Impact of DG on short circuit current detected by protection

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Abstract. DG (distributed generation) access causes the change of current detected by the protection, and then affects the sensitivity of the original protection. In order to solve the problem, the influences of DG capacity, DG access location and short-circuit location on short circuit current are analysed in this paper. When the DG capacity and grid-connected position remain unchanged, the unit current method is used to solve the short-circuit current by solving the transfer impedance. The relationship between the change of short circuit position and the impact degree of DG is discussed in detail, and the calculation formula of extreme point is derived. When the DG capacity and short circuit location remain unchanged, the impact of DG grid-connected position on the upstream and downstream current is analysed. The characteristic curve of the impact of DG position change on protection current detection is given, and the impact of DG grid-connected position on protection sensitivity is explained clearly. The conclusion provides an important reference for the selection of DG grid-connected position and the calculation of relay protection in distribution network with DG.

1. Introduction

DG has the advantages of energy saving, investment saving and flexible power supply. The access of high permeability DG is the inevitable trend of future power grid development [1-6]. However, due to the intermittence and fluctuation of DG, IEEE1547 clearly stipulates that when the power system fails, the DG must be out of operation immediately [7]. Therefore, works of literature put forward the corresponding protection scheme for the distribution network with DG [8-13].

The traditional distribution network is a single power radial grid structure. When there is a short circuit, only one system power supply provides short circuit current to the fault point. When a large number of DGS are connected to the distribution network, the power grid becomes a multi-source structure, and the short-circuit current will be provided by the system and DG together. Its direction will no longer be single, and its amplitude will also change. This fundamental change will have a profound impact on the coordination and adjustment of the original protection. Therefore, it is very important to study the impact of DG on the current of the original distribution network.
In reference [14], a new intelligent fault detection system is designed, which uses wavelet transform to extract current features and neural network to judge fault information, so as to achieve rapid fault isolation. In reference [15], a variable frequency relay protection scheme with new fault characteristics is proposed and the inverter source which can output variable frequency current is designed. In reference [16], the impact of DG access on the performance of inverse-time overcurrent protection is analyzed, and a voltage correction based inverse-time overcurrent protection method with high sensitivity is proposed, which takes into account the increasing effect of DG, but the weakening effect of DG access on the current of the original distribution network is not considered enough. The impact of inverter-interfaced distributed generation (IIDG) on current protection is analyzed in reference [17]. Although the access capacity of DG is discussed when the short circuit occurs at different positions, the impact of the change of DG access position on the grid current is not further analyzed. In reference [18], considering the load effect and phase to phase imbalance, a method for calculating the short-circuit current of distribution network with IIDG is proposed, but the change rate of fault current caused by DG access is not studied further.

In this paper, three factors, DG capacity, DG access location and short circuit location, are taken as the influencing factors. The impact of DG on the system current when different short circuit locations occur is discussed. The impact of DG on the upstream and downstream current and its change rate when DG is connected to the power grid from different locations is studied and the optimal DG grid-connected position is further discussed.

2. Impact of short circuit location change on current detected by the protection

When DG is connected to the distribution system and three-phase short circuit occurs, its equivalent circuit can be simplified to Figure 1. $U_S$, and $U_{DG}$, respectively correspond to system power supply and DG. $Z_S$, is the per-unit value of system power supply impedance. $Z_I$, is the per-unit value of DG upstream line impedance. $Z_2$, is the per-unit value of downstream line impedance between DG access location and short circuit location. $Z_{DG}$, is the per-unit value of DG impedance. The corresponding transfer impedance diagram is shown in Figure 2, where $Z_{SK}$, and $Z_{DGK}$, are the equivalent transfer impedances of the system power supply and DG to the short-circuit point, respectively, and their values are as follows.

$$Z_{SK} = Z_S + Z_I + Z_2 + \frac{(Z_S + Z_I)Z_2}{Z_{DG}}$$  \hspace{1cm} (1)

$$Z_{DGK} = Z_{DG} + Z_I + \frac{Z_{DG} Z_2}{Z_S + Z_I}$$  \hspace{1cm} (2)

**Figure 1.** Equivalent circuit of DG connected to power grid.

Before DG is connected to power grid, there are,

$$I_{1*} = I_{2*} = \frac{U_S}{Z_S + Z_1 + Z_2} = \frac{1}{Z_S + Z_1 + Z_2}$$  \hspace{1cm} (3)

After DG is connected to power grid, the current change detected by the system side (upstream side) protection is:

$$\Delta I = I_{1*} - I_{SK*} = \frac{1}{Z_S + Z_1 + Z_2} - \frac{1}{Z_S + Z_1 + Z_2 + \frac{(Z_S + Z_1)Z_2}{Z_{DG}}}$$  \hspace{1cm} (4)
When the DG capacity and access location remain unchanged and only the short-circuit location changes, that is, in equation (4), $Z_{s1}$, $Z_{c1}$, and $Z_{dc}$ remain unchanged, only $Z_{2c}$ changes.

$$\frac{d\Delta l}{dZ_{2c}} = -\frac{1}{(Z_{s1}+Z_{c1}+Z_{2c})^2 + \frac{1+Z_{s1}+Z_{c1}}{Z_{dc}}(Z_{s1}+Z_{c1}+Z_{2c}+\frac{Z_{s1}+Z_{c1}+Z_{2c}}{Z_{dc}})^2}$$

Let $\frac{d\Delta l}{dZ_{2c}} = 0$, it can be obtained that when

$$Z_{2c} = \frac{W(Z_{s1}+Z_{c1})}{1-W}$$

Where

$$W = \frac{Z_{dc}}{Z_{s1}+Z_{c1}} \left[\sqrt{\frac{Z_{s1}+Z_{c1}+Z_{dc}}{Z_{dc}}} - 1\right]$$

There will be a maximum value point for $\Delta l$.

From the above analysis, it can be seen that the impact of DG access on the current detected by the system power branch protection does not monotonously change with the distance from the short circuit location to the DG access location getting further and further. Before the extreme point determined by equation (6), the DG connection leads to the increase of $\Delta l$ and the decrease of current protection sensitivity of power branch. After the extreme point, the DG connection leads to the decrease of $\Delta l$ and the current protection sensitivity of power branch rises gradually. At the extreme point, $\Delta l$ reaches the maximum and the current protection sensitivity reaches the minimum.

3. Impact of DG access location and capacity on current detected by the protection

3.1. Analysis of impact on upstream current

When a three-phase short circuit occurs at the end of the line, then

$$I_{11} = \frac{u_{s1}}{Z_{s1}+Z_{c1}+Z_{dc}} \times \frac{Z_{dc}}{Z_{dc}} = \frac{u_{s1}}{Z_{s1}+Z_{c1}+Z_{dc}} \times \frac{Z_{11}+Z_{22}}{Z_{dc}}$$

Let $y = \frac{(Z_{11}-Z_{c1})Z_{s1}+Z_{dc}}{Z_{dc}} = \frac{Z_{11}}{Z_{dc}}$,

Then get

$$\frac{dy}{dZ_{11}} = \frac{Z_{11}-Z_{c1}}{Z_{dc}}$$

Obviously, when $Z_{11} = \frac{1}{2}Z_{12}$, get $\frac{dy}{dZ_{11}} = 0$.

Therefore, the impact of DG access location on the upstream current $I_{11}$ is obtained, and the following conclusions can be drawn from the above analysis.

(a) When the DG is connected to the distribution network from the middle position of the line from the system power supply to the short circuit location, the upstream current will reach the minimum value, at this time, the protection sensitivity is the lowest and the possibility of rejection is the greatest.

(b) The DG capacity only affects the magnitude of the current, but does not change the position of the amplitude point (still in the middle of the line). If the DG capacity increases, the current will be smaller and the sensitivity will be lower.

3.2. Analysis of impact on downstream current

The three-phase short circuit still occurs at the end of the line. Next, the impact of DG access location and capacity on the downstream current $I_{12}$ is analyzed. In order to simplify the derivation, it is considered that the system is an infinite power supply system, i.e. $Z_{s1} = 0$.

$$I_{12} = \frac{u_{s1}}{Z_{11}+Z_{dc}+Z_{dc}} = \frac{u_{s1}}{Z_{11}+Z_{dc}+Z_{dc}} \times \frac{Z_{dc}}{Z_{dc}} = \frac{u_{s1}}{Z_{11}+Z_{dc}+Z_{dc}} \times \frac{Z_{12}Z_{dc}+(Z_{12}+Z_{dc})}{Z_{11}+Z_{dc}+Z_{dc}} = \frac{u_{s1}}{Z_{12}Z_{dc}+(Z_{12}+Z_{dc})}$$

Let $y = \frac{Z_{11}+Z_{dc}}{Z_{11}} = \frac{1}{Z_{11}} + \frac{Z_{dc}}{Z_{11}}$

Then get
It can be seen that the impact of DG access location on the downstream current I2 varies monotonously with the line length Z1, and the following conclusions can be drawn.

(a) With the increase of Z1, the farther the DG access location is from the system power supply, i.e. the closer the short circuit location is, the greater the I2 is, and the more likely the protection mis-operation will be.

(b) The larger the DG capacity is, the higher the permeability is, and the greater the impact on the current detected by the protection is.

4. Simulation analysis

4.1. Simulation model

Establish simulation model as shown in Figure 3. The line parameters are as follows[19]: \( R = 0.013 \Omega/km, L = 0.9337 \times 10^{-3} H/km, C = 12.74 \times 10^{-9} F/km \). The load is 2.5MVA. By adjusting the line length parameters, different DG access positions and short-circuit fault positions can be realized. The current monitoring points are set in different positions of the line, and the detection is realized by using the modules such as Fourier and scope. From the perspective of relay protection, the short-circuit current provided by DG is mainly considered when the fault occurs. Therefore, the DG in this paper is represented by a simplified model of voltage source and impedance in series, which can better represent the current injection ability of DG to the fault point.

\[
\frac{dy}{dz_t} = -\frac{1}{z_t} - 2Z_{DG} \frac{1}{z_t^2}, \quad (13)
\]

Figure 3. Simulation experiment model.

4.2. Simulation waveform and analysis

Experiment 1: only short circuit location changes

According to the permeability not more than 10%, the allowable DG capacity is determined to be 0.25MVA. The DG access location is 3km away from the system power supply, and the total length of the line is 10km. When the short circuit occurs at different positions on the DG downstream line, the impact on the current protection sensitivity can be obtained according to the analysis in Section 2. As shown in Figure 4, the abscissa represents the location of three-phase short circuit, and the ordinate represents the current difference \( \Delta I \) through the power outlet protection before and after the DG is connected. It can be seen that when the three-phase short circuit occurs at 4.1km of the line, the maximum value point of \( \Delta I \), appears. When the three-phase short-circuit occurs on the line between the DG access location and the 4.1km position, \( \Delta I \) increases sharply, which shows that the impact of
DG on the system power branch current increases greatly. When the three-phase short-circuit occurs on the line between the 4.1km position and the end of the line (i.e. the 10km position), $\Delta I_s$ decreases slowly, which indicates that the impact of DG on the system power branch current is getting smaller and smaller.

**Figure 4.** The relationship between $\Delta I_s$ and location of short circuit.

**Figure 5.** The relationship between $I_{1C}$ and line location of DG access.

Experiment 2: impact of DG access location and capacity on upstream current

Set the short circuit position unchanged, which occurs at the end of the line, i.e. the 10km position. When DG capacity is 0.2MVA and 0.25MVA respectively, DG is connected to the distribution network from different positions of the line. The relation curve between DG access location and $I_{1C}$ is shown in Figure 5. The ordinate $I_{1C}$ is the amplitude of phase C current flowing through upstream protection 1 and the abscissa is the line location of DG access. It can be seen that when DG is connected from the middle of the power supply to the short circuit position, the upstream current value will be reduced to the lowest value. The larger the DG capacity is, the more the upstream current drops, but the extreme point is still in the middle position. It can also be seen that the change rate of upstream current varies with the DG access location. At the extreme point, when the DG access location changes, the current change rate is the smallest. When DG moves to the system power side or fault position, the slope of the curve becomes larger and larger. It is shown that the change rate of current increases with the change of DG position, that is to say, a small change of DG position may also lead to a large decrease of current value. Comparing the green and blue lines with different DG capacities, the larger the DG capacity is, the greater the impact of current change rate is.

Experiment 3: impact of DG access location and capacity on downstream current

**Figure 6.** The relationship between $I_{2C}$ and line location of DG access.
Set the short circuit position unchanged, which occurs at the end of the line, i.e. the 10km position. When DG capacity is 0.2MVA and 0.25MVA respectively, DG is connected to the distribution network from different positions of the line. The relation curve between DG access location and I2C is shown in Figure 6. The ordinate I2C is the amplitude of phase C current flowing through downstream protection 2 and the abscissa is the line location of DG access. It can be seen that the farther the DG is from the system power supply, i.e. the larger the abscissa in Figure 6, the larger the I2 is. At the same time, the larger the change rate of current caused by the change of DG position is, the larger the abscissa in Figure 6 is, the larger the slope is, that is, the closer the DG is to the short-circuit position, the greater the change of current will be caused by the small change of DG position. The larger the DG capacity, the steeper the curve, the greater the current value and the greater the impact of the current change rate. The closer the short circuit position is, the more obvious the impact of DG capacity on the current magnitude and change rate is.

In conclusion, considering the impact of DG on the upstream and downstream current, the analysis of the optimal DG grid-connected position is as follows.

(a) L=0km: I1 is the largest and I2 is the smallest, which is the origin of coordinates, that is, the centralized power supply mode.
(b) 0<L<5km: With the increase of L, the impact on I1 and I2 increases gradually.
(c) L=5km: The impact on I1 reaches the maximum value.
(d) 5km<L<10km: With the increase of L, the impact on I1 decreases gradually and the impact on I2 continues to increase.

4.3. Simulation analysis results

The DG access changes the topology of the original distribution network, which will cause the current value detected by the protection to change. Based on the above analysis and experiments, DG access has the following effects on the current detected by the distribution network protection:

(1) When the DG is connected to the middle position of the line from the power supply to the short-circuit point, the change of DG capacity only changes the current amplitude, while the position of the extreme point is always in the middle position. When the DG position moves from the extreme point to both sides of the system or the short-circuit point, the current change rate increases gradually.

(2) The larger the DG capacity is, the greater the impact on the current amplitude and the current change rate detected by the protection.

(3) The closer the DG is to the short circuit point, the greater the impact of its capacity on the current change.

Considering the three factors of DG capacity, DG access location and fault location, the conclusion of impact on current after DG access is shown in Table 1 below.

**Table 1.** Analysis of impact of DG access on current.

| DG capacity | DG access location | fault location | conclusion |
|-------------|--------------------|----------------|------------|
| 1 unchanged | unchanged          | change         | Determine the extreme point according to equation (6). If a short circuit occurs before the extreme point position, the impact of DG access will increase dramatically. If a short circuit occurs after the extreme point position, the impact of DG access will slow down. |
| 2 unchanged | change             | unchanged      | When DG is connected to the middle of the line from the system power supply to the short circuit position, the upstream current will reach the minimum value. The impact of DG on the downstream current is monotonous. The closer the DG is to the short circuit position, the greater the impact on the current. |
| 3 change    | unchanged          | unchanged      | The larger the DG capacity, the greater the impact on the current. |
5. Conclusions
The grid-connected operation of a large number of DGs is an important direction of future power system development. However, DG access has a profound impact on grid structure and short-circuit current distribution, which makes the relay protection of distribution network face new challenges. In this paper, three factors are considered: DG capacity, DG access location and short circu

(1) Short circuit location changes: When the short-circuit position moves along the downstream line of DG, there will be an extreme point in the current variation. Before the extreme point, the increasing impact of DG access on the downstream current will increase sharply, and after the extreme point, it will gradually slow down.

(2) DG access location changes: When DG is connected to the middle of the line from the system power supply to the short circuit position, the sensitivity of upstream protection is the lowest and the possibility of rejection is the greatest. The impact of DG on the downstream current is monotonically increasing with the line length.

(3) DG capacity changes: The larger the DG capacity is, the greater the system permeability is, and the more obvious the effect on the current value and change rate is.

These conclusions are of great value to ensure the reliable operation of distribution network with DGs.

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