

Article

An Approximate Single-Line-to-Ground Faulted Feeder Identification Method for 35 kV Resonant-Grounded Distribution Networks Based on Cross-State Apparent Admittance

Jindong Yang¹, Shan Wang², Hongwen Liu¹, Siyi Yuan³ and Yang Xiang^{3,*} 

¹ Electric Power Research Institute of Yunnan Power Grid, Kunming 650214, China; 13759381192@163.com (J.Y.); liuhongwen_19@163.com (H.L.)

² Yunnan Power Grid, Kunming 650214, China; gingerkashiwagi@163.com

³ State Key Laboratory of Disaster Prevention & Reduction for Power Grid, School of Electrical and Information Engineering, Changsha University of Science and Technology, Changsha 410114, China; 24205061260@csust.edu.cn

* Correspondence: eexy@csust.edu.cn

Abstract

Single-line-to-ground (SLG) faults are the most frequent fault type in medium-voltage distribution networks. In 35 kV networks equipped with Y/Y/ Δ transformers, the zero-sequence coupling with the transmission grid and inherent line asymmetry make reliable SLG faulted feeder identification highly challenging, especially under high fault resistance. To address these issues, this paper proposes an approximate cross-state apparent admittance method for identifying SLG faulted feeders in 35 kV asymmetric distribution networks. First, the pre-fault and post-fault zero-sequence current responses are analytically derived, accounting for the structural asymmetry of feeder phase-to-ground parameters and the neutral grounding branch. Then, a cross-state apparent admittance formulation is established using synchronized zero-sequence voltage and current phasors. Considering that the proposed criterion relies on the phase relationship of cross-state apparent admittances, its practical implementation requires a high-accuracy synchronized voltage and current measurement loop. Measurement-class CTs/PTs or equivalent high-precision acquisition channels are therefore recommended to ensure sufficient phase-angle accuracy for the admittance-plane criterion. For healthy feeders, the apparent admittance is represented by the inherent zero-sequence line-to-ground admittance under the adopted bus-voltage measurement configuration. For the faulted feeder, the nonlinear coupling term associated with the fault resistance is rigorously eliminated through system-level Kirchhoff's current law analysis, yielding a fault-resistance-independent analytical expression. A quadrant-based identification criterion is subsequently developed in the complex admittance plane. Finally, a simulation model based on the real architecture and parameters of an actual 35 kV substation is established in PSCAD/EMTDC. The simulation case studies demonstrate that the proposed method can identify the faulted feeder under the tested severe-asymmetry and high-impedance fault conditions up to 10 k Ω , provided that sufficiently accurate synchronized zero-sequence voltage and current phasors are available. In the simulation model, the zero-sequence voltage is measured at the bus or neutral grounding branch, and the feeder zero-sequence currents are measured at the outgoing feeder branches.



Academic Editor: Daniel Morinigo-Sotelo

Received: 7 May 2026

Revised: 10 June 2026

Accepted: 15 June 2026

Published: 20 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article

distributed under the terms and

conditions of the [Creative Commons](#)

[Attribution \(CC BY\)](#) license.

Keywords: single-line-to-ground fault; faulted feeder identification; power system modeling; cross-state apparent admittance; asymmetric distribution networks; practical substation engineering

1. Introduction

Single-line-to-ground (SLG) faults are among the most common fault types in medium-voltage distribution networks. In resonant-grounded systems, the Petersen coil compensates the capacitive current during an SLG fault, which improves supply continuity but also makes the residual fault current weak and difficult to distinguish from the background zero-sequence response [1,2]. To ensure the continuity of the power supply and extinguish the fault arc, resonant grounding systems equipped with Petersen coils at the neutral point are widely adopted [3]. In recent years, to further handle high-impedance faults (HIFs) and achieve full arc suppression, flexible active suppression devices (FASDs) have been introduced to operate in parallel with the Petersen coil. FASDs actively regulate the zero-sequence voltage to force the fault point voltage to zero, theoretically eliminating safety risks during the fault [4–6]. However, for permanent SLG faults, the fault will re-strike once the active suppression is withdrawn. Therefore, reliable faulted feeder identification (FFI) remains a critical necessity. Unfortunately, the weak fault current, background asymmetry, and compensation dynamics make FFI highly challenging in resonant-grounded distribution networks [7,8].

Currently, extensive research has been conducted on FFI methods, which can be broadly categorized into transient-based methods, synchronized-measurement-based differential methods, active regulation methods, and steady-state passive methods. Transient-based methods extract high-frequency or non-fundamental components generated at fault inception, such as transient energy, waveform similarity, and multi-band fault features [9–11]. However, these methods generally require high-bandwidth recording devices and reliable transient windows, and their performance may be affected by noise, fault inception angle, high fault resistance, and feeder parameter asymmetry [7,12].

In recent years, synchronized measurements have also been used to locate and classify distribution-network events by comparing pre-event and post-event voltage-current responses. For example, micro-PMU data have been used to locate the source of events in distribution systems, and synchronized Lissajous representations have been developed to detect and classify events from synchro-waveform measurements [13,14]. These studies demonstrate that high-resolution synchronized measurements can improve the observability of event-induced electrical characteristics. However, their objectives mainly focus on event source location or event classification, while the present work focuses on SLG faulted feeder identification in 35 kV resonant-grounded networks with Y/Y/ Δ transformers. In conventional 35 kV feeder protection, the available zero-sequence protection quantities are usually the bus zero-sequence voltage and the feeder zero-sequence currents. Therefore, a steady-state feeder selection method compatible with this measurement configuration is still required.

On the other hand, active regulation methods identify the faulted feeder by deliberately changing the neutral grounding condition, regulating the arc-suppression coil, or introducing controlled zero-sequence disturbances to amplify fault features [15,16]. These methods can improve feature observability under weak-current faults and high fault resistance. However, they are closely coupled with the control strategy of the neutral grounding device and usually require an additional active regulation process. For 35 kV resonant-grounded distribution networks with Y/Y/ Δ transformers and asymmetric feeder

parameters, passive steady-state feeder identification methods that explicitly consider zero-sequence network coupling and parameter asymmetry remain insufficiently studied.

In contrast, steady-state passive methods, particularly those based on zero-sequence admittance or phase-domain quantities, do not require deliberate signal injection or delayed arc suppression. They are attractive for engineering implementation because their decision variables can be obtained from fundamental-frequency voltage and current phasors [17]. Nevertheless, traditional admittance methods require additional consideration of measurement accuracy and feeder asymmetry when dealing with severe asymmetric line-to-ground parameters and high fault resistances [18,19]. More importantly, most existing FFI studies focus on conventional medium-voltage distribution networks whose zero-sequence circuit is mainly confined to the distribution side. In typical 10 kV systems supplied by Δ -connected transformer windings, the upstream transmission network is isolated from the zero-sequence circuit of the distribution network [8,17]. This assumption is no longer valid for the 35 kV Y/Y/ Δ transformer-based network studied in this paper.

A critical SLG fault scenario emerges in 35 kV distribution networks supplied by Y/Y/ Δ transformers. In this configuration, the 110 kV transmission side is Y-connected and solidly grounded, the 10 kV side is Δ -connected, and the 35 kV side is Y-connected. The 35 kV neutral point is grounded through a Petersen coil and an FASD for active arc suppression. Due to the magnetic coupling of the Y/Y/ Δ transformer, during an SLG fault on the 35 kV side, the zero-sequence circuit is no longer confined to the 35 kV distribution network. Instead, it forms a coupled pathway with the zero-sequence parameters of the 110 kV side. Equivalently, the line-to-ground parameters of the 110 kV network act as a parallel branch to the 35 kV neutral Petersen coil. This topological transformation fundamentally alters the zero-sequence current distribution mechanism, which changes the applicable conditions of conventional FFI methods and motivates the development of a targeted feeder-identification scheme.

To address the aforementioned gaps, this paper proposes a practical SLG faulted feeder identification method based on cross-state apparent admittance, specifically designed for 35 kV distribution networks with Y/Y/ Δ transformers and asymmetric ground parameters. By calculating the differences between the pre-fault and post-fault zero-sequence voltages and currents, the apparent zero-sequence admittance of each feeder is derived. Through rigorous mathematical analysis, it is proven that the proposed method intrinsically eliminates the influence of fault impedance and system parameter asymmetry. The proposed feeder selection criterion is independent of the zero-sequence voltage triggering threshold. After the fault-event data are acquired, the FFI is achieved by evaluating the quadrant distribution of the cross-state apparent admittance. For a healthy feeder, both the real and imaginary parts are positive. For the faulted feeder, the real part is negative.

It is worth emphasizing that the proposed criterion relies on the phase consistency of the measured zero-sequence voltage and feeder zero-sequence currents. Therefore, its engineering implementation should be based on a high-accuracy synchronized measurement loop, including measurement-class CTs/PTs or equivalent high-precision acquisition channels. If protection-class CTs/PTs with larger phase errors are directly used, especially together with additional time-synchronization errors, the angular margin between healthy feeders and the 90° quadrant boundary may be reduced, which may lead to incorrect feeder classification. Therefore, the proposed method is intended for applications where the phase-angle accuracy of the measurement loop can be guaranteed. Furthermore, since the proposed method is passive, it can be executed in parallel with the normal fault-handling process and does not require intentional neutral-point regulation during feeder identification.

The main contributions of this paper are summarized as follows.

1. The basic cross-state voltage-current comparison idea is derived from the feeder identification mechanism in [13,14]. This paper extends that mechanism to a 35 kV Y/Y/ Δ transformer-based resonant-grounded distribution network without feeder-level PMU infrastructure, while considering upstream zero-sequence coupling, feeder parameter asymmetry, and practical measurement-location constraints.
2. A zero-sequence equivalent circuit model for 35 kV distribution networks powered by Y/Y/ Δ transformers is established, revealing the coupling mechanism where the 110 kV zero-sequence parameters act as a parallel branch to the 35 kV neutral impedance during SLG faults.
3. A passive FFI method based on cross-state apparent admittance is proposed. The feeder selection criterion is independent of the zero-sequence voltage triggering threshold and identifies the faulted feeder using the quadrant distribution of the admittance components, avoiding the complex selection-threshold setting required by traditional admittance-based methods.
4. The proposed method is a passive feeder identification scheme that does not require additional active signal injection or intentional neutral-point regulation during the identification stage. Its applicability under high fault resistance and asymmetric line-to-ground parameters is verified by PSCAD/EMTDC simulations. The method requires accurate zero-sequence voltage and current phasor acquisition to preserve the phase-angle margin of the apparent admittance criterion.

The remainder of this paper is organized as follows. Section 2 analyzes the zero-sequence equivalent circuit of the Y/Y/ Δ transformer-based 35 kV distribution network. Section 3 details the mathematical derivation of the cross-state apparent admittance and the proposed FFI criterion. Section 4 presents comprehensive simulation case studies based on a practical substation model to verify the effectiveness of the proposed method. Section 5 concludes the paper.

2. Analytical Characterization of Zero-Sequence Responses in 35 kV Asymmetric Distribution Networks

2.1. Steady-State and Post-Fault Zero-Sequence Current Formulations

The target system investigated in this paper is a 35 kV active distribution network with a Y/Y/ Δ main transformer configuration of 110 kV/35 kV/10 kV. The neutral point of the 110 kV side is solidly grounded, and the neutral point of the 35 kV side is grounded through an arc suppression coil with inductance L . Figure 1 shows the zero-sequence equivalent circuit of the 35 kV distribution system. The voltage $\dot{U}_0$ denotes the measured zero-sequence voltage, and $\dot{I}_{0k}$ denotes the measured zero-sequence current of feeder k , with the positive direction defined from the bus to the feeder. Since these quantities are used to construct a cross-state voltage-current variation ratio, the resulting apparent admittance is treated as an identification variable rather than an exact local admittance. The equivalent neutral-to-ground admittance Y_N is expressed as:

$$Y_N = \frac{1}{j\omega L} + k_T^2 Y_{110} \quad (1)$$

where Y_N is the equivalent neutral-to-ground admittance, ω is the system angular frequency, L is the inductance of the ASC, k_T is the voltage transformation ratio from the 110 kV side to the 35 kV side, and Y_{110} is the aggregated zero-sequence admittance of the 110 kV side.

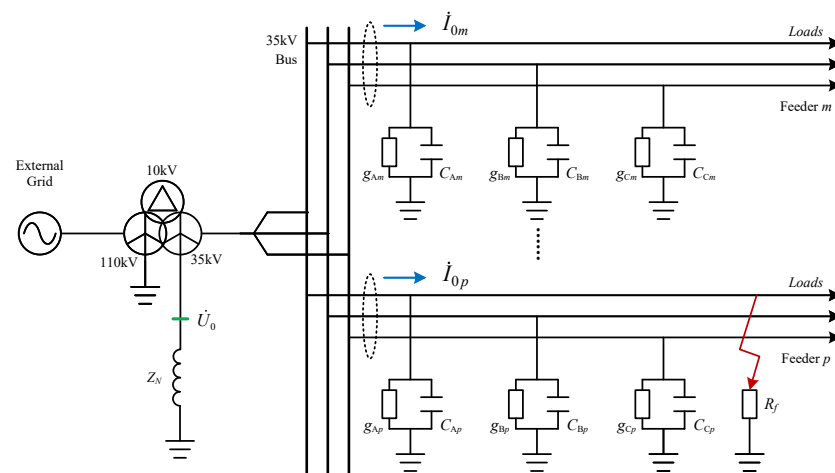


Figure 1. Equivalent zero-sequence circuit of the 35 kV asymmetric distribution network. The bus zero-sequence voltage $\dot{U}_0$ is referenced at the 35 kV neutral-point displacement location, and the feeder zero-sequence currents $\dot{I}_{0m}$ and $\dot{I}_{0p}$ are measured at the feeder sending ends with the positive direction defined from the bus toward the feeders. The neutral point of the 35 kV side is represented by the grounding branch Z_N , which equivalently accounts for the ASC grounding path and the zero-sequence coupling effect of the upstream grounded network.

In the pre-fault steady state (State I), the zero-sequence current (ZSC) measured at the sending end of an arbitrary feeder k is governed by the superposition of the phase source voltages and the neutral point displacement voltage (NPDV). For feeder k , the ZSC is expressed as:

$$3\dot{I}_{0k}^I = \sum_{X=A,B,C} (\dot{E}_X + \dot{U}_0^I)(g_{Xk} + j\omega C_{Xk}) \quad (2)$$

where the superscript I denotes the pre-fault state; $\dot{I}_{0k}^I$ is the zero-sequence current phasor of feeder k ; $\dot{E}_A$, $\dot{E}_B$, and $\dot{E}_C$ are the nominal three-phase source voltage phasors; and g_{Xk} and C_{Xk} ($X \in \{A, B, C\}$) represent the phase-to-ground leakage conductance and capacitance of phase X on feeder k , respectively.

Theoretically, if the distribution network were perfectly transposed and the phase-to-ground parameters were strictly symmetrical (i.e., $g_{Ak} = g_{Bk} = g_{Ck}$ and $C_{Ak} = C_{Bk} = C_{Ck}$), the term $\sum \dot{E}_X(g_{Xk} + j\omega C_{Xk})$ would vanish due to the balanced nature of the source voltages ($\dot{E}_A + \dot{E}_B + \dot{E}_C = 0$). In such an idealized scenario, $\dot{U}_0^I$ would be zero, and any observed ZSC would be exclusively driven by external zero-sequence injection sources. However, in practical 35 kV distribution networks, the inherent structural asymmetry of line parameters acts as an internal excitation. This asymmetry drives the generation of the NPDV $\dot{U}_0^I$, which in turn interacts with the line parameters to establish a background steady-state ZSC.

When a single-line-to-ground (SLG) fault occurs on phase F of feeder p with a fault resistance R_f , the system enters the post-fault state (State II). The ZSV shifts to $\dot{U}_0^{II}$, which is now a result of the complex coupling between the original structural asymmetry and the new fault boundary condition. For a healthy feeder m , the ZSC responds only to this voltage shift:

$$3\dot{I}_{0m}^{II} = \sum_{X=A,B,C} (\dot{E}_X + \dot{U}_0^{II})(g_{Xm} + j\omega C_{Xm}) \quad (3)$$

For the faulted feeder p , the ZSC is further compounded by the fault branch current, creating a highly coupled response:

$$3\dot{I}_{0p}^{II} = \sum_{X=A,B,C} (\dot{E}_X + \dot{U}_0^{II})(g_{Xp} + j\omega C_{Xp}) + \frac{\dot{E}_F + \dot{U}_0^{II}}{R_f} \quad (4)$$

2.2. Formulation of Cross-State Apparent Admittance

Traditional identification methods relying on absolute ZSC or admittance values are often compromised by the aforementioned steady-state bias $\dot{I}_{0k}^I$, which masks the fault-induced variations. To isolate the dynamic response exclusively driven by the fault, a cross-state calculation is performed.

The rationale of the cross-state apparent admittance calculation comes from the zero-sequence KCL relationship of the feeder and the whole network. For a healthy feeder, the post-fault zero-sequence current variation is only driven by the bus zero-sequence voltage variation. Therefore, normalizing the current variation by the voltage variation recovers the inherent feeder zero-sequence line-to-ground admittance. For the faulted feeder, the same operation gives an additional term associated with the fault branch. Although this term initially contains $1/R_f$, the pre-fault and post-fault system-level KCL equations show that it can be equivalently represented by the aggregated zero-sequence ground-admittance parameters of the whole network. This provides the physical basis for the cross-state apparent admittance expressions in Equations (5) and (6).

By defining the cross-state ZSV variation as $\Delta \dot{U}_0 = \dot{U}_0^{\text{II}} - \dot{U}_0^{\text{I}}$, where the superscript II denotes the post-fault state, the source voltage terms $\dot{E}_X$ remain invariant during the transition and can be analytically eliminated. For a healthy feeder m , the cross-state apparent admittance is obtained by subtracting Equation (2) from Equation (3):

$$Y_{\text{app},m}^{\text{I} \rightarrow \text{II}} = 3 \frac{\dot{I}_{0m}^{\text{II}} - \dot{I}_{0m}^{\text{I}}}{\dot{U}_0^{\text{II}} - \dot{U}_0^{\text{I}}} = \sum_{X=A,B,C} (g_{Xm} + j\omega C_{Xm}) = Y_{\Sigma m}^{(0)} \quad (5)$$

where $Y_{\text{app},m}^{\text{I} \rightarrow \text{II}}$ is the cross-state apparent admittance of healthy feeder m , and $Y_{\Sigma m}^{(0)}$ is the inherent zero-sequence line-to-ground admittance of feeder m . Equation (5) demonstrates that the cross-state operator acts as a structural decoupling filter, effectively removing the influence of both the NPDV and the source voltages to recover the physical line parameters.

The construction of the cross-state apparent admittance is based on the voltage-current variation comparison mechanism reported in previous studies [13,14]. In this work, this mechanism is adapted to a 35 kV Y/Y/ Δ transformer-based resonant-grounded network considering upstream zero-sequence coupling and limited practical measurement availability.

For the faulted feeder p , applying the same operation to Equation (4) yields:

$$Y_{\text{app},p}^{\text{I} \rightarrow \text{II}} = 3 \frac{\dot{I}_{0p}^{\text{II}} - \dot{I}_{0p}^{\text{I}}}{\dot{U}_0^{\text{II}} - \dot{U}_0^{\text{I}}} = \sum_{X=A,B,C} (g_{Xp} + j\omega C_{Xp}) + \frac{1}{R_f} \frac{\dot{E}_F + \dot{U}_0^{\text{II}}}{\dot{U}_0^{\text{II}} - \dot{U}_0^{\text{I}}} = Y_{\Sigma p}^{(0)} + \frac{1}{R_f} \frac{\dot{E}_F + \dot{U}_0^{\text{II}}}{\dot{U}_0^{\text{II}} - \dot{U}_0^{\text{I}}} \quad (6)$$

where $Y_{\text{app},p}^{\text{I} \rightarrow \text{II}}$ is the cross-state apparent admittance of the faulted feeder, and $Y_{\Sigma p}^{(0)}$ is the inherent zero-sequence line-to-ground admittance of feeder p . The second term on the right-hand side represents the apparent admittance contribution introduced by the fault branch.

In the faulted feeder's response, the apparent admittance is no longer a simple representation of the line parameters. It includes a residual term where the fault resistance R_f is nonlinearly coupled with the ZSV shift. Since $\dot{U}_0^{\text{II}}$ is itself a function of R_f and the total system asymmetry, the residual term ostensibly presents a significant challenge for stable feeder identification.

2.3. System-Level Analytical Decoupling of Fault Resistance

Although Equation (6) explicitly contains R_f in its denominator, numerical simulations often empirically suggest that the overall apparent admittance trajectory remains stable regardless of R_f . To provide a strict analytical proof for this phenomenon and completely

eliminate R_f from the expression, the topological relationship of the entire distribution network must be investigated via Kirchhoff's Current Law (KCL).

Let n be the number of feeders in the distribution network. The total aggregated phase-to-ground admittance of phase X is denoted as $Y_{\Sigma X}$, where $X \in \{A, B, C\}$. For example, $Y_{\Sigma A} = \sum_{k=1}^n (g_{Ak} + j\omega C_{Ak})$. In the pre-fault steady state (State I), the sum of all zero-sequence currents injected into the neutral point and the lines equals zero:

$$\dot{U}_0^I \left(\frac{1}{j\omega L} + k_T^2 Y_{110} \right) + \sum_{X \in \{A, B, C\}} (\dot{E}_X + \dot{U}_0^I) Y_{\Sigma X} = 0 \quad (7)$$

During the SLG fault on phase F (State II), the fault branch introduces an additional current leakage path. The global KCL equation is updated to:

$$\dot{U}_0^{II} \left(\frac{1}{j\omega L} + k_T^2 Y_{110} \right) + \sum_{X \in \{A, B, C\}} (\dot{E}_X + \dot{U}_0^{II}) Y_{\Sigma X} + \frac{\dot{E}_F + \dot{U}_0^{II}}{R_f} = 0 \quad (8)$$

By analytically subtracting Equation (7) from Equation (8), the nominal source voltages $\dot{E}_X$ are entirely eliminated from the system-level equations. This subtraction isolates the pure cross-state relationship:

$$(\dot{U}_0^{II} - \dot{U}_0^I) \left(\frac{1}{j\omega L} + k_T^2 Y_{110} \right) + \sum_{X \in \{A, B, C\}} (\dot{U}_0^{II} - \dot{U}_0^I) Y_{\Sigma X} + \frac{\dot{E}_F + \dot{U}_0^{II}}{R_f} = 0 \quad (9)$$

By reorganizing Equation (9) and factoring out the cross-state ZSV variation $\Delta \dot{U}_0 = \dot{U}_0^{II} - \dot{U}_0^I$, we can explicitly solve for the highly nonlinear fractional residual term present in Equation (6):

$$\frac{1}{R_f} \frac{\dot{E}_F + \dot{U}_0^{II}}{\dot{U}_0^{II} - \dot{U}_0^I} = - \left[\frac{1}{j\omega L} + k_T^2 Y_{110} + \sum_{X \in \{A, B, C\}} Y_{\Sigma X} \right] \quad (10)$$

where the left-hand side is the fault-branch residual term in the apparent admittance expression of the faulted feeder.

Substituting Equation (10) back into the apparent admittance of the faulted feeder (Equation (6)) yields the final analytical expression:

$$Y_{app,p}^{I \rightarrow II} = Y_{\Sigma p}^{(0)} - \left[\frac{1}{j\omega L} + k_T^2 Y_{110} + \sum_{X \in \{A, B, C\}} \sum_{k=1}^n (g_{Xk} + j\omega C_{Xk}) \right] \quad (11)$$

where the bracketed term represents the global zero-sequence structural admittance, including the ASC admittance, the reflected 110 kV zero-sequence admittance, and the total phase-to-ground admittance of all feeders.

Equation (11) shows that, after the KCL-based algebraic reduction, the fault resistance R_f and the actual fault boundary terms are eliminated from the final expression. The apparent admittance of the faulted feeder is therefore decoupled from R_f and is determined by its own physical admittance $Y_{\Sigma p}^{(0)}$ and a system-level structural term composed of the equivalent ASC parameter, the transferred 110 kV admittance, and the total system leakage conductances and capacitances. Geometrically, this structural term shifts the apparent admittance of the faulted feeder away from the healthy-feeder region described by Equation (5), thereby transforming the original nonlinear estimation problem into a structural recognition problem in the complex admittance plane.

3. Approximate Faulted Feeder Identification Criterion and Practical Implementation

3.1. Quadrant-Based Identification Criterion in the Complex Plane

According to Equations (5) and (11), healthy feeders retain positive line-to-ground admittance and remain in the first quadrant, whereas the faulted feeder contains a negative structural offset and is shifted to the second or third quadrant depending on the ASC compensation state. Its mathematical derivation is provided in Appendix A. Therefore, under the practical measurement configuration described above, the approximate feeder identification criterion can be expressed by the conductance component of the cross-state apparent admittance:

$$\begin{cases} G_{app,p} > 0, B_{app,p} > 0, & \text{healthy feeder,} \\ G_{app,p} < 0, & \text{faulted feeder.} \end{cases} \quad (12)$$

Equivalently, when the phase angle is expressed in the positive-angle range $[0^\circ, 360^\circ)$, healthy feeders satisfy $0^\circ < \angle Y_{app,p}^{I \rightarrow II} < 90^\circ$, whereas the faulted feeder satisfies $90^\circ < \angle Y_{app,p}^{I \rightarrow II} < 270^\circ$.

The compensation state is determined by the relationship between the ASC inductive current I_L and the total network capacitive current I_C . The cases $I_L < I_C$ and $I_L > I_C$ correspond to under-compensation and over-compensation, respectively, resulting in opposite signs of the imaginary component of the global zero-sequence structural admittance. Accordingly, the faulted feeder is mapped to different quadrants under the two compensation states.

To visually demonstrate the effectiveness of the proposed phase-angle-based criterion, the distributions of the cross-state apparent admittance for healthy and faulted feeders under different compensation conditions are illustrated in Figure 2. As shown in the figure, the apparent admittance of healthy feeders consistently lies in the first quadrant, whereas that of the faulted feeder shifts to the second or third quadrant under different compensation conditions.

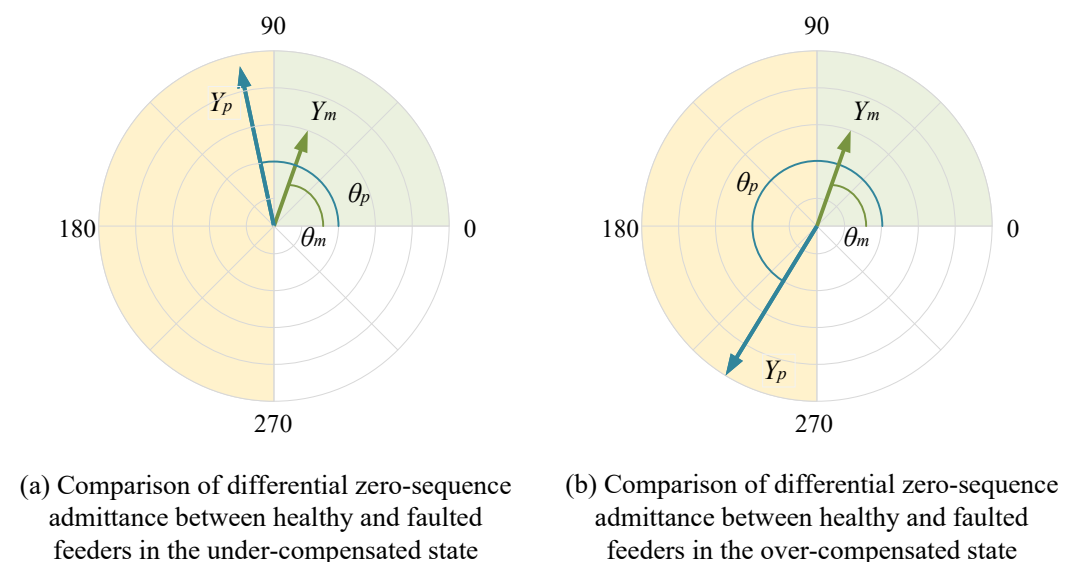


Figure 2. Comparison of cross-state apparent admittance between healthy and faulted feeders under different compensation conditions. (a) Under-compensated state. (b) Over-compensated state.

In summary, the proposed identification scheme utilizes the quadrant distribution of the apparent admittance in the complex plane. Healthy feeders are characterized by

positive conductance and positive susceptance, and thus remain in the first quadrant. In contrast, the faulted feeder exhibits negative conductance, causing its apparent admittance to move into the second or third quadrant. Therefore, the faulted feeder can be effectively distinguished from healthy feeders by examining the sign of the conductance or the phase angle of the apparent admittance.

3.2. Engineering Implementation Procedure

Based on the quadrant distribution characteristics of the apparent admittance in the complex plane, a practical faulted feeder identification scheme for single-line-to-ground faults in unbalanced distribution networks is developed. Since the proposed criterion depends on the phase relationship between the cross-state zero-sequence voltage variation and feeder zero-sequence current variation, the measurement loop must provide sufficient magnitude accuracy, phase-angle accuracy, and time consistency. In particular, protection-class CTs/PTs, such as 5P-class transformers, are mainly designed for fault-current reproduction and saturation performance, rather than high-precision phase measurement under small zero-sequence quantities. If their phase errors are superimposed with sampling or time-synchronization errors, the healthy-feeder apparent admittance angle may be shifted toward or even across the 90° quadrant boundary. Therefore, the proposed method should be implemented using measurement-class CTs/PTs or other high-accuracy synchronized acquisition channels. The overall procedure is illustrated in Figure 3, and the detailed steps are summarized as follows.

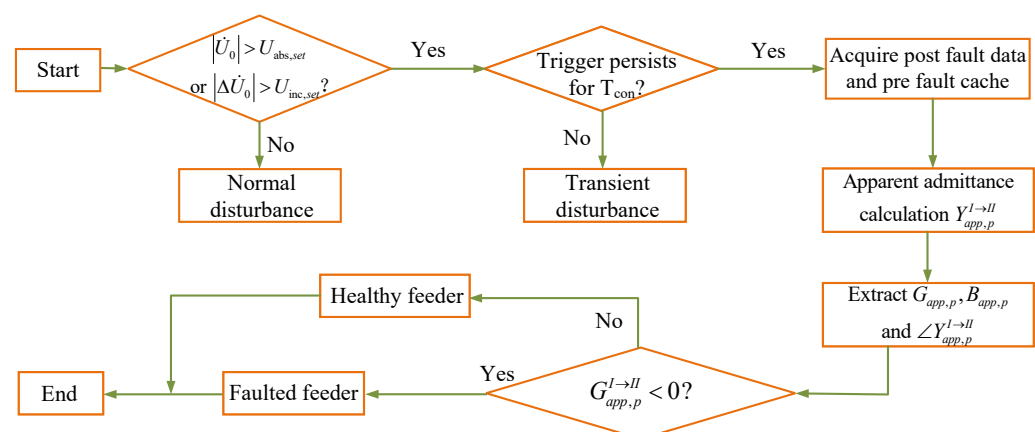


Figure 3. Flowchart of the proposed practical faulted feeder identification scheme. The startup condition is implemented by a combined triggering strategy based on the absolute zero-sequence voltage magnitude and the cross-state zero-sequence voltage increment. The triggering condition is used only for event recording and signal acquisition, whereas the final feeder identification is determined by the sign of the cross-state apparent-admittance conductance.

Step 1: Normal operation monitoring and event triggering. During normal operation, the bus zero-sequence voltage $\dot{U}_0$ and feeder zero-sequence currents $\dot{I}_{0p}$ are continuously measured. For high-impedance-fault-oriented recording, the event startup should not rely solely on a fixed absolute zero-sequence voltage threshold. Therefore, a combined triggering strategy is adopted in this study. The startup condition is satisfied when either the absolute zero-sequence voltage criterion or the incremental zero-sequence voltage criterion is met: $|\dot{U}_0| > U_{abs,set}$ or $|\Delta \dot{U}_0| > U_{inc,set}$, where $U_{abs,set}$ is the absolute zero-sequence voltage threshold for conventional ground-fault event recording, and $U_{inc,set}$ is the incremental threshold used to improve the sensitivity to weak high-impedance faults. The conventional threshold of $0.15 U_N$ can be used for ordinary ground-fault alarming, but it is not used as a fixed startup threshold for all high-resistance fault cases. The triggering condition is used only for event recording and phasor acquisition, and it

does not participate in the subsequent apparent-admittance-based feeder identification criterion. If no triggering condition is satisfied, the system is considered to operate normally, and the latest normal-state phasors are retained. Otherwise, proceed to Step 2.

Step 2: Fault confirmation and phasor acquisition. After the fault-event trigger is activated, a short blocking delay is introduced to suppress the influence of transient disturbances. The fault duration is further verified within a preset confirmation interval T_{con} , which is a configurable setting rather than a fixed constant. The zero-sequence voltage and feeder zero-sequence currents are then sampled to extract the post-fault fundamental-frequency phasors. If the abnormal zero-sequence condition persists during the confirmation window, the event is regarded as a sustained ground fault and Step 3 is executed. Otherwise, the disturbance is treated as a transient event, and the process returns to Step 1.

Step 3: Apparent admittance calculation. Once the fault is confirmed, the zero-sequence voltage and feeder currents in the post-fault cycle are acquired using standard phasor extraction algorithms, such as the Fourier transform. The pre-fault phasors used as State I are taken from the frozen stable window before the triggering instant, rather than from the data immediately adjacent to the fault confirmation instant. This avoids using a reference state that may have already been affected by an incipient high-impedance fault. Combined with the pre-fault synchronized phasor data, the apparent admittance of each feeder is calculated as:

$$Y_{\text{app},p}^{\text{I} \rightarrow \text{II}} = G_{\text{app},p} + jB_{\text{app},p} \quad (13)$$

where $G_{\text{app},p}$ and $B_{\text{app},p}$ are the conductance and susceptance components of $Y_{\text{app},p}^{\text{I} \rightarrow \text{II}}$, respectively.

Step 4: Feature extraction. The apparent admittance is decomposed into its conductance $G_{\text{app},p}$ and susceptance $B_{\text{app},p}$ components, and the phase angle $\angle Y_{\text{app},p}^{\text{I} \rightarrow \text{II}}$ is calculated to determine its position in the complex plane.

Step 5: Faulted feeder identification. According to the conductance-sign criterion derived from the quadrant distribution, feeders are classified as follows:

- If $G_{\text{app},p} > 0$ and the apparent admittance remains in the first quadrant, the feeder is identified as healthy;
- If $G_{\text{app},p} < 0$, the feeder is identified as faulted, because its apparent admittance is shifted to the second or third quadrant depending on the compensation state.

Equivalently, when the phase angle is expressed in the positive-angle range $[0^\circ, 360^\circ)$, the faulted feeder satisfies $90^\circ < \angle Y_{\text{app},p}^{\text{I} \rightarrow \text{II}} < 270^\circ$.

Remark on pre-fault reference selection. The proposed cross-state apparent admittance depends on the difference between the post-fault state and the pre-fault reference state. Therefore, the quality of the pre-fault reference is important in practical implementation. For a slowly developing high-impedance fault, directly updating the pre-fault cache at every cycle may incorporate weak fault components into the reference state and reduce the effective cross-state variation. To avoid this issue, the cache update is blocked once an abnormal trend of $\dot{U}_0$ or $\dot{I}_{0p}$ is detected. The final pre-fault reference is selected from the last stable window before the trigger. This cache-freezing strategy improves the robustness of the proposed method against incipient or slowly evolving high-impedance faults.

In summary, the proposed scheme forms a closed-loop process integrating state monitoring, stable pre-fault reference selection, fault confirmation, admittance calculation, and feeder identification. By clarifying the adjustable event-triggering threshold and adopting the cache-freezing strategy, the method reduces the risk of reference contamination under incipient or slowly evolving high-impedance faults. By exploiting the negative conductance characteristic of the faulted feeder, the method maintains stable classification performance under the tested fault-resistance conditions, provided that the stated measurement accuracy requirements are satisfied.

4. Simulation Verification Based on a Practical Substation Model

4.1. Practical Substation Model and Simulation Setup

To evaluate the effectiveness and applicability of the proposed approximate passive identification method, a comprehensive 35 kV distribution network model was established using the PSCAD/EMTDC software, version 4.6.3 environment, as illustrated in Figure 4. Importantly, this simulation model is built based on the real architecture and actual line parameters of a practical 35 kV substation, ensuring that the verification reflects true engineering conditions.

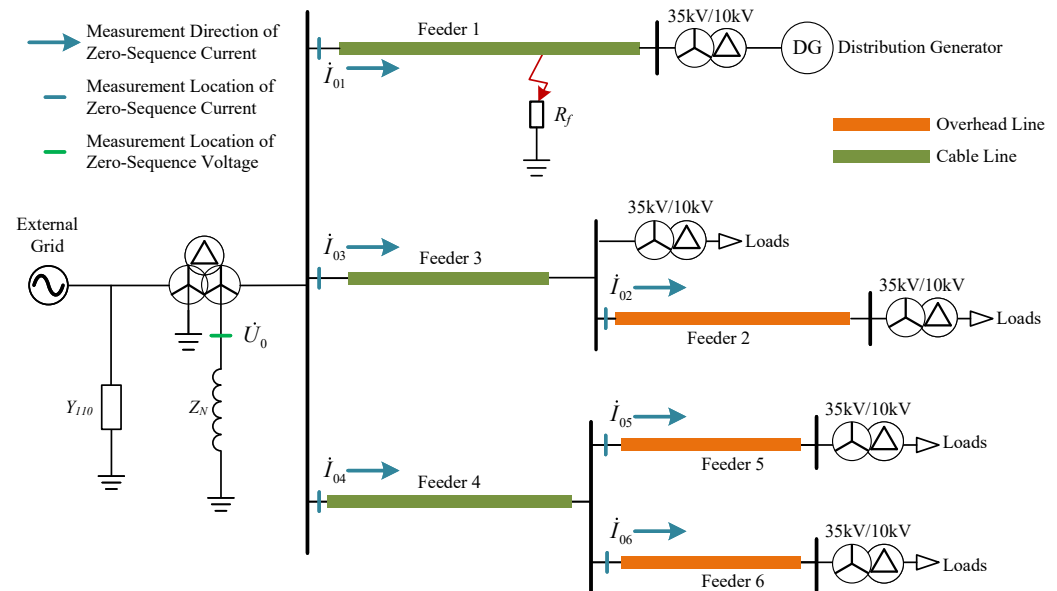


Figure 4. Simulation model of the 35 kV asymmetric distribution network established in PSCAD/EMTDC based on practical substation parameters. The measurement location of the bus zero-sequence voltage $\dot{U}_0$, the measurement locations of feeder zero-sequence currents $\dot{I}_{01}$ – $\dot{I}_{06}$, and the positive current measurement directions are explicitly marked. The zero-sequence voltage is measured at the 35 kV bus, and the feeder zero-sequence currents are measured at the sending ends of the corresponding feeders, with the positive direction defined from the bus toward each feeder.

The simulated system comprises six feeders L1 to L6 with a hybrid configuration of overhead lines and underground cables. A distributed generator DG is integrated into Feeder 1 to emulate active distribution network characteristics. Each feeder supplies local loads through 35 kV/10 kV step-down transformers. The network is energized by an external equivalent grid, and the neutral point of the main transformer is grounded through an arc suppression coil ASC.

The main electrical parameters of the source, main transformer, and feeders used in the PSCAD/EMTDC model are listed in Tables 1 and 2. These parameters define the external grid equivalent, transformer impedance, and feeder sequence characteristics required for reproducing the zero-sequence voltage and current responses at the 35 kV bus.

All feeders are modeled in PSCAD/EMTDC according to the equivalent sequence parameters listed in Table 2. The frequency-dependent distributed parameter model is adopted to capture both transient and steady-state responses. To emulate the inherent structural asymmetry of practical distribution systems, the phase-to-ground capacitances are assigned with random deviations ranging from 1% to 5% around the equivalent capacitance parameters. This setting preserves the unbalanced zero-sequence admittance characteristics required for validating the proposed cross-state apparent admittance method.

Table 1. Simulation parameters of the source and main transformer.

Component	Parameter	Value
Source	Rated line voltage/kV	110
Source	System frequency/Hz	50
Source	Equivalent resistance/ Ω	0.8929
Source	Equivalent reactance/ Ω	5.21
Main transformer	Rated capacity/MVA	250
Main transformer	Voltage level/kV	110/35/10
Main transformer	Winding resistance/p.u.	0.002
Main transformer	Leakage reactance/p.u.	0.08

Table 2. Equivalent sequence parameters of the feeders used in the PSCAD/EMTDC model.

Parameter	Unit	L1	L2	L3	L4	L5	L6
Line type	–	Cable	Overhead line	Cable	Cable	Overhead line	Overhead line
R_1	Ω	2.70	1.70	6.75	2.70	1.70	1.70
X_1	Ω	0.801	3.478	2.003	0.801	3.478	3.478
C_1	μF	3.760	1.150	9.400	3.760	1.150	1.150
R_0	Ω	27.00	3.20	67.50	27.00	3.20	3.20
X_0	Ω	3.484	11.184	8.710	3.484	11.184	11.184
C_0	μF	2.760	0.062	6.900	2.760	0.062	0.062

To comprehensively evaluate the robustness of the proposed criterion, diverse fault scenarios were simulated. Single-line-to-ground faults were applied to Feeder 1 at $t = 0.3$ s. The test matrix includes varying fault resistances $R_f \in \{50 \Omega, 1 \text{ k}\Omega, 10 \text{ k}\Omega\}$ and two neutral grounding compensation modes, namely the under-compensated state and the over-compensated state.

4.2. Performance Evaluation and Analysis

4.2.1. Transient and Steady-State Responses of Zero-Sequence Quantities

A series of simulations were conducted under the aforementioned scenarios. The steady-state zero-sequence voltage and zero-sequence current phasors were extracted before and after the fault. The raw electrical quantities and the corresponding apparent admittances are summarized in Tables 3 and 4.

As evidenced by the pre-fault columns in Tables 3 and 4, the system exhibits a noticeable steady-state neutral point displacement voltage before fault inception. For example, $\dot{U}_0 = -316.1 - j56.9$ V in the under-compensated state and $\dot{U}_0 = -964.1 - j677.8$ V in the over-compensated state. This directly reflects the inherent asymmetry introduced by the 1% to 5% capacitance deviation and confirms the theoretical premise of the pre-fault state.

Figures 5 and 6 show the dynamic responses of zero-sequence voltage magnitude and phase together with the magnitudes and phases of feeder zero-sequence currents under the low-resistance fault condition $R_f = 50 \Omega$. In both compensation modes, the fault causes a rapid increase in the zero-sequence voltage magnitude after fault inception, and the current responses of the feeders become clearly differentiated. The faulted feeder exhibits a pronounced deviation in both magnitude and phase, indicating that the fault signature is sufficiently strong under low-resistance conditions.

Table 3. Zero-sequence voltage and current before and after fault under under-compensation.

R_f/Ω	Feeder	$\dot{U}_0$ Pre/V	$\dot{U}_0$ Post/V	$\dot{I}_0$ Pre/A	$\dot{I}_0$ Post/A
50	L1	$-316.1 - j56.9$	$-14,737.2 + j4210.8$	$0.0 + j0.1$	$5.5 + j6.5$
	L2			$-0.3 - j0.2$	$-0.6 - j0.8$
	L3			$0.1 - j1.1$	$-11.3 - j32.8$
	L4			$0.1 - j0.1$	$-8.5 - j25.8$
	L5			$0.0 - j0.0$	$-0.1 - j0.3$
	L6			$0.0 - j0.0$	$-0.1 - j0.3$
1000	L1	$-316.1 - j56.9$	$-989.5 + j2175.3$	$0.0 + j0.1$	$1.3 - j0.0$
	L2			$-0.3 - j0.2$	$-0.4 - j0.3$
	L3			$0.1 - j1.1$	$-5.0 - j2.3$
	L4			$0.1 - j0.1$	$-4.0 - j1.2$
	L5			$0.0 - j0.0$	$-0.0 - j0.0$
	L6			$0.0 - j0.0$	$-0.0 - j0.0$
10,000	L1	$-316.1 - j56.9$	$-361.1 + j180.6$	$0.0 + j0.1$	$0.2 + j0.1$
	L2			$-0.3 - j0.2$	$-0.4 - j0.2$
	L3			$0.1 - j1.1$	$-0.5 - j1.2$
	L4			$0.1 - j0.1$	$-0.3 - j0.2$
	L5			$0.0 - j0.0$	$-0.0 - j0.0$
	L6			$0.0 - j0.0$	$-0.0 - j0.0$

Table 4. Zero-sequence voltage and current before and after fault under over-compensation.

R_f/Ω	Feeder	$\dot{U}_0$ Pre/V	$\dot{U}_0$ Post/V	$\dot{I}_0$ Pre/A	$\dot{I}_0$ Post/A
50	L1	$-964.1 - j677.8$	$-15,878.0 - j207.8$	$1.1 - j1.1$	$4.6 - j19.8$
	L2			$-0.3 - j0.3$	$-0.4 - j0.9$
	L3			$1.4 - j2.7$	$-1.6 - j35.9$
	L4			$1.2 - j1.3$	$-0.6 - j28.1$
	L5			$0.0 - j0.0$	$-0.0 - j0.3$
	L6			$0.0 - j0.0$	$-0.0 - j0.3$
1000	L1	$-964.1 - j677.8$	$-5909.0 + j3155.0$	$1.1 - j1.1$	$-2.3 - j8.3$
	L2			$-0.3 - j0.3$	$-0.5 - j0.5$
	L3			$1.4 - j2.7$	$-7.8 - j13.2$
	L4			$1.2 - j1.3$	$-6.0 - j10.0$
	L5			$0.0 - j0.0$	$-0.1 - j0.1$
	L6			$0.0 - j0.0$	$-0.1 - j0.1$
10,000	L1	$-964.1 - j677.8$	$-1431.7 - j0.8$	$1.1 - j1.1$	$0.4 - j1.8$
	L2			$-0.3 - j0.3$	$-0.3 - j0.3$
	L3			$1.4 - j2.7$	$-0.2 - j3.6$
	L4			$1.2 - j1.3$	$-0.1 - j2.1$
	L5			$0.0 - j0.0$	$-0.0 - j0.0$
	L6			$0.0 - j0.0$	$-0.0 - j0.0$

When the fault resistance increases to 10 k Ω , the dynamic responses become much weaker. As shown in Figures 7 and 8, the post-fault variations of both zero-sequence voltage and feeder currents are significantly reduced, especially for the faulted feeder current. Under the over-compensated condition, the change in the faulted feeder current is particularly small, which is consistent with the data in Table 4. Such weak increments are easily submerged by the asymmetric background response, which explains why conventional methods based directly on raw steady-state or post-fault quantities may become less distinguishable in high-impedance fault scenarios.

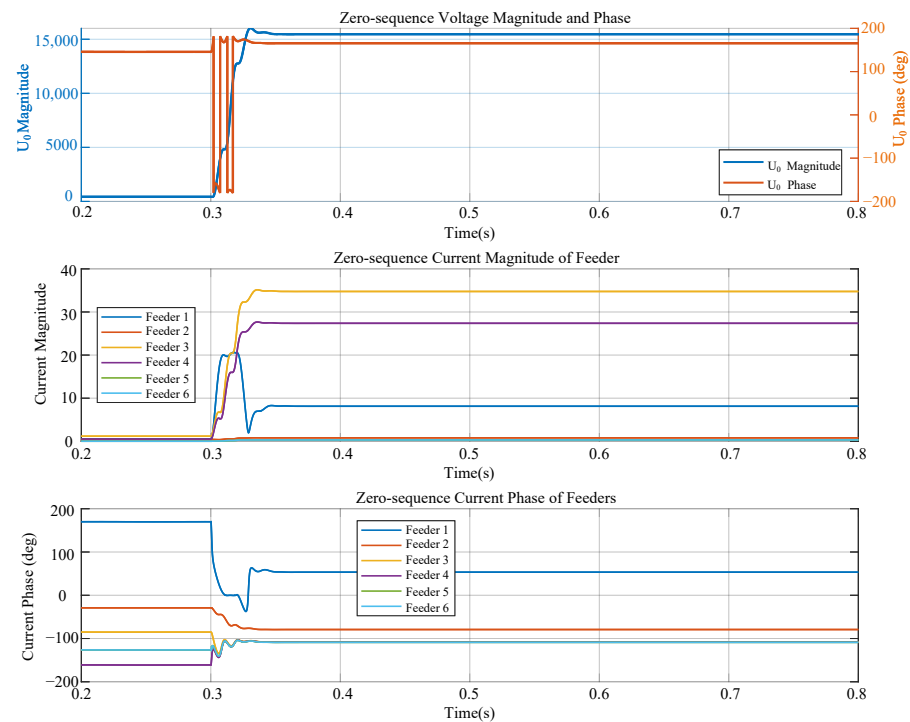


Figure 5. Dynamic responses of zero-sequence voltage and feeder zero-sequence currents in the under-compensated state with $R_f = 50 \Omega$.

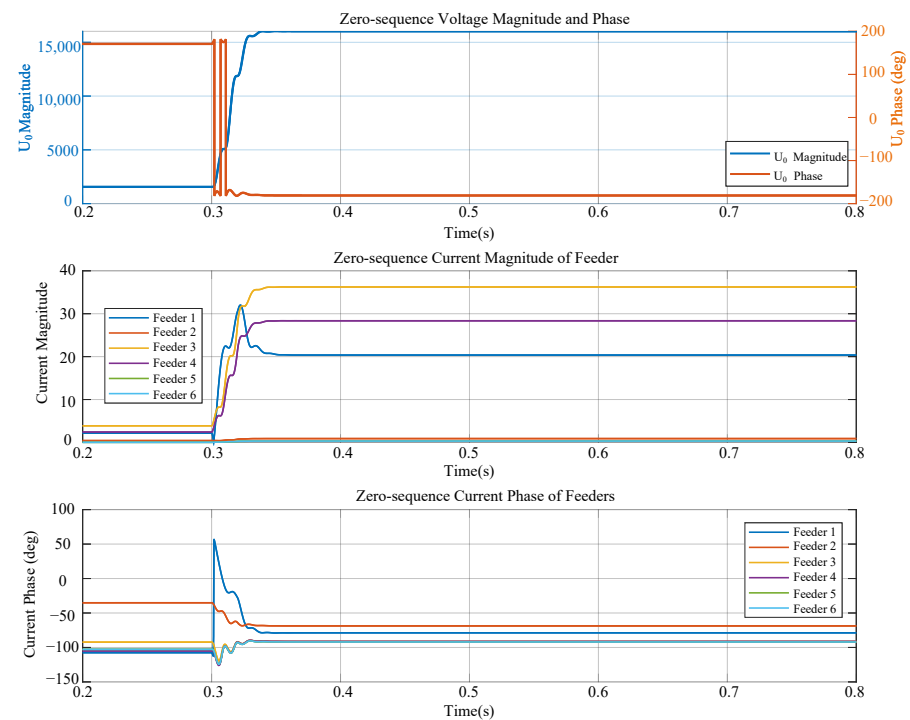


Figure 6. Dynamic responses of zero-sequence voltage and feeder zero-sequence currents in the over-compensated state with $R_f = 50 \Omega$.

The damped oscillation observed after fault inception is mainly caused by transient energy exchange among the feeder phase-to-ground capacitances, the ASC inductance, and the upstream zero-sequence network. During this short interval, the zero-sequence network changes abruptly to a fault-constrained state, and the equivalent zero-sequence impedance becomes frequency-dependent rather than equal to its fundamental-frequency steady-state value. Therefore, the proposed method extracts fundamental-frequency pha-

sors after a short blocking interval, and the transient oscillation is not directly used for feeder identification.

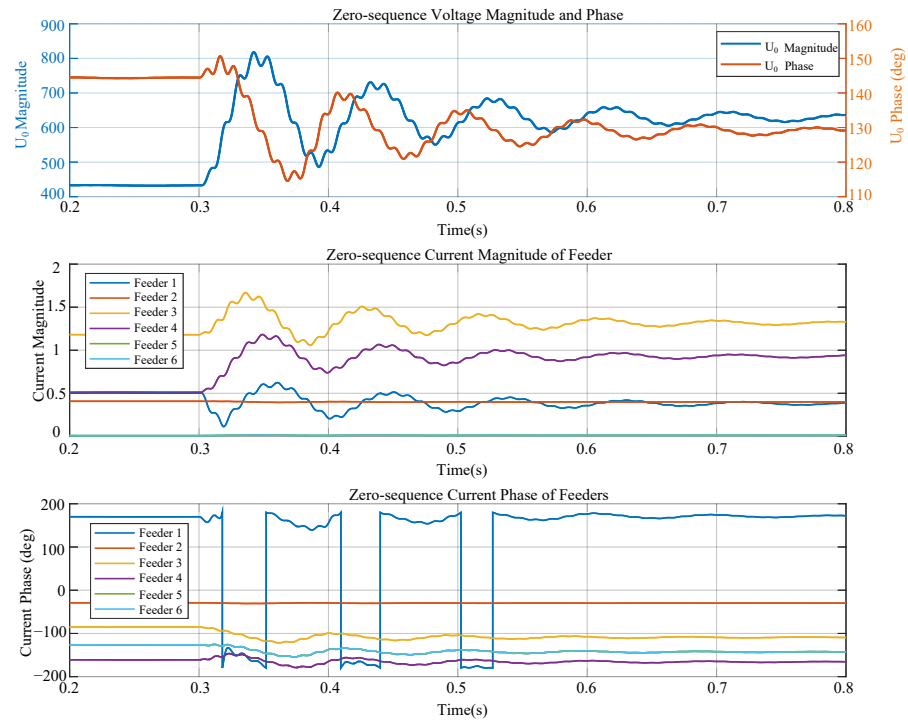


Figure 7. Dynamic responses of zero-sequence voltage and feeder zero-sequence currents in the under-compensated state with $R_f = 10 \text{ k}\Omega$.

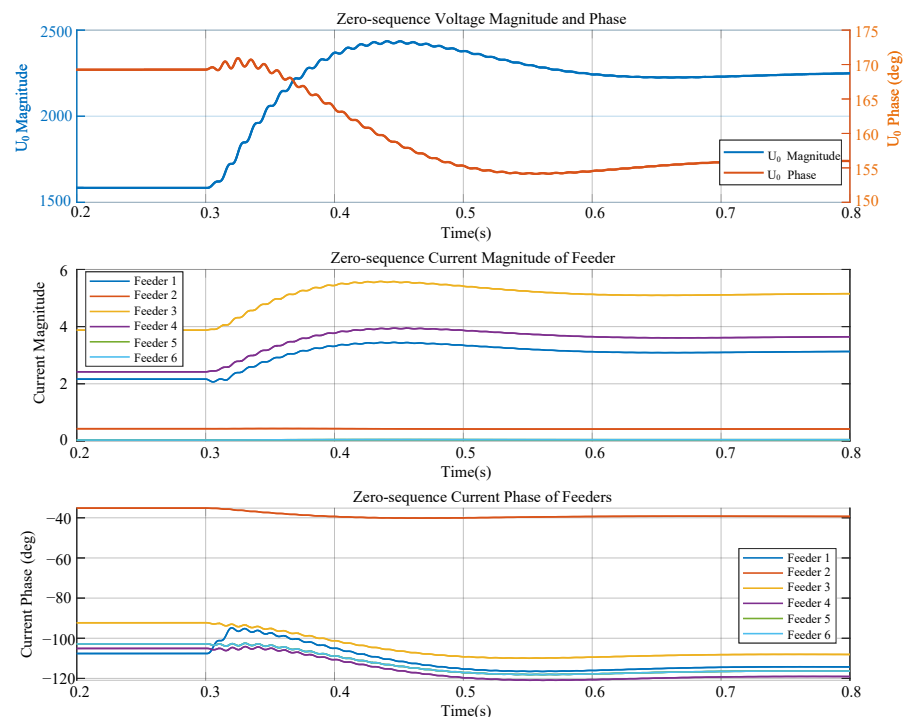


Figure 8. Dynamic responses of zero-sequence voltage and feeder zero-sequence currents in the over-compensated state with $R_f = 10 \text{ k}\Omega$.

It should be emphasized that the sending-end zero-sequence current magnitude is not a reliable indicator of the faulted feeder in resonant-grounded networks. In this paper, $\hat{I}_{0k}$ denotes the sending-end zero-sequence current of feeder k . The healthy-feeder current is mainly driven by the bus zero-sequence voltage and the feeder-to-ground capacitance.

Hence, feeders with larger zero-sequence capacitance, such as L3 and L4 in Table 2, may show larger post-fault zero-sequence currents than the faulted feeder. Therefore, the proposed method avoids direct magnitude comparison and uses the cross-state apparent admittance in the complex plane.

Therefore, the time-domain results demonstrate that the raw electrical quantities indeed contain useful fault information, but their direct discriminability decreases rapidly as the fault resistance increases. This observation further justifies the necessity of the proposed cross-state apparent admittance calculation.

4.2.2. Apparent Admittance Distribution and Identification Performance

It should be noted that the apparent admittance values reported in the following tables are calculated from the original unrounded PSCAD phasors, whereas the voltage and current phasors shown in the tables are rounded for presentation. Therefore, direct recalculation from the displayed values may lead to discrepancies, especially under high-resistance faults with small $\Delta\dot{U}_0$.

After applying the proposed cross-state operation, the raw zero-sequence responses are transformed into apparent admittances in the complex plane. Tables 5 and 6 summarize the calculated admittance values and phase angles for all feeders under different fault resistances and compensation conditions.

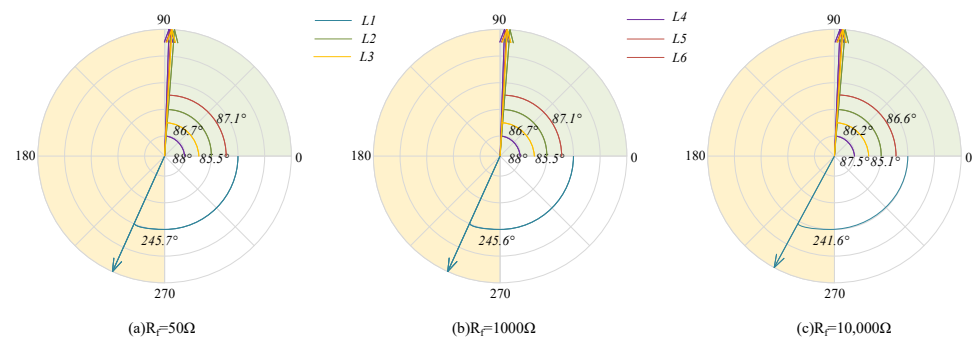
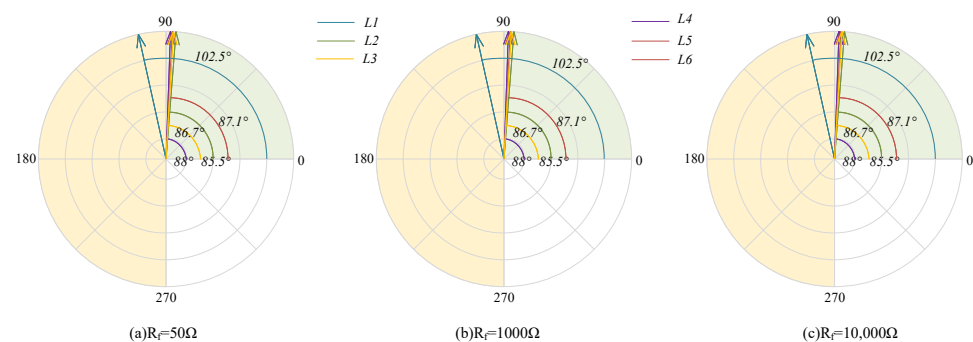
Table 5. Feeder identification results under under-compensation.

R_f/Ω	Feeder	Apparent Admittance/ μS	Phase Angle/($^\circ$)	Faulted Feeder
50	L1	$-687.7 - j1520.7$	245.7	L1
	L2	$9.5 + j121.9$	85.5	
	L3	$388.8 + j6707.1$	86.7	
	L4	$186.4 + j5397.9$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	
1000	L1	$-687.9 - j1517.4$	245.6	L1
	L2	$9.5 + j121.9$	85.5	
	L3	$389.2 + j6706.9$	86.7	
	L4	$186.7 + j5397.7$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	
10,000	L1	$-775.2 - j1434.7$	241.6	L1
	L2	$10.5 + j121.6$	85.1	
	L3	$442.9 + j6693.4$	86.2	
	L4	$230.5 + j5387.8$	87.5	
	L5	$3.0 + j58.6$	86.6	
	L6	$3.0 + j58.6$	86.6	

To visually demonstrate the spatial distribution characteristics of the proposed criterion, the phase-angle distributions of feeder apparent admittances under the under-compensated and over-compensated states are shown in Figures 9 and 10, respectively. In the under-compensated state, the faulted feeder L1 is consistently mapped to the third quadrant with phase angles around 246° to 242° , whereas all healthy feeders remain concentrated in the first quadrant with phase angles close to 85° to 88° . In the over-compensated state, the faulted feeder shifts to the second quadrant with a phase angle of approximately 102.5° , while the healthy feeders still remain in the first quadrant. Since the maximum healthy-feeder angle reaches approximately 88° , the angular margin to the 90° boundary is limited. This confirms that high-accuracy synchronized measurements are necessary for field implementation. Direct use of protection-class CTs/PTs with larger phase errors may reduce the reliability of the quadrant-based criterion.

Table 6. Feeder identification results under over-compensation.

R_f/Ω	Feeder	Apparent Admittance/ μS	Phase Angle/($^\circ$)	Faulted Feeder
50	L1	$-828.7 + j3750.4$	102.5	L1
	L2	$9.5 + j121.9$	85.5	
	L3	$388.8 + j6707.0$	86.7	
	L4	$186.4 + j5397.9$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	
1000	L1	$-828.7 + j3750.6$	102.5	L1
	L2	$9.5 + j121.9$	85.5	
	L3	$388.8 + j6706.9$	86.7	
	L4	$186.5 + j5397.9$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	
10,000	L1	$-830.3 + j3758.0$	102.5	L1
	L2	$9.6 + j121.8$	85.5	
	L3	$391.2 + j6705.1$	86.7	
	L4	$188.5 + j5396.4$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	

**Figure 9.** Phase-angle distributions of cross-state apparent admittances under the under-compensated state for different fault resistances.**Figure 10.** Phase-angle distributions of cross-state apparent admittances under the over-compensated state for different fault resistances.

These results are fully consistent with the theoretical derivation. For the healthy feeders, the apparent admittances converge to their inherent physical admittances and remain stably located in the first quadrant of the complex plane. By contrast, the apparent admittance of the faulted feeder undergoes a deterministic affine shift caused by the structural bias term derived in Section 2. Under the under-compensated condition, the network exhibits a net capacitive characteristic, and the faulted feeder is shifted into the third quadrant. Under the over-compensated condition, the network becomes inductive-dominant, and the faulted feeder is shifted into the second quadrant.

The results indicate that the proposed identification criterion remains insensitive to fault-resistance variation within the tested range. As R_f increases from 50 Ω to 10 k Ω , the phase-angle location of the faulted feeder remains within the expected quadrant, and the spatial separation between healthy and faulted feeders is preserved. Although slight numerical deviations appear under the 10 k Ω case, these deviations are very limited and do not alter the classification result. This observation agrees well with the analytical conclusion that the proposed apparent admittance of the faulted feeder is structurally independent of the fault resistance.

In summary, the simulation results verify the proposed method from both the time-domain and admittance-domain perspectives. The time-domain responses show that raw zero-sequence quantities become increasingly difficult to distinguish under high-impedance fault conditions, while the cross-state apparent admittance results demonstrate a clear and stable quadrant-based separation between healthy and faulted feeders. Therefore, the proposed method transforms the parameter-sensitive fault identification problem into a quadrant-based spatial classification problem under the stated modeling and measurement-accuracy conditions.

4.2.3. Sensitivity to Measurement Phase Errors

Since the proposed identification criterion depends on the quadrant location of the cross-state apparent admittance, the influence of measurement phase errors should be discussed. As shown by the phase-error derivation in Appendix B, the measured apparent admittance angle can be expressed as

$$\angle \tilde{Y}_{app,p}^{I \rightarrow II} = \angle Y_{app,p}^{I \rightarrow II} + \varepsilon_p \quad (14)$$

where ε_p denotes the equivalent phase error introduced by the zero-sequence voltage and current measurement channels. In this paper, the allowable total phase error is limited to

$$|\varepsilon_p| \leq 1^\circ. \quad (15)$$

According to the angular-margin condition derived in Appendix B and the results in Table 7, the maximum apparent admittance angle of the healthy feeders is approximately 88.1°. Therefore, limiting the total apparent-admittance phase error to 1° still keeps the maximum possible healthy-feeder angle at approximately 89.1°, which remains within the first quadrant. For the faulted feeder, the apparent admittance angle is approximately 102.5° in the over-compensated state and ranges from about 246° to 242° in the under-compensated state. Therefore, even considering a $\pm 1^\circ$ phase error, the faulted feeder remains in the second or third quadrant.

Table 7. Influence of 1° phase error on the quadrant-based criterion.

Feeder Type	Angle Range	Angle Range with $\pm 1^\circ$ Error	Criterion Result
Healthy feeders	85.1°–88.1°	84.1°–89.1°	First quadrant
Faulted feeder (under-compensation)	241.6°–245.7°	240.6°–246.7°	Third quadrant
Faulted feeder (over-compensation)	about 102.5°	101.5°–103.5°	Second quadrant

This analysis indicates that the proposed quadrant-based criterion remains valid when the total phase error of the measurement channel is controlled within 1°. It should also be noted that the proposed method is not recommended for uncalibrated protection-class measurement channels whose phase displacement may exceed this bound. For field appli-

cation, calibrated measurement-class CT/PT or equivalent high-precision synchronized acquisition channels should be used.

4.3. Verification Under Faults on Different Feeders

The preceding simulations were performed with the SLG fault applied to Feeder 1, where the distributed generator is connected. To further verify that the proposed criterion does not depend on the specific location of the distributed-generator feeder, an additional group of simulations was conducted by applying the SLG fault to Feeder 3. The same fault resistances, namely 50 Ω , 1 k Ω , and 10 k Ω , were considered under both under-compensated and over-compensated conditions. The pre-fault and post-fault zero-sequence voltage and current phasors were extracted in the same manner as in the previous cases, and the cross-state apparent admittance of each feeder was then calculated.

The feeder selection results under the under-compensated condition are listed in Table 8. When Feeder 3 is faulted, its apparent admittance is mapped to the third quadrant for all tested fault resistances. Specifically, the phase angles of Feeder 3 are 198.3°, 198.1°, and 189.3° for $R_f = 50 \Omega$, 1 k Ω , and 10 k Ω , respectively. In contrast, all healthy feeders remain in the first quadrant. Therefore, the proposed criterion correctly identifies L3 as the faulted feeder under the under-compensated condition.

Table 8. Feeder selection results when Feeder 3 is faulted under under-compensation.

R_f/Ω	Feeder	Apparent Admittance/ μS	Phase Angle/(°)	Faulted Feeder
50	L1	$174.7 + j5342.9$	88.1	L3
	L2	$9.6 + j121.9$	85.5	
	L3	$-473.8 - j156.5$	198.3	
	L4	$186.3 + j5397.8$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	
1000	L1	$175.0 + j5342.7$	88.1	L3
	L2	$9.6 + j121.9$	85.5	
	L3	$-473.8 - j154.7$	198.1	
	L4	$186.6 + j5397.5$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	
10,000	L1	$217.2 + j5323.3$	87.7	L3
	L2	$10.5 + j121.5$	85.0	
	L3	$-548.2 - j90.1$	189.3	
	L4	$229.2 + j5377.9$	87.6	
	L5	$3.4 + j58.5$	86.7	
	L6	$3.4 + j58.5$	86.7	

The feeder selection results under the over-compensated condition are listed in Table 9. In this case, the apparent admittance of the faulted Feeder 3 is located in the second quadrant, with a phase angle of approximately 96.9° for all tested fault resistances. The apparent admittances of the healthy feeders remain in the first quadrant, and their phase angles are still lower than 90°. Hence, the proposed method also correctly identifies L3 as the faulted feeder under the over-compensated condition.

Table 9. Feeder selection results when Feeder 3 is faulted under over-compensation.

R_f/Ω	Feeder	Apparent Admittance/ μS	Phase Angle/($^\circ$)	Faulted Feeder
50	L1	$174.8 + j5343.1$	88.1	L3
	L2	$9.5 + j121.9$	85.5	
	L3	$-614.6 + j5114.3$	96.9	
	L4	$186.4 + j5397.9$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	
1000	L1	$174.8 + j5343.1$	88.1	L3
	L2	$9.6 + j121.9$	85.5	
	L3	$-614.6 + j5114.4$	96.9	
	L4	$186.4 + j5397.9$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	
10,000	L1	$176.4 + j5341.1$	88.1	L3
	L2	$9.6 + j121.8$	85.5	
	L3	$-615.1 + j5120.6$	96.9	
	L4	$188.0 + j5395.9$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	

The above results demonstrate that the proposed cross-state apparent admittance criterion is not limited to the distributed-generator feeder. When the fault occurs on Feeder 3, the faulted feeder still exhibits a negative conductance component and is separated from the healthy feeders in the complex admittance plane. The identification results remain correct under both compensation modes and across the tested fault-resistance range. This verifies the applicability of the proposed method to faults occurring on different feeders.

4.4. Influence of Evolving Faults on Feeder Selection

In practical distribution networks, high-impedance ground faults may not always appear as abrupt and isolated events. A weak ground leakage may first occur and remain in the system for a short period, and another single-line-to-ground fault may subsequently develop under this abnormal operating condition. In such a scenario, the pre-fault reference state used in the cross-state calculation may already contain a weak zero-sequence disturbance. Therefore, it is necessary to verify whether the proposed method can still maintain correct feeder selection when the reference state is affected by a weak high-impedance fault signal.

To evaluate this issue, an evolving-fault scenario was further simulated. In this test, a 10 k Ω high-impedance ground fault was first applied to Feeder 1 to emulate a weak fault component existing in the system. Then, another single-line-to-ground fault was applied under this disturbed operating condition. The cross-state apparent admittance was calculated using the disturbed state as the reference state and the developed fault state as the post-fault state. Both under-compensated and over-compensated operating conditions were considered. The corresponding zero-sequence voltage and feeder zero-sequence current phasors are listed in Tables 10 and 11, and the feeder selection results are summarized in Tables 12 and 13.

As shown in Tables 12 and 13, the faulted feeder can still be correctly identified as Feeder 1 under both compensation modes. Under the under-compensated condition, the apparent admittance of Feeder 1 remains in the third quadrant, with phase angles ranging from 245.7 $^\circ$ to 243.3 $^\circ$. By contrast, all healthy feeders remain in the first quadrant, with positive conductance and positive susceptance. Under the over-compensated condi-

tion, the apparent admittance of Feeder 1 remains in the second quadrant, with a phase angle of approximately 102.5° , whereas the healthy feeders still stay in the first quadrant.

These results indicate that the weak high-impedance fault component existing in the reference state does not change the essential quadrant distribution of the cross-state apparent admittance. Although the pre-fault zero-sequence voltage and feeder zero-sequence currents are no longer identical to those in a completely normal operating state, the cross-state calculation still extracts the incremental admittance characteristic caused by the developed fault. Therefore, the proposed method remains effective when a weak high-impedance ground fault evolves into a more severe single-line-to-ground fault.

Table 10. Zero-sequence voltage and current before and after the evolving fault under under-compensation.

R_f/Ω	Feeder	$\dot{U}_0$ Pre/V	$\dot{U}_0$ Post/V	$\dot{I}_0$ Pre/A	$\dot{I}_0$ Post/A
50	L1	$-351.0 + j254.8$	$-14,864.5 + j4227.9$	$-0.5 + j0.1$	$4.8 + j6.5$
	L2			$0.4 - j0.2$	$0.1 - j0.8$
	L3			$0.1 - j1.2$	$-10.7 - j33.1$
	L4			$-0.5 - j0.2$	$-8.5 - j26.0$
	L5			$-0.0 - j0.0$	$-0.1 - j0.3$
	L6			$-0.0 - j0.0$	$-0.1 - j0.3$
1000	L1	$-351.0 + j254.8$	$-1168.4 + j2674.8$	$-0.5 + j0.1$	$0.9 - j0.1$
	L2			$0.4 - j0.2$	$0.3 - j0.2$
	L3			$0.1 - j1.2$	$-5.4 - j2.7$
	L4			$-0.5 - j0.2$	$-4.9 - j1.5$
	L5			$-0.0 - j0.0$	$-0.1 - j0.0$
	L6			$-0.0 - j0.0$	$-0.1 - j0.0$
10,000	L1	$-351.0 + j254.8$	$-452.3 + j723.8$	$-0.5 + j0.1$	$-0.2 + j0.0$
	L2			$0.4 - j0.2$	$0.3 - j0.2$
	L3			$0.1 - j1.2$	$-1.0 - j1.3$
	L4			$-0.5 - j0.2$	$-1.3 - j0.3$
	L5			$-0.0 - j0.0$	$-0.0 - j0.0$
	L6			$-0.0 - j0.0$	$-0.0 - j0.0$

Table 11. Zero-sequence voltage and current before and after the evolving fault under over-compensation.

R_f/Ω	Feeder	$\dot{U}_0$ Pre/V	$\dot{U}_0$ Post/V	$\dot{I}_0$ Pre/A	$\dot{I}_0$ Post/A
50	L1	$-1564.8 + j303.3$	$-16,002.9 - j211.7$	$-0.7 - j2.1$	$4.0 - j20.0$
	L2			$0.4 - j0.2$	$0.3 - j0.8$
	L3			$-0.2 - j3.9$	$-0.9 - j36.2$
	L4			$-0.6 - j2.3$	$-0.6 - j28.4$
	L5			$-0.0 - j0.0$	$-0.0 - j0.3$
	L6			$-0.0 - j0.0$	$-0.0 - j0.3$
1000	L1	$-1564.8 + j303.3$	$-7014.1 + j3774.7$	$-0.7 - j2.1$	$-3.5 - j9.8$
	L2			$0.4 - j0.2$	$0.2 - j0.5$
	L3			$-0.2 - j3.9$	$-8.6 - j15.6$
	L4			$-0.6 - j2.3$	$-7.2 - j11.9$
	L5			$-0.0 - j0.0$	$-0.1 - j0.1$
	L6			$-0.0 - j0.0$	$-0.1 - j0.1$
10,000	L1	$-1564.8 + j303.3$	$-2576.7 + j1472.8$	$-0.7 - j2.1$	$-1.8 - j3.7$
	L2			$0.4 - j0.2$	$0.3 - j0.3$
	L3			$-0.2 - j3.9$	$-2.9 - j6.0$
	L4			$-0.6 - j2.3$	$-2.8 - j4.1$
	L5			$-0.0 - j0.0$	$-0.0 - j0.0$
	L6			$-0.0 - j0.0$	$-0.0 - j0.0$

Table 12. Feeder selection results of the evolving fault under under-compensation.

R_f/Ω	Feeder	Apparent Admittance/ μS	Phase Angle/(°)	Faulted Feeder
50	L1	$-687.9 - j1520.7$	245.7	L1
	L2	$9.6 + j121.9$	85.5	
	L3	$388.9 + j6707.1$	86.7	
	L4	$186.4 + j5397.9$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	
1000	L1	$-688.0 - j1519.0$	245.6	L1
	L2	$9.6 + j121.9$	85.5	
	L3	$389.0 + j6707.0$	86.7	
	L4	$186.6 + j5397.8$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	
10,000	L1	$-742.1 - j1477.1$	243.3	L1
	L2	$10.1 + j121.7$	85.2	
	L3	$421.7 + j6697.9$	86.4	
	L4	$213.2 + j5391.0$	87.7	
	L5	$3.2 + j58.6$	86.8	
	L6	$3.2 + j58.6$	86.8	

Table 13. Feeder selection results of the evolving fault under over-compensation.

R_f/Ω	Feeder	Apparent Admittance/ μS	Phase Angle/(°)	Faulted Feeder
50	L1	$-828.7 + j3750.4$	102.5	L1
	L2	$9.5 + j121.9$	85.5	
	L3	$388.8 + j6707.0$	86.7	
	L4	$186.4 + j5397.9$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	
1000	L1	$-828.7 + j3750.5$	102.5	L1
	L2	$9.5 + j121.9$	85.5	
	L3	$388.8 + j6706.9$	86.7	
	L4	$186.5 + j5397.9$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	
10,000	L1	$-829.3 + j3754.8$	102.5	L1
	L2	$9.6 + j121.8$	85.5	
	L3	$390.1 + j6705.7$	86.7	
	L4	$187.5 + j5396.9$	88.0	
	L5	$3.0 + j58.7$	87.1	
	L6	$3.0 + j58.7$	87.1	

4.5. Applicability and Limitations

The applicability of the proposed approximate method is supported by the analytical formulation and simulation results under the tested conditions. The system-level KCL reduction shows that the apparent admittance of the faulted feeder is independent of the fault resistance, which accounts for the stable identification performance over a wide range of R_f . The simulation results further verify the effectiveness of the criterion under both under-compensated and over-compensated states, different faulted feeders, and evolving-fault conditions.

The proposed method uses fundamental-frequency zero-sequence phasors and does not require intentional neutral-point regulation during the feeder identification stage.

The cross-state formulation is designed to reduce the influence of pre-fault neutral displacement and feeder asymmetry under the tested modeling conditions. Its practical applicability depends on sufficiently accurate synchronized zero-sequence voltage and current phasors.

The main limitation of the proposed method is its sensitivity to measurement-location inconsistency and phase-angle errors. Since the calculated apparent admittance is constructed from non-coincident zero-sequence voltage and current measurements, it should be regarded as an approximate identification quantity rather than an exact local admittance. When the healthy-feeder admittance angle is close to the 90° decision boundary, CT/PT phase displacement, sampling-time error, and phasor extraction error may reduce the angular margin and lead to incorrect classification.

5. Conclusions

This paper proposes a practical approximate passive identification method for single-line-to-ground faults in asymmetric 35 kV resonant-grounded distribution networks. By exploiting the structural properties of cross-state apparent admittances, the proposed approach addresses the longstanding challenges of high-impedance fault detection and inherent system unbalance. The main conclusions are drawn as follows:

1. **Analytical Decoupling of Fault Resistance:** The analytical formulation shows that, under the adopted zero-sequence network model, the faulted-feeder apparent admittance can be expressed as a structural quantity with limited sensitivity to the tested fault-resistance variation. Instead of a parameter-dependent variable, it manifests as a deterministic affine transformation—shifting the physical admittance by a global structural bias governed by network capacitance and damping.
2. **Transformation into a Quadrant-Based Classification Task:** This theoretical property reformulates the fault identification problem into a quadrant-based spatial classification task. Under sufficiently accurate zero-sequence phasor measurement conditions, healthy feeders remain in the first quadrant, while the faulted feeder is mapped to the third quadrant under under-compensation or to the second quadrant under over-compensation.
3. **Engineering Feasibility under High-Accuracy Measurements:** The study highlights that the proposed method relies on the phase relationship of cross-state apparent admittances. Therefore, its practical implementation requires a high-accuracy synchronized measurement loop. The direct use of protection-class CTs/PTs with relatively large phase errors may reduce the angular margin of healthy feeders near the 90° boundary and may lead to incorrect classification. Measurement-class CTs/PTs or equivalent high-precision acquisition channels are recommended for field applications.

Extensive PSCAD/EMTDC simulations, based on the real architecture and parameters of a practical 35 kV substation, show that the proposed criterion maintains correct feeder identification for the tested fault-resistance range up to $10\text{ k}\Omega$ under the simulated background asymmetry and ASC compensation conditions. The method provides an approximate passive feeder identification approach for 35 kV resonant-grounded distribution networks with Y/Y/ Δ transformers. Its performance depends on accurate synchronized zero-sequence voltage and current phasor acquisition and may be affected by measurement-location inconsistency and phase-angle errors. Future deployment of PMUs, micro-PMUs, or other high-resolution synchronized measurement devices can further improve the robustness of the proposed criterion under high-resistance faults and measurement disturbances.

Author Contributions: Conceptualization, J.Y., S.W. and H.L.; methodology, J.Y. and S.W.; software, S.Y. and Y.X.; validation, J.Y., S.W., H.L. and S.Y.; formal analysis, J.Y. and H.L.; investigation, S.W. and S.Y.; resources, J.Y., S.W. and H.L.; data curation, S.W. and S.Y.; writing—original draft preparation, S.Y.; writing—review and editing, Y.X. and S.Y.; visualization, S.Y.; supervision, J.Y. and Y.X.; project administration, J.Y.; funding acquisition, J.Y. All authors have read and agreed to the published version of the manuscript.

Funding: This work is supported by the Electric Power Research Institute of Yunnan Power Grid (YNKJXM20240269) and the National Natural Science Foundation of China (52477073).

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: Authors Jindong Yang and Hongwen Liu were employed by the company Electric Power Research Institute of Yunnan Power Grid. Author Shan Wang was employed by the company Yunnan Power Grid. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Appendix A. Derivation of the Quadrant Property of the Cross-State Apparent Admittance

According to Equation (5), for a healthy feeder m , the cross-state apparent admittance is expressed as:

$$Y_{\text{app},m}^{\text{I} \rightarrow \text{II}} = Y_{\Sigma m}^{(0)} = \sum_{X=A,B,C} (g_{Xm} + j\omega C_{Xm}). \quad (\text{A1})$$

For a practical feeder, the phase-to-ground leakage conductance and capacitance satisfy:

$$g_{Xm} \geq 0 \quad (\text{A2})$$

and:

$$C_{Xm} > 0. \quad (\text{A3})$$

Therefore, the real and imaginary parts of the apparent admittance of a healthy feeder are given by:

$$G_{\text{app},m} = \sum_{X=A,B,C} g_{Xm} \geq 0 \quad (\text{A4})$$

and:

$$B_{\text{app},m} = \omega \sum_{X=A,B,C} C_{Xm} > 0. \quad (\text{A5})$$

Thus, in practical feeders with nonzero leakage conductance, the apparent admittance of a healthy feeder is located in the first quadrant. In the ideal lossless limit, it degenerates to the positive imaginary axis, which is still separated from the negative-conductance region of the faulted feeder.

According to Equation (11), for the faulted feeder p , the derived apparent admittance can be expressed as:

$$Y_{\text{app},p}^{\text{I} \rightarrow \text{II}} = Y_{\Sigma p}^{(0)} - \left[Y_N + \sum_{k=1}^n Y_{\Sigma k}^{(0)} \right] \quad (\text{A6})$$

where:

$$Y_N = \frac{1}{j\omega L} + k_T^2 Y_{110}. \quad (\text{A7})$$

Taking the real part of Equation (A6) gives:

$$G_{\text{app},p} = G_{\Sigma p}^{(0)} - \left[G_N + \sum_{k=1}^n G_{\Sigma k}^{(0)} \right]. \quad (\text{A8})$$

Since the summation includes the faulted feeder p , we have:

$$\sum_{k=1}^n G_{\Sigma k}^{(0)} = G_{\Sigma p}^{(0)} + \sum_{\substack{k=1 \\ k \neq p}}^n G_{\Sigma k}^{(0)}. \quad (\text{A9})$$

Substituting Equation (A9) into Equation (A8) yields:

$$G_{\text{app},p} = - \left[G_N + \sum_{\substack{k=1 \\ k \neq p}}^n G_{\Sigma k}^{(0)} \right]. \quad (\text{A10})$$

Because:

$$G_N \geq 0 \quad (\text{A11})$$

and:

$$G_{\Sigma k}^{(0)} \geq 0, \quad (\text{A12})$$

the conductance of the faulted feeder satisfies:

$$G_{\text{app},p} \leq 0. \quad (\text{A13})$$

If:

$$G_N + \sum_{\substack{k=1 \\ k \neq p}}^n G_{\Sigma k}^{(0)} > 0, \quad (\text{A14})$$

then:

$$G_{\text{app},p} < 0. \quad (\text{A15})$$

Appendix B. Mechanism and Derivation of the Phase-Angle Error Influence

The proposed criterion is based on the quadrant position of the measured cross-state apparent admittance. Therefore, the phase-angle errors of the voltage and current phasors directly affect the reliability of feeder identification.

The measured zero-sequence voltage and current phasors can be written as:

$$\dot{U}_{0,m}^s = \dot{U}_0^s e^{j\delta_U^s} \quad (\text{A16})$$

and:

$$\dot{I}_{0k,m}^s = \dot{I}_{0k}^s e^{j\delta_{Ik}^s}, \quad (\text{A17})$$

where:

$$s \in \{\text{I}, \text{II}\}. \quad (\text{A18})$$

The measured cross-state increments are:

$$\Delta \dot{U}_{0,m} = \dot{U}_{0,m}^{\text{II}} - \dot{U}_{0,m}^{\text{I}} \quad (\text{A19})$$

and:

$$\Delta \dot{I}_{0k,m} = \dot{I}_{0k,m}^{\text{II}} - \dot{I}_{0k,m}^{\text{I}}. \quad (\text{A20})$$

The measured apparent admittance is:

$$Y_{\text{app},k,m}^{\text{I} \rightarrow \text{II}} = 3 \frac{\Delta \dot{I}_{0k,m}}{\Delta \dot{U}_{0,m}}. \quad (\text{A21})$$

Thus, its phase angle satisfies:

$$\angle Y_{\text{app},k,m}^{I \rightarrow II} = \angle \Delta \dot{I}_{0k,m} - \angle \Delta \dot{U}_{0,m}. \quad (\text{A22})$$

The phase-angle error of the apparent admittance is defined as:

$$\varepsilon_k = (\angle \Delta \dot{I}_{0k,m} - \angle \Delta \dot{I}_{0k}) - (\angle \Delta \dot{U}_{0,m} - \angle \Delta \dot{U}_0). \quad (\text{A23})$$

Therefore:

$$|\varepsilon_k| \leq |\Delta \theta_{Ik}| + |\Delta \theta_U|, \quad (\text{A24})$$

where:

$$\Delta \theta_{Ik} = \angle \Delta \dot{I}_{0k,m} - \angle \Delta \dot{I}_{0k} \quad (\text{A25})$$

and:

$$\Delta \theta_U = \angle \Delta \dot{U}_{0,m} - \angle \Delta \dot{U}_0. \quad (\text{A26})$$

If the voltage and current channel phase errors are bounded by:

$$|\delta_U^s| \leq \delta_U \quad (\text{A27})$$

and:

$$|\delta_{Ik}^s| \leq \delta_I, \quad (\text{A28})$$

then the increment-angle deviations are bounded by:

$$|\Delta \theta_U| \leq \sin^{-1} \left(\frac{(|\dot{U}_0^{II}| + |\dot{U}_0^I|) \sin \delta_U}{|\dot{U}_0^{II} - \dot{U}_0^I|} \right) \quad (\text{A29})$$

and:

$$|\Delta \theta_{Ik}| \leq \sin^{-1} \left(\frac{(|\dot{I}_{0k}^{II}| + |\dot{I}_{0k}^I|) \sin \delta_I}{|\dot{I}_{0k}^{II} - \dot{I}_{0k}^I|} \right). \quad (\text{A30})$$

Therefore, the apparent-admittance phase-angle error satisfies:

$$|\varepsilon_k| \leq \sin^{-1} \left(\frac{(|\dot{I}_{0k}^{II}| + |\dot{I}_{0k}^I|) \sin \delta_I}{|\dot{I}_{0k}^{II} - \dot{I}_{0k}^I|} \right) + \sin^{-1} \left(\frac{(|\dot{U}_0^{II}| + |\dot{U}_0^I|) \sin \delta_U}{|\dot{U}_0^{II} - \dot{U}_0^I|} \right). \quad (\text{A31})$$

For the quadrant criterion to remain valid, the phase-angle error must be smaller than the angular margin to the decision boundary. The required condition is:

$$|\varepsilon_k| < \eta, \quad (\text{A32})$$

where:

$$\eta = \min[90^\circ - \max(\theta_h), \min(\theta_f - 90^\circ, 270^\circ - \theta_f)]. \quad (\text{A33})$$

Here, θ_h denotes the apparent-admittance angle of a healthy feeder, and θ_f denotes that of the faulted feeder.

In the tested simulation cases, the maximum healthy-feeder angle is approximately 88.1° , so the angular margin on the healthy-feeder side is approximately 1.9° . Therefore, limiting the total apparent-admittance phase-angle error to 1° preserves a conservative margin before the 90° boundary. This value is not a universal empirical constant. It is obtained from the angular separation under the tested system parameters.

This derivation also explains why the proposed method has relatively low robustness to phase-angle errors. When the cross-state voltage or current increment is small, the de-

nominator in the above error bound decreases, and the apparent-admittance angle becomes more sensitive to measurement phase errors.

References

- Barik, M.A.; Gargoom, A.; Mahmud, M.A.; Haque, M.E.; Al-Khalidi, H.; Maung Than Oo, A. A Decentralized Fault Detection Technique for Detecting Single Phase to Ground Faults in Power Distribution Systems with Resonant Grounding. *IEEE Trans. Power Deliv.* **2018**, *33*, 2462–2473. [\[CrossRef\]](#)
- Farughian, A.; Kumpulainen, L.; Kauhaniemi, K. Earth Fault Location Using Negative Sequence Currents. *Energies* **2019**, *12*, 3759. [\[CrossRef\]](#)
- Wang, Z.; Zeng, X.; Li, Z.; Yu, K.; Wu, C.; Jiang, Z.; Zhuo, C. An active voltage-type grounding fault protection method for medium-voltage distribution networks with neutral point voltage flexible regulation. *IEEE Trans. Power Deliv.* **2024**, *39*, 1538–1548. [\[CrossRef\]](#)
- Zeng, X.; Wang, Y.; Li, J.; Xiong, T. Novel Principle of Fault Arc Extinction and Feeder Protection Based on Flexible Grounding Control in Distribution Networks. *Proc. CSEE* **2012**, *32*, 137–143. [\[CrossRef\]](#)
- Zeng, X.; Li, L.; Yu, K.; Ni, Y.; Wang, Z.; Zhuo, C. A Novel Active Arc-suppression Principle by Injecting Phase Voltage into Neutral Point for Grounding Fault in Distribution Networks. *Proc. CSEE* **2023**, *43*, 2953–2966. [\[CrossRef\]](#)
- Yu, K.; Wu, C.; Zeng, X.; Xu, S.; Yang, L. Flexible voltage source grounding based active arc suppression technique for large-scale wind farm considering all collector lines. *IEEE Trans. Power Deliv.* **2025**, *41*, 56–68. [\[CrossRef\]](#)
- Ghaderi, A.; Ginn, H.L.; Mohammadpour, H.A. High Impedance Fault Detection: A Review. *Electr. Power Syst. Res.* **2017**, *143*, 376–388. [\[CrossRef\]](#)
- Tang, T.; Huang, C.; Li, Z.; Yuan, X. Identifying Faulty Feeder for Single-Phase High Impedance Fault in Resonant Grounding Distribution System. *Energies* **2019**, *12*, 598. [\[CrossRef\]](#)
- Yuan, J.; Hu, Y.; Jiao, Z. Faulty feeder detection method for SLG faults in distribution networks based on comprehensive fault characteristics across entire frequency spectrum. *Int. J. Electr. Power Energy Syst.* **2022**, *140*, 107835. [\[CrossRef\]](#)
- Wei, X.; Wang, X.; Gao, J.; Yang, D.; Wei, K.; Guo, L. Faulty Feeder Detection for Single-Phase-to-Ground Fault in Distribution Networks Based on Transient Energy and Cosine Similarity. *IEEE Trans. Power Deliv.* **2022**, *37*, 3968–3979. [\[CrossRef\]](#)
- Du, Y.; Liu, Y.; Shao, Q.; Luo, L.; Dai, J.; Sheng, G.; Jiang, X. Single Line-to-Ground Faulted Line Detection of Distribution Systems with Resonant Grounding Based on Feature Fusion Framework. *IEEE Trans. Power Deliv.* **2019**, *34*, 1766–1775. [\[CrossRef\]](#)
- Pirmani, S.K.; Mahmud, M.A. An intrinsic faulty feeder selection approach for resonant grounded power distribution networks in bushfire prone areas using zero-sequence current ratio. *IEEE Syst. J.* **2023**, *17*, 6460–6471. [\[CrossRef\]](#)
- Farajollahi, M.; Shahsavari, A.; Stewart, E.M.; Mohsenian-Rad, H. Locating the Source of Events in Power Distribution Systems Using Micro-PMU Data. *IEEE Trans. Power Syst.* **2018**, *33*, 6343–6354. [\[CrossRef\]](#)
- Izadi, M.; Mohsenian-Rad, H. A Synchronized Lissajous-Based Method to Detect and Classify Events in Synchro-Waveform Measurements in Power Distribution Networks. *IEEE Trans. Smart Grid* **2022**, *13*, 2170–2184. [\[CrossRef\]](#)
- Liu, B.; Zeng, X.; Zhang, H.; Ma, H. Distribution Characteristics of Injected Current in Feeders and Its Application in Grounding Fault Detection. *Power Syst. Technol.* **2021**, *45*, 2731–2740. [\[CrossRef\]](#)
- Lin, J.; Guo, M.; Zheng, Z. Active location method for single-line-to-ground fault of flexible grounding distribution networks. *IEEE Trans. Instrum. Meas.* **2023**, *72*, 3524712. [\[CrossRef\]](#)
- Wang, Y.; Huang, Y.; Zeng, X.; Wei, G.; Zhou, J.; Fang, T.; Chen, H. Faulty feeder detection of single phase-earth fault using grey relation degree in resonant grounding system. *IEEE Trans. Power Deliv.* **2017**, *32*, 55–61. [\[CrossRef\]](#)
- Luan, X.; Wu, S.; Jia, C.; Yang, Y.; Zhang, Z.; Luo, X. Principle of Single-phase Grounding Faulty Feeder Selection Based on Improved Zero-sequence Admittance Method. *Power Syst. Technol.* **2022**, *46*, 353–360. [\[CrossRef\]](#)
- Liu, B.; Xiang, Z.; Zeng, X.; Wan, Z.; Xiao, J. Faulty Feeder Selection Method Tolerant to Sensing Error for Asymmetrical Distribution Networks Based on Arc-suppression Component Compensation. In *Proceedings of the CSEE; Tongfang Knowledge Network Technology (Beijing) Co., Ltd.: Beijing, China, 2026*; pp. 1–12. [\[CrossRef\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.