The Influence of Distributed Energy Storage on Voltage Distribution

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Abstract. Distributed energy storage in the distribution network is mainly responsible for the peak load shifting, and it will also affect the voltage of the distribution network at the same time. Build the ieee33-node model with MATLAB/SIMULINK, and the distributed energy storage is connected to the node with weak voltage stability. Then analysis the influence of distributed energy storage from three aspects of access location, access capacity and access quantity. The simulation results show that the distributed energy storage connected to the distribution network can obviously improve the voltage stability and reduce line loss.

1. Introduction

At present, domestic energy storage power stations mostly undertake frequency regulation and peak regulation, improve operation stability, adjust frequency and compensate for load fluctuation, etc., such as Baoqing Shenzhen battery energy storage power station, the first megawatt-scale battery energy storage power station in China [1] and energy storage system project of Xingzhou industrial park in Wuxi. Use energy storage to solve other power quality problems such as voltage sag and flicker and harmonic is not put into practice on a large scale. In addition, energy storage is characterized by fast response speed, accurate control and two-way regulation [2], which can effectively improve power quality problems such as voltage fluctuation and flicker, voltage sag and harmonic [3,4]. But energy storage, which is dedicated to improving power quality, has not been put into practical operation on a large scale. As is known to all, the commonly used means to improve voltage deviation is to configure reactive power supply. However, during peak load periods, reactive power compensation cannot compensate the active power deficiency of the system [5]. Moreover, in the distribution network, the resistance and reactance of transmission lines are often at the same level, so the influence of reactive power on voltage deviation cannot be considered only.

There have been a lot of studies on the impact of distributed power supply to distribution network voltage [6,7]. However, compared with the distributed power supply, distributed energy storage are different in terms of capacity, grid control, and are different in the role in the distribution network, and there are two states to charge and discharge. It has important significance to analyze the access to energy storage for the optimal position from the perspective of stable node voltage stability. Reference [8] and reference [9] respectively defined a voltage stability index \( L_i \) and \( \delta_V \) to evaluate the impact of distributed power supply on the voltage of distribution network. Reference [10]
uses genetic algorithm to determine the optimal installation location of superconducting energy storage (SMES) based on voltage stability index L.

This paper first introduces the charging and discharging of battery energy storage model and grid control technology, and then a simple analysis of the energy storage mechanism of the impact of power distribution network voltage, finally built storage inverter grid model in the Matlab/Simulink, and connected to the ieee33 nodes distribution system, the simulation research of distributed energy storage access distribution network of distribution network voltage distribution and the effects of voltage sag.

2. Battery energy storage modeling and grid connection control technology

2.1. Energy storage system structure

Distributed energy storage grid is composed of battery pack, two-way converter, filter, control system and transformer, as shown in figure 1. Due to the bi-directional regulating capacity of energy storage, the energy-storage grid-connected converter is composed of a bi-directional current reversible chopper circuit and a three-phase bridge inverter circuit, as shown in figure 2. Among them, V1 and VD1 constitute a step-down chopper circuit, which provides power to the energy storage from the grid, and the energy storage is in the charging state. V2 and VD2 constitute booster chopper circuit, and the energy storage is in discharge state to output active power to the power grid.

2.2. Battery energy storage model

2.2.1 Constant current charging model of battery energy storage. When the battery SOC is low, the constant current control mode is usually adopted to ensure that the charging current remains unchanged. The block diagram of DC/DC constant current control is shown in figure 3.

2.2.2 Constant voltage discharge model of battery energy storage. When discharging, the energy storage battery usually adopts the constant voltage control mode to keep the discharging voltage unchanged. The block diagram of DC/DC constant voltage control is shown in figure 4.

2.3. Energy storage grid-connected control technology

In this paper, constant power control is adopted in modeling to invert the energy storage into the power grid through transformer, and the AC side of the inverter adopts the power grid frequency and
voltage, so that the distributed energy storage can output active power constantly. $P_{\text{ref}}$ and $Q_{\text{ref}}$ are given power reference value. $U_a, U_b, U_c$ and $I_a, I_b, I_c$ are AC side voltage current value. By tracking the reference current, the purpose of tracking the reference power can be achieved and the active power output of the inverter can be controlled by controlling the current. The principle diagram of PQ control is shown as figure 5.

$$\Delta U \approx \frac{PR + QX}{U_2}$$

(1)

After the energy storage is connected at the $U_2$, active power $P_b$ is transmitted to the system when energy storage is discharged,

$$\Delta U \approx \frac{(P - P_b)R + QX}{U_2}$$

(2)

Because of $(P - P_b) < P$, the voltage drop on the line decreases and increases, $U_2$ rise, voltage increases at distribution network nodes. At the same time according to $\Delta P = \frac{P^2 + Q^2}{U_2^2}$ the active loss on the line is correspondingly reduced. When the energy storage is in the charging state, $\Delta U \approx \frac{(P + P_b)R + QX}{U_2}$ but it is in the load trough state at this time, but $U_1$ is higher than the load peak period at this time. Specific quantitative analysis is shown in the calculation example simulation.
4. Simulation and experimental results

In this paper, ieee33 node distribution system is applied. The reference voltage at the first end is 12.66kv. The distribution network structure is shown in figure 7. Distributed energy storage is connected to different nodes of the distribution network through the above grid-connection method. Model and simulate the influence of different capacities and access locations on voltage distribution of the distribution network in MATLAB/SIMULINK.

Table 1 lists all access modes of energy storage in this paper, including access nodes and capacity.

| Mode | Bus | Power (kW) | Mode | Bus | Power |
|------|-----|------------|------|-----|-------|
| 1    | None | 200        | 6    | 17  | 200   |
| 2    | 5    | 200        | 7    | 5   | 400   |
| 3    | 8    | 200        | 8    | 5and11 | Respectively 200 |
| 4    | 11   | 200        | 9    | 5and11 | Respectively 200 |
| 5    | 14   | 200        | 10   | 11and30 | Respectively 200 |

4.1. Influence of single energy storage access location changing

Access mode 2-7 is 200kW energy storage in a single node. The energy storage is charged during the trough period of load. The load given by the ieee33 system is the load during the peak period, and the peak-valley difference of general load is more than 30%. 70% of the load is taken as the load value during the trough period. Figure 8 and figure 9 are the simulation results of single energy storage discharging position changes.

Figure 8. Voltage distribution of each node when single energy storage discharging position changes.

Figure 9. Voltage distribution of each node when single energy storage charging position changes.
After the single energy storage is connected to the distribution network, the voltage of each node increases to different degrees, and the obvious node is 10-17, 25-32, and the 10-17 changes significantly with the access location. The closer the distributed energy storage is to the terminal point, the greater the impact on the increase of voltage. When the access mode is 1-6 and the energy storage is in the charging state, the voltage at all nodes of the distribution network generally decreases, but the load is at the trough, and the voltage at the point without access is higher than that at the peak of the load. Take node 17 as an example, when no energy storage is added, the load peak voltage is 0.9563, the load trough voltage is 0.9717, and the access mode is 2-6. The voltage at point 17 in season 2-6 is 0.9689, 0.9666, 0.9647, 0.9616, 0.9587, all of which are higher than the load peak voltage when no energy storage is added.

4.2. Influence of single energy storage access capacity changing
Figures 10 and 11 show the simulation results when bus5 is connected to 200kW and 400kW. At the same location, the larger the energy storage capacity is, the more obvious the effect is to enhance the voltage of each node, and the more obvious it is to improve the voltage stability of the distribution network. When the access mode is 2 and 7, the voltage of node 17 is 0.9689 and 0.9663, which are both higher than the peak load voltage value of 0.9563 when the energy storage is not connected.

4.3. Influence of multiple energy storage access location changing
As shown in figure 12, under the condition of constant capacity, multi-position access to energy storage can better improve the voltage of multiple nodes at the end of branch than that of the same location. When the total energy storage capacity is 400kW, when the load is discharged at the peak, the voltage improvement is better when the two nodes are connected separately than when the load is discharged at a single node, and when the load is charged at the trough as shown in figure 13, the voltage drop is also more obvious than the single node. In the access mode 7-10, the voltage of node 17 is 0.9663, 0.9539, 0.9621 and 0.9622 respectively.
5. Conclusion
When the distributed energy storage is connected to the distribution network, the voltage distribution is obviously affected. When power load at the peak, distributed energy storage discharge during peak time, energy storage can not only provide power support, reduce the power grid distribution network from the superior absorption, can also influence the distribution network voltage distribution, improve the node at the end of the branch voltage, reduce the possibility of voltage instability. When the distributed energy storage is connected to the distribution network, the voltage at the charging period is lower than when it is not connected. However, when it is in the load trough period, the voltage at each node of the distribution network is generally higher than that at the peak load period, and the voltage of energy storage charging is higher than that at the peak load period when the energy storage is not connected.

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