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A Critical Review and Analysis on Energy Storage Systems Applicable in Micro Grids

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Abstract: With the rise of use of renewable Energy storage systems (ESSs) are gaining a lot of popularity. This paper reviews the different ESSs in power systems, especially microgrids showing their essential role in enhancing the performance of electrical systems. Therefore, the ESSs classified into various technologies as a function of the energy storage form and the main relevant technical parameters. In this review paper, the most common classifications are presented, summarized, and compared according to their characteristics. A specific interest in electrochemical ESSs, especially battery energy storage systems, focusing on their classifications due to their importance in the residential sector. Besides that, the benefits and drawbacks of Lithium-Ion (Li-Ion) batteries are discussed due to their significance. Finally, the environmental impact of these ESSs is discussed.
Keywords: energy storage system; electro chemical energy storage; thermal energy storage; mechanical energy storage; batteries; micro grids

I. INTRODUCTION

Energy storage is the formation of different styles of energy at one time, which can be used for some useful operations at different times. Generally speaking, electric energy needs to be transformed into another form of energy that can be stored. Energy can be stored in various forms, such as chemical, electrochemical, electrical, mechanical, and thermal systems. A better way to store energy is essential to improve energy storage efficiency. One of the keys to the progress of energy storage is to find new materials and understand the functions of current and new materials.

A microgrid is a small-scale power grid that can operate independently (Isolated mode) or collaboratively with the power grid (Grid connected mode), enabling net power flows with, distribution network distribution network. The essential elements within a micro grid are the loads, the generation systems either dispatch able generators or renewable energy sources, power electronic converters, and protection devices. The most significant share of renewable energy sources in microgrids is based on solar photovoltaic or wind turbine generation. Both sources rely on natural phenomena such as solar irradiance or wind speed. With the increasing penetration of renewable energy sources, the stability and there liability of the micro grid are affected as those energy sources are intermittent [5,6].The benefits of integrating ESSs in electrical power systems have been widely in-creased. This is due to the fact that renewable energy is intermittent and not always reliable in power systems, which is influenced by natural factors. ESSs are solving the inter mitten drawback of renewable energy and increase the reliability of the power system. Also, ESSs provide more advantages, for instance, peak shaving, valley filling, etc. This discussion aims to demonstrate how these ESSs play a key supporting role in the performance of electric systems. Even though these benefits are valid from large-scale generation down to the end-user applications, in particular, the benefits of ESS in microgrids are target [12–14]:

From the point of view of the generation, ESSs allow for:

1) Maintaining uninterrupted and stable power flow to the loads [9–11,15]: Due to the penetration of renewable generation sources, ESS is needed to provide power when the renewable sources are not able to supply energy to the system.
2) Giving support for black-start and reduce the risk of blackouts [5,6,14]: The black-start occurs when the system needs to be restarted after a blackout (collapse of failure or large power outage). It has been reported how some specific technologies (e.g., electrochemical batteries and super capacitors) have the capability of achieving such restoring features[20].
3) Enabling the use of mobile/remote applications [20]:It provides power for remote areas or stand-alone systems such as electric vehicles and port able devices.

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At the transmission level, ESS provides for:

a) Postponement of infrastructure upgrades and congestion relief [12]:The us-age of ESS reduces the need for new investments in order to have a suitable transmission capacity.

b) Voltage Regulation [13]: ESS allows for stabilizing the voltage levels between each end of the power lines in the system.

Finally, at the distribution level and end-user services, the implementation of ESS yields to:

- Improving the power quality [5,12,15–17,21–23]: In order to effectively minimize the effects of power quality issues (instantaneous voltage drop, transients and flicker, sag, swell, and harmonics), it required a fast response of the ESS. Super capacitors, super conducting magnetic storage systems, and fly wheels have a very fast response, within the range of milliseconds. These dynamics are followed by the performance of batteries, with characteristic responses in the order of seconds[20].
- Increasing reliability[12,16,17]:ESSs support customer loads in the case of the loss of total power.
- Providing voltage support[17]:Maintain the voltage with in an acceptable range.
- Postponement of the infrastructure upgrades [12]: Utilizing ESS reduces the need for new investments to have suitable distribution capacity to meet the increasing load demands. ESSs can mitigate the congestion and thus help utilities suspend there in for cement of the distribution network. This can be done using peaks having.
- Ride-through support [17]: ESS can provide energy to ride-through operation after disconnection due to a fault in the system and fault clearance.

II. ENERGY STORAGE SYSTEMS TECHNOLOGIES

In this section, a summarized review of the different ESS technologies suitable for electrical system applications is carried out. Depending on the physical form and mechanism in which the energy is stored, the energy stored could be mechanical, electrical, chemical, electrochemical, and thermal form.

A. Mechanical Energy Storage System

The energy is stored in the form of kinetic or potential energy.

Kinetic Energy Storage System:

Potential Energy Storage System

B. Electrical Energy Storage System

The energy is stored in the form of electrostatic or magnetic fields.

Electrostatic Energy Storage System

Magnetic Energy Storage System

C. Chemical Energy Storage System

Energy can be stored and recovered when some chemical substances are subjected to a transformation through a chemical reaction.

Hydrogen energy storage system (H_2ESS)

Synthetic natural gas(SNG)

D. Electrochemical Energy Storage System

This can be defined as a particular case of chemical energy storage, in which reversible chemical reactions in a combination of cells are used to store electrical energy. In electrochemical energy storage systems, the chemical energy contained inactive materials are converted into electrical energy during an electro chemical oxidation-reduction reaction[59].

1) Conventional rechargeable batteries [5,6,22,30,31,34].

2) Liquid-metal and molten-salt batteries [1,60,61].

3) Metal-air batteries[1,62–65].

4) Flow batteries [6,22,33,34].

5) Super capacitors[5,6,22,23,32–34]

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E. Thermal Energy Storage System (TESS) [5,6,22]

Heat is also a form of energy thatcan be used for electrical systems storage applications. Depending on the range of temperatures involved, two different sets of technologies can be identified:

1) Low/temperature thermal energy storage system[23,73,74]:
2) High-temperature thermal energy storage system(HTTESS)
3) Hybrid thermal energy storage system (HTESS)

III. DIVERSIFIED CLASSIFICATION OF ENERGY STORAGESYSTEM

Notice how some of these technologies are classified into different forms of energy depending on the technical literature references. The criterion followed in this classificationaimtosimplifythedefinitionsofthetechnologiesinvolved.

On the other hand, these technologies can also be classified based on their storage characteristic duration into short-term ESS used for power quality and voltage support, medium-term ESS used for grid congestion management, reliability, ride through sup-port, peak shaving and frequency response, and long-term ESS used for supply and demand matching, and postponement of infrastructure upgrades [5,6,12–14,16,21,32,55,88]. This classification provides an initial guide to choose the proper ESS depending on the application.

The following classification is thus carried out as a function of this characteristic time:

1) Short-term Energy Storage System (from seconds to minutes): The energy to power ratio is less than 1 (e.g., a capacity of less than 1kWh with a power of 1kW system).
   a) FESS.
   b) Conventional capacitors.
   c) Super capacitors
   d) SMESS.

2) Medium-term Energy Storage System (from minutes to hours): The energy to power ratio is between 1 and 10 (e.g., a capacity between 1kWh and 10kWh for a 1kW system).
   a) Conventional Rechargeable batteries.
   b) Liquid-Metal and Molten-Salt Batteries.
   c) ALTESS.
   d) CESS.
   e) SNG.

3) Long-term Energy Storage System (from hours to days to months): The energy to power ratio is greater than 10 (e.g., a capacity of greater than 10kWh for a 1 kW system).
   a) CAESS.
   b) PHESS.
   c) GESS.
   d) Metal-air batteries.
   e) Flow batteries.
   f) Fuel cells.
   g) H_2ESS.
   h) MSS andRTIL.
   i) Concrete storage.
   j) PCMs.
   k) HTESS.

IV. BATTERIES ENERGY STORAGE SYSTEM

Electro chemical batteries stand out as one of the most commonly used storage technologies both in industrial and residential applications of power systems, microgrid and nano grids [13,21]. The energy and the power ratings of the electrochemical battery need to be sized to fulfill the peak power demands, as well as any backup requirements under the islanding mode operation of the target application.

Using Batteries in different parts of the power system (power generation, transmission, distribution system) support system with batteries high power and energy density and there salient configuration, also battery energy storage systems (BESSs) are used in many fixed and moveable applications; as electric vehicles, submarine missions, aerospace operation. According to these merits batteries are widely used in the generation, transmission, distribution, and also power consumption [89–91].

V. CONCLUSIONS AND FUTURE TRENDS

A review of energy storage systems is exhibited, giving an initial guide to select the appropriate technology. In this paper, a short brief for prospective energy storage system is demonstrated, and various classifications for the set technologies are defined according to the form that the energy is stored and their characteristic time. The ESSs are increasing steadily in many countries and the residential sector is mainly utilizing electrochemical Batteries. Therefore, a detailed review of electrochemical battery technologies is discussed due to their importance in micro grids. Recently, the environmental impact of ESSs is gaining a lot of interest due to the world wide challenges to protect the environment.

Future research should cover the optimal size of ESSs depending on the application, and define the constraints and limits of ESSs. Also, an analysis on combing more than ESSs to form a hybrid ESS and a study on their effect on the efficiency and performance of the overall system. In addition, the diverse typologies used to connect these ESSs to the electrical grid should be explored. Finally, the cost of ESSs should be taken into account, considering low-cost energy with high efficiency.

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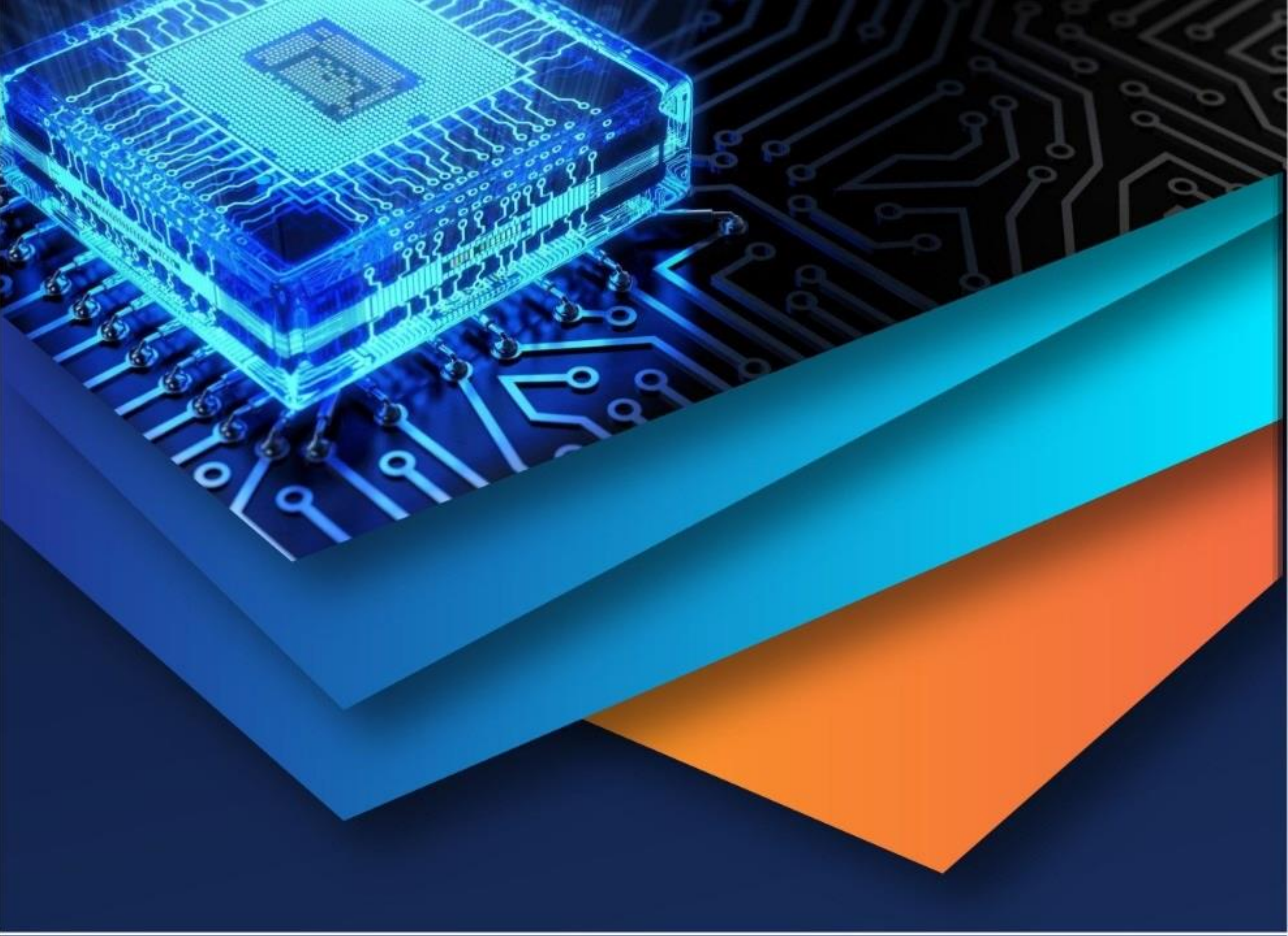

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