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Crucial Role of Energy Storage in the Use of Renewable Energy

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In recent years, in order to mitigate and adapt to climate change, a lot of renewable energies (*e.g.*, wind and solar energy) are being used. Nevertheless, exploitation of renewable energy sources, even when there is a good potential resource, may be problematic due to their variable and intermittent nature. At present, energy storage is a feasible way to solve such difficult problem. In this paper, we first discuss the purpose as well as the main types of energy storage, then some advantages of utilizing the thermal and electrical energy storage are reviewed with emphasizing their vital role in promoting the large-scale utilization of renewable energy. Finally, some future research and development demands are pointed out.

Keywords: Energy storage, Renewable energy, Electric energy storage, Thermal energy storage, Large-scale utilization.

INTRODUCTION

Today's world is at a turning point. Resources are running low, pollution is increasing and the climate is changing. As we are about to run out of fossil fuels in the next few decades, we are keen to find substitutes. The use of renewable energy increased greatly just after the first big oil crisis in the 1970s. At that time, economic issues were the most important factors, hence interest in such processes decreased when oil prices fell. The current resurgence of interest in the use of renewable energy is driven by the need to reduce the high environmental impact of fossil-based energy systems. Harvesting energy on a large scale is undoubtedly one of the main challenges of our time. Future energy sustainability depends heavily on how the renewable energy problem is addressed in the next few decades[1].

Although in most power-generating systems, the main source of the fuel can be manipulated, this is not true for solar and wind energies. The main problems with these energy sources are costly and availability wind and solar power are not always available where and when needed. Unlike conventional sources of electric power, these renewable sources are non-dispatchable-the power output cannot be controlled. Daily and seasonal effects and limited predictability result in intermittent generation.

A significant problem of integrating renewable energies into the electricity system is the temporally fluctuating energy production by wind and solar power plants. Thus, in order to meet the ambitious long-term targets on CO_2 emission reduction, long-term viable low-carbon options for balancing electricity will be needed.

Energy storage is one of the key enabling technologies for efficient use of renewable energy. The motivations for vigorously developing energy storage technologies are fourfold[2]: more renewable energy has to be integrated, energy efficiency has to be improved, fluctuating resources have to be balanced and unused energy has to be utilized.

Purpose of energy storage: Energy storage is the storage of some form of energy that can be drawn upon at a later time to perform some useful operation[3-5]. All forms of energy are either potential energy, chemical or gravitational energy: A wind up clock stores potential energy, a battery stores readily convertible chemical energy to keep a clock chip in a computer running even when the computer is turned off and a hydroelectric dam stores power in a reservoir as gravitational potential energy.

Energy storage became a dominant factor in economic development with the widespread introduction of electricity and refined chemical fuels, such as gasoline, kerosene and natural gas in the late 1800s. Unlike other common energy storage used in prior use, such as wood or coal, electricity must be used as it is generated. Electricity is transmitted in a closed circuit and for essentially any practical purpose cannot be stored as electrical energy. This means that changes in demand could not be accommodated without either cutting supplies (*e.g*., blackouts) or arranging for a storage technique. Many renewable energy technologies such as solar and wind energy cannot be used for base-load power generation as their output is much more volatile and depends on the sun or winds. Batteries and other energy storage technologies therefore become key enablers for any shift to these technologies. The power storage sector generally includes traditional batteries, but also covers hydrogen fuel cells and mechanical technologies like flywheels that are straight potential replacements for batteries. More and more research is also conducted in the field of nanotechnology as ultra-capacitors high energy, high power density electrochemical devices that are easy to charge and dischargeand nano-materials could significantly increase the capacity and lifetime of batteries.

In addition, grid energy storage lets electric energy producers send excess electricity over the electricity transmission grid to temporary electricity storage sites that become energy producers when electricity demand is greater, optimizing the production by storing off-peak power for use during peak times. Also, photovoltaic and wind turbine users can avoid the necessity of having battery storage by connecting to the grid, which effectively becomes a giant battery. Photovoltaic operations can store electricity for the night's use and wind power can be stored for calm times.

A new concept in pumped storage is to utilize wind turbines to drive water pumps directly. This could provide a more efficient process and usefully smooth out the variability of energy captured from the wind.

Types of energy storage: The main energy storage technologies involve the storage of energy in thermal, electrical, chemical and mechanical forms[3-6]:

Thermal: Thermal energy can be stored by sensible and latent heats at temperatures above or below the ambient temperatures. Heat is also stored for short or long-term applications. Thermal energy from the sun, for example, can be captured by solar collectors and stored in a reservoir for daily or seasonal use. Thermal energy for cooling can be stored in ice.

Electrical: Dams can be used to store hydroelectricity by accumulating large amounts of water at high altitudes. The water then turns a turbine and generates electricity. Also by using pumped-storage hydroelectricity stores energy by pumping water back into the reservoir. A capacitor can store electric charge as a part of electrical energy production system. Batteries can also store electric energy to be used in portable electrical devices.

Chemical: Stable chemical compounds such as fossil fuels store chemical energy. Biological systems can store energy in chemical bonds of energy-rich molecules, such as glucose. Other forms of chemical energy storage include hydrogen, synthetic hydrocarbon fuel and batteries.

Mechanical: Energy can be stored in pressurized gases such as in compressed air and used to operate vehicles and power tools. Hydraulic accumulator, flywheel and springs can also store mechanical energy.

Thermal energy storage (TES): Thermal energy can be stored thermo-chemically, or stored as sensible/latent heat. Thermal energy storage technologies balance the energy demand and energy production. For example, the solar energy would be available during the night time or in the winter season if it is stored previously. In hot climates, the primary applications of thermal energy storage are cold storage because of large electricity demand for air conditioning. Thermal energy storage may be planned for short term or seasonal. Some advantages of utilizing thermal energy storage are[7,8]: Reduced energy consumptions and carbon footprint, reduced initial equipment and maintenance costs, reduced pollutant emissions such as CO_2, increased flexibility of operation, efficiency and effectiveness of equipment utilization, process application in portable and rechargeable way at the required temperature, isothermal and higher storage capacity per unit weight and energy from any sourcethermal or electricalwhen needed.

There are two very different types of thermal energy storage: Thermal energy storage applicable to solar thermal power plants and end-use thermal energy storage.

Thermal energy storage for solar thermal power plants consists of a synthetic oil or molten salt that stores solar energy in the form of heat collected by solar thermal power plants to enable smooth power output during daytime cloudy periods and to extend power production for 1-10 h past sunset. End-use thermal energy storage stores electricity from off-peak periods through the use of hot or cold storage in underground aquifers, water or ice tanks, or other storage materials and uses this stored energy to reduce the electricity consumption of building heating or air conditioning systems during times of peak demand.

Generally, thermal energy storage is seen as an important enabling technology for large-scale deployment of variable renewable energy sources such as solar. However, many energy storage technology assessments ignore the potential use of thermal energy storage as a method of increasing the penetration of solar and other renewables. In this section, we discuss two forms of thermal storage[9]:

Use of thermal energy storage with concentrating solar power (CSP): CSP/TES is a highly dispatchable source of energy, with high ramp rates and range. This feature allows it to increase the flexibility of power systems, enabling greater use of other variable generation sources such as photovoltaics (PV) and wind.

Use of thermal energy storage for space cooling: In the United States, space cooling is a significant use of energy representing about 10 of total demand. Cooling also drives the peak electricity demand and the need for peaking generation capacity. Potentially a large fraction of this cooling electricity demand could be shifted *via* cold storage in ice or chilled water. End-use thermal storage could be dispatched to maximize the use of renewable sources and also to provide ancillary services.

Storing thermal energy is often more efficient than storing electrical energy. In concentrating solar power plants, thermal energy storage can achieve efficiencies well over 90 %. End-use thermal storage can also achieve very high efficiencies and has the ability to be sited at the load, avoiding losses in the transmission and distribution network.

The primary disadvantage of thermal energy storage is that it is tied to a single application and cannot be used to store grid electricity. (While theoretically it could be used for grid storage, the round-trip efficiency of this use would be well under 50 %). Concentrating solar power can only be deployed in locations with significant direct solar radiation, confining its application largely to the desert areas. Cold storage is economically restricted to locations with significant cooling demand. As a result, there are significant geographical restrictions on the use of thermal energy storage as a renewable enabling technology.

Electric energy storage (EES): Electric energy storage uses forms of energy such as chemical, kinetic, or potential energy to store energy that will later be converted to electricity. Such storage can provide three basic services[1-3,6]: supplying peak electricity demand by using electricity stored during periods of lower demand, balancing electricity supply and demand fluctuations over a period of seconds and minutes and deferring expansions of electric grid capacity.

Electric energy storage can potentially smooth the variability in power flow from renewable generation and store renewable energy so that renewable generation can be scheduled to provide specific amounts of power, which can decrease the cost of integrating renewable power with the electricity grid, increase market penetration of renewable energy and lead to greenhouse gas emission (GHG) reductions.

The major technology options for electric energy storage include the following:

Pumped hydro: Pumped hydro storage uses low-cost electricity generated during periods of low demand to pump water from a lower-level reservoir (*e.g.*, a lake) to a higher-elevation reservoir. During periods of high electricity demand (and higher prices), the water is released to flow back down to the lower reservoir while turning turbines to generate electricity.

Compressed air: Compressed air energy storage (CAES) is a hybrid generation/storage technology in which electricity is used to inject air at high pressure into underground geologic formations. When demand for electricity is high, the high pressure air is released from underground and used to help power natural gas-fired turbines. The pressurized air allows the turbines to generate electricity using significantly less natural gas.

Rechargeable batteries: Several different types of large-scale rechargeable batteries can be used for electric energy storage including sodium sulphur, lithium ion and flow batteries. Batteries could be used for both power quality and load-leveling applications.

Hydrogen: Hydrogen storage could be used for load-leveling or power quality applications. When electricity is needed the hydrogen can be used to generate electricity *via* a hydrogen-powered combustion engine or a fuel cell.

Flywheels: Flywheels can be used for power quality applications since they can charge and discharge quickly and frequently. In a flywheel, energy is stored by using electricity to accelerate a rotating disc. To retrieve stored energy from the flywheel, the process is reversed with the motor acting as a generator powered by the braking of the rotating disc.

Superconducting magnetic energy storage (SMES): Superconducting magnetic energy storage consists of a coil with many windings of superconducting wire that stores and releases energy with increases or decreases in the current flowing through the wire. Superconducting magnetic energy storage are used to improve power quality because they provide short bursts of energyin less than a second.

By using electric energy storage people can get many benefits, which often cross the traditional boundaries of generation, transmission and distribution. In this paper, they are categorized as environmental, economic and operational[1-3,10-12].

Environmental benefit: Electric energy storage enables greenhouse gas emission emission reductions by two main mechanisms:

Electric energy storage can be used instead of natural gas generators to smooth out the variable output of renewable resources such as wind or solar power from hour to hour and allow these resources to be scheduled according to daily fluctuations of electric demand. For example, the use of compressed air energy storage to smooth wind power generation would result in a 56 % reduction in CO_2 emissions per kilowatt-hour of electricity, compared to smoothing variable wind power with generation from a gas turbine.

Electric energy storage charged with electricity from low-carbon sources can be used to displace fossil fuel generation to provide regulation services by smoothing out the fluctuations between supply and demand over a period of less than 15 min. This use of electric energy storage could reduce the amount of fossil fuels burned by generators, leading to greenhouse gas emission and conventional emission reductions.

Economic benefit: Electric energy storage enables customers to change when they draw power from the grid to meet their demand. For customers on dynamic rates (*i.e.*, those who pay more for power during times of higher demand on the grid), electric energy storage allows energy arbitrage opportunities whereby the electric energy storage system charges when the cost of energy is low and discharges when the cost of energy is high.

Use of electric energy storage can reduce energy charges if the spread between on-peak and off-peak time of use rates is large enough. Even larger savings could come from reduced demand charges, if electric energy storage reliably reduces the size of the customer's maximum demand peak in a given month. Customers with photovoltaics systems can use an electric energy storage system to mitigate the intermittency of their photovoltaics panels' power production, thereby acting as a back-up to the photovoltaics system's output and ultimately reducing the customer's demand charge.

On the other hand, the electric energy storage market is currently an emerging market. Costs will be lowered in the future as a result of learning-by-doing, developing economies of scale and conducting additional research and development. Increased demand will spur electric energy storage manufacturers, integrators and installers to become more efficient which should further reduce future costs.

Operational benefit: The major ones are the following:

Improved power quality: ome commercial and industrial customers' manufacturing or other processes are harmed if their power varies in frequency and voltage. Electric energy storage can serve to eliminate these power quality inconsistencies.

Reliable and cleaner back-up power: Electric energy storage technologies can provide customers with electricity for a period of hours when utility power is not available, for instance, they can provide a source of back-up power for shorter outages.

Reduced need for peak generation capacity: By allowing customers, utilities or power generators to store energy off-peak and discharge on-peak, storage provides an alternative to the construction and operation of new generation and reserve capacity. The value of the avoided cost of peak generation capacity will continue to increase as peak demand grows and as carbon emissions become more expensive.

Reduced need for transmission and distribution capacity upgrades: Electric energy storage can be used to maximize existing transmission and distribution (T and D) resources. Electric energy storage can shift demand off-peak, delaying the need for new T and D upgrades. The value of T and D upgrade deferral varies greatly by location and is driven by the population density of the area, terrain, geology, weather and the type and amount of T and D equipment involved.

Increased and improved availability of ancillary services: Ancillary services are services necessary to support the transmission of energy from generation resources to consumers, while maintaining the reliable operation of the transmission system. Electric energy storage technologies are capable of providing regulation services as well as operating reservesthe former ensure the grid operates within an allowable range of interconnection frequencies and the latter ensure that more energy can be added to the system within a short period of time to meet unexpected increases in demand or reductions in supply.

Future R and D demands: Although a lot of progress have been made in the energy storage technologies, we believe there are also many R and D demands in this field. The following ones are important[1,2]:

Development and optimization of different energy storage technologiesnew materials and processes, including electrical, thermal, chemical and mechanical ones. Detailed and quantitative estimation of the storage demand for both integration of renewable energies and increase of energy efficiency. Development of methods for the comparison of storage technologies and the identification of the most suitable technology for the actual application.

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