A Research of Single Phase Grounding Fault Location Method Based on the Component of Zero Sequence Current in Distribution Network

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***Abstract* — With the improvement of people's life, the customer demands for more reliable power supplies. According to method of fault location in distribution network which has many limitation at present, a new fault location method based on the component of zero sequence current is displayed through analyzing the characteristic of the line fault on substation outlet and the characteristic of zero sequence current fore-and-after the fault point. A simulation model of single phase grounding fault in resonant grounded system based on DIgSILENT Power Factory is set up, the zero sequence current waveform and amplitude is put into simulation which has proven that the method can locate the fault line and the fault point accurately. At the same time, the influences of different compensation degree of Petersen coil on zero sequence current and fault location accuracy is also analyzed in this simulation.**

Keywords - Fault location; Zero sequence current; Resonant grounded; Compensation degree

I. INTRODUCTION

The ungrounded or resonant grounded (Petersen coil grounded) system is basically utilized in medium-voltage distribution network. When a single phase grounding fault occurs in the system, line voltage remains symmetrical, this will not affect the power supply. It could keep on running for extra one to two hours, since the voltage of the non-fault phase is increased to line voltage, it will cause the resonant grounding over-voltage and easily be expanded to inter-phase short circuit when the intermittent resonant grounding occurs. Therefore, the point of the fault needs to be located as soon as possible so as to fix it. As for the resonant grounded system, when a single phase grounding fault occurs, the fault current is too little to extract the fault features, and it was affected by the factors such as grounding transition resistance, the fault location, compensation degree of Petersen coil and short-circuit time, so the single phase grounding fault location has always been a technical problem in the distribution network.

Currently, fault location is researched in many papers in domestic and foreign. The amplitude and phase comparative methods of zero sequence current [3] and quintuple harmonics [4] are affected by the line length, when the line is short, the zero sequence current amplitude is very low, the phase error of the zero sequence current will be large, thus affects the accuracy of fault location. The zero sequence admittance fault location method [5, 6] is based on the analysis of the symbol change to the conductance in the zero sequence admittance fore-and-after the occurrence of grounding fault on the line, then locate the fault through distribution diagram of zero sequence admittance. The wavelet method and HHT method [7, 8] are proposed to locate the fault which firstly uses wavelet transform and Hilbert-Huang transform respectively and then locates the fault through to the fault location transient criterion which based on transient current. However, due to the transient process duration is too short to measure in distribution network, so the technical difficulty of acquiring transient signal is too great. The off-line fault location is based on traveling wave method [9, 10]. But people's demand for high reliability of power supply is increasing in practical application making its usefulness in greater restrictions.

In this paper, A simulation model of single phase grounding fault in resonant grounded system based on DIgSILENT Power Factory is set up to analyze the characteristics of the zero sequence current in fault line and non-fault line when a single phase grounding fault occurs, then put forward a fault detection method and then locate the fault based on the component of zero sequence current, and the fault location is determined through comparing and analyzing the zero sequence current and zero sequence voltage with the parameters changed in the Petersen coil. In addition, the influences of different compensation degree of Petersen coil on the zero sequence current and fault location accuracy is analyzed through simulation.

II. THE PRINCIPLE OF FAULT LOCATION METHOD BASED ON THE COMPONENT OF ZERO SEQUENCE CURRENT

By changing the parameters of Petersen coil can compensate system current when single phase grounding fault occurs in the resonant grounded system. Petersen coil in an over-compensated state under normal circumstances while it was adjusted to a full compensation when the fault occurred, and the size of current compensation will only be reflected in the zero sequence current of the fault line. In the 10KV substation with Petersen coil grounded system has many outlets, and each outlets has many branch lines .The zero sequence current has different characteristics in fault line and non-fault line, meanwhile, zero sequence current fore-and-after the fault point in line also has different characteristics.

A. Analysis of Line Fault Characteristics in 10KV Transformer Substation Outlets

Assuming a 10KV transformer substation contains four outlets, the zero sequence equivalent circuit of which fore-and-after the Petersen coil parameters changed are respectively shown in Figure.(1) and Figure.(2). when the fault of a single phase grounding occurred in Line 2. As shown in Figure.(1) and Figure.(2), The Petersen coil parameters will be changed when a single phase grounding fault occurred, which before and after the changes, the equivalent reactance and resistance of the Petersen coil are X_{L1}, R_1 and X_{L2}, R_2, zero sequence voltage are $\dot{U}_{01}$ and $\dot{U}_{02}$ respectively, zero sequence current are $\dot{I}_{01}$, $\dot{I}_{02}$, $\dot{I}_{03}$, $\dot{I}_{04}$ and $\dot{I}_{01}'$, $\dot{I}_{02}'$, $\dot{I}_{03}'$, $\dot{I}_{04}'$ respectively, the zero sequence current in the Petersen coil branch are $\dot{I}_{0L}$ and $\dot{I}_{0L}'$, and the grounded capacitance of each line is C_1, C_2, C_3 and C_4.

The zero sequence current of the non-fault line is as following.

$$\dot{I}_{0i} = j\omega C_i \dot{U}_{01} \qquad (1)$$

Where i=1, 3, 4. The zero sequence current of the fault line is as following.

$$\dot{I}_{02} = \dot{I}_{0L} - (\dot{I}_{01} + \dot{I}_{03} + \dot{I}_{04}) \qquad (2)$$

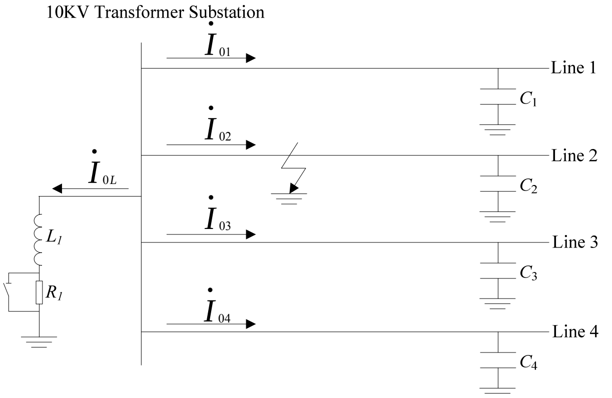

Fig.1 Zero Sequence Equivalent Circuit before Changing Petersen Coil Parameters

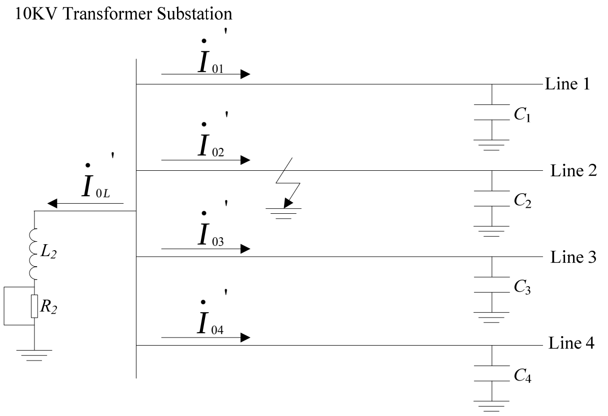

Fig.2 Zero Sequence Equivalent Circuit after Changing Petersen Coil Parameters

When a single-phase-to-ground fault occurs, the parameters of Petersen coil changed to compensate the system current. Now the zero sequence current of the non-fault line is in (3).

$$\dot{I}_{0i}' = j\omega C_i \dot{U}_{02} \qquad (3)$$

Where i=1, 3, 4. And the zero sequence current of the fault line is as in (4).

$$\dot{I}_{02}' = \dot{I}_{0L}' - (\dot{I}_{01}' + \dot{I}_{03}' + \dot{I}_{04}') \qquad (4)$$

When the single-phase metal grounded fault occurs, since $\dot{U}_{01} = \dot{U}_{02}$, the variation of zero sequence current is given as following.

$$\Delta \dot{I}_{0i} = \dot{I}_{0i} - \dot{I}_{0i}' = 0 \quad (5)$$

Where i=1, 3, 4.

$$\Delta \dot{I}_{02} = \dot{I}_{02} - \dot{I}_{02}' = \dot{I}_{0L} - (\dot{I}_{01} + \dot{I}_{03} + \dot{I}_{04}) - [\dot{I}_{0L}' - (\dot{I}_{01}' + \dot{I}_{03}' + \dot{I}_{04}')] = \dot{I}_{0L} - \dot{I}_{0L}'$$

$$= \dot{U}_{01} / (\mathrm{R}_1 + j\omega L_1) - \dot{U}_{01} / (j\omega L_2) \neq 0 \quad (6)$$

When a single phase grounding through resistance occurs，since changes of the Petersen coil parameters lead to zero sequence voltage changes, calculation of zero sequence current should be converted to the same zero sequence voltage.

As mentioned above, for the non-fault line, $j\omega C_i = \dot{I}_{0i} / \dot{U}_{01}$, $j\omega C_i = \dot{I}_{0i}' / \dot{U}_{02}$ ， therefore：

$$\dot{I}_{0i} = \dot{I}_{0i}' \times \dot{U}_{01} / \dot{U}_{02} \quad (7)$$

Convert the zero sequence current of each line before and after the change of Petersen coil to the same zero sequence voltage, the variation of zero sequence current are given as following.

$$\Delta \dot{I}_{0i} = \dot{I}_{0i} - \dot{I}_{0i}' \times \dot{U}_{01} / \dot{U}_{02} = 0 \quad (8)$$

Where i=1, 3, 4.

$$\Delta \dot{I}_{02} = \dot{I}_{02} - \dot{I}_{02}' \times \dot{U}_{01} / \dot{U}_{02} = \dot{I}_{0L} - (\dot{I}_{01} + \dot{I}_{03} + \dot{I}_{04}) - [\dot{I}_{0L}' - (\dot{I}_{01}' + \dot{I}_{03}' + \dot{I}_{04}')] \times \dot{U}_{01} / \dot{U}_{02} = \dot{I}_{0L} - \dot{I}_{0L}' \times \dot{U}_{01} / \dot{U}_{02}$$

$$= \dot{U}_{01} / (\mathrm{R}_1 + j\omega L_1) - \dot{U}_{01} / (j\omega L_2) \neq 0 \quad (9)$$

Through the formula (8) and (9)，when the parameters of Petersen coil changed, if the zero sequence current is converted to the same zero sequence voltage, the zero sequence current of the fault line will change, while the zero sequence current of the non-fault line will remain unchanged.

B. Analysis of the Zero Sequence Current Characteristics Fore-and-After the Fault Point

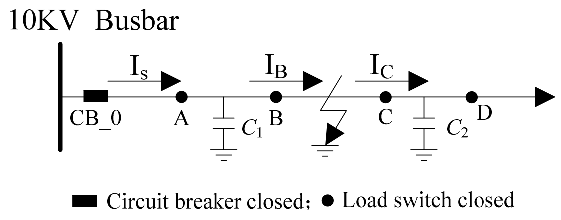

Fig.3 Characteristic Analysis Diagram of the Zero Sequence Current Fore-and-After Fault Point in Line

In Figure.(3),it can be seen that a single phase grounding fault occurs in a branch line between load switch B and C. The zero sequence current of the outlet of load switch A is related to the parameters of Petersen coil. Before the parameters of Petersen coil change, the zero sequence current of load switch B and C are given as following.

$$\dot{I}_B = \dot{I}_S - j\omega C_1 \dot{U}_{01} \quad (10)$$

$$\dot{I}_C = j\omega C_2 \dot{U}_{01} \quad (11)$$

When the parameters of Petersen coil changes, the zero sequence current of load switch B and C are shown in (12) and (13).

$$\dot{I}_B' = \dot{I}_S' - j\omega C_1 \dot{U}_{02} \quad (12)$$

$$\dot{I}_C' = j\omega C_2 \dot{U}_{02} \quad (13)$$

Similarly, convert the zero sequence current fore-and-after the change of Petersen coil to the same zero sequence voltage, the variation of zero sequence current are given as follows.

$$\Delta \dot{I}_B = \dot{I}_B - \dot{I}_B' \times \dot{U}_{01} / \dot{U}_{02} = (\dot{I}_S - j\omega C_1 \dot{U}_{01}) - (\dot{I}_S' - j\omega C_1 \dot{U}_{02}) \times \dot{U}_{01} / \dot{U}_{02} = \dot{I}_S - \dot{I}_S' \times \dot{U}_{01} / \dot{U}_{02}$$

$$= \dot{U}_{01} / (\mathrm{R}_1 + j\omega L_1) - \dot{U}_{01} / (j\omega L_2) \neq 0 \quad (14)$$

$$\Delta \dot{I}_C = \dot{I}_C - \dot{I}_C' \times \dot{U}_{01} / \dot{U}_{02} = 0 \quad (15)$$

From formula (14) and (15), when the parameters of Petersen coil changed, if the zero sequence current is converted to the same zero sequence voltage, the zero sequence current before the fault point in the line changes, the zero sequence current after the fault point in the line will remain unchanged.

To summer up, fault location using component of zero sequence current is simple and effective. In the practical application, "the first section, and then point" way can be used for fault location. Firstly, install zero sequence current sensors to measure the zero sequence current of its amplitude before and after the change in the parameters of Petersen coil, since the whole network is approximately equal to zero sequence voltage when the a single phase grounding fault occurs, the zero sequence voltage can be measured in the Petersen coil side, Thus the fault occurs at which outlet was determined in formula (8) and (9), and then the fault point within the scope of the line from formula (14) and (15) was determined as well.

III. SYSTEM SIMULATION AND ANALYSIS

A. System Modeling and Parameter Setting

Construct a four outlet overhead line and cable hybrid resonant grounded system using DIgSILENT Power Factory. As the main transformer winding side of 10KV distribution system is the triangle connection, it can not form neutral point. Therefore a Zigzag grounded transformer is needed to lead a neutral point; Inductance and resistance are added in the neutral of grounding transformer to constitute a resonant grounded system. The simulation model of Single-phase-to-ground fault in resonant grounded system is shown in Figure.(4), and it omits the 10/0.4KV distribution transformer and three-phase balanced load.

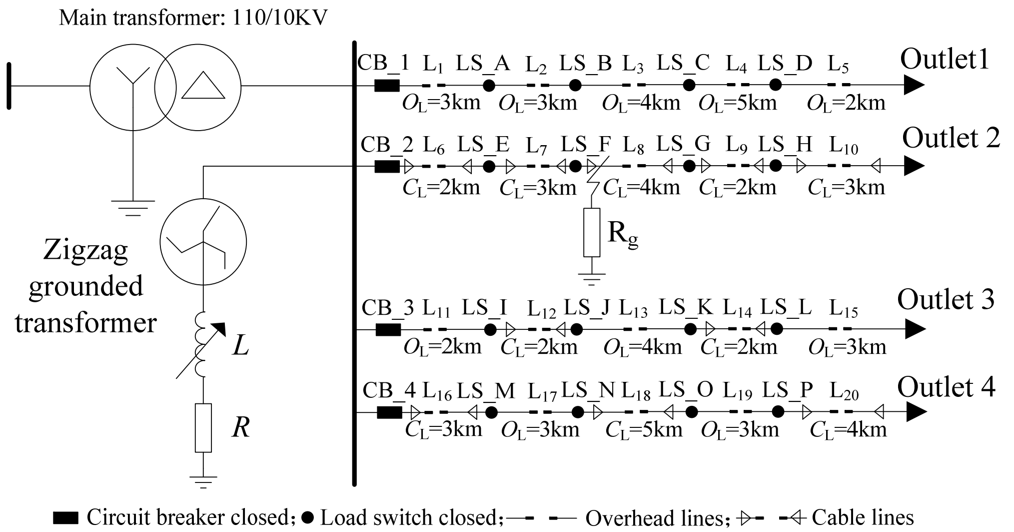

Fig.4 Simulation Model Diagram of Single Phase Grounding Fault in Resonant Grounded System

The main transformer uses Y_n/△ connection method, and the capacity is 31.5 MV · A, the zero sequence impedance is 10 ohms of zigzag grounded transformer, the distribution transformer adopts △/Y_n connection, the capacity is 1 MV • A. Active power of three-phase load is 0.35MW, the power factor is 0.95. Overhead lines and cables adopt distributed parameter model, the length of the line has been marked in Figure 4, where O_L represents the length of overhead line, *and* C_L represents the length of cable line. The parameters of overhead lines and cables are as shown respectively in Table I and table II [12, 13].

TABLE I. PARAMETERS OF OVERHEAD LINES

Phase sequence	R(Ω · km^{-1})	L(mH · km^{-1})	C(nF · km^{-1})
Positive sequence	0.170	1.210	9.7
Zero sequence	0.230	5.480	6. 0

TABLE II. PARAMETERS OF CABLE LINES

Phase sequence	R(Ω · km^{-1})	L(mH · km^{-1})	C(nF · km^{-1})
Positive sequence	0.078	0.270	695
Zero sequence	0.106	1.223	358

Under normal circumstances, the Petersen coil uses over-compensation mode to system, the compensation degree is *p*. Assuming that the system circuit of distribution capacitance value is C_Σ, so inductance L is as in (16):

$$L = 1/(1+p) \times 1/(3\omega^2 C_\Sigma) \qquad (16)$$

The Petersen coil is consist of the equivalent resistance and reactance, the active power loss of Petersen coil is about 2.5%~5% to the active power loss of inductance, this paper take 4% to calculate, so *R* is calculated as following.

$$R = 0.04\omega L \qquad (17)$$

When a single phase grounding fault occurs, the parameters of Petersen coil changed. The inductance can be calculated through formula (17), and the equivalent resistance is zero.

B. System Simulation and Analysis

Since for single phase grounding fault in resonant system is related to the compensation degree and other factors, this paper carries on simulation analysis of single-phase nonmetal fault (Rg=30Ω) which happens in the middle position of L_8 on branch of outlet 2 for different compensation degree, and get the transient waveforms of zero sequence current on each outlet lines and the fore-and-after the fault point load switch. Then through comprehensive analysis on the amplitude of zero steady-state current, the fault point can be located. In addition, the influences of different compensation degree of Petersen coil on the zero-sequence current and fault location accuracy is analyzed through simulation.

First, take the compensation degree is 15% as a example, the zero sequence current waveforms of outlet 1, 3, 4 and the load switch LS_F and LS_G of outlet 2 which locates in before and after the fault point are shown in Figure 5 and Figure 6. In following figure, the system will take place a permanent grounded fault for A phase in the moment that t is equal to 0.1s.

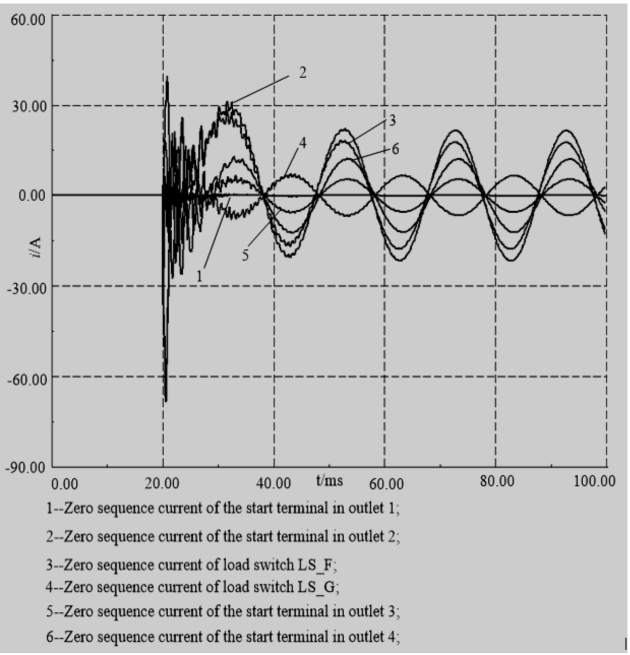

Fig.5 Zero Sequence Current Waveforms Before the Parameters of the Petersen Coil Changed

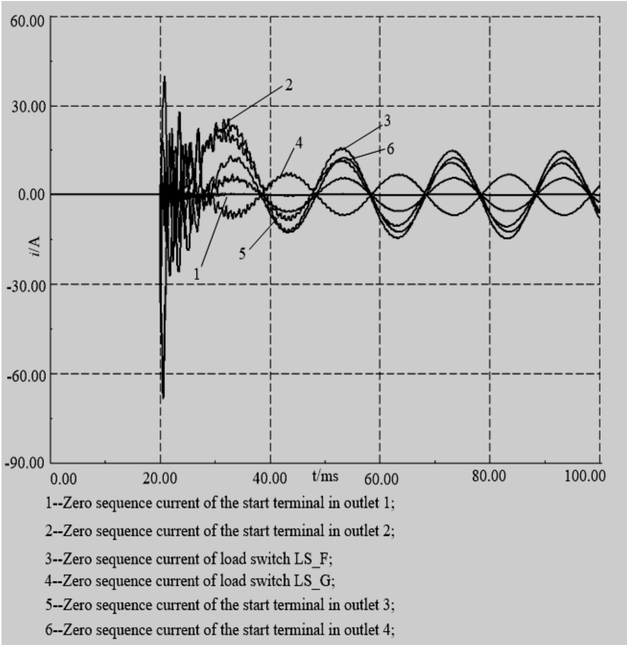

Fig.6 Zero Sequence Current Waveforms After the Parameters of the Petersen Coil Changed

As shown in Figure.(5) and Figure.(6), with the parameters of Petersen coil changes, zero sequence current waveforms of each line changes. While the duration of transient process is too low to measure, in order to accurately locate the fault point, the effective value of zero steady-state current of each line before and after the parameters of Petersen coil change needs to be recorded. And regarding to the zero sequence

voltage $\dot{U}_{01}$ and $\dot{U}_{02}$, convert zero sequence

currents to the same zero sequence voltage which the conversion value of zero sequence current has been got after the parameters of Petersen coil change.To analyze the influence of compensation degree to zero sequence current, the variable p is equal to 3%, 5%, 10%, 15%, and so on. Zero sequence current effective value and conversion value are shown in Table III. I_1, I_2, I_3, I_4 represent the zero sequence current of each outlet, and $I_{LS\text{-}F}$, $I_{LS\text{-}G}$ represent the zero sequence current of the load switch.

First, take "P=15%" as a example to illustrate the fault location, as shown in Table III ,the zero sequence currents of outlet 1, 3, 4 change a little(only a few mA) before and after the parameters of Petersen coil change, while the zero sequence currents of outlet 2 change a lot which is up to 3.415A. It can be concluded that fault point is on outlet 2. As for outlet 2, zero sequence current on load switch LS_F side changes 3.438A, while zero sequence current on load switch LS_G side changes 7mA. It can be judged that fault point is located between load switch LS_F and LS_G. Then compare and analyze zero sequence current in different compensation degree, with the improvement of the compensation degree for Petersen coil, zero sequence current increases a lot for fault line will remain unchanged(only a few mA)for non-fault line, then zero sequence voltage of the system changes very little. In addition, zero sequence current variation changed from 1.254A to 3.415A, it shows that the method based on the component of zero sequence current will more effective in a higher compensation degree under normal circumstances.

TABLE III. ZERO SEQUENCE CURRENT EFFECTIVE VALUE AND CONVERSION VALUE

Variation in zero sequence current		I_1/A	I_2/A	I_{LS_F}/A	I_{LS_G}/A	I_3/A	I_4/A
P=3%	Before changes	0.147	8.085	6.240	3.154	2.593	5.766
	After changes	0.149	6.930	5.026	3.199	2.631	5.852
	After conversion	0.147	6.831	4.954	3.153	2.593	5.767
P=5%	Before changes	0.147	8.411	6.564	3.152	2.590	5.761
	After changes	0.149	6.930	5.026	3.199	2.631	5.852
	After conversion	0.147	6.824	4.949	3.150	2.588	5.763
P=10%	Before changes	0.147	9.450	7.604	3.144	2.583	5.743
	After changes	0.149	6.930	5.026	3.199	2.631	5.852
	After conversion	0.146	6.803	4.934	3.140	2.583	5.745
P=15%	Before changes	0.146	10.200	8.357	3.138	2.576	5.730
	After changes	0.149	6.930	5.026	3.199	2.631	5.852
	After conversion	0.146	6.782	4.919	3.131	2.575	5.727

IV. CONCLUTION

In this paper, A simulation model of single phase grounding fault in resonant grounded system based on DIgSILENT Power Factory is set up, and conducts a lot of simulation and analysis for the single phase grounding fault, zero sequence current waveform and data is got through simulation, the conclusions are as following:

1) Present a fault location method based on the component of zero sequence current, and locate the fault line and fault point through analyzing and comparing the zero sequence current and zero sequence voltage, and the simulation result has proven that the method has its feasibility and

effectiveness;

2) With the improvement of the compensation degree for Petersen coil, zero sequence current increases a lot for fault line while remain unchanged for non-fault line and the line which after the fault point, the zero sequence current variation also changes a lot, which shows that the method based on the component of zero sequence current is more effective in a higher compensation degree under normal circumstances.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

REFERENCES

[1] Zhang Li, Yang Yi-han,Yang Xiu-yuan, et al. “Research and Implementation of Off-line Fault Location for Distribution Network[J].” Automation of Electric Power Systems,33(1): 70-74.2009,

[2] Qi-zheng, Yang Yi-han. “Analysis of Technology of Fault Line Selection for Single-Phase-to-Earth in Neutral Point Non-effectively Grounded System[J].” Automation of Electric Power Systems, 28(14): 1-5.2004

[3] Pang Qing-le, Chen Sheng-yin. “Artificial immune algorithm based faulty line detection method for indirectly grounding power system[J].” Power System Protection and Control,37(24): 27-31.2009

[4] Huang Qiang, Wang Yi, Liu Si-jia. “Fault Location for Undercurrent Earthed System by Quintuple Harmonics[J].” Electronic Instrumentation Customer, 15(1): 122-124.2008

[5] Zeng Xiang-jun, Yin Xiang-gen, Zhang Zhe, et al. “Study on feeder grounding fault protection based on zero sequence admittance[J] ” Proceedings of the CSEE, 21(4): 5-10. 2001

[6] Lin Xiang-ning, Gao Yan, Liu Pei, et al. “A novel method to identify the single phase-to-earth fault in the neutral un-effectual grounded system using the zero-sequence compensated admittance[J]. ” Proceedings of the CSEE, 26(10): 45-49.2006

[7] Wang Yao-nan, Huo Bai-lin, Wang Hui, et al. “A new criterion for earth fault line selection based on wavelet packets in small current neutral grounding system[J].” roceedings of the CSEE, 24(6) : 54-58,2004

[8] Zhang Yun-chuan, Su Hong-sheng. “New Method of Fault Location in Small Current Grounding System[J].” Proceedings of the CSU-EPSA, 27(2): 32-38.2015

[9] Dong Xin-zhou, Wang Jun, Shi Shen-xing, et al. "Principle and Algorithm of Traveling Waves Based Single-phase-to-ground Protection for Distribution Lines[J]." Proceedings of the CSEE, 33(10): 154-160.2013

[10] Liang Rui, Jin Zheng, Wang Chong-lin, et al. "Research of Fault Location inDistribution Networks Based on Integration of Travelling Wave Time and Frequency Analysis[J]." Proceedings of the CSEE, (28): 130-136,2013

[11] Zhou Quan, Ma Xiao-min, Chen Wei-gen, et al. "A solution based on Zigbee and component of zero sequence current for online fault location of single-phase fault in distribution network[J]". Power System Protection and Control, 40(9): 62-68．2012

[12] Li Lin, Feng Yong, Zheng Jian-fei, et al. "Comparison of Single-phase-to-ground Faults in Distribution Network with Two Kinds of Grounding Methods[J]." High Voltage Apparatus, 2008, 44(3): 239-242.

[13] Wang Yan-song, Xie-Fei. "Simulation and Analysis of Single-phase to Ground Fault in Distribution Networks[J]." High Voltage Engineering, 2008, 34(1): 123-127, 153.

[14] Guo Mou-fa, Liu Shi-dan, Yang Geng-jie, et al. "A Novel Approach to Detect Fault Lines in Distribution Network Using Similarity Recognition Based on Time-frequency Spectrum[J]." Proceedings of the CSEE, (19): 183-19,2013