Influence of the relative location of distributed energy sources on the current protection of the electric network

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Abstract. This article focuses on studying the influence of additional sources of electricity generation on the traditional distribution grid, which leads to a change in the direction of the power flow in the grid. Consequently, the sensitivity and speed of current protection are not provided due to the dynamic operation of distributed generation sources. This paper considers the effect of distributed generation on the protection of the power grid. A special emphasis is on problems which may occur in the power grid in the presence of distributed generation. The theoretical background of blinding and calculation of the effect is also presented. The studies presented are made by computer modelling in Matlab/Simulink.

1. Introduction

The integration of power plants in power systems requires a change in traditional protection methods to solve new problems. For example, the magnitude of the fault current and its direction will change when the distributed generation is input into the power grid [1], [11]. The level of electric power sources’ penetration and its type (synchronous generators are connected directly to the network or using a power electronic converter) have a fundamental impact on the protection circuit, which determines the level of short circuit current in the system.

In connection with the changing conditions of electric power systems, it is necessary to constantly recount short-circuit currents and change the parameters of relay protection devices. Therefore, the task itself is to calculate the contributions of the faults of the generation sources. Modern systems use a database or a table to search for the current state and take predefined precautions [2], [3], [10]. However, since distribution networks involve the deployment of new power plants and loads, these schemes are not practical. In addition, power plants based on alternative energy have the non-linear and variable characteristic [4], [5], [12]. In order to ensure a safe operation, it is necessary to control all the elements and make the necessary changes to their settings as the conditions of their operation on the network change.

2. Theoretical background

Traditionally, overcurrent protection is used as the main protection in electric networks. For this reason, the influence of distributed generations must be considered as changes in short circuit currents. Figure 1 shows a typical fragment of the mains DG connected to «B-2».
In order to analyze the influence of the local power plant on the value of the fault current in the feeder, the common feeder is from «B-1» to «B-3», where the power station is located at a distance \( L \), and a three-phase short circuit has occurred near «B-3».

\[
D = \frac{L}{L_o}
\]

where \( D \) – relative connection point and \( L_o \) is the total length of the feeder.

A single-phase equivalent circuit for calculating short-circuit currents is shown in Fig. 2, where \( U_{\text{grid}} \) and \( U_{\text{gen}} \) are power system’s and local power station’s source EMF, \( Z_{\text{grid}} \) and \( Z_{\text{gen}} \) are the internal resistance of the sources, \( Z_L \) is the line impedance.

To simplify the analysis, it is advisable to assume that \( U_{\text{grid}} = U_{\text{gen}} = U_{\text{th}} \), so in figure 3 the Thevenin equivalent of the network of figure 2 is shown [6]. In accordance with figure 3, the equivalent impedance will be equal to:
where \( Z_{\text{grid}} = Z_{\text{gen}} + Z_{\text{L-gen}}, \) \( Z_{\text{L}} \) – the total impedance of the line from the «B-1» to the place of a short circuit at the «B-3». Three-phase short-circuit current is calculated:

\[
I_{\text{fault}} = \frac{U_{\text{th}}}{\sqrt{3} \cdot Z_{\text{th}}} \tag{3}
\]

combining equation (2) and (3) yields:

\[
I_{\text{fault}} = \frac{U_{\text{th}} \cdot (Z_{\text{grid}} + D \cdot Z_{\text{L}} + Z_{\text{gen}})}{\sqrt{3} \cdot (Z_{\text{L}} \cdot Z_{\text{gen}} + Z_{\text{grid}} \cdot Z_{\text{gen}} + Z_{\text{grid}} \cdot Z_{\text{L}} + D \cdot Z_{\text{L}} (Z_{\text{L}} - Z_{\text{grid}}) - D^2 Z_{\text{L}}^2)} \tag{4}
\]

The current from the «B-1» to «B-2» will have the form:

\[
I_{\text{fault-grid}} = \frac{Z_{\text{gen}}}{Z_{\text{grid}} + D \cdot Z_{\text{L}} + Z_{\text{gen}}} \cdot I_{\text{fault}} \tag{5}
\]

combining equation (2) and (3) allows one to calculate the contribution of the grid to the short circuit current:

\[
I_{\text{fault-grid}} = \frac{U_{\text{th}} \cdot Z_{\text{gen}}}{\sqrt{3} \cdot (Z_{\text{L}} \cdot Z_{\text{gen}} + Z_{\text{grid}} \cdot Z_{\text{gen}} + Z_{\text{grid}} \cdot Z_{\text{L}} + D \cdot Z_{\text{L}} (Z_{\text{L}} - Z_{\text{grid}}) - D^2 Z_{\text{L}}^2)} \tag{6}
\]

The total short circuit current determined from equation (4) is non-linear and therefore the current from the power system is too. If the impedance from «B-1» to «B-2» is less than \( Z_{\text{gen}} \), then the short-circuit current will decrease in this branch. Equation (6) describes the contribution of the power system to the fault current in the «B-2», which includes a source of local electricity generation.

3. Computer simulation in Matlab/ Simulink

The grid contribution to the short circuit current will be determined by the feeder impedance, fault power, power and location of DG sources. The Matlab / Simulink computer model in Figure 4 is made to determine the impact of a local power plant [8].

![Figure 4. The Matlab/Simulink model](image-url)
The test network consists of a power system with a capacity of 250 MVA, a common feeder «line1» and «line2» with a length of 50 km, the local power station, the load, the measuring units and the three-phase short circuit block. In order to demonstrate the influence of the power of the local DG and its location on the contribution to the three-phase fault current, the connection location was changed in the test grid while maintaining the total length of «line1» + «line2» = 50 km. To study current power, repeated calculations are performed for the overhead line, where line1 increases and line2 decreases with a step of 1 km, after which the power of the local wind farm increases and the calculation is repeated [9]. The simulation result is shown in Figure 5, where it can be seen how the location of the DG and its power affect the contribution of current from the grid during a three-phase fault.

![Figure 5. $I_{\text{fault-grid}}$ as a function of the DG position on the feeder](image)

The maximum impact of local power by the current flowing from the network during a three-phase fault occurs when parts of «line1» and «line2» are equal, and the contribution of network is minimum. Moreover, the graph shows that when the power plant with the same pitch in the 1.5 MW reduction $I_{\text{fault-grid}}$ non-linearly. To study the influence of the power of the wind turbine in the computer model, the parameters «line1» and «line2» are set to 25 km, i.e., the impact of the generator will be maximum. Next, a repeated calculation of the model is performed with an increase in the power of the power plant in increments of 1 MW to the power of the main power system.

![Figure 6. $I_{\text{fault-grid}}$ as function of the DG power on the feeder](image)

From the simulation result shown in Figure 6, it can be noted that the change in the short circuit current depending on the capacity of the local power plant with constant system parameters is hyperbolic in nature.
4. Conclusion

Introduction of distributed generation sources reduces the contribution of the main power supply in the short-circuit current at the early stages of the network and depends on the power of the local station. For this reason, a short circuit is not detected by the overcurrent protection. Thus, distributed generation directly affects the sensitivity of the protective system and, therefore, its reliability. Blinding may result in total failure of the operation of the protection or it may cause some delay to the operation of the protection. Combined with increased fault levels and multiple faults current infeed, such malfunctions can easily lead to adequate thermal limits of components and lines. There the effects of planned DG units should be studied comprehensively enough in advance to find out the modifications required.

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