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Emerging Trends and Applications of Electrical Energy Storage System in Smart Grid

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ABSTRACT: Power demand varies from time to time and the price of electricity changes accordingly. The price for electricity at peak-demand periods is higher and at off-peak periods lower. This is caused by differences in the cost of generation in each period. During peak periods when electricity consumption is higher than average, power suppliers must complement the base-load power plants with less cost-effective but more flexible forms of generation, such as oil and gas-fired generators. During the off-peak period when less electricity is consumed, costly types of generation can be cut off. This is a chance for owners of electrical energy storage (EES) systems to benefit financially. This paper presents the emerging trends and application of electrical energy storage system in smart grid.

KEYWORDS: Electrical Energy Storage (EES), Smart Grid, Renewable Energy.

I. INTRODUCTION

Electrical Energy Storage, EES is one of the key elements in developing a Smart Grid. Smart Grid refers to modernizing the electricity grid. Through the addition of Smart Grid technologies the electrical grid becomes more flexible and interactive and can provide real-time feedback. In a Smart Grid, information regarding the price of electricity and the situation of the power system can be exchanged between electricity production and consumption to realize a more efficient and reliable power supply. As the power demand varies from time to time, its price changes accordingly. From the utilities viewpoint there is a huge potential to reduce total generation costs by eliminating the costlier methods through storage of electricity generated by low-cost power plants during the night being reinserted into the power grid during peak periods. With high PV and wind penetration in some regions, cost-free surplus energy is sometimes available. This surplus can be stored in EES and used to reduce generation costs. Conversely, from the consumers point of view, EES can lower electricity costs since it can store electricity bought at low off-peak prices and they can use it during peak periods in the place of expensive power. Consumers who charge batteries during off-peak hours may also sell the electricity to utilities or to other consumers during peak hours.

Overview of storage technologies are introduced in [1]. The paper also discusses the worldwide installed energy storage systems with their capacity and comparison of storage technology with investment cost. In [2,3,6] author present detail reports on electrical energy storage system and their implementation whereas in [4] author concluded with grid ready energy storage roadmap and phases of energy storage market development from 2010-2020.

II. EMERGING NEED FOR EES

Electrical Energy Storage has to played three main roles. First, EES reduces electricity costs by storing electricity obtained at off-peak times when its price is lower, for use at peak times instead of electricity bought then at higher prices. Secondly, in order to improve the reliability of the power supply and their third role is to maintain and improve power quality, frequency and voltage. Regarding emerging market needs, in on-grid areas, EES is expected to solve problems such as excessive power fl uctuation and undependable power supply which are associated with the use of large amounts of renewable energy. In the off-grid domain, electric vehicles with batteries are the most promising technology to replace fossil fuels by electricity from mostly renewable sources.

There are two major emerging market needs for EES as a key technology: i) to utilize more renewable energy and less fossil fuel and ii) the future Smart Grid.

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A) More Renewable Energy and Less Fossil Fuel:

i) On-Grid Areas

In on-grid areas, the increased ratio of renewable generation may cause several issues in the power grid. **Firstly,** in power grid operation, the fluctuation in the output of renewable generation makes system frequency control difficult and if the frequency deviation becomes too wide system operation can deteriorate. Conventionally, frequency control is mostly managed by the output change capability of thermal generators. With greater penetration of renewable generation this output margin needs to be increased, which decreases the efficiency of thermal generation even more. Renewable generation units themselves in most cases only supply a negative margin. If EES can mitigate the output fluctuation, the margins of thermal generators can be reduced and they can be operated at a higher efficiency. **Secondly,** renewable energy output is undependable since it is affected by weather conditions. Some measures are available to cope with this. One is to increase the amount of renewable generation installed, i.e. provide overcapacity, so that even with undependability enough power can be secured. Another is to spread the installations of renewable generators over a wide area, to take advantage of weather conditions changing from place to place and of smoothing effects expected from the complementary of wind and solar generators. These measures are possible only with large numbers of installations and extension of transmission networks. Considering the cost of extra renewable generation and the difficulty of constructing new transmission facilities, EES is a promising alternative measure.

ii) Off-Grid Areas

In off-grid areas where a considerable amount of energy is consumed, particularly in the transport sector, fossil energy should be replaced with less or non-fossil energy in such products as plug-in hybrid electric vehicles (PHEVs) or electric vehicles (EVs) . More precisely, fossil fuels should be replaced by low-carbon electricity produced mainly by renewable generation. The most promising solution is to replace petrol or diesel-driven cars by electric ones with batteries. In spite of remaining issues (short driving distance and long charging time) EES is the key technology for electric vehicles.

B) Future Smart Grid

EES is expected to play an essential role in the future Smart Grid. Some relevant applications of EES are described below:

First, EES installed in customer-side substations can control power flow and mitigate congestion or maintain voltage in the appropriate range. **Secondly,** EES can support the electrification of existing equipment so as to integrate it into the Smart Grid. Electric vehicles (EVs) are a good example since they have been deployed in several regions and some argue for the potential of EVs as a mobile, distributed energy resource to provide a load-shifting function in a smart grid. EVs are expected to be not only a new load for electricity but also a possible storage medium that could supply power to utilities when the electricity price is high. A **third** role expected for EES is as the energy storage medium for Energy Management Systems (EMS) in homes and buildings. With a Home Energy Management System, for example, residential customers will become actively involved in modifying their energy spending patterns by monitoring their actual consumption in real time. EMSs in general will need EES, for example to store electricity from local generation when it is not needed and discharge it when necessary, thus allowing the EMS to function optimally with less power needed from the grid.

III. ROLE OF EES TECHNOLOGY

Generally the roles for on-grid EES systems can be described by the number of uses (cycles) and the duration of the operation. For the maintenance of voltage quality (e.g. compensation of reactive power), EES with high cycle stability and short duration at high power output is required; for time shifting on the other hand longer storage duration and fewer cycles are needed. The following sections describe the roles in detail.

A) The roles from the viewpoint of a utility

1) Power quality

A basic service that must be provided by power utilities is to keep supply power voltage and frequency within tolerance, which they can do by adjusting supply to changing demand. Frequency is controlled by adjusting the output of power generators. EES can provide frequency control functions. Voltage is generally controlled by taps of

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transformers and reactive power with phase modifiers. EES located at the end of a heavily loaded line may improve voltage drops by discharging electricity and reduce voltage rises by charging electricity.

2) Emergency power supply for protection and control equipment

A reliable power supply for protection and control is very important in power utilities. Many batteries are used as an emergency power supply in case of outage.

3) Isolated grids

Where a utility company supplies electricity within a small, isolated power network, for example on an island, the power output from small-capacity generators such as diesel and renewable energy must match the power demand. By installing EES the utility can supply stable power to consumers.

4) Efficient use of the network

In a power network, congestion may occur when transmission/distribution lines cannot be reinforced in time to meet increasing power demand. In this case, large-scale batteries installed at appropriate substations may mitigate the congestion and thus help utilities to postpone or suspend the reinforcement of the network.

5) Time shifting

Utilities constantly need to prepare supply capacity and transmission/distribution lines to cope with annually increasing peak demand and consequently develop generation stations that produce electricity from primary energy. For some utilities generation cost can be reduced by storing electricity at off-peak times, for example at night and discharging it at peak times. If the gap in demand between peak and off-peak is large, the benefit of storing electricity becomes even larger. Using storage to decrease the gap between daytime and night-time may allow generation output to become flatter, which leads to an improvement in operating efficiency and cost reduction in fuel. For these reasons many utilities have constructed pumped hydro and have recently begun installing large-scale batteries at substations.

B) The roles from the viewpoint of consumers

1) Cost Savings

Power utilities may set time-varying electricity prices, a lower price at night and a higher one during the day, to give consumers an incentive toflatten electricity load. Consumers may then reduce their electricity costs by using EES to reduce peak power needed from the grid during the day and to buy the needed electricity at off-peak times.

2) Emergency power supply

Consumers may possess appliances needing continuity of supply, such as fire sprinklers and security equipment. EES is sometimes installed as a substitute for emergency generators to operate during an outage. Semiconductor and liquid-crystal manufacturers are greatly affected by even a momentary outage (e.g. due to lightning) in maintaining the quality of their products. In these cases, EES technology such as large-scale batteries, double-layer capacitors and SMES can be installed to avoid the effects of a momentary outage by instantly switching the load off the network to the EES supply. A portable battery may also serve in an emergency to provide power to electrical appliances.

3) Electric vehicles and mobile appliances

Electric vehicles (EVs) are being promoted for CO2 reduction. High-performance batteries such as nickel cadmium, nickel metal hydride and lithium ion batteries are mounted on EVs and used as power sources. EV batteries are also expected to be used to power in-house appliances in combination with solar power and fuel cells. These possibilities are often abbreviated as “V2H” (vehicle to home) and “V2G” (vehicle to grid).

C) The roles from the viewpoint of generators of renewable energy

1) Time shifting

Renewable energy such as solar and wind power is subject to weather, and any surplus power may be thrown away when not needed on the demand side. Therefore valuable energy can be effectively used by storing surplus electricity in EES and using it when necessary; it can also be sold when the price is high.

2) Effective connection to grid

The output of solar and wind power generation varies greatly depending on the weather and wind speeds, which can make connecting them to the grid difficult. EES used for time shift can absorb this fluctuation more cost-effectively than other, single-purpose mitigation measures (e.g. a phase shifter).

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IV. EES APPLICATIONS

Few new trends in EES applications are described below: renewable energy, smart grids, smart microgrids, smart houses and electric vehicles.

A) Renewable energy generation

In order to solve global environmental problems, renewable energies such as solar and wind will be widely used. This means that the future energy supply will be infl uenced by fluctuating renewable energy sources electricity production will follow weather conditions and the surplus and defi cit in energy need to be balanced. One of the main functions of energy storage, to match the supply and demand of energy (called time shifting), is essential for large and small-scale applications. Besides time shifting with energy storage, there are also other ways of matching supply and demand. With a reinforced power grid, regional overproduction can be compensated for by energy transmission to temporarily less productive areas. The amount of energy storage can also be reduced by overinstallation of renewable energy generators. With this approach even weakly producing periods are adequate for the load expected. A further option is so-called demand-side management, where users are encouraged to shift their consumption of electricity towards periods when surplus energy from renewables is available.

B) Smart Grid

Today's grids are generally based on large central power plants connected to high-voltage transmission systems that supply power to medium and low-voltage distribution systems. The power flow is in one direction only: from the power stations, via the transmission and distribution grid, to the fi nal consumers. Dispatching of power and network control is typically conducted by centralized facilities and there is little or no consumer participation. For the future distribution system, grids will become more active and will have to accommodate bi-directional power flows and an increasing transmission of information. Some of the electricity generated by large conventional plants will be displaced by the integration of renewable energy sources. An increasing number of PV, biomass and on-shore wind generators will feed into the medium and low-voltage grid. Conventional electricity systems must be transformed in the framework of a market model in which generation is dispatched according to market forces and the grid control centre undertakes an overall supervisory role (active power balancing and ancillary services such as voltage control).

The Smart Grid includes many technologies such as IT and communications, control technologies and EES. Examples of EES-relevant applications in the Smart Grid are given below.
1) Penetration of renewable energy requires more frequency control capability in the power system. EES can be used to enhance the capability through the control of charging and discharging from network operators, so that the imbalance between power consumption and generation is lessened.
2) In some cases, EES can reduce investment in power system infrastructure such as transformers, transmission lines and distribution lines through load levelling in certain areas at times of peak demand. EES for this purpose may also be used to enhance frequency control capability.
3) A further option is so-called demand-side management, involving smart grids and residential users. With intelligent consumption management and economic incentives consumers can be encouraged to shift their energy buying towards periods when surplus power is available. Users may accomplish this shift by changing when they need electricity, by buying and storing electricity for later use when they do not need it, or both. Electrochemical storage types used in smart grids are basically lead acid and NaS batteries, and in some cases also Li-ion batteries. For this application redox flow batteries also have potential because of their independent ratio of power and energy, leading to cost-effi cient storage solutions.

C) Smart Microgrid

A smart factory, smart building, smart hospital, smart store or another intermediate-level grid with EES may be treated as a "Smart Microgrid". For flexibility in resisting outages caused by disasters it is very important to deploy Smart Microgrids, that is, distributed smart power sources, as an element in constructing smart grids. EES is an essential component of a Smart Micro-grid, which should be scalable, autonomous and ready to cooperate with other grids. The architec-ture for the Smart Microgrid should have a single controller and should be scalable with respect to EES, i.e. it should adjust smoothly to the expansion and shrinkage of EES (battery) capacities according to the application in for

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example a factory, a building, a hospital or a store. The microgrid and EES should in general be connected to the network; even if a particular Smart Microgrid is not connected to a grid, for example in the case of an isolated island, it should still have similar possibilities of intelligent adjustment, because an isolated Smart Microgrid can also expand or shrink. Microgrids controlled in this way have the features of connecting and adjusting to the main grid intelligently, showing and using the input and output status of batteries, and controlling power smoothly in an emergency (including isolating the microgrid from the main grid if needed). These are the characteristics needed in Smart Microgrids, regardless of EES scale or applications.

D) Electric vehicles

Electric vehicles (EVs) were first developed in the 19th century but, since vehicles with conventional combustion engines are much cheaper and have other advantages such as an adequate driving range of around 500 km, electric vehicles have not been introduced in large quantities to the market. The main obstacle for building electricity-driven vehicles has been the storage of energy in batteries. Due to their low capacity it has not been possible to achieve driving ranges that would be accepted by the consumer. The emerging development of battery technology in recent years presents new possibilities, with batteries displaying increased energy densities.

In the transitional period of the next few years, mainly hybrid cars will come onto the market. They combine an internal combustion engine with an electric motor, so that one system is able to compensate for the disadvantages of the other. An example is the low efficiency in partial-load states of an internal combustion engine, which can be compensated for by the electric motor. Electric drive-trains are particularly well suited to road vehicles due to their precise response behaviour, their high effi ciency and the relatively simple handling of the energy storage. In spite of the advantages of electric motors, the combination of an electric drive-train with an internal combustion engine is reasonable. That is because electricity storage for driving ranges of up to 500 km, which are achieved by conventional drive-trains are not feasible today.

V. CONCLUSION

1) The potential market for EES in the future is much larger than the existing market, mainly driven by the extended use of renewable energy sources and the transformation of the energy sector, including new applications such as electric mobility. The market volume is relatedto the (future) renewable energy ratio and varies among regions.
2) If further cost reductions and technology improvement can be achieved, EES systems will be widely deployed, for example, to shift the demand, smooth renewable energy output and improve the effi ciency of existing power generation.
3) European studies indicate huge expectations for EES technologies to compensate for the fluctuation of renewable energy power output. Large installations of wind turbines and Pvs may require numerous EES systems, capable of discharging electricity for periods from two hours up to one day. Hence the market for conventional large-scale EES is attractive.
4) The extensive introduction of electrochemical EES such as NaS, Li-ion and RFB in the MW -MWh range is expected, for discharge times of hours to days.
5) Long-term energy storage is essential to achieving very high renewable energy ratios.The IEA report shows that further installation of renewable energy will lead to an insufficiency of thermal power generators for power control, and cause short-time output fluctuations. This scenario may be expected in Western Europe and China which have both set high renewable-energy-penetration targets.
6) To cover longer discharge times of days to months hydrogen and SNG technology have to be developed. The well-established natural gas grid and underground storage in regions such s Europe can be (partly) used for H 2 and SNG storage.
7) Smart Grid technology using many small, dispersed batteries, such as EV batteries, is attractive for many applications. But even if all EV batteries are used for this purpose they will be insuffi cient to cover future demand for EES.

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