



UNIT-I

The roles of electrical energy storage technologies in electricity use

1.1 Characteristics of electricity

Two characteristics of electricity lead to issues in its use, and by the same token generate the market needs for EES. First, electricity is consumed at the same time as it is generated. The proper amount of electricity must always be provided to meet the varying demand. An imbalance between supply and demand will damage the stability and quality (voltage and frequency) of the power supply even when it does not lead to totally unsatisfied demand. The second characteristic is that the places where electricity is generated are usually located far from the locations where it is consumed. Generators and consumers are connected through power grids and form a power system. In function of the locations and the quantities of power supply and demand, much power flow may happen to be concentrated into a specific transmission line and this may cause congestion. Since power lines are always needed, if a failure on a line occurs (because of congestion or any other reason) the supply of electricity will be interrupted; also because lines are always needed, supplying electricity to mobile applications is difficult. The following sections outline the issues caused by these characteristics and the consequent roles of EES.

1.2 Electricity and the roles of EES

1.2.1 High generation cost during peak- demand period

Power demand varies from time to time (see Figure 1-1), 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 (such as coal-fired and nuclear) 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 stopped. This is a chance for owners of EES systems to benefit financially. 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.

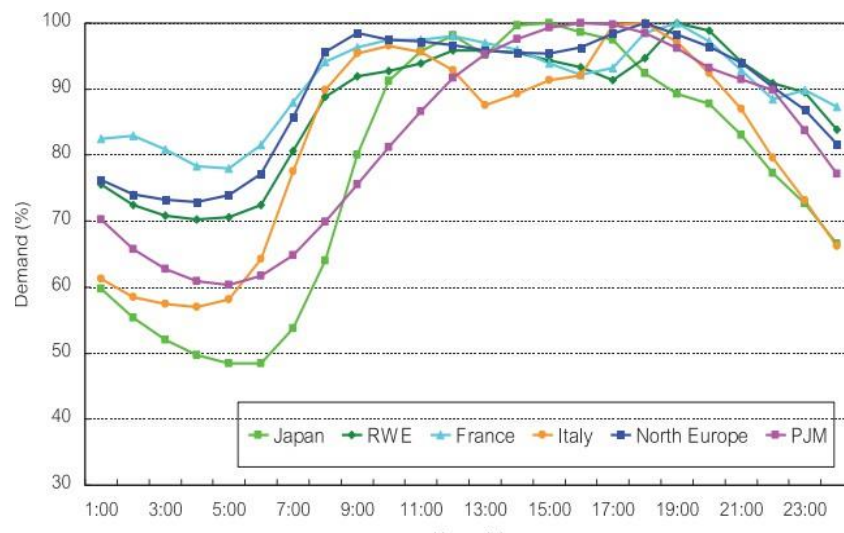


Figure.1.1 Comparison of daily load curves

1.2.2 Need for continuous and flexible supply

A fundamental characteristic of electricity leads to the utilities' second issue, maintaining a continuous and flexible power supply for consumers. If the proper amount of electricity cannot be provided at the time when consumers need it, the power quality will deteriorate and at worst this may lead to a service interruption. To meet changing power consumption appropriate amounts of electricity should be generated continuously, relying on an accurate forecast of the variations in demand. Power generators therefore need two essential functions in addition to the

basic generating function. First, generating plants are required to be equipped with a "kilowatt function", to generate sufficient power (kW) when necessary. Secondly, some generating facilities must possess a frequency control function, fine-tuning the output so as to follow minute-by-minute and second-by-second fluctuations in demand, using the extra power from the "kilowatt function" if necessary. Renewable energy facilities such as solar and wind do not possess both a kW function and a frequency control function unless they are suitably modified. Such a modification may be a negative power margin (i.e. decreasing power) or a phase shift inverter. EES is expected to be able to compensate for such difficulties with a kW function and a frequency control function. Pumped hydro has been widely used to provide a large amount of power when generated electricity is in short supply. Stationary batteries have also been utilized to support renewable energy output with their quick response capability.

1.2.3 Long distance between generation and consumption

Consumers' locations are often far from power generating facilities, and this sometimes leads to higher chances of an interruption in the power supply. Network failures due to natural disasters (e.g. lightning, hurricanes) and artificial causes (e.g. overload, operational accidents) stop electricity supply and potentially influence wide areas. EES will help users when power network failures occur by continuing to supply power to consumers. One of the representative industries utilizing EES is semi-conductor and LCD manufacturing, where voltage sag lasting for even a few milliseconds impacts the quality of the products. A UPS system, built on EES and located at a customer's site, can keep supplying electricity to critical loads even when voltage sag occurs due to, for example, a direct lightning strike on distribution lines. A portable battery may also serve as an emergency resource to provide power to electrical appliances.

1.2.4 Congestion in power grids

This issue is a consequence of the previous problem, a long distance between generation and consumption. The power flow in transmission grids is determined by the supply and demand of electricity. In the process of balancing supply and demand power congestion can occur. Utility companies try to predict future congestion

and avoid overloads, for example by dispatching generators' outputs or ultimately by building new transmission routes. EES established at appropriate sites such as substations at the ends of heavily-loaded lines can mitigate congestion, by storing electricity while transmission lines maintain enough capacity and by using it when lines are not available due to congestion. This approach also helps utilities to postpone or suspend the reinforcement of power networks.

1.2.5 Transmission by cable

Electricity always needs cables for transmission, and supplying electricity to mobile applications and to isolated areas presents difficulties. EES systems such as batteries can solve this problem with their mobile and charge/discharge capabilities. In remote places without a power grid connection recharging an electric vehicle may present a challenge, but EES can help realize an environmentally friendly transport system without using conventional combustion engines.

1.3 Emerging needs for EES

Electrical Energy Storage has to play 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 fluctuation 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.

1.3.1 More renewable energy, less fossil fuel

1.3.1.1 On-grid areas In on-grid areas, the increased ratio of renewable generation may cause several issues in the power grid (see Figure 1-2). First, 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. When used for this purpose thermal generators are not operated at full capacity, but with some positive and negative output margin (i.e. increases and decreases in output) which is used to adjust frequency, and this implies inefficient operation. 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 3. 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 complementarity 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.

1.3.1.2 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 plugin hybrid electric vehicles (PHEVs) or electric vehicles (EVs) (see Figure 1-2). 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.

1.3.2 Smart Grid uses

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.

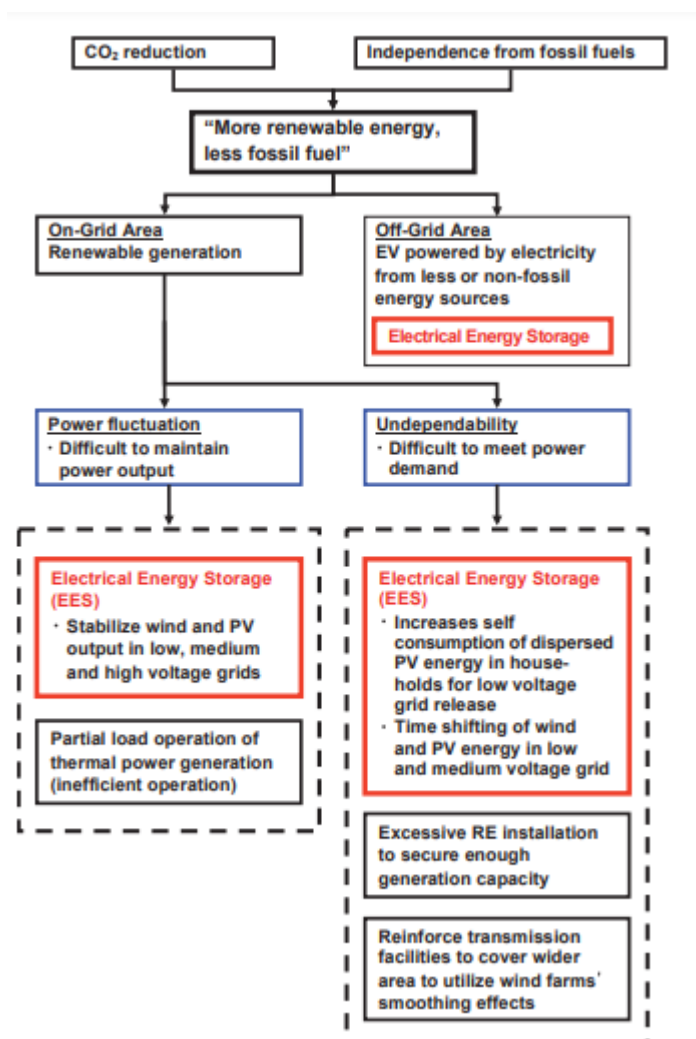


Figure.1.2. Problems in renewable energy installation and possible solutions

When it is not needed and discharges it when necessary, thus allowing the EMS to function optimally with less power needed from the grid.

1.4 The roles of electrical energy storage technologies

Generally the roles for on-grid EES systems can be described by the number of uses (cycles) and the duration of the operation, as shown in Figure 1-3. 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.

1.4.1 The roles from the viewpoint of a utility

1) 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.

2) 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 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.

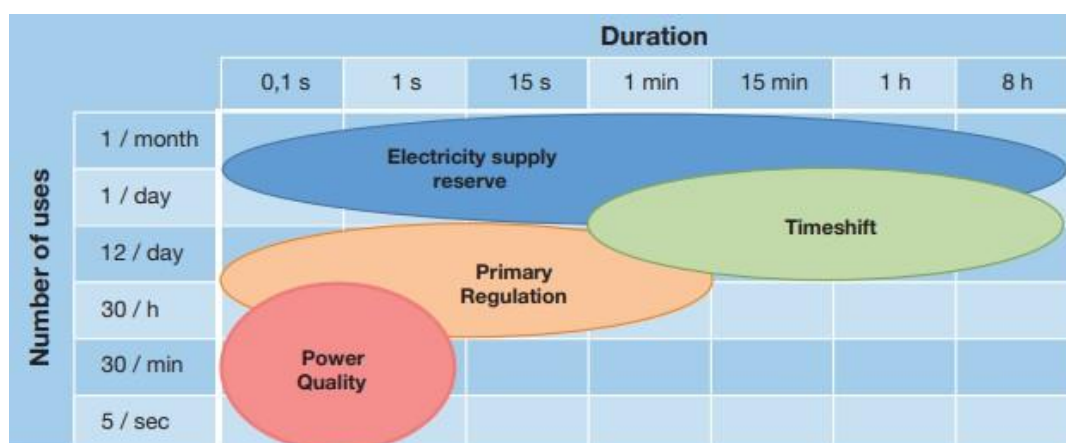


Figure 1.3. Different uses of electrical energy storage in grids, depending on the frequency and duration of

3) Making more 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. 4) 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. 5) 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.

1.4.2 The roles from the viewpoint of consumers

1) Time shifting/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 to flatten 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 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; at the same time, studies are being carried out to see whether they can usefully be connected to power networks. These possibilities are often abbreviated as “V2H” (vehicle to home) and “V2G” (vehicle to grid).

1.4.3 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).

Summary

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 related to 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 efficiency 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 as Europe can be (partly) used for H₂ 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 insufficient to cover future demand for EES.