APPLICATION AND EFFICIENCY OF ENERGY STORAGE SYSTEMS IN DISTRIBUTION NETWORKS

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Abstract: *In power systems, energy storage systems are of great importance in preventing the supply-demand imbalances of electrical energy and daily fluctuations in the load curve. The amount of energy produced by renewable energy sources is constantly changing due to their significant dependence on environmental conditions. Today, all modern energy systems require energy storage for many reasons such as supply reliability, system stability, more efficient use of energy resources, minimizing transmission / distribution network problems and costs. This study examines the most up-to-date storage techniques used in power systems and makes an assessment of their efficiency. Thus, it is aimed to provide a more accurate power balance in load planning and help to realize an effective unit commitment in energy.*

***Keywords**: Renewable Energy Sources, Energy Storage Systems, Supply Reliability, Distribution Network*

1. Introduction

Energy storage systems and its contribution to the power system are among the current study topics. Although there are many studies and researches on the application of different storage technologies on power systems, a very limited part of these studies has been implemented. Some of the main reasons for the limited number of applications to be implemented are stated below.

- It is difficult to determine / verify the economic benefits of storage technologies in use due to the excessive availability of production resources used to meet the supply-demand balance in the traditional power system and the interconnected structure of this system.
- Lack of practical experience, insufficiency of tools used in price optimization, determination / valuation of the benefits of storage technology at the planning stage (formation and decision stages of market models)

Energy Storage Systems can be connected from the distribution and transmission level as well as integrated into the network from the low voltage distribution level. Energy Storage Systems significantly affect the active-reactive power flow and voltage profile. Energy storage systems can also be used as an uninterrupted power supply in order to prevent energy cuts and ensure energy continuity. Similarly, energy storage systems can support the loads while these effects occur in order to protect the loads against disruptive effects such as voltage collapse or rises and malfunctions in the network.

2. Applications of Energy Storage Systems

There are various energy storage technologies used in power systems today. In the process of determining the most suitable among these technologies, many parameters such as cost, lifetime, reliability, size of the storage system, storage capacity and environmental impact should be carefully examined. During the evaluation of all these parameters, the total benefit of the energy storage system is an important criterion to be considered.

Energy storage technology: It has great potential to improve electrical power systems, increase electricity generation from renewable energy sources, and offer alternatives to petroleum-derived fuels in the transportation sector. In energy storage technologies, parameters such as power storage capacity, energy capacity, discharge time, efficiency and durability are the most important parameters to be considered in the planning phase. Cost, efficiency, and response time in the selection of energy storage systems. etc. parameters also play an active role. So, storage systems; It should be chosen according to the needs of the network. Storage systems are used as a resource for the balanced loading of the network, to achieve a flexible structure and at the same time to ensure the integration of more renewable generation resources. When analyzed locally, it enables the development of distribution network management systems, reducing costs and increasing efficiency. It will increase the use of intermittent wind and solar power plants while increasing the stability and flexibility of the grid [1]. The structure showing the benefits of storage technologies commonly used in power systems is shown in Figure 1 below.

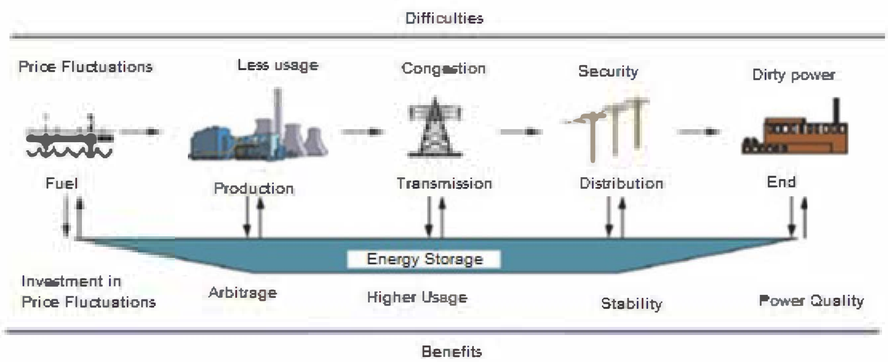

Figure 1. *Benefits of energy storage systems*

There are benefits of energy storage systems for each of the electrical grid stages given in Figure 1 and are basically listed below:

- Its Contribution to the Generation System: The use of the energy stored during peak times during the day when the demand for power is high will help reduce the generated power and therefore the traditional generation facility investments. In addition, it is an important issue to leave the loads in the system as spare reserves for emergencies. Storage units are also used for frequency control according to network conditions.
- Its Contribution to Transmission and Distribution System: It is extremely important for the system that the elements on the transmission system are synchronous. Storage systems: It

supports the stable operation of the transmission system. It can also be used for voltage regulation for both transmission and distribution system. In addition, the integration of storage systems allows postponement of additional investments in transmission and distribution systems. Thus, optimum use of capital can be achieved.

- Energy management system: Storage systems come into play at peak times and prevent the network from being strained during these times. At the same time, it acts as an uninterruptible power supply by intervening in central malfunctions and prevents customers from running out of energy [2].
- Integration of Renewable Energy Resources: With the integration of renewable energy sources into the grid, production costs have started to decrease significantly. The intermittent generation of solar, wind and wave energies require the grid to be flexible in terms of demand. The intermittent generation of renewable energy sources also forces network equipment when the production amount is higher than consumption. For this reason, unnecessary loading of system elements can be prevented by storing energy when the production amount is high.

Energy storage devices provide technical gains in many areas. Expectations in using storage devices in the distribution system are generally; improvement of the tension profile, peak time shifting, reduction of line loads, and reduction of losses [3].

The technical contributions of storage devices in distribution networks are listed in detail below [4]:

- Regulating the load curve by activating storage devices in case of network overload and reducing the energy consumption used from the distribution network
- If used with distributed generation resources that are dependent on natural conditions, ensuring that the time to benefit from these resources is increased
- Reducing the investments in network elements to be made by re-evaluating the distribution system structure as a result of the change of direction of energy consumption
- Ensuring that operating efficiency is increased in unreliable grid connections or when diesel fuel generators with low consumption and storage devices are used together.

The biggest obstacle to the high prevalence of renewable energy sources is that it has a fluctuating power output characteristic that changes with time. Most of the renewable energy sources cannot provide continuous and stable energy. A potential imbalance situation can occur between load demand and energy sources. Energy storage systems are an effective solution to eliminate these negative effects of renewable energy sources and to keep the network voltage and frequency values within acceptable limits. In Figure 2, wind and solar power plants and load profiles of the grid are shown [5,6]. Each energy storage technology has certain features, considering criteria such as cost, power, response time and storage capacity as specified in Table-1.

Table 1. *Comparison of energy storage systems* [7]

Storage Technology	Advantage	Disadvantage	Usage Area
Pumped water based storage	High capacity, low unit energy cost	Need for large and private space	Time shift energy applications, Integration of large powerful renewable energy sources
Compressed air based storage	Time shift energy applications,	High capacity, low unit energy cost	Need for large underground area, additional fuel cost, Integration of large powerful renewable energy sources
Hydrogen	No environmental impact	Low efficiency, high cost, storage units problems	Integration of renewable energy sources, electric vehicle applications
Battery	Matured technology, high power and energy density	Negative environmental effects, high production cost, medium or low cycle life	Portable devices, electric vehicles, small powerful renewable energy systems
Flywheel	High power density, fast response time, high cycle life	Low energy density, high cost	Power quality applications
Super capacitor	High power density, fast response time, high cycle life	Low energy density, high cost	Electric vehicles, power quality applications
Superconducting magnetic storage	High power density, fast response time, high cycle life	Low energy density, high cost,	Power quality applications

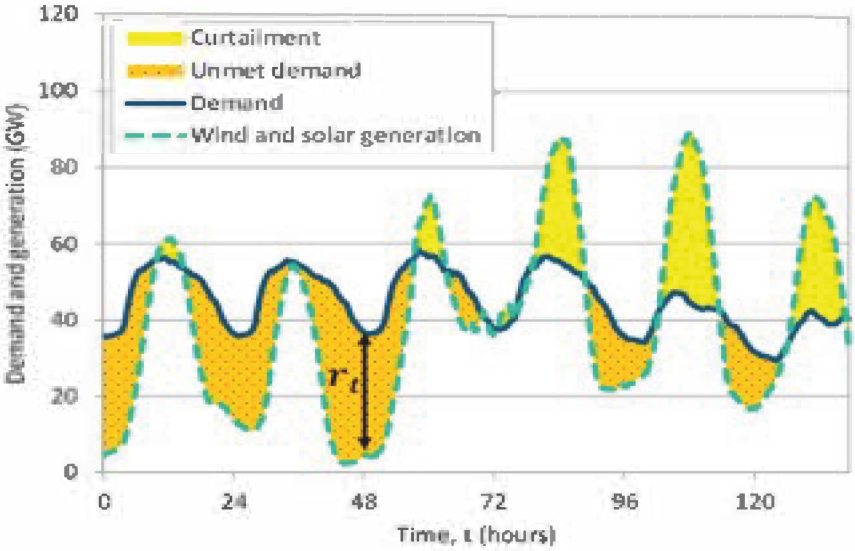

Figure 2: Wind, Solar and network load profiles

In addition to the specified technical contributions, storage devices are used in energy exchange and provide economic benefits.

The most efficient application of energy storage systems (EDS) is the application called "intermediate gain" (arbitrage). With this application, excess energy from the grid or from renewable energy sources is stored in the time period when the unit price of electrical energy is low (energy demand is low) and the stored energy is used to meet the demanded energy in the time period when the unit price of electrical energy is higher (energy demand is high). Thus, financial gain can be achieved by taking advantage of the tariff difference. Energy storage systems prevent the capacity overrun of the transmission and distribution network and delay investments by preventing additional investment costs. The arbitrage application defined as intermediate earnings is visually shown in Figure 3.

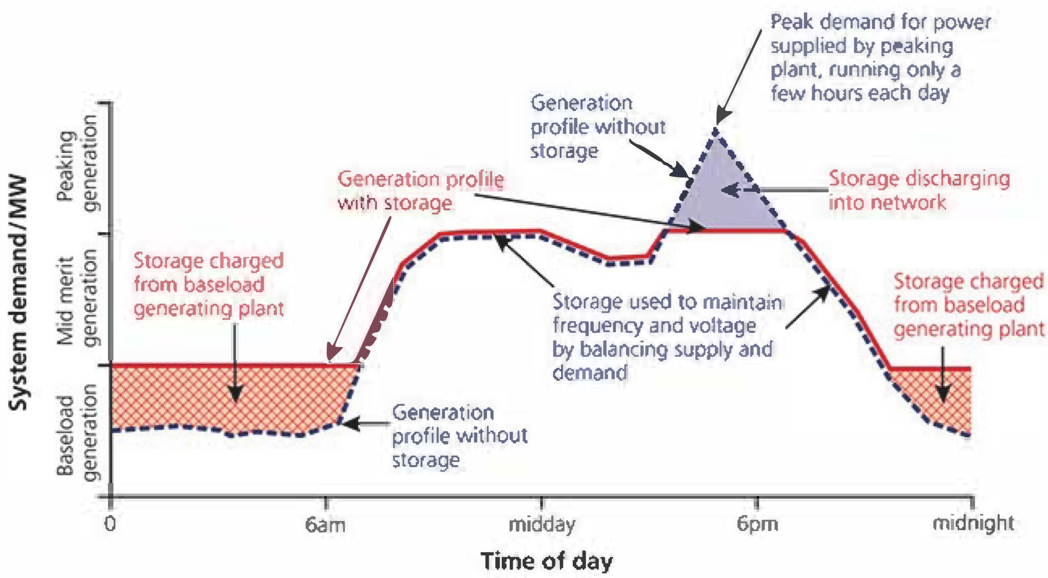

Figure 3: The effect of storage devices on daily load curves

2.1. Placement of Storage Devices in the Distribution Network and Financial Benefits

It is necessary to have hourly, daily, monthly or annual load profile information of the region to be studied in order to determine the most suitable points in terms of the placement of the storage devices in the electricity distribution network. According to the results of the load flow and load profile analysis to be made in the first stage, weak areas within the system should be determined by using parameters such as stress profile, equipment loading and loss analysis. It would be appropriate to use storage devices in weak areas within the area where it is planned to be placed, as it will technically contribute more. According to the results of the analysis, suitable locations can be selected in order to support regions with low voltage profile and high network load or due to their physical (geographic) location while selecting weak areas in the current system [8,9].

In the power system analysis to be made, the analyzes should be repeated for the maximum and minimum load profile conditions, different storage device capacity or different combinations if more than one storage device will be applied. Optimum values should be selected according to the control parameter in order to obtain maximum efficiency from the storage devices modeled at the points to be applied. In order to determine the charge and discharge status of the storage devices, the voltage profile of the selected control point and the loading of the equipment should be considered [10-12].

The current results should be compared with the parameters to be determined such as voltage profile, equipment loading and reduction of losses, etc. obtained as a result of power system analysis. According to the criteria to be determined, it should be evaluated whether the application of the storage device is technically sufficient. These criteria must meet the expectations that may arise if storage devices are implemented. For example, if a storage device is applied, it can be determined such as improving the voltage profile by 2%, reducing equipment loads and losses by 20% [13-15].

The application points where the storage device application situation is considered to be technically sufficient should also be evaluated economically. If storage devices are applied, a profit will be gained from the reduction of equipment losses. Considering the earnings, the storage device must cover the investment cost. In addition, as a result of storing energy when the price of energy is low and selling it according to the needs of the grid when the price is high, a gain will be obtained on the sale price of the energy [16].

The use of storage devices in electrical networks has more than one contribution, both directly and indirectly. These benefits are classified under two main headings as technical and general benefits. One of the technical effects of storage devices is to reduce technical losses in the network. Especially considering the distribution networks, any improvement that can be made in technical losses will save financially by reducing the amount of energy lost (therefore not sold). The use of storage devices contributes not only to the distribution network but also to the national economy when electrification is considered. Examples of these benefits in general terms are the gain from the tariff with peak time shifting and investment delay (delay or delay) [17-20].

While determining the optimum size and location of storage devices, the expected benefits from these devices increase, while the prices of storage devices should be minimized [21].

To give an example of international practices; Instead of building a new line, distribution system operators in Italy can show the solution of the detected problems as a result of a cost-benefit analysis showing that the application of a storage device is the lowest cost way. In Belgium, with the widespread use of storage devices, it may be allowed to use the intermediate earnings to be obtained as a result of storing energy at low hours and selling it at high hours, as long as it does not change the existing competition in the market.

Conclusion

Energy storage systems are of great importance in order to ensure the supply-demand balance of electrical energy and to prevent fluctuations in the load curve. The fact that renewable energy sources are far from consumption centers and cannot produce continuously increases the importance of energy storage systems. Today, all modern grid systems require energy storage for many reasons such as supply reliability, system stability, more efficient use of energy resources, minimization of transmission / distribution problems and costs. When the applications of energy storage systems in the world are examined, it is seen that they are used for support purposes, especially in order to regulate the voltage regulation in the distribution network. Storage systems are activated during peak times, preventing the distribution network equipment from being strained during these times. In addition to this situation, it prevents customers from losing energy by being activated in case of malfunction. It contributes to the optimum use of the budget by postponing investments as it helps to reduce the peak values by supporting overloads that occur during peak hours. It is seen that battery-powered storage systems can be suitable for increasing the integration of wind and solar power plants in our country.

Owning and operating energy storage devices by distribution companies can be arranged according to the purpose of use. The ownership and business ownership of storage devices by distribution companies may be restricted in applications that will provide advantage from price. Only storage devices with a specified small capacity and distribution network operators may be allowed to have generation licenses. Ownership and operation should be managed by private individuals, as large capacity storage devices will have more advantages over price. However, if the distribution company is to be used for the purpose of regulating the voltage profile of the storage devices, reducing equipment loads and losses and delaying investment, it can be allowed to own and own business without any restrictions. Allowing distribution network operators to own and operate storage devices will optimize their role in the system and make investments. By adding storage devices to the distribution network, total investment costs will be reduced due to shifting of peak times. The results will be more promising as the price of storage devices decreases in the future. Other benefits of storage devices can be considered to increase the reliability of the distribution system and reduce power quality problems. Interim gain will increase as more efficient storage device technology is used. However, the intermediate gain value will be significantly less than the installation and maintenance costs of the storage device. Currently, storage devices are in a position to compete economically only for the gain from energy. Therefore, according to the current costs of storage devices, no investor will install energy storage devices only to gain intermediate profits. In order to obtain maximum gain, it should be operated in the most optimum way according to each load situation. Another obstacle to the development of storage technologies is that the value of energy storage devices in future electrical systems is not understood. In order to encourage energy storage devices, changes in electricity markets should be aimed at reflecting the value of these devices to the system in the best way. The essential value of storage devices is the value of the entire system that increases energy system efficiency and should only be evaluated with an approach that takes into account alternatives such as interconnection and ancillary services.

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