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Energy Storage Method: Superconducting Magnetic Energy Storage

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ABSTRACT

Magnetic Energy Storage (SMES) is a highly efficient technology for storing power in a magnetic field created by the flow of direct current through a superconducting coil. SMES has fast energy response times, high efficiency, and many charge-discharge cycles. These qualities make SMES a good candidate for smoothing power fluctuations and enhancing grid resilience, as well as providing better stability for renewable energy systems. This paper covers the fundamental concepts of SMES, its advantages over conventional energy storage systems, its comparison with other energy storage technologies, and some technical and economic challenges related to its widespread deployment in renewable energy. The prospects for SMEs contributing to a more sustainable and efficient energy infrastructure are also considered.

KEYWORDS - *Superconducting Magnetic Energy Storage (SMES), energy storage, superconductivity, renewable energy, grid stability, cryogenic refrigeration, power efficiency, energy density, pulse power, PCS systems, technical challenges, sustainability.*

1. INTRODUCTION

The importance of renewable energy in the world is due to several interconnected factors. It is now more crucial than ever to analyze and assess renewable energy for environmental conservation, energy security, economic growth, and more. Our survival on this Earth depends on a sustainable supply of resources, such as solar, wind, water, geothermal, and biomass energies, which govern the long-term sources of endless power generation.

Remember the following information:

i. Greenhouse Gas Emissions: Burning fossil fuels (mostly coal, oil, and natural gas) releases large amounts of gases called greenhouse gases. These gases are the main cause of climate change, leading to rising sea levels, extreme weather conditions, and global warming. This can be avoided by using energy sources that emit few or no greenhouse gases during their use.
ii. Diversified Energy Options: Renewable energy sources offer versatility by allowing nations to choose from a variety of alternatives for powering their economies. Fossil fuels are scarce and located in specific places, requiring supplies to come from select locales. Importing energy leaves many countries vulnerable to interruptions or conflicts that can disrupt supply. In contrast, renewable sources are abundant and easily accessible in many regions. For example, solar and wind energy generation potential is plentiful across much of the globe, reducing the need to import power directly.
iii. Localized Energy Production: Increased energy security can be achieved by reducing dependence on large-scale energy infrastructure. Most renewable energy technologies, such as photovoltaic cells and wind turbines, can be installed at the community or individual level.

iv. Cost-Effectiveness: Renewable energy is now more affordable due to technological advancements and economies of scale. Solar and wind energy are becoming increasingly cost-competitive with traditional fossil fuels as costs decrease.

Most renewable energy comes from intermittent sources, such as wind and solar power. This makes energy storage crucial to ensure a consistent flow of power when more solar/wind energy is generated than needed. Energy storage can also be used to balance out fluctuations in demand. Superconducting Magnetic Energy Storage (SMES) is an emerging method of generating electricity in many regions of the world. (**1**)

2. SUPERCONDUCTING MAGNETIC ENERGY STORAGE (SMES)

"Superconductivity is the ability of certain materials to conduct an electric current with no resistance. This property can have important applications. Superconductors require low temperatures to function. When conductive materials and compounds with electromagnetic properties are cooled to low temperatures, they exhibit two critical properties of superconductors: they show no resistance to electric current and generate a magnetic field, entering a superconducting state. Since the discovery of superconductivity, researchers have found many materials that can become superconductors, but the transition temperature varies for each material. Various materials, including single elements and compound elements, have shown high-temperature superconductivity."

TABLE 1: Critical Temperatures for various elements

Critical Temperature given in Kelvin

MATERIAL	ELEMENT OF ALLOY	CRITICAL TEMPERATURE(K)
Aluminium	Element	1.20
Cadmium	Element	0.56
Lead	Element	7.2
Mercury	Element	4.16
Niobium	Element	8.70
Thorium	Element	1.37
Tin	Element	3.72
Titanium	Element	0.39
Uranium	Element	1.0
Zinc	Element	0.91
Niobium/Tin	Alloy	18.1
Cupric Sulphide	Compound	1.6

The main part of an SMES system is the superconducting coil, which stores energy in the magnetic field created by the circulating current. The maximum energy stored is determined by two factors:
a) Coil attributes such as size and shape, which define the inductance value of the coil. A larger coil can store more energy.
b) The characteristics of the conductor which determine the maximum current it can carry. Superconductors can carry large currents in high magnetic fields.
The coil of the SMES, which houses the wires, needs to be kept at a low temperature to become superconducting. This is achieved using a special cryogenic refrigerator that maintains the desired temperature by using helium as the coolant.

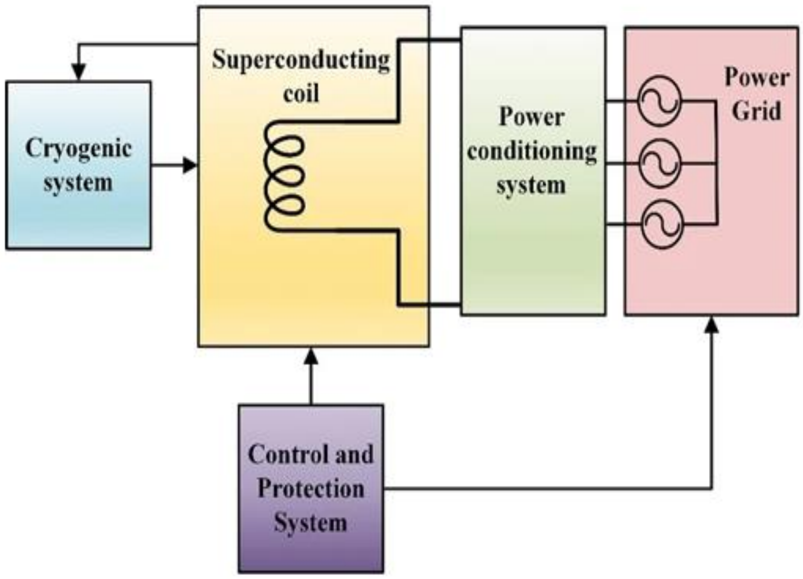

Fig 1: Schematic diagram of SMES

Helium is used in the refrigerator as the "working fluid" because nothing else remains fluid at these temperatures. Similar to a regular refrigeration system, electricity is used as the power source for the cryogenic refrigerator. The refrigeration equipment in a power plant's cryogenic refrigeration system consists of one or more compressors for gaseous helium and a vacuum enclosure known as the "cold box," which receives the compressed helium gas at ambient temperature and produces the liquid helium required for cooling the coil.

The charging and discharging of an SMES coil are not similar to the charging of other storage technologies. At any state of charge, the coil has a current carrying capacity. Although the current flows in one direction, the PCU must impose a voltage across the coil, which will be positive when energy is to be stored increasing the current consequently. Likewise for the discharging, the electronics in the PCS are controlled to charge it up in a manner that it gives the appearance of being a load across the coil. This creates a negative voltage which has the effect of discharging the coil. Hence the power is the product of the applied voltage and the instantaneous current. The coil current and the allowable voltage specified by SMES manufacturers have inherent margins in terms of safety and performance. Consequently, the rating power of the PCS often defines the rated capacity of the SMES unit. Thus, the PCS offers an intermediary between the stored energy, connected with the direct current running in the coil, and the AC in the power grid. The control system creates a relationship between the power request from the grid and the power feed into and out of the SMES coil. It receives dispatch signals from the power grid as well as status information from the SMES coil. The overall response of the SMES unit depends upon both the dispatch request and the charge level. The control system also monitors the state of the SMES coil, the refrigerator, and other Sure, here is the rewritten text with corrections. (**2**)

3. COMPARISON WITH OTHER ENERGY STORAGE SYSTEMS

SMES has several key advantages over various kinds of energy storage systems, such as batteries, Pumped Hydroelectric Storage (PHES), CAES, flywheels, and supercapacitors. One of its most significant advantages is its efficiency, which is often in excess of 95%. This is because the electric current carrying superconducting coils do not endure energy loss in the form of heat at their operating low temperatures. In comparison, batteries have an efficiency of 30-50%, pumped hydro has an efficiency of about 70-85% due to friction, and CAES has an efficiency of 40-70% where energy is lost in the compression and decompression steps. Additionally, SMES systems have the capability to respond to changes in power levels within milliseconds, which is helpful for most high-power applications. In contrast, batteries, pumped hydro, and CAES can only respond within minutes on average. Furthermore, SMES has almost infinite cycle life because there are no losses from chemical reactions or mechanical wear and tear, unlike batteries which last 500-3000 cycles. SMES also has a very high power density and can discharge energy very fast, making it ideal for grid stabilization. This is unlike batteries, which have restricted scenarios in which they can discharge instantly, and pumped hydro which is more suited for energy storage over a longer time. Flywheels have high power density but less energy storage capacity as compared to SMES. Additionally, SMES is environmentally friendly during its operation, as it neither emits any chemical agents nor requires fuel, unlike batteries that depend on chemical reactions and extraction of resources. CAES sometimes involves the burning of fossil fuels in the compression of air. Due to the fact that SMES consists of no moving parts, there are few maintenance requirements and no chemical reactions taking place.
The major concern is the cooling systems required to sustain superconductivity. In contrast, batteries need constant supervision, while pumped hydro and CAES systems call for frequent mechanical check-ups. Overall, SMES is well-suited for applications where high efficiency, short rise/fall time, long cycle life, and high power density are requested, and provides excellent performance in specific applications such as grid regulation and voltage control, even though the cost per energy density is much higher than battery or CAES. (**3**).

TABLE 2: Comparison of some energy storage technologies in electric power system

Type	Advantage	Disadvantage	Application
Pumped storage	Can be massive, natural technology	Limited location, larger investment project	System backup, frequency control,
Flywheel energy storage	Fast response, instantaneous power , faster response, environmental pollution	low energy density, high cost to ensure the safety of the system, big noise	Frequency control,UPS, power quality, peak shaving
Flow battery	Long life, easy combination, high efficiency	Small battery capacity	Reliability control, backup power, renewable energy
Lithium-ion battery	Lightweight, large storage capacity, small self-discharge coefficient	High-cost, immature large-scale mass production	power quality, reliability control, backup power, renewable energy
SMES	Fast response, high conversion efficiency, big specific power	High cost, difficult maintenance	Voltage support, power compensation, system stability improvement
Supercapacitors	Simple installation and run in a variety of environments	High cost, low-energy storage	Short-term, high-power load smoothness

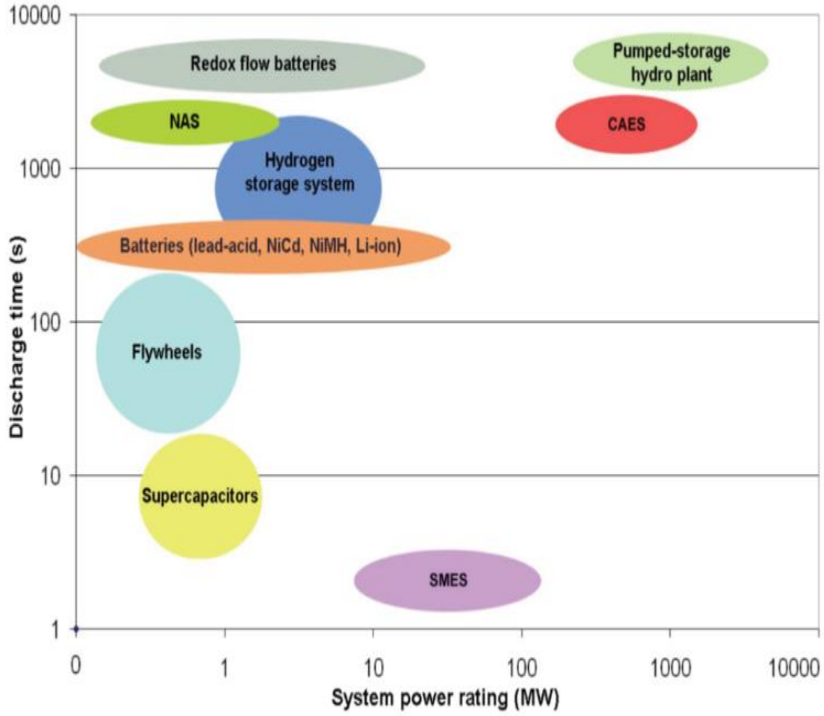

Fig 2: Graphic comparision of energy storage system.

4. TECHNICAL CHALLENGES

Superconducting Magnetic Energy Storage (SMES) faces several technical constraints that have limited its use in the market. One major problem is the need to cool the superconducting coils to operating temperature using liquid helium or liquid nitrogen, which requires extensive and energy-intensive cooling circuits.

These cooling systems result in large operational expenses and inefficiencies in the overall system because the superconducting state requires constant energy consumption. Additionally, superconducting materials like niobium-titanium or superconducting high temperature materials are not readily available in the market and are costly to produce. SMES systems also have low energy density, meaning the total stored energy is relatively low compared to other storage capacities, making them unsuitable for bulk energy storage. Another drawback is the production of a magnetic field by the superconducting coils, which may interfere with the operation of nearby equipment, necessitating the incorporation of isolation principles to limit such interferences. Furthermore, SMES systems face scalability challenges, as they are unable to effectively and economically scale up for large energy storage demands, being primarily used for peculiar, short duration, and high power instead of long-term energy storage. (4)

5. CONCLUSION

SMES is well-suited for power sources that operate for short periods, as its power density significantly exceeds its energy density. This makes it an ideal choice for uses like pulse sources, uninterruptible power supplies (UPS), or flexible alternating current transmission systems (FACTS) for electrical grids. While numerous SMES units have been successfully installed and operated for many years, the primary challenge for the broad commercialization of SMES is the high initial investment required. Power conversion systems (PCSs) with higher ratings and reduced harmonics should be created using innovative circuit designs and control techniques tailored to the substantial capacities of SMES systems. Additionally, there is a need to develop versatile SMES systems for different applications within power networks. These systems could be realized by combining various control methods and optimizing the configurations of PCSs, ultimately improving the performance-to-cost ratio of SMES systems and speeding up their practical adoption in power applications.

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