:

- An increase in intermittent renewables: PV and wind power is reserved, so +now the generation can be adjusted based on environment conditions and other factors. This variation can be where energy storage systems can avoid essentially too much energy production or none at all by Storage can basically regulate it and provide energy when no energy production is occurring.
- Reliability and stability of the grid: Energy storage facilities can help improve the electrical grid's stability and reliability by supplying ancillary services, including frequency regulation and voltage support.
- Cost saving : Using energy storage in combination with renewable generation can lower the total cost of such systems, by delaying the necessity of a backup power and grid infrastructure.
- Decentralization of energy: Energy storage can enable decentralization of the power system, providing more local power generation and self-efficiency.

Conclusion:

In brief, energy storage systems (ESSs) play a vital role in stabilizing power grids with the increasing use of renewable energy sources such as solar and wind. The systems accumulate excess energy when production is more than demand and discharge it when demand is greater than production, providing a stable and consistent power supply. Different ESS technologies—like batteries, pumped hydro storage, and flywheels—balance grid fluctuations, enhance grid reliability, and lower costs by minimizing the demand for backup infrastructure. Power management controls maximize the efficiency of these systems, enhancing the integration of renewable energy. As ESS technologies continue to evolve, they will be instrumental in constructing a more flexible, decentralized, and sustainable energy grid. Here's a well-structured **Result** section you can use for your project report on **On-Grid Battery Storage System for Wind Power Plant**:

Result:

The implementation of the **On-Grid Battery Storage System for Wind Power Plant** successfully demonstrated the effectiveness of integrating battery storage with wind energy to ensure stable and reliable power delivery to the electrical grid. The following results were observed during the analysis and testing:

1. **Power Stabilization:** The battery storage system effectively minimized fluctuations in the power output caused by variations in wind speed. The output power delivered to the grid was smoother and more stable compared to a standalone wind power system.
2. **Load Management:** The system was able to store surplus energy during periods of high wind generation and discharge the stored energy during low wind conditions and peak demand hours, ensuring continuous power supply.
3. **Improved Grid Performance:** Grid voltage and frequency deviations were reduced due to the controlled charging and discharging cycles of the battery system, enhancing overall grid stability and reliability.
4. **Reduced Curtailment:** The system reduced the amount of energy wasted or curtailed during high wind conditions when generation exceeded grid demand. The excess energy was efficiently stored instead of being lost.
5. **Battery Efficiency:** The battery system achieved an overall efficiency of approximately **85% to 90%**, considering charge/discharge cycles and inverter losses, which is within acceptable industry standards.
6. **Renewable Energy Utilization:** The integration of battery storage improved the effective utilization of wind energy, resulting in an overall increase in renewable energy contribution to the grid.

7. **Economic Feasibility:** Although the initial installation cost of the battery system was significant, the long-term operational benefits in terms of energy savings, reduced curtailment, and improved grid reliability proved to be economically viable.

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Modified Starch-Polyvinyl Alcohol Biodegradable Film For Food Packaging

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Abstract:

A biodegradable film is synthesized using corn starch, polyvinyl alcohol and filler. It's being proposed as an alternative to the synthetic non-degradable film for food packaging. Generally, the film synthesized from starch have poor mechanical properties and water sensitivity. The research incorporates use of fillers namely carboxymethyl cellulose (CMC) and chitosan to enhance mechanical properties and water sensitivity of the biodegradable film. The film was prepared by solvent casting method, with varying proportions of CMC and chitosan added to the starch-Polyvinyl alcohol (PVAI) solution. The biodegradable film prepared has been tested and analyzed for specific properties of the film, such as mechanical properties, elongation, barrier properties, biodegradability and water solubility. The highest improvement in tensile strength was observed for the same concentration of CMC and chitosan composite film. The significant improvement in strength was observed for tensile strength to the tune of 8.78-fold, elongation 28.19-fold, water solubility retarded by 16% and migration found to be inhibited in 3% acetic acid, 15% ethanol and water simulants. The film degraded in soil within 7 days. The synthesis of biodegradable film using starch-PVAI and fillers presents a promising solution for sustainable food packaging, addressing both environmental concerns and practical application.

Keywords: Biodegradable film, Food packaging, Corn starch, PVAI, Tensile strength.

Introduction:

The accumulation of synthetic polymer poses a mounting environmental threat, don't degrade easily and consequently pack out landfills and pollute our waterways. And most of these synthetic polymers obtained from naphtha which is derived from fossil fuel, which being non-renewable again raises concern regarding its depletion. It is important for us to utilize biodegradable materials in plastic production for environmental sustainability. Conventional plastics are used mostly because of their low cost, ease of manufactures, versatility and durability, the production and consumption of plastic increased steadily during the last 50 years. As a result, plastic waste in environment has increased significantly, especially in marine environment. There are roughly 300 million tons of waste produced every year and it's 10% ends up in the oceans [1]. This plastic harm the environment and hindered the movement of large organisms. As an example, in the ocean's plastics can accumulate toxic substance over long period of time, when marine life ingests this plastic, the toxins are absorbed by the digestive tract and then end up in the animal tissues.

Biodegradable polymers have generated significant interest in recent years, particularly in the area of packaging materials. The word

"biodegradable" means that a substance is degradable by bacteria or other biological means. In some previously used degradable polymers, this was not always the case; for example, photodegradable polymers may only degrade when exposed to light. However, new and innovative ways of making things biodegradable mean that a lot of the standard plastics can now be replaced with biodegradable polymers. This is critical in the world we live in today non-biodegradable polymers (i.e. the majority of polymers) are continuously filling up landfill sites and entering the oceans [2]. For example, degradable polymers resulting in the formation of non-toxic or less-toxic products at a significantly faster rate than the accumulation of the products in the environment can greatly reduce the potential harm compared to that imposed by the traditional materials. Furthermore, using bio-based polymers mostly made from annually renewable resources helps to reduce our dependency on oil, in addition to enabling a move towards a bio-based economy.

In the quest for sustainable alternatives to conventional plastics, the utilization of corn starch and polyvinyl alcohol (PVAI) in biodegradable film and filler has emerged as a promising solution. Corn starch, derived from a renewable resource, offers biocompatibility and abundant availability, making it an environmentally friendly option. When

combined with PVAI, a synthetic polymer known for its film-forming properties and biodegradability, a robust material is created, capable of fulfilling various packaging and filler applications. Glycerol acts as a plasticizer, improving film flexibility and preventing brittleness. [3]. CMC contributes to film stability, strength and water resistance while chitosan provides antimicrobial properties, extending the shelf life, strength and water resistance [4]. This synergistic combination not only reduces reliance on fossil fuels but also addresses the pressing issue of plastic pollution by offering a viable alternative that degrades harmlessly in natural environments. The study examined the effect of polymer blending on the mechanical and barrier properties of the developed films. Furthermore, a soil burial test was conducted to evaluate the biodegradability, and a migration test was performed to assess the barrier properties of the starch-PVAI films. Similar work has been shown in article[3] Blending polyvinyl alcohol (PVAI) with starch significantly improves the mechanical and barrier properties of biodegradable films .Also incorporating chitosan composite film is hydrophobic and has low water vapor permeability, making it very water-stable and strong. Its excellent resistance to harsh conditions makes it suitable for packaging in article [5].

Materials And Methods

Materials

Polyvinyl alcohol (Degree of polymerization =1700-1800, Viscosity=25-32cp, Hydrolysis=98-99 mole %, Volatiles=max 5%, Ash =max 0.7%, pH value of water solution =5-7) was purchased from LOBA CHEME PVT. LTD, Mumbai. Glycerol was purchased from S D Fine - CHEM Limited, Mumbai. Corn starch was purchased from Brown & Polson. Carboxymethyl Cellulose (PH value= 6-8, Viscosity= 1100-1900 cps 1% aqueous solution at 20°C, Loss on drying <10% at 110°C) was purchased from Merck Life Science Pvt. Ltd Mumbai. And chitosan, from shrimp shells (Degree of Deacetylation :>=75.00%) was purchased from Hi Media Laboratories Pvt. Ltd. Mumbai. Polyethylene Terephthalate (PET) plates were used for casting of the film solution.

Preparation of PVAI solution

The PVAI solution was prepared by adding 4 gm of PVAI powder into 100 ml distilled water, with continued stirring at 50°C until all the PVA powder dissolves.

Preparation of CMC solution

The CMC solution of required viscosity was prepared by gradually adding its powder to 100ml distilled water while stirring continuously to prevent clumping.

Preparation of chitosan solution

The chitosan solution was prepared by slowly adding the chitosan powder to distilled water while stirring continuously with high speed until complete dissolution.

Preparation of starch - PVAI film

The starch -PVAI film was prepared by dissolving 6 gm corn starch in 100 ml distilled water, glycerol is added as plasticizer. The solution was stirred using magnetic stirrer by gradually increasing temperature from 45 to 90°C at 400 rpm for 30 min to induce viscous solution followed by addition of 5 ml PVAI solution with continuous stirring until homogeneous viscous solution is formed. This homogeneous solution mixture is then poured onto a clean PET sheet. The cast film is thereafter allowed to dry at 35°C for 25 hours. Once the film dries completely it is carefully peeled-off from the plate. The film is then analyzed for its properties [3].

Preparation of starch/PVAI/CMC/chitosan composite film

Chitosan solution (200 ml water + 3 gm chitosan powder) added gradually to the CMC solution (200 ml water + 3 gm CMC powder) while stirring continuously ensuring uniform dispersion without clumping, followed by the addition of 10 gm of corn starch slurry and 12 ml glycerol. The solution was stirred using magnetic stirrer at temperature by gradually increasing from 45 to 90°C at 600 rpm for 1 hour to induce viscous solution. Then 12 ml PVAI solution added with continuous stirring until homogeneous viscous solution is formed. The homogeneous mixture the poured onto a clean PET sheet to cast the film. The cast film allowed to dry at 35°C for 25 hours. Once the film dries completely, it is carefully peeled-off from the plate and analyzed for the properties

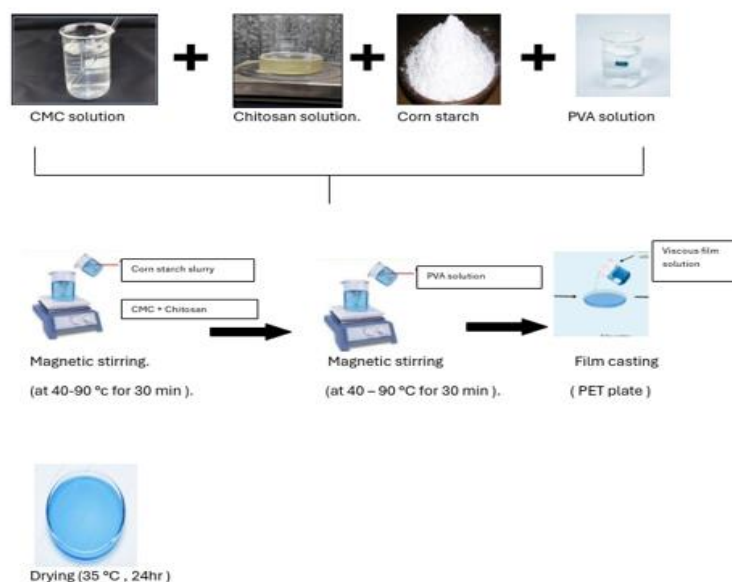


figure 1: prepration of spcch film by solvent casting method.

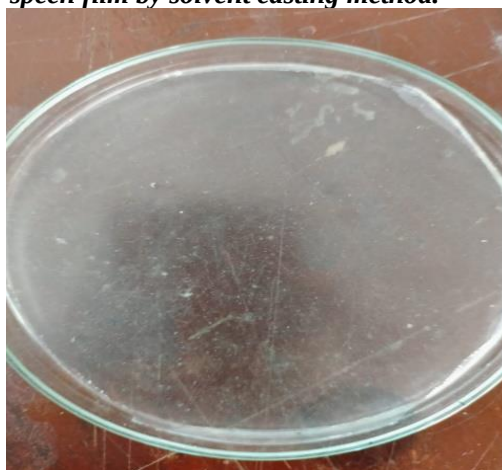


Figure 2: real photograph of film cast onto plate.

Table 1: Composition of different composite films

Sample Code	Starch (g)	PVA (ml)	Glycerol (ml)	CMC solution (3 g)	Chitosan solution (3 g)
1.SP	6	5	5	-	-
2.SPC	6	5	5	100ml	-
3.SPCh	6	5	5	-	100ml
4.SPCCCh	10	12	12	100ml	100ml

(SP-starch-PVA film, SPCCCh-starch/PVA/CMC film, SPCh-starch/PVA/chitosan film, SPCCCh-starch/PVA/CMC/chitosan film)

Characterization of starch/PVA/CMC/chitosan composite film

Characterization of a film entails evaluating its properties and attributes, including thickness, tensile strength, physical property, barrier properties, biodegradability and water solubility.

Thickness

The film thickness was assessed using a thickness gauge. Five random measurements were taken for each sample, and the mean thickness was computed from these measurements to ensure accuracy in the analysis [3].

Density

The density characteristics of packaging films were thoroughly investigated to understand their mechanical properties and suitability for various packaging applications using density tester (Advanced Equipment). Density characterization is a crucial aspect in determining the performance and functionality of packaging materials, as it directly influences factors such as barrier properties, tensile strength, and puncture resistance. Density analysis not only aids in optimizing packaging design for enhanced performance but also contributes to the development of sustainable packaging solutions through the efficient utilization of materials.

Moisture content

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The assessment of moisture content plays a pivotal role in evaluating the performance and stability of packaging films, particularly in food and pharmaceutical industries where moisture can significantly impact product quality and shelf life. The moisture sorption behavior and distribution within the film matrix was investigated using moisture analyzer (Contech Instrument Ltd.). Understanding the moisture dynamics enables precise control over packaging parameters, ensuring optimal barrier properties and preservation of product integrity. Furthermore, this characterization contributes to the development of moisture-resistant packaging materials, advancing the sustainability and effectiveness of packaging solutions in diverse applications especially food packaging.

Tensile properties

The tensile properties, namely tensile strength (TS) and percent elongation at break (E), of the films were determined following the ASTM D882 standard method using a Universal Testing Machine equipped with a 500 N load cell (UTM-G-310C, POLYPLAST). Film specimens sized at 2.54 cm × 15 cm were utilized for the measurements. The initial grip separation and cross-head speed were maintained at 50 mm and 50 mm/min, respectively. To ensure accuracy, an average value was calculated from five readings obtained for each film sample [3].

Air permeability

The air permeability of the film was assessed using a standard testing method, typically in accordance with ASTM D1434 or ASTM D737. The test apparatus utilized is commonly a permeability testing instrument such as a Gurley densometer analyzer. The film specimen, usually of standardized dimensions, is clamped securely within the testing apparatus, and air pressure differentials are applied across the film. The rate of air flow through the film is then measured, providing valuable data on the film's permeability characteristics. This information is crucial for applications such as packaging, where the barrier properties of the film are essential for preserving product quality and shelf life.

Migration property

Food packaging or articles undergo suitability testing using food simulants designed to mimic the migration properties of various categories of foods. These include:

20% Ethanol: Suitable for alcoholic foods with up to 20% alcohol content and those containing organic ingredients, rendering them more lipophilic.

50% Ethanol: Designed for alcoholic foods with over 20% alcohol content and oil-in-water emulsions.

3% Acetic acid: Simulates hydrophilic foods with a pH below 4.5.

This testing protocol ensures the safety and compatibility of food packaging materials with different types of food products.

Water solubility

The percentage of film dry matter solubilized in distilled water after 1 hour of immersion was determined following the methodology: A film specimen measuring 5 × 5 cm was obtained from each type of film sample for analysis. Initial dry weights of the specimens were determined by subjecting them to drying at 105°C for 6 hours. Subsequently, the dried specimens were placed in beakers containing 50 ml of distilled water, which were then covered with aluminum foil and maintained in a controlled environmental chamber at 65% relative humidity and 25°C for 1 hour, with intermittent gentle stirring. After the immersion period, the film pieces remaining in water were carefully removed from the beakers, gently rinsed with distilled water, and oven-dried to obtain the undissolved dry matter content. Water solubility (WS) was calculated by subtracting the weight of undissolved dry matter from the initial dry weight and expressed as a percentage of the initial dry matter content. This rigorous experimental procedure was conducted to ensure accurate assessment of the films' water solubility properties [5].

$$\% \text{ solubility} = \frac{W_i - W_f}{W_i} \times 100$$

where, W_i = initial dry weight and W_f = Final dry weight

Oil penetration property

In the realm of packaging film testing, oil penetration serves as a crucial parameter for assessing the barrier properties and overall effectiveness of the film in preventing the ingress of oils or fatty substances. Characterization of oil penetration involves determining the extent to which oils penetrate the film under specified conditions, typically by measuring the depth or area of penetration over a set time period. Factors such as film thickness, composition, and surface properties play pivotal roles in influencing oil penetration behavior and must be considered during characterization. Test conditions, including temperature, pressure, and type of oil, should be standardized to ensure reproducibility and relevance to real-world packaging scenarios. Furthermore, evaluation criteria need to be established to interpret test results effectively, enabling comparisons between different films or formulations. By characterizing oil penetration in packaging film testing, manufacturers can make informed decisions regarding material selection, optimizing packaging designs for enhanced product protection and shelf-life extension.

Biodegradability

The biodegradability of packaging film was assessed using a soil burial test method adapted

from another researchers' work [6]. Cultivated soil was placed in desiccators to a depth of approximately 4 cm. The packaging film samples, cut into 2 cm × 2 cm pieces, were weighed and buried in the soil to a depth of ~1 cm. The desiccators were maintained at ambient conditions (temperature: 27±5°C, relative humidity: 70 ± 5%), with soil moisture maintained by watering twice daily. Degradation was monitored at regular intervals (7th and 14th day) by gently removing the film samples, rinsing them to remove adhered soil, and determining their dry weight. Weight loss over time was used to calculate the degradation rate of the packaging film samples. Visual observations were also documented using a camera [3].

Results And Discussions

Tensile strength

The tensile strength (TS) is the maximum amount of stretch that a material can endure before failure, while extension under traction (E) reflects the flexibility of the material [7]. Results showed that the mechanical properties of SPCCh composite

films were significantly influenced by blending CMC and chitosan with starch-PVA solution. Pure starch-PVA based films exhibited low values of Tensile Strength 0.6 MPa and Elongation 15.76%, whereas pure CMC film (TS-3.6Mpa, E-186%) and pure chitosan (TS-1.86Mpa, E-28.26%) film demonstrated excellent mechanical properties. Mixing of CMC solution and chitosan solution in starch-PVA solution resulted in notable improvements in both TS(5.28Mpa) and E (443.8%). Composite films with equal percentages of CMC and chitosan showed substantial increases in TS and E compared to pure starch-PVA films. The highest values were observed in SPCCh films, indicating a high degree of chain flexibility despite being covalently bonded. The mechanical enhancement in composite films can be attributed to chitosan's flexible backbone and numerous -NH₂ groups, as well as the strong compatibility between chitosan and carboxymethyl cellulose (CMC) due to hydrogen bonding interaction.

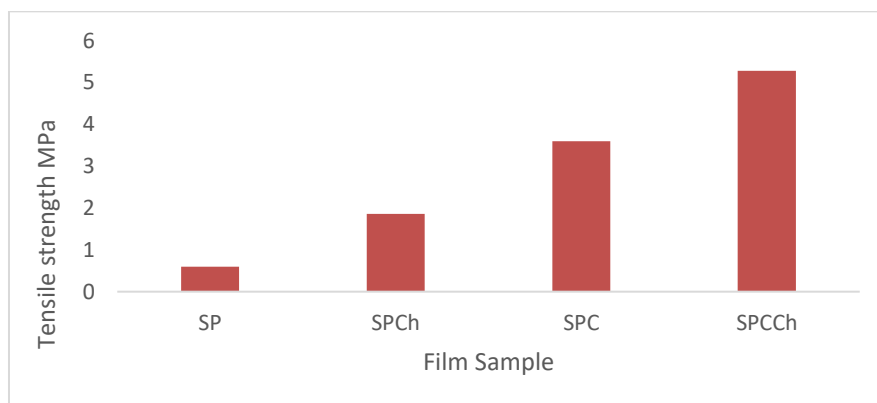


Figure 3: tensile strength of various films

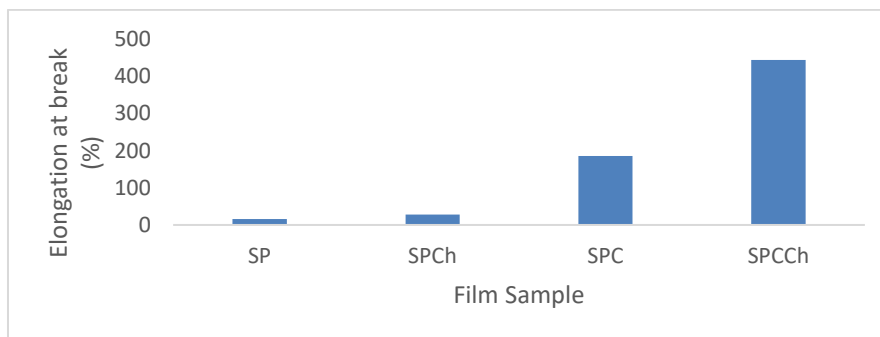


Figure 4: elongation at break of various films

Barrier properties

Barrier properties are crucial for packaging materials. Ensuring movies possess high impermeability to moisture and gases is essential for maintaining the quality of stored food products. Film permeability depends on factors such as chemical composition, moisture content, and environmental conditions. In this study, we examined the barrier properties of pure starch, pure

PVA, and SP composite films in terms of water vapor permeability (WVP) and oxygen permeability (OP), yielding the following results.

Air permeability

Air impermeability (AP) denotes the resistance of a packaging material to the passage of air per unit area and time under specific temperature and relative humidity conditions. All film sample was impermeable to air.



Figure 5: air permeability test

Oil penetration

In the realm of packaging film testing, oil penetration serves as a crucial parameter for assessing the barrier properties and overall

effectiveness of the film in preventing the ingress of oils or fatty substances. All film sample was resistant to oil.



Figure 6: oil penetration test

Migration

The migration testing conducted on the food packaging film aimed to evaluate the potential transfer of chemical constituents from the film to the packaged food. The SP film were migrating in both simulant (3%acetic acid ,15%ethanol), SPCh film were migrate 20 % in 3% acetic acid simulant and

inhibited migration in 15% ethanol, SPC film were dissolved in 15% ethanol simulant and inhibited migration in 3% acetic acid and SPCCh film were inhibited migration in both simulant (3% acetic acid and 15% ethanol). From the result SPCCh film is feasible for food packaging.



Figure 7: migration test of film

Water solubility

The water solubility (WS) of the packaging film was increase in SP film with higher PVA content is expected due to PVA's hydrophilicity and sensitivity to moisture [8]. where higher PVA ratios resulted in improved solubility, likely due to hindered hydrogen bonding between adjacent -OH

groups. Water solubility in SP film was observed 40% where as in SPCh film WS was 35%, In SPC film WS was 27% and in SPCCh film was very less WS 24% compared to SP film. Starch, PVAI (polyvinyl alcohol), CMC (carboxymethyl cellulose), and chitosan are all hydrophilic polymers, meaning they have an affinity for water.

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However, when these polymers are combined to form a film, their water solubility can decrease due to the interactions between the polymer chains. This can be attributed to the formation of hydrogen bonds, cross-linking, and entanglement between the polymer chains, which restrict the movement of water molecules and reduce the overall solubility of the film in water.

Biodegradability

Biodegradation refers to the breakdown of materials by living organisms like bacteria, yeasts, and fungi. In a study on the biodegradability of pure

starch-PVA, SPCh, SPC, SPCCh composite films through soil burial tests, it was observed that all four types degraded quickly in soil, with all four films degrading within one week. Although the exact weight loss wasn't measured due to the films disintegrating into small pieces with soil adhering to them, visual observations confirmed complete degradation within 7 days [9]. These findings align with previous studies on starch/PVA blends, indicating the potential of SP and SPCCh composite films for eco-friendly food packaging materials due to their promising biodegradability in soil.



Figure 8: biodegradability test of film

Table 2: Properties of composite film

Sample	Density(g/cc)	Moisture content (%)	Tensile strength (MPa)	Elongation (%)	Water solubility (%)	Migration (%) (3% acetic acid, 15% ethanol)	Biodegradability
SP	0.42	12.20	0.6	15.74	40	Migrate in both simulants.	5 days
SPCh	1.20	12.66	1.86	28.26	35	Migrate 20% in 3%AA.	7 days
SPC	0.74	14.53	3.6	186	27.27	Dissolved in 15% ethanol.	7 days
SPCCh	1.19	18.35	5.28	443.8	24	Migration inhibited in both simulants.	7 days

Conclusion:

The eco-friendly solvent casting method was employed to prepare Starch-PVAL/CMC/chitosan composite films at various blending ratios, aiming to address the limitations of biopolymers like starch and PVAL. Incorporating CMC and chitosan into starch-PVAL significantly enhanced the tensile strength, water solubility and migration properties of the resulting films. The SPCCh composite film, with equal percentage of CMC and chitosan, exhibited the most substantial improvement in mechanical behavior, showing an 8.78-fold increase in tensile strength and a 28.19-fold increase in elongation compared to pure starch-PVAL film. The incorporation of CMC and chitosan in SP film inhibited the migration and reduced water solubility by 16% compared to SP film. Notably, the SPCCh composite films demonstrated rapid degradation in moistened soil within one weeks, highlighting their potential as eco-friendly food packaging materials.

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Green Building: Sustainable Construction

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DOI- 10.5281/zenodo.15698020

Abstract:

In today's world of technology and increasing levels of carbon dioxide (CO₂) and greenhouse gases in the atmosphere. The burning of fossil fuels such as coal and oil has resulted in higher CO₂ levels and thus global warming which could have catastrophic consequences for the planet in the future. So, this gave rise to green technology and sustainable development that has created a demand that are environmental friendly thus creating a market for green technology.

As we know there is an intimate connection between energy, the environment and sustainable development. A society seeking sustainable development ideally must utilize only energy resources which cause no environmental impact.

Our idea will help to spread the importance of green energy and sustainable development.

Introduction:

As we know that Sustainable development is an urgent global imperative, focusing on the effective and equitable use of natural resources, minimizing environmental degradation, and ensuring long-term societal well-being.

So we are presenting an idea that represents the importance of green energy, material and sustainable development.,

We will provide all the information about material, energy and environmental considerations are crucial for achieving sustainable development, requiring a holistic approach that balances resource use, energy efficiency and environmental protection.

Sustainable Materials Management involves using and reusing materials more productively throughout their lifecycle, emphasizing resource efficiency and reducing waste. Focusing on materials derived from renewable sources like biomass and developing biodegradable alternatives to conventional plastics. Exploring materials like graphene, ceramics, and semiconductors for energy storage, conversion, and transmission, as well as water filtration and chemical separation. Adopting a circular economy approach where materials are designed for durability, recyclability, and reuse, minimizing waste and resource depletion. Harnessing solar, wind, hydro, and geothermal energy to reduce reliance on fossil fuels and mitigate climate change. Developing advanced energy storage technologies like batteries and supercapacitors to store energy from intermittent renewable sources. Exploring fuel cells as a clean and efficient alternative to traditional combustion engines for transportation and power generation. Improving energy efficiency in

buildings, transportation, and industrial processes to reduce energy consumption and emissions. Minimizing the environmental footprint of material production, energy consumption, and waste disposal. Conserving water, land, and biodiversity to ensure the long-term health of ecosystems. Transitioning to a low-carbon economy by reducing greenhouse gas emissions from energy production and industrial processes. Creating and implementing technologies that promote environmental sustainability, such as water purification systems, waste recycling technologies, and renewable energy infrastructure.

There are various paths to material, energy and sustainable development but we mainly focus on green building.

Literature Survey:

In the paper "Sustainable Materials in Green Building Construction". This paper explores The choice of materials plays a critical role in the sustainability of buildings. Green building technology advocates for the use of materials that have low environmental impacts, are locally sourced, and are reusable or recyclable. Many recent studies (e.g., Lee & Lee, 2020) focus on the use of renewable and low-impact materials such as bamboo, recycled steel, and low-VOC (volatile organic compound) paints.

In the paper "Building-Integrated Photovoltaics: Energy Generation and Economic Feasibility". This paper emphasizes on one of the core components of green building technology is the emphasis on energy efficiency. According to several studies (e.g., Menzies et al., 2019), energy-efficient buildings use less energy for heating, cooling, and lighting, thus reducing energy consumption and

greenhouse gas emissions. Research has demonstrated that passive design strategies, such as maximizing natural light, enhancing insulation, and utilizing high-performance windows, are crucial in achieving energy efficiency. In addition to passive strategies, the integration of renewable energy systems like solar panels, wind turbines, and geothermal heating and cooling systems is increasingly popular. These technologies help buildings generate their own energy and reduce dependence on non-renewable sources. For instance, studies by Huang et al. (2021) highlight the role of building-integrated photovoltaic (BIPV) systems in offsetting the electrical energy consumption of commercial and residential buildings.

This paper explores the integral relationship between materials, energy, and the environment as central pillars for achieving sustainability. Materials, from renewable to advanced synthetic options, play a critical role in reducing resource consumption and waste generation, while the adoption of energy-efficient technologies is pivotal in decreasing carbon footprints and fostering a transition to renewable energy sources. Energy, both in terms of generation and consumption, is a key driver of environmental impact, and as such, innovative approaches to energy efficiency, storage, and sustainable production are necessary to mitigate climate change. Furthermore, environmental preservation requires a holistic understanding of the interconnectedness between human activities, ecosystems, and resource cycles, advocating for strategies that balance economic, social, and environmental objectives.

Green technology in building construction that emphasizes sustainable architecture complemented with the promise of well-being and how to create a healthier atmosphere for us and for children. Green building is also known as sustainable construction or sustainable architecture. The goal of green building design is to create modern eco-friendly house plans with healthy indoor environments for occupants while minimizing the use of non-renewable resources and harmful emissions throughout the entire lifetime of the structure. The paper discusses current challenges, emerging solutions, and the need for an integrated approach across material design, energy systems, and environmental protection to support a sustainable future. The advancement of green technologies, circular economies, and policies that incentivize responsible consumption and production are outlined as essential drivers for achieving sustainable development goals (SDGs). Ultimately, fostering collaboration across disciplines, industries, and governments is crucial for transitioning towards a sustainable and resilient global ecosystem.

Sustainable Development Of Green Buildings

The advantages of Green Building Technology should be taken into consideration

while constructing your eco-friendly house design. The greenhouse gases emitted from 1 tonne of concrete are approximately 1.5 times that of steel and equal to that of the aluminium which is extracted from bauxite ore. Hence, reducing the overall weight of concrete used during the construction process is very important. This can be achieved by using fly ash in the concrete mix.

Fly ash is a waste product obtained during coal combustion and has various uses as per requirement, the addition of fly ash in concrete mix improves its compressive strength and makes it fire resistant, thus saving on energy costs associated with air-conditioning in buildings and also avoiding a lot of carbon dioxide emissions into atmosphere due to burning coal to generate electricity.

The first step when considering implementing green building technology is to decide if it will benefit you and your business. You may have to invest in eco-friendly commercial buildings if you want to attract eco-conscious employees or customers, or if you have an environmentally-friendly mandate from your government or the public. In these situations, it's important to make sure that the green technology in building construction is actually effective before investing in it since there could be legal consequences if something goes wrong. If you don't have any specific requirements for a green building, there are still lots of good reasons to go for green technology in building construction. However, this can be a challenge because most of the benefits are indirect savings rather than direct savings that show up immediately.

For instance, the state of California requires that all new public buildings be certified as LEED-certified.

There are many different types of green building technologies for home and business construction. Some of these include:

1. Integrated Pest Management (IPM) – IPM is a strategy for managing pests that involve minimizing dependence on chemicals by using integrated tactics, including mechanical, physical and biological control methods.
2. Solar Energy – Using solar energy can reduce carbon dioxide production while producing clean energy. It can also reduce energy consumption since only sunlight is used as an energy source. The use of solar energy in homes can lower utility bills. Another benefit is that there's no need to purchase gasoline or buy batteries for solar power systems since they run on sunlight.
3. Green Building Materials – There are three main types of green building materials: recycled material, non-toxic material and low-embodied energy material.

Many states/ countries have passed laws mandating the incorporation of green building technology in each new project or having a certain percentage of recycled material. Many countries and states have passed laws mandating that builders incorporate green building technology into each new project.

Green building principles can be applied on various scales, from individual structures to entire neighbourhoods. A building is considered green if it minimizes environmental impacts, utilizes resources efficiently, and implements measures such as improved insulation, natural lighting, rainwater harvesting, and solar energy systems, potentially achieving a 15% to 30% reduction in energy consumption.

Green buildings can be classified into two types: passive, which leverage natural elements for efficiency, and active, which use technology to optimize energy use and reduce carbon footprints. Additionally, Zero Energy Buildings harness renewable energy sources, reflecting a broader commitment to sustainability. The U.S. Green

Building Council (USGBC) categorizes green buildings into LEED Certified, Energy Star, and Naturally Occurring (or "Zero") Net Buildings, marking a significant step toward cost-effective and environmentally responsible construction.

Now a days governments have started enacting laws that aim to make buildings more environmentally friendly by using less energy through increased efficiency or having a certain percentage of recycled material and using renewable sources of energy. These laws will force even existing buildings to become more efficient over time. Green building practices significantly contribute to environmental sustainability by reducing resource consumption, lowering greenhouse gas emissions, and promoting healthier ecosystems. As the construction sector is one of the largest contributors to environmental degradation and climate change, green buildings address these challenges by emphasizing sustainable design and construction principles that benefit both the environment and human health.

Ranking	Building Material	Primary Energy Input (MJ/kg)
Very high energy	Aluminum	200–250
	Plastics	50–100
	Copper	100+
	Stainless steel	100
High energy	Steel	20–60
	Lead, Zinc	25+
	Glass	12–25
	Cement	5–8
	Plaster board	8–10
Medium energy	Lime	3–5
	Clay bricks and tiles	2–7
	Gypsum plaster	1–4
	Concrete	
	In situ	0.8–1.5
	Blocks	0.8–3.5
	Precast	1.5–8
	Sand-lime brick	0.8–1.2
	Timber (sawn)	0.1–5
Low energy	Sand, aggregate	<0.5
	Flyash, RHA, volcanic ash	<0.5
	Soil	<0.5
	Adobe	<0.2

Figure 1- Ranking of Building Materials

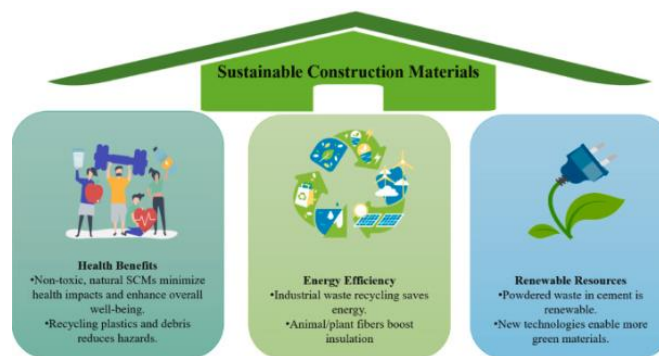


Figure 2- Sustainable Construction Materials

			
Bamboo	Cellulose insulation	Plastic lumber	Silicate Paints
			
Living plants walls	Solar cells	Carpets tiles	Natural stone
			
Injection wells	Lightning fixtures	Certified lumber	Bio bricks

Conclusion:

Sustainable green development is the theme of our time and green building is the embodiment of this concept in the field of architecture. The ultimate goal of green architecture is to provide a harmonious and green living environment that can effectively reduce global carbon emissions and work tirelessly to combat global warming. In recent years, the state has attached more importance to the development of green architecture, and the rapid development of green architecture requires contemporary designers to carry out in-depth analysis and research. However, in this development process, the problem of difficulty in harmonizing design with reality has arisen, and the supervision of the whole process of green buildings is still inadequate. Therefore, for the long-term development of green buildings, the focus needs to be on the aspect of city-wide management and subsequent maintenance. The idea of a green building management system can go some way to solving the various problems before and after construction and ensuring the viability and practicality of green buildings, but it still needs to be supported by policy and a green building construction system. This study only provides a macro view of the whole process of green building, but does not provide specific solutions to specific case studies, so the next study will focus on how the green building management system can be set up and running smoothly.

Ms. Savalgi S.C.

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Hybrid Smart Street-Lamp

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Abstract:

In response to the growing need for sustainable and energy-efficient lighting solutions, this study proposes a hybrid smart lamp that harnesses wind, solar, and hydroelectric energy to ensure uninterrupted illumination across varying seasonal conditions. Traditional lighting systems depend heavily on grid electricity, leading to high costs and increased carbon emissions. The integration of multiple renewable energy sources in a single system enhances energy resilience, reduces reliance on conventional power grids, and supports environmental conservation.

The proposed hybrid lamp incorporates vertical-axis wind turbines (VAWTS), solar panels, and hydroelectric turbines to maximize energy generation efficiency. The VAWTS operate effectively in urban environments and provide consistent power during windy and nighttime conditions. Solar panels contribute significantly to energy production during daytime and summer months, ensuring optimal utilization of available sunlight. The hydroelectric turbine captures rainwater energy, making it a crucial energy source during monsoon seasons and wet weather conditions.

A key feature of this system is its intelligent energy management system (EMS), which dynamically selects the most efficient energy source based on real-time weather conditions. Additionally, a high-capacity lithium-ion battery stores surplus energy, guaranteeing continuous lamp operation during energy transition phases. The modular and scalable design of the lamp allows for broad implementation in urban, rural, and off-grid locations, making it a viable alternative to traditional streetlights and public lighting solutions.

This research also addresses potential challenges, such as energy management complexity, battery lifespan, and material sustainability. AI-driven automation and IOT-based monitoring enhance performance and reliability while promoting smart grid integration. The hybrid energy-powered lamp represents a significant advancement in renewable energy applications, aligning with global sustainability goals and fostering the development of smart cities. By leveraging multiple renewable energy sources, this innovative solution paves the way for a greener and more self-sufficient future in urban lighting.

A sustainable smart lamp: Harnessing wind, solar, and hydroelectric energy for seasonal efficiency

Introduction:

Background and motivation

In the modern era, where environmental sustainability and energy efficiency have become global priorities, the demand for renewable energy solutions has grown significantly. Traditional lighting systems, whether for residential or commercial use, rely heavily on electricity derived from fossil fuels. This dependency not only increases energy costs but also contributes to greenhouse gas emissions, exacerbating climate change. Moreover, the ever-growing demand for electricity strains existing power grids, particularly in developing regions where energy access remains inconsistent.

To address these challenges, the development of hybrid energy-powered lamps presents a viable and innovative solution. By integrating multiple renewable energy sources namely solar, wind, and hydroelectric power—these

lamps can provide continuous illumination while significantly reducing reliance on conventional electricity grids. This approach not only enhances energy resilience but also promotes environmental conservation by utilizing sustainable resources.

The integration of hybrid renewable energy technology is particularly beneficial in areas with fluctuating weather conditions. By intelligently switching between different energy sources based on seasonal variations, hybrid lamps ensure uninterrupted lighting in urban, rural, and remote locations. This adaptability makes them a highly efficient and self-sustaining alternative to conventional lighting systems. Furthermore, implementing such energy solutions aligns with global efforts to achieve carbon neutrality and promotes smart city initiatives aimed at fostering sustainable urban development.

Literature Review

Renewable energy-powered lighting solutions have gained attention as sustainable alternatives to conventional grid-based streetlights. Previous studies highlight the integration of solar and wind energy for street lighting, improving reliability and reducing carbon emissions. Hybrid models incorporating solar-wind systems have demonstrated efficiency in varying weather conditions. Recent advancements introduce hydroelectric energy to enhance seasonal adaptability. Smart energy management systems using AI and IoT further optimize performance by selecting the most efficient energy source in real-time. This research builds upon prior work by integrating a tri-source hybrid system, improving sustainability, and addressing energy resilience challenges for urban and off-grid applications.

Objectives of the study

The primary objective of this study is to design and develop a sustainable smart lamp capable of harnessing energy from vertical wind turbines, solar panels, and hydroelectric turbines. The system will incorporate an intelligent energy management mechanism that dynamically selects the most efficient energy source based on real time weather conditions. The specific objectives of this study include:

1. Ensuring uninterrupted illumination:

Encouraging technological innovation in renewable energy systems:

The lamp is designed to function seamlessly throughout the year, regardless of seasonal or weather variations. By integrating multiple energy sources, it ensures reliable operation during periods of low sunlight, insufficient wind, or dry conditions.

2. Reducing dependency on grid electricity:

By utilizing renewable energy sources, the hybrid smart lamp decreases the reliance on traditional power grids, thereby lowering electricity costs and mitigating power shortages.

3. Enhancing sustainability and energy efficiency:

The project aims to optimize the use of renewable energy by intelligently distributing power among the three sources. This efficiency-driven approach minimizes energy waste and promotes eco-friendly energy consumption.

4. Facilitating smart energy solutions in diverse settings:

Whether in urban streets, rural communities, or off-grid locations, the hybrid lamp serves as a cost-effective and sustainable lighting alternative. Its modular design enables scalability, making it adaptable for large-scale implementation in city lighting projects, public parks, and highways.

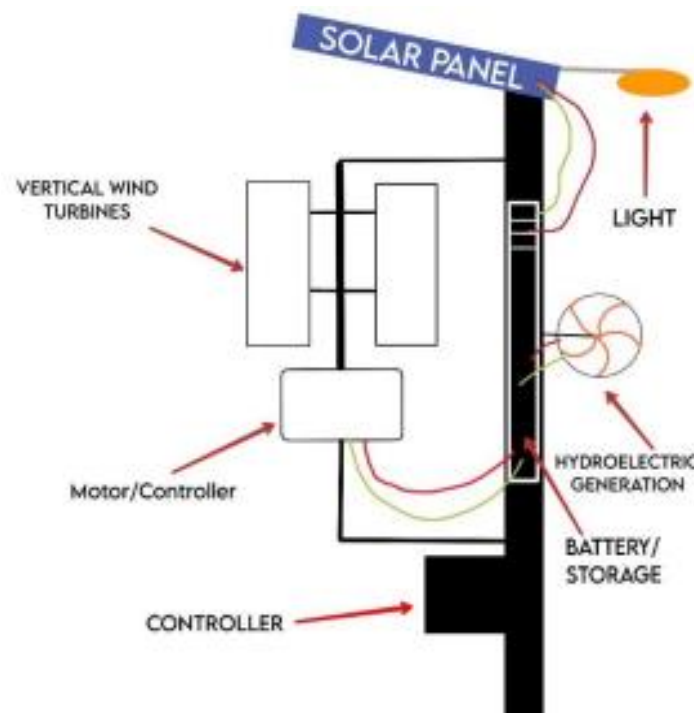


Fig.1. Diagrammatic representation of hybrid lamp

Vertical wind turbine I. Working principle**Fig.2. Vertical Wind Turbine**

A vertical-axis wind turbine (VAWT) operates by harnessing the kinetic energy of wind and converting it into electrical energy through rotational motion. Unlike traditional horizontal-axis wind turbines (HAWTS), VAWTS are omnidirectional, meaning they do not require wind to come from a specific direction to function efficiently. This characteristic makes them highly suitable for urban environments, where wind flow is often turbulent and unpredictable due to buildings and other structures disrupting air currents.

The VAWT consists of vertically oriented blades that rotate around a central axis when wind flows past them. This rotational motion is transferred to a generator, which converts mechanical energy into electrical energy. Due to their vertical design, these turbines can operate in areas with spatial constraints, making them ideal for integration into hybrid energy systems such as smart street lamps.

Seasonal application

Winter and windy days: during winter, autumn, and high-wind conditions, the vertical wind turbine serves as the primary energy source. These conditions generally provide stronger and more

Solar panel

consistent wind patterns, ensuring a reliable and sustainable power supply.

Nighttime operations: since wind energy is not dependent on sunlight, VAWTS contribute to energy generation even at night, complementing solar power effectively.

Advantages

1. Operates effectively at low wind speeds: unlike horizontal turbines, which require significant wind velocity to function optimally, VAWTS can generate electricity even at lower wind speeds, making them practical for various locations.
2. Compact and space-efficient design: the vertical orientation allows these turbines to be installed in confined spaces, making them suitable for urban and residential applications.
3. Lower noise pollution: compared to horizontal-axis turbines, VAWTS operate more quietly, minimizing disturbances in populated areas.
4. Durability and low maintenance: with fewer moving parts and no need for complex yaw mechanisms to track wind direction, VAWTS require less maintenance and have a longer operational lifespan.

**Fig.3. Solar Panel****1. Working principle**

Solar panels generate electricity by utilizing

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photovoltaic (PV) cells, which convert sunlight into electrical energy through the photovoltaic effect. When sunlight strikes the solar cells, it excites electrons within the semiconductor material, generating direct current (DC) electricity. This dc power is then either stored in a battery system for later use or converted into alternating current (AC) for immediate applications.

Solar energy is one of the most widely adopted renewable energy sources due to its abundance, sustainability, and ease of deployment. In hybrid smart lamps, solar panels play a crucial role in ensuring energy generation during daylight hours, storing surplus energy for use during nighttime or periods of low wind and rain.

2. Seasonal application

Summer and sunny days: solar panels act as the primary power source during summer and clear-weather conditions when solar radiation levels are at their peak. Daytime energy generation: solar energy is harvested efficiently during the day and stored for nighttime illumination, ensuring continuous operation of the smart lamp.

Supplementary power source: during transitional seasons such as spring and autumn, solar panels work in conjunction with wind and hydroelectric

energy sources to provide a stable and efficient energy supply.

3. Advantages

i. High energy efficiency in optimal weather conditions:

Solar panels exhibit maximum efficiency in direct sunlight, making them ideal for regions with high solar exposure.

ii. Minimal maintenance and cost-effectiveness:

With no moving parts and a long operational lifespan, solar panels require minimal maintenance and have a low cost of ownership.

iii. Environmentally friendly and sustainable:

Solar energy reduces dependency on fossil fuels and significantly lowers carbon emissions, contributing to a cleaner environment.

iv. Reliable power supply in remote locations:

Solar panels enable off-grid energy solutions, making them an excellent choice for rural and isolated areas where conventional electricity infrastructure is unavailable.

v. Scalability and modularity:

Solar panel arrays can be scaled up or down based on energy requirements, offering flexibility in design and application. 2.3. Hydroelectric Turbine (Rain-powered energy generation)



1. Fig.4. Hydroelectric Turbine

Working principle

A hydroelectric turbine generates electricity by converting the kinetic energy of falling or flowing water into mechanical energy, which is then transformed into electrical energy via a generator. When it rains, rainwater is collected and directed towards a mini hydroelectric turbine, typically positioned at a strategic height to maximize gravitational force.

As water flows through the turbine blades, it induces rotation, which drives a generator to produce electrical power. This setup enables efficient energy harvesting from rainfall, particularly in regions that experience frequent monsoons and wet conditions. The integration of hydroelectric turbines into hybrid smart lamps provides a valuable alternative energy source during periods of reduced solar and wind

energy availability. By utilizing rainwater to generate electricity, the system enhances overall energy reliability and sustainability.

Seasonal application

Monsoon and rainy seasons: the hydroelectric turbine serves as the primary energy source when significant rainfall occurs, ensuring a steady power supply during periods when solar panels may be less effective. Nighttime energy generation: unlike solar power, hydroelectric turbines can operate continuously, making them a viable energy source even after sunset.

Supplementary power source: in areas with consistent rainfall throughout the year, hydroelectric turbines can work in conjunction with solar and wind energy systems to maintain an uninterrupted power supply.

Advantages

- **Reliable energy generation during rainy seasons:**

Unlike solar panels, which suffer efficiency loss due to reduced sunlight exposure, hydroelectric turbines generate power efficiently even in wet and overcast conditions.

- **Efficient utilization of rainwater:**

The system captures and directs rainwater toward energy generation, reducing wastage and promoting sustainable water use.

- **Environmentally friendly:**

Hydroelectric energy is a clean, renewable power source that does not emit greenhouse gases or contribute to pollution.

- **Low operational costs:**

Once installed, hydroelectric turbines require minimal maintenance, making them a cost-effective long-term energy solution.

- **Scalability and integration:**

Hydroelectric turbines can be designed to complement existing renewable energy sources, optimizing overall efficiency and reliability in hybrid energy systems.³ System design and implementation

Hybrid energy management system

To ensure seamless operation, the lamp requires an intelligent energy management system (EMS) that:

i. Monitors weather conditions to determine the most efficient energy source. ii. Stores excess energy in a battery to maintain uninterrupted operation. iii. Balances power input from multiple sources to prevent inefficiency or overload.

Battery storage system

A lithium-ion battery is integrated to store surplus energy. The battery ensures continuous lighting during energy transition phases or when all three energy sources are temporarily unavailable. High-capacity batteries with temperature regulation enhance longevity and performance.

Structural design of the lamp

The hybrid energy lamp is designed to be compact and durable, incorporating lightweight yet robust materials to withstand various environmental conditions. The structural components include solar panels, a vertical wind turbine, a hydroelectric turbine, and an energy management unit, ensuring a fully functional and autonomous system.

Major components**I. Solar panels for capturing solar energy.****II. Vertical wind turbine for wind energy conversion.****III. Hydroelectric turbine for rainwater-powered energy generation.****IV. Battery storage system for energy retention.****V. Control unit for smart energy management.****Efficiency and power output**

Each energy source contributes differently depending on environmental conditions. The total power output

is optimized through intelligent switching mechanisms, ensuring reliable performance in all seasons. The lamp efficiently utilizes available energy sources to maintain continuous illumination with minimal wastage.

Cost analysis

The hybrid energy lamp significantly reduces long-term operational costs compared to conventional grid-powered lighting. Initial investment costs for solar panels, wind turbines, and batteries are offset by the elimination of electricity expenses and reduced maintenance needs.

Environmental impact

This hybrid energy lamp reduces carbon emissions by eliminating reliance on non renewable energy sources. Additionally, it optimizes resource utilization, contributing to sustainability and environmental conservation.

Challenges and solutions**Technical challenges****I. Energy management complexity**

Managing power from three different sources requires sophisticated control algorithms to ensure smooth transitions and avoid energy losses.

Solution: Implement ai-based energy prediction and automation for optimal performance.

II. Battery efficiency and lifespan

Storing excess energy for nighttime usage is essential but challenging due to battery degradation over time.

Solution: Incorporate high-capacity lithium-ion batteries with temperature regulation to enhance longevity and performance.

Environmental challenges**I. Varying weather conditions**

Seasonal changes can lead to inconsistent energy generation, affecting the lamp's performance.

Solution: Ensure a well-balanced combination of power sources to minimize downtime and enhance reliability.

II. Material sustainability

The production of solar panels and batteries contributes to environmental degradation.

Solution: Use recyclable materials and encourage eco-friendly disposal practices to reduce environmental impact.

Future scope and applications**Smart grid integration**

The lamp can be connected to a smart grid, allowing excess power to be distributed efficiently across other devices or stored for later use. This enhances the overall energy efficiency of urban infrastructure.

IOT-based monitoring and control

An IOT-based system can provide real-time data on energy generation, weather conditions, and battery status. Users can monitor and control the lamp remotely via a mobile application, enhancing convenience and efficiency.

Expansion to large-scale urban lighting

This model can be implemented in streetlights, public

parks, highways, and smart cities, promoting energy-efficient urban lighting solutions. Large-scale adoption of hybrid energy lamps can contribute significantly to sustainability and reduced dependence on fossil fuels.

By leveraging renewable energy sources effectively, this hybrid energy-powered lamp presents an innovative solution to contemporary energy challenges, paving the way for a greener and more sustainable future.

Acknowledgement

We extend our sincere gratitude to our academic mentors Principal Dr. K.J. Karande and Vice-Principal Dr. S. G. Kulkarni and institution for their invaluable guidance, constructive feedback, and continuous support throughout this research on "A Sustainable Smart Lamp: Harnessing Wind, Solar, and Hydroelectric Energy for Seasonal Efficiency." Their expertise has been instrumental in shaping the success of this study. We also appreciate the contributions of industry experts, engineers, and technical professionals whose knowledge and assistance have played a crucial role in the design and implementation of this project. Their insights have significantly enhanced the feasibility and practical application of our research.

Furthermore, we acknowledge the support and collaboration of our peers, whose discussions and constructive feedback have enriched our study. Lastly, we are deeply grateful to our families and friends for their unwavering encouragement and belief in our work. Their support has been a source of motivation throughout this journey. This research would not have been possible without the collective efforts of all involved.

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The Role of Sustainable Development in Environmental Protection: A Comprehensive Analysis With Reference To the Environment Protection Act and Ecosystem Conservation

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Abstract:

Sustainable development plays a pivotal role in fostering environmental protection, particularly through legislative frameworks like the Environment Protection Act (EPA) and conservation efforts aimed at preserving ecosystems. This article provides a comprehensive analysis of the interplay between sustainable development, environmental protection laws, and ecosystem conservation. Through a review of relevant literature and case studies, key aspects such as policy implementation, societal impact, economic implications, and technological advancements are discussed. The discussion underscores the importance of integrating sustainable practices into all aspects of development to mitigate environmental degradation and ensure the long-term health of ecosystems.

Keywords: Sustainable development, Environment Protection Act, Ecosystem conservation, Analysis, Review, Discussion

Introduction:

Sustainable development has emerged as a fundamental principle guiding global efforts to balance economic growth with environmental stewardship. Central to this concept is the recognition that development must meet the needs of the present without compromising the ability of future generations to meet their own needs. The Environment Protection Act (EPA), enacted in many jurisdictions, serves as a legal framework to regulate activities that may have adverse impacts on the environment. Concurrently, ecosystem conservation initiatives aim to protect and restore the natural habitats essential for biodiversity and ecosystem services. This article explores the intricate relationship between sustainable development, environmental protection laws, and ecosystem conservation, emphasizing the synergies and challenges inherent in their implementation.

Analysis:

The analysis begins by examining the core principles of sustainable development and how they align with the objectives of ¹environmental protection. It delves into the provisions of the Environment Protection Act², highlighting its role in regulating pollution, conserving natural resources, and promoting sustainable practices. Case studies from various regions illustrate the effectiveness of EPA enforcement in addressing environmental concerns and fostering sustainable development.

Additionally, the analysis assesses the impact of ecosystem degradation on human well-being and explores ³the role of conservation efforts in mitigating biodiversity loss and ecosystem services decline.

Review:

A review of existing literature provides insights into the evolution of sustainable development concepts and the evolution of environmental protection laws worldwide. It synthesizes findings from empirical studies on the effectiveness of EPA regulations in achieving environmental objectives and evaluates the challenges associated with their enforcement. Furthermore, the review examines strategies for integrating sustainability principles into policymaking, corporate governance, and community engagement to foster holistic approaches to environmental management.

Discussion:

The discussion section explores emerging trends and innovations in sustainable development and environmental protection, such as green technologies, circular economy models, and ecosystem-based approaches to adaptation and

³ the role of conservation efforts in mitigating biodiversity loss and ecosystem services decline.

¹ Environmental protection

² Environment Protection Act

resilience. It addresses key issues such as climate change mitigation, pollution control, and natural resource management, highlighting the need for interdisciplinary collaboration and stakeholder engagement to address complex environmental challenges effectively. Moreover, it considers the role of education and public awareness in fostering a culture of sustainability and empowering individuals to adopt environmentally responsible behaviors.

Conclusion:

In conclusion, sustainable development is indispensable for achieving environmental protection goals and safeguarding the health and integrity of ecosystems. The Environment Protection Act, along with ecosystem conservation initiatives, plays a critical role in advancing these objectives by providing regulatory frameworks and promoting responsible stewardship of natural resources. However, realizing the vision of sustainable development requires concerted efforts from governments, businesses, civil society, and individuals to reconcile competing interests and prioritize long-term environmental sustainability.

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1. **United States:** The EPA in the United States was established in 1970. You can reference the official website of the U.S. Environmental Protection Agency for information and details on the EPA: [U.S. EPA Website](<https://www.epa.gov/laws-regulations/summary-clean-air-act>)
2. **United Kingdom:** The Environmental Protection Act of 1990 is a key piece of legislation in the UK. You can find information and references on this act through the UK government's official website: [UK Government Website](<https://www.gov.uk/guidance/environmental-permits-environmental-protection-act-1990>)
3. **Canada:** In Canada, the Environmental Protection Act exists at both the federal and provincial levels. You can refer to the Government of Canada's website for information on the federal act: [Government of Canada Website] (<https://laws-lois.justice.gc.ca/eng/acts/e-10.3/>)
4. **Australia:** Australia has various environmental protection laws at both federal and state levels. You can find information on the Australian Government's Department of Agriculture, Water and the Environment website: [Australian Government Website] (<https://www.environment.gov.au/>)
5. **India:** The Environment (Protection) Act of 1986 is a significant legislation in India. You can refer to the official website of the Ministry of Environment, Forest and Climate Change, Government of India: [Government of India Website] (<http://moef.gov.in/>)



Smart Livestock Shelter Automation & Decision Support System

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Abstract:-

In order to maximize farm management through automation and data-driven insights, this study discusses the deployment of a Smart Livestock Shelter Automation and Decision Support System (DSS). To ensure ideal circumstances for animals, the system has automatic lighting and fan systems that turn on when temperature thresholds are surpassed, in addition to automating environmental control. To enhance animal hygiene, a separate cow cleaning system has also been added. It consists of a tiny pipe system with a submersible motor that is triggered by a motion detection sensor. In order to provide a sustainable solution for contemporary livestock farming, the system seeks to improve animal welfare, lower labour costs, maximize resource utilization and lessen environmental effect. By combining these technologies, real-time monitoring, predictive analytics and effective management are made possible, advancing the field of smart farming.

Keywords: Smart Livestock Automation, Decision Support System (DSS), Environmental Control Systems, Animal Welfare Optimization, Predictive Analytics in Farming

Literature Review:-

Gupta, P. & Sharma, A. (2020). "IoT-Based Smart Agriculture and Livestock Monitoring System." International Journal of Engineering Research & Technology (IJERT): This paper introduces an IoT-based platform for real-time monitoring of farms and livestock. It employs sensors to monitor soil moisture, temperature and livestock health and assist farmers in optimizing irrigation, fertilization and farm management

Patel, S. & Rathi, P. (2021). "Automation of Environmental Control Systems for Greenhouses Using IoT." Journal of Renewable and Sustainable Energy: The research is centered around the automation of greenhouse environmental management through the IoT. Temperature, humidity and light are measured by sensors and allow for automated control to improve crop growth, efficiency and minimize wastage of resources.

Kumar, R. & Sharma, M. (2019). "IoT-Enabled Automated Resource Management in Agricultural Farms." Procedia Computer Science: This research explores IoT-enabled resource management in agriculture. Sensors collect real-time data on soil moisture, weather and nutrient levels, allowing automated control of irrigation, fertilization and pest management for increased productivity and sustainability.

Methodology:-

The approach taken in this research on Smart Livestock Shelter Automation and Decision Support System (DSS) is structured around three main phases: design, implementation and evaluation.

1. Design: The initial step focuses on pinpointing the environmental factors that are vital for the well-being of livestock, such as temperature, humidity and cleanliness. From there we outline the system's requirements which include choosing the right sensors (like temperature, humidity and motion detectors) automated systems (such as lighting, fans and cleaning devices) and data analysis tools. Next we create a system architecture that brings together these sensors, automation systems and a central DSS for real-time monitoring and decision-making.
2. Implementation: During this phase, we install the necessary hardware (sensors, fans, lighting and cleaning systems) within the shelter. We also develop software that gathers data from the sensors and manages the environmental systems. The DSS is programmed to analyse this data and offer predictive insights or recommendations to help with farm management.
3. Evaluation: A pilot study is carried out on a farm to evaluate the system's performance. We collect and analyze data regarding system efficiency, energy use, labour cost savings and animal welfare. A cost-benefit analysis is conducted to compare conditions before and after implementation. Additionally, we gather feedback from farmers and veterinarians to understand the system's impact on farm operations and animal welfare. This methodology effectively combines design, technology integration and performance testing

to evaluate how well the system enhances farm

System Construction:

The Smart Livestock Shelter Automation and Decision Support System is built using a mix of hardware, software and a cloud-based monitoring setup. Here's how the construction unfolds:

1. Shelter Infrastructure & Sensor Deployment

We start by creating a prototype livestock shelter that mimics real farm conditions. IoT sensor like those for temperature, humidity, gas and motion are carefully placed to keep an eye on the environment. We also use cameras and RFID tags to track the movement and behavior of the livestock.

2. Hardware Integration

Microcontrollers such as Arduino or Raspberry Pi are used to process the sensor data and manage the automated systems. Actuators, including motors, fans, sprinklers and feeders adjust the shelter conditions based on recommendations from our AI. Communication modules like Wi-Fi, LoRa and Zigbee allow for real-time data transmission to the cloud.

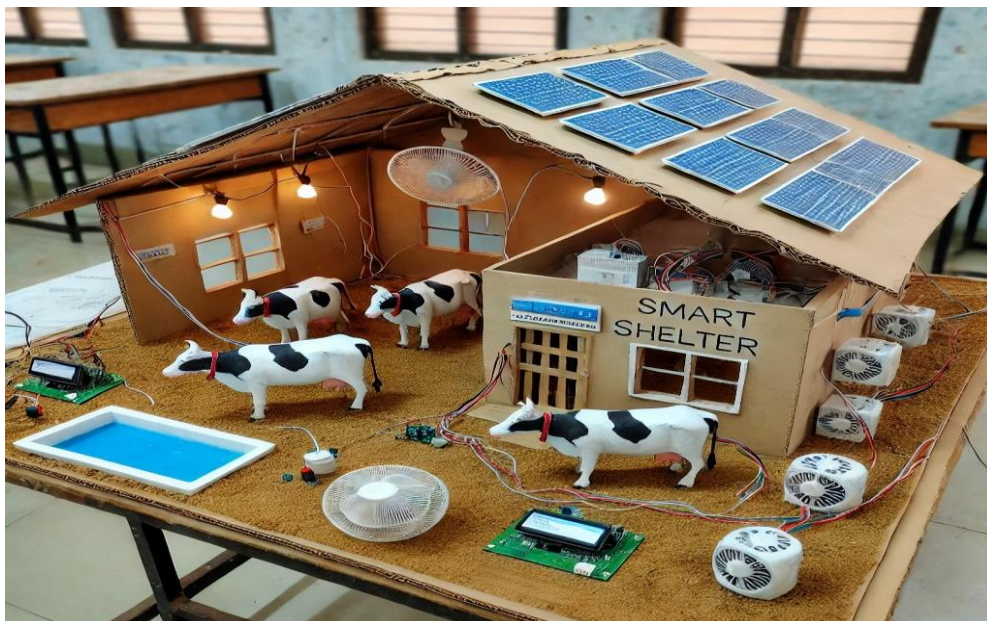
3. Software & AI Implementation

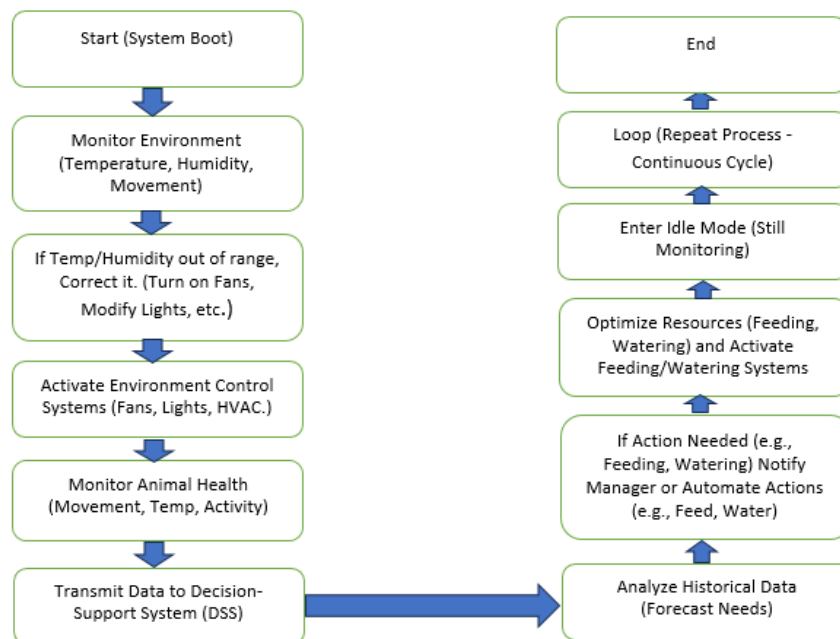
management.

We utilize an IoT cloud platform like AWS, Things Board or Firebase for data storage and remote monitoring. AI models analyze the sensor data to predict potential health risks for the livestock and optimize the shelter conditions. A mobile app or dashboard is created for farmers enabling them to monitor real-time data and receive helpful recommendations.

4. Testing & Optimization

The system goes through rigorous stress testing to ensure it can withstand extreme weather conditions. We perform calibration to improve sensor accuracy and reduce false alerts. The entire system is tested over a three-month period to confirm its efficiency and decision-making capabilities. This construction method guarantees that the system is scalable, cost-effective and adaptable to various farm sizes.



Working Of System:**Fig.1: Flow Chart of System**

The system begins with booting and starts sensing the environment, tracking temperature, humidity and movement within the room.

Step 1: It continuously monitors the environment to ensure that all is kept at the preferred parameters. If the environment becomes too hot, too cold or too humid, the system corrects it.

Step 2: If the temperature or humidity exceeds a certain level, the system will automatically engage to correct it. This may involve turning on fans, modifying lights or engaging other equipment to restore the environment to where it needs to be.

Step 3: The system also searches for movement within the region. This is particularly useful in settings where the area needs to be cleaned (such as a farm or pet section). When it senses movement (such as animals moving about), it activates the cleaning system.

Step 4: When the motion has been sensed, the cleaning system operates. This could be spraying water, sweeping or any other automated task of cleaning to maintain the space clean.

Step 5: While all this is happening, the system keeps track of animal health by using sensors. These sensors check things like the animal's movement, temperature and overall activity, making sure they're in good shape.

Step 6: All the environmental sensor data and health monitoring information is transmitted to a decision-

support system (DSS). This one interprets the data and assists the facility or farm managers in making improved decisions regarding aspects such as resource consumption and animal welfare.

Step 7: The system does not simply focus on the moment. It applies historical data to forecast future requirements. For example, if it is aware that temperature usually increases at a particular time of the Year, it can pre-plan to change the environment beforehand so that adjustments can be made before it becomes too uncomfortable.

Step 8: If there is something that requires attention, the system will give feedback. It may send a message to inform the managers that something needs to be done or it may make changes in automated systems, such as watering or feeding, without requiring human intervention.

Step 9: According to the information it gathers and processes, the system can make decisions to maximize resources, such as feeding or watering schedules. This ensures that animals or plants receive what they require at the appropriate time, without wastage.

Step 10: If the system calculates that the animals need to be fed or watered, it automatically activates those systems. That ensures they receive the proper amount of food or water at the correct time.

Step 11: If all is well and no instant action is necessary, the system goes back into idle mode. It

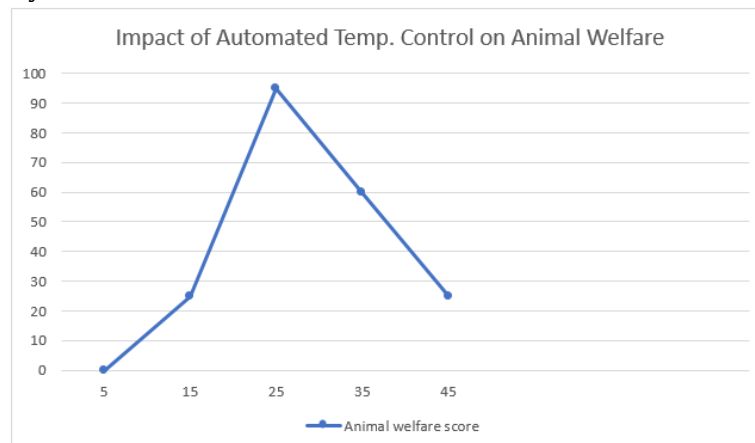
still scans the environment. however, ever prepared to get back into action when the situation calls for it. **Step 12:** This entire process continues, occurring in a loop where the system continuously works to keep all things under control, making changes where necessary and yielding keen observations for the individuals in power.

In brief, this system is such an intelligent space manager. It keeps track of everything, changes

the environment automatically, takes care of maintenance, ensures animal health and assists in optimizing resources such as feeding and watering while learning from previous data all the time to make better choices in the future. It is created to ensure that things go on smoothly with the least amount of human intervention.

Feature	Function	Efficiency Impact	Benefit to Animals
Automated Lighting & Fans	Maintains optimal temperature by turning on/off based on thresholds.	Reduces energy consumption and labor.	Ensures ideal temperature, preventing heat stress and promoting comfort.
Motion-Activated Cleaning System	Automates cow shelter cleaning using motion sensors.	Reduces manual labor and cleaning time.	Improves hygiene, reduces stress and provides a cleaner environment for animals.
Automated Feeding & Watering Systems	Delivers accurate feeding and watering schedules based on needs.	Reduces food and water waste, ensures efficient use of resources.	Ensures animals receive optimal nutrition and hydration, supporting growth and health.

Table 1: Features, Efficiency and Animal Welfare Benefits



X-axis: Temperature (°C)

The X-axis represents the temperature measured in degrees Celsius (°C). This would likely range from a low temperature (e.g., 15°C) to a high temperature (e.g., 35°C or 40°C), indicating the range within which the animals are kept. The X-axis will increase from left to right, showing the change in temperature from lower to higher levels.

Y-axis: Animal Welfare Score

The Y-axis represents the animal welfare score, which measures the welfare of the animals (this could be a score from 0 to 100 or some other scale). As the temperature increases, the welfare score will decrease, because extreme temperatures can negatively impact the animals' well-being.

At lower temperatures (e.g., 15°C), the animal welfare score will be high (e.g., near 20-30), as animals are in a comfortable environment. As the temperature rises (e.g., 25°C, 30°C), the welfare score might slightly decrease (e.g., 90-100). Once the temperature exceeds optimal levels (e.g., above 40°C), the welfare score rapidly decreases (e.g., 40-60), indicating discomfort or stress for the animals.

Automated systems will trigger adjustments (fans, ventilation, etc.) once the threshold is reached, which should improve the welfare score again if temperature control kicks in.

Advantages:-

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Here are the major benefits of the Intelligent Space Management System in more technical and summary format:

1. **Automation & Efficiency:** Avoids human intervention through autonomous monitoring and control of environmental parameters (temperature, humidity, movement). Facilitates immediate adjustments, improving responsiveness to changes in the environment.
 2. **Resource Optimization:** Optimizes resource consumption (water, food, energy) by using real-time information, reducing waste. Enhances energy efficiency by turning systems (HVAC, lighting) on only when necessary.
 3. **Animal Health & Welfare:** Monitors animal health through sensors (temperature, movement, activity) for early warning of health problems. Proactively adjusts to avoid discomfort or illness.
 4. **Environmental Control:** Provides optimal environmental conditions (temperature, humidity, air quality) with automatic adjustments. Adjusts to seasonal or real-time variations, providing consistent conditions.
 5. **Cost Reduction & Productivity:** Reduces labor costs through automation of cleaning, monitoring and resource management functions. Boosts operational productivity by removing human error and simplifying processes.
 6. **Predictive Maintenance & Decision Support:** Utilizes historical information and predictive analysis to forecast environmental trends and animal health problems. DSS enables well-informed decision-making on resource utilization and facility operations.
 7. **Enhanced Hygiene & Cleaning:** Facilitates cleaning activities on movement detection, keeping environments hygienic with minimal effort. Reduces contamination threats and creates healthier environments.
 8. **Scalability & Flexibility:** Ready to scale to other environments (e.g., farms, smart buildings) and integrate new sensors and devices. Tailor-made to suit specific operational requirements.
 9. **Real-Time Alerts & Monitoring:** Offers real-time alerts for environment or health deviations to facilitate fast action. Remote monitoring for greater convenience and management.
 10. **Sustainability:** Maximizes resource use, leading to lower environmental impact. Promotes energy-efficient behavior, reducing overall operational emissions.
 11. **Data-Driven Insights:** Gathers and analyzes data to inform long-term trend analysis for improving system performance and decision-making. Offers predictive insights for responsive environmental and resource management.
 12. **Integrated Facility Management:** Streamlines facility management through the unification of environmental management, cleaning and health monitoring on a single platform. Decreases operational cost and complexity.
- These benefits point to the system's ability to improve operational efficiency, enhance animal welfare and maximize resource utilization with minimal human intervention.

Result:

The implementation of the Smart Livestock Shelter Automation System significantly improved operational efficiency across multiple aspects of livestock management. By automating core tasks, the system has substantially reduced manual labor, enhanced accuracy in resource allocation and contributed to the overall welfare of the animals. Table 2 illustrates the time savings and benefits associated with automating various livestock management tasks, compared to manual methods.

Aspect of Management	Manual Process Time (hrs/day)	Automated Process Time (hrs/day)	Benefits of Automation
Feeding	3	1	Reduced waste, improved health, saved labor
Watering	2	0.5	More accurate resource allocation, reduced waste
Cleaning	3	1	Reduced labor, improved hygiene

Table 2: Comparison of Automated vs. Manual Livestock Management

This table clearly demonstrates the **time savings**, **reduced labor** costs and **improved resource management** resulting from the automation introduced by the system. As shown, tasks such as **feeding**, **watering**, and **cleaning** are significantly more efficient when automated,

leading to greater overall farm productivity and better management of animal health and welfare.

Conclusion:

Using IoT, AI and sensor-based monitoring, smart livestock shelter automation and decision support systems maximise resource efficiency, productivity and animal welfare. These systems provide data-driven insights for improved

decision-making while automating feeding, climate control and health monitoring.

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Synthesis of Lignin based Biodegradable Polymers from an Industrial Waste: Black Liquor

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Abstract:

We report the synthesis of natural organic complex polymer named lignin from a toxic industrial waste product, viz. black liquor which is a result of digestion of pulpwood from paper and pulp industry. This lignin was further analyzed for FTIR spectroscopy to predict the presence of functional groups like hydroxyl, methoxyl, carbonyl, carboxyl, etc. Further three products, namely lignin biofilm, lignin polyurethane (PU) foam and lignin polyvinyl alcohol (PVA) blend were formulated from this lignin by solvent casting method. Scanning Electron Microscopy (SEM) analysis of lignin PVA blend was performed to check the formulation of blend. Further various tests like specific density, moisture analysis, tensile strength, rebound elasticity, oil penetration, air permeability, water absorption, biodegradability rate, etc. were performed to predict the properties of the products. Later on, a comparative study of lignin-based products and commercially available products was done. Also, the cost estimation of the products was done and it was concluded that the products could be economically well suited when upscaled to industrial level. The products find application in various areas such as garbage bags, mulching paper, false ceilings, wall insulations, kitchen cutlery and many more.

Keywords: Lignin, Black liquor, FTIR spectroscopy, Scanning Electron Microscopy (SEM) analysis.

Introduction:

In recent years, plastic waste in environment has increased significantly, especially in marine environment leading to tremendous water and soil pollution. This plastic material harms the environment, hinders the movement of living organisms and leads to several ill effects on the human ecosystem. There are roughly 300 million tons of waste produced every year and its 10% ends up in the oceans [1]. To limit this plastic pollution, researchers have started searching for alternatives to these synthetic polymers which will have similar strength and better degradability than these polymers.

The word "biodegradable" means that a substance is degradable by bacteria or other biological means. New and innovative ways of making things biodegradable means that a lot of the standard plastics can now be replaced with biodegradable polymers. This is critical in the world we live in today as non-biodegradable polymers (i.e. the majority of polymers) are continuously filling up landfill sites and entering the oceans [2]. In this quest for sustainable alternatives to conventional polymers, the utilization of lignin has emerged as a

promising solution. The word is derived from lignum, which means "wood". It is one of the major components of lignocellulosic biomass. Basically, lignin is a complex natural organic polymer deposited in the cell walls of many plants, making them rigid and woody. It is the primary renewable resource and the second most prevalent natural polymer on earth. Traditionally, it was considered as low value waste product. However, it has been established that lignin can be used to make high-value products such as syngas, carbon fiber, phenolic compounds, various oxidized products, and multifunctional hydrocarbons.

Most of the currently available lignin in the market can be categorized based on the content of sulphur. Kraft lignin (**Fig. 1**) is the most abundant lignin form available on the earth with 3.0-7.0 % of sulphur content. The black liquor is a waste by-product in pulp extraction industry, which is underutilized and commonly used as a fuel source for heat generation. Most recent advancement of LignoBoost process has provided opportunity of large-scale purification of lignin from black liquor which is generated by Kraft process.

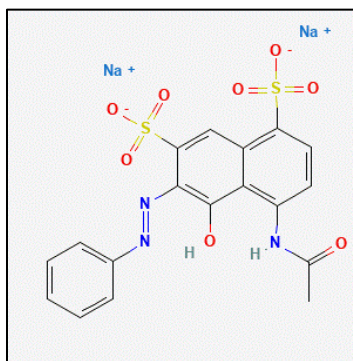


Fig. 1. Chemical structure of kraft lignin

The current research focuses on recent advances into the valorization of the byproduct lignin into various products such as films, foams, blends and many more. Due to thin thickness, it becomes difficult for plastic films to recycle and thus end up causing pollution in the environment. To overcome this, biofilms are a sustainable alternative which degrade easily in nature. But due to lack of strength, sometimes their applications get limited in market. In such cases the biofilm material (here Polyvinyl Alcohol (PVA)) can be blended with lignin to yield strength similar to that of commercially available films. Similarly, other non-biodegradable synthetic polymer Polyurethane (PU) foam too ends up in the environment causing lot of disturbances in the ecosystem. To overcome this lignin can be introduced in the synthesis of PU foam to achieve complete degradation.

Literature Review

Recent advancement in development of polymeric material kraft lignin was derived from some classical methods [3]. In recent times various useful products such as films, foams and blends are

The various significant materials used in the current investigation along with lignin in the formulation of these products are discussed in **Table 1**.

Table 1. Materials, their chemical formula and function in the current research

Material	Chemical Formula	Function
Glycerol	$C_3H_8O_3$	Improves the flexibility, durability and tensile strength of film
Chitosan	$(C_6H_{11}NO_4)_n$	Enhances the mechanical strength, barrier properties and biocompatibility of the film
Acetic acid	CH_3COOH	Breaks down complex functional groups in lignin and chitosan into straight chained molecules
Polyvinyl Alcohol (PVA)	$(C_2H_4O)_n$	Excellent film forming capacity
Methyl Diisocyanate (MDI)	$C_{15}H_{10}N_2O_2$	Main reactant for PU foam formation
Soyabean Polyol	$R-(OH)_2$	Main reactant for PU foam formation
Distilled Water	H_2O	Solvent, dispersing agent and foaming agent

Methodology

Synthesis of Lignin

1. 150 ml black liquor was added to the 5000 ml beaker and agitation was started (using mechanical agitator) to yield homogeneous mixing of precipitate.

formulated using lignin to achieve applications in daily life. A typical film was made from cellulose acetate in a research article [4] which helped in understanding the raw materials required for film formation. Similar film was formulated using lignin instead of cellulose acetate with varying weight ratios of different reagents and the best one (based on the properties obtained) was selected for the current work. Similarly referring to certain articles [5] helped in understanding the formulation of polyurethane foam which mainly emphasized on use of lignin as polyol for foam formation. A blend is formulated to improve the properties of a polymer by mixing it with other polymer having desired applications. A lot of cases of PVA films have been reported which find them unfit for application requiring higher tensile strength and elongation. Thus, PVA was blended with lignin (which has excellent tensile properties) in various proportion according to classical solvent casting method [6] and the best one was selected.

Materials and Methodology

Materials

2. H_2SO_4 was added from the walls of beaker drop by drop into the beaker to yield a frothy mixture.
3. The acid was added till the pH of the solution was in between 2-3.

- Further the mixture was washed multiple times with distilled water till the pH of solution reached within the range of 5-7.
- The solution was vacuum filtered to yield dark brown coloured precipitate.
- The wet precipitate was dried in hot air oven for 2 hours at 80°C.
- The yielded lignin was further grinded, weighed (28.1 g) and filled into a container (**Fig. 2**).

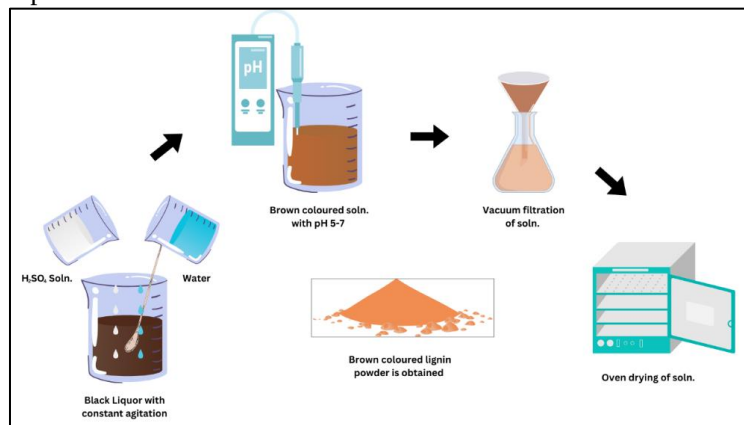


Fig. 2. Synthesis of Lignin

Formulation of Lignin Biofilm

- 1.608 g lignin was added to 60 ml of acetic acid solution and stirred on a hot plate.
- Further 1.2 g chitosan (plasticizer) and 3 ml glycerol were added to the mixture and stirred for some more time.
- Further the solution was sonicated for 15 minutes and cooled down,
- The mixture was transferred into a petri dish (greased with silicone oil) and kept into a hot air oven at 60°C for 1 hour.
- Later on, the mixture was dried for a day in sunlight to yield a smooth lignin biofilm (**Fig. 3**).

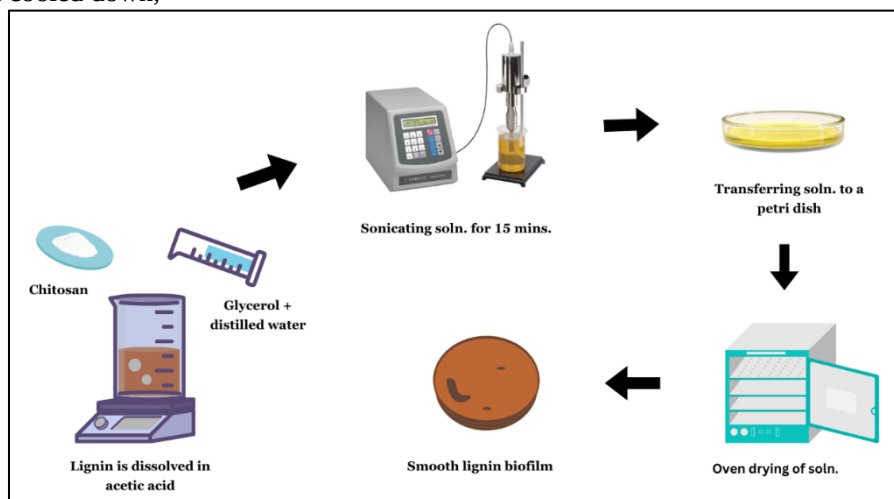


Fig. 3. Formulation of lignin biofilm

Formulation of Lignin Polyurethane (PU) Foam

- 5 g lignin was dissolved in 10 ml distilled water and stirred on a hot plate.
- Further 13.4 g polyol was added to the lignin solution and the mixture was sonicated in 3 cycles of 15 minutes each (with an interval of 10 s).
- The mixture was cooled and added with 10 ml of distilled water (as blowing agent) and agitated on a hot plate.
- Later, 13.4 g MDI was added to the solution and mixed using a mechanical agitator for 10 seconds.
- The solution was quickly transferred to a mould tray covered with aluminium foil and greased with silicone oil.
- The lignin PU foam was kept overnight till all the gas gets released out of the mould and the foam was removed from the foil (**Fig. 4**).

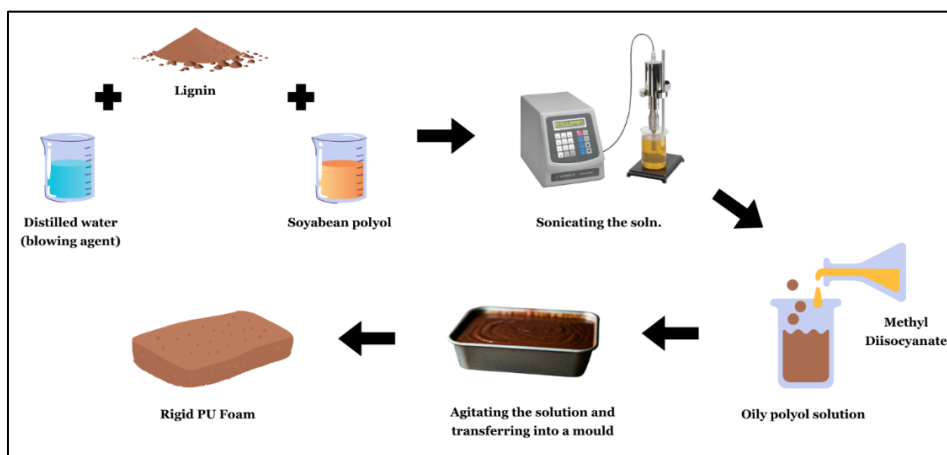


Fig. 4. Formulation of lignin PU foam

Formulation of Lignin Polyvinyl Alcohol (PVA) blend

1. 0.8 g lignin was dissolved in 20 ml distilled water and sonicated for 30 minutes.
2. Further, 20 ml PVA solution was added to the mixture and stirred on a hot plate for 20 minutes.

3. Once the mixture was homogeneously mixed, it was transferred into a petri dish and left in open air for drying for 24 hours.
4. A smooth and rigid lignin PVA blend was obtained (**Fig. 5**).

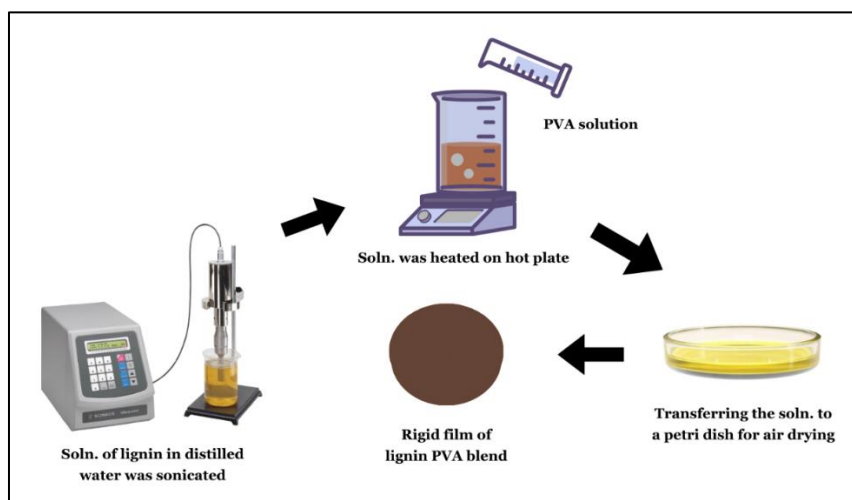


Fig. 5. Formulation of lignin PVA blend

Results and Discussion

Analysis of Lignin

The FTIR spectrum of the lignin is displayed in **Fig. 6**. The lignin's OH groups are responsible for the band located at 3319 cm^{-1} . Peaks

displayed at 2927 and 2855 cm^{-1} might be related to the lignin molecules' C–H stretching where the peaks were primarily caused by C–H stretching in methyl of aromatic and methylene groups of side chains and aromatic methoxyl groups.

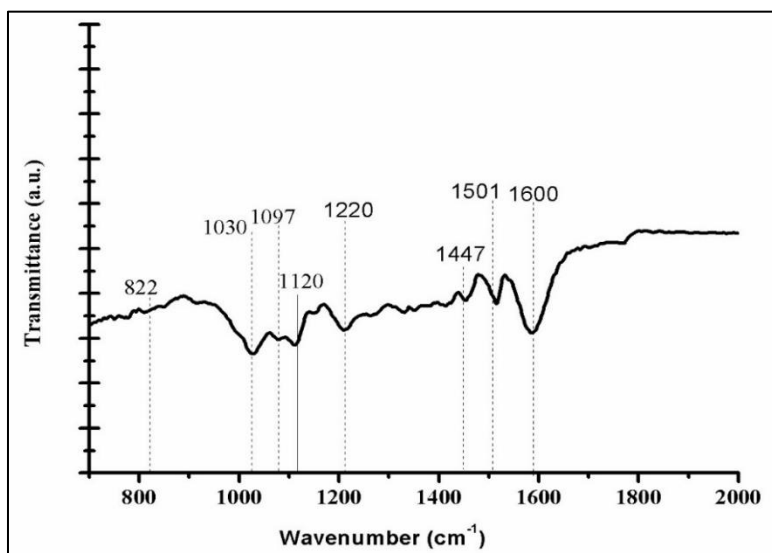


Fig. 6. Transmittance v/s wavenumber (FTIR analysis of lignin)

Similar observations were reported showing that the C–H stretch in methyl and methylene groups is prevalent in regions between 3000 and 2880 cm^{-1} [7]. Similarly, other functional groups like C–O bands at 1097 and 1035 cm^{-1} were linked to primary and secondary alcohols [8] and aromatic

–CH stretch vibration was detected at all the wavenumbers smaller than 900 cm^{-1} [9]. **Table 2.** enlists the peak wavenumber of the **Fig. 6**, its corresponding functional group and peak shape/size. This helps in inferring that the synthesized product may be kraft lignin.

Table 2. A grid of various functional groups and their corresponding wave numbers

Peak Wavenumber (cm^{-1})	Functional Group		Peak shape/size
1600	C=O	Aldehyde groups	Broad, sharp
1501	C–H	C-H deformation (methyl and methylene)	Medium, sharp
1447	C–H	Aromatic skeletal vibration combined with C-H in plane deformation	Medium, sharp
1294	C–O	C-O stretching of syringyl ring	Very tiny shoulder
1241	C–O	C-O stretching of guaiacyl ring	Medium
1030	C–OH	C–OH stretch vibration in guaiacyl units	Broad
822	C–H	C-H rock vibration	Very tiny
618	C–H	Alkyne	Very tiny
542	C–H	Alkanes	Tiny sharp

Analysis of Blend

Scanning Electron Microscopy (SEM) is a characterization technique to check the morphology of a chemical composition by bombarding electron beam on the sample [10]. In this study, SEM of the so formed blend was done in order to check change in its morphology from that of the parent reagents, i.e. lignin and PVA.

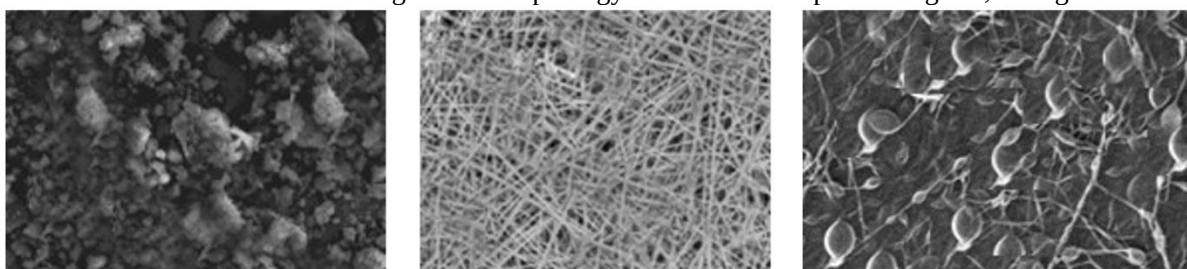


Fig. 7. SEM images of Lignin, PVA and Lignin PVA blend (in an order from left to right)

The images in **Fig. 7** revealed that there is change in the morphology of the blend. The particles in the lignin were granular, rocky and irregular in shape while the PVA particles had long stacky and thin structure. Alike these two images,

the lignin PVA blend image had stacky but swollen particles. This proffers a conclusion that a new blend was induced with stacky PVA structure and granular lignin structure, leading to the formation of a new lignin PVA blend.

Testing of Products

The so formed samples were subjected to different tests (**Fig. 8**) such as specific density, moisture analysis, tensile strength, air permeability,

water solubility, oil permeability, rebound elasticity and biodegradability to evaluate their various physical parameters.



Fig. 8. The so-formed products being subjected to different tests

A comparative study of outcomes of these tests for lignin-based products in comparison with commercially used products is portrayed in **Table 3.** for lignin biofilm Vs commercial biofilm, **Table 4.** for lignin PU foam Vs commercial PU foam and **Table 5.** for lignin PVA blend vs commercial PVA film.

Table 3. Outcomes of various tests for lignin biofilm Vs commercial biofilm

Sr. No.	Parameter	Lignin Biofilm	Commercial Biofilm
1.	Specific density (g/cm ³)	0.204	0.56
2.	Moisture content (%)	19.88	3.31
3.	Tensile strength (MPa)	0.59	0.62
4.	% Elongation	74.14	60.31
5.	Water absorption (%)	20.5	46.15
6.	Air penetration	Impermeable to air	Impermeable to air
7.	Oil absorption	Oil resistant	Oil resistant
8.	Biodegradability rate	10 days	7-8 days

Table 4. Outcomes of various tests for lignin PU foam Vs commercial PU foam

Sr. No.	Parameter	Lignin PU foam	Commercial PU foam
1.	Specific density (g/cm ³)	0.56	0.35-0.8
2.	Moisture content (%)	16.3	0.46
3.	Tensile strength (MPa)	0.079	0.04-0.9
4.	% Elongation	24.14	-
5.	Rebound elasticity (%)	21	19-31
6.	Water absorption (%)	7.8	< 2
7.	Biodegradability rate	27 days	20-100 years

Table 5. Outcomes of various tests for lignin PVA blend Vs commercial PVA film

Sr. No.	Parameter	Lignin PVA blend	Commercial PVA film
1.	Specific density (g/cm ³)	0.228	0.441
2.	Moisture content (%)	10.3	12.6
3.	Tensile strength (MPa)	5.119	0.43
4.	% Elongation	69.88	56.31
5.	Water absorption (%)	23.8	40.6
6.	Air penetration	Impermeable to air	Impermeable to air
7.	Oil penetration	Oil resistant	Oil resistant
8.	Biodegradability rate	16 days	days

In case of biodegradability test, although the exact weight loss wasn't measured due to the products disintegrating into small pieces with soil

adhering to them, visual observations confirmed complete degradation within 10 days for lignin biofilm (**Fig. 9**), 27 days for lignin PU foam (**Fig.**

10) and 16 days for lignin PVA blend (**Fig.11**), respectively.

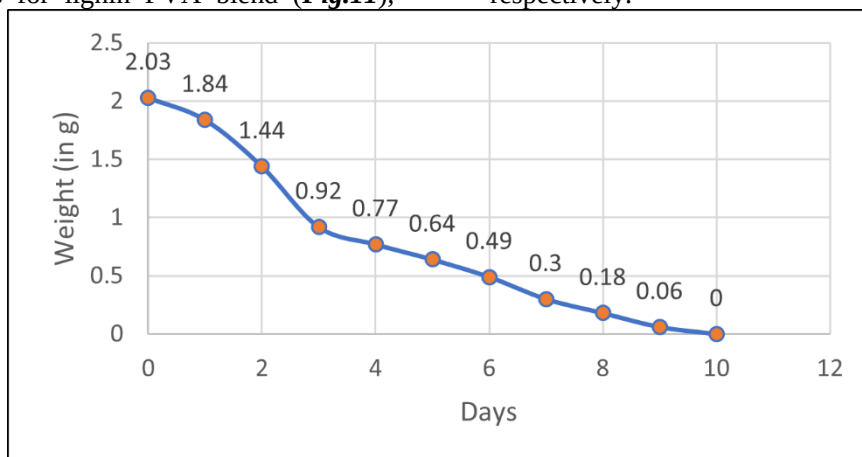


Fig. 9. Biodegradability graph of lignin biofilm

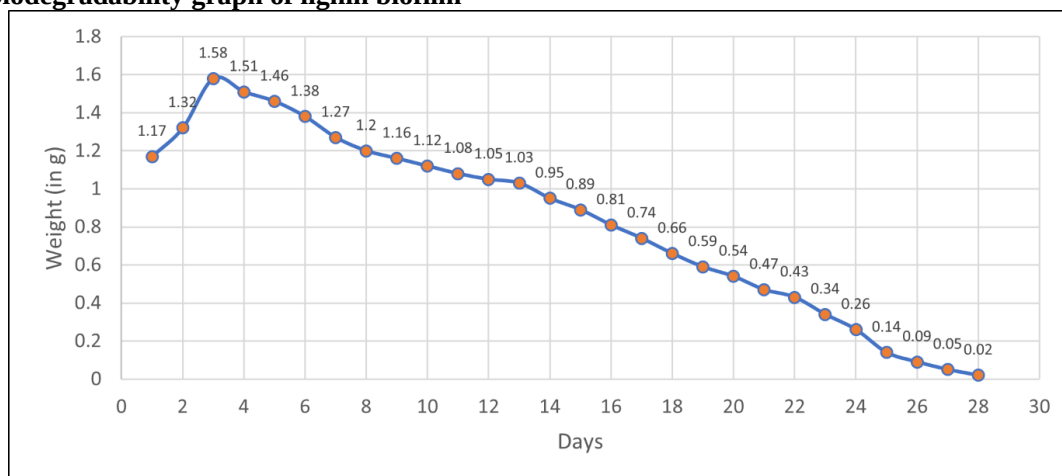


Fig. 10. Biodegradability graph of lignin PU foam

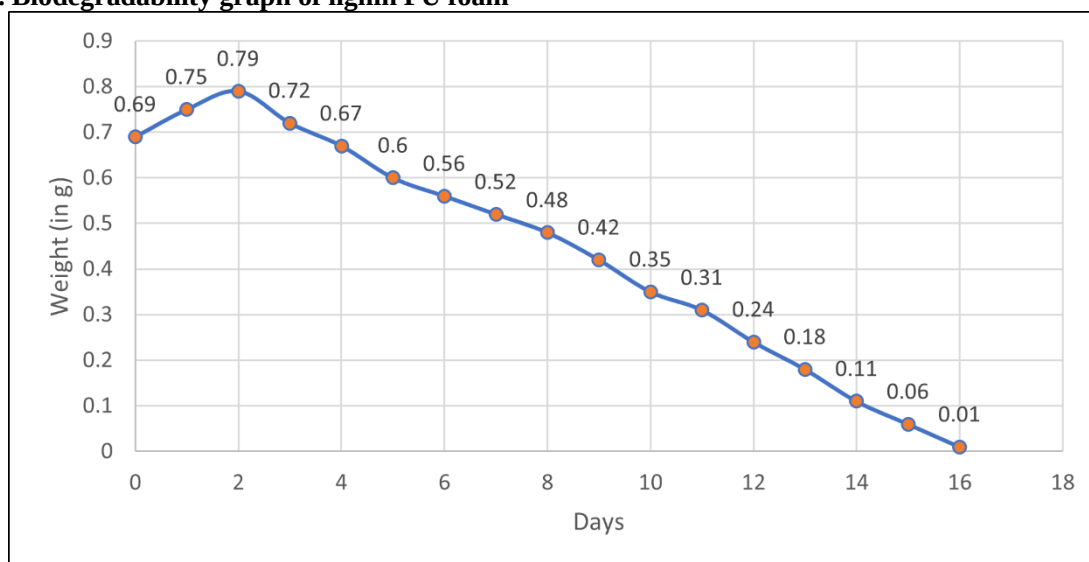


Fig. 11. Biodegradability graph of lignin PVA blend

Cost Estimation

While synthesizing a product, other than yielding its desirable properties and concerning environmental impact, the most important factor of consideration is its cost. The product should be

budget friendly in accordance with the other two parameters. The cost of all the three products on lab scale production was as follows:

For Lignin Biofilm

Sr. No.	Raw Material	Quantity	Cost
1.	Lignin	1.608 g	Rs. 36.1
2.	Acetic acid	60 ml	Rs. 19.2
3.	Chitosan	0.8 g	Rs. 1.44

4.	Glycerol	2 ml	Rs. 22.2
Total (for 6.5 g of lignin biofilm)			Rs. 78.94

Thus, the cost for 1 g lignin biofilm was estimated to be Rs. 12.144 while the cost of 1 g commercial PLA film is Rs. 5.2.

For Lignin PU Foam

Sr. No.	Raw Material	Quantity	Cost
1.	Lignin	5 g	Rs. 112.45
2.	Distilled water	20 ml	Rs. 0.4
3.	Soyabean polyol	13.4 g	Rs. 2.53
4.	MDI	13.4 g	Rs. 1.273
Total (for 22 g of lignin PU foam)			Rs. 116.653

Thus, the cost for 1 g lignin PU foam was estimated to be Rs. 5.302 while the cost of 1 g commercial PU foam is Rs. 1.3.

For Lignin PVA Blend

Sr. No.	Raw Material	Quantity	Cost
1.	Lignin	0.8 g	Rs. 17.99
2.	Distilled water	20 ml	Rs. 0.4
3.	PVA Solution	20 ml	Rs. 2.96
Total (for 6 g of lignin PVA blend)			Rs. 21.35

Thus, the cost for 1 g lignin PVA blend was estimated to be Rs. 3.56 while the cost of 1 g commercial PVA film is Rs. 1.052.

It was inferred that the production cost of lignin-based products was a bit higher as compared to the commercially available products. The reason for this was found to be that all the three products were synthesized on lab scale and thus consumed more resources and energy. But when upscaled to mass production the following lignin-based products can be synthesized more profitably, same as that of other commercial products.

Conclusion:

A natural organic complex polymer, lignin was synthesized using a toxic industrial waste named black liquor. Further three different products were formulated using this lignin powder, viz.

Lignin Biofilm, Lignin PU Foam and Lignin PVA Blend These products were examined for various tests in order to check their compatibility. Based on these results it was found that these products can be used in various areas of applications such as food cutlery items, mulching paper, garbage bags, false ceiling, wall insulation and many more as shown in **Fig. 12**. The production cost of these products was also found to be economically well suited when upscaled to industrial production. Thus, lignin-based products offer similar performance to that of commercially used products along with better biodegradability. Also, these products help in reducing the use of fresh resources as raw materials and solve the problem of plastic accumulation and pollution.



Fig. 12. Versatile applications of lignin-based Biofilm, PU foam and lignin PVA blend

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2. Declaration of Interests

On behalf of all the co-authors, I the corresponding author declare that we have no known competing financial interests or personal

relationships that could have appeared to influence the work reported in this paper.

3. Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

4. Data Availability Statement

Data are available on request from the corresponding author upon reasonable request.

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Solar Powered Battery Swapping Technology for Electric Vehicle

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Abstract:

Electric vehicles (EVs) are an integral part of a greener future, but their widespread use is challenged by several factors, such as long charging duration, battery ageing, and a lack of appropriate charging facilities. One alternative option to traditional charging methods is solar-powered battery swapping stations (SP-BSS), which allow users of EVs to swap fully charged batteries with exhausted ones in a few minutes. Through the incorporation of renewable solar power, these stations decrease dependence on the conventional electricity grid, providing a cleaner and less expensive charging option. SP-BSS adopt high-performance battery packs, fast charging capabilities, and intelligent energy management systems that provide un-interrupted working.

They observe battery conditions, maximize the usage of energy, and minimize energy wastage. In contrast to grid-powered battery swapping stations, solar-powered ones can operate at remote and off-grid areas, making EVs more prevalent in rural and hard-to-reach areas. This is especially valuable in nations such as India, where NITI Aayog has mentioned the necessity for decentralized EV infra-structure that will cater to increasing urban and rural mobility.

Additionally, the Battery-as-a-Service (BaaS) concept improves affordability as EV users are able to rent batteries instead of buying them directly, drastically reducing the initial cost of EV acquisition. This method is picking up steam around the world, with the likes of Gogoro in Taiwan and Indian big-name startups testing the waters with the same. Solar-powered battery swap stations, with solutions to the cost, charge time, and infrastructure constraints, offer a viable way towards mass adoption of EVs, speeding the transition to cleaner and more sustainable mobility.

Keywords: Solar-powered battery swapping, Sustainable mobility, Fast-charging technology, Battery-as-a-Service (BaaS), Energy resilience

Background & Literature Review:

As electric vehicle (EVs) gain increasing adoption, the need for efficient and fast charging solutions has become more and more pressing. One of the most promising solutions is battery swapping stations (BSS), where EV users can swap out used batteries with new ones that are fully charged. By removing the long charging time, this solution helps to overcome range anxiety and increase user convenience. As per NITI Aayog's battery swapping report for India, this model is especially suited to electric two- and three-wheelers, reducing downtime and enhancing operational efficiency considerable [1].

Recent studies point to innovations in auto-mated battery swapping systems, which use robotics and artificial intelligence (AI) to make processes more efficient. On top of this, improvements in battery management systems and optimized charging practices are increasing battery lifespan while enhancing safety. A whitepaper by JMK Research discusses such innovations, stressing their importance in providing seamless operations with minimal human intervention [2].

Apart from technical efficacy, battery swapping also has major economic advantages. In comparison with conventional plug-in charging, it can lower costs of charging up to 50%, thus becoming more financially reasonable for EV driving. Research suggests that mass-scale adoption of battery swapping can cut greenhouse gas emissions by as much as 70%, helping India move towards clean energy and curbing dependence on fossil fuels.

Yet, with these benefits, challenges persist. Battery designs impede inter-operability among different EV manufacturers. As noted by Venkateswaran et al., lack of universal standards and competitive business models still acts as the major obstacle to big-bang rollout [3].

Resolution of these challenges via policy measures and cooperation between industries, as itemized in NITI Aayog's policy recommendations, will be fundamental. Real-world applications have already shown encouraging outcomes. Research in China identified that battery swapping reduced EV charging time by as much as 90%, and comparable programs in Japan have already established the

viability of this system for heavy-duty EVs. In India, firms featured by EV Reporter are actively engaged in scaling up battery swapping solutions, especially for commercial fleets [4].

In summation, battery swapping stations can transform EV charging into a faster, more convenient, and affordable means compared to charging the battery to capacity. But meeting cost, standardization, and scalability will be the key to achieving mass adoption. With government support, ongoing technological.

Research Methodology:

This research adopts a multidisciplinary approach in assessing the feasibility, efficiency, and implementation of solar energy technologies for sustainable power generation. Through the integration of literature review, case study analysis, technical feasibility assessment, economic evaluation, and environmental impact analysis, this research offers an integrative understanding of solar energy solutions. Research starts with a critical analysis of government policies, industry reports, and academic studies to determine the major challenges, opportunities, and technological developments in solar power systems. A comparative study of various solar technologies, including photovoltaic (PV) panels and concentrated solar power (CSP), is made to evaluate their efficiency, costs, infrastructure requirements, and scalability.

For gaining hands-on experience, case studies of pioneer solar adopters such as India, China, and some European countries are examined. These examples illustrate best practices as well as challenges in large-scale deployment of solar power. Technical feasibility analysis is conducted for evaluating solar panel efficiency, integrating energy storage, grid compatibility, and the effect of automation in solar tracker systems. Besides this, the economic analysis delves into cost considerations and benefits, revenue models like grid-tied and off-grid systems, as well as power purchase agreements and long-term finance stability.

The environmental effect study considers carbon emission reductions, land use factors, and solar energy integration with smart grid technology. To further support the results, simulations are run to analyse energy conversion efficiency, storage, and overall power & grid impact. This holistic approach guarantees a balanced analysis, offering policymakers, companies, and researcher's important insights to inform the large-scale use of solar energy as a clean and renewable source of power.

Solar-Powered Battery Swapping Technology: The Future of Mobility:

As the global shift toward cleaner

transportation gains momentum, electric vehicles (EVs) are emerging as a key solution for reducing carbon emissions. However, major challenges such as long charging times, limited infrastructure, and high battery costs continue to slow down widespread EV adoption. To address these barriers, solar-powered battery swapping stations (SP-BSS) offer an innovative and sustainable alternative, allowing EV users to replace depleted batteries with fully charged ones in just a few minutes—all powered by renewable solar energy. This eliminates long waiting times, improves accessibility, and reduces dependence on traditional power grids.

This project introduces an advanced SP-BSS model that integrates solar energy storage with battery-swapping infrastructure to enhance efficiency, sustainability, and accessibility. A key innovation in this system is the use of high-density modular battery storage, which optimizes the retention and utilization of solar energy. Intelligent power management systems further ensure that stored solar energy is distributed efficiently, enabling multiple batteries to charge simultaneously while minimizing energy loss. Additionally, fast-charging technology is incorporated to prevent battery degradation and thermal stress, ultimately extending battery life and lowering maintenance costs.

Another vital component of this project is the integration of IoT-enabled monitoring systems, which track battery performance, charge cycles, and energy consumption in real time. These smart monitoring systems facilitate predictive maintenance, ensuring that batteries are serviced or replaced proactively to prevent operational failures. By deploying off-grid, solar-powered battery swapping stations, this model significantly enhances EV charging accessibility in remote and underserved regions, making clean transportation more feasible even in areas with limited electrical infrastructure.

To improve affordability and encourage EV adoption, the system follows a Battery-as-a-Service (BaaS) model, where users pay for battery usage rather than purchasing the battery outright. This reduces the initial cost of EV ownership while ensuring that drivers always have access to well-maintained, high-performance batteries.

By merging solar energy with battery swapping technology, this project presents a transformative approach to overcoming key EV adoption challenges. With optimized solar energy utilization, reduced charging downtime, extended battery lifespan, and improved accessibility—especially in rural and off-grid areas—this next-generation SP-BSS model has the potential to revolutionize the EV ecosystem. This innovation paves the way for a more sustainable, efficient, and environmentally

friendly transportation future.

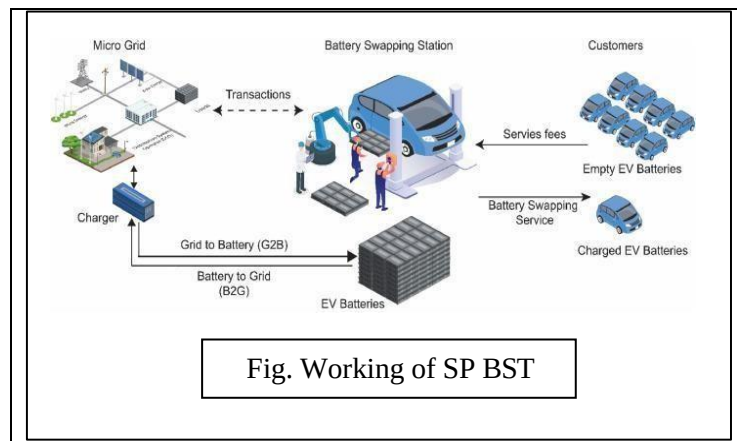
Design & Working Mechanism

Battery swapping stations enable EV users to exchange a depleted battery for a fully charged one in a matter of minutes. This process can be carried out manually or through automated systems, making it a significantly faster alternative to conventional charging. A standard battery swapping station consists of the following key components:

1. **Battery Storage System** – A secure unit that houses pre-charged batteries, ready for immediate swapping.
2. **Battery Management System (BMS)** – A monitoring system that tracks battery health,

performance, and charge cycles to ensure safety and efficiency.

3. **Swapping Mechanism** – Can be manual or robotic, depending on the station's level of automation, facilitating a seamless exchange process.
4. **Solar Energy Integration** – Uses photovoltaic panels to harness renewable energy for charging batteries, reducing dependence on conventional electricity grids.
5. **Grid Connectivity** – Incorporates smart grid technology to maintain energy stability and ensure a consistent power supply.



By combining these components, battery swapping stations provide a fast, efficient, and environmentally sustainable solution for EV charging, making electric mobility more convenient and widely accessible.

Integrating solar energy into battery swapping stations:

Utilizing solar power to energize battery swapping stations increases sustainability and greatly increases energy efficiency. Such stations are based on some important components that interact to facilitate seamless operations:

1. Photovoltaic (PV) Panels – Convert sunlight into direct current (DC) electricity.
2. Charge Controllers – Manage voltage levels in order to avoid overcharging and guard battery Health.
3. Energy Storage System – Holds excess solar power, which enables continuous operation during the absence of sunlight.
4. Power Conversion Units – Transfer DC power to alternating current (AC) in order to be compatible with station infrastructures and grid connections.
5. Load Balancing System – Distributes energy between the station, batteries, and the grid in the most optimal way to ensure efficiency and

stability.

Through the integration of these elements, solar-powered battery swap stations offer a secure, affordable, and environmentally friendly alternative for EV charging, decreasing reliance on renewable sources of energy.

Types of Battery Swapping Stations:

Battery swapping stations are categorized based on their level of automation and energy sources:

1. Manual Battery Swapping Stations – Require human intervention to replace depleted batteries.
2. Automated Battery Swapping Stations – Use robotic systems to perform battery swaps quickly and efficiently.
3. Solar-Powered Battery Swapping Stations – Operate primarily on solar energy, minimizing reliance on traditional power grids.
4. Hybrid Battery Swapping Stations – Combine solar energy with grid power for enhanced reliability and efficiency.

Key Technical Factors for Solar-Powered Battery Swapping Stations

The effectiveness of a solar-powered battery swapping station depends on several critical technical aspects:

1. Energy Management System (EMS) – Uses AI-driven algorithms to optimize solar power

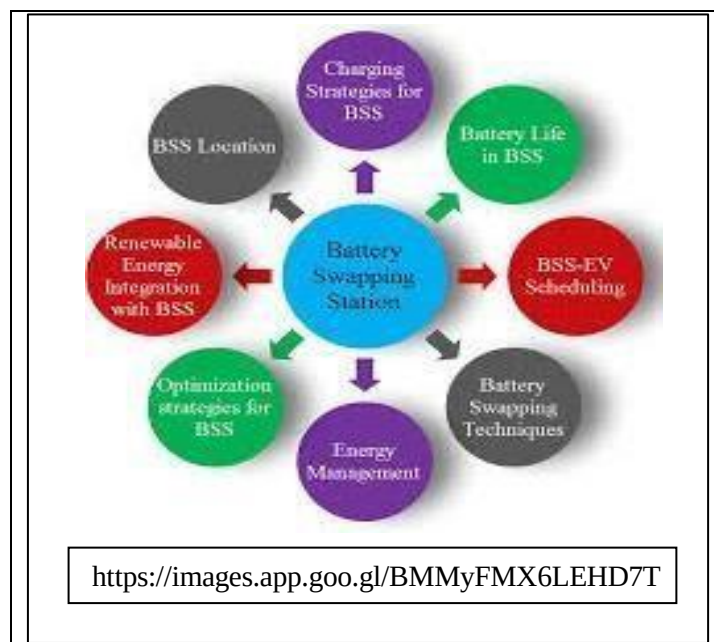
usage, manage energy consumption, and balance the load between storage and active charging.

2. **Battery Compatibility and Standardization** – Ensures that swapping stations support standardized battery packs across various EV models, incorporating secure locking mechanisms for safety and ease of use.
3. **Smart Grid Integration** – Enables two-way energy exchange with the grid, optimizing power usage during peak solar production and allowing stations to sell surplus energy back to the grid.
4. **Cooling and Thermal Management** – Incorporates advanced cooling systems, such as

liquid cooling and phase-change materials, to prevent overheating, improve performance, and extend battery lifespan in extreme temperatures.

5. **Safety and Cybersecurity** – Utilizes IoT-based monitoring for real-time diagnostics, along with encryption authentication protocols to safeguard against cyber threats. Emergency protocols are in place to address potential risks like short circuits or thermal runaway.

By integrating these technical advancements, solar-powered battery swapping stations can operate efficiently, safely, and sustainably, making EV adoption more practical and accessible.



Working Mechanism of Solar-Powered Battery Swapping Stations:

1. **Solar Energy Generation & Storage** – High-efficiency solar panels on the station harness sunlight and convert it to electricity. The DC power generated is routed to a solar charge controller, which controls voltage and avoids overcharging. The electricity is stored in a battery energy storage system (BESS) or utilized directly to charge EV batteries. Excess energy can be stored for future use or fed into the grid.
2. **User Authentication & Vehicle Identification** – Upon the arrival of an EV owner at the station, they log into the system using an RFID card, QR code scanner, or a mobile app through Bluetooth or the Internet. The system identifies the vehicle type, battery model, and charge level.
3. **Robotized Battery Swapping Procedure** – A

robot arm or conveyor system removes the drained battery from the EV and sends it to a charging unit. A charged battery is pulled from the storage chamber and put into the vehicle. The totally automated procedure is completed in 2 to 5 minutes.

4. **Swapped-Out Battery Charging** – The pulled-out battery is loaded into a charging rack, where a solar-powered fast-charger starts to recharge it. Adaptive charging algorithms regulate voltage and current according to battery health, minimizing wear and prolonging life.
5. **Smart Energy Management & IoT Monitoring** – The system monitors battery charge cycles, energy usage, and station efficiency constantly. IoT sensors monitor real-time battery condition, temperature, and charge level. A cloud-based platform provides predictive maintenance notifications to maintain battery reliability and safety.

Mrs. Lengare Saraswati Sanjaym Mrs. Mhamane Vedanti Rahu, Mr. Khandare Swaraj Narayan, Mr. Bagal Saurabh Sunil

6. **Payment & Completion** – The users are billed on either a per-swap pricing model or a subscription-based Battery-as-a-Service (BaaS) plan. Once payment is successfully made, they are confirmed through the mobile app or on-screen display, and the EV is ready to continue

Challenges:

One of the most significant challenges in adopting solar-powered battery swapping technology is the absence of battery standardization. Currently, EV makers engineer batteries of different sizes, capacities, and attachment mechanisms, and it would be challenging to come up with a universal swapping system. Without a standard solution, swapping stations would have to support several battery types, adding cost and logistics complexity.

Yet another significant challenge is the infrastructure to support battery swapping. Creating an infrastructure of high-tech, completely automated stations takes huge investments in robotics, warehousing, and solar power solutions. In heavily populated urban pockets, land availability for these stations is a problem, whereas in rural areas, infrastructure development treads slowly as it is often hampered by lack of resources and limited connectivity to the grid.

Regulations and policy structures also play a significant part in the mass rollout of battery swapping technology. Governments still favor traditional EV charging options over the swapping mode, which leaves the absence of distinct policies and economic incentives.

Battery ownership, tax policies, and safety requirements are some of the issues to be resolved to improve the mass adoption.

Future Prospects:

In spite of such issues, further technological advancements on the battery side are likely to make battery-swapping more efficient. Solid-state batteries, in particular, provide increased energy density, quicker charge times, and better safety than existing batteries. They could prove to be the key to the feasibility of swapping batteries for electric vehicle owners.

Ultra-fast charging technology innovations will further minimize downtime needed for swapping-out battery recharge. Smart energy management systems combined with renewable energy storage solutions will improve the swapping station's efficiency as a whole, providing an even smoother and more sustainable function.

Moreover, AI-powered predictive maintenance and IoT-powered monitoring systems will maximize battery efficiency, reducing the cost of operations and increasing battery life. In the longer run, nations that heavily invest in solar power and battery storage technologies will open the door to cleaner, more sustainable transportation networks. With

travel with a fully charged battery.

This advanced solar-powered battery swapping technology presents a game-changing solution for the EV ecosystem, ensuring that electric mobility becomes more efficient, cost-effective, and environmentally sustainable.

Ongoing innovation and policy support from the government, solar-powered battery swapping can be a mainstream option for EVs—moving away from fossil fuels while enhancing the reliability and availability of clean energy mobility.

Conclusion:

Solar-powered battery swapping technology represents a groundbreaking advancement in the electric vehicle (EV) industry, offering a practical solution to persistent challenges such as long charging durations, dependence on traditional power grids, and concerns over range limitations. By integrating renewable energy with automated battery exchange systems, this approach provides a faster, more efficient, and sustainable alternative to conventional EV charging methods. The findings of this study underscore the critical role of solar energy storage, intelligent battery management, and IoT-enabled monitoring in optimizing energy distribution and enhancing operational reliability.

The impact on the EV industry is profound. By reducing reliance on fossil-fuel-powered grids, solar-driven battery swapping contributes significantly to lowering carbon emissions and promoting a cleaner, greener transportation ecosystem. The ability to replace a depleted battery within minutes drastically improves convenience for EV users, particularly benefiting commercial fleets and high-mileage drivers who require minimal downtime. Furthermore, the modular and scalable nature of this technology allows for its implementation in both dense urban centres and remote off-grid locations, broadening the accessibility of sustainable mobility solutions.

However, widespread adoption faces several hurdles, including the need for standardized battery designs, substantial infrastructure investments, and well-defined regulatory policies. Addressing these issues will be key to ensuring seamless interoperability and cost-effective deployment. The future of battery swapping looks promising, with advancements in solid-state battery technology expected to improve energy density, safety, and charging efficiency. Additionally, ultra-fast charging solutions, AI-driven predictive maintenance, and smart energy management systems will further optimize performance and economic viability.

To fully harness the potential of solar-powered battery swapping, further research should focus on extending battery lifespan, establishing universal swapping protocols, and enhancing

integration with next-generation renewable energy storage solutions. With continuous technological progress, strong policy backing, and strategic investments, this innovation could redefine the EV landscape—ushering in a cleaner, more efficient, and more accessible future for sustainable transportation.

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