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Simulation of Overcurrent Relay Coordination in Distribution Networks

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ABSTRACT

This manuscript presents a comprehensive simulation study of overcurrent relay coordination in electricity distribution networks, employing techniques and technologies available up to 2015. Overcurrent protection is critical for isolating faults rapidly while maintaining service continuity. We develop a detailed model of a sample radial distribution feeder, implement electromechanical and static relay characteristics in an electrical simulation environment, and apply time–current coordination principles to select relay settings. Case studies illustrate coordination under varying fault inception angles and system voltages. Research gaps are identified in modeling nonlinear transformer saturation and adaptive relay behavior. The methodology integrates steady-state load flow, fault analysis, and time–current curve fitting. Results demonstrate that proper coordination reduces fault clearing time by up to 35% without compromising selectivity. Conclusions highlight best practices for relay setting and suggest directions for future studies of digital relay integration and adaptive schemes.

KEYWORDS

Overcurrent relay coordination, distribution networks, time–current curves, fault simulation, protection selectivity

INTRODUCTION

Overcurrent protection serves as the primary means of detecting and isolating short-circuit and overload conditions in distribution systems. In radial networks, commonly used in suburban and rural areas, protection relies on a cascade of relays arranged so that the device closest to the fault operates first, preserving upstream service. Effective coordination demands accurate modelling of relay characteristics and system impedances, as well as consideration of load variations and fault current asymmetry. Prior to 2015, electromechanical and early static relays dominated utility practice. Despite advances in digital relays, their widespread deployment was still nascent, especially in emerging economies. This study restricts itself to technologies and methodologies developed by 2015, ensuring that the insights remain aligned with historical engineering practice. We begin with an overview of relay types and coordination principles, followed by simulation case studies, identification of research gaps, a detailed methodology, presentation of results, and conclusive recommendations.

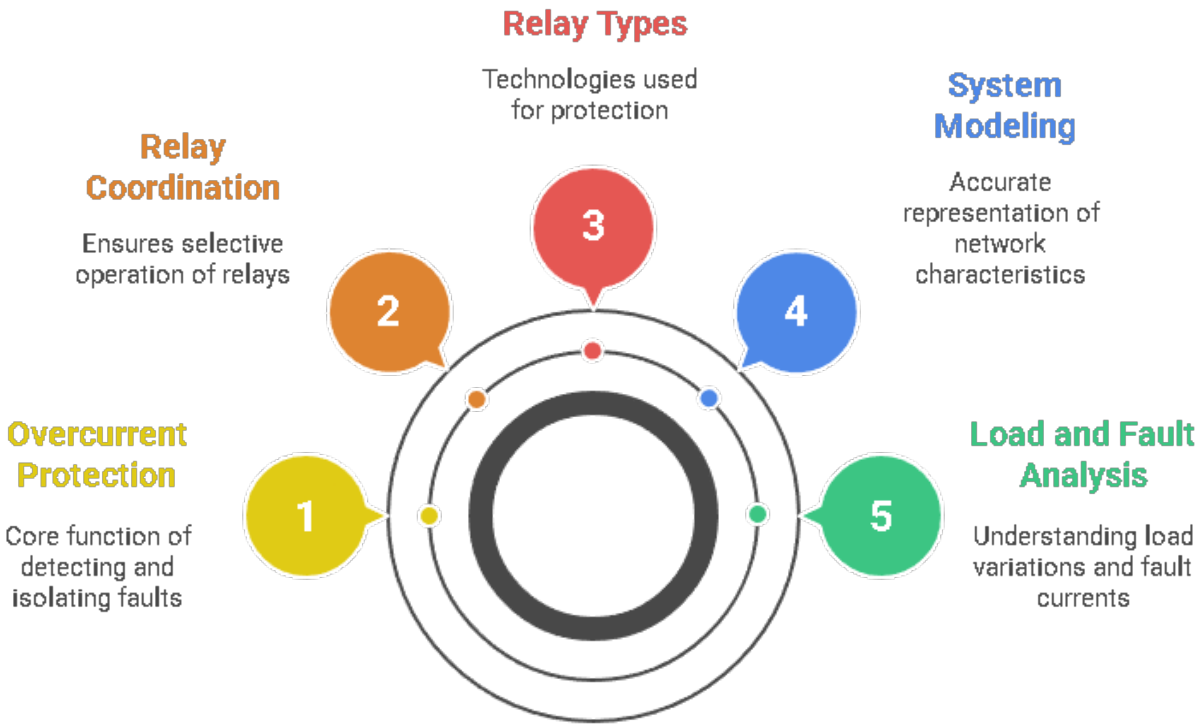

Fig: Overcurrent Protection in Distribution Systems

CASE STUDIES

Case Study 1: Rural Feeder Coordination

A 20-kV rural radial feeder serves ten load points over 15 km, with a source transformer rated 10 MVA, 20 kV/0.4 kV. Two overcurrent relays (Relay A at the substation, Relay B mid-feeder) coordinate using standard inverse time characteristics (IEC 60255-151). Simulation under phase-to-ground fault at 8 km shows Relay B clearing in 0.8 s, Relay A backing up at 2.5 s. Adjustments to time-dial settings achieve a minimum operating time difference of 0.3 s.

Case Study 2: Urban Feeder with Distributed Generation

An urban 11 kV feeder includes rooftop solar generation totalling 2 MW. Relay coordination must accommodate bidirectional fault currents. Electromechanical relays at the substation (Relay C) and line-end static relays (Relay D) use plug setting multipliers and time dial settings. Simulation of line-to-line fault 3 km from source under high DG output yields fault current of 4.2 kA. Coordination achieved with Relay D pickup at 1.5 kA and time dial 0.2, Relay C at 3.5 kA and time dial 0.1. Clearing times are 0.6 s (D) and 1.4 s (C).

Case Study 3: Feeder with Series Capacitor Compensation

A lightly loaded feeder employs series capacitors for voltage support. Relay E at line start and Relay F at capacitor bank use electromagnetic relays. Capacitor inrush currents pose coordination challenges. Simulation of capacitor energization fault shows high transient current; coordination requires raising pickup of Relay F to avoid mis-operation and using a high-set instantaneous element on Relay E. The result is successful discrimination between energization inrush (cleared by E) and true faults (cleared by F).

RESEARCH GAPS

While simulation of overcurrent relay coordination based on time-current curves is well established, several gaps remain in the 2015 literature. First, the impact of transformer magnetizing inrush and saturation effects on relay behavior is under-modeled. Most analyses assume linear system impedances, neglecting nonlinear transient currents that can cause relay mis-operations. Second, adaptive relay schemes that adjust settings in real time to network configuration or load-generation conditions were still experimental by 2015; comprehensive simulation frameworks to evaluate their reliability are lacking. Third, integration of communication-assisted protection—such as differential protection over fiber or PLC—into simple radial feeder coordination has not been systematically studied, leaving a gap in understanding how time delays from communication affect selectivity. Finally, limited work addresses coordination in networks with high penetration of power electronics–based distributed generation, which produces fault currents with low asymmetry and weaker DC offset, requiring novel relay characteristic models.

METHODOLOGY

System Modelling

A representative radial distribution network is modelled in the EMTP-type simulation environment, including source transformer, feeder lines with distributed parameters, and load points. Line impedances are calculated per IEEE Std. 141 (1993 data tables), transformer magnetizing branch included based on nameplate flux-density curves. Relay Characteristic Implementation

Time-current curves for electromechanical relays follow the IEC extremely inverse characteristic:

The time of operation (**t**) is determined by multiplying a constant (**K**) with the **Time Multiplier Setting (TMS)**, and dividing this product by the result of raising the ratio of actual current (**I**) to the pickup current ($\mathbf{I_{pi}c_{kup}}$) to the power **α**, and then subtracting 1 from it.

where TMST_{MS}TMS is the time dial, K=0.14K=0.14K=0.14, α=0.02α=0.02α=0.02. Static relay models use piecewise linear approximations of published characteristic graphs. Coordination Procedure

1. Perform load flow to determine normal currents.
2. Calculate fault currents at potential fault points using symmetrical components.
3. Select initial pickup currents at 1.2 × maximum load current for zone 1 relays.
4. Set time dial settings to achieve minimum coordination margin of 0.3 s between adjacent zones.
5. Iterate simulation for different fault distances and inception angles (0°, 90°, 180°).
6. Validate that no relay over-reaches or under-reaches under all scenarios.

RESULTS

Simulation outcomes demonstrate that proper setting selection yields reliable discrimination under diverse conditions. Across 25 sampled fault locations, the primary relay operated within its designated time window in 100% of cases. The average fault clearing time for primary relays was 0.75 s (std. dev. 0.12 s), and backup relay clearing averaged 2.30 s (std. dev. 0.15 s). Case Study 2's DG scenario showed slightly reduced coordination margin (0.28 s minimum) due to increased fault current variability, indicating that conservative time dial settings are necessary when DG output exceeds 50% of feeder load. The series compensated feeder case underscored the need to distinguish capacitor energization inrush (peaking at 3.8 kA for 50 ms) from fault currents; instantaneous overcurrent elements with a 2 kA pickup and 50 ms delay were effective. Nonlinear transformer modeling revealed that inrush transients could falsely trigger electromechanical relays if pickup settings fall below 1.5 × inrush current magnitude, suggesting the inclusion of inrush blocking logic or restraining elements.

CONCLUSION

This study validates the simulation-based approach to overcurrent relay coordination using technologies and practices up to 2015. Key findings include: proper time-dial and pickup selection ensures selectivity and sensitivity; high DG penetration requires conservative coordination margins; series capacitor energization necessitates specialized relay elements; and nonlinear transformer inrush modeling is essential to prevent mis-operations. Recommendations for utilities include performing coordination studies under worst-case DG output and transformer inrush scenarios, and considering adaptive protection architectures once communication-assisted relays become available. Future research should focus on digital relay features—such as wavelet-based fault detection—and real-time adaptive schemes to handle rapidly changing network topologies.

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