THE ENERGY STORAGE APPLICATION STRATEGY IN DIFFERENT VOLTAGE LEVELS OF DISTRIBUTION SYSTEM

Zuping ZHANG
CEPRI – China
zpzhang@epri.sgcc.com.cn

Sige LIUE
CEPRI – CHINA
sgliu@epri.sgcc.com.cn

Huishi LIANG
CEPRI - CHINA
lianghs@epri.sgcc.com.cn

ABSTRACT

Energy storage is an important party for future power system development. It can curtail the difference between load peak and valley, which will effectively reduce system backup capacity. In this paper, the application of energy storage in different voltage levels of distribution system is presented and the corresponding calculation steps and mathematical models are analysed. To reduce the power between peak and valley, the results for centralized energy storage in the substation of high voltage (HV) distribution network and for decentralized energy storage in medium voltage (MV) distribution networks and low voltage (LV) distribution network are obtained. The both results are compared for the best energy storage technology strategy, which can provide a reference for the future planning and construction of intelligent distribution network. The proposed methods are applied to a simulated test distribution system.

Keywords*—Energy storage, distribution systems, voltage level, load curtailment*

INTRODUCTION

Power production is a continuous process in which power generation, transmission, substation, distribution and utilization are simultaneously completed. So the power production and consumption must always be balanced in spot. But the load level in most power systems has peak-valley difference, which requires power systems to have adequate backup capacity to meet the peak load demand. In some developing counties, with the rapid load growth, new facilities of power systems have not been able to be built fast enough to meet these new demands as a result of economic, environmental, technical, and governmental constraints. At the same time, more and more electronic devices are being used in power system, so quality of power supply has become a critical issue to be considered. Power system engineers facing these challenges are seeking solutions to allow them to operate the system in a more flexible, controllable manner [1-2].

Energy storage technologies have active prospect to solve those problems in which they can effectively curtail peak-valley difference, improve reliability and stability, reduce backup capacity and decrease expected energy not supply (EENS) [3-4]. In addition, with the increasing scale of new energy generation and the continuous development of distributed generation (DG) technologies, the importance of energy storage system is also becoming increasingly prominent.

This paper mainly focuses on distribution planning problem that integrated with energy storage application.

In high voltage (HV) level, energy storages mainly use to curtail peak-valley difference that will result in two consequences. First, energy storage can decrease backup capacity for peak load level that can save related equipment investment (such as investment of transformer, power line and etc.). Second, optimal dispatching of energy storage can smooth generation output and save related cost of unit commitment.

In medium voltage (MV) level, energy storage often integrates with DG, in which it can support DG in three ways. First, energy storage can be used for stabilization purposes, permitting the DG to run at a constant, stable output level, even if the load fluctuates greatly and rapidly. Second, proper amounts of energy storage can provide energy to ride through periods when the DG unit is unavailable, for example, during the nighttime for solar power, or when the DG unit of any type is being maintained or repaired. Third, energy storage can permit a non-dispatched DG unit to operate as a dispatched unit by permitting its output at any moment to differ from the power being released to the demand or into the grid.

In low voltage (LV) level, energy storages mainly use to support demand side management (DSM), micro-grid systems, uninterrupted power supply (UPS) systems or emergency lighting systems. On the other side, Electric vehicles normally connect in LV level those also can regard as energy storage units.

This paper is organized as follows. In section 2 it mainly discuss the application of energy storage systems in the future distribution system. In section 3, an assignment strategy of energy storage in distribution systems is proposed and discussed. In section 4, an actual system is presented to test validity of the proposed methodology. Finally, in section 5 some conclusions are drawn.

STATE-OF-THE-ART ENERGY STORAGE TECHNOLOGY

Electrical energy in an AC system cannot be stored electrically. However, energy can be stored by converting the ac electricity and storing it electromagnetically, electrochemically, kinetically, or as potential energy. Each energy storage technology usually includes a power conversion unit to convert the energy from one form to another. Two factors characterize the application of an energy storage technology. One is the amount of energy that can be stored in the device. This is a characteristic of the storage device itself. Another is the rate at which energy can be transferred into or out of the storage device. This depends mainly on the peak power rating of the power conversion unit, but is also impacted by the response rate of the storage device itself. Relate energy storages are displayed as bellowing Tab.1.

Tab.1 List of energy storages

Type	Output Power (MW)	Power density (W/kg)	Cost of per power ($/kW)
Pump	100-5000	--	5-100
NaS battery	0-8	150-230	300-500
Lead acid battery	0-50	75-300	200-400
Flywheel	0-1650	400-1500	1000-5000
SMES	0-10	500-2000	103-104
Super Capacity	0-0.0003	500-5000	300-2000

(SMES-Superconducting Magnetic Energy Storage)

This paper mainly analyses practical energy storage technologies that can be used for active power and energy balance in distribution planning stage. So the relative energy storages include pump storage and battery storage.

Pump storage

Pumped storage reservoirs aren't really a means of generating electrical power. They are a way of storing energy so that we can release it quickly when we need it. Pumped storage hydroelectricity is a method of storing and producing electricity to supply high peak demands by moving water between reservoirs at different elevations. At times of low electrical demand, excess electrical capacity is used to pump water into the higher reservoir. When there is higher demand, water is released back into the lower reservoir through a turbine, generating hydroelectricity. Reversible turbine/generator assemblies act as pump and turbine (usually a Francis turbine design). Some facilities use abandoned mines as the lower reservoir, but many use the height difference between two natural bodies of water or artificial reservoirs.

Pumped storage projects are net consumers of energy in that for every one kWh of energy generated during peak periods, more than one kWh of off-peak energy is required for pumping. Due to evaporation losses from the exposed water surface and mechanical efficiency losses during conversion, only between 70% and 85% of the electrical energy used to pump the water into the elevated reservoir can be regained in this process. Still, this system is economical as it flattens out the variations in the load on the power grid, permitting base-load power stations to continue operating at their most efficient capacity, while reducing the need to build special power plants which run only at peak demand times using more costly generation methods.

Because of the energy losses inherent in pumped storage, the CO_2 emissions associated with its use will be higher than that of the original power source. When coal-fired power is the driver of the pumped storage, there is likely a net increase in system CO_2 emissions. However, a net reduction in greenhouse gas emissions can be realized with pumped storage when the fuel providing electricity for pumping has a lower carbon content (or no carbon content as in the case of wind energy or nuclear power) than the fuel being displaced by the pumped storage generation.

Advantage

- Without some means of storing energy for quick release, we'd be in trouble.
- Little effect on the landscape.
- No pollution or waste

Disadvantage

- Expensive to build.
- Once it's used, you can't use it again until you've pumped the water back up.
- But the industry is very good at predicting when the surges in power demand will happen, so good planning can get around this problem

Battery storage [5-8]

Batteries are one of the most cost-effective energy storage technologies available, with energy stored electrochemically. A battery system is made up of a set of low-voltage/power battery modules connected in parallel and series to achieve a desired electrical characteristic. Batteries are “charged” when they undergo an internal chemical reaction under a potential applied to the terminals. They deliver the absorbed energy, or “discharge,” when they reverse the chemical reaction. Key factors of batteries for storage applications include: high energy density, high energy capability, round trip efficiency, cycling capability, life span, and initial cost.

There are a number of battery technologies under consideration for large-scale energy storage. Lead-acid batteries represent an established, mature technology. Lead-acid

Battery storage stores electrical energy in a reversible chemical reaction. The renewable energy (RE) source (PV, wind, or hydro) produces the energy, and the battery stores it for times of low or no RE production. Most batteries employed in renewable energy systems use the same electro-chemical reactions as the lead-acid battery in your car. But, unlike your car battery, they are specifically designed for deep cycling. And most renewable energy systems have batteries which store between ten and hundreds of times more energy than a car battery. This doesn’t guarantee you will have a consistent performance with batteries. One should consider backup power in case your batteries become discharged due to lack of renewable energy in the RE system or an over consumption of energy.

There are many brands and types of batteries available for RE systems. It is important to find the right battery for your situation and wallet. The two most common batteries are the L-16 and golf cart sizes. With proper care, RE system batteries have a lifetime of five to ten years, but there are more expensive batteries that are warranted to last ten to twenty years.

Battery capacity is rated in amp-hours. 1 amp-hour is the equivalent of drawing 1 amp steadily for one hour, or 2 amps steadily for half an hour. A typical 12 volt system may have 800 amp-hours of battery capacity. This battery can draw 100 Amps for 8 hours if fully discharged and starting from a fully charged state. This is the equivalent of 1,200 watts for eight hours (watts = amps x volts), or about the same power consumed as running a small hair dryer for eight hours.

However, completely discharging your battery decreases its longevity, and can ruin it in short order. Most home power users will only tap into a portion of available capacity to keep their batteries alive longer. Opinion varies as to the appropriate depth of discharge, but most agree that 50% (and many say 30%) is the maximum a battery should be routinely discharged. Never go below 80% depth of discharge. 50% means that the above 1200

watt hair dryer would only be used for 4 hours instead of the 8 indicated by the maximum capacity of the batteries.
Batteries typically are encased in plastic and need to be wired together in series and parallel strings by the installer. Some larger batteries are pre-wired and encased in steel containers.
Batteries do not belong inside your living space. They have dangerous chemicals in them, so they must be contained to avoid spills. They also put out hydrogen and oxygen gas while being charged, so they should be vented to the outdoors. Their tops and connections must be periodically cleaned to avoid energy losses. Batteries must also be routinely topped off with distilled water. Finally, they need to be "equalized" with an occasional controlled overcharge to keep the individual cells at equal states of charge.

Advantage

- Without some means of storing energy for quick release, we'd be in trouble.
- Little size compare to substation
- Little effect on the landscape.

Disadvantage

- Expensive to build.
- Pollution or waste

ASSIGNMENT STRATEGY OF STORAGE SYSTEM OF DISTRIBUTION SYSTEM

In distribution planning stage, energy storage assignment strategy should be considered with voltage level.

Energy storage in HV distribution system

In HV distribution system, energy storages are used to curtail peak-valley difference. The capacity of energy storage and setting site of it should be considered in detail. In Fig.2 one example sequencing load cure is presented. In this curve, 5% duration load level more than average load level (56% peak load). To maintain the security, system should take additional backup capacity to meet the peak load that duration time no more than 5% peak load.

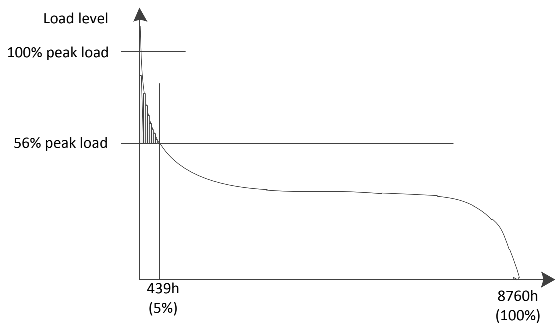

Fig.1 Sequencing load curve

In this situation, the additional capacity for 5% duration average peak load will result in low efficient and high investment. If we use energy storages in this HV system, it can effectively decrease additional backup capacity and save investment of electrical equipment. On the other hand the investment of energy storage is not cheap that maybe exceed the investment of additional capacity. The amount of additional capacity is decided by the shade area of Fig.1, which should meet the capacity of pump storage that is determined by water reservoir capacity and pump generation output level.
So the decision process of energy storage application can be show as following Fig.2.

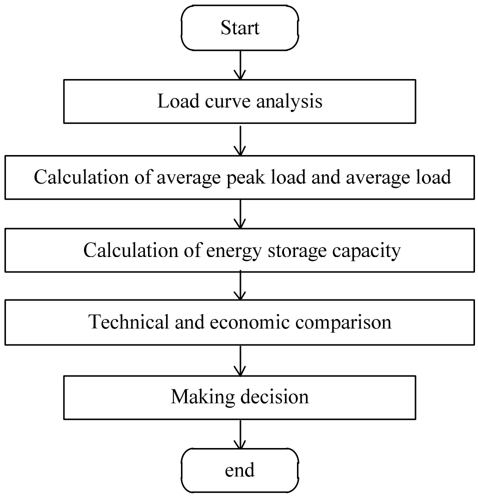

Fig.2 Decision process of energy storage application

Energy storage in MV distribution system

In medium voltage (MV) level, energy storage often integrates with DG, in which it can support DG in three ways: energy stabilization, ride through capacity and enhance dispatch ability.

Tab.2 The three major applications of energy storage with DG in MV Level

Planning	Reason Why Energy Storage Is Being Applied in Conjunction with DG System		
aspect	Energy Stabilization	Ride-Through	Dispatch ability
Reason	Shave needle peaks in the non-coincident load curve due to large appliances, etc.	Provide energy to serve load during periods when DG output unavailable.	Provide energy store to stabilize D(availability to mee various schedules.
Benefit	Lowers peak DG capacity needed. Improves voltage regulation.	Service from PV, etc., can now be maintained during nighttime, etc.	DG owner can nov bid and sell powe contracts for arbitrar schedules.
Storage	Must be enough to "shave" appliance peaks and meet then short term needs.	Dictated by load during DG unavailable times.	Must be enough t transform the D(schedule into th desired sales schedul(
Peak	Relatively great: all the energy stored must be released in just a few minutes.	Usually Vi day's energy Relatively small, only one eighth to one-tenth of stored energy.	Requires more tha for ride though bu much less, relatively than for energy stab.
Method	Based on detailed assessment of daily load curve, on a minute-to-minute basis.	Based on hourly analysis of load needs over a year and DG availability stats.	Based on hourl analysis of desire schedules, D(availability stat business cases.
Design	Typically high energy low storage design with enough capacity to avoid deep cycle.	Must achieve size balance between storage size and DG	Must achieve an overall balance amon DG unit size, storage size, and total cost.

The DG unit will see something akin to a coincident load curve as its load, if the load is connected in parallel with energy storage, so that the energy for the needle peaks is drawn from the storage unit, not the DG unit, with the energy "paid back" by the DG during the next valley. This permits the DG unit to run on a smooth, steady schedule, bottom. The energy storage filters, or "smooth out," the non-coincident load curve. It permits a generator to have a smaller capacity than the needle's magnitude and yet still serve the load with good power quality.

Beyond this, during those periods when it is the sole source of power, the battery will have to be able to meet all the needle peak demands, not just help augment a DG unit. It will need a greater peak capacity, too. Generally, the DG planner will evaluate these energy storage needs using a load duration curve or an hourly simulation analysis, which would examine how often over the year, for how long each time, how much energy would have to be stored in the storage unit for it to do its job. This analysis would also make certain that there is enough DG capacity to "charge" the energy storage unit during off-peak periods.

The differences in planning storage to achieve dispatch ability, versus only ride-through capability, are related to more complex and demanding definition of "success" and exacerbated by the planner's knowledge (or lack of it) of the expected production schedule which the dispatchable generation must meet. In planning ride-through, the planner generally has a good idea of the load to be served: one household load. Often detailed data on that load and its behavior over time are available, but even when they are not the target is clearly identified. By contrast, dispatch ability means freedom to vary production schedule to meet a variety of schedules by changing output times and amounts. The DG storage planner must answer the question "how much freedom is needed in being able to control and shape the net output power schedule?" Once that has been determined, a load duration curve or hourly load curve analysis of the extremes of the range desired can be carried out.

Energy storage in LV distribution system

In low voltage (LV) level, energy storages mainly use to support demand side management (DSM), micro-grid systems, uninterrupted power supply (UPS) systems or emergency lighting systems. On the other side, Electric vehicles normally connect in LV level those also can regard as energy storage units.

(1) Demand Side Management (DSM)

DSM involves actions that encourage end - users to modify their level and pattern of energy usage. Energy storage can be used to provide a suitable sink or source in order to facilitate the integration of DSM. Conversely, DSM can be used to reduce the amount of energy storage capacity required in order to improve the network. A report will be carried out investigating the possibilities relating to DSM by CPI.

(2) Emergency Backup

This is a type of UPS except the units must have longer energy storage capacities. The energy storage device must be able to provide power while generation is cut altogether. Power ratings of 1 MW for durations up to one day are most common.

(3) Emergency Backup

Battery Electric - Vehicles (BEV) is plugged into the LV level and act as additional storage. In contrast, Smart Electric Vehicles has the potential to communicate with the distribution system. For example, at times of high wind production, it is ideal to begin charging electric vehicles to avoid ramping centralized production. In addition, at times of low wind production, charging vehicles should be avoided if possible until a later stage. Vehicle to Grid (V2G) electric vehicles operate in the same way as SEV, however, they have the added feature of being able to supply power back to the distribution system. This increases the level of flexibility within the system once again.

CONCLUSIONS

This paper analyzes the application of energy storage in different voltage level of distribution system and draws some conclusions.

In future distribution system planning, we should consider the influence of energy storage. In HV distribution system, pump storage should be applied to curtail the peak-valley difference of power load in system. In MV distribution system, battery storage should be applied for DG operation. In LV distribution system, battery system is applied on decentralized form for DSM, UPS, EV and etc..

REFERENCE

[1] Paulo F. Ribeiro, Brian K. Johnson, Mariesa L. Crow, Aysen Arsoy, AND Yilu Liu, "Energy Storage Systems for Advantaged Power Applications", *Proceedings of the IEEE*, Vol. 89, No. 12, December 2001.

[2] J. McDowall, "Conventional battery technologies—Present and future", Proceeding, IEEE Power Engineering Society Summer Meeting, Vol. 3, July 2000, 1538–1540.

[3] Wenyuan Li, 2005, *Risk Assessment of Power System*, Wiley & Sons.

[4] J. McDowall, "Conventional battery technologies—Present and future," *in Proceeding 2000 IEEE Power Engineering Society Summer Meeting*, Vol. 3, July 2000, pp. 1538–1540.

[5] M. A. Casacca, M. R. Capobianco and Z. M. Salameh, "Lead-acid battery storage configurations for improved available capacity", *IEEE Trans on Energy Conversion*, Vol. 11, Mar. 1996, 139–145.

[6] W. R. Lachs and D. Sutanto, "Battery storage plant within large load centers", *IEEE Trans on Power System*, Vol. 7, May 1992, 762–769.

[7] World Energy Outlook 2000, International Energy Agency, Paris (2000).

[8] D. Linden and T.B. Reddy, eds., Handbook of Batteries, 3rd ed., Mac Graw-Hill, New York (2002).