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Analysis of the impact of accessing the distributed energy storage system on power distribution network

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Abstract: When distributed energy storage on user side is connected to the distribution network, it will have a significant impact on the distribution network. So the reasonable access for energy storage system has become a key problem. Therefore, this paper analyzes the impact on power distribution network loss and voltage stability by accessing distributed energy storage on user side. Firstly, the relationship between voltage stability of distribution network and distributed energy storage access is studied. It is concluded that the distributed energy storage is beneficial to the voltage stability of distribution network. Then the calculation method of distribution network loss before and after distributed energy storage access is analyzed. Finally, the access location of distributed energy storage is simulated and analyzed. Considering the network loss and voltage stability, it is concluded that small capacity distributed energy storage should be connected at the end of the line, and a certain large capacity distributed energy storage should be connected at the beginning of the line.

1. Introduction

With the rapid development of energy Internet, energy storage technology is gradually introduced to the power grid side. It can realize the coupling of different energy networks and improve the safety of system operation, etc. Compared with the grid side, distributed energy storage on the user side also plays an important role. The access of distributed energy storage can reduce the pressure of load fluctuation on power grid peak shaving. In addition, planning distributed energy storage in a reasonable way can effectively improve the economy and voltage stability of distribution network [1-3]. However, a large number of distributed energy storage accesses on user side will change the direction and size of the power flow of the distribution network, which will have an impact on the network loss of the distribution network. At the same time, it will also have a certain impact on the stability of the voltage.

Based on the above analysis, this paper analyzes the influence of distributed energy storage on voltage stability and network loss of power distribution network. A distributed energy storage configuration scheme for voltage stability and loss reduction in distribution network is proposed, which is beneficial to the rational planning of distributed energy storage.

2. The structure of distributed energy storage on user side

Based on the battery energy storage system, the structure of distributed energy storage on user side is established in this paper. It is mainly composed by battery system and PCS (power conversion system). PCS system can be used as inverter during discharging and rectifier when charging. It can realize the four-quadrant operation of distributed energy storage on the user side and provide two-way active and reactive power for the system [4].

PCS is a device composed of power electronic conversion devices which is connected to the battery system and the AC grid. It is a key component of distributed energy storage and energy exchange with the outside system. Its main functions include: Charging and discharging the battery system in two different working modes, and switching between the two working modes. The four-quadrant operation of the energy storage system is realized through a control strategy, so that bidirectional controllable active and reactive power is provided for the system, and active and reactive power balance of the system is realized. In short, PCS is the most important component of distributed energy storage on the user side.

The following are the operation conditions of distributed energy storage on the user side. (1) When the distributed energy storage runs with the lag power factor, it sends out or absorbs active power, but it always sends out reactive power to the distribution network. (2) When the distributed energy storage operates with advanced power factor, it absorbs active or sends out active power from distribution network but it always absorbs reactive power from the distribution network.

3. Impact on power distribution network by accessing distributed energy storage

3.1 Demand analysis of distributed energy storage access to distribution network

As we all known that the generation of renewable energy sources such as distributed wind power and photovoltaic have randomness and volatility. When it is connected to the distribution network, it will have an impact on the operation control of the system. Energy storage system can smooth the active power fluctuation of distributed wind-solar power generation. When distributed energy storage is connected to the distribution network, the impact of distributed wind and solar power generation on the power grid can be reduced. It can promote the grid's ability to accept high permeability distributed renewable energy for power generation, improve power quality, and enhance the ability to track planned output. Now, the types of load on user side are increasing, the requirements of load on energy supply quality are increasing, and energy storage has the superior ability to regulate and control the energy supply quality. When the power supply on user side stops running for some reasons, the energy storage system can provide power support according to the situation to stabilize the energy supply quality.

The access of large-scale distributed energy storage will have a certain inpact on the operation of distribution network. Whether this effect is positive or negative is closely related to the access mode, access location and access capacity of distributed energy storage. Through making a certain plan to control the access of distributed energy storage, it will bring positive impact on the distribution network.

3.2 Modeling and analysis of distributed energy storage access to distribution network

3.2.1 Voltage stability criterion for distribution networks

In this paper, static analysis method based on power flow is used to analyze voltage stability. The steady state of the system can be described by a set of nonlinear algebraic equations, if the equation is solvable, the system is considered stable. The voltage stability L index is derived based on the solvability of power flow [5].

The distribution network contains N nodes, and any branch is a_{ij}, i and j are respectively two nodes of the branch, and the power flow flows from node i to node j. The loads flowing through nodes i and j are $S_i=P_i+jQ_i$ and $S_j=Pj+jQ_j$, equivalent impedance of the branch is $Z_{ij}=R_{ij}+jX_{ij}$. The expression is as follows:

$$\dot{U}_j = \dot{U}_i - \frac{\left(R_{ij} + jX_{ij}\right)\left(P_j - jQ_j\right)}{\dot{U}_j^*} \quad (1)$$

In the formula: $\dot{U}_i$, $\dot{U}_j$ is the voltage phasor of the *i* and *j* nodes, respectively, $\dot{U}_j^*$ is the conjugate of $\dot{U}_j$, R_{ij} is the resistance between the *i* and *j* nodes, X_{ij} is the reactance between the *i* and *j* nodes, P_j is the active power at the end of *ij* branch, Q_j is the reactive power at the end of *ij* branch. Then unwrap the imaginary part and the real part, and write the equation. According to the existence criterion of the real solution of the quadratic equation, we can get:

$$\frac{4\left[\left(P_j X_{ij} - Q_j R_{ij}\right)^2 + \left(P_j R_{ij} - Q_j X_{ij}\right)U_i^2\right]}{U_i^4} \geq 1 \quad (2)$$

Formula (2) is the voltage stability condition of the first type of distribution network. Therefore, we can use *L* to define the voltage stability index of branch a_{ij} as follows:

$$L = 4\left[\left(P_j X_{ij} - Q_j R_{ij}\right)^2 + \left(P_j R_{ij} - Q_j X_{ij}\right)U_i^2\right] \Big/ U_i^4 \quad (3)$$

Each variable in the calculation formula of *L* is a standard value. We use the largest *L* value in each branch as the *L* value of the system. If $L \leq 1$, the voltage of the system is stable, if $L > 1$, the voltage of the system is unstable. *L* reflects the voltage stability of the entire distribution network. The smaller the *L* value, the more stable the distribution network voltage. The next work of this paper is to consider the relationship between the location of distributed energy storage access and *L*.

3.2.2 Network loss model of distribution network with distributed energy storage

The distribution of power flow and voltage of the distribution network will be changed after the distributed energy storage on user side is connected to the distribution network. This paper takes the *n* segment of the distribution network as an example to analyze the loss changes of the distribution network before and after the distributed energy storage accessed, as shown in figure 1.

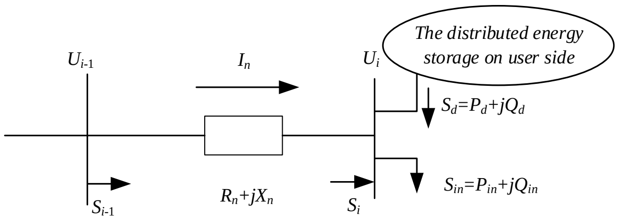

Figure 1. *i* being connected to distributed energy storage at the end node of the *n* segment

When distributed energy storage is unconnected, the network loss [6] of line *n* is

$$P_{n1} = \left(P_{in}^2 + Q_{in}^2\right)R_n \Big/ U_i^2 \quad (4)$$

The net injected power after the distributed energy storage accessing node *i* is

$$S_i = P_i + jQ_i = \left(P_{in} - \alpha P_d\right) + jQ_i \quad (5)$$

The network loss of line *n* is

$$P_{n2} = \left[\left(P_{in} - \alpha P_d\right)^2 + Q_i^2\right]R_n \Big/ U_i^2 \quad (6)$$

In this paper, we use the ratio *M* of distributed energy absorption/emission to total active power load of distribution network to measure the power of distributed energy absorption/emission on user side. The relations are as follows:

$$M = P_d \Big/ \sum_{n=1}^{N-1} P_i \quad (7)$$

In formulas (4)~(7), N is the total nodes number of the distribution network, P_d is the power absorption/emission of the distributed energy storage on user side. P_i and Q_i are the net injection active power and net injection reactive power of node i respectively, P_{in} and Q_{in} are the active and reactive power of the load, R_n is the resistance of line n, respectively, the U_i is the voltage of node i. When the distributed energy storage is discharging, α is 1, if the distributed energy storage is charging, α is -1.

The distribution network losses before and after the user-side distributed energy storage access are P_1, P_2, respectively.

$$P_1 = \sum_{n=1}^{N-1} P_{n1} \tag{8}$$

$$P_2 = \sum_{n=1}^{N-1} P_{n2}$$

(9)

In order to get a clearer change of the network loss of the distribution network before and after the user-side distributed energy storage access, we propose an index η to measure the change of the network loss.

$$\eta = \frac{P_2 - P_1}{P_1} \cdot 100\% \tag{10}$$

It can be seen from (10) that the larger the absolute value of the network loss change rate η is, the larger the change amount before and after the distribution network loss is. When $\eta>0$, the distribution network loss is increased, and distribution network loss is reduced when $\eta<0$.

4. Case study

This paper uses the IEEE33 node system shown in figure 2 to study the impact of access location of distributed energy storage on voltage stability and network loss of distribution network. The total active load of the system is 2850 kW, reactive power load is 1150 kVar, first terminal voltage is 10 kV.

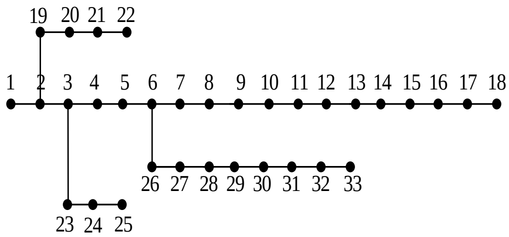

Figure 2. System diagram of IEEE33

4.1 Impact on voltage stability of different access locations of distributed energy storage

From the above, we have already obtained the criterion of voltage stability of distribution network. Next, we will further analyze the voltage stability at different nodes when the distributed energy storage system is accessed. 2 MW distributed energy storage is respectively connected to some nodes of the system in a power control mode to obtain an L_1 value. At the same time, the L_0 value under the condition that each node is not connected with distributed energy storage is considered. The results are shown in table 1.

Table 1. Voltage stability L index of some nodes before and after energy storage access

L	Number of node															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

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L_0	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
L_1	0.3	0.3	0.3	0.29	0.28	0.28	0.27	0.27	0.26	0.26	0.25	0.24	0.24	0.23	0.24	0.25

From table 1, we can know that the L_0 value in each node of the original system is 0.3, when the distributed energy storage system is accessed to different node positions of the system, the value of L_1 will change to some extent. At the beginning of the line $L_0 \approx L_1$, with the access position moves backward, L_1 begins to drop continuously. When distributed energy storage is connected to node 14, L_1 is the minimum 0.23. At this time, it is already close to the end of the line. After that, there will be a increase. We can conclude that with the access location of small capacity distributed energy storage closing to the end of the line, the value of L_1 becomes smaller and smaller, voltage stability is generally on the rise, and the closer the access point is to the terminal, the faster the voltage stability is improved. We can consider connecting small capacity distributed energy storage to the end of the line to make the system operate more stably. However, we also notice that the value of L_1 has an upward trend at nodes 15 and 16. When a certain large capacity of energy storage is connected to the end of the system, the voltage stability of the system may not be too superior. There may be a value equal to the L_0 value of the original system.

4.2 Impact on network loss of distributed energy storage access

Access to distributed energy storage at different locations will have different effects on distribution network loss. In the distribution network, the user-side distributed energy storage is connected to nodes 1, 2, 3, ..., 16 respectively to calculate the power flow of the distribution network. The results are shown in table 2 and table 3 (1, 2, ..., 16 are the number of node, 5%, 10%, 15%, 20% are the value of *M*).

Table 2. Network loss of distributed energy storage at different location during charging

M	Number of node															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
5%	196	199	200	210	200	200	200	210	205	200	200	210	208	200	200	200
10%	197	199	250	250	250	300	300	310	340	350	350	360	380	380	400	390
15%	197	199	250	250	300	370	380	400	410	420	415	600	680	700	750	780

Table 3. Network loss of distributed energy storage at different location during discharging

M	Number of node															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
5%	194	195	195	190	185	180	175	175	170	160	165	165	160	160	158	155
10%	188	190	180	160	155	140	140	130	135	130	135	135	140	145	148	148
15%	180	185	170	150	130	110	110	80	110	120	130	130	150	155	160	180

20%	180	195	155	150	110	80	110	115	140	160	170	170	210	215	230	240

We can get from table 2 that when *M* is 5% the degree of network loss change is not large. When *M* is 10% and distributed energy storage is connected to node 12, the significant changes have taken place in the network loss of the distribution network. The network loss has increased dramatically, and the distribution network loss continues to increase from nodes 13 to 16. We can conclude that the closer the access location to the end of the line, the more the network loss increases. The larger the *M*, the more the network loss increases. That is, when large-capacity energy storage is connected to the end of the distribution network, the more the network loss increases.

From table 3 we can know that when the distributed energy storage is discharging and when *M* is 5% the network loss of the distribution network almost continuously decreases with the backward movement of the access location, but the network loss is big. When M>5%, the network loss of distribution network decreases first and then increases with the backward shift of access location, and when M=20%, η is about -20% minimum, that is, the network loss is reduced faster. Therefore, we can deduce that there must be a maximum energy storage capacity. When accessing to the distribution network at the beginning of the period, the network loss will not increase, but will significantly reduce the network loss, and a minimum value of network loss will be obtained.

Considering the economy of operation, small capacity distributed energy storage is best to connect at the end of the line, large capacity distributed energy storage should be avoided at the end of the line.

5. Conclusions

The reasonable access of distributed energy storage plays an important role in improving system voltage stability and reducing network loss. In this paper, the impact of distributed energy storage on voltage stability and network loss of power distribution network are summarized comprehensively. The conclusions are as follows:

When small capacity distributed energy storage is connected to the distribution network, considering voltage stability and distribution network loss, it can be known that the closer to the end of the line, the better for the operation of the system. When a certain large capacity of distributed energy storage is connected to the distribution network and discharging, a minimum network loss will be obtained. The closer to the end of the line when charging, the bigger the network loss. But the difference of voltage stability between the end and the beginning of the line is not very large, therefore, it is best to approach the beginning of the line when accessing distributed energy storage.

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References

[1] Yao Y., Liu D., Liao H., et al. (2010) Loss Reduction Analysis of Distribution Network with Energy Storage Battery. J. East China Electric Power., 38(5): 677-680.
[2] Ma S., Yang J., Cui C., et al. (2018) Research on Application of Energy Storage Technology in Energy Internet. J. Power Generation Technology., 39(5): 412-418.
[3] CARPINELLI G., CELLI G., MOCCI S., et al. (2013) Optimal Integration of Distributed Energy Storage Devices in Smart Grids. J. IEEE Transactions on Smart Grid., 4(2): 985-995.
[4] Du P., Peng Y., Huang J., et al. (2018) Analysis of distribution network loss reduction with distributed energy storage on the user side. J. Electric Power Science and Engineering., 34(8): 30-35.
[5] Wu R., Xia Y., Zhang Q., et al. (2017) Distribution Network Voltage Stability Criterion Considering Distributed Generation. J. Science & Technology Vision., 17: 35-37.

[6] Zhang T., Yuan X., Xiong W., et al. (2017) Influence of Photovoltaic Power Generation on Distribution Network Voltage and Network Loss Based on OpenDSS. J. Journal of Guizhou University (Natural Sciences)., 34(5): 49-54.