# Simulation and Research on Self-Healing Control Technology of Single Radiative Distribution Network Based on Multisim

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**Abstract.** Because of the national "dual carbon" goals and the growing penetration of high - proportion renewable energy, the topology of distribution networks has become more complex and failures occur more frequently, so the traditional model based on "manual inspection and on-site rush repair" cannot adequately meet the needs of self - healing operations in smart grids. Therefore, this paper studies a single radial distribution network and proposes a relevant solution. the paper gives a very clear treatment of its self-healing control technology: first it explains the logical structure of the "perception - decision - execution" closed-loop control framework, together with the fundamental theories of fault detection, localization, isolation, and power supply restoration, and then proceeds naturally to build a simplified simulation model in Multisim to simulate the whole process from "normal operation" to fault trigger. the paper first introduces the "fault isolation - power supply restoration" method, proves its technical feasibility, then points out the existing problem of the shortage of intelligent devices, and accordingly proposes effective optimization strategies. Therefore, it provides clear, solid reference for the engineering implementation of distribution network automation upgrading and self-healing control technologies.

**Keywords:** Dual Carbon Goals, High-proportion Renewable Energy, Distribution Network.

## 1. Introduction

Because the "dual carbon" goals have given rise to smart grids being regarded as the main support for renewable energy accommodation and efficient energy utilization, it is natural and logical to recognize that distribution networks, as the direct link between users and the power system, determine the overall operational efficiency and power supply quality of the grid. Hence, recent years have seen large-scale integration of distributed photovoltaic and wind power.

Since electric vehicles and energy storage systems both lead to complicated distribution network topology and increased short-circuit faults, the traditional "manual inspection and on-site repair" mode has low positioning efficiency and slow response, hence it can no longer satisfy the self-healing requirements of smart grids [1]. Therefore, self-healing control realizes automatic fault detection, location, isolation and service restoration, which significantly reduces outage time and makes it a vital technology for distribution automation as well as for integrating high-proportion renewable energy.

It is well known that extensive work has been done globally on this topic: Liu Jian et al. developed an algorithm system for fault location and isolation in distribution networks with distributed generators and showed how to improve low accuracy [2], while Wu Yuehua et al. proposed a distributed self-healing scheme for active distribution networks which allows fast local fault handling and reduces communication dependence [3]. However, a clear drawback of most existing simulation models is that they are too complicated and cumbersome, hence making efficient verification of the core self-healing logic difficult.

Since the paper establishes a simplified simulation model of self-healing control for single-radial distribution networks using Multisim, it naturally and logically focuses on fault isolation and service restoration, then rigorously verifies the technical feasibility of the proposed method with low complexity and high efficiency [4], thus providing a very useful model reference for distribution automation.

## 2. Theoretical Fundamentals Analysis

### 2.1. Core Concepts and Working Principles of Distribution Network Self-Healing Control

Distribution network self - healing control is the fundamental technology of intelligent distribution automation, and when a fault occurs in the distribution network, it employs a closed - loop control method that integrates automatic fault detection, accurate fault location, rapid fault isolation, and service restoration in non - faulty areas, thus eliminating faults at an early stage and realizing the system's “self - restoration” with minimal impact scope [5]. Therefore, its primary objective is to enable self - healing of the distribution network, thereby improving power supply reliability, enhancing system operation stability, and most importantly, facilitating the stable operation of distribution networks with high - proportion new energy.

Distribution network self - healing control is a coordinative process of three distinct stages: perception, decision - making, and execution, which together form a complete closed loop as shown in Figure 1. Consequently, the implementation can be neatly summarized: voltage and current sensors are first used to measure electrical quantities and determine whether a fault exists, after which the collected monitoring data are analyzed. The reset control logic is employed first to identify the fault state and its location, after which commands for fault isolation and service restoration are issued, and then execution devices such as switch cabinets and circuit breakers carry out the necessary actions to isolate the faulty section from the healthy sections and restore power. Hence, the whole process is rapid, automatic, and requires no human intervention [6].

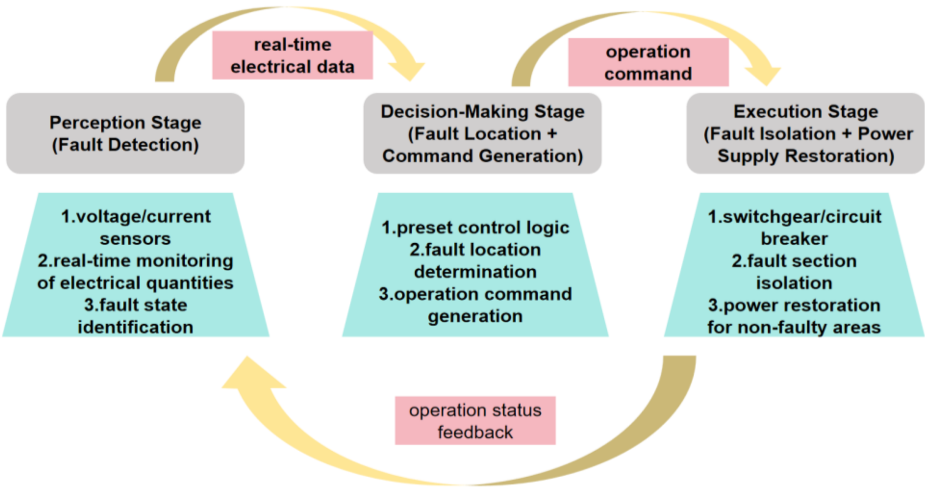


**Figure 1.** Schematic diagram of the three stages: Perception - Decision - Execution.

### 2.2. Theory of Fault Detection and Location in Distribution Networks

Since fault detection and localization form the basis of self-healing control in distribution networks, their accuracy directly affects the response speed and actual performance of self-healing control, it is therefore natural and reasonable to consider the two main technical approaches: fault feature identification and sectionalized localization.

Since the voltage and current on the lines of a distribution network under normal operation are stable, a short-circuit fault will cause the fault point to exhibit very clear, abrupt changes: a sharp voltage drop and a sudden current rise. Therefore, faults can be reliably detected by real-time monitoring of line electrical parameters and detecting such abnormal fluctuations, after which the self-healing control process can be promptly initiated [7].

Since radial distribution networks lend themselves naturally to fault localization using sectionalized switches, which divide the whole network into several independent supply sections, it is straightforward and reliable to determine the faulty section from the monitoring data collected by these sectionalized switches. Therefore, this method localizes faults rapidly and enables subsequent fault isolation to be more precise, thus avoiding the inefficiencies caused by imprecise fault localization in self-healing processes [8].

### 2.3. Theory of Fault Isolation and Power Supply Restoration

Since fault isolation and service restoration constitute the core execution stage of self-healing control in distribution networks, it is natural and correct to say that they directly affect the speed of power recovery in non-faulty areas, hence the coordination between the two steps is vital for good self-healing control performance.

The essential measure in fault isolation is to open the sectionalized switches on both sides of the faulty section, thereby physically separating the fault zone from the main line and all healthy sections, thus preventing the fault from spreading to normal lines, protecting the safe electrical operation of the main line and non-faulty sections, and ultimately creating favorable conditions for the later power restoration of non-faulty areas [9]. More importantly, due to the clear topological characteristics of a single radial distribution network, fault isolation can be elegantly and reliably accomplished by simply opening the sectionalized switch corresponding to the faulty branch.

After fault isolation is accomplished, the objective of power restoration is clearly and simply to restore the normal electrical connection between the main line and non-faulty sections, so that the main source can continue to supply stable electric energy directly to the healthy sections, thereby achieving automatic, rapid service restoration [10]. In a single radial distribution network, the main line is not persistently affected by branch faults, hence after fault isolation, power can be directly and reliably restored to all non-faulty branches, allowing load equipment in each healthy area to return to normal operation swiftly.

### 2.4. Theory of Fault Detection and Location in Distribution Networks

Because single radial distribution networks have a simple structure and a well-defined operating mode, they are by far the most commonly used topology in urban and rural distribution systems. Under normal conditions, each network is supplied by a single power source feeding loads along the line with a fixed power flow direction, hence fault detection and location are greatly facilitated [11].

When a short-circuit fault occurs in a certain line section, the control system can rapidly and accurately locate the fault by monitoring changes in current and voltage electrical quantities, and after fault location is determined, the self-healing control system acts in a clear, well-defined sequence as shown in Figure 2: first it trips the switches at both ends of the faulty section to isolate the fault, then once the fault area is reliably disconnected, it reconnects the non-faulty sections to the grid via restoration switches, thereby restoring power in the shortest possible time. Thus, the sectional isolation and hierarchical restoration control logic minimizes the power outage area, directly improving the power supply reliability and fault handling efficiency of single radial distribution networks [12].

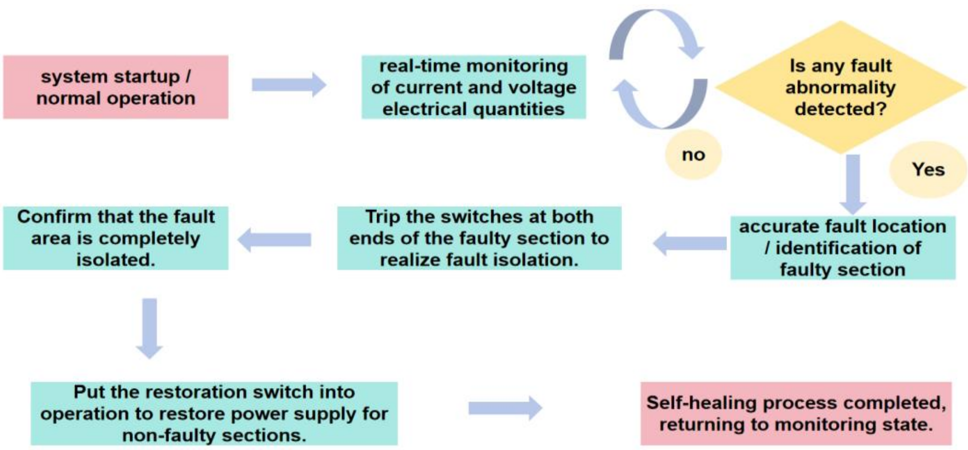


**Figure 2.** Flowchart of self-healing control for single radial distribution network.

# 3. Multisim Simulation Design and Implementation of Distribution Network Self-Healing Control

## 3.1. Fundamentals of Simulation Design

Since this simulation takes a single radial distribution network as the research object, it is natural and proper to simulate the whole process of normal operation, fault occurrence, fault isolation and power supply restoration by means of a simplified circuit model, thereby directly and convincingly verifying the core self-healing control logic of isolating faults via sectional switches and restoring power supply in non-faulty areas.

The simulation uses a typical single-radial structure composed of an AC power supply, a main line, and two parallel branches, and thus can very naturally be described as follows: there is an AC power supply with a peak value of 311V and a frequency of 50Hz (hence an RMS value of about 220V), a main switch and main line impedance, which splits into two parallel feeders, each having a sectional switch. Since line impedance and a load are present in the circuit, a short-circuit fault switch is installed on one branch to simulate a fault point, and upon fault occurrence, the sectional switch of the faulty branch is opened to isolate the fault and let the healthy branch continue operating normally. Therefore, this topology is very natural and realistic for low-voltage distribution networks, making it ideal for simulating the self-healing control process.

## 3.2. Simulation Model Parameters and Configuration

From the analysis presented in Figure 3 it is evident that the simulation model employs only basic components in Multisim, and all parameters are chosen in a straightforward, physically meaningful way to represent a low-voltage distribution network. Specifically, the main line resistance is 0.5Ω, each of the two branch lines has a resistance of 1Ω to simulate line transmission impedance, two 100 Ω resistors are used as loads to model user electrical equipment. The model includes one main switch, two branch sectional switches, and one short - circuit fault switch, all of which are single - pole single - throw virtual switches used to control circuit on/off states and simulate faults. A ground symbol is properly included to form a complete closed circuit.

Since two multimeters are used in the measurement section and set to AC voltage measurement mode, connected in parallel across the loads of each branch, therefore the voltage variations measured can be taken as a direct and reliable indication of the power supply status of the loads at each stage, which is ideal for testing the self-healing control logic.

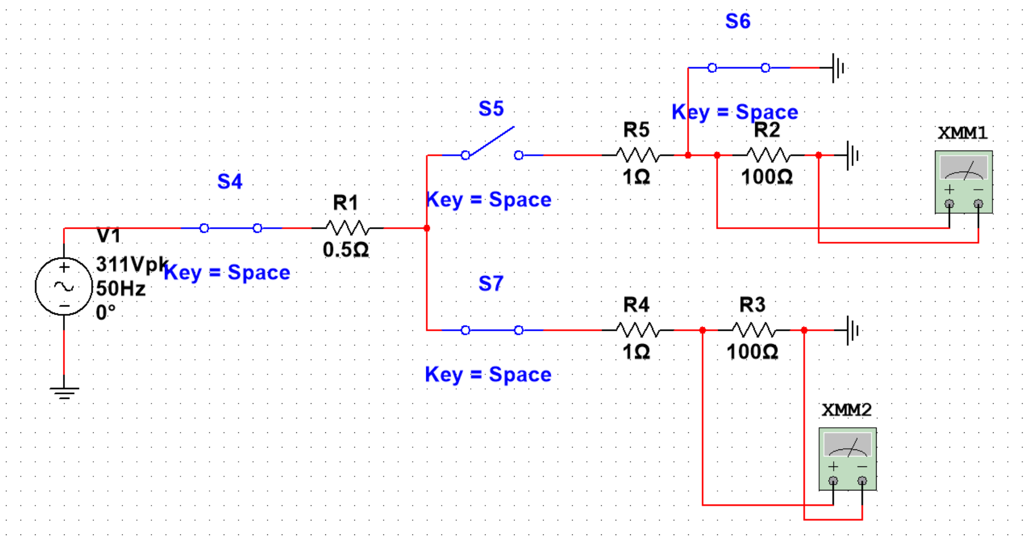


**Figure 3.** Circuit Construction Model.

### 3.3. Simulation Flow and Result Verification

The simulation is performed in four clearly defined, consecutive stages with the simulation proceeding uninterruptedly, and different operating cases are generated by switching the virtual switches on and off. The voltages measured by the multimeters are then used to verify the self healing control logic, with the results given in Table 1.

**Table 1.** Voltage of Load 1 and Load 2.

| Simulation Stage | Voltage of Load 1 | Voltage of Load 2 | Phenomenon Summary |
|---|---|---|---|
| Normal Operation | 215.589V | 215.589V | All loads are supplied normally. |
| Fault Occurrence | 14.609mV | 144.668V | The voltage of the faulty section drops sharply to 0, while the voltage of the non-faulty section decreases significantly. |
| After Fault Isolation | 218.818pV | 216.652V | The voltage of the non-faulty section returns to normal. |

From the simulation results it can be very clearly and systematically observed that the voltages of Load 1 and Load 2, as well as the associated phenomena, behave as follows during the various stages: Normal Operation215. 589V215. 589VAll loads are supplied normally. Fault Occurrence14. 609mV144. 668VThe voltage of the faulty section drops sharply to 0， while the voltage of the non-faulty section drops considerably. After Fault Isolation218. 818pV216. 652VThe voltage of the non-faulty section has returned to normal. As is evident from Figure 4, during the normal operation stage, since the main switch and the sectional switches of the two branches are closed, the short-circuit fault switch is open, and the simulation has been started, multimeter measurements confirm that the voltages across both loads are stable at 215.5 V. The corresponding theoretical value calculated is 216.7 V, and the deviation between the two is well within the acceptable range. Therefore it can be conclusively stated that the power supply of each line in the distribution network is normal and the model is operating stably.

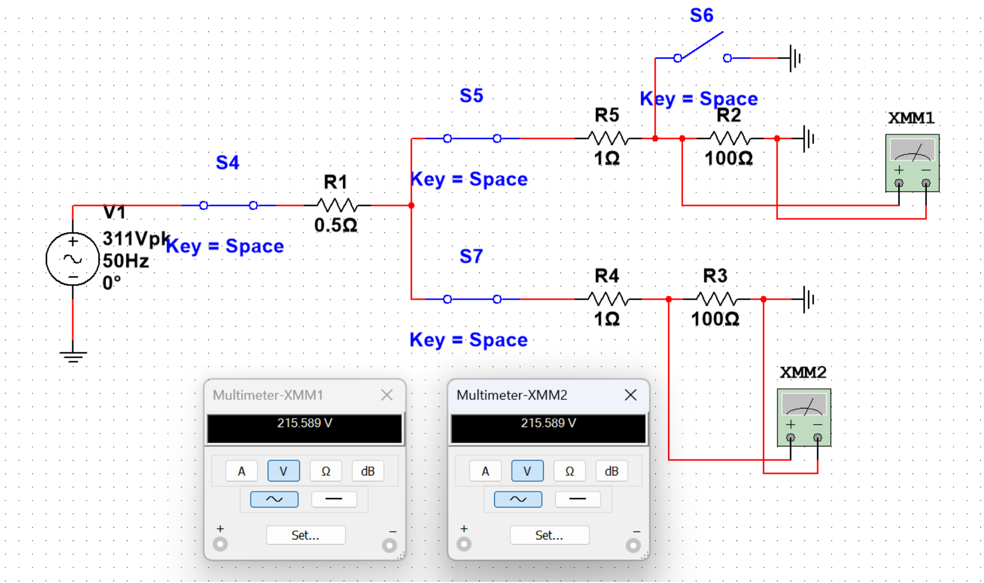


**Figure 4.** Normal Operating Voltage.

From the analysis given in Figure 5 it is very clearly and logically shown that during the fault occurrence stage all other switches remain as they are, and the short-circuit fault switch is closed to simulate a branch short-circuit fault. Hence, the load voltage of the faulty branch drops sharply to nearly 0V, and the voltage of the healthy branch also drops considerably, confirming that a short-circuit fault has indeed spread to the main line, as expected in a real distribution network fault.

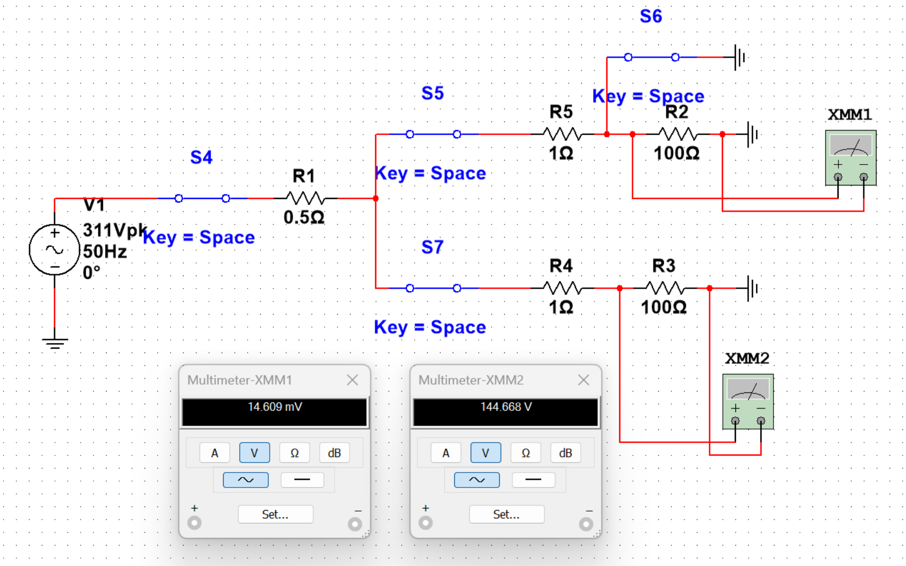


**Figure 5.** Voltage under Fault Condition.

From the discussion in Figure 6 it is very clearly and unambiguously seen that during the fault isolation stage the short-circuit fault switch remains closed and the sectional switch of the faulty branch is opened, thus physically isolating the fault section from the main line. As a result, the load voltage of the faulty branch stays at nearly 0V, whereas the voltage of the non-faulty branch recovers rapidly to 216. 6V. From the analysis it can be clearly and unambiguously seen that the fault isolation operation was successful, the short-circuit effect on the main line has been fully eliminated, stable power supply has been restored in the non-faulty area, hence the distribution network has completed the entire self-healing control process, thereby naturally verifying the feasibility of the core logic for distribution network self-healing via sectional switch control.

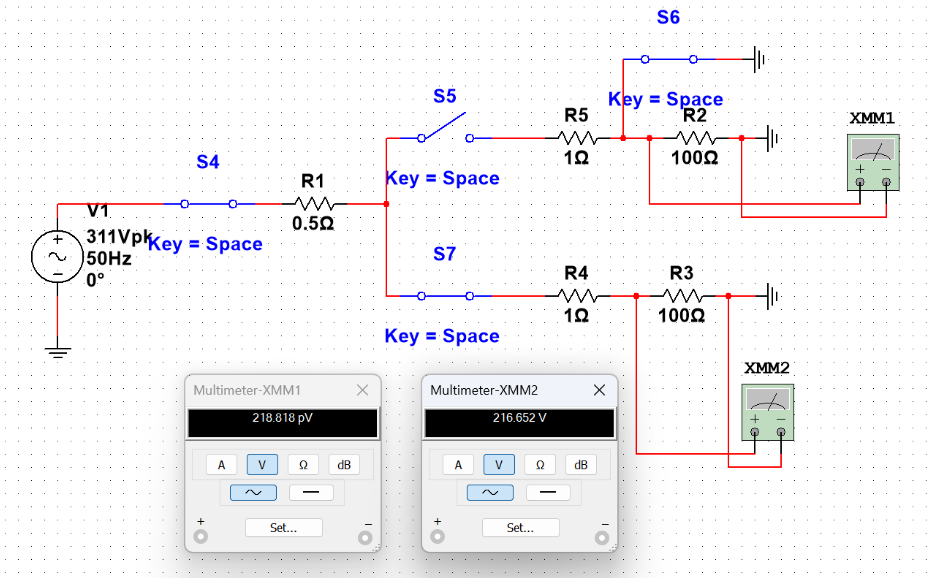


**Figure 6.** Voltage after Fault Isolation.

## 4. Challenges and Optimization Analysis of Distribution Network Self-Healing Control

Although the fundamental logic of distribution network self-healing control has been convincingly verified as feasible by simulation, it is well recognized that moving from laboratory simulation to practical engineering application involves numerous practical constraints such as hardware configuration, communication transmission, and field condition adaptation, which have already revealed many practical problems. Therefore, practical optimization strategies must take the field operation characteristics of the distribution network into account [13].

### 4.1. Major Existing Challenges

Because the present intelligent equipment configuration of the distribution network has evident deficiencies, it is clear that a large number of old distribution networks still use traditional switches and circuit breakers, which do not support remote control or remote signaling functions and therefore cannot receive automatic operation commands from the self-healing control system. As a result, fault isolation and power restoration still require manual on-site operation, directly reducing the response efficiency of self-healing control.

Since the distribution network has a large coverage area, wireless communication in remote areas is subject to considerable geographical and climatic interference, hence transmission delays and signal interruptions are common for self-healing control commands. Furthermore, intelligent devices made by different manufacturers use different communication protocols, so interconnection and interoperability are difficult to achieve, which in turn results in improper execution of control commands and failure to obtain the intended self-healing control performance.

Since present self-healing control strategies for distribution networks are mainly designed for single fault scenarios, they have poor adaptability, and given that the large-scale integration of distributed power sources changes the electrical characteristics of lines, while real-time power load fluctuations further complicate fault characteristics, it follows that existing fault identification strategies have low accuracy and hence the subsequent fault handling actions lack pertinence and effectiveness [14].

### 4.2. Targeted Optimization Strategies

Promote the intelligent upgrading of distribution network equipment, systematically replace distribution equipment with intelligent sectionalizers and intelligent circuit breakers having remote control and remote signaling functions, improve the real-time monitoring system for distribution network operation status, enhance the remote operation capability of equipment switching, and thus lay a reliable hardware foundation for the implementation of self-healing control.

Since the distribution network's overall communication network architecture can naturally be optimized by adopting a hybrid communication mode of optical fiber and wireless private network, it is reasonable to unify the communication protocols of intelligent devices from different manufacturers to eliminate communication barriers, thereby improving communication signal coverage in remote areas and ensuring reliable, fast, and accurate transmission of self-healing control commands.

Since the actual operating conditions of the distribution network vary, it is reasonable to improve the adaptive adjustment strategy of self-healing control and dynamically adjust the fault criteria in accordance with the integration of distributed generation and load fluctuations. Therefore, for complex scenarios such as distributed generation access and multiple superimposed faults, simple, efficient self-healing strategies should be designed to enhance the adaptability of control strategies and guarantee good performance in complex situations [15].

## 5. Conclusion

This paper takes a single radial distribution network as the research object and therefore gives a clear, logical presentation of the closed-loop core logic of perception - decision - execution, as well as the process of normal operation–fault triggering–fault isolation–power supply restoration, and verifies the technical feasibility using a simplified Multisim model. Hence it is very suitable for urban distribution networks, since rural and industrial park areas are well suited for improving power supply reliability, it is natural and reasonable to address the existing problems of insufficient intelligent equipment, unstable communication, and poor scenario adaptability by means of equipment upgrading, network improvement, and strategy perfection. Therefore, future research can reasonably move toward complex distribution network topologies and multi-fault scenarios, directly supporting the automatic upgrading of distribution networks.

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