

# A Review of Energy Storage Systems (ESS) for Integrating Renewable Energies in Microgrids

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**Abstract**—This review's primary goal is to include an energy storage system for incorporating renewable energy into microgrids. Both the integration of renewable energy sources with microgrids and the use of inappropriate storage systems are detrimental to renewable energy. Energy Storage Systems (ESS) are essential for facilitating the efficient integration of renewable energy sources in microgrids and resolving the intermittency and variable issues posed by these sources. Modern energy storage techniques and their use in microgrids are thoroughly reviewed in this paper. Renewable energy sources like solar panels, wind turbines, and occasionally biomass or small-scale hydropower are being integrated into microgrid designs more and more. Resilient and sustainable energy supplies are enhanced by this integration. Continuous advancements are made in the dynamic field of microgrid integration with renewable energy sources. However, there are still a lot of difficulties with integration, such as intermittent and variable performance, financial and technological obstacles, policy and regulatory problems, and grid connection difficulties. The review investigates how ESS can enhance grid stability, enhance energy management, and maximize the use of renewable energy sources. Various challenges of Renewable Energy Storage System have also been reviewed in this paper. Additionally, it looks at the opportunities and difficulties of adopting ESS in microgrids, including the requirement for effective deployment and control strategies. To show how effectively ESS enables the integration of renewable energies in microgrids, case studies and practical applications are discussed. The analysis concludes with suggestions for future research initiatives, highlighting the significance of developing ESS technologies to create robust and sustainable energy systems. This paper could end with suggestions for future research directions in the field of energy storage systems for microgrids, as well as recommendations for practitioners, policymakers, and researchers.

**Keywords**—Energy Storage System, Renewable Energy, Microgrid, Biomass, Hydropower, Integration, Renewable Energy

## I. INTRODUCTION

In order to mitigate the erratic and intermittent nature of renewable energy sources, like solar and wind, Renewable Energy Storage System, or RESS, is essential. When demand is strong or renewable generation is low, these storage systems release the excess energy they have stored during times of high renewable energy production. In order to successfully integrate renewable energy sources into the

world's energy mix, renewable energy storage systems are essential to the shift toward a more resilient and sustainable energy infrastructure. The effectiveness and affordability of these storage systems are still being improved by ongoing research and development. The main advantage of RESS over typical energy storage system is that, RESS specifically emphasizes the integration of renewable energy sources into the storage system. RESS combines renewable energy sources like solar and wind power with energy storage technology like batteries or flywheels [1]. RESS are used to store extra energy produced by renewable sources so that it can be released into the grid when it is required. This enables grid independence during power outages, ensuring a stable and reliable energy supply. RESS provide a number of benefits over conventional energy storage systems, including a decrease in the grid's carbon footprint and dependence on fossil fuels [2]. Additionally, they can contribute to lower electricity prices as well as increased grid stability and dependability. Integrating renewable energies into microgrids has emerged as a crucial technique to improve energy efficiency and lower greenhouse gas emissions as the globe moves more and more toward sustainable energy solutions. Renewable energy sources, including solar and wind, present substantial problems for the stability and dependability of the grid due to their inherent intermittency and variability. By offering a way to store extra energy during times of high generation and release it during times of low generation, Energy Storage Systems (ESS) play a crucial part in resolving these issues by maintaining a constant and dependable power supply [3].

RESS do, however, come with a number of problems, including expenses, effectiveness, and safety. In order to solve these difficulties and improve the affordability, effectiveness, and safety of RESS, researchers are attempting to create new technologies and methodologies. RESS are a crucial component of microgrids and other power systems because they may boost the uptake of renewable energy sources while enhancing the grid's dependability and stability.

The function of Energy Storage Systems (ESS) in effectively supporting the integration of renewable energies in microgrids is thoroughly examined in this review [4]. We explore into different ESS systems, examining their features, benefits, drawbacks, and uses in microgrid scenarios.

Batteries, supercapacitors, pumped hydro, and flywheels, among other prominent ESS technologies, are assessed based on their energy capacity, efficiency, cost-effectiveness, and scalability. The analysis looks at the advantages of deploying ESS in microgrids, emphasizing its critical role in improving power quality, grid stability, and managing peak loads and voltage. ESS technologies aid in maximizing the integration of renewable energies into microgrids by reducing the intermittent nature of renewable sources [5]. However, there are difficulties in deploying ESS in microgrids, such as the necessity for effective control and management techniques, appropriate sizing, and ideal placement of storage systems. To comprehend the consequences of economic and technological ESS improvements for wide-scale implementation in microgrids, they are examined.

Case studies and real-world applications are presented throughout the review to highlight effective ESS technology integrations in microgrid projects. These real-world examples show how well ESS works to improve energy security and aid in the switch to greener, more sustainable energy sources. The goal of this review's conclusion is to offer insightful information about the importance of Energy Storage Systems (ESS) in incorporating renewable energy sources into microgrids. We can open the door for the widespread use of renewable energy sources and the development of robust and environmentally friendly microgrid systems by comprehending the advantages and disadvantages of various ESS technologies and looking at their successful applications. The analysis is concluded with a discussion of potential future research areas, highlighting the significance of ongoing innovation and improvements in ESS technologies for a future with greener and more sustainable energy.

Energy storage systems (ESS) play a critical role in integrating renewable energy sources into microgrids. ESSs are used to store excess energy generated by renewable sources, such as solar and wind, and then release it into the grid when needed [6]. This allows for a more stable and reliable supply of power, as well as the ability to operate the microgrid independently from the main grid during power outages. An important contribution to the development of microgrids and sustainable energy is the assessment of Energy Storage Systems (ESS) for integrating renewable resources. A thorough and in-depth overview of several energy storage technologies, such as batteries, supercapacitors, pumped hydro, and flywheels, is provided in the review. Researchers, engineers, and policymakers can use the review as a useful tool to decide which ESS technology is best for a certain microgrid application by viewing the technical features, benefits, limitations, and applications of each ESS technology.

The advantages of ESS deployment in microgrid operations are carefully examined in the paper. It focuses on the ways in which ESS technology can enhance voltage regulation, peak load management, and energy management. ESS increases the efficiency and resilience of microgrids by maximizing the use of renewable energy while reducing energy costs and promoting environmental sustainability [7]. The review discusses how energy storage technologies may have an impact on the environment, which adds to the growing focus on sustainable energy options. The review

highlights how crucial it is to take environmental sustainability into account when making decisions about energy storage by analyzing the life cycle assessments of various ESS technologies. The development of sustainable energy solutions is considerably advanced by the evaluation of Energy Storage Systems (ESS) for the use of renewable energy sources in microgrids [8]. The review includes incisive recommendations for accelerating the transition to a more robust and sustainable energy future and maximizing microgrid development by giving readers a thorough understanding of ESS technologies, their benefits, commercial viability, and practical applications.

The main contribution of Energy storage systems is to play a crucial role in easing the integration of renewable energy sources into microgrids by resolving their unpredictability and intermittency, assuring grid stability, and improving the overall efficiency and dependability of the energy system. These contributions are essential steps in the direction of a sustainable and eco-friendly energy future and for the researchers to work for the society.

## II. LITERATURE REVIEW

The literature evaluation for "A Review of Energy Storage System (ESS) for Integrating Renewable Energies in Microgrids" includes an extensive analysis of the critical function that ESS performs in supporting the seamless integration of renewable energies into microgrid systems. Batteries, supercapacitors, pumped hydro, flywheels, and other energy storage devices have all been the subject of extensive research into the technological aspects, benefits, and limitations. These studies demonstrate the applicability of several ESS technologies for various microgrid applications, aiding decision-makers in selecting the most suitable options. The research also reviews the economic viability of deploying ESS in microgrids, providing insightful information on cost-effectiveness and prospective revenue streams. Researchers and governments may choose wisely where to invest in sustainable energy by highlighting the economic advantages of ESS use. The review's real-world case studies and examples of effective implementations provide more evidence of the ESS's capacity to improve the operation of microgrids as a whole while increasing the use of renewable energy sources and grid stability. The review examines ESS technologies' life cycle assessments and the effects they have on sustainability in order to recognise the significance of environmental factors. Overall, the literature review is a useful resource that compiles a wealth of knowledge about ESS technologies and their integration with renewable energy sources in microgrids, enabling stakeholders to make defensible decisions for the construction of future resilient and environmentally friendly energy systems.

In-depth analysis of several energy storage technologies, such as batteries, supercapacitors, pumped hydro, and flywheels, as well as their applicability for incorporating renewable energies in microgrids, are provided in [9]. The authors offer insights into each technology's ideal deployment in microgrid systems by analyzing its technical traits, benefits, and drawbacks. In their research, they focus on the role of energy storage systems in microgrid energy management [10]. They examine different control strategies

and optimization techniques for effectively utilizing energy storage to balance renewable energy generation and demand, ensuring stable and reliable microgrid operation. Research focuses on the function of energy storage devices in microgrid energy management in [11]. They look at various optimization and control mechanisms for efficiently deploying energy storage to balance the production and consumption of renewable energy, assuring stable and dependable microgrid operation.

An economic analysis of energy storage systems in microgrids is done in [12]. The study examines possible revenue streams and advantages associated with their integration in addition to assessing the cost-effectiveness of various ESS technologies. The authors stress the significance of taking economic feasibility into account when making well-informed decisions about the implementation of energy storage. This study in [13] investigates the impact of energy storage systems on microgrid stability and power quality. The authors present case studies demonstrating how ESS technologies can help maintain grid frequency, voltage, and power balance during fluctuating renewable energy generation. The effect of energy storage systems on the stability and power quality of microgrids is examined in this study [13]. The authors give case examples that show how ESS systems can support preserving the frequency, voltage, and power balance of the grid during erratic renewable energy generation.

In [14] review real-world implementations of energy storage systems in microgrid projects. They analyze successful case studies from different regions, showcasing how ESS technologies have been integrated into microgrids to enhance renewable energy utilization and grid reliability. In their review of actual energy storage system deployments in microgrid projects. They examine case studies that have been effective in integrating ESS technologies into microgrids to increase grid dependability and the use of renewable energy sources. The most recent developments in energy storage systems for microgrids are summarized in a report in [15]. The study looks at new ESS innovations such solid-state and redox flow batteries and their potential to increase energy storage capacity and efficiency. Researchers examine the environmental effects of energy storage devices used in microgrid applications [16]. The carbon footprint and environmental sustainability of various ESS technologies are evaluated by the authors through life cycle analyses.

### III. METHODOLOGY OF RESS

The building process for a Renewable Energy Storage System (RESS) will vary depending on the precise storage technology employed, as well as the system's location and size. There are some common construction methodologies for different types of RESS:

#### A. Battery Energy Storage Systems (BESS)

Batteries, inverters, and control systems are the main components of BESS [17]. Site preparation, foundation and support structure installation, battery and inverter equipment installation, and grid connection are all possible parts of the BESS construction process. The batteries can be lead-acid, flow, lithium-ion, or other types. BESS offers quick response times to balance supply and demand, which improves grid stability. Batteries, however, may store less energy per unit

of volume or weight than other energy storage methods because they generally have lower energy densities.

#### B. Pumped Hydro Energy Storage Systems (PHESS)

In PHESS, a dam and reservoir are built at a higher elevation, and a power plant is built at a lower elevation [18]. When there is an excess of energy produced, water is pumped from the lower reservoir to the upper reservoir, where it is then stored until needed for power production. Site preparation, building of the dam and reservoir, installation of the pumping and power generation machinery, and grid integration can all be included in the PHESS construction process. Systems using photovoltaic energy harvesting (PHES) have high conversion efficiencies, usually reaching 70–80%. However, PHES needs particular geographic circumstances, such as the presence of appropriate locations with varying elevations and accessibility to bodies of water.

#### C. Compressed Air Energy Storage Systems (CAESS)

In the CAESS system, air is compressed at times of peak energy production and then released to power a turbine and produce electricity when needed. Preparing the site, installing the compression and power generation equipment, and connecting the system to the grid are all possible components of the CAESS building process. Large-scale energy storage is possible with CAES systems, enabling the long-term storage of substantial amounts of energy. In comparison to certain other storage technologies, the round-trip efficiency of conventional CAES systems is lower. Efficiency is the goal of adiabatic and advanced adiabatic CAES designs.

#### D. Flywheel Energy Storage Systems (FESS)

The FESS is made up of rotating flywheels that store kinetic energy. Site preparation, the installation of the flywheel and other power producing hardware, and the grid connection are all possible components of the FESS building process.

Thermal Energy Storage Systems (TESS): Thermal energy is stored using TESS, either as heat or cold. Site preparation, storage media installation, and grid integration may all be a part of the TESS building process. The general building process for a RESS will be determined by the specific technology employed, as well as the location and scale of the system. Before deciding whether or not to invest in a RESS, it's crucial to thoroughly assess all the elements involved in the construction process and take into account the long-term costs and benefits of one. Energy produced from renewable sources, such as solar or wind, is often stored using battery energy storage systems (BESS), a popular kind of renewable energy storage system (RESS). A BESS is typically built following a number of important steps.

#### E. Site Preparation

This entails deciding on a suitable location for the BESS, securing required approvals and permits, and getting the site ready for construction. This can entail grading the land, putting in foundations, and creating site access.

#### F. Equipment installation

This includes installing the battery and inverter equipment, as well as any other necessary components such as control systems, transformers, and switchgear. The

batteries are usually either lithium-ion, lead-acid, flow batteries, and others.

### G. Electrical Connection

This means connecting the BESS into the grid, which can entail setting up electrical substations, power transformers, and other tools. In this step, the BESS must also be integrated with other energy sources, such as solar or wind. Commissioning and testing: To make sure that the BESS is running properly and following all relevant safety and performance standards, it must be tested and commissioned after it has been installed and linked to the grid. Maintenance and operation: Once the BESS is operational, it will need ongoing maintenance and supervision to guarantee that it is performing successfully and efficiently. It's crucial to keep in mind that the building procedure may change according on the size, location, and battery technology employed for the BESS. It's crucial to take into account any legal or policy requirements that could have an impact on the construction process. Overall, building a BESS is a difficult procedure that needs careful planning, carrying out, and upkeep. To guarantee that the system is built and operated in a safe, dependable, and effective manner, it is crucial to collaborate with experienced contractors and engineers.

## IV. CLASSIFICATION OF RESS

There are several types of ESSs that can be used in microgrids, including Lithium-ion batteries, Flow batteries, Lead-acid batteries and Flywheels. Microgrids are localized, small-scale energy systems that can function both separately and in tandem with the larger electrical grid. They are made up of control systems that facilitate effective and dependable energy management as well as distributed energy resources (DERs), which include energy storage, distributed generators, renewable energy sources, and other DERs. Microgrids have various benefits in terms of energy resilience, sustainability, and flexibility and can supply electricity to a particular region, neighborhood, or establishment. The cost, efficiency, and lifetime of each of these storage technologies each have advantages and drawbacks of their own. Various factors, including the microgrid's size and location, the types of renewable energy sources employed, and the anticipated length of power outages, must be taken into consideration when choosing an adequate storage system. Recent research demonstrates that microgrids with ESSs can achieve significant renewable energy penetration rates and decrease their reliance on fossil fuels. Additionally, ESSs can aid in lowering the microgrid's carbon impact and electricity costs. All things considered, ESSs are essential for successfully integrating renewable energy sources into microgrids, and a variety of storage technologies are available to meet various needs and specifications. The usage of ESSs can aid in boosting the microgrid's dependability and stability and can encourage the use of renewable energy sources, which is crucial for a sustainable future.

### A. Lithium-Ion Batteries

Many electronic items, including smartphones, computers, electric cars, and power tools, use rechargeable lithium-ion batteries. Because of their higher energy density, which enables them to store more energy in a smaller, lighter

form factor, they are preferred over other battery types. A lithium-ion battery is made up of one or more cells, each of which has a positive electrode (the cathode), a negative electrode (the anode), and an electrolyte that allows ions to move between the two electrodes shown in Fig. 1. During a battery charge, lithium ions go from the cathode to the anode, where they are stored. As the battery is discharged, lithium ions reverse the process and move from the anode to the cathode, producing an electrical current that may be used to power electronic devices.

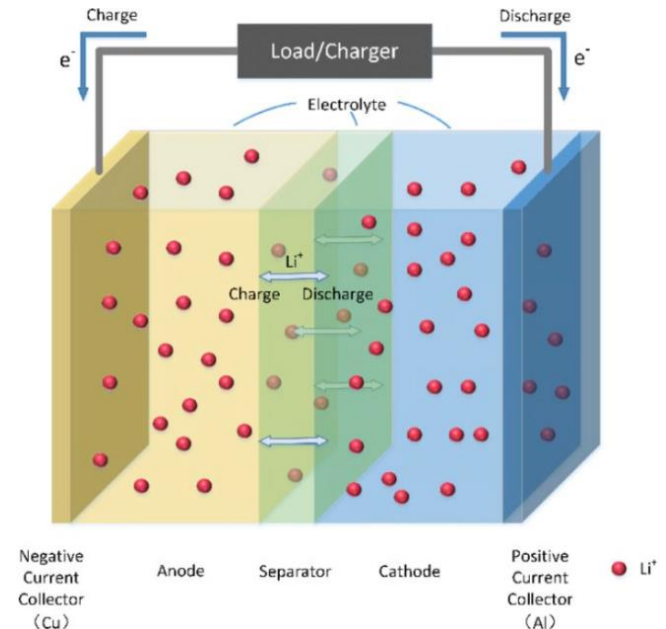


Fig. 1. Schematic diagram Lithium-ion battery structure [19]

The fact that lithium-ion batteries have a relatively low self-discharge rate and can maintain their charge for longer periods of time than other rechargeable battery types is one of their benefits. They normally endure for several years before needing to be replaced. They also have a long lifespan. The performance and lifespan of lithium-ion batteries can be impacted by their high cost of production, sensitivity to temperature fluctuations, and potential for overcharging.

### B. Flow Batteries

Flow batteries are rechargeable batteries that flow liquid electrolytes through an electrochemical cell system to store electrical energy. Flow batteries, as opposed to conventional batteries, store energy in liquid electrolytes that may be kept in external tanks, giving them a potentially limitless energy capacity.

Two different liquid electrolytes, each of which includes chemical species that can be oxidized or reduced to store or release electrical energy, are circulated in a flow battery's basic operating system. The two electrolytes are kept separate and pumped through a flow cell shown in Fig. 2. A membrane keeps the two electrolytes apart but permits ions to pass through, preventing the two electrolytes from combining.

One electrolyte is pumped through the flow cell during battery charging, where it is oxidized and releases electrons that travel through an external circuit before returning to the battery at the opposite electrode. The energy and electrons released by the first electrolyte are stored by the second electrolyte as it is reduced and pushed through the flow cell

at the same time. The procedure is reversed and the two electrolytes are pumped through the flow cell in the opposite direction when the battery is discharged. The energy and electrons released by the first electrolyte are stored by the second electrolyte as it is reduced and pushed through the flow cell at the same time. The procedure is reversed and the two electrolytes are pumped through the flow cell in the opposite direction when the battery is discharged.

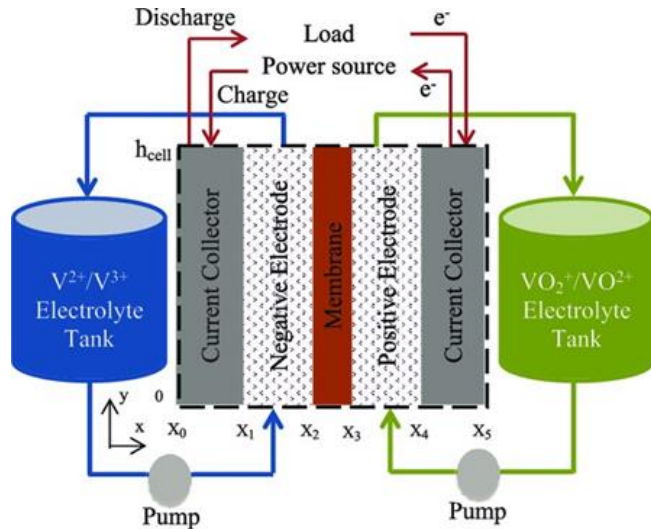


Fig. 2. Schematic diagram of an all vanadium redox flow battery structure [20]

### C. Sodium Ion Batteries

In contrast to lithium ions used in lithium-ion batteries, sodium ions are employed as the charge carriers in sodium-ion batteries, which are rechargeable shown in Fig. 3. They could potentially provide a more sustainable and affordable energy storage solution than lithium-ion batteries because sodium is more readily available and less expensive than lithium.

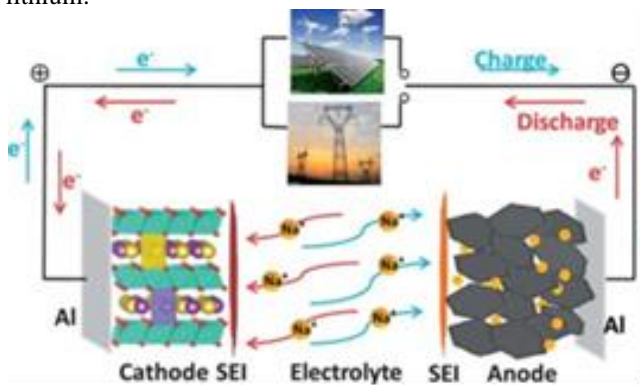


Fig. 3. Principle diagram of sodium ion battery work [21]

A sodium-ion battery functions similarly to a lithium-ion battery in its fundamentals. It is made up of a cathode, which is a positive electrode, an anode, which is a negative electrode, and an electrolyte, which allows sodium ions to travel between the two electrodes. Sodium ions flow from the cathode to the anode, where they are stored, as the battery is charged. The process is reversed during battery discharge, and the sodium ions migrate from the anode back to the cathode, creating an electrical current that can be utilized to power electronic devices. The fact that sodium-ion batteries

use a more readily available and affordable element than lithium has the potential to lower the price of energy storage. Additionally, they have a lot of energy.

### D. Lead Acid Batteries

Since the middle of the 19th century, lead-acid batteries have been a popular type of rechargeable battery. They are extensively utilized in many different fields, such as automotive, backup power systems, and uninterruptible power supplies (UPS).

A lead-acid battery's fundamental structure consists of a number of lead plates or grids that are submerged in an electrolyte solution of sulfuric acid and water shown in Fig. 4. The lead plates and sulfuric acid react when the battery is discharged, creating lead sulfate and releasing electrons. The process is reversed as the battery is being charged, turning the lead sulfate back into lead plates and sulfuric acid.

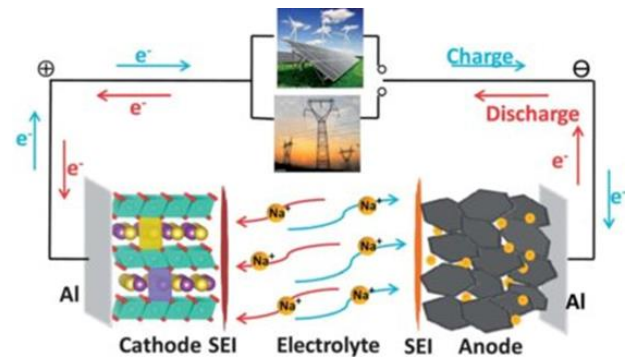


Fig. 4. Block diagram of a Lead-acid batteries [22]

Lead-acid batteries are suited for use in automobiles and other high-demand applications because they are very cheap and can generate large surge currents. They may be recharged several times before needing to be replaced and have a relatively long service life. Lead-acid batteries do, however, have significant disadvantages as well. They can be difficult to employ in portable devices or in applications with limited space because of how hefty and clumsy they are. Over time, they are also vulnerable to sulfation and other types of degradation, which can affect their functionality and service life. Additionally, due to its strong corrosiveness and potential for chemical burns, the electrolyte solution in lead-acid batteries can be hazardous if handled improperly.

### E. Flywheels

A mechanical tool used to store rotational energy is a flywheel. It comprises of a large rotating disk or wheel that can spin quickly and is positioned on a shaft shown in Fig. 5. The kinetic energy of the flywheel can be employed to drive a variety of equipment or be stored for later use. In transportation systems like trains and buses, flywheels are frequently utilized to store kinetic energy produced by braking and subsequently use it to power acceleration.

Because they can deliver high power output for limited periods, flywheels are chosen over alternative energy storage devices in some applications where huge amounts of power are needed for transient periods of time. They are also very effective, with minimal energy losses from friction and other sources. Flywheels do have some restrictions, though. They can be challenging to integrate into some systems due to their weight and girth. They also need to be precisely balanced in

order to avoid vibration and other issues. Furthermore, if a flywheel malfunctions, the high-speed rotation could cause the wheel to disintegrate or break apart, posing a serious safety threat.

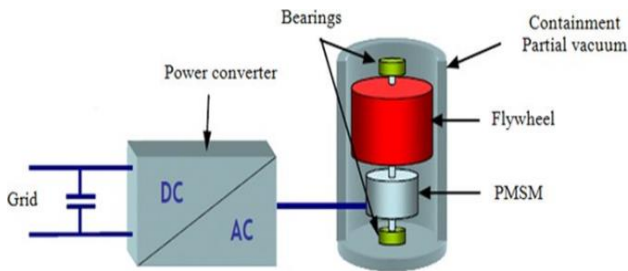


Fig. 5. Block diagram of a flywheel system [23]

#### F. Hydrogen Energy Storage System

Because it can be created from a variety of sources, including renewables like solar and wind, hydrogen is an appealing energy storage alternative. Hydrogen energy storage systems produce hydrogen through electrolysis, compress it, store it, and then use a fuel cell to turn it back into power. Here are the basic steps involved in a hydrogen energy storage system:

**Production of hydrogen:** Numerous processes, such as electrolysis, steam methane reforming, and biomass gasification, can be used to make hydrogen. The most popular technique for generating hydrogen from renewable energy sources like wind and solar electricity is electrolysis. Schematic diagram of hydrogen fuel cell Fig. 6.

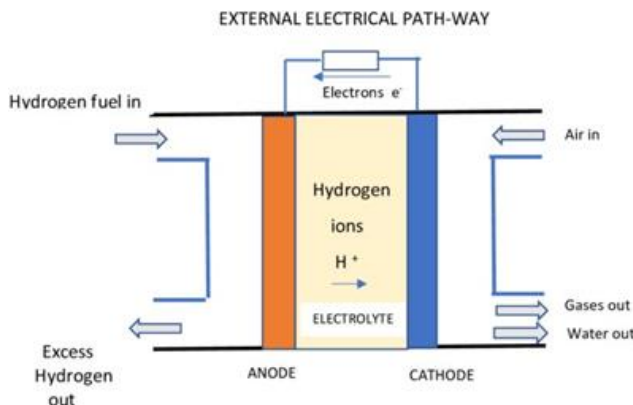


Fig. 6. Schematic diagram of hydrogen fuel cell [24]

**Compression and storage of hydrogen:** Normally compressed and kept in tanks or underground storage facilities after being produced, hydrogen. Because of its high energy density, hydrogen can store a lot of energy in a small amount of space.

**Conversion back to electricity:** The stored hydrogen is pumped into a fuel cell when power is required, where it interacts with airborne oxygen to create energy, heat, and water vapor.

Systems for storing energy using hydrogen provide a number of benefits, including the capacity to store enormous amounts of energy, the potential for long-term storage, and the ability to generate clean energy from renewable resources. The high cost of manufacturing and storage, the requirement for infrastructure to transport and store hydrogen, and safety issues with regard to the storing and

handling of hydrogen are some of the difficulties involved with hydrogen energy storage, though.

#### V. DIFFERENCE AMONG ESSS

The various energy storage systems (ESSs) that can be utilized in microgrids differ in a number of significant ways, including:

**Lithium-ion batteries:** These batteries have a high energy density, a long lifespan, and require minimum maintenance, making them popular in microgrids [25]. When compared to other ESSs, they are quite pricey and sensitive to high temperatures. **Flow batteries:** These batteries are particularly well suited for long-term storage since they store energy using a liquid electrolyte. Compared to lithium-ion batteries, they are more expensive and have a lower energy density, but they last longer.

**Sodium-ion batteries:** These batteries contain a sodium-based electrolyte, which makes them more cost-effective and durable than lithium-ion batteries. Compared to lithium-ion batteries, they are less effective and have a lower energy density, but they can withstand higher temperatures. **Lead-acid batteries:** These batteries are often used in microgrids because of their inexpensive cost and long lifespan. They are less efficient and have a lower energy density than other ESSs, but they are also less expensive. **Flywheels:** Due to the fact that they store energy as kinetic energy, these systems are excellent for short-term storage. They are more expensive and have a shorter lifespan than batteries, while having a higher energy density.

In terms of the discharge rate, Lithium-ion batteries have a high discharge rate which makes them suitable for peak shaving, frequency regulation, and spinning reserve. Whereas, flow batteries and lead-acid batteries have a lower discharge rate which makes them suitable for long-duration storage, load leveling, and backup power. In terms of durability, sodium-ion batteries outperform lithium-ion batteries. Lead-acid batteries have the longest lifespan of any ESS. The least expensive ESSs are lead-acid batteries, whereas the most expensive are lithium-ion batteries. In general, a microgrid's specific needs, such as its size and location, the kinds of renewable energy source it employs, and the projected duration of power outages, determine which effective ESS is most suited for it.

#### VI. CHALLENGES OF EESS

When it comes to integrating energy storage systems (ESSs) into microgrids, there can be a number of difficulties. Some of these difficulties include:

ESSs can be relatively expensive, especially when compared to more traditional energy storage methods like fossil fuels [26]. Due to the limited lifespan of ESSs, they must be replaced or maintained over time, which can be costly [27]. ESSs, especially those that use lithium-ion batteries, can present safety hazards like fire and explosion if not properly maintained and operated. The incompatibility of these systems and technologies with those used in the microgrid may limit the usefulness of ESSs. ESSs are not as suitable for long-term storage as fossil fuels since they still have a lower energy density [28]. The grid must be correctly connected to ESSs for them to store and release energy as needed.

## VII. TECHNICAL ASPECT OF RESS

Renewable Energy Storage System (RESS) are systems that combine renewable energy sources, such as solar and wind energy, with energy storage technologies, such as batteries or flywheels. This involves developing and implementing systems that can effectively catch, store, and release energy as needed. **Energy Capture:** The first step in a RESS is the extraction of energy from renewable sources, such as solar cells or wind turbines [29]. Then, this energy is changed into a usable form, such as direct current (DC) electricity. **Energy Storage:** After being gathered, the energy is then placed in energy storage devices like batteries or flywheels. These devices are designed to store energy over extended periods of time and release it when required.

**Energy Management:** The stored energy is next managed and controlled by an energy management system (EMS) [30]. This system is in charge of monitoring the energy storage systems' condition, controlling the energy flow, and ensuring the RESS operates efficiently and safely. **Energy Conversion:** The energy that was previously stored is subsequently converted back into a usable form, such as alternating current (AC) electricity, for utilization. **Grid Integration:** After this, the RESS is integrated into the grid, allowing it to draw electricity from it when renewable energy sources aren't available and to provide the system with energy when it does [31]. By doing this, it is ensured that the RESS will be able to operate regularly and stably.

Making sure the system is developed and put into use in a way that is secure, dependable, and effective is another technical part of RESS. This entails making sure that the RESS is effectively integrated into the grid, that the energy management system is properly designed and calibrated, and that the energy storage devices are appropriately scaled and maintained. RESS can make use of a variety of technologies, including lead-acid batteries, flow batteries, sodium-ion batteries, lithium-ion batteries, and flywheels for energy storage. The technology to be utilized will be determined by the system's unique requirements, such as the RESS size and location, the types of renewable energy sources used, and the expected duration of power outages. The technical side of RESS includes designing and implementing systems that can effectively capture, store, and release energy from renewable sources. It also includes ensuring that the system is safe, dependable, and efficient, and integrating the system into the grid to ensure that it can operate in a stable and reliable manner.

## VIII. ECONOMICAL ASPECT OF RESS

The economics of Renewable Energy Storage System (RESS) refers to the costs associated with designing, building, operating, and maintaining the system [32]. **Initial expenses:** The upfront expenses of a RESS consist of the cost of purchasing and installing energy storage devices like batteries or flywheels as well as the cost of purchasing and installing renewable energy sources like solar or wind energy. These costs could be very expensive, depending on the size and location of the system [33].

**Operating Costs:** A RESS operating costs consist of the costs incurred to operate its energy management system, as well as to maintain and repair its renewable energy sources and energy storage technology. These costs could be very

expensive, depending on the size and location of the system. **Financial Incentives:** As financial incentives for the deployment of RESS, governments and organizations may offer grants or tax credits, which can assist in offsetting some of the initial and continuing expenditures [34]. **Energy cost savings:** Using RESS can help to reduce the cost of power by reducing the requirement for fossil fuels and the amount of energy that must be obtained from the main grid.

**Return on Investment:** The RESS return on investment may be impacted by a number of factors, such as the system's size and location, the types of renewable energy source it employs, and the projected duration of power outages. In some cases, the return on investment may not appear for several years. The economics of RESS also involves balancing the benefits of lessening reliance on fossil fuels, lowering energy costs, and improving grid stability and reliability against the costs of designing, building, operating, and maintaining the system [35]. The system's scalability and return on investment should be taken into consideration while determining whether to adopt RESS.

## IX. COST ANALYSIS OF RESS

A cost analysis can be used to assess the economic viability of a Renewable Energy Storage System (RESS) and identify potential cost-saving options [36]. The cost study should consider the system's original investment as well as ongoing costs for operating and maintaining it. Initial expenses for a RESS include:

- **Equipment costs:** These cover the price of the battery or other storage device as well as any additional equipment, including transformers, inverters, and control systems [37].
- **Costs associated with installation:** These expenses cover the price of preparing the site, building the foundations and supporting structures, and setting up the storage apparatus.
- **Costs of financing:** These expenses include the interest paid on any loans used to finance the project as well as any taxes or other charges that may be incurred. A RESS ongoing expenses include:
- **Operating expenses:** These cover any additional expenses related to running the system, such as labor and maintenance expenditures, as well as the cost of power used to charge and discharge the storage system.
- **Replacement costs:** These expenses cover the cost of changing the storage device or other system parts when their useful lives are up.

The overall cost of the system is divided by the total energy produced or stored by the system to get the cost of energy for a RESS. A RESS cost analysis can help determine the system's economic sustainability and point out areas where expenses can be cut [37]. To conduct a complete and accurate cost analysis, it is crucial to carefully analyze all pertinent expenditures and to cooperate with qualified professionals.

## X. COST OF ENERGY FOR RESS

The cost of energy for a Renewable Energy Storage System (RESS) depends on a variety of factors, including the storage technology used, the storage system's capacity, and the cost of the renewable energy source (such as solar or

wind) being stored [38]. Additional factors that could affect the price of electricity from a RESS include the cost of any necessary equipment or infrastructure, as well as any maintenance or operating expenses connected to the system.

When calculating the cost of energy for a RESS, the cost of the renewable energy source being stored, the cost of the storage technology, and any additional costs like equipment, installation, and maintenance must all be taken into consideration. Once you are aware of this, you can use the formula:

$$\text{Cost of Energy} = \frac{(\text{Total Cost of the System})}{(\text{Total Energy Stored or Produced by the System})} \quad (1)$$

This will then have the energy cost in dollars per kWh, which you may compare to the cost of energy from other sources to ascertain the RESS economic viability.

In addition to the previously listed factors, the location and climate of the installation, as well as the regulatory and legislative framework in which the system is operating, can affect the cost of the energy produced by a RESS. As an illustration, the cost of energy from a RESS may be higher in an area with limited sunlight or wind, or in an area where equipment and labor are expensive.

It's important to consider the RESS efficiency and performance, as well as the system's expected lifespan and replacement or upgrade costs. The price of electricity generated by a RESS can also be influenced by the system's scale, grid integration, and other energy sources.

When calculating the cost of energy from a RESS, the cost of capital, which includes the cost of funding the system, should be taken into consideration. This can pay for loan interest, any taxes, and other project-related expenses. The cost of energy for a RESS depends on a number of factors, including the specific system and location. It's vital to thoroughly consider each of these factors and take into consideration the long-term costs and benefits of one before selecting whether or not to invest in a RESS. A RESS may have an effect on the price of power.

## XI. NET PRESENT VALUE FOR RESS

The financial viability of a Renewable Energy Storage System (RESS) project can be determined using a financial metric known as Net Present Value (NPV). It determines the value of the RESS project in terms of future cash flows, accounting for both project costs and the time value of money. If a project's estimated net present value (NPV) is positive, it is regarded as a viable investment.

You would need to know the anticipated cash flows from the project, the project expenses, and the discount rate in order to calculate the NPV for a RESS project [39]. The following is the NPV formula:

$$\text{NPV} = (\text{Sum of the present value of all future cash flows}) - (\text{Initial Investment}) \quad (2)$$

$\text{NPV} = (\text{Sum of the present value of all future cash flows}) - (\text{Initial Investment})$

Where the present value of future cash flow is calculated as:  
Present Value = (Cash flow / (1 + r)<sup>t</sup>)

Where:

Cash flow = the expected cash flow for each period

r = the discount rate

t = the number of periods in the future

Therefore, the total cost of the RESS would need to be considered, which would include financing costs as well as costs for the equipment, installation, maintenance, and operation.

It's important to keep in mind that the discount rate and the projected future cash flows have a big influence on the NPV calculation, and even little changes in these inputs can have a big influence. As a result, it is essential to estimate these variables as precisely as feasible while also accounting for any associated uncertainty. By comparing the RESS to other energy generation options using NPV calculations, it is possible to determine which technology is the most cost-effective [39].

## XII. EFFECT OF RESS FOR INTEGRATING RENEWABLE ENERGIES IN MICROGRIDS

The incorporation of renewable energy sources into microgrids can be significantly impacted by the usage of Renewable Energy Storage System (RESS) [40]. Among the main impacts are:

**Increased Renewable Energy Penetration:** The microgrid's utilization of renewable energy sources, such as solar and wind energy, can be increased thanks to the ability to store excess energy produced by these sources.

**Increased Grid Stability and Dependability:** RESS, which provide a method to store energy when it is produced and release it when it is needed, can boost the stability and dependability of the microgrid. When the primary grid is affected by power outages or other circumstances, this is vital. **Lessened Dependence on Fossil Fuels:** RESS can reduce the dependence on fossil fuels by enabling the microgrid to operate independently of the main grid and by providing an electrical supply when renewable sources aren't available.

**Lessening of Carbon Footprint:** RESS can help to lessen the microgrid's carbon footprint by reducing the amount of power generated from fossil fuels. **Cost Savings:** RESS can help bring down the price of power by lowering the amount of energy that must be acquired from the main grid and by acting as a backup source of energy when renewable sources aren't available.

RESS can be quite helpful when it comes to integrating renewable energy sources into microgrids. They can reduce dependency on fossil fuels, increase the stability and reliability of the microgrid, and increase the usage of renewable energy sources. But it's important to keep in mind that, before making a decision, one must consider the costs and challenges involved in the deployment of RESS.

## XIII. DISCUSSION

Insightful information regarding the crucial role of energy storage in addressing the challenges presented by intermittent renewable sources is provided by the evaluation of energy storage system (ESS) for integrating renewable energies in microgrids. As the world progresses toward a more sustainable energy future, integrating renewable energies into microgrids has become a major issue. The intrinsic erraticness of sources like solar and wind energy, however, greatly hinders grid stability maintenance and the provision of a consistent supply of electricity.

Systems for storing energy become a useful solution to these issues. Excess energy from renewable energy sources is either released or collected when production is high. This method, known as energy storage systems (ESS), effectively reduces fluctuations and guarantees a constant supply of electricity to meet the needs of the microgrid. Among the other ESS technologies examined in the review, batteries, pumped hydro storage, flywheels, and thermal storage demonstrate their capacity to store energy at different scales and respond to variations in renewable energy generation at different response times.

Energy storage equipment's versatility also aids in maximizing the usage of renewable energy sources. ESS can act as a buffer when the production of renewable energy is strong, enabling microgrid management to store excess energy and release it when demand exceeds supply. This not only boosts the use of renewable resources but also reduces dependency on fossil fuels and lowers carbon emissions, all of which are in accordance with the goals for the global climate.

The study highlights the developments and benefits of present energy storage technologies, but it also highlights the importance of continued research and development to further enhance their usability and cost. For instance, advances in battery technology have already led to higher energy densities, longer useful lifetimes, and lower costs, making them more financially viable for microgrid applications. To fully utilize energy storage systems' potential for integrating renewable energies into microgrids, collaboration amongst stakeholders is crucial. Policymakers who must create an accommodating regulatory framework must promote the use of ESS technology in microgrids. Utility firms and energy planners should look into integrating energy storage into their grid architecture to improve grid resilience and effectiveness.

In its conclusion, the review emphasizes the vital significance of energy storage technologies for the successful integration of renewable energies into microgrids. Because they effectively reduce intermittency problems, enhance grid stability, and maximize the use of renewable resources, ESS technologies are essential in hastening the transition to a more sustainable, clean energy future. Energy storage technologies must be adopted and developed if reliable, efficient, and eco-friendly microgrid systems are to be made practical. This will help the fight against climate change and provide energy security on a global scale.

#### XIV. CONCLUSION

The conclusion of the analysis of energy storage systems (ESS) for integrating renewable energy sources in microgrids highlights their crucial role in resolving the issues faced by intermittent renewable sources. Energy storage systems have been proved to be effective for balancing supply and demand variations, enhancing grid stability, and maximizing the usage of renewable energy sources. A wide variety of ESS choices, including batteries, pumped hydro storage, compressed air energy storage, and more, are easily accessible to satisfy specific microgrid requirements depending on factors like capacity, power rating, and response time. The report emphasizes the need for continued ESS technology research and development to improve their general reliability, lower costs, and raise efficiency. As the

usage of renewable energy in microgrids rises, energy storage technology will be essential in supporting a smooth transition to sustainable and resilient energy systems. Regulators, energy planners, and stakeholders must comprehend the importance of integrating energy storage devices into microgrids in order to fully utilize renewable energy sources and create a cleaner, more predictable energy environment. By accepting these innovations and promoting collaboration between governmental, commercial, and academic institutions, we can create a more environmentally friendly future with a sustainable energy paradigm.

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