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A Comprehensive Study on Energy Storage Technology for Microgrid

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ABSTRACT: A microgrid comprises several interconnected loads and distributed energy. Because of rising electricity consumption and environmental pollution, many researchers and scientists are focusing on power grid features and distributed generation to provide a reliable and sustainable power supply. The current paper examines and highlights the numerous energy storage system (ESS) technologies used in microgrids, as well as their architectures, configurations, performances, benefits, and drawbacks, also by providing a tangible outline for prospective efficient and sustainable ESS. As a result, there is also a comparison of the various technologies. As a consequence, there is also a comparison of the different technologies. Finally, some of the present ESS concerns and difficulties are explored.

KEY WORDS: Microgrid, Distributed energy resources, Energy storage, Power systems.

I. INTRODUCTION

The high rate of population expansion and rates of urbanization enhance power consumption, Emissions of carbon dioxide, and higher power demand. CO2 emissions and oil consumption would climb by 130 percent and 70 percent, respectively, by 2050 if substantial global change and policy were not implemented. As a result, the earth's average temperature will rise by 6 degrees Celsius [1]. The literature offers several different strategies to accomplish and perform energy system sustainability in order to overcome these difficulties. As a result, renewable energy sources (RES) have been widely utilized to meet electrical energy demand while reducing the greenhouse gas emissions [2]. Microgrid (MG) has also been utilized to increase the performance of renewable energy storage (RES), reduce CO2 emissions, and meet the power demand at the peak time.

The microgrid is portrayed in many applications as a local energy system made up of various distributed energy supplies, energy storage units, consumers, and operational islands or grid links. Energy storage systems are now acknowledged as an essential component of the contemporary energy system because they increase the efficiency of energy systems in microgrids and offer grid stability.

Although, to store electrical energy, a number of energy storage devices have been investigated and analyzed. Many researchers concentrated on the efficiency of their energy conversion technique. As a result, numerous energy storage systems, such as mechanical, electrical, chemical, electrochemical, and thermal, are used. Nano-solar cells, nano-super capacitors, nano-batteries, and fuel cells are some of the technologies that have been used in microgrids. As a result, the availability and dependability of supercapacitors in microgrids will help energy systems reach and perform sustainability.

This paper is organized as follows. Section II describes the microgrid and different energy storage systems employed on market including electrochemical, mechanical, chemical, thermal, and electrical energy storage. Then, Section III shows a comparison of energy storage systems based on their many uses, power rating, storage length, lifespan, and capital cost. Section IV provides_trends and challenges of energy storage technology. Finally, Section V presents conclusion.

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II. MIROGRID AND ENERGY STORAGE SYSTEM

Four types of microgrids, they are classified as follow: Large grid-connected, small grid-connected, large remote, and small remote. Microgrids with energy storage may increase electricity dependability while also lowering their costs. besides being a voltage source, ESS provides several additional benefits [3].

In microgrid, there are commonly two types of ESS configurations: aggregated and distributed ESS. ESSs are deployed in numerous places throughout the microgrid in a distributed design, but in an aggregated system, they are all installed in a single bus system. As a result of the comparisons between the two systems, the dispersed and aggregated ESSs perform similarly.

EES is used in various applications classified into five categories: electrochemical, mechanical, chemical, thermal, and electrical energy storage. There are a variety of battery energy storage systems (BESS) on the market, including lead-acid, nickel, sodium-sulphur, lithium-ion, metal-air batteries, and so on. The five energy storage categories, as well as their related technologies, are shown schematically in Figure 1.

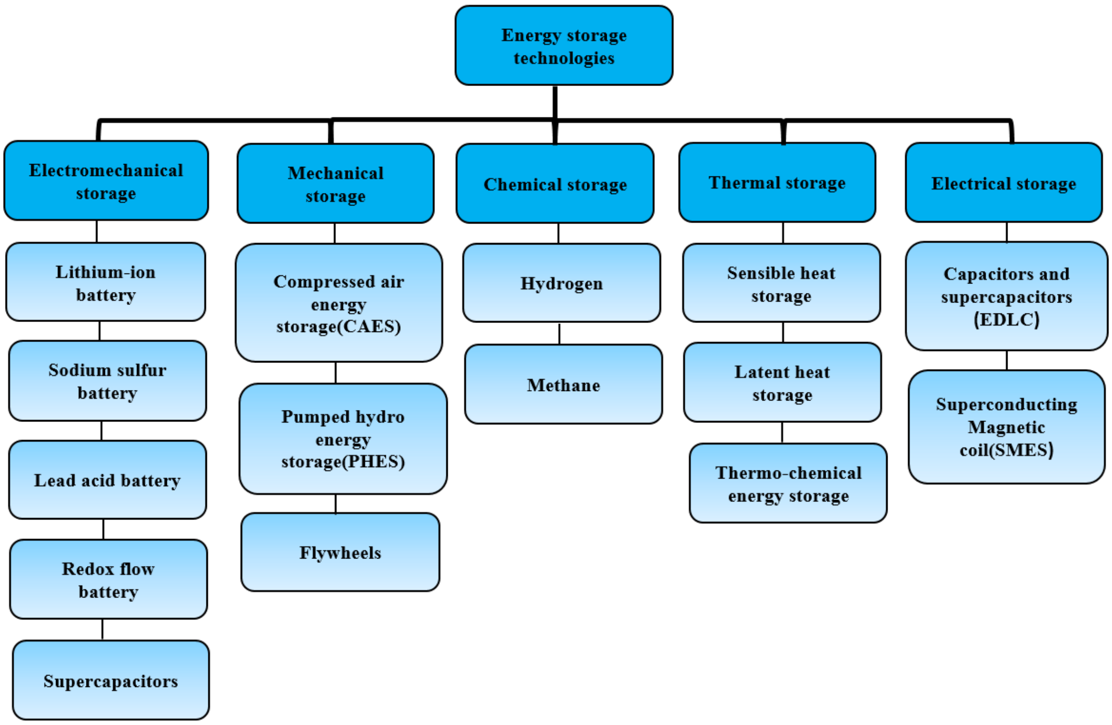

Fig. 1. Classification of energy storage technology [5]

A) Chemical energy storage systems

Sorption and thermochemical reactions are two novel chemical and thermochemical energy storage technologies that are mostly used for long-term operations or storage. Coal, gasoline, diesel fuel, biodiesel, butane, and liquefied petroleum gas are the only few chemical fuels available on the market (LPG).

- *Hydrogen: The electrolysis process uses hydrogen to create electrical energy, and only water vapor is emitted after burning. A hydrogen producing unit (electrolyzer), a hydrogen storage tank, and a fuel cell make up the hydrogen storage system. They're mostly used in gas turbines and hydrogen automobiles. The benefits of hydrogen include minimal emissions, increased efficiency, and quiet operation.*

- *Synthetic natural gas (SNG): Natural gas, which is mostly composed of CH4, is the most widely used gas fuel. Synthetic natural gas, or SNG, is a kind of gas made from coal that may be used in replacement for natural gas and combined with it to reduce its drawbacks and price. It offers an alternate energy source and can be transmitted using natural gas pipes.*
- Biofuel: It is a kind of energy generated from living stuff through biological processes. They come from both food (items intended for human consumption) and non-food sources. Biofuels (biodiesel, alcohol fuels, or biomass) are therefore used more often than hydrocarbon fuels [6].
- Thermo-chemical energy storage (TCES): Their key advantages are its high storage density and low heat losses.

B) Electrochemical energy storage systems

The benefit of batteries and fuel cells, as shown in Figure 2, is that they have high energy density. ECs, on the other hand, can reach great power density with extremely quick charge/discharge periods in various applications.

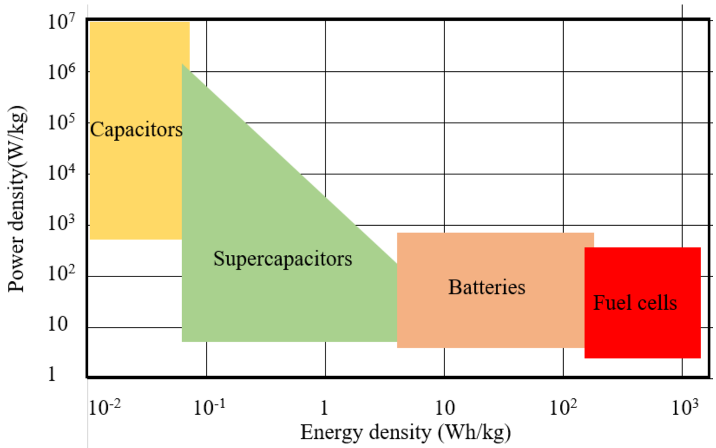

Fig. 2. Power density vs. energy density of various energy storage systems

C) Electrical energy storage systems (EESS)

They can store large amount of electricity and later provide it to the load. Changing magnetic fields with capacitors or superconducting magnets is a way for storing energy in the EESS. The three primary forms of EESS are capacitors, super capacitors, and superconducting magnetic energy storage (SMES).

D) Mechanical energy storage systems (MESS)

Mechanical energy storage uses heat, water, or air in conjunction with compressors, turbines, and other equipment to provide reliable alternatives to electro-chemical battery storage. Flywheel energy storage, pumped hydro storage and compressed air energy storage are among them.

- *Flywheel energy storage systems (FESS):* By increasing the spinning speed of the flywheel, the energy is stored in a flywheel as kinetic energy and released on demand by rotating the flywheel. Flywheel energy storage systems (FESS) are an environmentally friendly and cost-effective way to balance supply and demand in energy networks.
- Pumped hydro storage system (PHSS): Water is transported from the lower to the higher reservoirs using the PHSS system. During high-demand hours or peak time, a turbine generates electricity by releasing the same water from the upper reservoir into the lower reservoir.
- *Compressed air energy storage (CAES) system*

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A sealed enclosure is used in this structure. The released heat is re-used during the expansion. It's mostly used in high pressure storage facilities and subsurface caverns, where energy conservation, pressure stability, and low maintenance costs are important.

E) Thermal energy storage (TES) systems

TES systems may store heat or cold for later use in the event of a temperature change. Sensible heat, latent heat, and thermochemical TES are the three most common TES technologies. They are mostly used in applications like as space heating and cooling, as well as process heating and cooling.

III. ENERGY STORAGE SYSTEM COMPARISON

The comparison of energy storage technologies regarding their storage capacity and discharge power duration is given in figure 3.

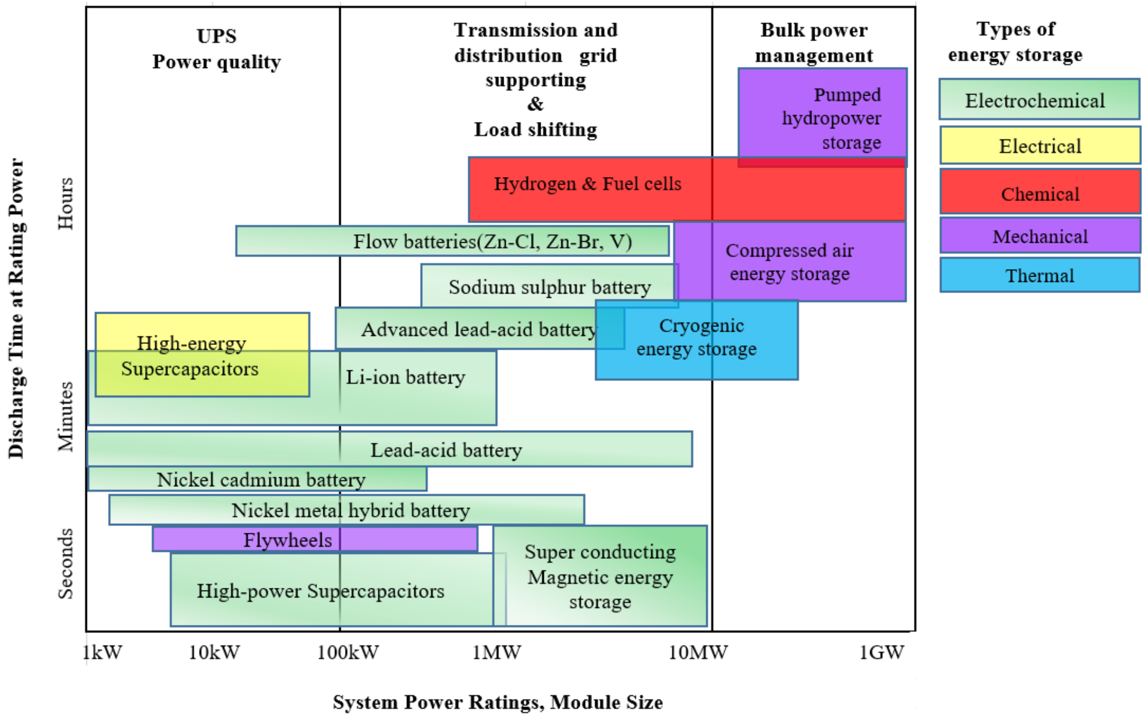

Fig. 3. ESS's comparison by rated power, energy and discharge duration [7] [8]

Table 1 shows a comparison of energy storage systems based on their many uses, power rating, storage length, lifespan, and capital cost.

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Tab. 1. Comparison of EESs [9][10]

Storage system	Applications	Power rating(MW)	Storage duration	Life time(Years)	Capital cost	
					$/kW	$/kWh
Pumped hydro storage(PHS)	Frequency control	0.1-5k	Small	40-60	0.6-2k	5-100
Compressed air energy storage (CAES)	Voltage control	5-300	Small	20-40	400-800	2-50
Flywheel	Load levelling	0-0.25	100%	15	250-350	1-5k
Supercapacitor	Voltage control	0-0.3	20-40%	0.5-5k	100-300	300-2k
SMES	UPS	0.1-10	10-15%	20+	200-300	1-10k
Lead-acid	Residential storage system	0-20	0.1-0.3%	5-15	300-600	200-400
Li-ion (Lithium ion)	UPS	0-0.1	0.1-0.3%	5-15	1.2k-4k	0.6-2.5k
Nickel cadmium(NiCd)	Emergency lighting	0-40	0.2-0.6%	10-20	0.5-1.5k	0.8-1.5k
ZEBRA	Renewable energy storage	0-0.03	15%	10-14	150-300	100-200
Network attached storage	Island grids	0.05-8	20%	10-15	1-3k	300-500
Vanadium redox battery (VRB)	Power quality	0.03-3	Small	5-10	0.6-1.5k	0.15-1k
Zinc-bromine flow batteries (ZnBr)	Long term storage	0.05-2	Small	5-10	0.7-2.5k	0.15-1k
Polysulfide bromide battery (PSB)	UPS	1-1.5	Small	10-15	0.7-2.5k	0.15-1k
Fuel cells	Electric hybrid automobiles	0-50	Negligible	5-15	10k+	-
Metal-Air		0-0.01	Very small	-	100-250	10-60
Low temperature thermal energy storage	Frequency control	0-5	0.5%	10-20	-	20-50
High temperature thermal energy storage	Voltage control	0-60	0.05%-1.0%	5-15	30-60	-

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IV. TRENDS AND CHALLENGES OF ENERGY STORAGE TECHNOLOGY

The trends and challenges of energy storage technology in microgrid applications are as follow:

- *Optimization of ESS configuration:* The optimum configuration of ESSs in constructing microgrids should be an amazing accomplishment, as should developing and creating correct models, software, and tools.
- *Modelling Software and tools:* The ESS's complexity necessitates the use of software-based modeling, which allows for effective analysis and optimization. As a result, trnsys, iGrhyso, ares, homer, dymola/modelica, and other software and tools have been widely used in a variety of applications.
- *Advanced lead-acid:* Advanced lead-acid batteries are increasingly employed in various industrial applications due to their safety and great performance. However, capacitor pricing, carbon price and availability, graphene additions, and other factors impact their costs.
- *Carbon Nanowalls (CNW) and Carbon Nanotubes (CNT) supercapacitors:* CNTs have great mechanical properties, electrical properties, and a high aspect ratio, making them ideal for supercapacitor electrodes. They had higher energy density and long battery durations as well (up to 100,000 cycles). As a consequence, they are the most advanced supercapacitor technology currently available.
- *Hybrid ESS*:High-power demand, transients, quick load variations, and high efficiency are all provided by hybrid ESS, which combines two or more energy storage technologies. Researchers focused on energy efficiency, charge and discharge management, optimum power flow, and improved control algorithms to produce sustainable hybrid ESS systems.
- *Smart ESS*: A hybrid energy storage system, a short-term storage module, and a medium/long-term storage module are all part of the smart energy storage system. Smart storage systems comprise power electronics devices, greater smart metering, controllers, human-machine interfaces, and networking interfaces.

V. CONCLUSION

The proper detailed profile of global energy storage is reviewed, evaluated, and presented in this article, emphazing microgrid (MG) applications. Because of their capacity to store energy during off-peak hours and deliver electricity during peak hours, MG with energy storage systems (ESS) has prominently developed. Creating an effective ESS for MG applications is a difficult task. The key problems for EES are to improve microgrid stability, power balance, sustainability, and environmental protection. Modeling, evaluation, and optimization of ESS may give comprehensive approaches and valuable contributions to the future generation of ESS systems. Consequently, the present study concentrates on EES setups, classifications, techniques, and energy conversion processes. The review revealed that each energy storage technique has its own set of optimal qualities, requirements, and size of energy storage. Finally, future ESS trends and difficulties are discussed.

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