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# INVESTIGATION OF AN EFFECTIVE BATTERY ENERGY STORAGE SYSTEM FOR THE INTEGRATION OF DISTRIBUTED RENEWABLE ENERGY SOURCES

**By**

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***Abstract***

*This study explores advancements in integrating Battery Energy Storage Systems (BESS) with Renewable Energy Sources (RES) to address challenges in power generation and distribution, driven by the need to reduce greenhouse gas emissions and diversify energy sources. Despite progress in renewable energy adoption, significant research gaps remain, particularly in determining suitable storage technologies for specific applications. The study assesses various BESS options, such as lithium-ion, sodium-sulfur, and nickel-based batteries, and identifies lithium-ion as the most efficient for large-scale RES integration. By focusing on modular, scalable BESS designs within supportive regulatory frameworks and enhanced monitoring systems, this paper provides valuable insights for improving grid resilience, stability, and flexibility, supporting the broader adoption of distributed renewable energy sources.*

***Keyword**: Battery energy storage systems, Renewable energy sources, distribution networks, power generation and distribution.*

## 1.0 Introduction

The growing integration of renewable energy sources (RES) into the power grid poses substantial challenges for sustaining grid stability, owing to the intermittent and variable characteristics of these energy sources. Battery Energy Storage Systems (BESS) have become essential for addressing these difficulties by delivering grid services, including frequency regulation, load balancing, and energy arbitrage [1]. As energy systems evolve globally, driven by technological advancements, decarbonization efforts, and the rise of renewable resources, the reliance on fossil fuels is diminishing due to their scarcity and high greenhouse gas emissions. This shift has propelled the transition towards low-carbon energy sources like solar and wind power, with energy storage systems (ESS) playing a crucial role in managing surplus renewable energy generated. This study focuses on battery energy storage systems (BESS), particularly their integration with distributed renewable energy sources to stabilize and support power grids. BESS stands out for its rapid response, adaptability, and environmental benefits, positioning it as a vital solution for enhancing grid flexibility, reliability, and sustainability in the face of climate change and energy shortages [2].

The integration of renewable energy sources (RES) and battery energy storage systems (BESS) in power systems has gained significant attention as the demand for sustainable energy rises and efforts to reduce greenhouse gas emissions intensify. Renewable energy sources, including solar, wind, hydropower, and biomass, offer considerable environmental benefits. However, their intermittent nature creates challenges for power grid stability and complicates the balance of supply and demand [3]. Solar and wind energy, for instance, are dependent on weather conditions and time of day, making them non-dispatchable and unsuitable for meeting demand consistently without effective storage solutions. Hydropower, while reliable and highly efficient, is limited by geographical constraints, thus restricting its scalability and implementation in diverse locations [4].

Biomass energy, on the other hand, is dispatchable, meaning it can be controlled and used on demand. This unique characteristic makes biomass a valuable addition to the renewable energy mix as it can provide electricity during periods of high demand and compensate for the variability of other RES. In corporate institution such as universities and research institutions hospitals and many more, RES integration is crucial to achieving a more flexible and reliable power system that minimizes environmental impacts. Despite the advantages, managing these resources in a distributed generation environment requires a robust and adaptable energy storage solution [5].

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Battery energy storage systems (BESS) emerge as a promising solution to address these challenges, offering a flexible, efficient, and cost-effective approach to integrating distributed RES into power grids [6]. BESS technology allows for the storage of excess power generated during peak renewable energy production and dispatches it as needed to stabilize fluctuations in supply and demand. This capability is essential for maintaining a steady power supply at a corporate institution, where renewable resources are abundant but variable [7];[8].

BESS technology also provides benefits in terms of scalability and rapid response to changes in energy demand, making it a vital component in enhancing power system stability, efficiency, and resilience [9]. The integration of BESS with RES not only aligns with environmental sustainability goals but also serves as a model for deploying energy storage technologies in similar distributed renewable systems. This review highlights the potential of BESS to transform grid dynamics by improving the reliability and effectiveness of RES integration, while also examining classifications, device comparisons, and system requirements essential to optimal performance [10].

## 2.0 Materials and Methods

This study employs battery modeling to analyze the behavior and performance of electrochemical energy storage systems, focusing on critical parameters that influence battery efficiency, thermal stability, and energy retention. The model incorporates key variables such as open circuit voltage (Voc), internal capacitor voltage (Vp), and terminal voltage (Vb). The battery's charging, discharging, and internal resistances are represented by Rc, Rd, and Rb, respectively, while the polarization capacitance is denoted as C. The current (Ib) is considered positive during discharge and negative during charging. To model the discharging process, loop equations governing the circuit are established, with a similar approach applied during charging. This modeling framework provides a detailed understanding of the battery's operational dynamics under varying conditions, enabling a comprehensive assessment of its performance the loop equations on the circuit model are represented by equation;

$$\dot{V} = \frac{1}{C}\left((V_{oc} - V_p)/R_d - I_b\right)$$
$$V_b = V_p - I_b R_b \tag{1}$$

This model is found by defining the state variables.

$$x_1 = V_p; x_2 = \frac{1}{R_d C}; x_3 = \frac{V_{oc}}{R_d C}; x_4 = \frac{1}{C}; x_5 = R_b \tag{2}$$

so that the nonlinear time-varying state space model is then;

$$\dot{x}_1 = -x_1 x_2 + x_3 - I_b(t) x_4$$
$$\dot{x}_2 = 0$$
$$\dot{x}_3 = 0$$
$$\dot{x}_4 = 0$$
$$\dot{x}_5 = 0$$
$$V_b = x_1 - I_b(t) x_5 \tag{3}$$

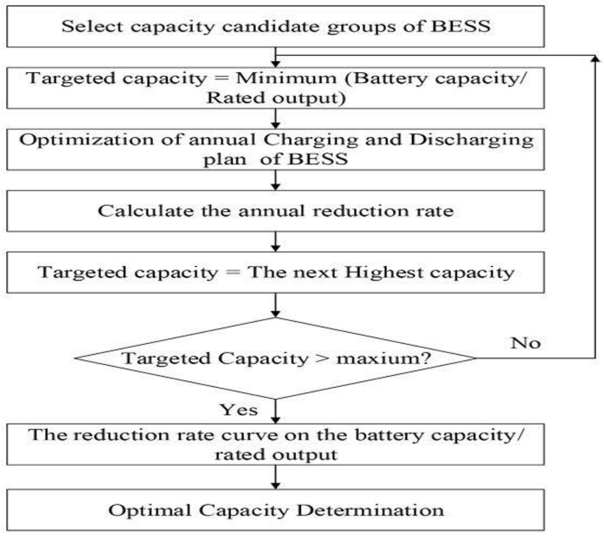


Figure 1. Optimal approach to ascertain BESS capability

The estimation of battery lifespan is articulated as follows:

$$L_{BESS} = \frac{T}{\sum_{i=1}^{M} \frac{N_i}{CF_i}} \tag{4}$$

where T represents the simulation duration in years, Ni denotes each DoD, and CFi indicates the number of cycles to failure at the corresponding DoD.

The optimization of both battery capacity and battery lifespan is crucial, since it directly impacts the operational costs of the entire BES system.

## 3.0 Results and Discussion

### 3.1 Results Obtained from Identification of Battery Storage and Application

The different energy storage systems considered for this study are Displayed in Table 1. Every technology possesses inherent restrictions or drawbacks that render it practicable or inexpensive for only a restricted array of applications.

**Table 1. Application of various electrochemical storage**

| S/No | Battery Storage | Application |
|---|---|---|
| 1 | Lithium - Ion Batteries | Portable devices such as mobile phones and laptops. Thermometers, remote automobile locks, laser pointers, MP3 devices, |

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| | | |
|---|---|---|
| | | auditory aids |
| 2 | Lead – Acid Batteries | Emergency lighting<br>Electric motors<br>Diesel-electric submarines |
| 3 | Flow Batteries | UPS<br>Can be utilized in conjunction with solar and wind energy for load balancing<br>EV |
| 4 | Sodium-Sulphur Batteries | Load balancing<br>Secondary UPS<br>EV |
| 5 | Solid-state Batteries | EV<br>Consumer Electronics |
| 6 | Super-capacitors | EV |

It can be observed from Table 1 that Lithium-Ion batteries are mostly used for everyday gadgets like mobile phones, remote car locks, hearing aids, thermometers, and MP3 players.

### 3.2 Results Obtained from the Evaluation of Battery Energy Storage Systems

Each storage type possesses distinct features, including capacity, energy, power output, charging and discharging rates, efficiency, life cycle, and cost, which must be considered for potential applications. For the evaluation of battery energy storage systems, factors like life cycle, efficiency, specific energy, and energy density are presented in Table 2. Table 2 provides a comparative overview of various battery energy storage systems, evaluating their life cycle, efficiency, power and energy density, advantages, limits, and applications.

**Table *2*. Evaluation of battery energy storage systems**

| Battery Storage | Life Cycle at 80% DOD | Efficiency (%) | Specific energy (Wh/L) | Energy density (W/L) |
|---|---|---|---|---|
| Lithium-Ion | 5000 – 7000 | < 90% | 200 – 500 | 250 – 693 |
| Lead – Acid | 200 – 1500 | 70% - 76% | 50 – 80 | 80 – 90 |
| Flow Batteries | 5000 – 14000 | 75% - 85% | 40 | - |
| Sodium-Sulphur | 2100 – 4500 | 85% - 90% | 150 – 300 | 10000 |
| Solid state | 5000 – 10000 | 90% - 95% | 250 – 500 | 300 – 500 |
| NiMH | 2000 | 60% - 92% | 60 – 120 | 140 – 300 |
| Super-capacitor | 10000> | 95% | 5 – 10 | 2.5 – 10 |

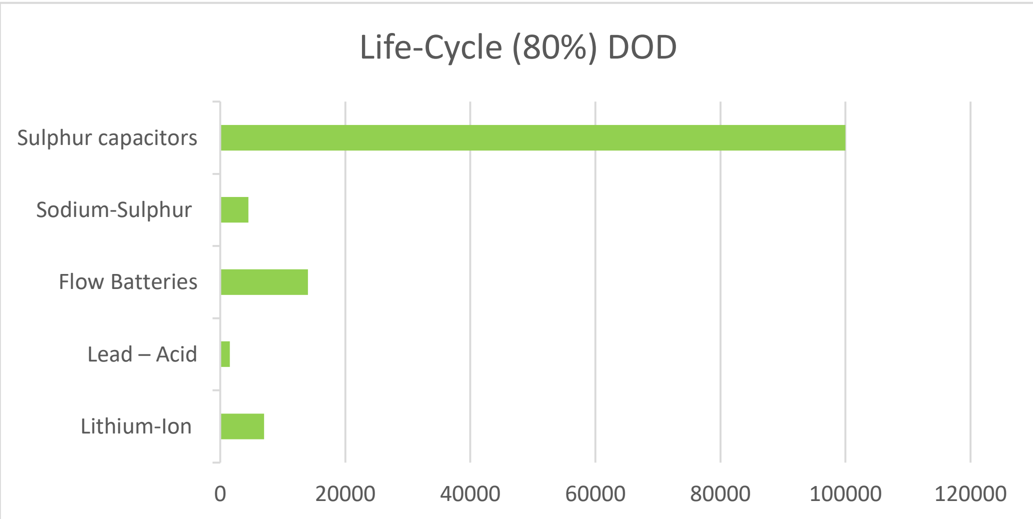


**Figure 2. Life-Cycle of each Battery**

Figure 2 shows that supercapacitor has the highest life cycle with an 80% depth of discharge (DOD) of 100000, 1500 for lead acid batteries, 7000 for lithium-ion batteries, 14000 for flow batteries, 4500 for sulfur batteries, and 2000 for Nickel-electrode (NiMH).

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The cycle efficiency of EES systems during one charge-discharge cycle is illustrated in Figure 3. The cycle efficiency is the ‘‘round-trip” efficiency defined as $g = \frac{E_{out}}{E_{in}}$ , with g, Eout, and Ein being the cycle efficiency, electricity input, and electricity output, respectively.

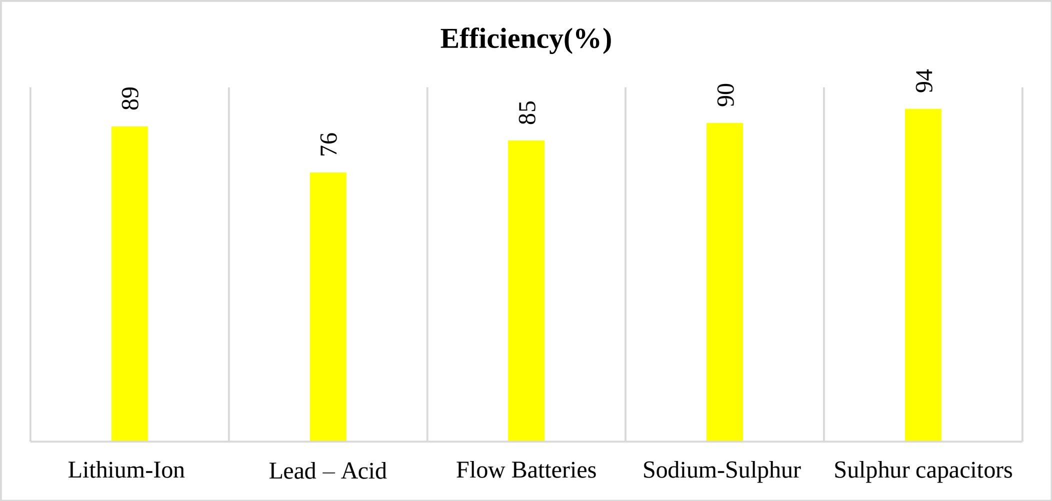


**Figure 3. Efficiency of each Battery**

It can be deduced from Figure 3 that all the batteries have efficiencies greater than 75% while Sulphur capacitors have the highest efficiency of 94%. Flow batteries and conventional capacitors have a 60–90% cycle efficiency.

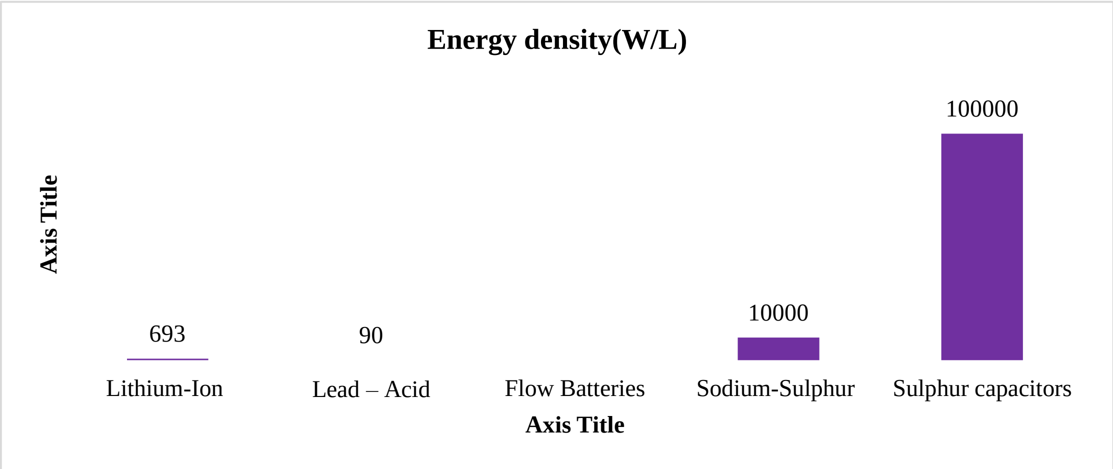


**Figure 4. The Energy Density of each Battery**

Figure 4 depicts the energy density of each battery with super capacitors having the highest energy density of 10000.

Flow batteries and conventional capacitors have a 60–90% cycle efficiency.

### 3.3 Effect of Battery Energy Storages on Integration Distributed Renewable Energy

The integration of distributed renewable energy sources (RES) presents several challenges despite their numerous benefits. One of the main issues is intermittency, as renewable sources like wind and solar depend on weather conditions, causing fluctuations in energy delivery that impact grid stability. Energy storage systems help mitigate this by accumulating surplus energy during peak generating intervals and discharging it during low generation intervals. Another challenge is harmonics, caused by power electronic devices in RES, which can distort the grid’s power waveform, but proper design and grid codes can help mitigate this. Land use concerns arise due to the space required for solar and wind infrastructure, which can affect local ecosystems, although integrating renewable systems into existing infrastructure can help reduce this impact. High capital costs for renewable energy infrastructure remain a barrier, though costs have been decreasing due to advances in technology and regulations. Energy storage remains essential for managing the intermittent nature of RES, and ongoing advancements in storage technologies are crucial for their integration. The availability of renewable resources varies geographically, which requires careful regional planning. Finally, integrating RES into existing grid infrastructure necessitates improvements to accommodate their unique characteristics, such as intermittent generation and bidirectional power flows. Despite these challenges, Renewable energy possesses the capacity to markedly diminish greenhouse gas emissions and foster a more sustainable, resilient energy future.

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## 4.0 Conclusion and Recommendation

### 4.1 Conclusion

This study investigates efficient energy storage techniques to incorporate distributed energy sources and enhance battery stability and reliability, utilizing existing knowledge of diverse storage systems. Through a review of prior research and graphical analysis, the study identifies lithium-ion batteries, sulfur capacitors, and nickel electrode batteries as the most efficient options for corporate institutions. The findings offer critical guidance for selecting sustainable energy storage solutions, providing insights into environmental impacts and potential advantages for policymakers, engineers, and investors. Future research intends to evaluate the costs associated with electricity generation through plastic waste pyrolysis, furthering the study's emphasis on environmental sustainability.

### 4.2 Recommendations

To optimize battery energy storage systems (BESS), concentrate on six principal strategies: (1) utilize advanced batteries, such as lithium-ion and sodium-sulfur, for their superior efficiency and longevity, suitable for extensive energy storage; (2) incorporate smart grid technologies to enhance energy distribution and reliability via advanced metering and real-time management; (3) develop scalable, modular BESS for adaptable, incremental growth; (4) bolster grid resilience by employing BESS to provide backup power and mitigate fluctuations; (5) perpetually monitor BESS performance to facilitate enhancements and inform upgrades; and (6) enact supportive regulatory policies, including incentives and safety standards, to encourage widespread BESS adoption. Subsequent research ought to evaluate the economic viability of BESS by comprehensive cost analysis, encompassing the assessment of the unit cost of energy generation using techniques such as plastic waste pyrolysis. Furthermore, studies may investigate novel battery technologies and their prospective functions in decentralized energy systems.

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