Analysis of Single-phase Grounding Fault with Distributed Generation in Distribution Network

Chen ZhuoLin, Tang YuanChun and Lin WenQin
Economic and Technological Research Institute of State Grid Fujian Electric Power Co. Ltd., 350012 Fuzhou, China
czl9320@163.com, 1006479723@qq.com, 13960725532@139.com

Abstract. Different distributed generation (DG) types and neutral grounding methods affect single-phase ground fault current characteristics of distribution network. To analyse the single-phase ground fault current characteristics, this paper establishes a single-phase ground fault model with rotating and inverter-type DG accessed using symmetrical component method. By considering different grounding methods of distribution bus side and DG side, distribution characteristics and change laws of fault current as well as sequence currents on both sides of fault point when single-phase short circuits occur in different positions of system are discussed. To verify correctness of analysis, simulation experiments of models is carried out by Simulink. The results of this paper can provide reference for system relay protection configuration and neutral grounding method selection.

1. Introduction
Distributed generation (DG) has the advantages of clean, environmentally friendly, safe and economical. With the environmental problems becoming increasingly prominent, DG has been used on a large scale[1].

The connection of a great amount of DG in the distribution grid will cause a significant change in the magnitude of the fault current[2]. Simultaneously, there is a difference between the DG neutral grounding method and the system grounding method. The difference will change the distribution of the zero-sequence impedance of system, which affects the distribution characteristics of short-circuit current under ground-fault. These phenomenon increases the difficulty of coordination between relay protection devices. However, the configuration of relay protection and the selection of neutral grounding methods is highly related to the characteristics of fault current. Therefore, it’s essential to study the characteristics of fault current under different grounding methods in DG-containing distribution grid.

DG can be divided into rotary DG and inverter Interfaced DG (IIDG) according to the grid-connected interface type. Rotary type DG mainly includes hydraulic turbines as well as direct-drive wind turbines, while IIDG includes photovoltaic power generation, fuel cells, and gas turbines[3,4]. Different types of DG exhibit different current characteristics during faults. The fault current of rotating DG is mainly affected by its capacity and model. The fault current of IIDG mainly depends on the control strategy of its inverter, which is generally limited to 1-2 times the rated current[5].

The grounding methods in medium-voltage distribution grid include non-grounding, direct neutral grounding, grounding via small resistance, grounding via arc suppression coil in existing research[6]. The distribution of system fault current is related to the zero-sequence impedance. While the
magnitude of the zero-sequence impedance is affected by the neutral grounding method. Thus, it is necessary to consider the DG type, system grounding method, fault location and other influencing factors at the same time to comprehensively analyse the characteristics of the system fault current and its changing law.

When calculating the short-circuit current of DG-containing distribution grid, the voltage source series impedance model is usually used to replace rotary DG equivalently[7]. The decoupling phase component method is also proposed to calculate the short-circuit current at the fault point with the help of phase-sequence parameter transformation technology[8]. The calculation model of rotary DG is mature. For IIDG, according to the output characteristics of IIDG using P-Q control strategy, reference [9-10] establishes the fault equivalent model of IIDG by iterative calculation. Reference [11] proposed a voltage-controlled current source equivalent model for the IIDG controlled by the positive-sequence component. It also analysed the phase-to-phase short-circuit fault, but ignored the influence of the negative-sequence current in the fault. On this basis, reference [12] established a sequence component current source model for short-circuit calculation of IIDG considering the negative-sequence current injection of IIDG when asymmetrical short-circuit occurs in the power grid. Furthermore, it used the symmetrical component iterative algorithm to calculate the fault current. Reference [13,14] started from the IIDG's low voltage ride-through control strategy, analysed the relationship between its control strategy and the fault current characteristics, and then deduced the inverter-type fault current calculation method. The above reference s have conducted many studies on short-circuit current calculation, but they have not considered the influence of the neutral grounding method of the distribution grid.

Single-phase ground fault is the most common fault occurring in the distribution grid, which accounts for about 70% of the total faults[15]. A lot of research on the analysis of single-phase ground fault current in DG-containing distribution grid has conducted. Reference [16] established a fault component sequence network model with rotary DG for the distribution grid grounding via small resistance. Then it analysed the distribution characteristics of fault current under different grounding methods on the DG side. Reference [17] analysed the distribution of fault current after IIDG was connected to the distribution grid grounding via small resistance. Reference [18] established the fault equivalent model of IIDG from the perspective of zero-sequence current protection, and proposed an iterative solution algorithm for zero-sequence current. In summary, the existing researches are all based on the distribution grid grounding via small resistance. And the distribution characteristics of single-phase grounding fault current under different neutral grounding methods are not discussed.

In this paper, the single-phase grounding fault models of rotatory DG and IIDG are developed respectively by utilizing the symmetrical component method, considering the different grounding methods on the bus side and the DG side. Proposed model is used to analyze the distribution characteristics of sequence current and the magnitude of fault current. The changing law of fault current with the movement of the fault point is also discussed. Finally, the correctness of proposed model and the theoretical deduction result is verified by MATLAB/Simulink simulation.

2. Analysis of the single-phase ground fault upstream in connection point of DG

The distribution grid structure with DG is shown in Figure 1. T1 and T2 are respectively the main grid-side grounding transformer and the DG-side grid-connected transformer. PCC (Point of Common Coupling) represents the public connection point where DG is connected to the grid. l is the distance between the distribution network bus and PCC. F1 represents the single-phase ground fault point. Different positions of the switch represent different grounding methods and DG types. The positions 1-4 indicate grounding via small resistance, direct neutral grounding, non-grounding, grounding via arc suppression coil respectively. The positions I and II indicate rotating-type DG and the IIDG connected to grid respectively.

When single-phase grounding fault occurs at point F1 in Figure 1, rotating-type DG can be equivalent to voltage source series impedance model. For the IIDG controlled by the PQ power control strategy, when an asymmetric fault occurs, it can be equivalent to current source model containing positive-sequence and negative-sequence components. According to the fault boundary conditions of
single-phase grounding, the symmetrical component method is used to draw the positive-sequence, negative-sequence, and zero-sequence network diagram, as shown in Figure 2.

![Figure 1. Single-line diagram of a single DG system](image1)

![Figure 2. Sequence network of single-phase earth fault at F1](image2)

Where \( Z_{S(1)} \) and \( Z_{S(2)} \) are the positive-sequence and negative-sequence impedances of the generator and transformer of the distribution grid. \( Z_{T(0)} \) is the zero-sequence impedance of the grounding transformer \( T_1 \). \( Z_{a(1)} \), \( Z_{a(2)} \), \( Z_{a(0)} \) are the positive-sequence, negative-sequence and zero-sequence impedance of the line between PCC and the fault point, respectively. \( Z_{DG(1)} \), \( Z_{DG(2)} \) are the positive-sequence and negative-sequence impedances of rotary DG respectively. \( I_{IIDG(1)} \), \( I_{IIDG(2)} \) are the steady-state fault current positive-sequence and negative-sequence components of IIDG respectively. \( I_{e(1)} \), \( I_{e(2)} \), \( I_{e(0)} \) are the positive-sequence, negative-sequence, and zero-sequence fault current components on the bus side and DG side of the distribution grid respectively. \( I_f \) is the positive-sequence (negative-sequence or zero-sequence) fault current components. The fault current of fault point \( I_f = 3I_e \). \( U_{PH} \) is fault voltage of fault point. \( U_{j(m)} \), \( U_{j(2)} \), \( U_{j(3)} \) are the positive-sequence, negative-sequence, and zero-sequence fault voltage components. \( R_1 \), \( R_2 \) are the neutral grounding resistance of grid side and DG side respectively. \( Z_C \) is the impedance of arc suppression coil grounded in neutral point.

There are lots of references analyzing the fault current when distribution grid is grounding via small resistance. Thus, the method grounding via small resistance will not be described in this paper. When the grid-connected transformer of DG is non-grounding, and the distribution grid on bus side is non-grounding or grounding via arc suppression coil, the steady-state fault current appears as capacitive current to the ground or over-compensated inductive current, which is so small that it can be ignored. Therefore, this paper only analyses the other four grounding methods.

### 2.1. Connecting to rotary DG in the distribution grid
2.1.1. Current analysis at fault point. Suppose the positive-sequence, negative-sequence and zero-sequence impedance of the unit length of the line are respectively Z11, Z12 and Z10, and the distance between the fault point and the distribution grid bus is x.

1) Both the bus side and the DG side adopt direct neutral grounding method

Suppose the Positive-sequence, negative-sequence, zero-sequence equivalent impedance on the bus side of the distribution grid are respectively Z_{a(1)}, Z_{a(2)}, Z_{a(0)}, and the same impedance on the DG side are Z'_{a(1)}, Z'_{a(2)}, Z'_{a(0)}. They can be written as

\[\begin{align*}
Z_{a(1)} &= Z_{a(2)} = Z_{S(1)} + xZ_{11} \\
Z_{a(0)} &= Z_{T(0)} + xZ_{10}
\end{align*}\]

(1)

\[\begin{align*}
Z'_{a(1)} &= Z_{T_2} + (l-x)Z_{11} + Z_{DG(1)} \\
Z'_{a(0)} &= Z_{T_2} + (l-x)Z_{10}
\end{align*}\]

(2)

The capacity of the rotary DG connected to the distribution grid is generally small. And, the impedance of the DG and grid-connected transformer is large. Hence, there is the following relationship between the impedance of generator and transformer of the distribution grid[6].

\[\begin{align*}
Z_{S(1)} &\ll Z_{T_2} + Z_{DG(1)} \\
Z_{S(2)} &\ll Z_{T_2} + Z_{DG(2)}
\end{align*}\]

(3)

Therefore, the fault current can be approximated as

\[I_f \approx 3I = \frac{3U}{2Z_{a(1)} + Z_{a(0)} + Z'_{a(0)}} = \frac{3U}{2(Z_{S(1)} + xZ_{11}) + (Z_{T(0)} + xZ_{10})(Z_{T_2} + (l-x)Z_{10})} \]

(4)

From equation (4), it can be seen that the fault current is higher than when the DG is not connected. Assume that the impedance of the grounding transformer T1 and the grid-connected transformer T2 are equivalent, that is, Z_{T(0)} \approx Z_{T_2}. When the fault location is close to the bus side, \[|Z_{e(0)}| < |Z'_{e(0)}|\]. When the fault point is far away from the bus side, the parallel value of the positive-sequence and zero-sequence impedance both increase, and the fault current shows a decreasing trend. When \[|Z_{e(0)}| \geq |Z'_{e(0)}|\], the magnitude of the positive-sequence impedance increase is greater than the magnitude of the zero sequence impedance decrease, as the fault point moves. So, the fault current is still gradually decreasing, and the rate of decrease is slightly slower than the aforementioned situation.

2) The bus side adopt non-grounding method while the DG side adopt direct neutral grounding method

The zero-sequence equivalent impedance on the bus side and DG side can be written as

\[\begin{align*}
Z_{a(0)} &= \infty \\
Z'_{a(0)} &= Z_{T_2} + (l-x)Z_{10}
\end{align*}\]

(5)

The current at the fault point can be expressed as

\[I_f \approx 3I = \frac{3U}{2(Z_{S(1)} + xZ_{11}) + Z_{T_2} + (l-x)Z_{10}} \]

(6)

According to equation (6), it can be seen that the current at the fault point is slightly larger than when the DG is not connected. But it is smaller than when both the bus side and DG side adopt direct neutral grounding method. When the fault point is far from the bus side, the positive-sequence, negative-sequence impedances of the line increase. But the increase amplitude is smaller than the reduction amplitude of the zero-sequence impedance. So the fault current gradually increases, and the change trend is slightly slower than that of the direct neutral grounding method.

3) The bus side adopt grounding via arc suppression coil method while the DG side adopt direct neutral grounding method

At this time, the current at the fault point can be expressed as
\[ I_f \approx 3I = \frac{3U}{M} \left( \frac{Z_{S(1)} + xZ_{l}}{2(Z_{S(1)} + xZ_{l} + Z_{Z(1)} + xZ_{l})} \right) \]  

(7)

From equation (7), it can be seen that the fault current is slightly smaller than the direct neutral grounding method, and slightly larger than the ungrounded method. As the fault point is far from the bus on main grid, the fault current gradually decreases, and the decreasing trend is also between the above two methods.

4) The bus side adopt direct neutral grounding method while the DG side adopt non-grounding method

At this time, the current at the fault point can be expressed as

\[ I_f \approx 3I = \frac{3U}{M} \left( \frac{Z_{S(1)} + xZ_{l}}{2(Z_{S(1)} + xZ_{l} + Z_{Z(1)} + xZ_{l})} \right) \]  

(8)

According to the analysis of equation (8), when the location of the fault point is close to the bus side, the fault current is larger than that when the bus side adopt non-grounding method while the DG side adopt direct neutral grounding method. When the location of the fault point is close to the DG side, the fault current is smaller. In above situations, the fault current is all smaller than that when the bus side adopt grounding via arc suppression coil method. As the fault point moves to the DG side, the fault current gradually decreases. Its changing trend is slightly faster than that when both the bus side and DG side adopt direct neutral grounding method.

2.1.2. Analysis of sequence currents on the bus side and DG side of the distribution grid. Under various grounding methods, the positive-sequence current on the bus side and DG side of the distribution grid can be expressed as

\[ \begin{align*}
I_{a(1)} &= \frac{Z_{a(1)}'}{Z_{a(1)} + Z_{a(1)}'} I = M_1 I \\
I_{a(1)'} &= \frac{Z_{a(1)'}'}{Z_{a(1)} + Z_{a(1)'}'} I = (1-M_1) I
\end{align*} \]  

(9)

In the formula, \( M_1 \) is the ratio of the positive-sequence current on the main grid side to the positive-sequence fault current. From equation (3), it can be seen that \( |M_1| \approx 1 \). So almost all the fault current circulates on the main grid side. And the ratio of negative-sequence current is the same with positive-sequence current.

The analysis of zero-sequence current on the main grid side and DG side is as follows:

1) Both the bus side and DG side adopt direct neutral grounding method

\[ \begin{align*}
I_{a(0)} &= \frac{U}{M} \left( \frac{2(Z_{S(1)} + xZ_{l})(Z_{T(1)} + Z_{T(2)} + lZ_{l0})}{Z_{T(1)} + l-xZ_{l0}} \right) \\
I_{a(0)'} &= \frac{U}{M} \left( \frac{2(Z_{S(1)} + xZ_{l})(Z_{T(1)} + Z_{T(2)} + lZ_{l0})}{Z_{T(1)} + l-xZ_{l0}} \right)
\end{align*} \]  

(10)

According to the analysis of equation (10), the magnitude of the zero-sequence current is greater than that of the traditional distribution grid without DG. As the fault point moves to the DG side, the zero-sequence current on the bus side gradually decreases. When the fault point is close to the bus side, the zero-sequence current on the DG side gradually decreases as the fault point moves to the DG side. When the fault point is close to the DG side, the zero-sequence current on the DG side gradually increases.

2) The bus side adopt non-grounding method while the DG side adopt direct neutral grounding method
It can be seen from (11) that there is zero-sequence current only on the DG side. The amplitude of the zero-sequence current is larger than that when both the bus side and DG side adopt direct neutral grounding method. As the fault point moves to the DG side, the amplitude of the zero-sequence current gradually increases, and the change trend is slightly faster than direct grounding.

3) The bus side adopt grounding via arc suppression coil method while the DG side adopt direct neutral grounding method

\[
\begin{aligned}
\dot{I}_{a(0)} &= 0 \\
\dot{I}_{f(0)} &= \frac{\dot{U}/|U|}{2(2Z_{S(1)} + xZ_{l1} + Z_{T1} + (l-x)Z_{l0})} + \frac{\dot{U}/|U|}{2Z_{T1} + (l-x)Z_{l0}} + \frac{\dot{U}/|U|}{2Z_{l1} + (l-x)Z_{l0}} + \frac{\dot{U}/|U|}{2Z_{l2} + (l-x)Z_{l0}}
\end{aligned}
\]

According to (12), it can be seen that the zero-sequence current on the bus side is slightly smaller than that when both the bus side and DG side adopt direct neutral grounding method. As the fault point moves to the DG side, the zero-sequence current on the bus side gradually decreases. The decreasing trend is more slightly than direct grounding. The magnitude of the zero-sequence current on the DG side lies between the direct grounding and non-grounding methods on the bus side. The changing trend and speed are almost the same as the direct grounding method.

4) The bus side adopt direct neutral grounding method while the DG side adopt non-grounding method

\[
\begin{aligned}
\dot{I}_{a(0)} &= \frac{\dot{U}/|U|}{2(2Z_{S(1)} + xZ_{l1} + Z_{T1} + (l-x)Z_{l0})} + \frac{\dot{U}/|U|}{2Z_{T1} + (l-x)Z_{l0}} + \frac{\dot{U}/|U|}{2Z_{l1} + (l-x)Z_{l0}} + \frac{\dot{U}/|U|}{2Z_{l2} + (l-x)Z_{l0}}
\end{aligned}
\]

It can be seen from equation (13) that there is zero-sequence current only on the main grid side. The magnitude of the zero-sequence current is larger than that when the bus side adopt grounding via arc suppression coil method. As the fault point moves to the DG side, the fault current gradually decreases. The changing trend lies between that when the bus side adopt direct neutral grounding method and that when the bus side adopt grounding via arc suppression coil method.

From the above analysis, it can be seen that the change of the grounding method will not change the ratio of the shunt of the positive-sequence and the negative sequence fault current on both sides of the fault point, but only affects its amplitude and change law. The magnitude of the zero-sequence current, it’s shunt ratio between the bus side and the DG side, and the law of change are all related to the grounding method of the main grid and the DG side.

2.2. Connecting to IIDG in the distribution grid

2.2.1. Current analysis at fault point. Through the node analysis of the network shown in Figure 2, the current of each sequence at fault point can be expressed as

\[
I_f = \frac{3(\dot{U}/|U| + (\dot{I}_{\text{IIDG}} + \dot{I}_{\text{IIDG}})Z_{a(1)})}{2Z_{a(1)} + Z_{a(0)}}
\]

Where \(I_{\text{IIDG}} = f(C, S, Z)\), which means the fault current of IIDG is jointly determined by C, S, and Z. C, S and Z respectively represent the control strategy, capacity and impedance of IIDG. Since the inverter of IIDG is controlled by power electronic components, its response speed is faster after the fault, which means the transient process would last very short. As such, the influence of the transient process can be ignored, and only analyse the steady-state fault current. The capacity of DG connected to the
distribution grid is generally small, and the steady-state fault current generated by it is also relatively small. Therefore, when the grounding method is changed, the change of the IIDG output current can be ignored.

When the topology of the distribution grid is constant and other fault conditions are the same, the closer the fault point is to the IIDG, the greater the steady-state fault current output by it.[19] Combining equation (4), and comparing equation (12) with equation (5), it can be seen that the connection of IIDG increases the magnitude of the fault current compared with rotary DG. Under above four different grounding methods, when the fault point is close to the DG side, the magnitude and change trend relationship of the fault point current are the same as when the rotatory DG is connected. The fault current change trend is faster than that when the rotary DG is connected only in situation that the bus side adopt non-grounding method. In other situations, the change trend is relatively slow.

2.2.2. Analysis of sequence currents on the bus side and DG side of the distribution grid. Under the aforementioned four grounding methods, the positive-sequence and negative-sequence fault currents on the main grid side and DG side are respectively expressed in (15), (16).

\[
\begin{align*}
I_{a(1)} & = I - I_{IIDG(1)} \\
I'_{a(1)} & = I_{IIDG(1)} \\
I_{a(2)} & = I - I_{IIDG(2)} \\
I'_{a(2)} & = I_{IIDG(2)}
\end{align*}
\]  

(15)

(16)

It can be seen from equations (15) and (16) that the distribution of positive-sequence and negative-sequence fault currents on both sides of the fault point has little to do with the neutral grounding method. Only the value is affected by the change of the neutral grounding method. In the case of a certain grounding method, the larger the IIDG capacity connected in the distribution grid, the larger the current amplitude of the fault point and the greater the proportion of the fault current of the positive-sequence and negative-sequence network on the IIDG side. The distribution and change law of the zero-sequence current on both sides of the fault point are the same as those of rotary DG. But the amplitude is slightly larger than that of the rotary DG.

3. Simulation analysis

3.1. Collection of Wi-Fi Data for Learning

The 10 kV distribution network simulation model shown in Figure 1 is built in MATLAB/Simulink to verify the theoretical analysis of this article. The rated capacity of the step-down transformer on the main network side is 63 MVA, the transformation ratio is 110/10 kV, \( Z_{R1}=Z_{R2}=j0.2 \) \( \Omega \); the rated capacity of the grounding transformer on the distribution network side is 1.5 MVA, \( Z_{T1}=j5 \) \( \Omega \); the rated capacity of rotating-type DG is 2 MVA, rated voltage is 0.4 kV, direct axis synchronous reactance \( X_d=1.305 p.u \), quadrature axis synchronous reactance \( X_q=0.474 p.u \), stator resistance \( R_s=2.8544\times10^{-3} p.u \); the rated capacity of IIDG is 2 MVA, the rated voltage is 0.69 kV, the filter inductance is 0.12 mH, the filter capacitor is 700 \( \mu F \), and the DC rated voltage is 1500 kV; the rated capacity of grid-connected transformer is 2.5 MVA, and the transformation ratios of the grid-connected transformers for rotating-type DG and IIDG are 10/0.4 kV and 10/0.69 kV, respectively, \( Z_{11}=j10 \Omega \); 10kV distribution network line data is \( Z_{11}=Z_{22}=0.21+j0.42 \) \( \Omega/km \), \( Z_{00}=0.621+j1.196 \) \( \Omega/km \).

Under different grounding methods, when a fault occurs at different locations in a distribution network with rotating-type DG connected, the magnitude of the fault current, the change trend of the zero sequence current on the bus side and the DG side with the movement of the fault location is shown in Figure 3.
In the above figure, the simulation data points are sequentially connected and drawn into a curve, and the different color curves indicate different grounding methods. Blue means that the distribution network and DG side are both directly grounded, orange means that the distribution network side is not grounded and the DG side is directly grounded, gray means that the distribution network side is grounded through the arc suppression coil and DG side is directly grounded, yellow means that the distribution network side is directly grounded and the DG side is not grounded. It can be seen from Figure 3(a) that when a single-phase ground fault occurs at point F1, the fault current amplitude of the mode that distribution network and DG side are both directly grounded is the largest, and the fault current gradually decreases as the fault point moves to the DG side, and the change trend is in the second place among the four grounding methods. The second is that the distribution network side is grounded through the arc suppression coil and DG side is directly grounded, the fault current amplitude is in the second place, and the reduction rate is in the third place among the four methods.

When the fault location is close to the distribution network bus side, the fault current amplitude that the distribution network side is directly grounded and the DG side is not grounded is in the third place, and the fault current reduction rate is the fastest. While the current amplitude that the distribution
network side is not grounded and the DG side is directly grounded is the smallest, especially when there is a fault at the distribution network bus, the fault current is about 1/3 of the direct grounding method on both sides, and the fault current shows an increasing trend, the increase rate is the slowest among the four methods. When the fault point is close to the DG side, the fault current amplitude that the distribution network side is not grounded and the DG side is directly grounded exceeds the mode that the distribution network side is directly grounded and the DG side is not grounded.

In Figure 3(b), the zero-sequence current that the distribution network side is not grounded and the DG side is directly grounded is zero. As the fault point moves to the DG side, the zero-sequence current on the distribution network side decreases. Similarly, in Figure 3(c), the zero-sequence current that the distribution network side is directly grounded and the DG side is not grounded is zero. When the fault point moves to DG side, the zero-sequence current that the distribution network side is directly grounded and the DG side is directly grounded or through the arc suppression coil has experienced a process of first decreasing and then increasing. While the mode that the distribution network side is not grounded and the DG side is directly grounded has an increasing trend.

Under different grounding methods, when a fault occurs at different locations in a distribution network containing IIDG, the magnitude of the fault current, the change trend of the zero-sequence current on the bus side and the DG side of the distribution network with the movement of the fault location is shown in Figure 4.

In Figure 4(b), the distribution network busbar side zero sequence current that the distribution network side is not grounded and the DG side is directly grounded is zero, and the DG side zero sequence current that the distribution network side is directly grounded and the DG side is not grounded is also zero in Figure 4(c). From the comparison of Fig. 3 and Fig. 4, it can be seen that the magnitude of the fault current is slightly larger than when the the rotating DG is connected to distribution network. As the fault point moves to the DG side, the fault current decreases more slowly than rotating-type DG, while the increasing trend is slightly faster.
(b) Variation law of zero sequence current on DG side

Figure 4. Change of fault current with IIDG in distribution network

To sum up, after different types of DGs are connected to the distribution network, when single-phase grounding faults occur at different locations, the current at the fault point, the distribution of sequence currents on the bus side and DG side, and the change law with the fault point movement are consistent with the theoretical analysis, which verifies the correctness of the theoretical analysis in this article.

4. Conclusion
When the grounding methods of the busbar side and the DG side are different, the single-phase grounding of the system exhibits different fault current characteristics. This paper uses the symmetrical component method to analyze the single-phase ground faults of different grounding methods in distribution networks with DG connected, and verifies them through simulation. The results show that:

(1) In the case of the same capacity, the inverter-type DG will generate a larger fault current than the rotating-type DG.

(2) The change of the neutral grounding method mainly affects the distribution of zero sequence current, and the difference between different grounding methods is large, which brings difficulties to the relay protection setting and fault line selection of the distribution network after the DG is connected.

(3) When both the busbar side and the DG side of the distribution network are directly grounded, a fault current with a larger amplitude will be generated. In the actual distribution network, this grounding method should be avoided as much as possible.

5. References
[1] Huang S J, Hsieh C W, Wan H H. Confirming the Permissible Capacity of Distributed Generation for Grid-Connected Distribution Feeders[J]. IEEE Transactions on Power Systems, 2015, 30(1): 540-541.
[2] Peng Ke, Zhang Cong, Xu Bingyn ,et al. Key Issues of Fault Analysis on Distribution System With High-density Distributed Generations[J]. Automation of Electric Power Systems, 2017, 41(24): 184-192.
[3] Guo W, Mu L, Zhang X. Fault Models of Inverter-Interfaced Distributed Generators within a Low-Voltage Microgrid[J]. IEEE Transactions on Power Delivery, 2017, 32(1): 453-461.
[4] Wang Q, Zhou N, Ye L. Fault Analysis for Distribution Networks With Current-Controlled Three-Phase Inverter-Interfaced Distributed Generators[J]. IEEE Transactions on Power Delivery, 2015, 30(3): 1532-1542.
[5] Alwash S F, Ramachandaramurthy V K ,Mithulananthan N. Fault-Location Scheme for Power Distribution System with Distributed Generation[J]. IEEE Transactions on Power Delivery, 2015, 30(3): 1187-1195.
[6] Xue Yongduan, Guo Liwei, Zhang Linli, et al. Selection Problems of Neutral Grounding Mode in Active Distribution Networks[J]. Automation of Electric Power Systems, 2015, 39(13): 129-136.

[7] Alwash S F, Ramachandaramurthy V K, Mithulananthan N. Fault-Location Scheme for Power Distribution System with Distributed Generation[J]. IEEE Transactions on Power Delivery, 2015, 30(3): 1187-1195.

[8] Fu Xu. Decoupling Phase Domain Method for Fault Analysis of Distribution System with Distributed Generation[J]. Electric Power Automation Equipment, 2009, 29(06): 19-23.

[9] Hong Shubin, Fan Chunju, Chen Shi, et al. Research on Fault Equivalence Method for Multiple Inverter-Interfaced Distributed Generation Based on PQ Control Strategy[J]. Power System Technology, 2018, 42(04): 1101-1109.

[10] Pan Guoqing, Zeng Dehui, Wang Gang, et al. Fault Analysis on Distribution Network With Inverter Interfaced Distributed Generations Based on PQ Control Strategy[J]. Proceedings of the CSEE, 2014, 34(4): 555-561.

[11] Wu Zhengrong, Wang Gang, Li Haifeng, et al. Analysis on the Distribution Network With Distributed Generators Under Phase-to-phase Short-circuit Faults[J]. Proceedings of the CSEE, 2013, 33(1): 130-136.

[12] Zhou Niancheng, Ye Ling, Wang Qianggang, et al. Asymmetric Short-circuit Current Calculation for Inverter Interfaced Distributed Generators With Negative Sequence Current Injection Integrated in Power Systems[J]. Proceedings of the CSEE, 2013, 33(36): 41-49+8.

[13] Tan Huizheng, Li Yongli, Chen Xiaolong, et al. Influence of Inverter-Interfaced Distributed Generator with Low-Voltage Ride-Through Capability on Short Circuit Current of Distribution network[J]. Electric Power Automation Equipment, 2015, 35(08): 31-37+52.

[14] Liu Sumei, Bi tianshu, Wang Xiaoyang, et al. Fault Current Characteristics of Inverter Interfaced Renewable Energy Generators with Asymmetrical Fault Ride-through Capability[J]. Automation of Electric Power Systems, 2016, 40(03): 66-73.

[15] Wang Y, Huang Y, Zeng X, et al. Faulty Feeder Detection of Single Phase-earth Fault Using Grey Relation Degree in Resonant Grounding System[J]. IEEE Transactions on Power Delivery, 2017, 32(1): 55-61.

[16] Guo Liwei, Xue Yongduan, Zhang Linli, et al. Analysis of Single-phase Earth Fault in Low Resistance Grounded Distribution Network Containing DG[J]. Automation of Electric Power Systems, 2015, 39(20): 116-123. [10] Pan Guoqing, Zeng Dehui, Wang Gang, et al. Fault Analysis on Distribution Network With Inverter Interfaced Distributed Generations Based on PQ Control Strategy[J]. Proceedings of the CSEE, 2014, 34(4): 555-561.

[17] Xu Yuqin, Yang Hao, Li Peng. Earth Fault Analysis on Low Resistance Grounded Distribution Network with Inverter Interfaced Distribution Generation[J]. Electrical Measurement & Instrumentation, 2018, 55(16): 63-69+77.

[18] Yang Weitao, Zeng Dehui, Wang Longjun, et al. Influence of Inverter Interfaced Distributed Generators on Zero-Sequence Current Protection for Feeder of Low Resistance Grounding System [J]. Electric Power Automation Equipment, 2018, 38(09): 162-168.

[19] Changzhongxue, Yang Zhongli, Song Guobing, et al. Analysis on Asymmetric Fault Current Characteristics of Inverter Interfaced Distributed Generator under Positive-Sequence and Negative-Sequence Current Respective Control Strategy [J]. Electric Power Automation Equipment, 2018, 38(01): 44-51.