Grenze International Journal of Engineering and Technology, June Issue

Research on Characteristics and Location Technology of Low-Current Line-to-Ground Faults in Distribution Networks

Mahesh N. Patel[1], Nilaykumar A. Patel[2], Keya N. Patel[3] and Ayushi S. Patel[4]
[1-4]Dept. of Electrical Engineering, CSPIT-CHARUSAT University, Changa, Gujarat, India
Email: 23ee019@charusat.edu.in, nilaypatel.ee@charusat.ac.in, keyap675@gmail.com, d24ee021@charusat.edu.in

***Abstract*— One popular technique for enhancing the dependability of power distribution networks is neutral point inadequate grounding. However, due to the very weak current of Line-to-Ground faults, it is difficult to locate the fault. Currently, many places in India rely on manual line inspections to illegally determine the fault location, which not only increases the workload of maintenance but also causes prolonged power outages, affecting the stability of the power supply for users. Based on the current research status at home and abroad, this paper first conducts transient analysis of single-phase grounding faults and phase frequency analysis of neutral point grounding via Petersen coils. Then, it focuses on the fault location technology of single-phase grounding under transient composite-sequence current, presents its matrix algorithm, and conducts simulation studies using MATLAB. It is hoped that this will provide a theoretical basis for future applications in low-current grounding fault diagnosis.**

***Index Terms*— Grounding; Low current; Distribution network; Fault diagnosis.**

I. INTRODUCTION

In India, for a low-voltage distribution network, the small-current grounding method is often used. Since there is no direct circuit between the system and the land, the short-circuit current at the grounding point during a fault is generally small, and the voltage remains three-phase symmetrical. In this way, the system will not trip immediately, and the power supply continuity is good. However, if the disturbance is not addressed, overvoltage may occur, leading to accidents such as phase-to-phase short circuits [1]. Therefore, the location of the fault point should be determined and repaired in a timely manner. Since the current of a Line-to-ground fault in the system is very weak, it is difficult to locate the fault. [2] At present, many places in India use manual line inspection to illegally determine the fault location. This not only increases the maintenance workload but also causes long-term power outages, affecting the stability of users' power supply. The method used abroad to deal with this fault is to calculate the fault point location through software to isolate the fault for treatment. [3-4] The transient process of a low-current earth fault is very short, usually only 0.5 to 2 power frequency cycles, but the current amplitude of the transient process is very large. Therefore, compared with the steady-state location, the reliability of transient fault location is higher [5]. A cumulative sum-based fault detection technique [6] are used for fault detection but at present, the main fault location methods based on transient signals are: first half-wave method, transient current direction method, transient energy method, transient composite sequence current method, and transient zero sequence admittance method [7].

Grenze ID: 01.GIJET.12.2.828_26

Based on the current research status globally, a transient analysis of single-phase grounding faults was first performed, and a phase frequency analysis of neutral point earthing through a Petersen coil was performed [8]. Then, the fault location technology of single-phase grounding under transient composite sequence current was studied. It is hoped that this will provide help for future research and application of small current grounding fault diagnosis.

II. TRANSIENT ANALYSIS OF LOW-CURRENT GROUND FAULTS

After a Line-to-Ground fault occurs in a distribution network, the distribution system will first experience a transient process, followed by a new steady-state process. Since the current and voltage distributions in the transient and steady-state processes differ significantly [9], this section focuses on analyzing the changes in capacitive current and voltage during the transient process. First, an equivalent circuit for the Line to Ground fault system is established, as shown in Figure 1.

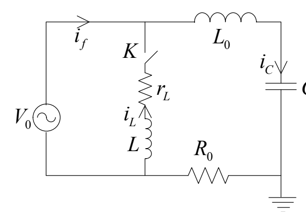

Figure 1. Equivalent circuit of a line-to-ground fault

A single-phase grounded system's equivalent zero-sequence power supply is denoted by V0 in Figure 1, its zero-sequence equivalent resistance by R0, its zero-sequence equivalent inductance by L0, its capacitance to ground by C0, the equivalent resistance of the Petersen coil by RL, its equivalent inductance by L, and a switch by K. When K is closed, the system is grounded through the Petersen coil with the neutral point as the ground. Assume that the transient current at the fault point is if, the current in the capacitor is ic, and the current in the inductor is iL. Because iL and ic decay at different rates in the short time after the fault [10], the transient ground current is very large, which can help in fault location. During a single-phase grounding process, the natural oscillation frequency of the transient process is very high, and the inductance L of the Petersen coil is much larger than the equivalent zero-sequence inductance L0 of the system. Therefore, the Petersen coil branch in Figure 1 can be ignored and regarded as the other components connected in series. Its differential equation is [11-12].

$$R_0 i_c + L_0 \frac{di_c}{dt} + \frac{1}{C}\int_0^t i_c dt = V_{cm} \sin\left(\omega t + \phi\right) \quad (1)$$

In the formula, Vcm is the phase voltage value. The transient current ic is composed of the free component ic′ and the power frequency component ic″. Equation (1) is obtained by performing a Laplace transform and substituting the initial conditions.

$$i_c = I_{cm}\left[\left(\frac{\omega_f}{\omega}\sin\phi\sin\omega t - \cos\phi\cos\omega_f t\right)e^{-\frac{t}{\tau_c}} + \cos\left(\omega t + \phi\right)\right] \quad (2)$$

In the formula, Icm is the capacitor current value; τc is the time coefficient and fω is the angular frequency of the component. From equation (2), it is obvious that when the time constant is large, the free oscillation decays slowly. When the initial phase angle ϕ = 0, the free oscillation component is the smallest; when ϕ = 90°, the free oscillation component is the largest.
The transient inductor current is...

$$i_L = I_{Lm}\left[e^{-\frac{t}{\tau_c}}\cos\phi - \cos\left(\omega t + \phi\right)\right] \quad (3)$$

The fault ground current is

$$i_f = i_L + i_c \quad (4)$$

In summary, the fault grounding current can be separated into two parts: a transient component and a steady-state component. The steady-state component can be controlled by adjusting the Petersen coil current value I_{Lm}. The transient component consists of two parts: a capacitive oscillation component and an inductive decay component. However, due to the large inductance of the coil, the inductive component changes more slowly than the capacitive component. Therefore, the current characteristics of the fault grounding point mainly originate from the characteristics of the transient capacitance.

III. Transient Composite Sequence Current Single-Phase Grounding Fault Location

A. Principle of Transient Composite Sequence Current Method

India's power distribution network has a composite structure and many lines. Considering the cost of engineering, only current transformers are generally installed on the lines. Therefore, line-to-ground fault location technology can only rely on current signals [13]. As mentioned above, the fault location methods based on transient signals mainly include: first half-cycle method, transient current direction method, transient energy method, transient composite sequence current method, transient zero-sequence admittance method, etc. This section will locate single-phase grounding faults based on the transient composite sequence current method

The sum of the transient components of the positive-sequence and negative-sequence fault current is defined as the composite-sequence current. However, due to the decaying nature of the transient current and considering the large calculation error, the composite-sequence current is set to equal the fault current minus the zero-sequence current.

The steps of the transient composite current method are as follows: First, compare the current values at the outlets of each feeder; select the largest effective current value I_{st} as the benchmark; then, compare the current value I'_{asn} on each line segment with I_{st}. Set a judgment variable M; when $\frac{I'_{asn}}{I_{st}} < 0.2$, set M=0; otherwise, M=1. Once the criterion of M=1 is entered into the system, a search is performed along the fault direction from the bus. Once a line with M=1 is found, the search stops immediately; the line between the two detection points is the fault section.

In the composite-sequence current method, the transient current values of the faulty line and the normal phase differ significantly, resulting in better fault location sensitivity compared to traditional methods. Furthermore, the composite-sequence current method only requires current for fault location, thus only current transformers need to be installed in the distribution network, making it less expensive than other methods. However, the current amplitude used in the composite-sequence current method is obtained after three-phase conversion, and the three-phase conversion error may significantly affect the accuracy of the predicted fault location.

B. Matrix Algorithm

Fault location is generally achieved using a matrix algorithm. When a small-current earth fault occurs in the distribution network, the monitoring point reports the fault information to the central control station. The central control station constructs a fault information database matrix using the equivalent value of the composite sequence current and calculates it using the topology matrix, thereby quickly locating the fault point and disconnecting power to users in the faulty section that is not in the faulty section. When constructing the matrix algorithm, first, the distribution network is modeled, then the buses and line end loads in the network are numbered, and according to the network structure, the relationship between N nodes can be represented as an N-order square matrix. Figure 2 shows a tree network model of a simple distribution network.

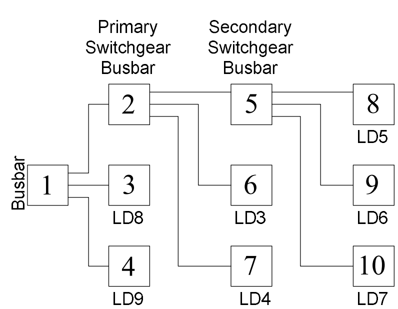

Figure 1. Tree network model of a simple power distribution network

This N-order square matrix is represented as

$$D = \left[d_{ij} \right]_{NXN} \left(i, j = 1, 2, 3, \ldots N \right)$$

And there are

$$d_{ij} = \begin{cases} 1, \text{ The nodes are connected by lines and i } \neq \text{ j;} \\ 1, \ i = j \\ 0, \text{ Other situations} \end{cases}$$

The network topology matrix of the distribution network shown in Figure 2 is as follows:

$$D = \begin{bmatrix} 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Assuming a neutral ground fault occurs at point LD6 in Figure 2, the fault zone should be the segment between nodes 5 and 9. Using the information, a set of judgment values is derived: the line segment with M=1 corresponds to matrix element 1, and the rest are 0. As shown in Figure 2, the nodes affected by the fault are 1, 2, 5, and 9, and their fault information vector is

$$\boldsymbol{G} = [1\ 1\ 0\ 0\ 1\ 0\ 0\ 0\ 1\ 0]$$

The fault information vector can be used to obtain the fault judgment matrix. Based on the fault-judgment quantities on the matrix, the direction of the composite-sequence current flow after LD6 fails is shown in Figure 3. Figure 3 shows that the neutral-point grounding fault occurs between node 5 and node 9.

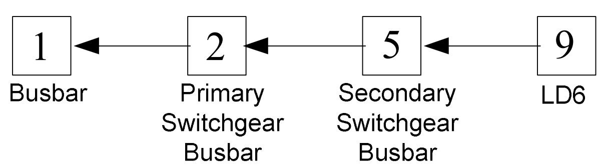

Figure 3. Schematic diagram of composite sequence current direction

IV. Simulation of Transient Composite Sequence-Current Method

MATLAB software is typically used in the simulation of the transient composite sequence-current approach to confirm the method's accuracy. A 110kV/10kV distribution network is constructed in the software. The transformers are connected in a delta configuration, and a switch is installed at the neutral grounding point. Three lines, L1, L2, and L3, are led out from the 10kV bus. The positive-sequence impedance of the lines is (0.17 + j0.38) Ω/km, and the zero-sequence impedance is (0.23 + j0.215) Ω/km. The lengths of lines 1, 3, 8, 9, and 16 are 5 km; lines 2, 10, 11, 15, and 18 are 4km long; lines 5, 6, 7, 12, and 17 are 3 km long; and the rest are 6km long. To simplify the analysis, the load on each branch is assumed to be equal in the simulation, and the equivalent impedance of the line load is taken as (0.129 + j0.08)Ω. The Petersen coil parameters are L=0.84 H, R=26 Ω, the frequency is 4kHz, and the simulation step size is 1μs. The distribution network simulation model is shown in Figure 4.

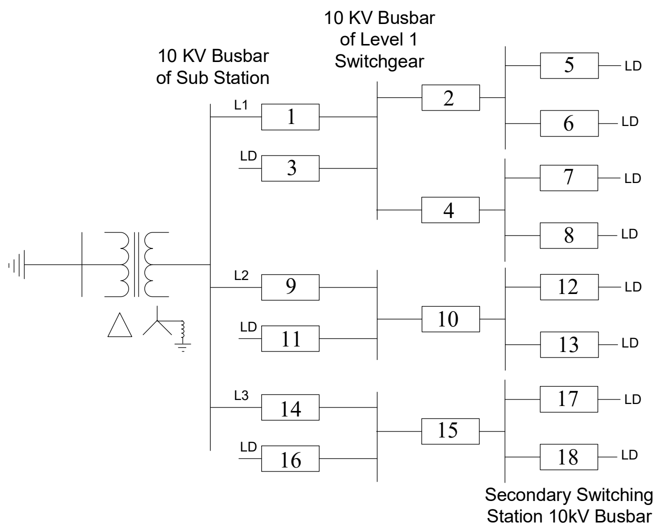

Figure 4. Simulation model of the Distribution network

Figure 5 shows the waveform changes of the fault current before and after the Petersen coil was connected, obtained through MATLAB simulation.

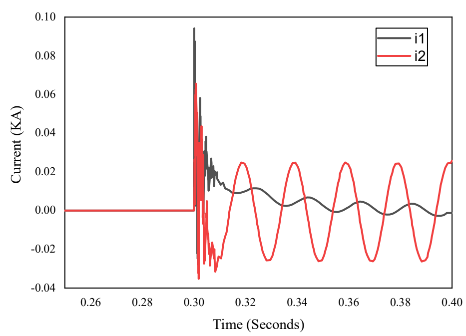

Figure 5. Changes in fault current waveform before and after the Petersen coil connection

Assuming the fault occurs in sections 1, 2, 3, and 5 of line L1, the Petersen coil's influence on fault location is studied. The initial phase angle of the composite sequence-current is assumed to be 0°, and the grounding resistance is 5Ω. Simulation data for the ungrounded neutral system are shown in Table 1, and simulation data for the neutral-grounded system via the Petersen coil are tabulated in Table 2.

TABLE I: SIMULATION RESULTS WITH ISOLATED NEUTRAL POINT

Location	Effective value of composite sequence current at monitoring point M / kA							
	M1	M2	M3	M4	M5	M6	M9	M14
1	5.72	0.035	0.007	0.038	0.009	0.009	0.0015	0.0015
2	4.72	5.5	0.008	0.028	0.02	0.02	0.0015	0.0015
3	4.9	0.025	6.2	0.026	0.007	0.008	0.0015	0.0025
4	4.2	5.00	0.005	0.025	5.5	0.019	0.0025	0.0015

TABLE II. SIMULATION RESULTS OF NEUTRAL POINT GROUNDING THROUGH PETERSEN COIL

Location	Effective value of composite sequence current at monitoring point M / kA							
	M1	M2	M3	M4	M5	M6	M9	M14
1	5.62	0.029	0.005	0.032	0.009	0.008	0.0015	0.0015
2	4.62	5.18	0.006	0.025	0.015	0.018	0.0015	0.0015
3	4.7	0.02	5.65	0.020	0.006	0.007	0.0025	0.0025
4	4.05	4.82	0.004	0.018	5.12	0.014	0.0015	0.0015

Simulation results show that after a neutral-point grounding fault occurs in a distribution network, the composite-sequence current generated at the fault point flows to the system side because the load impedance is much higher than the system's total impedance. The composite-sequence current method is not affected by factors such as Petersen coils or ground capacitance. The composite-sequence current method only requires a current signal, is simple to measure, and has good practicality.

V. CONCLUSION

A line-to-ground fault location method based on transient current was proposed, with a focus on the fault location technology for line-to-ground faults under transient composite-sequence current. The ground fault current is found to be the vector addition of transient capacitive current and transient inductive current, but the current characteristics at the fault point mainly originate from the transient capacitance. The composite-sequence current generated at the fault point flows towards the system side. The composite-sequence current method is not affected by factors such as Petersen coils and ground capacitance. Simulation results verify the composite-sequence current location method and demonstrate its good practicality.

REFERENCES

[1] Zięba, Beata, Bartosz Olejnik, and Iwona Grobelna. "Application of Under-Impedance Criterion to Protect against Effects of Phase-to-Phase Short Circuits in Medium-Voltage Networks." Energies 17, no. 2 (2024): 505.

[2] Baldwin, Thomas, Frank Renovich, Lynn F. Saunders, and David Lubkeman. "Fault locating in ungrounded and high-resistance grounded systems." IEEE Transactions on Industry Applications 37, no. 4 (2002): 1152-1159.

[3] Sreejith, P. R., M. M. Fathima, and V. N. Krishnaprasad. "Powerline Fault Detection and Location Tracking with GSM." In 2024 7th International Conference on Circuit Power and Computing Technologies (ICCPCT), vol. 1, pp. 1331-1336. IEEE, 2024.

[4] Patel Sharadchandra J., Patel Nilaykumar A., "A Novel Scheme to Identify Faults Occurring During Power Swing for a Series-Compensated Line", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. vol. 5, no. 4, pp. 2452-2459. ISSN (Print): 2320 – 3765 ISSN (Online): 2278 – 8875, April 2016.

[5] Jetpissov, Merey, Kazhybek Tergemes, Saken Sheryazov, Algazy Zhauyt, Toleuserik Sadykbek, Abdissattar Berdibekov, and Gulbarshyn Smailova. "A Selective Method for Identifying Single-Phase Ground Faults with Transient Resistance in Isolated Neutral Medium-Voltage Networks." Energies 18, no. 21 (2025): 5699.

[6] Patel Sharadchandra J., Patel Nilaykumar A., "A cumulative sum based fault detection technique for the series compensated line during power swing", International Journal of Advance Engineering and Research Development (IJAERD), November 2015, IJAERD, pp. 1-10, vol.2, no. 11. e-ISSN: 2348-4470, print-ISSN: 2348-6406.

[7] Bayati, Navid, Lasse Kappel Mortensen, Mehdi Savaghebi, and Hamid Reza Shaker. "A localized transient-based fault location scheme for distribution systems." Sensors 22, no. 7 (2022): 2723.

[8] Ustinov, Denis, Aleksander Nazarychev, Denis Pelenev, Kirill Babyr, and Andrey Pugachev. "Investigation of the effect of current protections in conditions of single-phase ground fault through transient resistance in the electrical networks of mining enterprises." Energies 16, no. 9 (2023): 3690.

[9] Guillén-López, Daniel, Xavier Serrano-Guerrero, Antonio Barragán-Escandón, and Jean-Michel Clairand. "Transient and steady-state evaluation of distributed generation in medium-voltage distribution networks." Energies 17, no. 22 (2024): 5783.

[10] Gouda, Osama E., Adel Z. El Dein, Elsayed Tag-Eldin, Matti Lehtonen, and Mohamed MF Darwish. "Proposed approach to investigate the current and voltage distributions of isolated and grounded systems during earth fault conditions." IEEE Access 11 (2023): 98362-98375.

[11] Elkholy, Ahmed M., Dmitry I. Panfilov, and Michael G. Astachev. "Assessment of Various Technologies Influence to Reduce the Impact of Single-Phase Earth Faults in Distribution Systems with an Isolated Neutral." In 2024 6th International Youth Conference on Radio Electronics, Electrical and Power Engineering (REEPE), pp. 1-8. IEEE, 2024.

[12] Wang, Bin, and Xin Cui. "Nonlinear modeling analysis and arc high-impedance faults detection in active distribution networks with neutral grounding via Petersen coil." IEEE Transactions on Smart Grid 13, no. 3 (2022): 1888-1898.

[13] Fernando, Warnakulasuriya Sonal Prashenajith, Md Apel Mahmud, Shama Naz Islam, Md Abdul Barik, and Nasser Hosseinzadeh. "A comprehensive review of control techniques for compensating the fault current in resonant grounded distribution networks: From the perspective of mitigating powerline bushfires." IET generation, transmission & distribution 17, no. 1 (2023): 1-16