B. V. RAJU INSTITUTE OF TECHNOLOGY

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Vishnupur, Narsapur, Medak (Dt.), Telangana 502313

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

Seminar on

Integration of Hybrid Energy Storage Systems in AC/DC Microgrids

Presented by

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For the academic year 2024-25

Under the Guidance of

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CERTIFICATE

This is to certify that the Seminar report titled **"Integration of Hybrid Energy Storage Systems in AC/DC Microgrids"** is the bonafied work carried out by **A PAVAN RAJ 22215A0208** of B. Tech in partial fulfillment of the requirements for the award of Bachelor of Technology (B. Tech) in Electrical & Electronics Engineering (EEE) by JNTU Hyderabad during the academic year 2024 – 2025.

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A PAVAN RAJ - 22215A0208

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ABSTRACT

The limited supply of fossil fuels and increasing energy use around the world create serious energy problems. To solve these problems, the electric power system is turning to renewable energy sources for cleaner energy. However, using renewable energy can be unpredictable because of changing weather conditions. To handle these challenges, storage devices are used along with renewable energy sources. Combining different types of storage devices creates a hybrid energy storage system (HESS), which helps solve issues in small power grids. Proper control and management of power in these grids are essential for keeping the power system strong and reliable. This paper looks at various ways to connect and use HESS, exploring different interconnection topologies and their benefits. It also reviews how to manage and control these storage devices to avoid early wear and tear and make the best use of them, considering both technical and economic aspects. The integration of HESS into microgrids is analysed to ensure optimal performance and efficiency. This article offers a guide for designing and implementing a hybrid AC/DC microgrid, highlighting the importance of coordinated control strategies and advancements in energy storage technologies

CHAPTER-1

INTRODUCTION

The world is facing serious energy challenges due to the decreasing availability of fossil fuels and the growing need to reduce pollution. Renewable energy sources (RES), like solar power, wind energy, and hydropower, are becoming popular because they are clean and sustainable. These energy sources help reduce greenhouse gas emissions, but their performance depends heavily on the weather, making energy production inconsistent. This creates difficulties in ensuring a steady and reliable power supply. To address these issues, microgrids have been developed. A microgrid is a small, local power system that connects renewable energy sources, energy storage devices, and electricity users within a specific area. It can operate independently (islanded mode) or alongside the main power grid (grid-connected mode). Microgrids are ideal for making the most of renewable energy while maintaining stable and reliable electricity supply.

A key part of microgrids is the Hybrid Energy Storage System (HESS), which combines different types of energy storage devices. For example, batteries, which store large amounts of energy, can be paired with supercapacitors, which respond quickly to sudden energy demands. Together, they ensure that the system can handle both normal energy use and unexpected changes. This combination helps improve reliability, reduce power fluctuations, and protect storage devices from wear and tear. Managing power in microgrids is very important for their stability and efficiency. Power management ensures the proper flow of electricity between renewable sources, storage devices, and users. Traditional methods, such as droop control or filters, are simple to use but may not handle complex situations well. Advanced methods, like fuzzy logic and model predictive control, use intelligent algorithms to deal with unpredictable changes in renewable energy supply. This review focuses on how microgrids manage power, particularly in hybrid systems that mix renewable energy with HESS. It explains how different storage devices can be connected, the benefits and challenges of each approach, and how modern control techniques are improving microgrid performance. By using these technologies, microgrids can provide clean, reliable, and efficient energy, helping reduce dependence on fossil fuels while meeting growing energy demands.

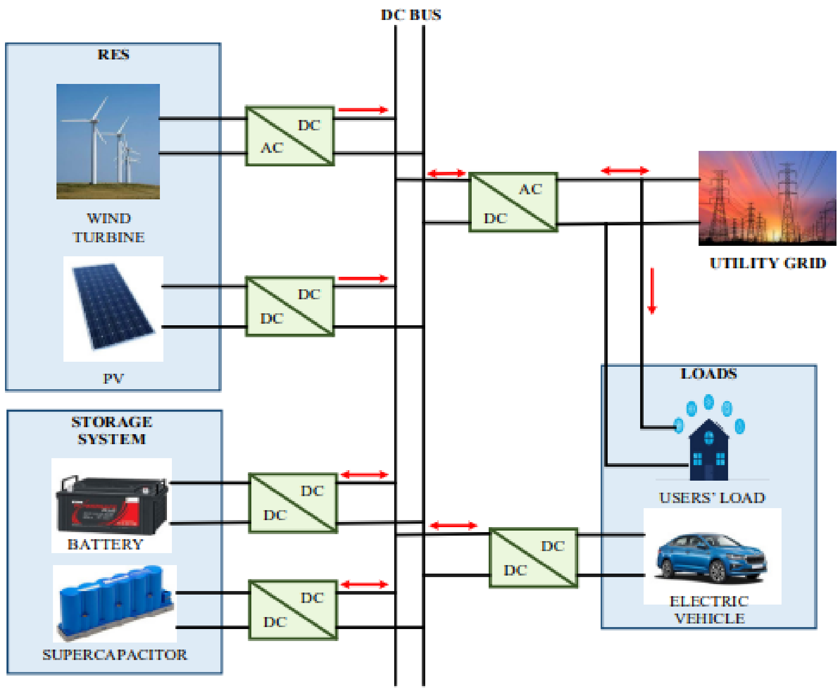

Figure 1. Outline of a microgrid.

This diagram shows a hybrid AC/DC microgrid system where renewable energy sources like wind turbines and solar panels generate electricity. Wind turbines produce AC power, which is converted to DC, while solar panels generate DC power directly. A central DC bus connects everything, including energy storage systems like batteries (for long-term energy) and supercapacitors (for quick energy bursts), ensuring smooth power flow. The system supplies energy to household appliances and electric vehicles while also connecting to the utility grid to exchange power when needed. Converters manage the flow of energy between the AC and DC systems, making the microgrid efficient and reliable.

HESS TECHNOLOGY :-

A Hybrid Energy Storage System (HESS) combines two different types of energy storage devices, typically batteries and supercapacitors, to leverage their strengths and compensate for their individual weaknesses. Batteries have high energy density, meaning they can store and supply energy steadily over a long period, making them ideal for meeting regular energy demands. However, batteries can wear out quickly if subjected to sudden or frequent power fluctuations. On the other hand, supercapacitors have high power density, enabling them to respond quickly to sudden changes in power demand due to their fast charging and discharging capabilities. By combining these two devices, HESS ensures a steady energy supply from the battery while the supercapacitor manages short-term power surges, protecting the battery and extending its lifespan. This hybrid system is especially useful in microgrids that integrate renewable energy sources like solar and wind, as it improves power stability, ensures consistent voltage, enhances power quality, and maintains frequency stability, all while supporting both steady and transient power demands.

Storage Device	Efficiency (%)	Power Density (W/L)	Energy Density (Wh/L)	Life Span (Year)	Response Time	Cost
Flywheel	80–85	1000–2000	20–80	15–20	ms–s	High
Supercapacitor	65–98	500–5000	2.5–15	10–20	8 ms	Medium
Lead-Acid Battery	70–90	10–400	50–80	5–16	s	Low
Li-Ion Battery	78–99	500–2000	200–480	5–16	20 ms–s	Low
Superconducting Magnetic Energy Storage (SMES)	80–85	1000–4000	0.5–15	5–15	<100 ms	High
Fuel cell/Hydrogen Storage	20–50	0.2–20	750 (at 250 bar pressure)	5–20	<1 s	High

Table 1. Characteristics of Different Storage Devices

HESS Interconnection Topologies:-

The performance and efficiency of a Hybrid Energy Storage System (HESS) largely depend on how its components are interconnected, known as the interconnection topology. HESS can be connected directly to a DC or AC bus or through power converters. Most storage devices supply DC voltage, making DC bus coupling simpler, more efficient, and cost-effective compared to AC bus coupling, which often requires additional conversion. The connection topology also determines factors like efficiency, lifespan, charging/discharging characteristics, and system flexibility. Based on the use of power converters, HESS connections are classified into three types: passive, semi-active, and active topologies. Passive topology involves direct connections without converters, offering simplicity and low cost. Semi-active topology uses a converter for either the battery or supercapacitor, allowing moderate control and flexibility. Active topology employs converters for both devices, providing high control and dynamic performance but increasing complexity and cost. The choice of topology depends on the system's requirements and power management strategy.

Topology	Flexibility	Fluctuation in DC Bus Voltage	Space Requirement	Complexity in Control Scheme	Cost	Applications
Passive [32,33]	Much less	Yes	Less	Low	Less	In small capacity systems where cost is the main determining factor.
Semi-active [34]	Medium	Moderate	Medium	Medium	Moderate	Extension of battery life is compromised with slight increase in cost.
Active [30,35]	High	No	High	High	High	In a large capacity system for better transient response.

Table 2. Comparison of Different HESS Interconnection Topologies.

Passive Connection:-

A passive connection is the simplest and cheapest way to connect a Hybrid Energy Storage System (HESS) to a microgrid. In this setup, the battery and supercapacitor are directly connected to the DC bus without using any power converters. This makes the design straightforward and cost-effective. The battery provides steady energy for long-term needs, while the supercapacitor, with its fast response, handles sudden changes in power demand. However, this type of connection has some big challenges. The voltage of the HESS must exactly match the DC bus and the connected load, which is hard to achieve without power converters. Also, the power shared between the battery and supercapacitor depends only on their natural properties (internal impedance), so there’s no way to control or adjust it. This limits flexibility and makes it difficult to fully use the storage system. Another issue is maintaining balance in the system. The battery reacts slowly to changes, while the supercapacitor reacts quickly. This difference makes it hard to manage the state of charge (SOC) of the devices and keep the DC bus voltage stable. Additionally, since the HESS is directly connected, any fault in the system can spread easily, increasing the risk of failures. Because of these problems, passive connections are rarely used in microgrids, where reliability and control are very important.

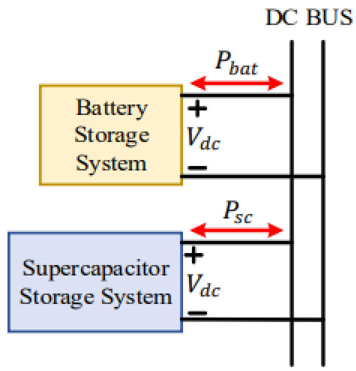

Figure 2. Passive connection of HESS

Semi Active Connection:-

A semi-active connection is an improved version of the passive connection. In this setup, one energy storage device (ESS) is connected directly to the DC bus, while the other is connected through a bidirectional DC/DC converter. This design provides better control and flexibility compared to a passive connection. For example, in a battery semi-active topology, the battery is connected to the DC bus through a converter, while the supercapacitor is connected directly to the bus. The converter allows the battery's charging and discharging to be controlled more effectively, even during sudden changes in power demand. Additionally, the battery's terminal voltage doesn't need to match the DC bus voltage, which simplifies its operation. However, since the supercapacitor is directly connected, its terminal voltage is not controlled. This can cause fluctuations in the DC bus voltage, leading to instability and poor power quality. To stabilize the system, a very large supercapacitor would be needed, which can be expensive and impractical. While semi-active connections offer more control than passive ones, they still have limitations in maintaining stable voltage and cost efficiency.

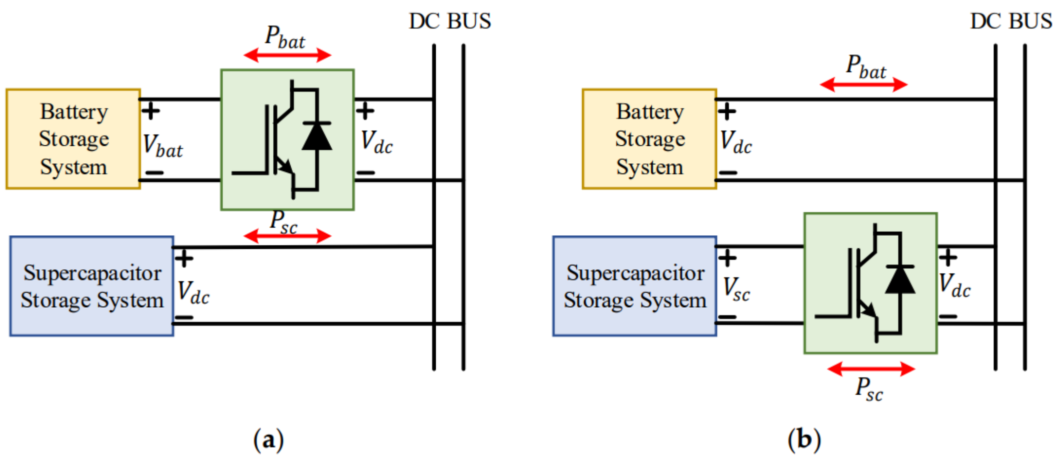

Figure 3. (a) Battery semi-active topology, (b) SC semi-active topology

In a supercapacitor semi-active topology, the battery is directly connected to the DC bus, while the supercapacitor (SC) is linked through a DC/DC converter. This allows the SC to work efficiently over a wider voltage range and handle sudden power demands. However, the battery may face stress during system faults, reducing its lifespan. Additionally, if the SC is directly connected, it can cause voltage fluctuations, and if connected through a converter, the design must handle power surges, increasing complexity. These challenges make this setup less common in microgrid applications.

Active Connection:-

An active connection topology connects both the battery and the supercapacitor (SC) to the DC bus through separate DC/DC bidirectional converters. This design offers the highest flexibility and control, enhancing the system's performance, efficiency, and lifespan. In the cascaded active connection, the battery and SC are isolated from the DC bus by two converters connected in series. The converter linked to the battery is current-controlled, protecting the battery from rapid charging and discharging caused by sudden fluctuations in renewable energy sources (RES) or load demands. Meanwhile, the converter connected to the SC is voltage-controlled, helping stabilize the DC bus voltage by managing high-frequency power components. Despite these advantages, the cascaded configuration has limitations. Both converters must be rated for the total power capacity of the system, which increases power losses and reduces efficiency. Additionally, this setup can lead to significant voltage variations when operating across a wide voltage range, making it less commonly adopted in practice.

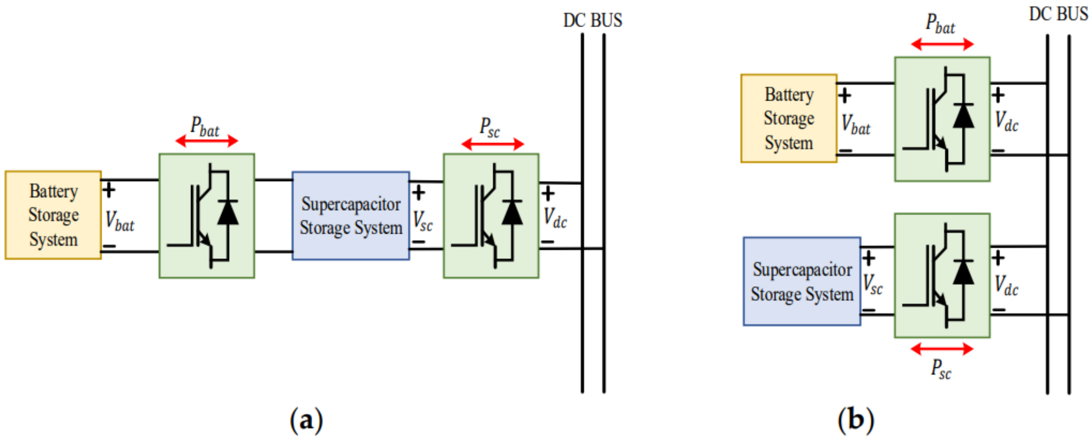

Figure 4. (a) Cascaded active topology, (b) Parallel active topology

A parallel active connection is a type of connection where both the battery and supercapacitor (SC) are connected to the DC bus through their own separate DC/DC converters. This type of connection is the most commonly used in microgrid applications because it combines the advantages of both the battery and the SC effectively. In this setup, the battery handles the average power needs because of its high energy density, which allows it to supply power over long periods. On the other hand, the supercapacitor (SC) handles short-term, high-frequency power demands due to its high power density. These two storage devices complement each other, and their combined use allows for the optimal operation of the Hybrid Energy Storage System (HESS). The parallel active connection has several benefits. First, it improves system flexibility because the battery and SC can be controlled separately. Second, it allows for different types of control strategies to be implemented, whether centralized or decentralized. Third, the battery and SC terminal voltages are independent of the DC bus voltage, which adds to their versatility and makes the system more efficient.

Overall, the parallel active connection is a preferred choice because it offers better control, flexibility, and improved performance, making it highly suitable for microgrid applications.

CHAPTER-2

LITERATURE REVIEW

S No	Title	Author	Journal/Conference	Year	Observation
1	Power Management Strategies in a Hybrid Energy Storage System Integrated AC/DC Microgrid: A Review	A. Bharatee, P. K. Ray, B. Subudhi, A. Ghosh	Energies	2022	Reviews strategies for power management in hybrid systems, emphasizing reliability and optimal performance
2	Dynamic Energy Management Scheme for Hybrid Energy Storage Systems	Punna, S., Manthati, U. B.	SN Applied Sciences	2022	Focuses on energy management for a hybrid storage system to extend lifespan and improve efficiency
3	Intelligent Energy Management for HESS Using Optimization	A. Gupta, B. Singh	Energies	2021	Uses particle swarm optimization for efficient power allocation between storage units
4	Hybrid AC/DC Microgrid Power Sharing Techniques	M. Ramesh, L. Srinivasan	IEEE Transactions on Industrial Electronics	2018	Investigates hybrid grid power-sharing strategies to optimize load distribution
5	Control of Hybrid Energy Storage System in DC Microgrid for Power Quality Improvement	S. Li, Y. Zhang	IEEE Transactions on Power Electronics	2020	Explores HESS control mechanisms in DC microgrids

6	Optimized Energy Management for Hybrid Energy Storage Systems in Renewable-Powered Microgrids	R. Singh, M. Kumar	Journal of Clean Energy Technologies	2021	Proposes optimization algorithms for energy management in hybrid energy storage systems
7	Sliding Mode Control of HESS in Microgrids	P. Manthati, S. Kumar	International Journal of Control	2019	Analyzes sliding mode control to improve robustness and transient performance in HESS
8	Model Predictive Control for HESS in Microgrids	K. Tan, X. Liu	Renewable Energy	2021	Demonstrates model predictive control for balancing battery and supercapacitor usage
9	Comparative Analysis of Storage Technologies in Hybrid Microgrids	A. Nandi, S. Bose	Applied Energy	2020	Compares different storage systems in hybrid microgrids, highlighting battery and supercapacitor hybridization
10	Supercapacitor and Battery Hybrid Systems for Microgrids	H. Kim, Y. Lee	Energy Reports	2021	Analyzes supercapacitor-battery hybrid systems for load balancing in microgrids

CHAPTER-3

OBJECTIVES

- **Efficient Energy Utilization**
  Hybrid Energy Storage Systems (HESS) use different types of energy storage, like batteries and supercapacitors, to get the best out of both. Batteries can store energy for a long time, while supercapacitors can quickly release energy when needed. By combining these, the system becomes more efficient and lasts longer, as each type is used for what it does best.
- **Improved Grid Stability**
  Renewable energy sources like solar and wind don't produce energy at a constant rate. This can make the grid unstable. HESS helps balance these energy fluctuations by storing energy when there's extra and supplying it when there's less. This keeps the grid stable and ensures there's always enough energy to meet demand.
- **Cost Optimization**
  Running an energy storage system can be expensive, especially if one type of storage is overused. HESS helps reduce costs by using each storage type efficiently. For example, supercapacitors handle quick bursts of energy, which reduces the strain on batteries. This lowers maintenance and replacement costs, saving money over time.
- **Increased Reliability**
  By combining fast-reacting supercapacitors with batteries that store more energy, HESS ensures a steady and reliable energy supply. Even if there's a sudden change in energy demand, the system can quickly respond and provide the required energy without interruptions.
- **Enhanced Integration with Renewable Energy**
  Renewable energy sources like solar and wind can be unpredictable. HESS makes it easier to use these sources by storing energy when it's available and supplying it when needed. This helps ensure a smooth and continuous energy flow, making renewable energy more practical for use in grids.

CHAPTER-4

RESULTS AND ANALYSIS

Parameter	Core Findings
System Stability	HESS improves microgrid stability by managing fluctuations in renewable energy sources (solar, wind) and changes in demand.
Quick Response to Sudden Demand	Supercapacitors respond very quickly to sudden changes in energy needs, reducing the load on batteries.
Better Power Quality .	Combining batteries and supercapacitors smooths energy supply and demand mismatches, ensuring fewer interruptions
Different Connection Options	Three types of HESS connections were analyzed: Passive, Semi-active, and Active. Active connections perform the best but are more expensive.
Extended Life for Batteries and Supercapacitors	Supercapacitors handle short power surges, reducing stress on batteries and extending their life span.
Reduced Costs	Optimized use of HESS lowers operational costs by improving efficiency and minimizing wear and tear on components.
Better Use of Renewable Energy .	HESS stores excess renewable energy when supply is high and supplies it during shortages, ensuring consistent energy availability

Table 3: Key Results of HESS Integration into Microgrid Systems

The integration of Hybrid Energy Storage Systems (HESS) with renewable energy sources in microgrids improves system stability and reliability by addressing the unpredictable nature of renewable energy. HESS combines batteries and supercapacitors to balance steady and quick energy demands—batteries supply consistent long-term power, while supercapacitors respond quickly to sudden changes in demand. This combination enhances power quality by reducing supply fluctuations and supporting grid stability. Different connection types, like passive, semi-active, and active interconnections, affect system performance, with active connections providing better control and efficiency despite being more complex. Additionally, supercapacitors help manage sudden power demands, preventing overuse of batteries and extending their lifespan. Overall, HESS improves system response, provides backup during power fluctuations, and ensures reliable performance while managing the life span of storage components effectively.

CHAPTER-5

CONCLUSIONS

Hybrid Energy Storage Systems (HESS) are very important for making microgrid systems more stable and reliable. They solve problems like irregular power supply and changing energy needs by combining the strengths of two types of storage: batteries and supercapacitors. Batteries provide long-lasting, steady energy, while supercapacitors react very quickly to sudden changes in energy demand. Together, they ensure a reliable and smooth power supply.

HESS also makes it easier to use renewable energy like solar and wind. Renewable energy can be inconsistent, but HESS stores extra energy during times of high production and supplies it when there isn't enough, ensuring that the power supply stays steady and reliable.

The way HESS is connected to the system affects how well it works. There are different connection options like active, semi-active, and passive types. Active connections perform the best because they respond quickly to changes and faults, but they are also more expensive. Choosing the right connection type can improve how the system works and responds to changes in energy demand.

HESS reduces the strain on batteries and supercapacitors by sharing the energy demand between them. This shared use leads to less wear and tear, allowing both types of storage to last longer and require less maintenance.

HESS is cost-effective because it optimizes how the two storage types work together, reducing costs by preventing overuse and extending their life spans. It also solves key problems like unstable voltage, renewable energy supply issues, and power quality problems

REFERENCES

[1] Bharatee, A., Ray, P.K., Subudhi, B., Ghosh, A. (2022). Power Management Strategies in a Hybrid Energy Storage System Integrated AC/DC Microgrid: A Review. Energies, 15(19), 7176

[2] Punna, S., & Manthati, U.B. (2022). Dynamic Energy Management Scheme for Hybrid Energy Storage Systems. SN Applied Sciences, 4(1).

[3] Li, S., & Zhang, Y. (2020). Control of Hybrid Energy Storage System in DC Microgrid for Power Quality Improvement. IEEE Transactions on Power Electronics, 35(8), 7822-7835.

[4] Gupta, A., & Singh, B. (2021). Intelligent Energy Management for HESS Using Optimization. Energies, 14(5), 1284.

[5] Ramesh, M., & Srinivasan, L. (2018). Hybrid AC/DC Microgrid Power Sharing Techniques. IEEE Transactions on Industrial Electronics, 65(6), 4781-4790.

[6] Singh, R., & Kumar, M. (2021). Optimized Energy Management for Hybrid Energy Storage Systems in Renewable-Powered Microgrids. Journal of Clean Energy Technologies, 9(3), 545-552.

[7] Manthati, P., & Kumar, S. (2019). Sliding Mode Control of HESS in Microgrids. International Journal of Control, 92(12), 2567-2578.

[8] Liu, M., & Lee, J. (2020). A Fuzzy Logic-Based Power Management for Hybrid Storage Systems. IEEE Access, 8, 22324-22335.

[9] Nandi, A., & Bose, S. (2020). Comparative Analysis of Storage Technologies in Hybrid Microgrids. Applied Energy, 275, 115424.

[10] Kim, H., & Lee, Y. (2021). Supercapacitor and Battery Hybrid Systems for Microgrids. Energy Reports, 7, 3156-3165.