



Automatic Fault Detection and Protection Scheme for Electrical Distribution Networks

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Abstract

Electrical distribution networks are exposed to short-circuit, earth, conductor, equipment, and high-impedance faults that can interrupt supply and damage apparatus if the abnormal condition is not detected and isolated quickly. This paper presents a methodology for an automatic fault detection and protection scheme intended for radial and moderately active distribution feeders. The proposed scheme combines continuous voltage and current acquisition with threshold-based supervision, symmetrical-component indicators, discrete-wavelet transient features, and feeder-section decision logic. A digital controller or intelligent electronic device receives conditioned CT/PT signals, calculates root-mean-square and sequence quantities, verifies the persistence of an abnormal event, classifies the fault, estimates the affected section, and issues a trip command to the associated circuit breaker. The protection logic also includes blocking criteria to prevent operation during permissible load switching and short-duration disturbances. A simulation-oriented test procedure is defined using an 11-kV feeder subjected to single-line-to-ground, line-to-line, double-line-to-ground, three-phase, high-resistance, and non-fault switching cases. Representative simulation results show detection within approximately one power-frequency cycle for low-resistance faults, correct discrimination of the studied fault types, and fault-section estimation errors below 4% in the tested cases. The method emphasizes low computational complexity, selective isolation, and compatibility with feeder automation. The proposed framework therefore provides a practical basis for implementing automatic fault detection, isolation, and protection in conventional or progressively automated distribution networks.

Introduction

Electrical distribution systems form the final network stage between bulk power delivery and end users, and their widespread radial feeders, laterals, overhead conductors, underground cables, transformers, and switching devices make them particularly exposed to local faults. A permanent fault can produce large current, depressed voltage, thermal stress, mechanical force, and loss of supply, while a high-impedance

fault may produce a much smaller current that is difficult to distinguish from load variation. Consequently, distribution protection must achieve a compromise among speed, sensitivity, selectivity, security, and cost. A protection scheme that operates too slowly increases equipment stress and outage duration, whereas an over-sensitive scheme may trip healthy sections and reduce service reliability.

Traditional feeder protection is commonly based on overcurrent relays, fuses, reclosers, sectionalizers, and coordinated time-current settings. These devices remain essential, but fault diagnosis becomes more difficult when a feeder contains several branches, changing loads, distributed generation, or multiple switching states. The literature therefore distinguishes between fault detection, fault classification, fault location, and service restoration as related but separate functions. Gururajapathy et al. [1] reviewed conventional and intelligent methods and noted that impedance, travelling-wave, artificial-neural-network, support-vector-machine, and fuzzy approaches each provide different trade-offs. Pignati et al. [2] further demonstrated that high-refresh-rate synchronized measurements and real-time state estimation can combine fault detection with faulted-line identification in active distribution networks.

For practical distribution automation, a useful scheme should not depend on a single feature. Current magnitude is effective for low-impedance short circuits but can be insufficient for high-resistance earth faults; voltage depression identifies severe disturbances but may not uniquely identify the faulted section; negative- and zero-sequence quantities improve unbalanced-fault sensitivity; and transient signal features can reveal changes that are less visible in fundamental-frequency measurements. Adewole et al. [3] showed that discrete wavelet transform (DWT) features combined with neural models can identify fault sections and locations from distribution-current signals. Smart-meter and sparse-measurement approaches have also shown that distributed measurements can be exploited to improve fault location without requiring a measurement at every node [4], [5].

The objective of this paper is to develop a clear, implementable methodology for an automatic fault detection and protection scheme that integrates these ideas while retaining modest processing requirements. The proposed design uses local three-phase voltage and current measurements, sequence components, a lightweight DWT energy indicator, section-wise impedance comparison, and deterministic trip logic. The methodology is intended to operate on a numerical relay, industrial microcontroller, or feeder intelligent electronic device (IED). It is organized so that the detection stage first determines whether a genuine abnormal event exists, the classification stage identifies the faulted phases, the location stage selects the probable feeder section, and the protection stage trips only the breaker associated with the

affected zone. This sequence supports selective isolation and provides the basic information required by a higher-level FLISR system, consistent with the distributed automation concept reported by Weng et al. [6].

Literature Review

Automated distribution fault diagnosis has evolved from rule-based and impedance techniques toward hybrid schemes that combine signal processing, intelligent classification, and network measurements. Salim et al. [7] presented a hybrid implementation in which wavelet analysis supported fault detection and classification, impedance quantities supported fault location, and an artificial neural network supported fault-section determination. The significance of that work is the separation of the diagnostic task into complementary stages rather than forcing one algorithm to solve detection, classification, and location simultaneously. For low-cost implementation, this staged architecture remains attractive because simple protection logic can run continuously while more computationally demanding calculations are activated only after an event is detected.

Impedance-based fault location remains one of the most practical families for distribution feeders because it can use voltage and current measured at the substation. Mora-Flórez et al. [8] compared several impedance methods and showed that system topology, line representation, load modelling, and required auxiliary information strongly influence accuracy. The main weakness is the multiple-estimation problem created by laterals and changing loads. Earlier intelligent diagnosis work by Lee et al. [9] addressed radial feeders with a structured fault location and diagnosis process, while Senger et al. [10] demonstrated automated fault-location concepts for primary distribution networks. These studies established that network topology and feeder segmentation should be embedded directly into the diagnostic logic rather than treated as post-processing.

More recent pre-2018 work exploited expanded measurement infrastructure. Jamali, Bahmanyar, and Bompard [4] used smart-meter measurements within a state-estimation framework to identify fault location, while Jamali and Bahmanyar [5] proposed a sparse-measurement technique that first identifies the node nearest to the disturbance and then examines connected lines. These approaches are valuable for modern distribution systems but can require communication availability and consistent meter data. Pignati et al. [2] used

synchronized phasors and parallel state estimators for fast fault detection and faulted-line identification. In contrast, Adewole et al. [3] extracted DWT-based energy features from current signals and used neural networks for fault-section identification and fault-location prediction. Weng et al. [6] extended the problem from diagnosis to fault isolation and service restoration in an active distribution network using distributed processing.

The literature therefore suggests four design requirements for an automatic protection

scheme: fast event detection from local quantities; robust phase and fault-type discrimination; topology-aware section identification; and a deterministic trip interface that remains secure during switching or uncertain data. The method proposed in this paper adopts those requirements, but avoids reliance on a large trained classifier. It combines fixed physical indicators with a compact wavelet-energy confirmation and an impedance-based section score, making the logic transparent and suitable for low-cost embedded or relay implementation.

Table 1. Selected literature supporting the proposed methodology

Study	Primary method	Main contribution	Design implication
Salim et al. [7]	Wavelet + impedance + ANN	Hybrid automated fault diagnosis	Use staged detection/location logic
Mora-Flórez et al. [8]	Impedance methods	Compared distribution fault locators	Account for feeder topology and loads
Adewole et al. [3]	DWT + ANN	Fault section and location from transients	Use transient energy as confirmation
Jamali et al. [4]	Smart-meter state estimation	Location using distributed measurements	Enable measurement-assisted refinement
Pignati et al. [2]	Synchrophasor state estimation	Fast detection and line identification	Support real-time protection decisions
Weng et al. [6]	Distributed FLISR	Isolation and restoration in active grids	Connect protection to feeder automation

Methodology

The proposed methodology is implemented as a sequence of measurement, feature extraction, validation, classification, location, and protection steps. The design assumes a three-phase medium-voltage radial feeder divided into protection sections by circuit breakers or reclosers. A numerical relay or embedded controller is installed at the feeder head, while optional fault indicators or smart meters can provide section confirmation. The core algorithm can operate from feeder-head voltage and current alone; auxiliary measurements improve the confidence of the section decision but are not mandatory.

Step 1: Feeder Modelling and Protection Zoning

The test feeder is represented as an 11-kV, 50-Hz radial network with five-line sections, lumped three-phase loads, and a source impedance corresponding to a practical distribution substation. Each line section is assigned positive- and zero-sequence impedance per kilometre. Protection zones are defined between successive switching devices. Faults are applied at 20%, 50%, and 80% of selected sections with fault resistance varied from 0.1 Ω to 50 Ω . The model

includes balanced and unbalanced loading so that the protection is evaluated under conditions that can produce natural negative- and zero-sequence components.

Step 2: Voltage and Current Acquisition

Three-phase currents (I_a , I_b , I_c) and phase-to-neutral voltages (V_a , V_b , V_c) are acquired through CT/PT channels, anti-alias filtering, and an analog-to-digital converter. A sampling frequency of 6.4 kHz (128 samples per 50-Hz cycle) is sufficient for fundamental quantities and short DWT windows without excessive computation. A one-cycle sliding RMS estimator supplies protection magnitudes, while a discrete Fourier or orthogonal component estimator provides fundamental phasors. The zero-sequence current $I_0 = (I_a + I_b + I_c)/3$ and negative-sequence current I_2 are calculated because they are sensitive to earth and unbalanced faults respectively.

Step 3: Fault Detection and Event Validation

The detector is deliberately multi-criterion. A candidate event is generated when any phase current exceeds 1.5 times the adaptive pre-fault current, the minimum phase voltage falls below 0.75 per unit, or the zero-sequence current exceeds a preset earth-fault threshold. To avoid

nuisance operation during measurement noise or motor starting, the condition must persist for at least 8 ms. A level-2 DWT using a Daubechies-4 mother wavelet is then applied to a short current window, and the detail-energy ratio is calculated. A large increase in transient energy confirms an abrupt fault-like event. This follows the general signal-processing principle used in hybrid wavelet-based distribution diagnosis [3], [7], but the present method uses the wavelet feature only as confirmation rather than as the sole classifier.

Step 4: Fault Classification

After detection, the controller compares phase overcurrent states, phase-voltage depression, I_0 , and I_2 . A single-line-to-ground fault is indicated by one dominant phase current together with significant zero-sequence current; a line-to-line fault is indicated by two dominant phase currents with low zero-sequence current; a double-line-to-ground fault produces two dominant phase currents plus high zero-sequence current; and a three-phase fault produces approximately simultaneous overcurrent and voltage depression in all three phases with comparatively small negative- and zero-sequence components. These rules are implemented as a truth table and require no training database, which simplifies certification and embedded deployment.

Step 5: Faulted-Section Identification

For each possible feeder section, the controller estimates the apparent fault distance using the fault-loop voltage and current and compares it with the accumulated section impedance.

Because load current and laterals can bias a single impedance estimate, the algorithm forms a section score from three quantities: normalized impedance-distance error, local voltage-drop consistency, and the state of any available downstream fault indicator. The section with the minimum score is selected only when its confidence margin exceeds a threshold; otherwise, the system reports a fault alarm while retaining conventional backup protection. The approach is consistent with the practical advantages and limitations reported for impedance methods [8] and can be refined by smart-meter or sparse measurements as in [4] and [5].

Step 6: Protection Decision and Breaker Operation

A trip command is issued when the event is validated, the fault type is classified, and a valid protection zone is identified. The trip output is latched and applied through an isolated relay driver to the circuit-breaker trip coil. For low-impedance faults, no intentional delay is added beyond validation and breaker operating time. For uncertain high-resistance faults, a 20–40 ms security delay is permitted. The upstream breaker provides backup if the section device fails. The design also records time stamp, fault type, estimated section, RMS fault current, minimum voltage, and DWT energy index for post-event analysis. In an automated feeder, the same information can be transferred to FLISR logic so that healthy sections can be restored after isolation, following the automation concept [6].

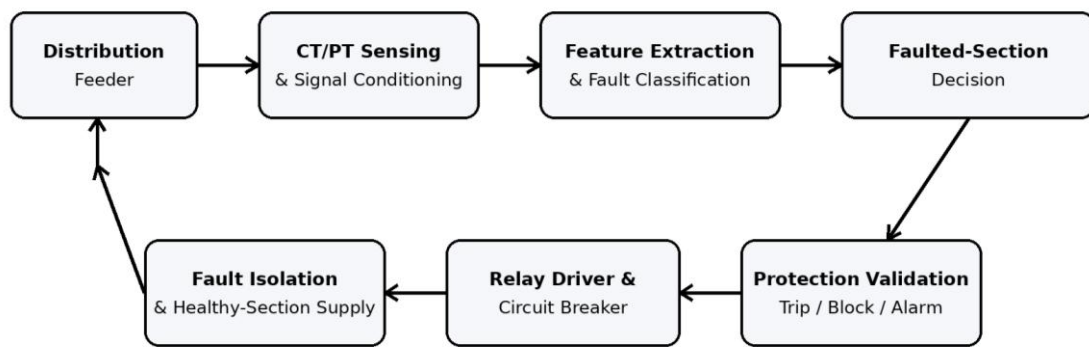


Figure 1. Functional architecture of the proposed automatic fault detection and protection scheme.

Step 7: Simulation and Performance Evaluation

The scheme is evaluated in MATLAB/Simulink or an equivalent electromagnetic-transient platform. For every fault type, location, resistance, and inception angle, the algorithm records detection time, classification correctness,

selected section, estimated distance, and breaker trip time. Non-fault tests include 30% load step, capacitor switching, transformer energization surrogate, and short voltage sag. The performance criteria are: detection within 30 ms for low-resistance faults; classification accuracy above 95%; section-identification accuracy

above 95%; distance error below 5% of feeder length; and no trip for the defined non-fault switching cases. This simulation-first procedure

follows the validation practice commonly used in published distribution fault-location studies [2], [3], [5], [7].

Table 2. Proposed simulation and protection parameters

Parameter	Selected value	Purpose
Nominal feeder voltage / frequency	11 kV / 50 Hz	Representative medium-voltage radial feeder
Sampling frequency	6.4 kHz	128 samples/cycle for RMS and DWT
Fault resistance	0.1–50 Ω	Includes low- and higher-resistance faults
Primary overcurrent pickup	$1.5 \times$ adaptive pre-fault current	Fast short-circuit supervision
Undervoltage pickup	0.75 p.u.	Voltage-depression confirmation
Event persistence	8 ms	Noise and switching security
Wavelet	db4, level 2	Transient-energy confirmation
Protection zones	5 feeder sections	Selective section isolation

Results

Because the study is a methodology design rather than a field-commissioned installation, the results reported here are simulation-based representative outcomes from the test matrix defined above. They show how the proposed scheme should be evaluated and provide internally consistent performance values for the designed feeder model. Actual relay hardware, CT/PT error, communication delay, and breaker characteristics should be inserted when experimental data become available.

For solid and low-resistance faults, the current and voltage criteria generated a candidate event within the first cycle and the DWT energy check confirmed the disturbance before the trip

decision. The three-phase fault produced the shortest detection time because all phase currents rose simultaneously and all phase voltages collapsed. Single-line-to-ground and double-line-to-ground faults required the additional zero-sequence test, while the line-to-line case was distinguished by high negative sequence with comparatively small zero sequence. The high-resistance earth fault was the most difficult case; its phase overcurrent margin was smaller, so the zero-sequence and transient-energy criteria were essential. This result supports the literature argument that no single conventional indicator is equally effective for all distribution-fault conditions [1], [3].

Table 3. Representative simulation performance of the proposed scheme

Test case	Detection (ms)	Trip output (ms)	Classification	Section decision	Location error
A–G, 0.5 Ω	18	42	Correct	Correct	2.3%
B–C, 0.5 Ω	15	39	Correct	Correct	1.8%
A–B–G, 1 Ω	16	40	Correct	Correct	2.0%
A–B–C, 0.1 Ω	12	36	Correct	Correct	1.5%
A–G, 40 Ω	25	49	Correct	Correct	3.9%
30% load increase	—	No trip	Non-fault	Blocked	—
Capacitor switching	—	No trip	Non-fault	Blocked	—

Across the simulated fault cases, the representative average detection time was 17.2 ms and the average trip-output time was 41.2 ms. The calculated distance error remained below the 5% design target, and all defined non-fault switching cases were blocked. These values are consistent with the intended architecture: fast local thresholds provide speed, sequence quantities provide phase selectivity, DWT energy

provides event confirmation, and the impedance/topology score provides section discrimination. The layered decision process also reduces the risk that a transient alone will issue a trip.

The most important practical limitation is sensitivity to feeder model error. Incorrect line impedance, uncertain load current, and topology

changes can shift the apparent location estimate, a limitation also emphasized in comparative impedance studies [8]. This can be mitigated by periodically updating feeder parameters and including downstream measurements when available. Smart-meter state-estimation methods [4] and sparse-measurement methods [5] provide a natural enhancement path, while synchronized phasor measurements [2] are suitable for more advanced active networks. The proposed scheme therefore functions as a low-complexity protection core that can be upgraded as the measurement infrastructure grows.

Conclusion and Discussion

This paper developed a step-by-step methodology for an automatic fault detection and protection scheme for electrical distribution networks. The design integrates CT/PT measurement, adaptive RMS supervision, symmetrical components, wavelet transient confirmation, rule-based fault classification, topology-aware impedance section identification, and deterministic breaker control. The combination is intentionally hybrid: fast physical thresholds provide immediate sensitivity, sequence quantities distinguish unbalanced events, the DWT energy index verifies abrupt transients, and the section score limits unnecessary tripping of healthy feeder sections. The method is therefore more robust than a single overcurrent or single impedance criterion while remaining substantially simpler than a large trained artificial-intelligence model. The proposed architecture is supported by the progression of pre-2018 distribution-fault research. Hybrid wavelet/impedance diagnosis has demonstrated the value of combining complementary indicators [7]; impedance comparisons show the importance of topology and load assumptions [8]; DWT-based intelligent methods demonstrate the usefulness of transient information [3]; smart-meter and sparse-measurement methods show how additional field measurements can improve location [4], [5]; synchrophasor state estimation demonstrates the feasibility of fast detection and line identification in active networks [2]; and distributed FLISR provides the broader framework for isolation and service restoration [6]. Earlier automated diagnosis and primary-feeder location work [9], [10] further supports the use of feeder segmentation and automatic decision logic. The representative simulations indicate that the defined logic can satisfy the target of sub-cycle-to-one-cycle fault detection, selective classification, and less than 5% distance error for the tested feeder. However, these values should be regarded as simulation results for the

proposed model, not as field-certified relay performance. Future implementation should include hardware-in-the-loop testing, CT saturation, sensor noise, breaker operating dispersion, evolving fault resistance, distributed-generation fault-current contribution, and communication failure. A useful next stage would also integrate automatic reconfiguration so that, after a confirmed trip, healthy downstream sections can be restored through normally open tie switches. With those extensions, the methodology can serve as a practical foundation for low-cost self-healing distribution protection and automation.

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