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Problems and Prospect of Energy Storage Technology and Its Application in Power Systems

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Abstract
The power system is always designed to fulfill the energy demand of the country. Most effective way to meet the momentary rise in energy demand is to develop advanced storage systems and technologies. Power source, energy storage has many potential applications in renewable energy generation grid integration, power transmission and distribution, distributed generation, micro grid and ancillary services such as frequency regulation, etc. In this article, the latestenergy storage technology profile is analyzed and summarized, in terms of technology maturity, efficiency, scale, lifespan, cost and applications, taking into consideration their impact on the whole power system, including generation, transmission, distribution and utilization. The application scenarios of energy storage technologies are reviewed and investigated, and global and Nigeria potential markets for energy storage applications are described. The challenges of largescale energy storage application in power systems are presented from the aspect of technical and economic considerations. Meanwhile, the modern energy storage systems and technologies can be broadly classified as mechanical, electrochemical /electrical, electromagnetic and thermal storages among which mechanical energy storage systems are described with their advantages and limitations is discussed in this article. Not only that this article also gives idea about different parameters of energy storage systems.

Keywords: *Problems; Energy Storage & Power Plants*

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I. Introduction

In order to establish a sustainable energy system and overcome energy and environmental crisis caused by the utilization of fossil fuels, a new energy revolution is taking shape in that with electricity as the central form of energy. It is characterized with the development and utilization of large-scale renewable energy. With the development of smart grid, supported by investment and government policies, the prospect of energy storage application are gradually emerging. Its potential applications could be suchas generation, transmission, distribution and utilization (Hu, 2015). These applications include increasing penetration level of large- scale renewable energy, improving power grid's efficiency, postponing and reducing construction cost of generation and power systems, improving power quality and energy efficiency, ensuring a high-quality, safe, realizable power supply, promoting the optimization of grid planning, scheduling management and operation control (Wang, 2015).

Energy storage is now becoming the integral part of the power generation infrastructure. Energy storage is highly required to balance supply and demand. However when both demand and supply are fluctuating rapidly continuously with time, the grid, which is the interface of power distribution, faces several problem in managing the power generation and distribution according to the demand (Wang, 2014). The grid balance can also be achieved through the use of different energy storage technologies. More over Higher levels of energy storage are required for grid flexibility and grid stability and to cope with the increasing use of intermittent renewable energy sources. Consequently, an energy reserve is required and energy storage devices can be very useful for an efficient energy management. Energy storage technologies basically perform two functions: Storing the excess energy generated in the system, and

Providing the stored energy for use whenever demanded by the system .Different Energy storage technologies such as compressed air energy storage, various types of batteries, flywheels, superconducting capacitors, etc., provide for multiple applications: energy management, backup power, load leveling, frequency regulation, voltage support, and grid stabilization (Hu, 2015).

The development and commercialization of energy storage technology will have a significant impact on power system in terms of future system model. In recent years, both engineering and academic research have grown at a rapid pace, which lead to many achievements. Due to rapid development of energy storage technology, the research and demonstration of energy storage are expanding from small-scale towards large-scale. Nigeria government is also paying attention to the development of energy storage technology, from strategic planning to demonstration projects, and the related policies associated with energy storage application value and potential markets are shown on the aspects of Nigeria energy, electric power, science research, transportation, environmental protection and so forth (USD, 2010).

So far main energy storage technologies have reached commercial or demonstration level all over the world, the developed technologies include pumped storage, com- pressed air, flywheel, lead acid batteries, lithium ion bat- teries, sodium sulfur batteries, flow battery, super capacitors and superconducting magnetic energy storage, etc. With fast development of material science, researches on new energy storage tech- nologies such as graphen based energy storage technolo- gies, are also carried out. In terms of scale up application in energy storage at present, hundreds of MW level energy storage demonstration projects have been built worldwide.

Current Status of Energy Storage Technology Development

According to the way of energy stored, the energy storage technology can be classified into five major categories, i.e. mechanical energy storage, heat-energy storage, electrochemical energy storage, magnetic energy storage and chemical energy storage (Zhu, 2014).

Mechanical energy storage

The mechanical energy storage technologies mainly include the pumped storage, compressed-air energy storage and flywheel energy storage. The pumped storage is the most mature technology, which is characterized with having large capacity, long service lifespan and low unit cost. However, the construction of the pumped storage power station is restricted by geographical conditions, the construction period is longer, and the overall investment is large. The compressed-air energy storage has the advantages of large capacity, long operation time, long service lifespan, etc. And also it is capable of supplying combined heat, cold, and electricity by converting the compressed-air into other alternative energy. However its efficiency is low, the system is complex, and the location requirement for the air storage mine tunnel is high. The flywheel energy storage has the advantages of high efficiency, fast response, long service lifespan, less demands on operation and maintenance, good stability, short construction period, small footprint and no pollution, but the energy density is low, easy to be self-discharge which is only suitable for short time applications.

Heat storage

Heat storage technologies are categorized into sensible heat storage and latent heat storage. The sensible heat storage can achieve the purpose of heat storage by increasing the temperature of the heat storage material, generally uses the water as the heat storage medium. The latent heat storage uses the regenerative material achieving phase change heat storage, which is implemented on the solar thermal power generation. The heat storage system in the photothermal system can provide the heat energy nee- ded or generate electricity when the solar radiation is insufficient in rainy days for example (Xu, 2013). Molten salt storage technology is currently a research hotspot which is applied to the concentrated solar thermal power plant. It has the advantages of low cost, high heat capacity and safety. However the problems in its practical application are still very prominent, in which corrosive characteristic is one of its shortcomings. In addition the molten salt solidification temperature is high, and easy to cause equipment scrapped.

Electrochemical Energy Storage

Electrochemical energy storage technologies include lead-acid battery, lithium-ion battery, sodium-sulfur battery, redox flow battery. Traditional lead-acid battery technology is well-developed and has the advantages of lowcostandeasymaintenance.

Electromagnetic energystorage

The electromagnetic energy storage mainly contains super capacitor and superconducting magnetic energy storage. Super capacitor has advantages of high power density, fast response, high efficiency, long cycle life, low maintenance, wide operational temperature range and so on. However, due to the low energy density, super capacitor is suitable for application in combination with other energy storage technologies (Zhang, 2016). The charging/dis- charging rate of superconducting magnetic energy storage is critical, and it has advantages of high power density, fast response, high energy conversion efficiency, long service lifespan, etc. It is suitable for high power requirement. But there are many disadvantages such as high cost, low energy density and complex maintenance.

Chemical Energy Storage

Chemical energy storage is considered as a secondary energy carrier using hydrogen or synthetic gas, of which hydrogen is electrolyzed, and it can also be synthetized into natural gas (i.e. methane) with carbon dioxide. This green technology without any pollution could lead to formation of large-scale energy storage which can store more than 100GWh energy. However it has problems of low energy conversion efficiency which is only 50%–60%, high cost, large investment and low security. At present, hydrogen energy storage technology has also been demonstrated in many countries (Qureilidis, 2016).

Applications of Energy Storagesin powersystems

The energy storage technology is a breakthrough to electrical ‘‘generation’’ and ‘‘use up’’ simultaneously which is the feature of conventional electrical energy technology, and it is adequate for various application fields, including renewable energy grid integration, power transmission and distribution, distributed generation, microgrid and frequency regulation (Xu, 2013). As a flexible power source, energy storage can be widely implemented and applied in power generation, transmission, distribution and utilization. The application scenario of energy storage canbe divided into five types described below.

Renewable energygeneration

Due to the fluctuating and intermittent characteristics of wind and solar power generation, the problems associated with integrating renewable energy and managing power system stability are becoming more and more prominent. Meanwhile, the severe impacts caused by large power system incidents highlight the urgent demand for high-efficiency, large-scale energy storage technology. Therefore, through the application of energy storage, redundant wind and solar power can be stored and power grid is in turn to be able to provide more stable power output, which provides fast support to the active power, enhances the capability of grid frequency regulation, and leads to large-scale wind and solar generation connecting to grid both stableandreliable.Therefore,energystoragetechnologyhas become one of central tools for integrating renewable energy generation with power grid.

Transmission anddistribution

With vigorous development of wind and solar power generation, it is difficult to realize complete absorption of renewable energy because of insufficient flexible resources and transmission corridor. Meanwhile, with the increase of wind and solar power penetration in power system, the intermittency and fluctuation will inevitably cause a volatility, high uncertainty and complexity in renewable energy generation, and will require more flexible resources for frequency regulation, load tracking and base-load supply. Moreover, renewable energy generation does not have the capability of stabilizing the power system disturbance. The integration of renewable energy generation will definitely affect the reliability and operational stability of power system. The application of energy storage technology in power system can postpone the upgrade of transmission and distribution systems, relieve the trans- mission line congestion, and solve the issues of power system security, stability and reliability.

Energy Storage application

Global Energy Storage Application

The applications of energy storage technology are distributed in all aspects of power systems (Zhang, 2016). In global energy storage projects, the energy storage is most widely applied for the grid-connected renewable energy projects, and the cumulative installed capacity accounted for 45%. Recently, this proportion is showing gradual reduction. The application of sodium sulfur battery is the most widely applied technology, and the installed capacity accounts for 68%. The installed capacity of sodium sulfur battery has reached338.9MWworldwide,accountedfor 46%,whichis only next to lithium ion battery. The core technology of sodium sulfur battery has been mastered by NGK.

Mechanical Systems

a**. Flywheel :**

Flywheel is the mechanical form of energy storage system in which mechanical inertia is the basis and kinetic energy is stored in the rotor which is actually a huge rotating cylinder. The main parts of the flywheel energy storage system are

i. Rotating body

ii. Bearing

iii. Electrical machine(generator/motor mounted on the shaft.)

iv. Power converter.

v. Containment chamber.

The rotating body is mainly composed of more energy dense composite and alloy materials. Ceramic superconducting materials can also be used in flywheel energy storage system. The rotor is kept at constant speed maintaining the energy in the flywheel. An increase in speed of the flywheel results in the increase in storage of the energy. The rotational speed of the flywheel can be increased by use of electrical motor and when the speed gets reduced then electricity is produced by the same electrical machine which now acts like a

generator. The operation of flywheel energy storage system mainly faces the loss due to friction. So to increase the efficiency of the system by reducing frictional loss two methods are opted. Firstly the flywheel is rotated in vacuum to reduce air friction loss and the spinning rotor is kept on the stator by magnetically levitated bearing which not only reduces frictional loss but also increases the lifespan than that of conventional bearings. The electrical machines that are used in the flywheels are mainly permanent magnet , Induction and reluctance machines but permanent magnet machines are preferred to eliminate the copper losses and there by mitigating heat losses in the vacuum environment of flywheel energy storage system.
There are several advantages of flywheel energy storage system. Some of them are given below.
1. Longer life span and requires very less maintenance.
2. The system is very eco-friendly and does not cause any pollution.
3. Rapid response due to less complex arrangements.
4. It can provide high quality, highly reliable uninterrupted power supply when required for several field of applications like communication networks, commercial facilities, industrial manufacturing, etc.
5. It can produce high peak power without any overheating issues.

b. Compressed Air Storage System (CAES):

This technology is mainly based up on the compression of air and storage in the underground cavern. It is actually a considered as the hybrid generation/storage system as it requires the combustion in gas turbine. When the air is compressed then the heat is produced and if this heat is not stored then the compressed air in which with natural gas and fuel is mixed must be reheated and ignited before the expansion in turbine which is connected to a generator. Some additional energy (via a recuperator) is put into preheating stored air to prevent chilling and brittling of turbine blades to improve efficiency of combustion and thereby increasing efficiency of the CAES plant .This process is called the diabetic CAES .Again it should be remembered that the heat produced if not stored then the heat dissipated will be treated as loss. So another technology named as advanced adiabatic compressed energy storage system is used in which the heat produced during the compression transferred by heat exchangers to other heat storage sites. During discharge of the compressed air the heat storage sites provide the necessary heat to avoid the combustion of the compressed air which is required to prevent the freezing of the turbine blades and vastly Carbon dioxide neutral.

c. Pumped hydro storage system (PHS):

Pumped hydro storage system is one of the dominant energy storage system in the world which is really feasible technology capable of storing huge amount of energy for relatively longer period of time. This storage technologies work in a reverse way than that of the traditional hydropower generation plant. There are two types of pumped hydro storage system according to their installation sites – underground and over ground (conventional). Conventional pure PHS system makes use of two reservoirs at different elevations-an upper storage reservoir providing head to the hydro power turbine and another to collect water back into the upper reservoir using surplus electricity during off period hours. When electrical energy required during peak hours the water is allowed to flow from higher reservoir to the lower reservoir powering a turbine with the generator and thus produces electricity while in pump back PHS system ,only one reservoir is used and as a result later is more economic and also provides uses related to the base load generations specially during the time of excess flow. In case of underground PHS system unused salt or coal mines can be used as the lower reservoir while depending up on the circumstances upper reservoir can be built in caverns. However the underground PHS system is much more expensive than conventional PHS system and also faces many difficulties like fracturing of soil due to pumping of huge amount of water up and down in high pressures. In this storage technology, the ratio of energy supplied to the network and the energy consumed while pumping must be considered to evaluate the overall efficiency of the energy storage system.

Need of Energy Storage Systems and Technologies:

The major need of energy storage system is due to importance given to utilize more renewable sources of energy and diminishing the use of fossil fuel and for the development of the future smart grid. Not only that there are other factors which encourages the need for the advanced storage systems such as-
1. **High generation cost during peak hours**. There is a huge scope to reduction of total generation costs through storage of electrical energy generated by lowcost power plants during the night and being reintroduced into the power grid during peak demand periods.
2. **Sometimes the distance between generating stations and consumers are very large**. As a result there is a great probability of power interruption for several causes like natural disasters or due to some other reasons like over load or operational accidents which may result in disruption of the supply and potentially affect large areas. Thus energy storage systems and technologies comes into act to supply power continuously for a certain period of time.

3. Sometime difficulty in meeting up power demand as well as output power fluctuations also occurs which can be minimized by these energy storage systems and there by stabilizing the transmission and distribution grid.

Different Parameters

There are different parameters which determine the quality of the storage devices .Some of them are given below :

1. **Storage Capacity**: It is defined as the amount of energy that the device can hold after completing the charging cycle.
2. **Energy Density**: It can be defined as the amount of energy that can be supplied from a particular storage device or technology per unit weight. The energy density determines the quantity of the energy that the device can deliver or can store energy.
3. **Discharge time**: it can be defined as the period of time for which the energy storage device or technologies completely discharge the stored energy.
4. **Efficiency:** it can be defined as the ratio of the total energy released is to total energy stored.
5. **Durability**: It is given by the number of times the storage device can be discharged. It can be expressed as the number of cycles each cycle consisting of one charging and discharging process.
6. **Autonomy** : it is the defined as the maximum time that the system continuously releases energy.

Challenges of Energy Storage Application

The energy storage technology has promising application prospect in renewable energy generation grid integration, distributed generation, microgrid, transmission and distribution, smart grid and ancillary services. In the 2050 development agenda in Nigeria is simulated, which shows that the energy storage demand will be between 560 and 780 GW. Meanwhile the electricity demand will attain between 2 and 3 billion kWh without considering grid constraints among regions in Nigeria. However, the large scale application of energy storage technology still faces challenges both in the technical and economic aspects.

Technology Problems

First of all, the development of energy storage technology requires the innovation and breakthrough in capacity, long-lifespan, low-cost, high-security for electrochemical energy storage. And also, physical storage technology with high-efficiency, low-cost is required.

Secondly, the research should be focused on the energy storage simulation and operation optimization in multiple applications, which can support the application of energy storage technology from theoretical viewpoint, anddevelop demonstration projects and comprehensive evaluation to promote the industrialization and commercialization of energy storage. At the same time it is necessary to establish a complete and rigorous professional cohesion, reasonable classification, transparency, openness and energy storage standards, which will provide strong support for research and development, production and application of energy storage, and promote the development of energy storage technology and relatedindustries.

Economic Problems

Currently, energy storage industry in Nigeria is still facing with challenges of lack of policy support, high cost,unclear application value, unhealthy market mechanism and other issues. Two aspects should be considered in the future: on the one hand, it is necessary to propose energy storage system solutions with the participations from electricity users, electrical enterprises, researcher, economical organizations and social originations, and on the other hand, the suitable industry market mechanism and the subsidy policy should be promoted. We should encourage numerous researches and applications of energy storage, establish a sustainable development model and achieve commercial operation of energystorage.

Prospects of Energy Storage Technology Development

With the trends of rapid power system expansion and large-scale renewable energy development, each country has under- taken the grid planning for next 10–20 years taking into consideration the energy storage, and various types of energy storage technologies are evaluated and many demonstrations have been planned or built, which can vigorously promote the development and application of energy storage technology in the smart grid. According to the investigation results, energy storage is deployed as fast response product for frequency regulation service in many counties, and most power system companies are willing to purchase thisservice.

Power Research Institute (PRI) has classified and outlined fourteen categories for energy storage technology applications in power systems (USD, 2010). Energy storage has significant impacts on large-scale renewable energy grid integration, load shifting, postponing power grid constructions and improving power system security. These will also create a great opportunity for energy storage development at the same time.

Even if the energy storage has many prospective markets, high cost, insufficient subsidy policy, indeterminate price mechanism and business model are still the key challenges.

From the application point of view, with the promotion of government of Nigeria, the development of energy internet will promote wide application of energy storage, and will be with rapid growth in installed capacity. Within the background of continuous promotion and application of electric vehicle, it will play a greater role in the energy internet architecture as it can be considered as mobile modular unit for energy storage. Although Nigeria energy storage industry is still faced with problems such as lack of policy support, unclear technical specification, small scale, high cost, low value and unhealthy mechanism, etc, the rapid application development of future energy storage industry is a foregone conclusion due to its capability in increasing renewable energy penetration level and improving electric energyefficiency.

Limitations of Energy Storage Technologies

The some drawback of this storage system can be summarized as

1. Dependance on topographical conditions and large land use.
2. This storage technologies requires a huge water resource which may not be available at all places.
3. High capital cost, long development time, long payback periods and uncertain profitability are also problems regarding this technology.

II. Conclusion

Storage of large amount of energy will be a challenge in upcoming years to meet up the demand during peak hours. Pumped hydro storage plant is currently the most economical solution for this purpose. Another alternative for pumped hydro storage plant is adiabatic CAES plant which also have a very high efficiency rate. This paper presents the most relevant properties of mechanical energy storage technologies currently being developed in the design of power systems. It describes the most important parameters that characterize the behavior of different mechanical energy storing technologies.

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