Simulation analysis of current protection in distributed power distribution network

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Abstract: The massive access of distributed power sources makes the distribution network into an active network with bidirectional power flow, which increases the economics and flexibility of grid operation. However, the protection configuration of traditional distribution systems is based on a single power system. And distributed power has a certain randomness, and its fault current characteristics will change, which complicates the protection of distribution network with distributed power. In order to solve this problem, this paper first builds a distribution network with multiple distributed power sources based on the RTDS simulation platform, and simulates the fault current characteristics of the line faults. Then it sets up a three-stage current protection and supplies power based on the two-sided power supply The network calculates its setting value; finally analyzes the problems existing in the three-stage protection under the network and proposes the idea of using wide area protection as a backup protection.

1. Introduction
Distributed generation (DG) system generally refers to the power generation with small power (generally between several kilowatts to 50MW) distributed in the vicinity of users or users in order to meet the specific needs of users and support the economic operation of the distribution network[1]. The system is usually connected to a low-voltage distribution network (generally a 380V or 10kV distribution network). After a large number of distributed power sources are connected to the power grid, it has a great impact on power grid operation scheduling, relay protection devices, and automatic safety control[2].

In order to ensure the safe and stable operation of the distribution network under the condition of distributed power access, scholars at home and abroad have proposed improved protection schemes for distribution networks with DG from different perspectives[3]. At present, there are three main directions: First, restricting the access capacity of DG. At present, many literatures start from different constraints and analyze the access position and access capacity of DG in the distribution network. For example, considering the impact of the protection capacity, protection reliability [1], and coordination constraints between protections on the input capacity; second, the improved adaptive protection scheme, DG access may cause protection misoperation, sensitivity reduction, etc. Problem, the setting value of the original protection is no longer applicable. In order to adapt to the impact of DG on distribution network protection, the literature [5] analyzed the protection setting values in different situations according to the compound sequence network under different fault types and fault locations. Reference [6] changed the estimation direction of traditional protection setting values, and recursively set values from downstream to upstream, thereby reducing the protection action time in special cases.; third, fault location based on communication technology. Literature [7] uses communication equipment such as Feeder Terminal Unit (FTU) to exchange information, and judges the faulty section according to the current amplitude phase, protection action, power direction information and unit fault
distance in the distribution network. This article uses the above-mentioned setting value analysis method to modify the three-stage protection setting value and simulates the verification.

2. Distribution network model with distributed power
Figure 1 is a 10kV distribution network topology diagram with distributed power. There are 4 feeders in the distribution network, and each feeder is connected to a distributed power source. Among them, DG1 and DG3 are DFIG, and the remaining DGs are powered by photovoltaic and energy storage. The system frequency is 50Hz, and the power source S can be considered as an equivalent model of a large power source. The system-side voltage is selected from the rated voltage of 10.5kV, that is, 

\[ E_S = \frac{10.5}{\sqrt{3}} \angle 0^\circ \text{kV} \]

According to the power design manual, select the 10kV voltage level line model and resistance and reactance parameters. The feeders in the system are all overhead lines. The types and parameters of overhead lines: LGJ, LJ-120 (steel core aluminum stranded wire), \( R = 0.27 \Omega/\text{km} \), \( X = 0.335 \Omega/\text{km} \). According to the length of the model line and the unit line parameters, it can be concluded that the parameters of each line are

\[ Z_L = 1.62 + j2.082 \Omega \]

3. Fault characteristics analysis of distribution network with distributed power
In this part, we study the fault characteristics of DG when a line fault occurs and the fault characteristics of a circuit breaker.

3.1 Simulation waveforms of internal transient response characteristics of distributed power sources during external grid failure
Next, the external fault characteristics of DFIG and photovoltaics are introduced separately.

3.1.1 Waveform when the DFIG has a three-phase short circuit externally

(a) Voltage at DFIG outlet
As can be seen from Figure 2, when the external power grid fails, the grid-connecting point voltage drops instantaneously, and the coupling between the stator and the rotor causes the rotor current to increase. At this time, the current exceeds the limit. Within kV, the converter is safe. The DFIG can provide reactive power during a fault, allowing it to pass smoothly through the low-voltage ride-through phase. After 0.2s, the active and reactive power returns to the rated value.

3.1.2 Waveform when photovoltaic three-phase short circuit occurs externally

(a) Voltage and current waveforms of photovoltaic grid-connected points
It can be known from figure 3 that the voltage at the grid-connecting point drops instantly when an external fault occurs, causing the grid-connecting current to increase. At this time, the output power of the photovoltaic grid-connecting point is less than the actual power output. During the fault, the active power decreases, and it is restored to the original value after adjustment after the 0.2s fault. Energy storage is similar to photovoltaic system control, so internal failures of the energy storage battery are no longer analyzed separately.

3.2 Simulation waveforms of distribution network fault characteristics with distributed power

Taking three-phase short circuit as an example, the fault waveforms on both sides of line AB when three-phase short circuit occurs in the middle of line AB are studied.

As can be seen from FIG. 4, (a) is the current and voltage waveform on the protection side. After a three-phase short circuit occurs, the current increases and the voltage decreases. (b) In order to protect the current and voltage waveforms on the two sides, the fan loses the voltage support of the large power grid after a three-phase short circuit, and the voltage drops to near zero. Because the fan only supplies power after the fault, the fault current is small, and it will return to the original amplitude after 0.37s. Comparing the two figures, it can be seen that the fault current on the system side is about 4 times larger than the fault current on the fan side. After the fault is recovered, the system side current and voltage recovery speed is faster.

4. Including current protection of distributed power distribution network

Current protection has the advantages of simplicity, reliability and economy. For power grids of 35 kV and below, three-stage current protection plus reclosing protection is usually adopted. For complex networks or networks with higher voltage levels, it is difficult to meet the requirements of selectivity, sensitivity, and quick action. Three-phase current protection is usually sufficient[8].

According to the protection setting calculation principle: Instantaneous current protection, set according to the maximum three-phase short-circuit current that avoids the short circuit at the end of this line. As shown in formula(1), action current setting value of instantaneous current protection:
\[ I_{\text{set},1} = K_{\text{rel}} I_{K.C.\text{max}} \] (1)

In the formula (1): 
- \( K_{\text{rel}} \) - Reliability coefficient of instantaneous current protection, usually set to 1.2 ~ 1.3;
- \( I_{K.C.\text{max}} \) - Short-circuit current when the three-phase short-circuit at the end of this line is in the maximum operation mode.

The short-circuit current when the three-phase short-circuit at the end of this line is in the maximum operating mode is shown in formula (2):

\[ I_{K.C.\text{max}} = \frac{E_g}{Z_{\text{min}} + Z_{B-C}} \] (2)

After the distributed power is connected to the power distribution network, it becomes a double-sided power supply network, with power at both ends to supply power. When a line fails, in order to prevent protection from malfunctioning, directional components need to be installed on both sides to define the flow from the bus. The line is the positive direction of the short-circuit power, that is, the direction of the protection action; otherwise, the line is the reverse direction, and the protection does not operate. Take feeder 1 in Figure 1 as an example. Protections 1 and 3 are powered by an infinite power supply, and protections 4 and 2 are powered by DG1. The impedance of the distributed power source is estimated as follows:

Obtain the reactance standard value \( X_{\text{f}} = \frac{I_B}{I_f} \) from the standard value formula \( \frac{I_B}{I_f} = \frac{U_B}{S_B} \). Famous reactance: \( X_{\text{f}} = \frac{U_B}{S_B} \), \( S_B = 100\text{MVA} \), where \( I_f \) is the famous value of short-circuit current.

Time delay instantaneous overcurrent protection, that is, the current protection stage II, set in coordination with the adjacent line I stage. Set according to the operating current of the first line of the next line. As shown in formula (3), action current setting value of time delay instantaneous overcurrent protection:

\[ I_{\text{set},2} = K_{\text{rel}} I_{\text{set},1} \] (3)

In order to ensure the selectivity, the time limit for operation is one time step \( \Delta t \) higher than that of the next section of section I. In this paper, \( \Delta t \) is taken as 0.5.

Overcurrent protection, that is, the current protection stage III, is set according to the maximum load current that escapes the line, the setting value is calculated as shown in formula (4):

\[ I_{\text{set}} = \frac{K_{\text{rel}} K_{\text{ss}}}{K_{\text{re}}} I_{L,\text{max}} \] (4)

In the formula (4):
- \( K_{\text{rel}} \) — Reliability coefficient, generally 1.15 ~ 1.25;
- \( K_{\text{ss}} \) — Self-starting coefficient, the value is greater than 1, determined by the specific wiring and load characteristics of the network;
- \( K_{\text{re}} \) — Return coefficient of current relay, generally take 0.85. In order to ensure the selectivity, the action time limit of each protection from the load to the power supply is increased by \( \Delta t \) in order, where \( \Delta t \) is taken as 0.5.

The protection is configured according to the calculated values of the above calculations. The current protection operation is as follows. As can be seen from the figure, when a three-phase short circuit occurs on the line AB, the protection on both sides can operate correctly.
5. Conclusion
It is verified by simulation that after the fault occurs, the protection provided by the infinite power supply can operate correctly. After analysis, it can be seen that the distributed power supply is powered separately after the fault occurs, and the short-circuit current flows from the distributed power source to the fault point. After the independent power supply, the large grid voltage support is lost. The current amplitude is reduced to a small value. At this time, although the distributed power source is still continuously injecting short-circuit current to the fault point, the harm caused by the small value is small. Based on this, an idea of using wide-area protection as backup protection is proposed. By transmitting and processing all current and switching information in a centralized manner, the circuit breaker trip is controlled.

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