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Review on EES Application in Power Engineering System

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***Abstract:** In view of the projected global energy demand and increasing levels of greenhouse gasses and pollutants, there is a well-established need for new energy technologies which provide clean and environmentally friendly solutions to meet end user requirements. Present review work is an effort to study the electrical power generation because of the need to reduce greenhouse gas emissions and to introduce mixed energy sources. Review based on the present and future Electrical Energy Storage (EES) system which is recognized as underpinning technologies to have great potential in meeting these challenges, whereby energy is stored in a certain state, according to the technology used, and is converted to electrical energy when needed. Review work starts with an overview of the operation principles, technical and economic performance features and the current research and development of important EES technologies, categories based on the types of energy stored. Work intends to mitigate this problem by providing a comprehensive and clear picture of the state-of-the-art technologies available, and where they would be suited for integration into a power generation and distribution system. Moreover, the comparison had been made between RES and EES system.*

***Keywords:** Electrical Energy Storage and Power Engineering.*

INTRODUCTION

The growing demand for technologies that can stabilize power generation and delivery is driving research toward developing new technologies. This is increasing the number of systems under investigation across the entire innovation chain from very early stage research through to the development of conventional devices to increase performance and reduce cost. As with all new technologies there remain many technical challenges facing the developers of future electrochemical power systems, however, the increased understanding of the value of these technologies is leading to an increase in the scale of programs looking to improve these technologies. It is unclear which new technologies will emerge as leaders in the future power market but it is clear that there will be a significant improvement over current devices in terms of cost reduction, performance, and availability over the next decade. Electrical power generation is changing dramatically across the world because of the need to reduce greenhouse gas emissions and to introduce mixed energy sources. The power network faces great challenges in transmission and distribution to meet demand with unpredictable daily and seasonal variations. Electricity is not usually stored per se. Energy storage technologies instead convert electricity to other energy forms (gravitational, pneumatic, kinetic, chemical), with a characteristic turnaround efficiency usually driven by the simplicity or complexity of conversion and reconversion between electricity and the stored energy form. For example, it can be 90-95% efficient to convert electricity to kinetic energy and back again by speeding up or slowing down a spinning flywheel. Storing electricity by compressing and later re-expanding air is usually less efficient (75%), since rapid compression heats up a gas, increasing its pressure, making further compression difficult. The electric energy lost in energy storage drives up the overall cost of generating reliable electricity from the wind or solar power. Another cost of energy storage is the capital investment required for the energy storage system. These costs are driven by the weight of material or volume of containment vessels needed to store a given amount of energy, termed energy density (kWh/kg or kWh/liter), again characteristic of each energy storage form.

Electricity systems require the energy supply to match the fluctuating demand of energy on a second by second basis. Renewable energy systems usage is increasing worldwide, yet, power industries do not depend solely on them due to the intermittent supply. Renewable energy systems intermittency is mainly due to the unavailability of the natural phenomena that causes the generation of the energy throughout the day. Additionally, RES cannot be easily regulated or dispatched to the energy supply chains because they produce high energy generation when not needed. The main solution to this problem is to deploy energy storage systems (ESS) allowing the storage of the electrical energy [1-5]. Electrical Energy Storage (EES) is recognized as underpinning technologies to have great potential in meeting these challenges, whereby energy is stored in a certain state, according to the technology used, and is converted to electrical energy when needed. EES technology refers to the process of converting energy from one form (mainly electrical energy) to a storable form and reserving it in various mediums; then the stored energy can be converted back into electrical

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energy when needed [6-10]http://www.sciencedirect.com/science/article/pii/S0306261914010290?np=y - b0020. EES can have multiple attractive value propositions (functions) to power network operation and load balancing, such as: (i) helping in meeting peak electrical load demands, (ii) providing time varying energy management, (iii) alleviating the intermittency of renewable source power generation, (iv) improving power quality/reliability, (v) meeting remote and vehicle load needs, (vi) supporting the realization of smart grids, (vii) helping with the management of distributed/standby power generation, (viii) reducing electrical energy import during peak demand periods.

In many scenarios, demand for EES and selection of appropriate EES technologies have been considered to be important and challenging in countries with a relatively small network size and inertia. For example, the UK electric power network currently has a capacity of Pumped Hydroelectric Storage (PHS) at 27.6 GW h. Although PHS facilities have been built worldwide as a mature and commercially available technology, it is considered that the potential for further major PHS schemes is restricted in the UK. Therefore, it is of great importance that suitable EES technologies in addition to PHS are explored. Derived from the study of recent publications, various EES technologies had potentials to address the challenges faced by the UK energy systems. Many countries potentially need to address similar challenges which can be solved or improved by suitable EES technologies [11-15]. Many researchers had reviewed electrical energy storage technologies for stationary applications [16-20].

However, the wide variety of options and complex characteristic matrices make it difficult to appraise a specific EES technology for a particular application. This review work is intended to mitigate this problem by providing a comprehensive and clear picture of the state-of-the-art technologies available, and where they would be suited for integration into a power generation and distribution system.

DISCUSSION AND CONCLUSION

The application outlooks and potentials of EES in power system operations have been widely reported in recent years [4-9]. EES is a promising option for various applications with corresponding specifications. The applications of EES technologies cover a wide range including the maintenance of power quality, power system protections and energy management. The EES technologies used for maintaining power quality will need to have very fast response time (at the millisecond level). Flywheels, conventional batteries, SMES, capacitors, and supercapacitors are well suited for this service. Some flow batteries, such as VRB and PSB, are also technically suitable for this service. The applications of VRB systems to maintain power quality have been studied. One example from the study is the Sumitomo Electric Industries (SEI) VRB facility (rated power 170 kW) which works in combination with a wind turbine (275 kW) for stabilization of wind turbine output fluctuations; the system demonstrated good performance. When EES is adopted for bridging power, they are required to have moderate power rating (100 kW–10 MW) and response time (up to around 1 s), in order to provide the continuity of power supply at energy gap periods (up to several hours), such as the time interval for switching the system from one source of power generation to another. Conventional batteries and flow batteries are suitable for this application. Flywheels, supe capacitors, and fuel cells are also reported for such types of applications. Piller Power Systems Ltd. has practical experiences in using flywheels as ride-through power sources. The P–Q control strategy of a supercapacitor energy storage system for low voltage ride-through as well as damping enhancement of the doubly fed induction generator system. The fault ride-through capability of the generator has been investigated for a severe symmetrical three-phase to ground fault on the grid bus.

EES plays an important role in energy management for optimizing energy uses and decoupling the timing of generation and consumption of electric energy. Time shifting and peak shaving are typical applications in energy management. Energy management application can be further classified based on the application power rating: large-scale (above 100 MW) and medium/small-scale (~1–100 MW). PHS, large-scale CAES and TES can be used for large-scale energy management. Flow batteries, large-scale conventional batteries, fuel cells and solar fuels are more suitable for small/medium-scale energy management. For instance, both the Huntorf and the McIntosh large-scale CAES plants provide the functions of energy management. Integration of renewable power generation: The inherent intermittent renewable generation can be backed up, stabilized or smoothed through integration with EES facilities. Emergency and telecommunications back-up power: In the case of power failure, EES systems can be operated as an emergency power supply to provide adequate power to important users including telecommunication systems until the main supply is restored, or to ensure the system enabling orderly shutdown. For emergency backup power, instant-to-medium response time and relatively long duration of discharge time are required. For example, one of the world's first utility (hybrid) CAES backup systems was recently installed at a Co-op Bank data center to provide an emergency supply of electricity. For telecommunications back-up, the instant response time is essential. Ramping and load following: EES facilities can provide support in following load changes to electricity demand. Time shifting: Time shifting can be achieved by storing electrical energy when it is less expensive and then using or selling the stored energy during peak demand periods. EES technologies are required to provide power ratings in the range of around 1-100 MW. PHS, CAES and conventional batteries have experience in this service; flow batteries, solar fuels and TES have demonstration plants or are potentially available for this application. Peak shaving and load leveling: Peak shaving means using energy stored at off-peak periods to compensate electrical power generation during periods of maximum power demand. This function of EES can provide economic benefits by mitigating the need to use expensive peak electricity generation. Load leveling is a method of balancing the large fluctuations associated with electricity demand. Conventional batteries and flow batteries in peak shaving applications, as well as in load following and time shifting, need a reduction in overall cost and an increase in the cycling times to enhance their competitiveness. Low voltage ride-through: It is crucial to some electrical devices, especially to renewable generation systems. It is a capability associated with voltage control operating through the periods of external grid voltage dips. High power ability and instant response are essential for this application. In order to smooth the fast wind-induced power variations and to reinforce the low voltage ride-through capability, the integration of a super capacitor EES device in a doubly fed induction generator designed. A VRB-based EES system was simulated, to improve low voltage ride through capability and to stabilize output power of direct-drive permanent magnet wind power system. Transmission and distribution stabilization: EES systems can be used

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to support the synchronous operation of components on a power transmission line or a distribution unit to regulate power quality, to reduce congestion and/or to ensure the system operating under normal working conditions. Instant response and relatively large power capacity with grid demand are essential for such applications. Black-start: EES can provide capability to a system for its start-up from a shutdown condition without taking power from the grid. A typical example is the Huntorf CAES plant that provides black-start power to nuclear units located near to the North Se. Voltage regulation and control: Electric power systems react dynamically to changes in active and reactive power, thus influencing the magnitude and profile of the voltage in networks. With the functions of EES facilities, the control of voltage dynamic behaviors can be improved. Several EES technologies can be used or potentially used for voltage control solutions. Grid/network fluctuation suppression: Some power electronic, information and communication systems in the grid/network are highly sensitive to power related fluctuation. Spinning reserve: In the case of a fast increase in generation (or a decrease in load) to result in a contingency, EES systems can feature the function of spinning reserve. The EES units must respond immediately and have the ability of maintaining the outputs for up to a few hours. Transportation applications: Providing power to transportation, such as HEVs and EVs. High energy density, small dimension, light weight and fast response are necessary for implemented EES units. For instance, a hybrid power train using fuel cell, battery, and supercapacitor technologies for the tramway was simulated based on commercially available devices, and a predictive control strategy was implemented for performance requirements. The vast availability of ESS technologies, RES would be easily integrated into the current power industries, yet, when comparing that ESS against each other, it is clear that most of these technologies have low efficiencies i.e. 95% and for power industries hence directly neglected resulting in huge losses. Based on the comparison, it is noted that super capacitor and superconducting magnetic energy storage and flywheel energy storage are branded with best efficiencies, in addition, to faster response time, an important aspect for the rapidly changing intermittence in the RES. Finally, their lifetime is an adequate lifespan to convince power industries to accept the RES penetration into their power grids. Since these ESS technologies are unrelated to the geothermal energy storage mechanism, the geothermal energy storage is not suitable for RES. Possibility of achievement: Higher charging and discharging rate, Durability resulting in lower overall cost for a 20 year lifetime, environmentally friendly, especially at disposal time and Temperature independent storage capacity. This review work provides an overview of the current development of various types of EES technologies, from the recent achievements in both the academic research community and industrial sectors. A comprehensive analysis is carried out based on the relevant technical and economic data, which leads to a number of tables and figures showing a detailed comparison of various EES technologies from different perspectives. Further discussion on EES power system application potentials is given based on the current characteristics of EES and the relevant application specifications. The overview has shown a synthesis of the state-of-the-art in important EES technologies, which can be used for supporting further research and development in this area and for assessing EES technologies for deployment. Finally, within the context of the power system itself, it's important to recognize how interrelated energy efficiency is with grid reliability. In many areas of the US, transmission constraints have reached the point where they not only cost consumers billions of dollars in congestion charges, they threaten the integrity of the power system itself. Over the past twenty years, the situation has continued to deteriorate to the point where now the question of installing a new line is nearly moot in some locations. By the time it was completed, demand would long since have outstripped the ability of the local grid to meet it, so a short-term solution must be implemented in the interim. FACTS devices offer a good example of how efficiency and reliability improvements often go hand in hand. Unlike sifting and building a new transmission line, FACTS devices can be implemented quickly (less than a year from purchase to completion in some cases). They immediately boost the transmission capacity of the given line while also providing voltage support and bolstering the local grid's ability to withstand disturbances. As the reliable supply of energy, especially electric energy, continues to grow in importance, the potential impact of energy efficiency cannot be overstated. With the array of technologies and methodologies now available, efficiency stands ready to play a much larger role in the energy equation.

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