# Matlab-Based Simulation Analysis of Fault Characteristics in Low-Current Grounding Systems (Postprint)

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## Abstract

This paper employs Simulink, the dynamic simulation tool of MATLAB software, and its Power System Blockset (PSB) to conduct fault simulation for small-current grounding systems, and elaborates on the model construction procedure. It primarily analyzes the waveform characteristics of zero-sequence voltage and zero-sequence current for ground fault types; examines the waveform characteristics of short-circuit current for two-phase and three-phase short circuits; and investigates the waveform characteristics of zero-sequence components and fault-phase voltage for two-phase-to-ground short circuits. By simulating waveforms at the inception ends of main fault lines and at both terminals of fault sections in the system, observing these waveforms facilitates easier identification of the principal features of each fault, comprehension of differences in waveform characteristics among various faults, and consequently, benefits subsequent research on fault detection and identification. This provides a basis for analyzing fault patterns in small-current grounding systems and is of significant importance for the development of fault detection algorithms and equipment for small-current grounding systems.

## Full Text

## Preamble

### Simulation and Analysis of Fault Characteristics in Small Current Grounding Power Systems Based on Matlab

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## Abstract

This paper employs Matlab' s dynamic simulation tool Simulink and its Power System Blockset (PSB) to simulate faults in small current grounding systems, detailing the model construction process. The analysis focuses on waveform characteristics of zero-sequence voltage and current for ground faults, short-circuit current waveforms for two-phase and three-phase faults, and zero-sequence components along with fault-phase voltage waveforms for two-phase-to-ground faults. By simulating waveforms at the beginning of main fault lines and at both ends of fault sections, the primary features of each fault type become readily identifiable, facilitating understanding of differences among various fault waveform characteristics. This provides a foundation for subsequent fault detection and identification research, offering critical support for analyzing fault patterns in small current grounding systems and for developing fault detection algorithms and equipment.

**Keywords:** Matlab, model, analysis, detection

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## 1 Introduction

In China' s 10 kV distribution networks, the primary fault types include single-phase grounding faults, two-phase-to-ground short circuits, two-phase short circuits, and three-phase short circuits [1]. Single-phase grounding faults occur most frequently, accounting for over 60% of all faults. Previous research on distribution network fault simulation and detection algorithms has primarily focused on single-phase grounding faults. Following a single-phase grounding fault, the voltages of the two healthy phases increase, potentially escalating into phase-to-phase short circuits [2]. Therefore, this paper not only simulates the current and voltage waveforms of single-phase grounding faults but also examines the most prominent characteristics of two-phase-to-ground, two-phase, and three-phase short circuits. The study presents waveforms at the beginning of each line and further analyzes current and voltage waveforms on both sides of fault points [3-4], providing fundamental fault characteristics for distinguishing fault types, fault line selection, and fault section location methods in power systems.

## 2 Establishing the Simulation Model

Matlab' s Power System Blockset (PSB) contains component models required for power system simulation, enabling realistic fault simulations [5]. Simulation data can be exported to the Workspace for subsequent plotting and algorithm implementation. The simulation model schematic is shown in [Figure 1: see original paper].

In the simulation model, the power source is an internally connected 10 kV infinite bus. Transmission lines use the "Three-Phase PI Section Line" model. In actual 10 kV distribution systems, line lengths are generally within 20 km [6]; thus, the five transmission lines L1-L5 are set to 20 km, 12 km, 13 km, 17 km, and 18 km respectively. Line parameters are: positive- and zero-sequence resistance [0.0812 Ω/km, 0.2864 Ω/km]; positive- and zero-sequence inductance [1.21 mH/km, 5.48 mH/km]; positive- and zero-sequence capacitance [9.697 nF/km, 6.124 nF/km]. The arc suppression coil operates with 10% overcompensation, with an inductance value of 6.4 H and series resistance of 200 Ω. The transmission capacity of 10 kV single-circuit overhead lines is generally within 2 MW. Line loads Load1-Load5 use the "Three-Phase Series RLC Load" model, with terminal load power consumption of 0.6 MW, 1.0 MW, 1.2 MW, 1.4 MW, and 1.7 MW respectively, while other parameters use default values.

"Three-Phase V-I Measurement" modules are installed at the beginning of lines L1-L3 and at points 10 km from the bus on line L1 to read line voltage and current data. Faults occur in the MN section of line L1. The "Three-Phase Fault" module simulates line faults, allowing configuration of fault type, interphase resistance, grounding resistance, and fault timing. The simulation model functional block diagram is shown in [Figure 2: see original paper].

## 3 Fault Waveforms in Small Current Grounding Systems

This section presents simulations of typical waveforms corresponding to relevant fault characteristics. Ground faults primarily include single-phase grounding and two-phase-to-ground short circuits. According to literature [6-9], the main characteristics of ground faults are voltage drop in the faulted phase and generation of zero-sequence components. Therefore, ground fault simulations focus on phase voltage, zero-sequence voltage, and zero-sequence current waveforms. For two-phase short circuits, three-phase current waveforms are examined for both metallic and non-metallic faults, with voltage and current waveforms on both sides of fault points simulated. For three-phase short circuits, three-phase currents on both sides of the fault point are simulated [10].

### 3.1 Single-Phase Grounding Fault

Single-phase grounding faults constitute the highest proportion of power system faults. Post-fault phase voltages become unbalanced, and lines discharge through ground capacitance, generating zero-sequence components. However, the fault current is weak and difficult to detect. Meanwhile, the two healthy phase voltages increase, potentially causing secondary faults such as phase-to-phase short circuits, posing significant hazards to the grid. Although the system may continue operating for 1-2 hours after such faults, they must be cleared promptly due to the substantial risk to stable grid operation.

An A-phase grounding fault occurs at 0.02 s on line L1, 10 km from the bus, with a transition resistance of 1 Ω. Zero-sequence currents and voltages for lines L1-L3 in the isolated neutral system are shown in [Figure 3: see original paper], while those for the arc-suppression coil grounding system are shown in [Figure 4: see original paper]. Three-phase voltages and zero-sequence currents on both sides of the fault point are shown in [Figure 5: see original paper] and [Figure 6: see original paper].

As shown in [Figure 3: see original paper], after a single-phase grounding fault, the zero-sequence current of the faulted line L1 differs from other lines, exhibiting maximum amplitude and opposite phase. The zero-sequence voltage leads line L1' s zero-sequence current by 90° while lagging all healthy lines' zero-sequence currents by 90°. [Figure 4: see original paper] reveals that with arc-suppression coil grounding, the overcompensation effect causes L1' s waveform to share the same phase as L2 and L3, though L1 contains significant DC components due to coil compensation. All line zero-sequence currents share consistent phase, leading the zero-sequence voltage by 90°.

[Figure 5: see original paper]a-b and [Figure 6: see original paper]a-b show that in both isolated neutral and arc-suppression coil systems, the faulted A-phase voltage amplitude drops nearly to zero while B and C phases increase, with no significant difference between source-side and load-side three-phase voltages. [Figure 5: see original paper]c-d and [Figure 6: see original paper]c-d demonstrate that in isolated neutral systems, zero-sequence currents on the source and load sides of the fault point are opposite in phase. With arc-suppression coil grounding, they share the same phase. The source-side zero-sequence current contains substantial DC components, while the load-side current is weak. Since the source side includes all healthy lines and the faulted line' s capacitance to ground is large, while the load side only includes the downstream portion with shorter length and smaller capacitance, the difference is significant [11]. The source-side transient zero-sequence current has large amplitude and low resonant frequency, whereas the load-side has small amplitude and high resonant frequency [12]. Frequency spectra for one power-frequency cycle after fault are shown in [Figure 7: see original paper], clearly showing the spectral differences between source and load sides. This distribution difference, minimally affected by neutral grounding method, provides fundamental characteristics for novel transient-based fault section location algorithms.

### 3.2 Two-Phase Short Circuit Fault

Two-phase short circuits account for 10% of power system faults, causing dramatic voltage and current changes that severely impact system stability. Fault characteristics vary with inter-phase resistance. This analysis examines both metallic and non-metallic short circuits.

An A-B phase short circuit occurs at 0.02 s on line L1, 10 km from the bus, with inter-phase transition resistances of 0.1 Ω and 10 Ω. Three-phase voltage waveforms on both sides of the fault point are shown in [Figure 8: see original paper], with current waveforms in [Figure 9: see original paper].

[Figure 8: see original paper] shows that during metallic two-phase faults, source-side A and B fault-phase voltages decrease with equal amplitude and reduced phase difference, becoming nearly in-phase. Load-side A and B voltages decrease with equal amplitude and identical phase. The healthy C-phase voltage remains unchanged. During non-metallic faults, A and B fault-phase voltages decrease on both sides with different magnitudes, and their phase difference reduces.

[Figure 9: see original paper] reveals that during metallic faults, source-side A and B fault-phase currents increase with equal amplitude and opposite phase, while healthy C-phase current remains unchanged. Load-side A and B currents decrease with equal amplitude and identical phase. During non-metallic faults, source-side A and B currents increase with equal amplitude and opposite phase, while C-phase remains unchanged. On the load side, as transition resistance increases, the phase difference between A and B varies from 0° to 120°, and amplitudes gradually approach normal conditions [13].

When line L1 experiences an inter-phase short circuit, A and B fault-phase currents only decrease with increasing inter-phase resistance, but the pattern of increased, opposite-phase currents remains unchanged. Therefore, only the case with 0.1 Ω resistance is simulated, as shown in [Figure 10: see original paper]. At 0.02 s, the A-B phase fault causes significant current increase in phases A and B with equal amplitude and opposite phase, while phase C remains unchanged. Healthy lines L2 and L3 show no significant current variation.

### 3.3 Two-Phase-to-Ground Short Circuit Fault

If single-phase grounding faults are not cleared promptly, increased healthy-phase voltage may cause flashover in weak insulation points, evolving into two-phase-to-ground faults. These faults have unique characteristics but share similarities with both inter-phase and single-phase grounding faults.

The most obvious difference lies in the three-phase voltage waveforms. Simulations of pre- and post-fault three-phase voltages on both sides of the fault point show that source- and load-side power-frequency voltage waveforms exhibit no significant difference. Faulted phases A and B show reduced voltage with decreased phase difference, while healthy phase C voltage increases.

### 3.4 Three-Phase Short Circuit Fault

Three-phase short circuits are the most hazardous fault type. Though only 5% of total faults, they cause dramatic three-phase current increases that severely impact grid stability. Simulations focus on three-phase current variations before and after fault occurrence.

A three-phase short circuit occurs at 0.02 s on line L1, 10 km from the bus, with 0.1 Ω transition resistance. Three-phase current waveforms on both sides are shown in [Figure 12: see original paper]. The main characteristics of three-phase faults in small current grounding systems are:

1. Similar to two-phase faults, fault line L1 experiences significant three-phase current increase, while healthy lines L2 and L3 show no significant change.
2. Post-fault source-side three-phase currents increase dramatically, while load-side currents decrease.

## 4 Conclusion

This paper simulates and analyzes typical characteristics of four common fault types in small current grounding systems, yielding the following conclusions:

1. **Ground faults** are characterized by zero-sequence component generation. Fault line selection and section location can be achieved through differences in zero-sequence current steady-state quantities between faulted and healthy lines, between source and load sides of fault points, and through transient zero-sequence current frequency component differences.
2. **Two-phase-to-ground faults** can be distinguished from two-phase faults by detecting zero-sequence current and voltage, and from single-phase grounding faults by analyzing voltage changes in the two faulted phases.
3. **Two-phase and three-phase short circuits** can be identified by the characteristic of dramatically increased fault-phase currents after fault occurrence. Fault section location can be achieved based on differences in voltage and current effective values before and after the fault point.

## References

[1] Liu Wanshun. *Power System Fault Analysis* [M]. Beijing: China Electric Power Press, 1998.

[2] Zhang Bo, Wang Yue. Analysis of two-phase grounding fault of isolated neutral system [J]. *Power System Protection and Control*, 2007, 35(15): 59-61.

[3] Tang Jinrui, Yin Xianggen, Zhang Zhe, et al. Survey of fault location technology for distribution networks [J]. *Electric Power Automation Equipment*, 2013, 33(5): 7-13.

[4] Chen Li, Yang Honggeng, Wu Xiaoqing. Fault location for distribution networks based on pattern recognition technique [J]. *Advanced Technology of Electrical Engineering and Energy*, 2012, 31(1): 88-91.

[5] Yu Qun. *Matlab/Simulink Power System Modeling and Simulation* [M]. Beijing: Mechanical Industry Press, 2011.

[6] Zhang Li, Yang Yihan, Yang Xiuyuan, et al. Method of mobile phase-comparison for fault location of distribution network [J]. *Proceedings of the CSEE*, 2009, 29(7): 91-97.

[7] Zheng Rihong, Gu Xiufang, Wang Fei, et al. A new method for identifying fault of short circuit in power distribution network [J]. *Electric Engineering*, 2012, 8(8): 27-30.

[8] Liu Jian, Zhang Xiaoqing, Zhang Zhihua, et al. Location and restoration of two-phase grounded short-circuit in distribution system [J]. *Automation of Electric Power Systems*, 2013, 37(5): 105-110.

[9] Li Tianyou, Chen Bin, Xie Jing, et al. New earth fault detection technology for automatic boundary switches in non-solidly earthed network [J]. *Power System and Clean Energy*, 2014, 30(1): 20-25.

[10] Wu Haowei, Zhou Liang, Sun Chaohui, et al. Study on fast detecting scheme of power system short-circuit fault [J]. *Power System Protection and Control*, 2010, 38(24): 88-92.

[11] Zhang Haishen, He Zhengyou, Zhang Jun. Frequency spectrum characteristic analysis of single-phase grounding fault in resonant grounded systems [J]. *Automation of Electric Power Systems*, 2012, 36(6): 79-84.

[12] Zhang Shu, Yang Jianwei, He Zhengyou, et al. Fault section location of the distribution network based on transient center frequency [J]. *Proceedings of the CSEE*, 2015, 35(10): 2463-2470.

[13] Zheng Rihong, Gu Xiufang, Han Ruyue, et al. Analysis of short circuit faults of distribution network and research of its identification methods [J]. *Industry and Mine Automation*, 2012, 38(4): 23-29.

*Note: Figure translations are in progress. See original paper for figures.*