

Research on the Distribution Network's Single-phase Short-circuit Faults with Wavelet Transform

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Abstract. According to the problem that the single phase grounding fault location is difficult to detect, a novel method of identifying fault line for single phase grounding fault is presented, based on the detailed analysis of the transient zero sequence network's fault characteristics in the small current neutral grounding power system. Experiments show that this method is immune to many factors such as the initial fault current switch angle, fault distance, transition resistance, power arc, the power distribution system operation mode and so on. It not only can detect the single phase high impedance grounding fault accurately which occurs at the terminal of transmission line, it also can detect the fault which occurs when the phase voltage is near zero.

Introduction

As is well known, there are several kinds of neutral grounding model according to the power actual circumstance and synthesis consideration by now, such as Neutral non-grounded way, Petersen-coil way, Neutral grounded way, Neutral non-grounded with resistance and so on [1][2]. The neutral grounding model is determined by the insulation level, power reliability and human safety and it also affects the fault current of grounding and the protection case. In distributions, because of its low-level voltage, its neutral point is usually disconnected to the ground in order to improve its reliability. As for this kind of distribution network, the single phase grounding fault location for transmission line is a problem in power system fault detection. There are many methods to deal with this problem, such as signal injection method, DESIR (Detection Selective par les Intensites Residuells), higher harmonic signals and so on [3][4]. But they are all ineffective.

In this paper, a novel method of identifying fault line for single phase grounding fault is presented, based on the detailed analysis of the transient zero sequence network's fault characteristics in the small current neutral grounding power system. At first, wavelet transform is applied to the data of every feeder's transient zero sequence current. Then the wavelet coefficients are employed to calculate the wavelet high frequency energy and the wavelet low frequency energy. In the end, the fault line of the single phase grounding fault is identified by comparing three phase line's maximum energy of the wavelet high or low frequency, because the energy spectrum features are different when the faults occur near the peak and zero point of the line-to-neutral voltage. Many simulations have been done and the results indicate that this method is immune to many factors such as the initial fault current switch angle, fault distance, transition resistance, power arc, the power distribution system operation mode and so on. It not only can detect the single phase high impedance grounding fault accurately which occurs at the terminal of transmission line, it also can detect the fault which occurs when the phase voltage is near zero.

Analysis about the Fault Transient Characteristics of Zero Sequence Current

In small current neutral grounding power system, the zero sequence network diagram of a single phase ground fault can be shown as Fig1 when there is a single phase ground fault. In this diagram, K is a switch. When it starts to operate, the neutral point is grounded via extinguisher. On the

contrary, when it is closed, the neutral point is ungrounded. The overhead lines can be considered as an equivalent π network. L_{0i} is the zero sequence line inductance, R_{0i} is the zero sequence line resistance, C_{0i} is the distributed capacitance, U_0 is the bus's zero sequence voltage, L is the zero sequence inductance of the arc suppression coil, R_{f0} is the zero sequence transition resistance, U_{f0} is the voltage drop of the phantom power in the zero sequence network at the fault location. n is the number of the outgoing feeder line.

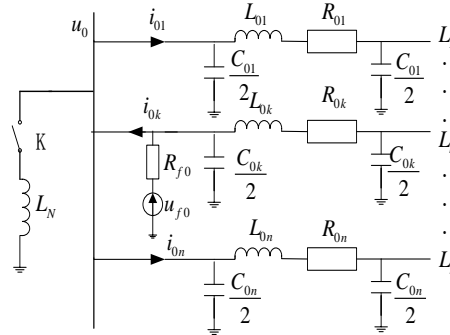


Fig.1. Zero sequence network diagram of a single phase ground fault
In the Fig.1, any feeder line's zero sequence current can be described as (1) [5].

$$R_{0i}i_{0i} + L_{0i} \frac{di_{0i}}{dt} + \frac{1}{C_{0i}} \int_0^t i_{0i} dt = U_0 \sin(\omega t + \varphi) \quad (1)$$

When there is a single phase ground fault in the system, the total transient zero sequence current in the fault line is equal to the sum of the transient inductance current and the transient capacitance current. The total transient zero sequence current is described as (2):

$$i_{0k} = i_L + i_C \quad (2)$$

As for the transient inductance current is described as type (3):

$$i_L = i_{Ldc} + i_{Lst} = I_{Lm} [\cos \phi e^{t/\tau_L} - \cos(\omega t + \phi)] \quad (3)$$

In the type: i_{Ldc} is the transient direct component of the inductance current; i_{Lst} is the steady state fundamental frequency component of the inductance current; ϕ is the initial phase angle of phase voltage when there is a fault; I_{Lm} is the amplitude of the inductance current; τ_L is the time constant of the inductance circuit.

The transient capacitance current can export as (4):

$$i_C = i_{Cos} + i_{Cst} = I_{Cm} [(\frac{\omega_f}{\omega} \sin \phi \sin t - \cos \phi \cos \omega_f t) e^{-\delta t} + \cos(\omega t + \phi)] \quad (4)$$

In the type: i_{Cos} is the transient component of free oscillation; i_{Cst} is the steady state fundamental frequency component of the capacitance current; I_{Cm} is the amplitude of the capacitive current; δ is the decay factor of the free oscillation component; ω_f is the angular frequency of the transient free oscillation component.

If there is a single phase grounding fault, the transient inductance current and the transient capacitance current which decreased more slowly are generated in the fault lines. The transient

inductance current usually is much less than the transient capacitance current and the extinguisher can't work very well in preliminary period of fault, so the zero sequence current's transient characteristics of the fault line and the non-faulted line are decided by the transient capacitance current if the fault occurs near the peak of the phase voltage. The relevant energy mainly focuses on high frequency (300-1500HZ) [6][7]. On the contrary, when the fault occurs near the zero-crossing point of the phase voltage, the total energy of transient zero sequence current in the non-faulted lines mainly focuses on low frequency (0-50HZ), because the transient capacitance current's free oscillation component is zero and the fundamental frequency component is large. The transient inductance current is composed by DC component and the fundamental frequency component, so the energy of the fault line mainly focuses on low frequency (0-50HZ) [5] [8].

Due to the excellent time-frequency characteristic, wavelet transform which is a multi-scale signal analysis method is suitable for analyzing transient and time-varying properties of non-stationary signals and has been well applied in recent years. When there is a single phase grounding fault in distribution network, the zero sequence current is non-stationary signal which is nonlinear and very complex. Wavelet transform is suitable for the extraction of the zero sequence current's transient characteristics, being of a multi-resolution feature [4][6].

The theory of multi-resolution analysis is the fundamental of the wavelet transform and it meets the demands of the two-scale equation.

$$\varphi(t) = \sqrt{2} \sum_{n=-\infty}^{+\infty} h(n)\varphi(2t - n) \quad (5)$$

$$\psi(t) = \sqrt{2} \sum_{n=-\infty}^{+\infty} g(n)\varphi(2t - n) \quad (6)$$

In (5) and (6): $\varphi(t)$ is the scaling function; $\psi(t)$ is the wavelet function; $h(n)$ and $g(n)$ are the coefficients of the wavelet decomposition filter banks.

The discrete time signal is operated by up to a certain times by discrete wavelet transform. Then the wavelet coefficients high frequency component and the wavelet coefficients low frequency component are gained. The wavelet energy of single scale is the sum of squares of the wavelet coefficients. It is known that db series wavelet functions preserve many properties, such as orthogonality, compact support, much sensitive to irregular signals and so on. The db6 series wavelet functions are selected [7].

Theory about fault line selection based on maximum of the wavelet energy

The amplitude of transient zero sequence current in fault feeder is equal to the total amplitude of the transient zero sequence current in non-fault feeder. The wavelet energy is the sum of squares of the wavelet coefficients. In all, the accuracy of the fault selection is increased, because the difference of the fault judging quantity in fault feeder and non-fault feeder is increased by comparing every line's maxima wavelet energy [8]. In this paper, the fault line selection based on the maxima of the wavelet energy is introduced as follows.

1) The amplitude of transient zero sequence current in fault feeder is equal to the total amplitude of the transient zero sequence current in non-fault feeder. The wavelet energy is the sum of squares of the wavelet coefficients. In all, the accuracy of the fault selection is increased, because the difference of the fault judging quantity in fault feeder and non-fault feeder is increased by comparing every line's maxima wavelet energy [8]. In this paper, the fault line selection based on the maxima of the wavelet energy is introduced as follows.

2) Based on the db6, wavelet decomposition is employed to the zero sequence current of every outlet lines. Then the wavelet coefficients high frequency component and the wavelet coefficients low frequency component are applied to calculate the wavelet high frequency energy E_h and the

wavelet low frequency energy E_l respectively.

3) When the minimum of the wavelet high frequency energy E_h is less than the threshold E_{set} which is set previously, it is considered that the fault occurs at the time when voltage is 0 and it is need to compare the wavelet low frequency energy E_l . On the contrary, it is need to compare the wavelet high frequency energy E_h . E_{set} can be set based on the construction site and the detection accuracy of the device.

4) Every feeder's wavelet energy is compared and the feeder which contains the maximum wavelet energy is got. In the end, the maximum wavelet energy is compared to another feeder's

$$\max E_j \geq \sum_{\substack{i=1 \\ i \neq j}}^n E_i$$

energy. When the maximum energy is greater than sun of another feeder's energy , the relevant feeder is the fault line. On the contrary, the bus is the fault line. The whole process can be shown in Fig 2.

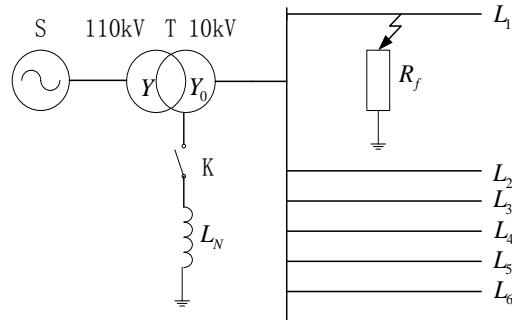
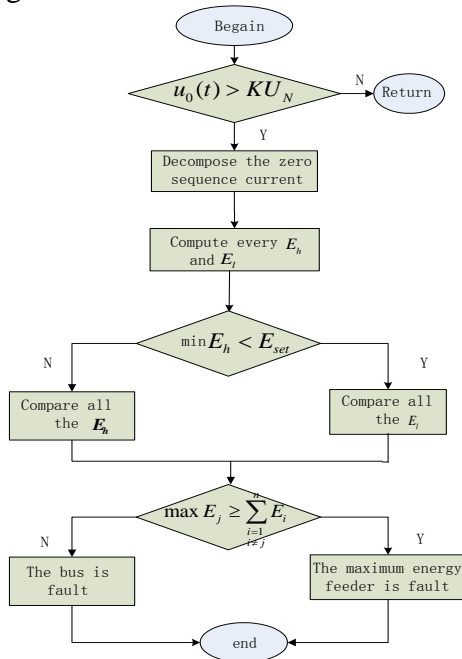


Fig.2. Course of the fault line selection Fig.3. Example of the fault line selection Simulation

Test results

The schematic of the single phase grounding fault is shown in Fig.3. This simulation system contains a substation which has 6 lines of 110KV/10KV. The connection of the transformer is Y/Y_0 . The line parameters are as follows:

$$r_1 = 0.17\Omega/km, \quad l_1 = 0.38 \times 10^{-3} H/km, \quad c_1 = 9.69 \times 10^{-9} F/km, \quad r_0 = 0.23\Omega/km, \quad l_0 = 1.72 \times 10^{-3} H/km, \quad c_0 = 6 \times 10^{-9} F/km.$$

The parameters of every line are as follows: $L_1 = 3km$, $L_2 = 6km$, $L_3 = 9km$, $L_4 = 12km$, $L_5 = 15km$, $L_6 = 20km$, and their equivalent load are $Z_L = (400 + j20)\Omega$. The sample frequency is 10KHZ. The wavelet high frequency energy E_h and the wavelet low frequency energy E_l is calculated based on the d4 coefficient and a5 coefficient respectively. The time window is 10 milliseconds. E_h is set as 10.

When the K is on, the neutral point is grounded via the Petersen-coil and the formula for L_N is as (7):

$$L_N = \frac{1 \times 10^6}{3(1 + v\%)(2\pi f_N)^2 l c_0} \quad (7)$$

In (7): l is the total length of the lines; f_N is 50HZ; c_0 is the zero sequence capacitor; ν is the degree of detuning, $\nu = (I_c - I_L)/I_c$.

The PSCAD/EMTP is applied to simulate the system. Many simulations are done and the results are analyzed with Matlab. The results are as follows in Fig.4.

When the fault happens at the end of the feeder 4, the fault angle is 90° , the grounding resistance is 100Ω , the overcompensation degree is 6%, the fault occurs at 0.32S, the simulation of all the feeder's zero current sequence is displayed in Fig.5 and the relevant wavelet energy E_h is in Fig.6. From the Fig.6, it shows that the fault is in line 4 and the result is right.

l_i	R_f / Ω	$\theta / (^\circ)$	K	X_f / km	Wavelet energy E_i $i=16$						result
1	5	0	over 8%	1	374	20	17	15	13	11	right
	100	60	unground	1.5	935	45	43	42	31	28	right
	1000	90	under 8%	2	224	90	91	93	87	88	right
4	5	90	unground	6	755	654	604	14268	476	404	right
	100	30	over 15%	2	31	35	30	757	31	25	right
	1000	0	under 18%	8	88	83	82	215	80	76	right
6	5	45	under 4%	12	27	23	22	21	14	514	right
	100	0	unground	10	577	574	572	568	565	142867	right
	1000	90	over 20%	4	65	66	72	58	70	5	right
Bus	5	0	over 5%	0	35	31	26	22	18	14	right
	100	90	unground	0	89	97	92	80	72	60	right
	1000	60	under 9%	0	65	60	59	75	68	55	right

Note: l_i is the fault line; R_f is transition resistance; θ is the fault angle; K is the compensation mode; X_f is the distance to the fault.

Fig.4. Results of the fault line selection

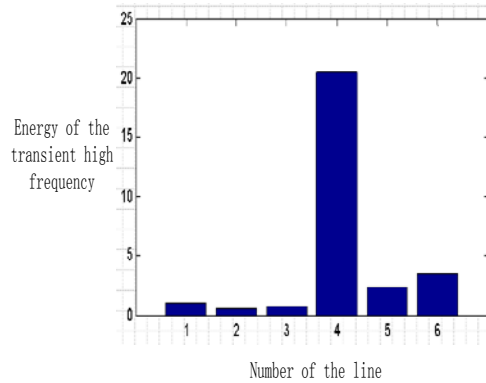
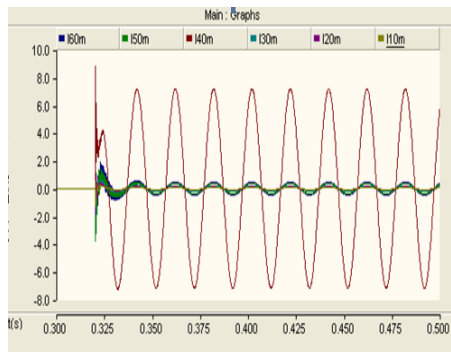


Fig.5. Results of the fault line selection Fig.6. Results of the fault line selection

Conclusion

Based on the analysis of the transient zero sequence network's fault characteristics in the small current neutral grounding power system, it not only can detect the single phase high impedance grounding fault accurately which occurs at the terminal of transmission line, it also can detect the fault which occurs when the phase voltage is near zero.

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