Impacts on the Voltage Profile of DC Distribution Network with DG Access

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Abstract. With the development of electronic, more and more distributed generations (DGs) access into grid and cause the research fever of direct current (DC) distribution network. Considering distributed generation (DG) location and capacity have great impacts on voltage profile, so use IEEE9 and IEEE33 typical circuit as examples, with DGs access in centralized and decentralized mode, to compare voltage profile in alternating and direct current (AC/DC) distribution network. Introducing the voltage change ratio as an evaluation index, so gets the general results on voltage profile of DC distributed network with DG access. Simulation shows that, in the premise of reasonable location and capacity, DC distribution network is more suitable for DG access.

1. Introduction

With the development of electronic technology, more and more distributed generations (DGs) are introduced into grid. However, when the position and capacity are inappropriate, it will lead to the increase of the power loss and the irregular changes of voltage.

In order to solve the problem above, DC distribution network has been widely concerned. It is proposed in recent years, the output of DG are mostly DC, so compared with the AC distribution network, DC distribution network maybe more suitable for the access of DG [1].

At present, domestic and foreign research institutes and colleges, has carried out the relevant research for DC power distribution technology, some of which have begun to put into practice. Domestic DC power distribution technology is mainly used in ship and subway power supply system, as well as boost substation, communication room and such industries systems, but its large-scale commercial applications are still in further study [2, 3].

In this paper, mainly do the research of the voltage profile of the DC distribution network with DG access, and introducing the voltage change ratio as an evaluation index, and do simulation with the typical IEEE circuit [4], to compare the results of the AC and DC networks.

2. DC distribution network and voltage change ratio

2.1. DC distribution network
DC distribution network topology is mainly radial, ring and grid. At present, the research about DC is mainly focused on devices, but the research about voltage profile after DG access, the interaction between DC distribution network and large power grid is very lacking. In paper [3] and [5], the current research of DC grid efficiency, topology, system stability, power flow calculation and control, relay protection and so on are introduced in detail.

2.2. Voltage change ratio

This paper adopts radiation structure, shown in Figure 1. Set the system bus as the reference node, line voltage is \( U_0 = U_0e^{j0} \). After DG access, to keep power flow in the same direction, need to constraint the DG capacity, so the capacity of the installed DG does not exceed the load size of the node, i.e. \( P_{DG} < P_k \).

**Figure 1.** Radial distribution network

**Figure 2.** Single-phase equivalent circuit

At the same time, assuming all the loads are three-phase balance. The single-phase equivalent circuit of the feeder is shown in Fig. 2. According to Kirchhoff’s law of voltage, there is:

\[
V_S = V_L + (R + jX) \cdot I = V_L + R \cdot I + jX \cdot I
\]  

(1)

Considering the phase between the power supply side and the load side is usually small. Therefore, the voltage drop across the line is approximately equal to:

\[
V_{drop} \cong \text{Re}(Z \cdot I)
\]  

(2)

After DG access, the node voltage:

\[
u_n = u_0 - \sum_{i=1}^{n} I_l \sum_{i=1}^{1} z_i - \sum_{i=1}^{n} I_l \sum_{i=1}^{n} z_i + l_{dg} \sum_{i=1}^{n} z_i
\]  

\( (1 \leq n < K) \) (3)

\[
u_n = u_0 - \sum_{i=1}^{n} I_l \sum_{i=1}^{K} z_i - \sum_{i=1}^{n} I_l \sum_{i=1}^{n} z_i + l_{dg} \sum_{i=1}^{n} z_i
\]  

\( (K \leq n < N) \) (4)

\[
u_n = u_0 - \sum_{i=1}^{n} I_l \sum_{i=1}^{1} z_i + l_{dg} \sum_{i=1}^{n} z_i
\]  

\( (n = N) \) (5)

According to the above derivation process, it can get a series approximate value of the node voltage of DC grid. The voltage change rate \( \varepsilon \) is:
\[ \varepsilon = \frac{U_n' - U_n}{U_n} \cdot 100\% \]  

(6)

The more the \( \varepsilon \) value changes, the more obvious the influence of DG on the node voltage.

### 3. Impacts Analysis on Voltage Profile after DG Access

#### 3.1. Basic experiment

The basic experiment is to simulate the system before and after DG access, and compare the voltage profile of AC / DC distribution network. In the calculation of DC power flow, the line admittance is neglected, and the reactive power is not taken into account, and the Newtonian Loughson method is used for calculation [6-8].

| Table 1. Active power generation and loss after DG accessing (9 notes) unit: pu. |
|---|
| DG access ratio | 10%~15% | 30~40% | 60~70% |
| Active power loss (DC) | 0.048 | 0.084 | 0.096 |
| Active power loss (AC) | 0.049 | 0.06 | 0.097 |
| Active power supply (DC) | 2.883 | 1.955 | 1.046 |
| Active power supply (AC) | 2.884 | 2.17 | 1.047 |

From Table 1, after DG access, the output of active power reduced, but active losses increased with the increase of DG access capacity.

| Table 2. Active power loss after DG accessing (33 notes) unit: kW |
|---|
| DG access mode | centralized | decentralized | Different location |
| Active power loss (AC) | 196.59 | 160.44 | 163.68 |
| Active power loss (DC) | 191.48 | 156.6 | 159.58 |

From Table 2, if DG access in different ways, when adopts the decentralized mode, the active power loss is minimum, and DC is less than the AC system.

#### 3.2. Centralized and decentralized access

First take 9-node system as an example, DG access information is shown in Table 3.

| Table 3. Location information of DGs (9 notes) |
|---|
| Node No. with DG | 5 | 6 | 8 | No DG access | Decentralized access DG | Centralized i |
| Location No. | W5 | W6 | W8 | W0 | FS | Wi |

![Node Voltage after DG access (AC)](image1)

![Node Voltage after DG access (DC)](image2)

Figure 3. Voltage curves of DG accessing in centralized and decentralized mode (9 notes)
From Fig.3, we can see in the AC system, when the DGs access centralized, the voltage of access point improves obviously, but the other nodes change small. In the DC system, no matter what access mode, after DG access, the voltage of each node is increased obviously.

Second, take 33-node system as an example, DG access in a centralized and decentralized mode, and access to the front, middle and end of the system, the results are shown in Fig.4.

![Image of voltage change ratios in AC and DC systems](image)

Legend of DG access location: red line denotes front; green line denotes middle; blue line denotes end.

(a) Voltage change ratio of AC  
(b) Voltage change ratio of DC

**Figure 4.** Voltage ratios of DG accessing in centralized and decentralized mode (33 notes)

From Fig.4, we can see in the AC system, when DGs connect to the end in a decentralized method, the voltage change ratio of each node is the most obvious, when DGs connect in a centralized method, the voltage change ratio of each node is small. So with DG access, the access position has a significant impact on the node voltage.

In the DC systems, the voltage variation trend of each node is similar to that of AC system. The difference is that when DGs connect in decentralized mode, the voltage variation of each node is larger than that in AC system.

In general, when DGs access to the central and end of the system, the impact on the node voltage is more obvious, and the DC system is more sensitive to the DG access mode.

### 3.3. Constant capacity access in different positions

In the premise of keeping the capacity unchanged, DGs connect in different position, and do the simulation to analyze the voltage profile. First, use 9-node system as an example, DG access information is shown in Table 4.

| Node No. with DG | 5&6 | 5&8 | 6&8 | No DG access |
|------------------|-----|-----|-----|-------------|
| Location No.     | W1  | W2  | W3  | W0          |

Table 4. Location information of DGs (9 notes)

Set the access capacity of DG up to 60% of the total load. From Fig.5, shown the results of voltage profile with DG access in the same capacity but different location in 9-node system. In the AC system,
there is a decrease and increase in the voltage of each node with different DG access location. In the DC system, after DG access, the node voltage improve obviously; and with different location, node voltage change small, so it can be think that it is not affected much by the DG access location comparing capacity.

Figure 5. Voltage curves of different locations with the same capacity (9 notes)

Second, take the 33-node system as an example, DG access also has a certain impact on the active loss and output. The DGs with certain capacity connect to the front, middle and end of the system respectively. The simulation results are shown in Table 5.

| Access location | end  | front | middle |
|-----------------|------|-------|--------|
| Active power loss (AC) | 160.44 | 195.7  | 165.31 |
| Active power loss (DC) | 156.6  | 190.43 | 161.17 |

From Table 5, when DG access to the end of the system, the system active loss is minimal and the DC system active loss is significantly smaller than that of the AC system.

After DG access the system, the node voltage significantly improved, especially when DGs access in the middle and end of the system, the system voltage increases the most obvious; and comparing AC system, the voltage of DC system increase more.

4. Results
Through the theoretical analysis and simulation with IEEE9 and IEEE33 system, the experimental data of the AC / DC distribution network are compared and analyzed in detail. First do basic examination; second, DG access in centralized and decentralized method; third, DG access in the front/middle/end part of the grid with the constant capacity. After DGs access in different location and capacity, the voltage profile of AC and DC grid are compared, and the active and reactive power loss are listing clearly.

The general conclusion is drawn. In the premise of proper access capacity and location, the main influences on voltage profile with DG access to DC distribution network are as follows: (1) the DG access position is less important to the DC system than the AC system; (2) After DG access, the voltage level of the DC system can be improved, and the grid voltage profile is more balance than the AC system; (3) After DG access, the active output is significantly reduced in DC system, and
power loss is smaller than that of AC system. In summary, the DC system is more suitable for DG access than the AC system.

While, there is still some challenges. In order to simplify the study, this paper does some equivalent, but the actual distribution network is more complicated. At the same time, this paper mainly considers DG access position, but the DG access location and capacity is a pair of inseparable factors to voltage profile of distribution network. So, under the consideration of the system output and power loss and etc., how to get the best DG access location and capacity in distribution network still needs further studied.

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