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A Novel Method of Impedance Measurement Used in Islanding Detection Based on Controllable Short-circuit Technology

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Abstract. It is very important for a distributed generating system to have an islanding detection part. Focused on the problem of islanding, this paper proposes a new and effective islanding detection scheme: a thyristor is placed between any two phases just by the port of the distributed generator (DG). An artificial short time phase-to-phase short circuit is formed by triggering the thyristor periodically when the voltage between this thyristor is almost equal to zero, so the short-circuit current and voltage pulse can be extracted out. Because that short-circuit current and voltage pulse contain plentiful frequency components, the frequency response of system can be acquired according to the theory of harmonic impedance, so that the impedance measured from DG port can be obtained. Whether the DG is islanding can be determined quickly by monitoring the changes of impedance. This method is proved to be correct and effective by theoretical analysis and simulation.

Introduction

Nowadays, distributed generating technologies are considered more and more important all around the world. When the breakers which connect the main grid and the distributed generating system trip out, the DG and its local loads are isolated to be an island. When the DG runs into the islanding state, it may cause damages to the user's power devices and itself, threaten the safety of the operators, and affect the power quality of power supply in the island[1][2]. So that, the islanding detection of the distributed generating system is one of the important parts to ensure safety and the reliability.

To solve the problem of islanding detection in distributed generating systems, many kinds of islanding detection schemes have been proposed at home and abroad. [3][4] proposed the method based on under/over voltage and under/over frequency. This method works on the principle that a power imbalance in the islanded system will lead to frequency drift. However, they cannot function properly if the active and reactive power of the grid are small.

Because of the big change of impedance before and after islanding state, impedance measurement has been proposed. According to this idea, focused on high-current grounding system in North America, the islanding detection based on the short-circuit current of DG has been discussed simply in [5]. But, the sensitivity is not good.

In this paper, according to the distributed generating system in China, a new method by using harmonic impedance technology has been proposed. Several aspects will be discussed as follows: Section Ⅱ is to introduce the principle of operation of this islanding detection; in Section Ⅲ, a distributed generating system is formed and the theoretical calculation is finished; finally, introduce harmonic impedance. At the same time, create simulation model of this islanding detection scheme. This method is proved to be correct by theoretical analysis and simulation.

Principal and Theoretical Analysis

The Proposed Scheme. In a distributed generating system, the equivalent impedance of main grid is much less than that of the DG. Due to that reason, the impedance measured from the DG port will change a lot before and after the islanding state. It is easier to determine whether the DG is islanding from those changes of the impedance. There are a lot of ways to measure the impedance[6][7]. The

easiest way of impedance calculation is the ratio of voltage and short-circuit current. Based on this idea and the impedance measurement using controllable short-circuit technology, a new and effective method which is focused on the distributed generating system in China is proposed in this paper: a thyristor is placed between any two phases just by the port of the distributed generator. An artificial short time phase-to-phase short circuit is formed by triggering the thyristor to conduct periodically when the voltage between this thyristor is almost equal to zero, so a short circuit current and voltage pulse can be extracted out. The specific implementation scheme and the waveforms of short-circuit pulse current and voltage are shown in Fig. 1and Fig. 2.

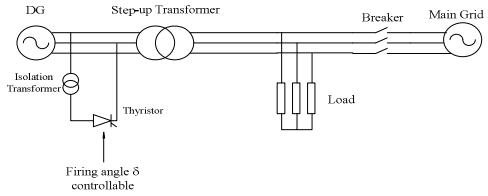

Fig. 1. Scheme

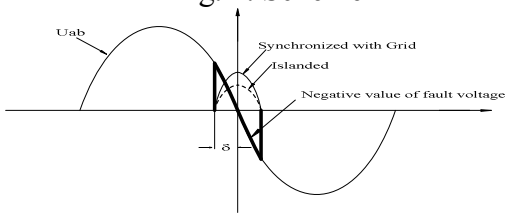

Fig. 2. Waveforms of Short-circuit Current and Voltage

Mathematical Expressions of Short-circuit Pulse Current and Voltage. According to the principle of fault analysis of power system, fault state can be equal to the sum of steady state and additional fault state. In this case, the steady state refers to the situation when the thyristor does not work and the additional fault state means that the controllable short circuit between two phases happens when the thyristor turns on. That is to say, the controllable short-circuit pulse current only exists on additional fault state. According to that, the short-circuit pulse current and voltage can be calculated through an additional fault state model of the distributed generating system which is simplified to Fig. 3.

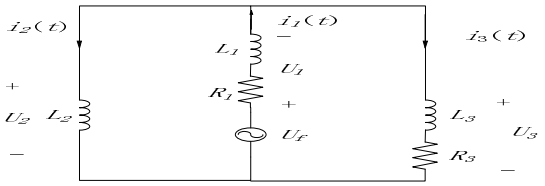

Fig. 3. Equivalent Circuit Simplified

1. *Fault Voltage*

Let the phase fault happens between Phase A and B, the additional fault voltage is U_f, so that, $U_{ab}+U_f=0$, that is to say, $U_f=-U_{ab}$.

Donate the fault voltage as:

$$U_f = U_m \sin(\omega t + \varphi) \tag{1}$$

2. *Short-circuit Pulse Current*

The differential equations of the circuit shown in Fig. 3 are as follows:

$$\begin{cases} i_1(t) = i_2(t) + i_3(t) \\ U_2(t) = L_2 \dfrac{di_2(t)}{dt} = R_3 i_3(t) + L_3 \dfrac{di_3(t)}{dt} \\ U_f(t) - R_1 i_1(t) - L_1 \dfrac{di_1(t)}{dt} = U_2(t) \end{cases}$$

The answer of the differential equations shown above is given as follows:

$$i_1(t) = \frac{1}{R_1^2 + \omega^2 L_1^2}[U_m R_1 \sin(\omega t + \varphi) - U_m \omega L_1 \cos(\omega t + \varphi) - (R_1 D + C\omega L_1)\sin\omega t + (D\omega L_1 - R_1 C)\cos\omega t] - \frac{A}{r_1 L_1 + R_1} e^{r_1 t} - \frac{B}{r_2 L_1 + R_1} e^{r_2 t} + C_0 e^{-\frac{R_1}{L_1} t} \quad (2)$$

Where, A, B, C, and D are parameters which are influenced by the components of the system.

Based on the equation of short-circuit pulse current, if the voltage of system is constant, the value of short-circuit pulse current is in relation to the components of the system, the firing angle of thyristor, and the system state. If the firing angle is constant, the changes of short-circuit pulse current are mainly influenced by R_3 and L_3. That is to say, the changes will be more obvious by measuring the system impedance.

The short-circuit pulse current before and after the islanding state is plotted by MATLAB. It is easy to know from Fig. 4 that the calculated short-circuit pulse current is much higher when the DG is connected in parallel to the utility than that when the DG is islanded. The rate of the change, however, is not that clear, especially in actual systems where there are a lot of interferences. So a new and effective indicator is needed. If the harmonic impedance can be measured using short-circuit voltage and current, islanding detection can be determined by it.

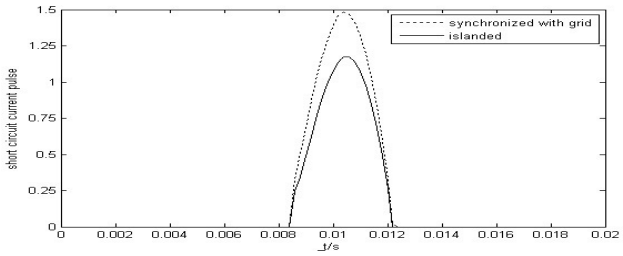

Fig. 4. Short-circuit pulse current before and after islanding state

Harmonic Impedance. In this paper, the harmonic impedance is obtained by using the short-circuit pulse current and fault voltage.

In the system shown in Fig. 1, when the thyristor is fired, a short-circuit pulse current is produced. It contains plentiful frequency components which can be obtained by the Fourier Transform. Meanwhile, the short-circuit pulse current will produce a fault voltage. The voltage also has plentiful frequency components. Because of that, the harmonic impedance measured from the thyristor port can be calculated. So that, islanding state can be detected by the change of the harmonic impedance[8].

Let $I(jn\omega)$ and $U_f(jn\omega)$ be the Fourier Transform of short-circuit current and fault voltage, the harmonic impedance can therefore be expressed as:

$$Z(jn\omega) = \frac{U(jn\omega)}{I(jn\omega)} \quad (3)$$

Simulation Analysis

Model of Simulation. To validate this scheme, simulations are conducted using SIMULINK in MATLAB. The components of this model are shown as follows:

1. DG: U_N=0.38kV, S_N=1MVA, PF=0.8(lagging), X_G^*=0.20(pu).
2. Step-up transformer: R_T=0.6592Ω, X_T=3.6Ω, L_T=0.0115H.
3. Transmission line: R=4.5Ω, L=1.17×10^{-2}H.
4. Isolation transformer: R_T=0.0481Ω, X_T=0.0193Ω, L_T=6.14×10^{-5}H.
5. Load: 1MW with PF=0.8(lagging)
6. Main grid: U_N=10kV, S_N=200MVA, Thus, X_s=0.5Ω, L_T=1.59×10^{-3}H.

Figures of Simulation. When the load is 1.0MW with *PF*=0.8(lagging) and the firing angle of the thyristor is 5°, the short-circuit pulse current before and after islanding state is shown in Fig. 5.

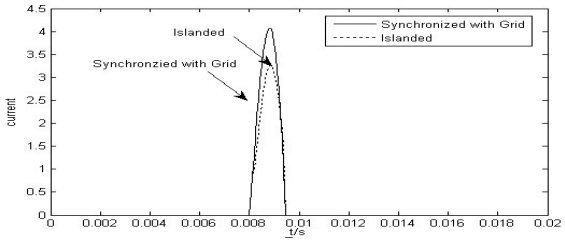

Fig. 5. Short-circuit pulse current got from simulation before and after islanding state

It is known that pulses are the same with those calculated and also share the disadvantages.

Voltages across the thyristor, fault voltage U_f, and thyristor current waveforms are shown in Fig. 6.

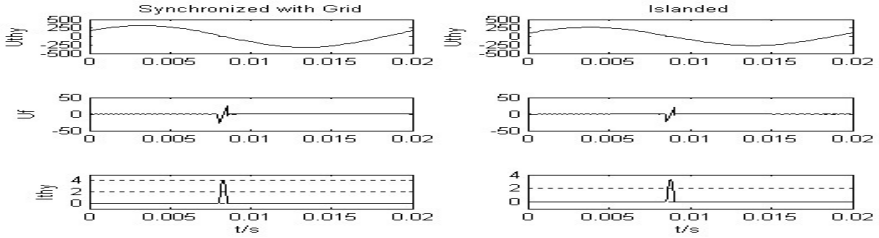

Fig. 6 Waveforms in normal and islanded

The data of the fault voltage and the short-circuit pulse current got from the scopes can be used to calculate the harmonic impedance.

Data Processing of Simulation. The harmonic impedance measured above in normal and islanded are shown in Fig. 7, and Fig. 8.

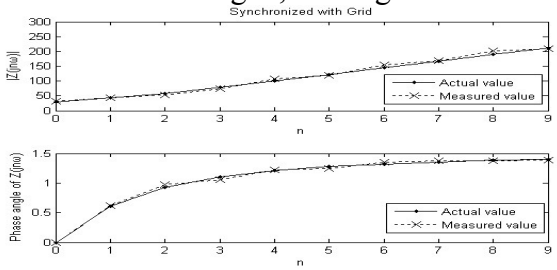

Fig.7. Harmonic impedance in normal

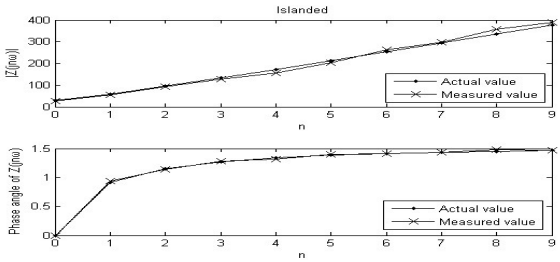

Fig.8. Harmonic impedance islanded

As we can see, the harmonic impedances measured in this way are consistent with their actual values. The real parts of harmonic impedances change a little before and after the islanding state, while the imaginary parts do a lot. The reason is that the thyristor must connect the grid behind an isolation transformer for safety. Usually, the small capacity of the isolation transformer gives rise to the big leakage reactance which plays an important role in impedance measurement. Due to a constant leakage reactance before and after the islanding state, the real parts of harmonic impedances change a little. In conclusion, islanding state can be determined effectively using the imaginary parts of harmonic impedance. Mostly, the fundamental wave is chosen.

Let $k = \dfrac{\mathrm{Im}(Z_1) - \mathrm{Im}(z_1)}{\mathrm{Im}(Z_1)} \times 100\%$, where Z_1 is the fundamental wave impedance in normal state; z_1 is the one islanded. When the firing angle is 5° , k=41.9%. The sensitivity is high.

The sensitivity at different firing angles is shown in Fig. 9.

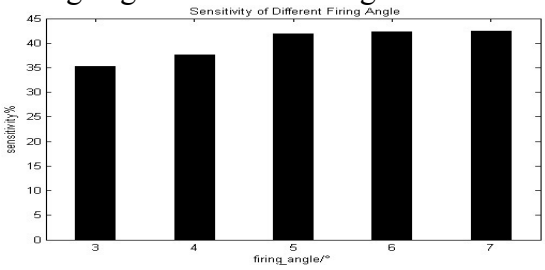

Fig.9. Sensitivity at different firing angles

As we can see, this method is effective when the firing angles are different. However, if the angle is too big, it will do harm to the power quality. Mostly, 5° is proper.

Conclusion

A new method based on the controllable short-circuit technology to detect islanding state is proposed in this paper. Because the impedance measured from the DG port will change a lot before and after the islanding state, this method based on the harmonic impedance is effective. The short-circuit pulse current and the voltage are controllable in virtue of the thyristor whose firing angle is controllable. According to that, the needs of signal measurement can be satisfied by regulating the firing angle. So that, the harmonic impedance can be calculated more accurately and the islanding state can be detected more effectively.

Acknowledgment

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