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A new short-circuit calculation method of power system with photovoltaic power sources

A new short-circuit calculation method of power system with photovoltaic power sources

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Abstract. A large number of photovoltaic power sources connected to the grid will increase short-circuit current level of power system, and its fault transient process will change the fault characteristics of power grid. In this paper, the equivalent models of transient and steady state faults are obtained, by analysing the full current expression of photovoltaic power sources and its current characteristics in different fault stages. Based on the superposition theorem, the short-circuit current calculation method of power system with photovoltaic power sources is proposed. Finally, the effectiveness of the proposed method is verified by the analysis of actual power grid calculation examples, and the results can be used for power grid planning and relay protection setting.

1. Introduction

In recent years, with the gradual increase of grid-connected capacity of renewable energy such as wind energy and solar energy in the power system, a series of problems have also emerged that need to be resolved. For example, when the power grid fails, the short-circuit current at the fault point will increase due to its influence [1-4], and short-circuit calculation is the basis of power grid planning and design. Therefore, it is necessary to accurately assess the short-circuit current of renewable energy grid-connected.

Most of the renewable energy sources are converter-type power supplies. Currently, there are literatures on their fault transient characteristics and influencing factors [5], converter-type power supply control strategies, calculation models [6, 7], and algorithmic principles of short-circuit currents [8] etc. conducted in-depth research. However, the above literature still has some limitations, and the characteristics of the fault current of the converter power supply are not fully considered.

This paper takes the photovoltaic power supply as an example to discuss its equivalent models in the fault transient and steady-state phases. Finally, based on the superposition theorem, a method for calculating the short-circuit current of the power system under grid-connected photovoltaic power supply is proposed. And the actual grid calculation example verifies the effectiveness of the method.

2. Fault short-circuit current analysis of photovoltaic power sources

Different from conventional power supply, the short-circuit current of photovoltaic power supply is affected by the control strategy and presents current limitation characteristics. However, the short-circuit current change still exists in transient state from normal state to steady state of short-circuit. It mainly includes the attenuated ac periodic component and the attenuated dc component. Taking the steady-state phase of short-circuit current into consideration, the a-phase full current expression of photovoltaic power supply in the case of three-phase short-circuit of power grid is written as:

$$i_{\mathrm{a}}(t)=\left[\left(I'_{\mathrm{m}}-I_{\mathrm{m}\infty}\right)e^{-\frac{t}{T'}}+I_{\mathrm{m}\infty}\right]\cos\left(\omega t+\theta_0\right)+\left(I_{\mathrm{m}|0|}\cos\delta_0-I'_{\mathrm{m}}\cos\theta_0\right)e^{-\frac{t}{T_{\mathrm{a}}}} \tag{1}$$

Where, I'_{m} is initial amplitude of ac component, which decays to steady-state value $I_{\mathrm{m}\infty}$ according to time constant T', f is power grid frequency, and amplitude of current before short-circuit is $I_{\mathrm{m}|0|}$. The last term in the formula is the starting value of dc component, T_{a} is the attenuation time constant of dc component, θ_0 is the phase angle between current and voltage, and δ_0 is the phase angle between current and voltage before short-circuit.

As the three-phase short-circuit current ac component of photovoltaic power supply is symmetrical, the expressions of phase b and phase c can be obtained by substituting (±120°+ 0), (±120°+ 0) for δ_0 and θ_0.

3. Short-circuit current calculation of power system with photovoltaic power sources

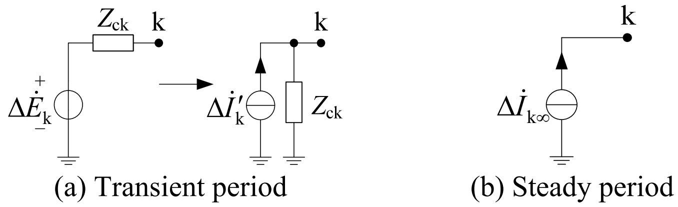
3.1. AC fault component equivalent circuit

When the system fails, the photovoltaic power supply will inject a short-circuit current into the fault point. The short-circuit current is divided into a normal component and a fault component. The fault component is shown in equation (2):

$$\begin{aligned}\Delta i_{\mathrm{k}}(t)&=i_{\mathrm{k}}(t)-i_{\mathrm{k}|0|}(t)\\&=\left[I_{\mathrm{m}\infty}\cos\left(\omega t+\theta_0\right)-I_{\mathrm{m}|0|}\cos\left(\omega t+\delta_0\right)\right]+\left(I'_{\mathrm{m}}-I_{\mathrm{m}\infty}\right)e^{-\frac{t}{T'}}\cos\left(\omega t+\theta_0\right)\\&=\Delta i_{\mathrm{k}\infty}(t)+\Delta i'_{\mathrm{k}}(t)\end{aligned} \tag{2}$$

where, k represents grid connection point, $i_{\mathrm{k}}(t)$, $i_{\mathrm{k}|0|}(t)$ and $\Delta i_{\mathrm{k}}(t)$ are short-circuit current, normal component and fault component injected by photovoltaic power source respectively, $\Delta i'_{\mathrm{k}}(t)$ and $\Delta i_{\mathrm{k}\infty}(t)$ are fault transient component and fault steady component of short-circuit current respectively. The above AC component will decay to a steady state value with time. In engineering calculations, the initial and steady-state values of the transient AC component are calculated with t=0 and t=∞, respectively.

The equivalent model of the AC fault component of the photovoltaic power supply is shown in Figure 1. In Figure 1(a), during the fault transient phase, Norton's theorem is used to equate the voltage source to the current source. In the steady state phase of the fault in Figure 1(b), the photovoltaic power source injects current into the grid connection point.



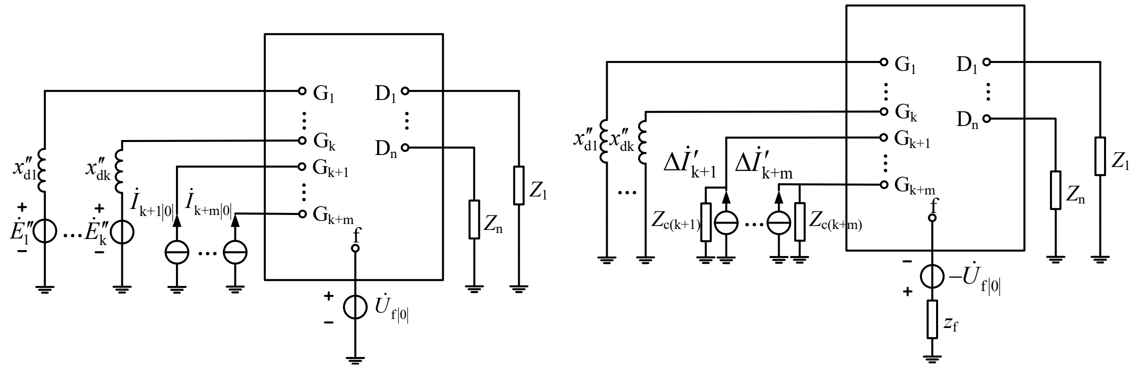
(a) Transient period (b) Steady period

Figure 1. Equivalent circuit of AC fault-component

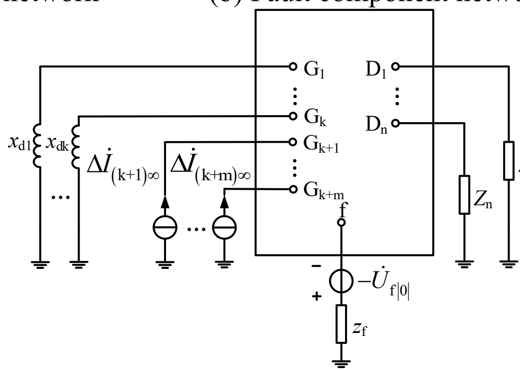
3.2. AC component calculation

In the network shown in Figure 2, there are m photovoltaic power sources connected to the grid, and a three-phase short circuit occurs at point f. In the figure, G_1~G_k represent conventional power access points, and G_{k+1}~G_{k+m} are photovoltaic power grid connection points, D_1~D_n are the load access points.

In Figure 2 (a), photovoltaic power source injects current $\dot{I}_{|0|}$ towards the node in normal component network and voltage at point f is normal operation voltage $\dot{U}_{\mathrm{f}|0|}$. Figure 2 (b) and (c) are fault component networks during transient period and steady period respectively, where voltage source $-\dot{U}_{f|0|}$ and z_f are added at fault terminal.



(a) Normal component network (b) Fault component network during transient period



(c) Fault component network during steady period

Figure 2. Normal circuits and fault circuits of AC components during a fault

Since the normal current value can be obtained by power flow calculation, only the calculation of the fault component is analysed here. The node voltage equation of the above network is as follows:

$$\boldsymbol{\Delta U_i} = \boldsymbol{Z I_i} \tag{3}$$

where the left side of the equation is the fault component of the node voltage; the coefficient matrix $\boldsymbol{Z}$ is the node impedance matrix; the current $\boldsymbol{I_i}$ is injected toward the outside of each node. Voltage fault components at short-circuit point in equation (3) are separately listed out, and the following can be obtained through superposition theorem:

$$\begin{cases} \Delta\dot{U}_f = \begin{bmatrix} Z_{f(k+1)} & \cdots & Z_{f(k+m)} & Z_{ff} \end{bmatrix} \begin{bmatrix} \Delta\dot{I}_{(k+1)\infty} \\ \vdots \\ \Delta\dot{I}_{(k+m)\infty} \\ -\dot{I}_{f\infty} \end{bmatrix} \\ z_f \dot{I}_{f\infty} = \dot{U}_{f|0|} + \Delta\dot{U}_f \end{cases} \tag{4}$$

Arranging formula (4), the AC component of the short-circuit current can be obtained as:

$$\dot{I}_{f\infty} = \frac{\dot{U}_{f|0|} + \begin{bmatrix} Z_{f(k+1)} & \cdots & Z_{f(k+m)} \end{bmatrix} \begin{bmatrix} \Delta\dot{I}_{(k+1)\infty} \\ \vdots \\ \Delta\dot{I}_{(k+m)\infty} \end{bmatrix}}{Z_{ff} + z_f} \tag{5}$$

Substituting the short-circuit current $\dot{I}_{f\infty}$ into equation (3), the voltage fault component at any point can be calculated, and the voltage after each node fault is obtained using the superposition theorem is:

$$\begin{aligned}\dot{U}_{i} &= \dot{U}_{i|0|} + \Delta\dot{U}_{i} \\ &= \dot{U}_{i|0|} + \begin{bmatrix} Z_{i(k+1)} & \cdots & Z_{i(k+m)} & Z_{if} \end{bmatrix} \begin{bmatrix} \Delta\dot{I}_{(k+1)\infty} \\ \vdots \\ \Delta\dot{I}_{(k+m)\infty} \\ -\dot{I}_{f\infty} \end{bmatrix}\end{aligned} \tag{6}$$

Using the above method, the voltage and current distribution of the system node after the fault can be finally obtained. In the calculation of the fault transient phase, the secondary transient reactance is used to replace the synchronous reactance in the conventional power supply, and the grounding branch Z_c is added to the photovoltaic power supply node; the initial AC component value of the short circuit current is calculated according to equations (3)-(6).

4. Simulation analysis

In the calculation example, this paper uses the above method to calculate the short-circuit current under different node faults, and establishes a simulation model, and compares the calculation results with the simulation results to verify the correctness of the proposed method. The example network structure is shown in Figure 3.

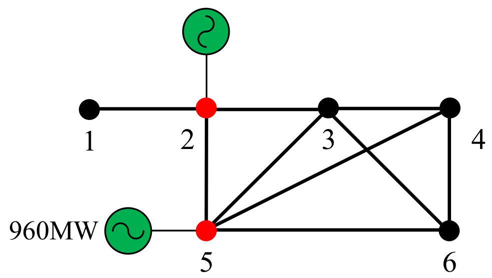
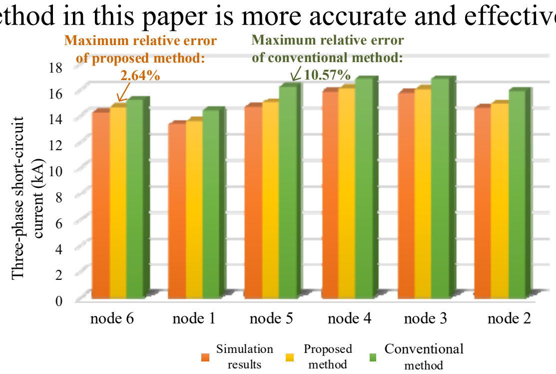
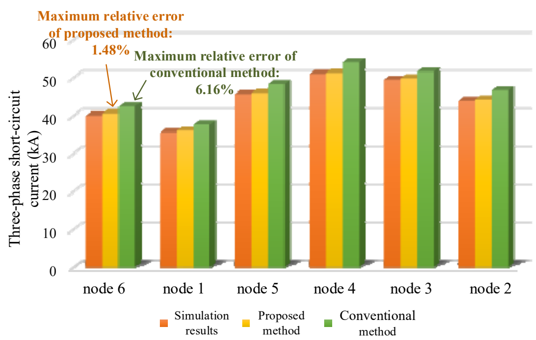


Figure 3. 500kV network structure

In addition, this paper treats photovoltaic power as a conventional voltage source, and the results are compared with the calculated and simulated values of the method in this paper. When six substations have three-phase short circuits, the steady-state short-circuit current and initial AC component of the fault point are as follows Figure 4 shows. It can be seen from Figure 4 that the results obtained by the method in this paper are closer to the simulation value, and the error from the simulation results is lower than the traditional method, whether it is relative error or absolute error, thus further verifying that the method in this paper is more accurate and effective.



(a) Steady short-circuit current



(b) Initial AC component value

Figure 4. Three-phase short-circuit current of each substation

5. Conclusion

This paper discusses the equivalent models of photovoltaic power supply at different stages of faults, and uses the superposition theorem to further propose a three-phase short-circuit current calculation method for power systems containing photovoltaic power generation. Finally, an example is used to verify the method in this paper, and the calculation results can be used to provide a basis for grid planning and protection calculation.

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