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Suppression strategy of arc grounding overvoltage in ZnO nonlinear resistance grounding mode[1]

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Abstract. With the increase of capacity of distribution network, the problem of arc grounding overvoltage is more prominent. Firstly, the paper estimate symmetry element method to analyze the distributing system with consideration of system capacity and operating mode of power system. And a new method for determining voltage-current (V-I) characteristics of ZnO nonlinear resistance is given. Then based on the propagator method, the V-I characteristics of ZnO nonlinear resistance is obtained. Finally analysis of the zero sequence current by using wavelet multi-scale, and high frequency component energy ratio within the time window is calculate, combined with the effectiveness of the ZnO nonlinear resistance, the ZnO nonlinear resistance grounding mode identification method is designed. Results illustrate that the parameter of the ZnO nonlinear resistance in this paper can suppress arc grounding overvoltage, and the new ground mode is more secure and reliable.

Key words. Arcing ground overvoltage, ZnO nonlinear resistance, piecewise linearization, wavelet analysis, relay protection..

1. Introduction

In recent years, as the enlargement scale and the complication of distribution network, and the mass use of the power cable, the capacitive currents are increased significantly. Therefore when failures happen, the grounding arc cannot extinguish itself, which will cause severe arc grounding overvoltage [1], [2].

Research has shown that neutral grounding mode is closely related to the amplitude of the arc grounding overvoltage, it will directly affect the multiple of overvolt-

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age. In China, neutral grounding mode can be classified into neutral isolated, neutral grounded by low-resistance and by Peterson coil. Neutral isolated mode has a high reliability, but it will cause severe overvoltage when a single-phase to ground fault occurs in the system; neutral grounded by Peterson coil reduce the probability of high amplitude overvoltage, but the weakness for this mode is fault line selection and capacity of the Petersen-coil regulation; For the neutral grounded by low-resistance mode, it can be tripping immediately when the fault occurs, which can effectively limit the arc grounding overvoltage, but still the problem for this mode is the high trip rate and low power supply reliability. [3]–[6]

Therefore the research of new grounding mode would be particularly important, neutral grounded by nonlinear resistance mode was first proposed in article [7], by analyzing and calculating the connection scheme, it is considered that this kind of grounding mode would make good restriction to the overvoltage, which could be used as a new grounding mode. [8]–[10]

In order to overcome this problem, this paper proposed a method to determine the volt-ampere characteristic of nonlinear resistance on the new grounding mode, and further built 10 kV distribution system based on actual case. The system is simulated by using ATP-EMTP software. This paper studies the inhibitory effects of new grounding mode to arc grounding overvoltage in order to provide theoretic support and practical reference for the development of power networks.

2. The neutral grounded by ZnO nonlinear resistance mode

Figure 1 illustrates a typical 10 kV distribution system, which includes 5 outgoing lines, 1 overhead line and 4 outgoing cables. The key point of this new mode is connecting ZnO nonlinear resistance through the grounding transformer.

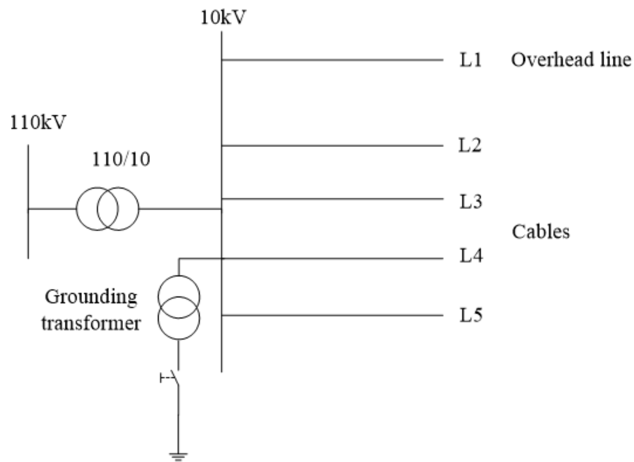

Fig. 1. 10 kV distribution system

Here, U_{ph} denotes the phase voltage, K is the inflection point coefficient and R_1

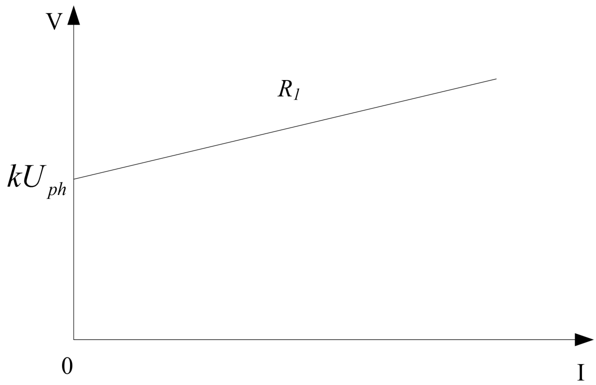

Fig. 2. The ideal V-I characteristic of ZnO nonlinear resistance

stands for the nonlinear resistance.

In order to determine the suitable parameters of ZnO nonlinear resistance, this article proposed the determining method of each segment based on segmental linearization, which is shown in Fig. 3.

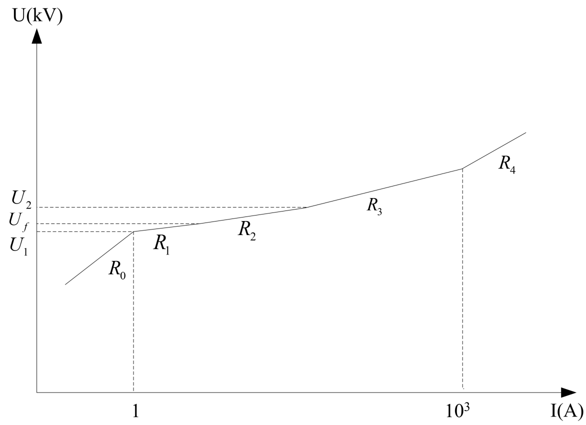

Fig. 3. The segmental linearization mode of ZnO nonlinear resistance

The parameters include U_1, U_{flash}, U_2, R_0, R_1, R_2, R_3, R_4. The curve of V-I characteristic is approximated by the five segments; the first one is R_0, equivalent to the infinite resistance. U_1 is the start voltage of nonlinear resistance. The second segment is R_1, when it goes into R_1, it means into the breakdown region, but at this time the resistance is relatively large, therefore this segment is not suitable to limit the arc ground overvoltage and transient overvoltage, U_{f} is the inflexion voltage. The third segment is R_2 is determined by the method of selecting low resistance. U_2 is the margin voltage. Similarly, R_3 is determined by the method of selecting low resistance. The margin voltage is set for a better limitation of transient process and overvoltage due to the operation mode of network is changed frequently. In this article, the main purpose is to determine R_2, R_3. The phase voltage of 10 kV system is 5773.50 V, when a single-phase to ground fault occurs in the neutral isolated system, the neutral-point voltage increases to the phase voltage, therefore set the inflexion voltage of nonlinear resistance U_{f} 5773.50 V (this is equivalent to the inflexion coefficient is 1). From the development progress of intermittent arc ground overvoltage, it is known that the value of neutral grounding low-resistance range is from 5 to 8.6 Ω, therefore set R_2 is 8.6 Ω and R_3 is 5 Ω. After the failure, in the process of the ZnO nonlinear resistance converted form small resistance state to large resistance, it will produce displacement voltage in the neutral point. A large quantity of simulation data indicates that the value of the U_{1mA} is between 3000 V to 4000 V, and the displacement voltage will below 200 V in the process of transition. According to the requirement of gapless metal oxide arrester and residual voltage of non linear resistance, the U_{1mA} is set as 3200 V, U_{5kA} is set as 6400 V and U_{10kA} is set as 7150 V. Meanwhile, the margin voltage is set as 6080.75 V which is the average of U_{f} and U_{5k}. Then the volt-ampere characteristic parameter meter of the Ac ZnO resistors used in the ZnO nonlinear resistance grounding mode can be obtained as Table 1.

Table 1. Transformer performance parameters

I	1 mA	671.34 A	1217.35 A	5000 A	10000 A
V	3200 V	5773.5 V	6086.75 V	6400 V	7150 V

3. Simulated analysis of abstraction of characteristics of different fault signals

Relaying protection should operate properly when different types of faults occur in the ZnO nonlinear resistance grounding power system [11]. For the intermittent arc grounding fault, it can be eliminated automatically by the influence of ZnO nonlinear resistance. For permanent ground fault, ZnO nonlinear resistance increases the zero sequence current and meets the setting requirement. Therefore, this requires that set different relay protection configuration scheme for different fault types. After studying the method of faults diagnosis under the new grounded pattern in order to relay protections can operate correctly and improve the reliability of power supply.

In this paper, the simulations of single-phase faults, high-impedance ground faults and intermittent arc grounding faults which occur in the ZnO nonlinear resistance ground neutral system have obtained based on wavelet multi-scale product. This paper assumes that failure occur in the end part of the overhead lines, sampling frequency set as 100 kHz, making analysis on zero phase sequence current based on the db6 wavelet. The results under the 2^1, 2^2, 2^3, 2^4, 2^5 have obtained and represented in Fig. 4, Fig. 5 and Fig. 6.

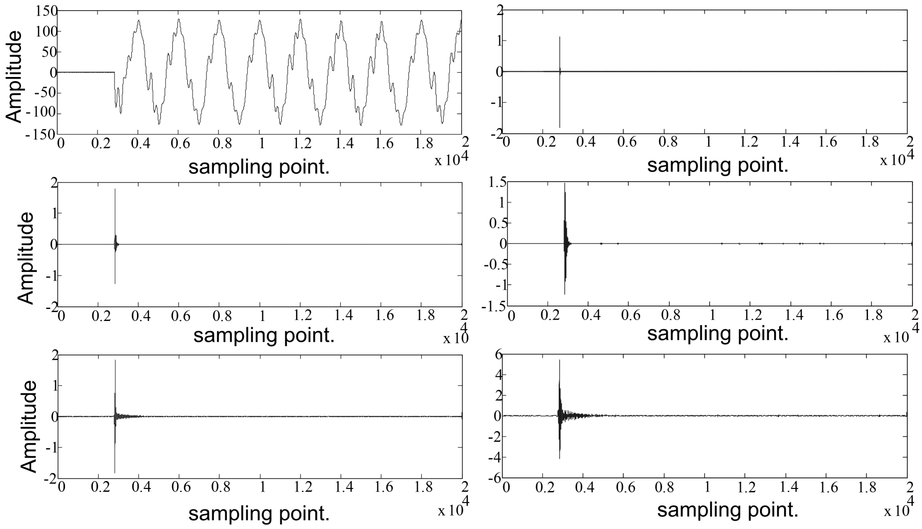

Fig. 4. Single phase grounding fault

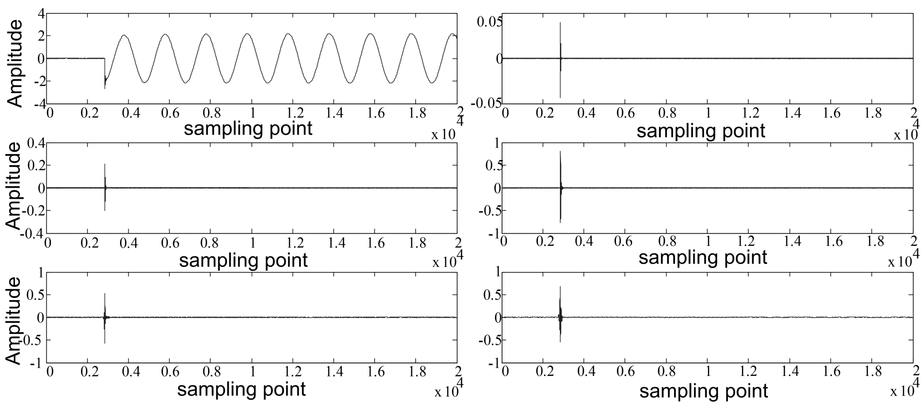

Fig. 5. High impedance fault

For single-phase grounding fault, Fig. 4 shows that there is an obvious mutation, there are two main reasons for this phenomenon, one is there is a high frequency transient component in incipient defects, and the high frequency transient components appeared lasting decay tendency on each scale, the other one is the ZnO nonlinear resistance grounding mode leads to the original waveform distortion waveform. Figure 5 shows that the characteristics of high impedance ground fault and single-phase earth fault is similar. There is a high frequency transient component which attenuation rapidly in incipient defects. For intermittent arc grounding fault, there are six obvious mutation points as shown in Fig. 6. Six times arc burn and arc extinguish will cause high frequency oscillation. The reason for the amplitude before the burning arc point and the mutation point is smaller is ZnO nonlinear resistance

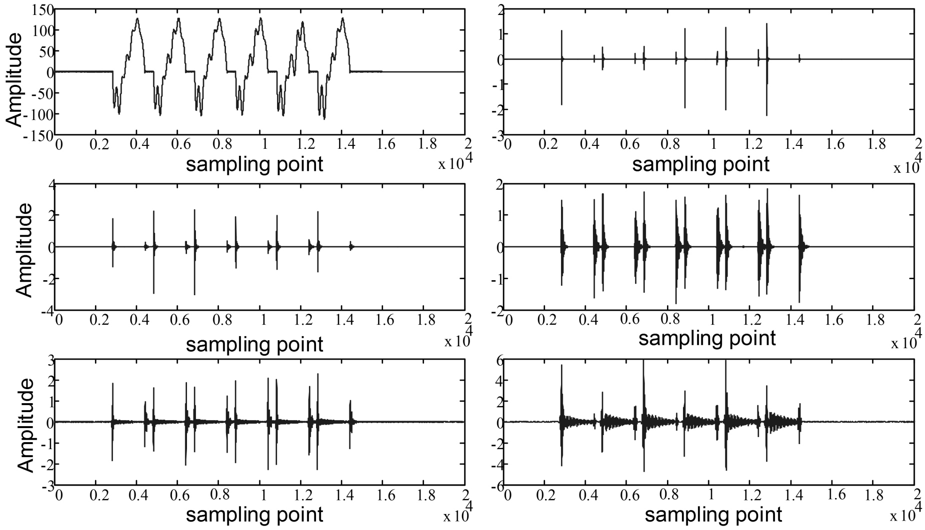

Fig. 6. Intermittent arc grounding fault

shift from low resistance to large resistance when the neutral point voltage is lower than ZnO nonlinear starting voltage. Figure 7 shows that there are mutations in different scales, the slow attenuation phenomenon was also found.

This paper has obtained the energy of zero phase sequence current in fixed time window based on use wavelet transform with fixed time window to calculate the square of detail coefficients, meanwhile, according to the differences between energy change of different fault, a simple and practical criterion is specified in the paper. The detail coefficient's energy of each scale after Db6 wavelet transformation are as follows, the time window is set as 10 ms.

$$E_i = (i\Delta T) = \sum_{n+f\times\Delta T\times(i-1)}^{n+f\times\Delta T\times i} D_k^2\,. \tag{1}$$

Sampling for six consecutive time window fault information after the failure, calculate the energy of zero phase sequence current once a time window. By taking the energy's change of fault under the scale of 2^3, 2^4 as an example. Table 1 shows that obvious attenuation phenomena were found in the permanent fault, the larger energy value appeared in the first time window, the following five time window's energy value decay quickly, it's energy value has little change, and keep in a small order of magnitude. In other side, for the intermittent arc grounding fault, the first time window and the following five time windows' energy has little change both. Therefore, according to the difference between energy integral function of different fault direction, a widely area longitudinal protection based on energy integral directional principle is proposed. The energy ratio of the first time window to the following five time windows is presented with the following formula

$$J_i = \frac{E_1}{E_i}\ (i = 2 \sim 6)\,. \tag{2}$$

The permanent fault has large difference between first window and the following five time windows, but intermittent arc grounding fault has small difference. Thus when $J_i > 50$ appear more than three times, a fault is thought to occur online. The permanent fault can be classified into type A which protective relaying must be respond quickly when faults occur. In addition, the intermittent arc grounding fault can be classified into type B which whether protective relaying tripping is determined by certain conditions.

Table 2. Energy of detail coefficient in 2^3

2^3 (6250 Hz $\sim$ 12.5 kHz) the energy of the detail coefficients			
	Single-phase earth fault	High-impedance ground fault	Intermittent arc grounding
1	34.6544	6.2222	34.6544
2	0.0018	1.3333×10^{-8}	78.3270
3	0.0040	6.1977×10^{-10}	47.3212
4	0.0017	3.7702×10^{-11}	91.3051
5	0.0061	2.3292×10^{-12}	49.4706
6	0.0029	3.1629×10^{-13}	64.7081

4. The fault identification method of ZnO nonlinear resistance grounding mode

Figure 7 shows the chart of fault recognition. When the zero sequence current is abnormal, the detail coefficients at different scales were obtained base on wavelet multi-scale analysis, and then calculating the energy ratio. If the energy ratio of the first time window to the second three time windows were greater than 50, a permanent fault which is classified into type A is considered occur in the system, and the circuit breaker act. When the energy ratio of the first time window to the second three time windows were greater than 0 and less than 50, a intermittent arc grounding fault or a fault can progress to a permanent fault is occur, no matter the zero sequence current can reach setting value or not, the system will be checked again after a second. In the second period, the ZnO nonlinear resistance will limit the development of transient process or accelerate process of develop to permanent fault. If the zero sequence current is still there after a second, then the fault can be judged to a permanent fault and the circuit breaker act. On other side, if the

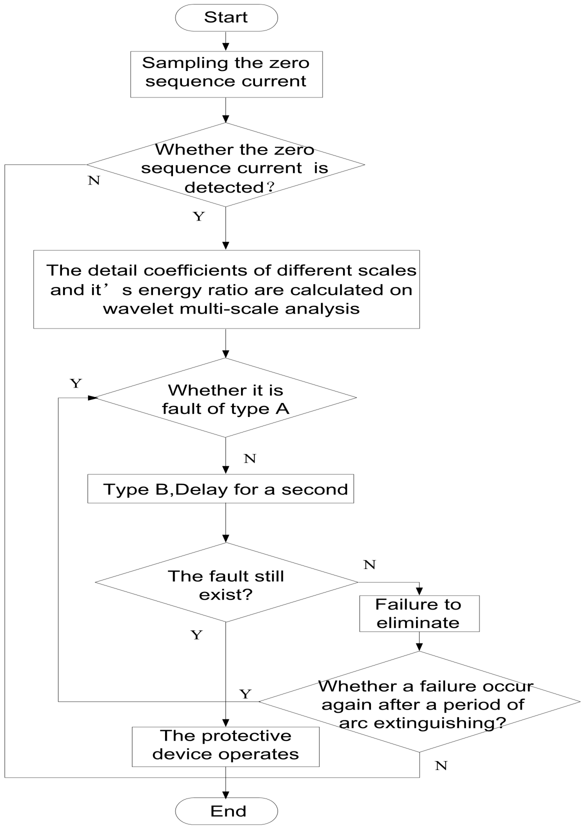

Fig. 7. Flow chart of fault recognition

value of zero sequence current is zero after a second, and the fault being eliminated. If the transmission line detects abnormalities again after a while, then whether the permanent fault or the intermittent arc grounding fault, the circuit breaker need to act to protect the power system.

This method of identifying faults can be verified as follows simulation experiment results. Test results are shown in Table 3.

Table 3. Simulation results of fault recognition when different faults of the lines

2^3 (6250 Hzsim12.5 kHz) the energy of the detail coefficients			
Discriminant result	Permanent faults	Intermittent failures	Permanent faults
E_1/E_2	1.9167×10^4	0.4424	4.6668×10^8
E_1/E_3	8.6393×10^3	0.7323	1.0040×10^{10}
E_1/E_4	2.0421×10^4	0.3795	1.6503×10^{11}

The result of simulation indicated that this method of identifying faults can recognize the pattern of faults correctly in different faults position and operating condition.

5. Conclusions

According to the mechanism of suppress arc grounding overvoltage in the ZnO nonlinear resistance grounding system, the method of the $V - I$ characteristic of ZnO nonlinear resistance which is applied to a practical distribution system is determined. Based on this method, this paper analysis zero sequence current by uses the multi-scale wavelet analysis technology, and proposes failure criterion basis the difference of energy ratio. Finally, put forward the fault identification method of ZnO nonlinear resistance grounded system according to the characteristics of the ZnO nonlinear resistance. Through a comparative study of the simulation results in different conditions, the fault identification's effectiveness is verified, meanwhile and the simulation proves the effectiveness of ZnO nonlinear resistance's suppression role.

References

[1] S. Ait-Amar, J. B. Ducourneau, G. Serrie, M. Abplanalp: *Arc extinguishing method of SPD type 1.* IEEE Transactions on Dielectrics and Electrical Insulation *16* (2009), No. 3, 711–717.

[2] H. Guo, X. J. Zeng, J. Y. Hu, T. T. Xiong: *Analysis for the arc-suppression technologies of grounding fault in distribution networks.* International Conference on Advanced Power System Automation and Protection, 16–20 October 2011, Beijing, China, IEEE Conference Publications *2* (2011) 1548–1552.

[3] J. K. Huang, J. Y. Wu, G. Wang, H. F. Li: *Study on zero-sequence current distribution characteristics in low resistance grounding mode.* International Conference on Advanced Power System Automation and Protection, 16–20 October 2011, Beijing, China, IEEE Conference Publications *2* (2011), 1039-1043.

[4] P. Wang, B. Chen, C. Tian, B. Sun, M. Zhou, J. Yuan: *A novel neutral electromagnetic hybrid flexible grounding method in distribution networks.* IEEE Transactions on Power Delivery *32* (2017), No. 3, 1350–1358.

[5] H. Wang: *Study on the neutral resistance grounding technology for power distribution system*, International Conference on Advanced Power System Automation and Protection, 16–20 October 2011, Beijing, China, IEEE Conference Publications *2* (2011), 1638–1642.

[6] N. I. Elkalashy, M. Lehtonen, H. A. Darwish, M. A. Izzularab, A. I. Taalab: *Modeling and experimental verification of a high impedance arcing fault in MV networks.* IEEE PES Power Systems Conference and Exposition, 29 October–1 November 2006, Atlanta, GA, USA, IEEE Conference Publications (2006), 1950–1956.

[7] W. Shi, F. Li, Y. Han, Y. Li: *The effect of ground resistance on secondary arc current on an EHV transmission line.* IEEE Transactions on Power Delivery *20* (2005), No. 2, 1502–1506.

[8] J. Hu, L. Wei, J. McGuire, T. Liu: *Flux linkage detection based ground fault identification and system diagnosis in high resistance grounding systems.* IEEE Transactions on Industry Applications (2016), No. PP99, 1–1.

[9] J. C. Das: *Selective high-resistance grounding system for a cogeneration facility.* IEEE Transactions on Industry Applications *51* (2015), No. 6, 5270–5280.

[10] Y. Wang, Y. Yu, J. He, S. Chen, R. Zeng, B. Zhang: *Performance of shipboard medium-voltage dc system of various grounding modes under monopole ground fault.* IEEE Transactions on Industry Applications *51* (2015), No. 6, 5002–5009.

[11] M. Farshad, J. Sadeh: *Accurate single-phase fault-location method for transmission lines based on k-nearest neighbor algorithm using one-end voltage.* IEEE Transactions on Power Delivery *27* (2012), No. 4, 2360–2367.

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