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Analysis of Distributed Power Fault Characteristic Calculation Model

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Abstract

With the large-scale access of DG(Distributed Generation), its influence on the operation safety of power grid is increasingly prominent. Because of the flexible operation mode of microgrid with DG, the traditional protection principle and configuration of distribution network based on radial structure will no longer be applicable. In order to analyze and solve this problem, this paper studies the distributed power fault characteristic calculation model from the fault characteristic of IBDG (Inverter-based Distributed Generation). The fault analysis method of IBDG is put forward. The control mode and limiting conditions of inverter power supply are described by equations. The simulation results show that when symmetrical three-phase short circuit or asymmetrical two-phase short circuit occurs at different positions in the distribution network, the simulation results are very close to the theoretical value. The IBDG with low voltage crossing characteristic is equivalent to a voltage-controlled current source model, and the power fault analysis method based on this model is correct and can meet the actual requirements of power fault characteristic analysis.

Keywords

IBDG; Power Fault; Distributed Generation.

1. Introduction

For a long time, the power industry has adopted the mode of centralized large-capacity power generation and long-distance transmission and distribution based on fossil energy. With the large-scale access of DG(Distributed Generation), its influence on the operation safety of power grid is increasingly prominent. In order to prevent the impact on the power grid caused by the large-scale disconnection of DG during the power fault period and ensure the safe and stable operation of the power grid, the grid-connection regulations clearly require that DG should have good low-voltage ride-through operation capability [1-2]. Because of the flexible operation mode of microgrid with DG, the traditional protection principle and configuration of distribution network based on radial structure will no longer be applicable. In order to analyze and solve the above problems, this paper studies the distributed power fault characteristic calculation model from the fault characteristic of IBDG (Inverter-based Distributed Generation). The fault analysis method of IBDG is put forward. The control mode and limiting conditions of inverter power supply are described by equations.

2. Research Method

2.1 Model Simplification of IBDG

Usually, the DC bus in front of the IBDG inverter is connected with a capacitor, which can provide electric energy in the transient state, which is equivalent to the rotational energy storage provided by the rotating shaft of the synchronous generator to maintain the transient energy balance. Take the DC-

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AC grid-connected mode as an example, in which the generator and DC boost module can be replaced by a DC voltage source [3-4].

Common power sources connected to the grid through inverter devices include photovoltaic power generation, wind turbines, micro gas turbines and energy storage devices. The research shows that the DC voltage is basically constant when the inverter power supply unit is connected with the inverter, so the dynamic response of the power generation unit can be ignored. At this time, the characteristic output of the inverter power supply is basically determined by the inverter control strategy [5]. Therefore, when it is necessary to analyze the characteristic fault of inverter power supply when power fault occurs, the control strategy of inverter is mainly studied.

The control circuit of the inverter adjusts the duty ratio according to the control system goal and triggers the switching devices to make its output voltage equivalent to sine wave, thus achieving the same function as the traditional AC power supply [6-7]. For single-phase sine wave PWM inverter, the potential expression is:

$$u_{inv} = KU_d \cos(\omega t + \theta) \tag{1}$$

Where u_{inv} is equivalent AC phase electromotive force of inverter, K is duty ratio (modulation coefficient), U_d is DC side voltage, and θ is reference phase.

When the access capacity of IBDG is small and the permeability is low, the adoption of non-low voltage ride-through control during power fault has no significant impact on the safe and stable operation of the power grid to which IBDG is connected. In order to avoid the influence of large-scale off-grid of IBDG on the safe operation of power grid, all countries have issued the grid-connected specification of IBDG [8].

In this paper, the control method aimed at eliminating the negative sequence component in the output current of IBDG and making IBDG only output three-phase symmetrical positive sequence current is adopted to control IBDG. At this time, the instruction value of $i_d^{+^*}, i_q^{+^*}, i_d^{-^*}, i_q^{-^*}$ is:

$$\begin{cases} i_d^{+^*} = i_d^+ \\ i_q^{+^*} = i_q^+ \\ i_d^{-^*} = i_q^{-^*} = 0 \end{cases} \tag{2}$$

In this way, the current command value $i_d^{+^*}, i_q^{+^*}, i_d^{-^*}, i_q^{-^*}$ is obtained. It can also be seen that when this control method is adopted, there is only positive sequence voltage in the control equation, and there is no negative sequence voltage.

2.2 Power Fault Calculation Model with IBDG

Under normal circumstances, the DC power supply directly supplies power to the system through inverter inversion for power frequency alternating current, such as photovoltaic power supply and fuel cell. Non-power frequency AC power supply needs to be rectified first and then inverted and then integrated into the power grid, such as direct-drive wind turbine [9]. But no matter what kind of power supply unit mentioned above, there is usually a large capacitor on the DC side of its inverter to keep its DC side voltage constant. Inverter is the electrical interface for IBDG to be integrated into the power grid. The filter unit usually uses a series-parallel filter [10] of inductance and capacitance to filter the DC component and high-frequency harmonics in the voltage and current output by IBDG.

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Because constant power control is different from constant voltage and constant frequency control, its purpose is to make the constant active power and reactive power output by IBDG unable to maintain the voltage and frequency of the system. Therefore, under isolated island operation, IBDG with constant power control cannot operate alone with load, and it needs IBDG with constant voltage and constant frequency control to supply power to the system.

In normal operation, the output power of IBDG is shown in Formula (3).

$$\dot{S} = P + jQ = 3I^2\left(Z_{line} + Z_{load}\right) \tag{3}$$

When a three-phase metallic grounding fault occurs at the end of the line, the relationship among the voltage, current and power at the outlet of IBDG is shown in Formula (4).

$$\dot{S} = 3I^{'2} \cdot Z_{line} = 3\dot{U}^{'} I^{'*} \tag{4}$$

It can be seen that since the system impedance is reduced from $Z_{line} + Z_{load}$ to ZLine after the fault, in order to maintain a constant output power, IBDG with constant power control increases the output current from I in normal operation to $I^{'}$, and accordingly, the outlet voltage drops from U to $U^{'}$.

In the traditional power fault analysis method, the same motor is usually simply equivalent to the series form of potential source and impedance. When IBDG adopts the control strategy of low voltage ride-through and restraining negative sequence current, there are only three-phase symmetrical positive sequence components in the short circuit current output by IBDG, that is, IBDG is not included in the negative sequence equivalent network. The fault model of IBDG can be equivalent to a voltage-controlled current source. As shown in Figure 1.

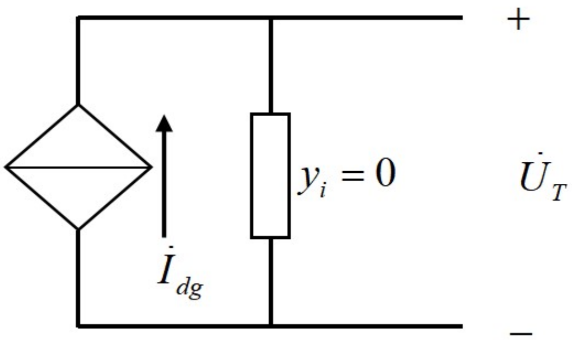

Figure 1. IBDG equivalent voltage controlled current source model

The equivalent voltage-controlled current source model of IBDG is similar to the current source model of traditional generators, only the equivalent admittance $y_i = 0$. When the positive sequence voltage of IBDG meets $U_T / U_N < 0.4$, IBDG only outputs reactive current. Available:

$$\begin{cases} I_{dg} = 1.2\dfrac{P_{dg}}{U_T} \\ \varphi_{ui} = -90^{\circ} \end{cases} \tag{5}$$

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Where P_{dg} is the active power output before the failure of IBDG; U_T is the rated voltage of the parallel connection point.

The above analysis is based on the steady-state response of the inverter interface power supply when it is operating in the microgrid island. Compared with the power supply in the traditional short-circuit current calculation, the equivalent model of IBDG is characterized in that its internal potential changes with the response of the control system to the operating state, which is an electrical quantity to be solved and cannot be assumed as a constant quantity. When IBDG is incorporated into the distribution network, the electrical characteristics after the fault are different with the location of the fault point and power supply [11].

According to the characteristic that IBDG only outputs positive sequence current without negative sequence current under any fault condition, it is equivalent to a controlled positive sequence current source, and each sequence equivalent circuit is constructed respectively [12]. The actual positive sequence voltage of node i after short circuit fault is:

$$\dot{V}_{i(1)} = \dot{V}_{i(1)}^{(0)} + \Delta\dot{V}_{i(1)} = \dot{V}_{i(1)}^{(0)} + \sum_{k\in G_2} Z_{ik}\Delta\dot{I}_{DG,k} - Z_{if}\dot{I}_{f(1)} \tag{6}$$

Use Equation (7) to obtain the voltage of each sequence at each fault point:

$$\begin{cases} \dot{V}_{f(1)} = \dot{V}_{f(1)}^{(0)} + \sum\limits_{k\in G_2} Z_{if}\Delta\dot{I}_{DG,k} - Z_{ff}\dot{I}_{f(1)} \\ \dot{V}_{f(2)} = -Z_{ff(2)}\dot{I}_{f(2)} \\ \dot{V}_{f(0)} = -Z_{ff(0)}\dot{I}_{f(0)} \end{cases} \tag{7}$$

Due to the current limiting measures adopted in the IBDG control system, the inverter power supply becomes a nonlinear power supply. When the output current does not reach the limit, the closer the fault point is to the power supply, the greater the output current of the power supply. When the output current of the inverter power supply reaches the limit, even if the fault point is at the power supply outlet, its output current cannot continue to increase. Compared with the distribution network, the ability of IBDG to provide short-circuit current is very low. Therefore, the protection configuration and setting of the distribution network side should consider or adapt to the difference of fault current between grid-connected and isolated island operation.

3. Simulation Verification

In order to fully verify the correctness of the proposed calculation method of power fault with multiple DG connections, a power grid simulation model with multiple DG connections is constructed by using PSCAD/EMTDC simulation software. Among them, DG includes three types: doubly-fed wind turbine with crowbar protection action, doubly-fed wind turbine with excitation regulation characteristic and inverter power supply.

The parameters of IIDG model are as follows: rated capacity is 10.0 MVA; The rated voltage is 10.5 kV; The filter inductance is 8 h; The equivalent resistance of the filter inductor is 0.5m.

Table 1 shows the comparison between the theoretical calculated values and the simulated measured values of the fault current and fault point current fed by IBDG in the case of three-phase symmetrical short circuit in f1.

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Table 1. Comparison between theoretical value and experimental value when three-phase short circuit occurs at fl point

	Short-circuit current provided by IBDG/kA	Short circuit point current/k A
Theoretical value	0.28∠90.00°	1.63∠-113.72°
Actual value	0.28∠89.93°	162.74∠-114.01°

The output power of DG in the case of three-phase short circuit in isolated island area is shown in Figure 2.

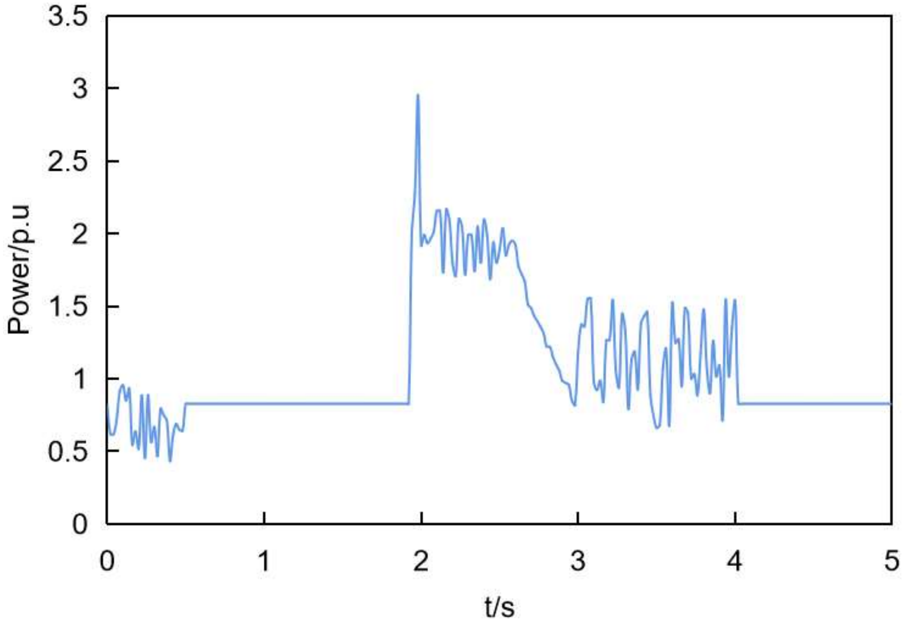

Figure 2. DG output power in isolated island area with three-phase short circuit

When the inverter outputs the same power, the slope angle of the characteristic curve under the capacitive equivalent output impedance is less than 90°, which has the effect of increasing the system frequency with the increase of output power and decreasing the system frequency with the decrease of output power. Therefore, after the short circuit and fault removal under the island, the capacitive equivalent output impedance controller makes the system frequency deviation smaller than that of the inductive equivalent output impedance controller.

When symmetrical three-phase short circuit or asymmetrical two-phase short circuit occurs at different positions in the distribution network, the simulation results are very close to the theoretical value. Therefore, the above experimental data verify the effectiveness of the fault analysis method proposed in this paper. The IBDG with low voltage crossing characteristic is equivalent to a voltage-controlled current source model, and the power fault analysis method based on this model is correct and can meet the actual requirements of power fault characteristic analysis.

4. Conclusion

In order to prevent the impact of DG's large-scale off-grid during power fault and ensure the safe and stable operation of the power grid, it is clearly required in the grid-connected regulations that DG should have good low-voltage ride-through operation ability. In order to analyze and solve this problem, this paper studies the distributed power fault characteristic calculation model from the fault characteristic of IBDG. The simulation results show that when symmetrical three-phase short circuit or asymmetrical two-phase short circuit occurs at different positions in the distribution network, the simulation results are very close to the theoretical value. The IBDG with low voltage crossing characteristic is equivalent to a voltage-controlled current source model, and the power fault analysis method based on this model is correct and can meet the actual requirements of power fault characteristic analysis.

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