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Ground Fault Line Selection with Improved Residual Flow Incremental Method

Wenhong Li*, Tingqiang Guan, Xueguang Qi, Gonghua Wang
Shandong University of Science & Technology, China
No. 17 Shenglizhuang Road Tianqiao District of Ji'nan in Shandong province of China
*Corresponding author, e-mail: liwenhong110@163.com

Abstract

According to the shortcoming of single-phase ground fault line selection method in the resonant grounded system such as the uncertainty of its device by fast compensation with the automatic compensation equipment, an arc suppression and residual flow incremental method is proposed to effectively choose the earth fault line. Firstly, when the single-phase ground fault occurs, the arc suppression coil parameters are adjusted to realize compensation and arc suppression. Then the arc suppression coil inductance values are modulated to make the zero-sequence current of fault line changed, at the same time, the zero-sequence current value is detected and its change will be captured to select the fault line. The simulation experiments prove that the arc grounding over voltage damage can be effectively reduced by arc suppression coil full compensation and fault line can be effectively selected by arc suppression and residual flow increment method.

Keywords: *resonant grounded system, fault line selection, arc suppression and residual flow increment method*

1. Introduction

In China, the resonant grounded system is mainly used in low-voltage power grid. This method can effectively limit the single-phase grounding fault current, which greatly reduce the harm caused by the fault of power system.

However, for the resonant grounded system, fault current is smaller, and, by the current compensation, it is not easy to measure zero sequence current to select the fault line.

In order to solve the problem above, an arc suppression and residual flow increment method is proposed, which change the arc suppression coil inductance values at neutral point to adjust the compensation degree and then change the zero-sequence current size. Firstly, arc suppression coil parameters are adjusted to fully compensate the arc, which reduced the grounding arc hazards, and then the fault line is determined by detecting the change of the zero sequence current magnitude. It overcomes the effect of grounding resistance, and solves the problem of fault line selection effectively. Finally, system simulation experiments are made to prove that this method is effective [1-4].

2. Arc Suppression and Residual Flow Increment Method

2.1. The Basic Principle of Residual Flow Increment Method

During the period of single-phase earthing fault, if appropriate changes in arc suppression coil detuning, only the zero-sequence current of fault line will become incremental, so fault line can be accurately determined. When single-phase permanent grounding fault happened, detuning of arc suppression coil is increased automatically, at the same time, the zero sequence current of each feeder is real-time acquired, synchronously recorded, intensively processed and analyzed, and compared by use of microcomputer, then the feeder whose zero sequence current (residual current) appears increment is the fault line.

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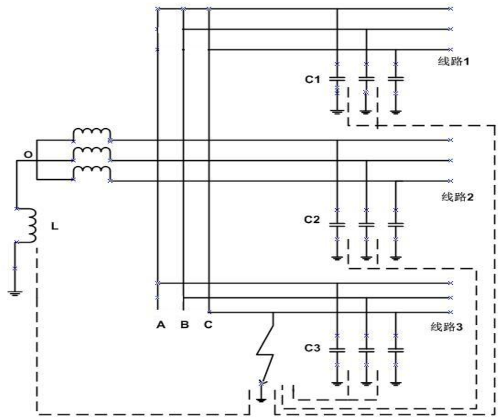

Figure 1. The Zero Sequence Current Circuit Diagram

2.2. The Residual Flow Increment Method Criterion
2.2.1. Single Phase Metal Grounding Fault

If the fault type is metal grounding, the zero sequence voltage is constant and the capacitances current to lines are constant whether the arc suppression coil parameters are changed or not, then the variation of the zero sequence current in the fault path is equal to the arc suppression coil inductance current variation, and the zero sequence current variation in other path is equal to 0. When arc suppression coil reactance is changed, if the change of the zero sequence current mode value of this point is very big, which is approximately equal to that of the arc suppression coil inductance current, the detection point is located at the fault path, and if the change of the zero sequence current mode value of this point is very small, which is approximately equal to 0, the detection point is located at a non-fault path [5-9].

The derivation of principle of remnant current increment method criterion under metal grounding conditions is shown as follows:

In Figure 1, the zero sequence current distribution pattern is shown after single-phase ground fault occurred in resonant grounded system. The system has 3 lines, where phase A is metal grounding, and the equivalent capacitances of the lines are C_1, C_2, C_3. The effect of line resistance can not be considered for metal grounding temporarily, and will be analyzed for resistance grounding. Therefore, the zero sequence equivalent network circuit diagram can be made as Figure 2.

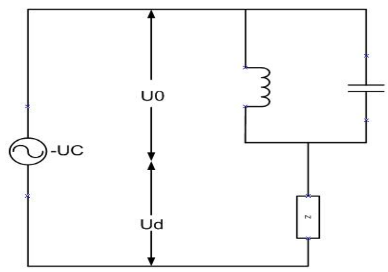

Figure 2. Zero Sequence Equivalent Network Circuit Diagram

Zero-sequence current of non-fault line :

$$\dot{I}_{0i} = U_0 j3\omega C_i (i = 1, 2) \quad (1)$$

Zero-sequence current of arc suppression coil branch :

$$\dot{I}_L = -\frac{\dot{U}_0}{j\omega L} = j\frac{\dot{U}_0}{\omega L} \tag{2}$$

Zero-sequence current at the outlet of the fault line :

$$\dot{I}_{03} = \dot{I}_L - \sum_{i=1}^{2} \dot{I}_{0i}(i=1,2) = \dot{U}_0 j\left(\frac{1}{\omega L} - 3\omega C_{\Sigma}\right) \quad (C_{\Sigma 1} = C1 + C2) \tag{3}$$

According to the formula (3), zero sequence current at the outlet of the fault line is equal to the sum of all non-fault line zero sequence current and arc suppression coil inductance current, and the phase between zero-sequence current and zero-sequence voltage is determined by arc suppression coil inductor current.

The short-circuit current of fault point :

$$\dot{I}_d = \dot{I}_L - \sum_{i=1}^{3} \dot{I}_{0i}(i=1,2,3) = \dot{U}_0 j\left(\frac{1}{\omega L} - 3\omega C_{\Sigma}\right) \quad (C_{\Sigma 2} = C1 + C2 + C3) \tag{4}$$

After analysis, zero sequence voltage of the arc suppression coil is the same as voltage across equivalent capacitance, therefore, the gear of arc suppression coil can be adjusted to change the coil inductive current to compensate the capacitive current, so as to change zero sequence current at the outlet of the fault line [10]. And because both zero sequence voltage and equivalent capacitance of line are constant, the zero-sequence current of non-fault lines will not be changed, which can be used to distinguish the fault line.

2.2.2. Single Phase Resistance Grounding Fault

For resistance grounding fault, according to the formula (5), when arc suppression coil parameters are changed, zero sequence voltage mode value will lead to the changes on the non-fault line, and residual flow increment method can not be directly used to select the fault line, and should be improved [7].

Therefore, before and after the change of arc suppression coil, the corresponding zero sequence current should be converted to that corresponding to the metal grounding conditions respectively, and the difference between them can be used to detect the fault line, that is, its change is great for fault path, and its change is approximately 0 for non-fault path.

The derivation of principle of remnant current increment method criterion under resistance grounding conditions is shown as follows:

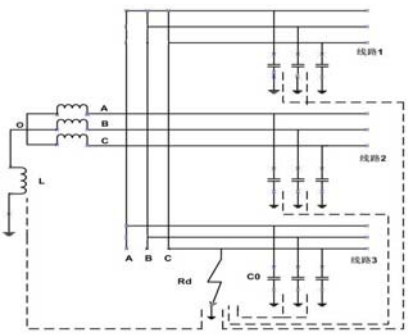

Figure 3. The Zero Sequence Current Circuit Diagram with Resisitance Grounding

As shown in the Figure 3, neutral point is single-phase grounding via arc suppression coil system with resistance. Supposing that, U_A, U_B, U_C are the power supply voltage, U_0 is neutral point voltage, C_0 is the equivalent capacitance, and R_d is transition resistance. If in the formula (4), the short point is as the node, the sum of the branch inflow current is zero according to Kirchhoff's current law, thus:

$$(\dot{U}_A+\dot{U}_0)Y_A+(\dot{U}_B+\dot{U}_0)Y_B+(\dot{U}_C+\dot{U}_0)Y_C+\dot{U}_0Y_L=0 \quad (5)$$

$$Y_A=Y_B=j\omega C_0, Y_C=j\omega C_0+\frac{1}{R_d}, Y_L=\frac{1}{j\omega L} \quad (6)$$

And formula (6) is substitued for the corresponding part of formula (5), we get formula (7).

$$\dot{U}_0=-\frac{\dot{U}_A}{1+3jR_d(\omega C_0-\frac{1}{\omega L})} \quad (7)$$

According to the formula (7), when the fault occurs, the gear of arc suppression coil is adjusted and inductor value is changed, then the inductor current $\dot{I}_L$ becomes $\dot{I}_L{}'$ by the formula (2), neutral zero sequence voltage $\dot{U}_0$ becomes $U_0{}'$, at the same time, zero sequence current of the sequential circuit changes.

At this time, all currents are converted to that corresponding to the metal grounding conditions. Since the line's capacitance to ground is unchanged, and the zero sequence voltage $\dot{U}_0$ of metal grounding is taken as a reference value, the zero sequence voltage is changed for the non-fault line, and the change value of zero sequence current is:

$$\Delta I_{i(i=1,2)}=\frac{U_0}{U'}I'-\frac{U_0}{U''}I''=\frac{U_0}{U'}\cdot\frac{U'}{j\omega C_0}-\frac{U_0}{U''}\cdot\frac{U''}{j\omega C_0}=0 \quad (8)$$

Both the zero-sequence voltage and zero sequence current are changed, and because, according to the formula (5), zero sequence current at the outlet of fault line is:

$$I_3'=\frac{\dot{U}'}{j\omega L}-(\dot{U}_A+\dot{U}_B+2\dot{U}')j\omega C_0=\frac{\dot{U}'}{j\omega L}-k\dot{U}'j\omega C_0=(\frac{1}{j\omega L}-kj\omega C_0)\dot{U}' \quad (9)$$

Where, U' is zero sequence voltage.

After adjusting arc suppression coil and converting the current to that corresponding to the metal grounding conditions, the change value of zero sequence current of fault line is:

$$\Delta I_3=\frac{U_0}{U'}I'-\frac{U_0}{U''}I''=(\frac{1}{j\omega L'}-kj\omega C_0)U_0-(\frac{1}{j\omega L''}-kj\omega C_0)U_0$$
$$=j(\frac{1}{\omega L'}-\frac{1}{\omega L''})U_0 \quad (10)$$

According to formula (8) and (10), after converted, the change of zero-sequence current at the outlet of non-fault line is 0, while the change of zero sequence current at the outlet of the fault line is equal to that of inductance current, which can be used to find out the fault line.

Because of the system voltage fluctuation, the measurement error and other factors, there are some difference between the actual measured variation of zero sequence current and the theory, and the threshold limitation should be set [9-12].

2.3. Arc Suppression and Residual Flow Increment Method

2.3.1. Harm of Overvoltage to the Power Grid for Arc Grounding

For power grid, when its neutral point is not grounding, the overvoltage or arc grounding is 3~5 times as the phase voltage, and even higher. Therefore, when the grid voltage of single-phase grounding extend over a longer period of time, if effective measures do not be taken in time, the network equipment insulation may be affected, and the insulation weak device can be destroyed by the electric shock, which can further lead to interphase short circuit, equipment damage and severe accident. With the middle and low voltage network continuing to expand, and the length of power supply bus wire loop growing, capacitive current of the single phase grounding is significantly increased, which lead to that single-phase grounding arc cannot automatically extinguish and appear ground arc. Then, the arc reignition and quenching process will lead to intermittent power capacitor and inductor circuit of electromagnetic oscillation, so as to generate overvoltage of arc grounding [11].

2.3.2. The Limitation of Traditional Zero Sequence Current Increment Method

Since zero sequence current increment method was introduced, it began to to get recognition for its simple principle. In practice, to ensure the line selection, it need to have at least 4 to 5A current increment, which makes the grounding residual current increased,and it is not conducive to extinguish the arc, and can also aggravate the fault degree.

2.3.3. Arc Suppression and Residual Flow Increment Method

According to the shortcoming of traditional increment method, in this paper, Arc suppression and residual flow increment method is proposed to effectively solve the arc and greatly improve the reliability of fault line selection, while keeping the advantage of the original incremental method. The automatic tuning arc suppression coil grounding compensation is adopted to realize full compensation, and damping resistance is added in primary circuit in series to reduce the neutral resonant overvoltage, which makes the amplitude is 5~10% that of the phase voltage. In the formula (4), we change arc suppression coil inductance to compensate the capacitive current fully, and limit the neutral point voltage to permissible values. Thus, we can achieve the best way to work with minimal residual flow (the full compensation way) without causing arc grounding overvoltage. In all, this method firstly suppress the arc of the ground point to reduce the adverse effect of arc extinction, then after 2s, the traditional residual flow increment method is used [11-13].

3. Implement of Arc Suppression and Residual Flow Increment Method

3.1. Zero Sequence Current Signal Acquisition Method

3.1.1. Peripheral Structure Design

FPGA can be used to design, programe, test, modify and analyze in the workplace, thereby to realize digital system design and application of single chip. The peripheral structures of system is shown in Figure 4, mainly used for data acquisition. FPGA peripheral signals such as the analog signal can be acquired into conversion chip, then be transferred to the FPGA. Among this system, the conversion chip AD7641A is controlled by EP3C40F484C6, and a MCU joined in peripheral chips is used to control FPGA, and most of the treatments are mainly the inside the FPGA.

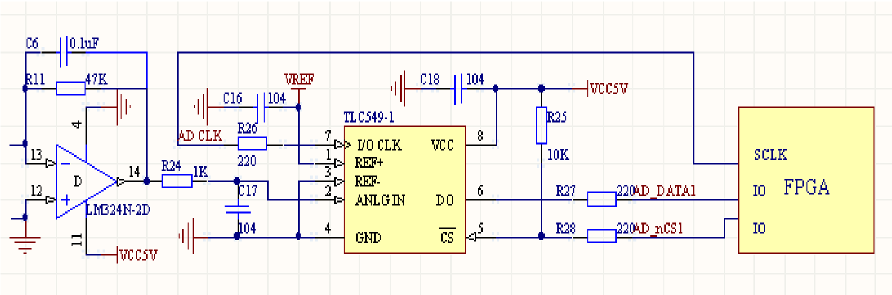

Figure 4. The FPGA and A/D Converter Connection Diagram

The internal functions of FPGA are mainly based on the specific design, and the scalability of the system is considered for hardware platform design, and the system resource is assessed from the choice of devices.This paper adopts FPGA SMD chip EP3C40F484C6 with

240 pins, 39600 LE, and 26 RAM of 4K (239616bits in total), containing 2 high performance PLL and 185 IO defined by user. After received MCU signal, FPGA chip control A/D conversion chip and receive the converted digital signals. And flow chart of the program is shown in Figure 5 [6].

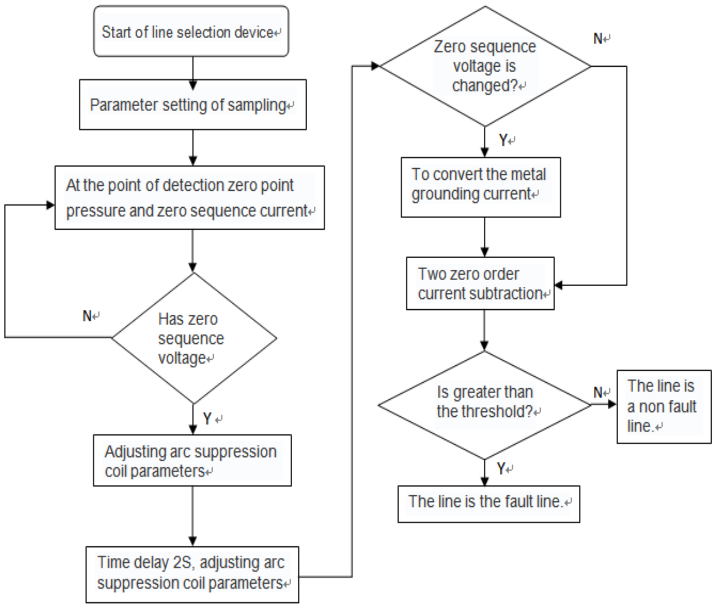

Figure 5. Flow Chart of the Program

3.2. System's Simulation Model and Parameters

Topological structure of 10kV network simulation system is shown in Figure 6. The system model is equipped with 3 feeders with π type equivalent circuit, where, $L_0 = 4.126mH / km$, $C_0 = 0.00775\mu F / km$, and 150, 100, 60km in length respectively [11]. Supposed, single phase ground fault of route 3 occurs at 0.01s.

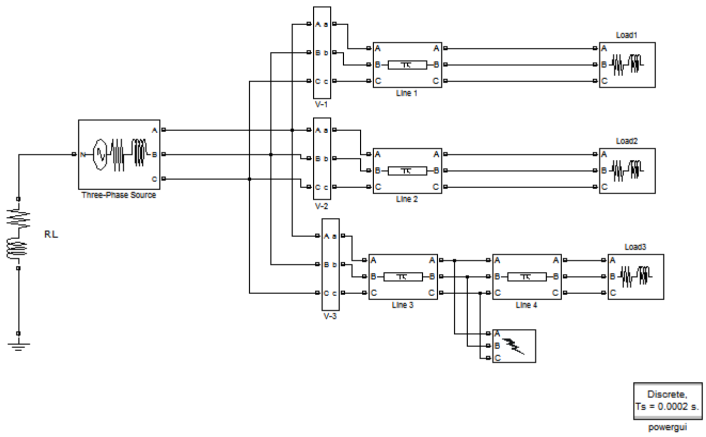

Figure 6. Simulation Circuit Diagram

3.2.1 Fault of Metal Grounding

Before and after adjusting arc suppression coil parameters, the zero sequence voltage is almost the same, and the changes of zero sequence current magnitude in each measuring point are shown in Table 1.

Table 1. Metal Grounding Fault

Fault line 3 zero sequence current variation								
t/s	0.01	0.05	0.1	0.15	0.2	0.25	0.3	0.35
Before the change I/A	5.4204	6.4339	2.4532	1.354	0.1601	0.4628	0.2055	0.3119
After the change	10.176	9.0386	0.5278	3.6113	2.5909	2.943	2.8207	2.8633
Magnitude difference	-4.756	-2.605	1.9254	-2.257	-2.431	-2.48	-2.615	-2.551
Non fault line 1 zero sequence current variation								
t/s	0.01	0.05	0.1	0.15	0.2	0.25	0.3	0.35
Before the change I/A	12.582	7.776	7.3232	7.2906	7.2789	7.2825	7.2819	7.2818
After the change	12.537	7.7918	7.3015	7.2768	7.2634	7.2672	7.2665	7.2665
Magnitude difference	0.045	-0.016	0.0217	0.0138	0.0155	0.0153	0.0154	0.0153
Non fault line 2 zero sequence current variation								
t/s	0.01	0.05	0.1	0.15	0.2	0.25	0.3	0.35
Before the change I/A	7.4987	4.5629	4.8616	4.8026	4.8003	4.8021	4.8017	4.8017
After the change	7.4802	4.5593	4.848	4.7933	4.7901	4.792	4.7916	4.7916
Magnitude difference	0.0185	0.0036	0.0136	0.0093	0.0102	0.0101	0.0101	0.0101

3.2.2. Fault of Resistance Grounding

Grounding resistance is 100 ohms, and arc suppression coil inductance is adjusted and converted to that corresponding to the metal grounding fault condition, and the changes of zero sequence current magnitude in each measuring point are shown in Table 2.

Table 2. The Resistance Grounding Fault

Fault line 3 zero sequence current variation								
t/s	0.01	0.05	0.1	0.15	0.2	0.25	0.3	0.35
Before the changeI/A	-15.63	-0.106	-0.416	0.4114	-0.412	0.412	-0.4117	0.41174
After the change	-15.76	2.2764	-2.593	2.593	-2.593	2.593	-2.5932	2.5932
Before the change（Convers	2.3949	6.1343	16.133	12.362	13.782	13.25	13.448	13.373
After the change（Conversio	2.8192	8.2676	17.988	14.909	15.882	15.57	15.672	15.641
Magnitude difference（Conv	-0.424	-2.133	-1.855	-2.547	-2.1	-2.327	-2.224	-2.268
Non fault line 1 zero sequence current variation								
t/s	0.01	0.05	0.1	0.15	0.2	0.25	0.3	0.35
Before the changeI/A	8.6443	7.929	-7.903	7.9021	-7.902	7.902	-7.9019	7.9019
After the change	8.588	7.6987	-7.677	7.6762	-7.676	7.676	-7.676	7.676
Before the change（Convers	13.793	8.5251	8.3839	8.3936	8.3952	8.395	8.39453	8.39471
After the change（Conversio	13.743	7.8287	7.738	7.7463	7.7474	7.747	7.74692	7.74709
Magnitude difference（Conv	0.0502	0.6964	0.6459	0.6474	0.6478	0.647	0.64761	0.64763
Non fault line 2 zero sequence current variation								
t/s	0.01	0.05	0.1	0.15	0.2	0.25	0.3	0.35
Before the changeI/A	5.6877	5.2043	-5.188	5.1878	-5.188	5.188	-5.1877	5.1877
After the change	5.6422	5.0523	-5.039	5.0387	-5.039	5.039	-5.0386	5.0386
Before the change（Convers	9.0755	5.5955	5.504	5.5105	5.5116	5.511	5.51112	5.51124
After the change（Conversio	9.0495	5.1445	5.0893	5.0946	5.0955	5.095	5.09517	5.09528
Magnitude difference（Conv	0.026	0.4511	0.4147	0.4159	0.4161	0.416	0.41595	0.41596

From Table 1 and 2, according to the residual flow increment method, with the change of arc suppression coil parameters, the change of the zero sequence current mode value of fault line is very big, while the change of the zero sequence current mode value of non-fault line is constant or very small for the error changes. Then, fault line can be found by the numerical comparison.

Simulation results indicate that, for a metal grounding or resistance grounding, arc suppression and residual flow increment method can be used to select the fault line accurately.

4. Conclusion

According to the shortcoming of single-phase ground fault line selection method in the resonant grounded system, a new method named arc suppression and residual flow increment method is proposed, which has the advantages as follows:

(1) The principle of arc extinction residual flow increment protection is very simple, and zero sequence current increment is only produced in the fault line.
(2) For arc suppression and residual flow increment method, the harm of arc grounding overvoltage can be effectively reduced by arc suppression coil full compensation.
(3) The method is not only suitable for the metal grounding fault, but also for the resistance grounding fault after converted.
(4) The method combines FPGA with computer to realize zero-sequence variables' acquisition, simultaneous recording and centralized treatment, and finally identifies the fault line [11].

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