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A Review of Trends of Energy Storage and Their Applications for Effective Power Generation in India

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Abstract—*The global demand for electricity is huge and it is governing by approximately 3.6% annually. According to International Energy Association (IEA), up to 2040 CO_2 is doubled and earth's temperature is increases by 7% due to largely consumption of conventional energy resources which leads the global warming. At present, U.S. has about 18.25%, Canada 2.16% and India has 5.13% of total electricity production. So, the use of Renewable energy (RE) resources is become an alternative for conventional power generation. The use of Energy Storage Technologies (EST), in today's electricity network can minimize the threat of global warming. EST are a strategic importance to India. EST would improve the voltage regulation, flexibility, reliability and dynamic grid stability of the power system by providing stable and energy reserves. According to India Energy Storage Alliance (IESA), up to 2022, the market potential for energy storage systems in renewable energy applications would be 6000MW and of this 2000MW in OFF-GRID Renewable energy market. The Ministry of New and Renewable Energy (MNRE), India has set an ambitious target to generating over 175 GW of Renewable Energy by 2025. In the following paper, I will be introducing some basic knowledge of EST, their type with applications and futuristic use of EST in India.*

Keywords*: International Energy Association (IEA), Global Warming, Renewable Energy (RE), Energy Storage Technology (EST), India Energy Storage Alliance (IESA), Electricity Network, OFF-GRID system, Ministry of New and Renewable Energy (MNRE)*

1. INTRODUCTION

In todays throughout the world, the demand of reliable power is increases continuously. Both households and industries required large amount of energy. According to International Energy Association (IEA), the requirement of worldwide energy has increases to more than doubled from 1970 to present era and it is growing up by approximately 3.6% annually [1]. The demand of power increases due to population growth and increased prosperity. The production of electricity is from conventional and non-conventional sources of energy. About 80% of total energy is derived from conventional sources of energy such as coal, petroleum oil, natural gas, etc. and similarly it leads the emission of carbon dioxide (CO_2) which increases the global warming, a major anthropogenic greenhouse gas (GHG) [2].

So, the renewable energy resources are a promising solution for a safe and environmentally compatible energy supply. About 17.5% of the total global energy is derived from the renewable energy resources. These resources include wind power, solar power, hydropower, biomass, biofuel and geothermal energy [3].

India is rich in renewable energy resources and their potential has not been properly tapped due to technological growth and India is the first country in world to established separate ministry for renewable resources i.e. Ministry of New and Renewable Energy (MNRE) and setup a target of generating 175 GW of renewable energy by 2025 and investment of US dollar 150 billion [4]. In India, renewable energy resources are biomass, biofuel, solar, wind and hydropower and also contribute 5% of total power production [5].

The continuous growth of energy consumption, recent technology advances in power generation and environmental consideration leads to application of renewable energies. But due to small capacity and power quality or imbalance between supply and demand may occur. To mitigate the power quality issues, Energy Storage Technology (EST) systems are widely used. The use of EST system, combined with energy generation system (solar panels, wind turbine, water turbines, etc.) has been considered to improve the reliability and overall usefulness of the power systems [6]. They provide various kind of grid services such as frequency regulation, spinning reserve and improved power quality.

This paper talks about all the energy storage technologies (EST) classified on the basis of the form of energy being stored and their futuristic applications.

2. ENERGY STORAGE TECHNOLOGY (EST) SYSTEMS

Energy Storage Technology (EST) system is the capture of energy produced at one time for use at a later time. EST stores electrical energy when it too much generates by the energy generating system and supplies electrical energy to grid system when it generates too little energy [7]. Energy Storage is the storage of any form of energy that can be used further to perform some useful operations. Energy Storage is now a dominant factor in our economic development with the extensive introduction of electricity [8]. It is the most promising technology to lower the fuel consumption in the transport sector.

3. CLASSIFICATION OF ENERGY STORAGE TECHNOLOGY (EST) SYSTEMS

There are various methods to classify the various energy storage technologies, for example, in terms of their functions, response time and suitable storage durations. The most commonly used method to classify the EST is based on the form of energy stored in the system as shown in Fig.1[9].

3.1 Electrochemical energy storage system: -

In electrochemical EST, the chemical energy contained in the active material is converted directly into electrical energy. The storage of energy is due to the chemical reactions between the two different chemicals and release high amount of energy and most common example of electrochemical storage is battery [10]. Batteries are to be considered more efficient compared to other EST in terms of scalability, lifetime, efficiency, discharge time weight and mobility of system. Among batteries the rechargeable lithium ion batteries are the most successful EST [9-11].

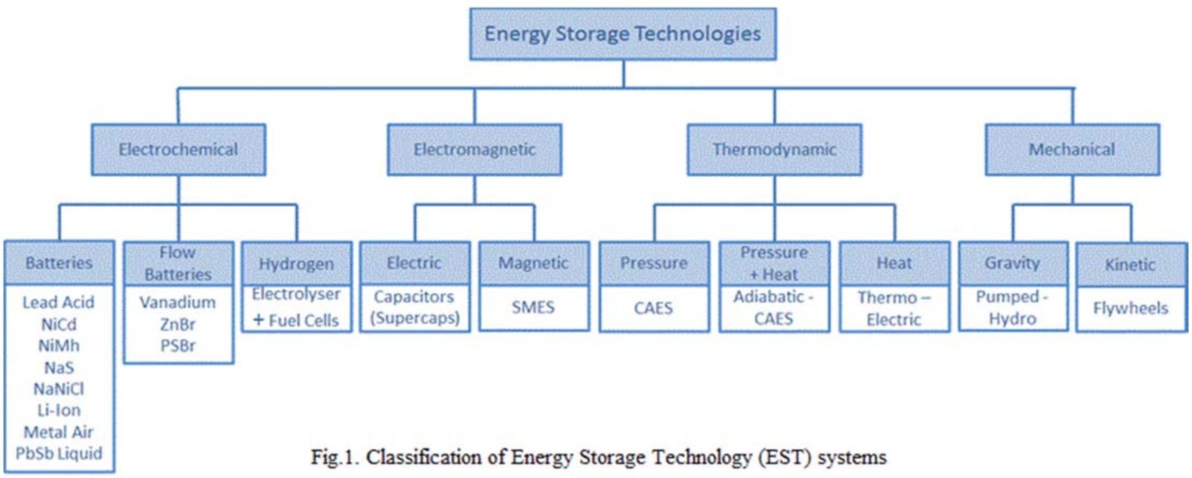

Fig.1. Classification of Energy Storage Technology (EST) systems

Hence, the operational voltage and current levels are generated through series or parallel combination of cells. A simplest circuit of battery and an explanation of its operation is shown in Fig.2. [11]

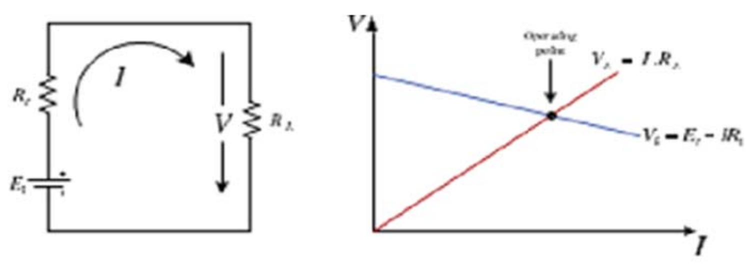

Fig.2. Equivalent circuit of a battery and its operating point

3.2 Electromagnetic energy storage system: -

Electromagnetic EST is an emerging technology, it stored the energy in the form of magnet. The development of electromagnetic energy storage includes the material advancement for the better utilization of superconducting materials, which have low electrical resistance at low temperatures [12]. It allows the large currents at low electrical resistance transferred with minimal losses and has applications for central power stations. The amount of energy is stored in the magnetic form and dependent on the intensity of the magnetic field and permeability of the materials.

It has significant advantages because it has no heat losses and rapid discharging times but still it requires research to determine the suitability and economic feasibility of magnetic energy storage systems [13].

3.3 Thermodynamic energy storage system: -

It is extensively investigated as an environmentally-friendly technology. This technology would store the intermittent energy that can be available to use when it is required. Solar energy is an example of intermittent energy. Thermodynamic EST stores the solar energy in daytime and it is used during the night time.

The high fluctuations in the availability of solar energy is present a major challenge for systems to store and use this resource effectively.

i. **Compressed Air Energy Storage (CAES): -** It is a way to store large amounts of renewable power by compressing air at very high pressure (approx. 70 bar) and temperature (approx. 180^{o}C) beneath the underground caverns, depleted wells or aquifers [14].
ii. **Adiabatic Compressed Air Energy Storage: -** It is the advanced version of conventional CAES because it worked without combustion of natural gas and does not require the storage of fossil fuel. Its actual efficiency is about 70-75 % [15].
iii. **Thermoelectric: -** It is based on the combination of thermodynamic cycles. During charging process, electricity is used to drive a heat pump which heats up a thermal storage medium while cooling another medium at lower temperature. During discharging the temperature departure between hot and cold thermal storages is used to drive a thermal engine and finally thermal energy converted into electrical energy [16].

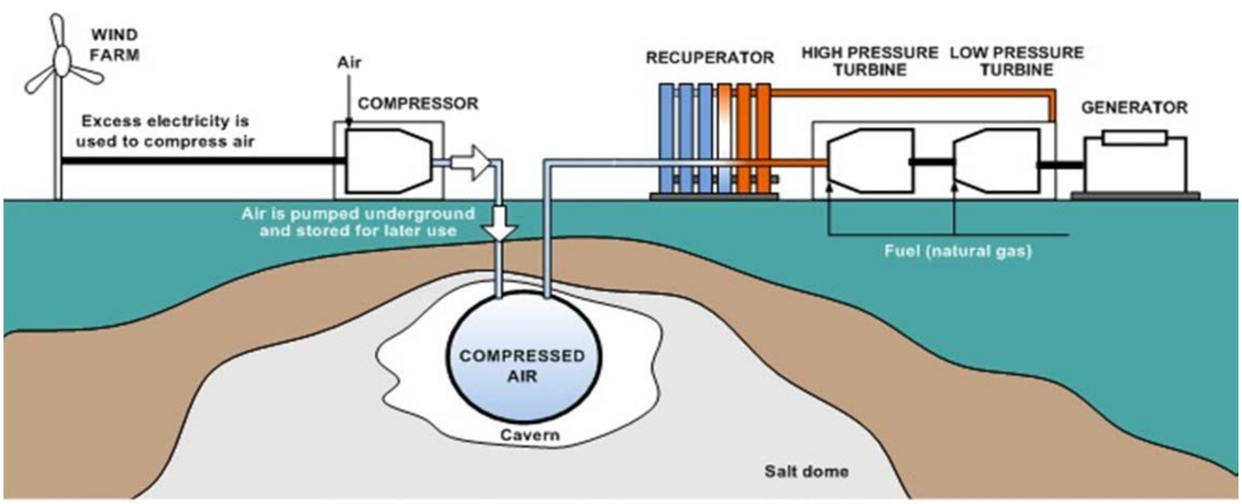

Fig.3. Adiabatic Compressed Air Energy Storage

3.4 Mechanical energy storage system: -

This system typically convert electricity into various forms of energy. Hydro storage is a simple example of mechanical EST. but its efficiency is low about 50% due to system ineffectiveness. Mechanical EST is of three types-

i. **Pumped Hydro Energy Storage (PHES): -** It is a well-established and acceptable technology in many commercially sectors for better utility-scale electricity storage and has been used since 1890s. Its flexibility and stability makes it possible to improve grid stability. The pumped hydro energy storage (PHES) systems is the most suitable technology for autonomous island grids and massive energy storage. In practice its efficiency is between 70% to 80% and it generates electricity ranges from 1000-3000MW [17].
ii. **Flywheel Energy Storage System (FESS):** - It is one of the oldest storage energy devices storage energy devices and it has several benefits. Flywheel Energy Storage System (FESS) employs the mechanical energy of a spinning rotor to store energy. There are of two types: low speed (under 10,000rpm) and high speed (above 10,000rpm). Low

speed systems are popular in industry [18]. FESS is used in hybrid vehicles, railway, wind power system, hybrid power generation system, marine, space and other applications. The given Fig.4. shows the construction of FESS.

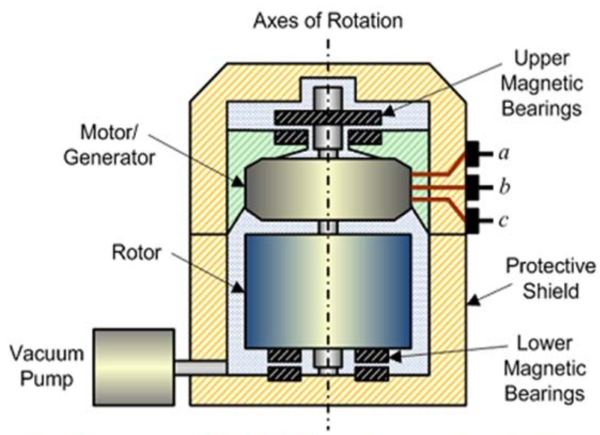

Fig.4. Construction of Flywheel Energy Storage System [18]

4. RENEWABLE ENERGY SYSTEMS IN INDIA

Renewable energy can be defined as an energy that comes from resources which are continually replenished by nature in the form of sunlight, wind, rain, geothermal heat, biomass, waves and tides, etc. [19]. There are seven renewable/sustainable energies have been identified such as solar energy, wind energy, hydro energy, geothermal energy, biomass energy, tidal power and wave energy.

Brief summary of renewable energy system in India is shown in Table 1. [19].

S.N.	Renewable Energy System in India	Available (in GW)	Being Used (in GW)	Unused (in GW)	Future Plans
1.	Solar Energy	700-2100	2.20836	Approx. 698-2098	Produce 20 GW of solar power by 2022
2.	Wind Energy	102	21.1363	Approx. 81	Ministry of New and Renewable Energy (MNRE) Projection to install another 20,000 MW by 2022
3.	Hydro Energy	150	39.788	Approx. 110	A target of expanding small hydro capacity to 7 GW by the end of the 12th Plan in 2017
4.	Geothermal Energy	10.6	0	10.6	Chhattisgarh government has decided to establish the first geothermal power plant of the country in the newly formed Balrampur district of the state
5.	Biomass Energy	23	1.285	21.715	Biodiesel is not sold on the Indian fuel market, but the government plans to meet 20% of the country's diesel requirements by 2020 using biodiesel
6.	Tidal Energy	8		8	The Ministry sanctioned a project for setting up of a 3.75 MW demonstration tidal power plant
7.	Wave Energy	40	0.001	Approx. 40	The Government of Maharashtra and Government of India have plans to announce policies to attract private investors in this field on a BOO (Build Own Operate) basis

Table 1. Renewable Energy System in India. [19].

5. BARRIERS TO ADOPT ENERGY STORAGE TECHNOLOGIES SYSTEM (EST)

There are various types of barriers which limited the installation and use of energy storage technologies system in various countries but especially in India. The barriers are categorized into four parts:

i. Financial factors
ii. Technological factor
iii. Environmental factor

iv. Social/economic/political factor

Some of the barriers are explained below.

5.1 High Initial Capital Cost: - Most of the technologies are imported from some developed countries because they give high efficiency output but they have large capital which makes it more expensive [20].

5.2 Lack of Financing Mechanism: - There is lack of sufficient government financing mechanisms to promote and adoption of EST systems by industries [20].

5.3 Inefficient Technology: - Compared to the average emissions from coal and oil fired thermal power plants in European Union (EU-27) countries, India's thermal power plants emit 50-120% more CO_2 per kWh Produced [21]. Inefficient technology becomes obsolete prematurely. Lack of proven reliability for the technology in India is the barrier to adopt advanced EST systems.

5.4 Geographical Conditions: - The Geographical conditions and weather of India are diverse in nature. For example, solar energy is limited in day hours, along with an uneven geographic distribution of solar resources; solar power is intermittent. The technical potential takes into account geographical restrictions. For example, land-use cover that reduces the theoretical potential [22].

5.5 Lack of research and development (R&D) work: - EST systems in India are now still in development stage because of small concentration on research and development work. Large investment also required in R&D work which also makes a barrier [20,22].

5.6 **Technology complexity: -** Most of the energy storage technologies are complex in nature. For example, Flywheel energy storage system, adiabatic compressed air EST, etc. [21].

5.7 **Unable to meet electricity power demand alone: -** The demand of electrical energy in India for 2021–2022 is expected to be at least 1915 tera watt hours, with a peak electric demand of 298 GW [23]. If current average transmission and distribution average losses remain the same (32%), India needs to add about 135 GW of power generation capacity, before 2017, to satisfy the projected demand after losses

S.N.	Dimensions of barriers to adopt energy storage technologies system (EST)	barriers to adopt energy storage technologies system (EST)
1.	Financial factor	i. High initial capital cost ii. Lack of financing mechanism iii. Transmission & distribution losses
2.	Technological factor	i. Lack of awareness of technology ii. Less efficiency iii. Technology complexity iv. Lack of research & development work v. Lack of trained people & training institutes vi. Lack of local infrastructure vii. Lack of national infrastructure
3.	Environmental factor	i. Scarcity of natural & renewable resources ii. Geographic conditions iii. Ecological issue
4.	Social/economic/political factor	i. Lack of experience ii. Rehabilitation controversies iii. Faith & Beliefs iv. Lack of political commitment v. Lack of adequate government policies vi. Lack of public interest litigations
5.	Market factor	i. Lack of consumer awareness to technology ii. Lack of sufficient market base iii. Unable to meet electricity power demand alone iv. Lack of paying capacity

Table 2. Barriers to adopt energy storage technologies system (EST)

6. APPLICATIONS OF ENERGY STORAGE TECHNOLOGIES (EST) [1,5,20,22]: -

i. Frequency support (spinning reserve) during loss of generation.
ii. Enhancing transient and dynamic stability.
iii. Providing dynamic voltage support.
iv. Improving power quality.
v. Increasing the overall security and reliability of power systems.
vi. Transmission capacity enhancement
vii. Area protection

7. CONCLUSIONS

The energy storage technologies (EST) system can play a very important role in the power system operation and dynamics. It ranges from transient stability enhancement. So, in this review paper, we provide a knowledge of most of the energy storage systems and classified them on the basis of form of energy being stored. Energy storage technologies are the fundamental requirement for innovative, and future energy production by the use of renewable energy resources.

Similarly, the selection of a correct energy storage system depends on different parameters and requirements specified by the application. The choice of which storage device should be used can be made on basis of necessary rated power, bridging time, footprint of the system, total cost, environmental conditions and restrictions, etc.

Also, discussed about the applications of energy storage system such as it improves the reliability of the system, improves dynamic stability and enhanced power quality of system, transmission capacity enhancement, and also give area protection.

Many energy storage solutions are available but they are different in their technology and specifications which make difficult to select. Most of the energy storage technologies are undergoing in research and development (R&D) like electromagnetic energy storage systems.

India is a country which is very rich in renewable energy sources, viz., solar, wind, biomass and hydro energy. Many of these resources has provide good potential employment opportunities, and offer better manufacturing condition locally. However, to achieve this goal, a number of barriers will have to be overcome, partially or completely, to increase the market penetration and acceptance of renewable energy technologies.

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