Analysis of influence of distributed power supply on distribution network voltage considering permeability

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Abstract. After a large number of distributed generation (DG) access to the distribution network, it will have a great impact on the static voltage stability of the distribution network. How to effectively reduce the impact of distributed power supply on the distribution network voltage after grid connection has become an urgent problem to be solved. Based on the IEEE33 node distribution network and Matlab simulation software platform, the distributed power supply to the distribution network is studied through multi-angle analysis of access location, access quantity, output capacity, power factor, permeability and network loss. The effect of voltage distribution. The results show that only by properly configuring the distributed power supply can the node voltage of the distribution network be effectively improved.

1. Introduction
Distributed Generation (DG) can effectively reduce transmission line losses and provide users with low-cost, high-quality, high-reliability power supply[1-2]. With the introduction of DG, the distribution network has changed from a radial passive network to an active network with small and medium power sources, which will greatly affect the distribution of distribution network voltage, the transmission of active and reactive power, and the loss of the whole system. This requires a multi-angle study of the distribution network connected to DG to improve the security and economy of the distribution network.

At present, many experts and scholars at home and abroad are committed to analyzing the impact of distributed generation on distribution network. Reference[3] A multi-agent based approach to improve the static voltage stability of distribution networks with distributed generators is proposed. Reference [4] proposes a voltage stability index based on the existence of power flow to calculate the optimal installation location and access capacity of DGs, but which don’t study the impact of multiple DGs on distribution networks.

Based on IEEE33 bus test system, this paper analyzes the DG access to distribution network by establishing equivalent DG model and distribution network model. The influence of DG on the steady-state voltage distribution of active distribution network is studied through several simulation examples. The general law of DG access to distribution network is obtained. Finally, some suggestions for improving the power quality of distribution network are given.

2. Voltage distribution of distribution network with DG
A uniform distribution line is shown in Figure 1. Each concentrated load is regarded as a node along the feeder and numbered. Starting from the bus bar of the substation, it is numbered 1, 2, ..., k, ..., N in
The $N$ loads is evenly distributed at the beginning and the end of the line, and the size of each load is $P_l + jQ_l$.

Set any point $k$ on the distribution line in Figure 1. The active and reactive loads before the point $k$ are:

$$\begin{align*}
P_{1-k} &= (k-1)P_l \\
Q_{1-k} &= (k-1)Q_l
\end{align*}$$

The active and reactive loads after the point $k$ are:

$$\begin{align*}
P_{k-N} &= (N-k+1)P_l \\
Q_{k-N} &= (N-k+1)Q_l
\end{align*}$$

$$\Delta U_k = \Delta U_{k1} + \Delta U_{k2}$$

$$\Delta U_{k1} = k \left( \frac{\Delta U + x \Delta U}{U_N} \right) = \frac{k}{2} \left( k - 1 \right) \frac{rP_l + xQ_l}{U_N}$$

$$\Delta U_{k2} = k \left( \frac{\Delta U + x \Delta U}{U_N} \right) = \frac{k}{2} \left( k - 1 \right) \frac{rP_l + xQ_l}{U_N}$$

On the above-mentioned distribution line, DG is located at any load node $m$. As shown in Figure 1, the effect of DG on voltage loss is on the line from DG to the system, that is, before the point $m$, because the system of power side is short-circuited and the impedance in the line is small relative to the load. According to the direction of voltage loss in the previous section, the voltage loss at DG here is negative to the line, as shown in Figure 2.
Using superposition theorem, the voltage loss of distribution lines containing DG is as follows:

$$\Delta U = \Delta U_k + \Delta U_{DG},$$

That is,

$$\Delta U = \begin{cases} 
\frac{k}{2}(2N - k + 1)C - kD, & k \in [1, m] \\
\frac{k}{2}(2N - k + 1)C - mD, & k \in [m+1, N] 
\end{cases}$$

(6)

$$u_k = \begin{cases} 
u_0 - \frac{k}{2}(2N - k + 1)C + kD, & k \in [1, m] \\
u_0 - \frac{k}{2}(2N - k + 1)C + mD, & k \in [m+1, N] 
\end{cases}$$

(7)

For $u_0$, the initial voltage of the line, take $u_0 = 1.05$. When the capacity and access point of DG are determined, C, D, N and $u_0$ are all fixed values. Voltage distribution can be obtained by substituting the above formula. It can be seen from the above formula that the main factors affecting the distribution network voltage distribution are: DG access point $m$, DG output $P_{DG}$, $Q_{DG}$ and system load, DG output and system load changes reflect the permeability of DG.

At present, the research on voltage distribution of DG distribution network is mainly focused on the capacity and access position of DG, but the research on voltage effect caused by system load variation is very few. In this paper, the influence of DG interconnection on distribution network voltage is analyzed from the aspects of power factor, permeability change and network loss.

The Penetration Level (PL) reflects the relationship between the capacity of all distributed generators in the system and the active load of the system. It is the ratio of the total capacity of distributed generators to the total active load of the system.

$$PL_{DG} (\%) = \frac{\sum P_{DG}}{\sum P_l} \times 100\%$$

(8)

Among of them, the total active power of DG is $\sum P_{DG}$, the total active load of the system is $\sum P_l$.

3. Example analysis

![Figure 3. IEEE33 node distributed system.](image-url)
This example is a standard IEEE33 node network, as shown in Figure 3. The rated voltage of the distribution network is 12.66 kV. Statistics show that the total active load of the distribution network is 3715 kW and the reactive power load is 2300 kvar. In order to minimize the impact of DG input/exit on distribution network, all DGs are maintained at high power factor. In this simulation, the centralized power supply adopts a voltage source model with a frequency of 50 Hz. The load and line models use the modules in the simulation software. Because of the neglect of transient process and dynamic voltage adjustment when DG is connected to distribution network, the DG model is based on controlled current source. The output power and power factor of the model can be controlled by controlling the magnitude and phase of the current.

3.1. Influence of DG access location on voltage

In order to study the influence of different DG access locations on distribution network voltage distribution, DG is connected to nodes 5, 9, 13 and 17 with the capacity of 500KW + j250kVAr, and its influence on distribution network voltage is analyzed by simulation. The voltage curves of each node before and after access to DG are shown in Figure 4.

![Figure 4](image1)

**Figure 4.** The voltage distribution curves of the DG nodes.

![Figure 5](image2)

**Figure 5.** Voltage distributed curve of DG access quantity change.

3.2. Influence of DG’s access quantity on voltage

Plan 1 is at node 5, plan 2 is at node 5 and 9, plan 3 is at node 5, 9, 13, DG is installed respectively, the node output capacity is 500KW + j250kVAr.

From the figure 5, it can be seen that the influence of different number of DGs on the voltage distribution of system nodes is obvious, and the more DGs connected to the grid, the greater the supporting effect on system voltage. Considering the economy of operation, the control strategy, the grid structure and the constraints of the voltage ceiling, it can not be increased indefinitely. It should be planned reasonably to make it have a higher utilization rate.

3.3. The influence of DG’s output capacity on voltage

Capacity is also one of the factors to be considered in grid connection. The output of each distributed power supply is changed by installing the distributed power supply in node 9, which is 250KW+j100kVAr, 500KW+j200kVAr, 750KW+j300kVAr, 1000KW+j400kVAr.

From the simulation results in Figure 6, it can be seen that the supporting effect of DG on the grid voltage is proportional to its total capacity without changing the access point. The larger the capacity of DG, the greater the supporting function of the system voltage, the higher the overall voltage level of the system.
3.4. **DG Influence of power factor on voltage**

Reactive power is an important factor affecting voltage. It is necessary to consider the effect of the output reactive power on the node voltage after DG is connected to the grid. When the DG capacity is fixed, the influence of reactive power on the steady voltage distribution of the feeder is analyzed by changing the DG power factor. The power factor of DG is 1.0, 0.95 (lag) and 0.9 (lag), respectively. The variation curve of node voltage with the power factor of DG is shown in Figure 7.

Figure 7 shows that with the decrease of power factor, the active power of DG output decreases, the reactive power increases, and the voltage level rises. The effect of reactive power of DG output on voltage is greater than that of active power. When the power factor gradually decreases from 1 to 0.9, the voltage curve moves upward and the overall voltage level of the node rises. With the increase of reactive power generated by DG, when the reactive power is greater than the reactive power absorbed by the load at the access point, the reactive power will be transmitted inversely, and the node voltage will first decrease and then rise, and the overall voltage will assume a V-shaped.

3.5. **Effect of DG’s permeability on voltage**

The output of DG is directly proportional to the permeability. DG is installed at nodes 5 and 9 respectively, and the output of each DG is changed. The voltage varies with the permeability as shown in Figure 8.

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**Figure 6.** Simulation of voltage distributed curve with DG capacity changes.

**Figure 7.** DG of different power factors installed at the feeder node voltage curve.

**Figure 8.** Voltage change curve caused by DG permeability.

**Figure 9.** DG grid-connected position on the system network loss.
The simulation results of Figure 8 show that the distribution network voltage with DG is affected by the DG permeability without changing the DG access position. The higher the permeability, the greater the voltage support of the system and the higher the overall voltage level.

3.6. DG Influence of access on system network loss
The grid-connected capacity is $500\text{KW} + j250\text{kVAR}$, and the 1-17 nodes in feeder 1 are connected respectively. The influence of DG grid-connected position change on system network loss is calculated. The comparison results are shown in Figure 9. It can be concluded from Figure 9 that: 1) DG grid-connected effectively improves the system loss; 2) with the DG grid-connected position away from the bus terminal, the system loss first decreases and then rises.

![Image of Figure 10](image)

**Figure 10.** The effect of DG grid capacity on system network loss.

The injection capacity of DG is changed to 0.0, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500 kVAR respectively, and the corresponding numbers are connected to the node 14 of feeder 1 in turn to compare the impact of network loss on the system. The comparison result is shown in Figure 10. It can be seen from Figure 10 that: 1) when the DG grid-connected position is determined, the system network loss will first decrease and then increase with the increase of DG grid-connected capacity. When the DG grid-connected capacity continues to increase to a certain value, the system network loss will exceed the network loss without DG grid-connected; 2) in order to ensure that the system is strictly absorbed, the DG grid-connected capacity generally does not exceed the grid-connected capacity. Load capacity of incoming feeder.

4. Conclusions
Conclusion Based on the 33-node radial distribution network system, the influence of DG on distribution network voltage distribution and network loss is summarized through several simulation experiments, and the following important conclusions are drawn.

1) The voltage distribution formed by the same capacity DG access in different locations is very different, and the closer the DG access point is to the end node, the greater the influence on the line voltage distribution;

2) Voltage support depends on the number and capacity of DGs in the case of grid-connected state and unchanged DG access location. The more DGs and the larger the capacity, the stronger the ability to improve the voltage, and the higher the overall voltage level of the distribution network.

3) The effect of reactive power output of DG on voltage is significant. In order to reduce the influence of DG on voltage and prevent terminal voltage from exceeding the limit, DG should operate with higher power factor.
4) Without changing the DG access position, the voltage support is determined by the permeability of DG. The higher the permeability, the greater the voltage support and the higher the overall voltage level.

5) When the grid-connected capacity of DG increases infinitely to a certain value, the system loss will exceed the grid loss without DG, so the capacity of DG should be selected correctly and scientifically.

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