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Fuse Maintenance to Solve Protection Problems in Active Distribution Networks in the Presence of Distributed Generation Sources

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Abstract

Renewable energy sources offer geographical opportunities for enhanced energy efficien-cy. However, the substantial integration of renewable energy production into distribution systems introduces uncertainties and technical complexities by impacting the network per-formance and protection mechanisms. Distributed generation (DG) enhances power grid efficiency, yet its influence on protection systems raises concerns about fault detection and isolation within active distribution networks. This study introduces a method to coordinate protection devices by inverter current control of distributed production sources during faults. The paper compares the impact of dispersed resources on flow dynamics during fault conditions. ETAP software simulations validate the proposed approach, addressing challenges in coordinating and regulating protection devices when integrating diverse re-sources into the network. This method restores coordination and enhances the reliability of protection systems. In summary, this research emphasizes the challenges of integrating re-newable energy into distribution systems, highlighting the need for effective protection co-ordination. The proposed method contributes to mitigating these challenges, ensuring de-pendable and efficient active distribution networks.

Keywords: Distributed generation, Distribution network, Power system protection, Renewable energy sources, Resource impact.

1. INTRODUCTION

Many countries around the world get some of their energy from renewable energy sources [1,2].

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Renewable energies have spread in different geographical areas.

The rapid deployment of renewable energy and the development of energy utilization technologies have led to greater energy security, climate change mitigation, and economic benefits [3,4].

Renewable energy can be used for electricity generation, water heating and cooling, and transportation [5,6]. Renewable energy sources are natural resources that can be converted into clean and usable energy [7,8].

The electricity industry is one of the most vital industries of any country. Electrical energy distribution networks are the meeting place of electricity industry subscribers [9,10]. The increasing development, lack of proper design, and lack of technological progress always bring problems in the electrical energy distribution system [11,12].

The power distribution system is one of the main parts of the power system that is directly connected to the load. The aggregation of renewable and scattered energy sources at the distribution level is an important and fundamental issue in the power system [13,14].

One of the issues that the use of renewable energy sources creates in the distribution system is intermittent feeding. The widespread use of renewable resources causes the distribution feeders on current relays to be interrupted frequently, which can affect the distance relays of the transmission system. However, the electrical distance between the producer and the consumer is reduced by using distributed generation resources, as well as improving the voltage profile, reactive power, and reducing problems between distribution and transmission [15,16].

So far, various studies have been conducted in the field of distribution system protection with the presence of distributed resources [17,18].

To solve the connection protection problem of distributed generation (DG) connected to a radial distribution system, a method is investigated in [19]. In this method, a feed-forward neural network is used to identify the location of the error and then protect the system.

An adaptive scheme for the restoration of protection coordination in distribution networks with high penetration levels of DG units is presented in [20]. A multi-agent system (MAS) structure is used, and the main protection technique is the lateral fuse current, monitored by an intelligent electronic device to estimate the fuse operating time, and send this data to the upstream reclosers.

In this paper, the purpose of modifying the protection settings is to restore the coordination of the protection plan with the least change and by introducing scattered sources with high penetration coefficient. The structure of the article is as follows. In section 2, the radial distribution network under study is mentioned. The proposed control strategy is explained in section 3. In section 4, analysis and discussion of simulation results are presented. Finally, the conclusion of the paper is stated in section 5.

2. DISTRIBUTION NETWORK

The power distribution system is located after the substation, which is fed from the transmission system, and delivers the electrical energy to the final consumer [21-26].

In other words, the distribution system is placed between transmission and consumption. In these systems, protective equipment is usually used [27,28].

The types of power distribution systems are: radial system [29,30], ring system [31], and mesh system [32], each of which is different in terms of configuration and has advantages and disadvantages.

The most common configuration used in power distribution networks is the radial distribution system, which is the simplest and cheapest structure for an electrical distribution network [33,34]. This system has a tree-like topology, and there are no closed loops, so power is delivered from one bus to another. In this structure, if a line is cut for any reason, it will be difficult to provide power to all the lines below it. This type of distribution system is only used for short distances due to its limitations. The radial system can be expanded by adding more tires [35,36].

In this study, a distribution network with a radial structure according to Fig. 1 is considered [37]. As can be seen, the current reaches the network loads in the side branches from one side and through the upstream power station.

The existing protection system employs a conventional approach with a fuse protection scheme in place. At the outset of the main feeder, a recloser is strategically utilized, while each side branch is equipped with a fuse. However, due to transient faults during fuse operation, the reclosers are frequently engaged to safeguard the fuse from burning out or melting. This issue has resulted in extended outage durations for customers, increased network load, and escalated power system expenses.

To address this concern, a reduction in the time interval between the reclosers and corresponding fuse 4 is proposed, influenced by the production volume of the PV source. As the PV source's penetration coefficient rises, the injected current during fault conditions intensifies, subsequently the operation time of protective devices decreases. This reduction in operational time can potentially lead to diminished coordination between the reclosers and fuse 4, even to the extent of causing a protection mismatch.

Additionally, distributed generation sources feature inverters as a crucial protective component. These inverters are integral to connect these sources to the network, necessitating their protection against faults and short circuits. This

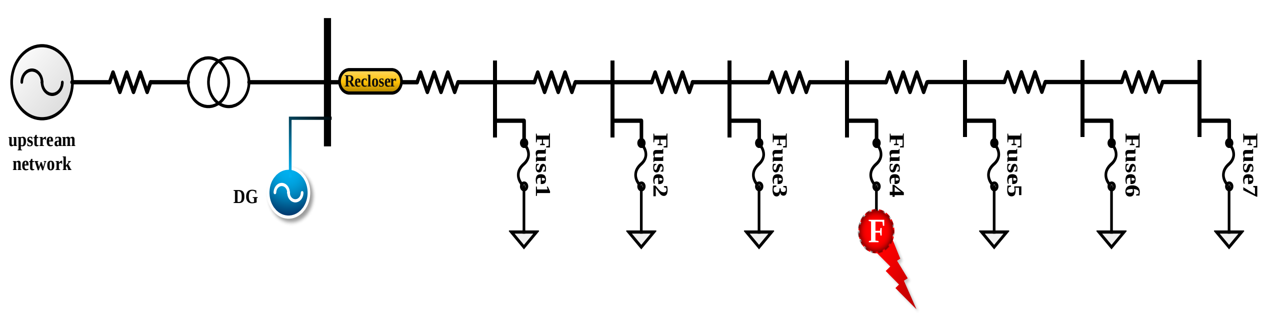

Fig. 1. Distribution Network Single-Line Diagram within ETAP Environment for Study.

safeguard is inherently provided by the inverters themselves, limiting permanent short circuit currents. This restriction is established through the inverter's internal settings, often represented as a K-factor ranging between 200% to 300% of steady-state current.

In line with the proposed method, the configuration adjustments are to be implemented specifically for inverter-based distributed generation sources. This modification aims to enhance protection and coordination within the distribution network.

3. CONTROL STRATEGY

Distributed generation sources, especially renewable energy sources, are used with the aim of obtaining maximum power from the power source.

In photovoltaic systems, to protect the internal circuits of the inverter, a sudden increase in the output current is prevented [38,39]. These sudden current increasements occur in the condition of voltage drop, such as failure mode in the network [49,41].

In the condition of voltage drop from the nominal value, according to the specifications of the photovoltaic system, the production current increases, so that the output power of the photovoltaic system remains constant. In the severe voltage drop caused by the connection in the network, the increase in the source current damages the inverter and internal circuits and is limited at a certain level. Therefore, in this mode, the inverter working mode changes from the working mode with constant power to the working mode of constant current, which is called fault ride-through (FRT) working mode.

4. SIMULATION RESULTS

The simulation results are presented in this section using ETAP software. Fault occurrence conditions and protection coordination checks in the presence of distributed generation resources are shown to evaluate the method. The studied system is a distribution network, which is shown in Fig. 2. The network has a radial structure, with voltage levels of 20 and 0.4 kV, and the network loads are located in the side branches. Each side branch is modeled with a microgrid, where the assembly, 20 kV bus, 0.4-20 kV transformer, 0.4 kV bus, and finally the connected load is placed. The short circuit level of the network is 450 MVA and the length of each part of the feeder is 2 km.

In the common feeder protection scheme (coordinated fuse protection scheme), reclosers are placed at the beginning of the feeder, and fuses are installed at the beginning of each side branch. According to this design, for any short circuit that occurs in the protection zone of the fuses, the reclosers are responsible for the quick repair of the fault, which is prevented in the network due to the burning of the fuses due to transient connections. If the occurred error is stable, after disconnecting and connecting the reclosers several times and finally locking, the aforementioned error is solved by burning the fuse.

As shown in eq.1, based on the curve set on the reclosers, the operating time should be less than 75% of the fuse operating time.

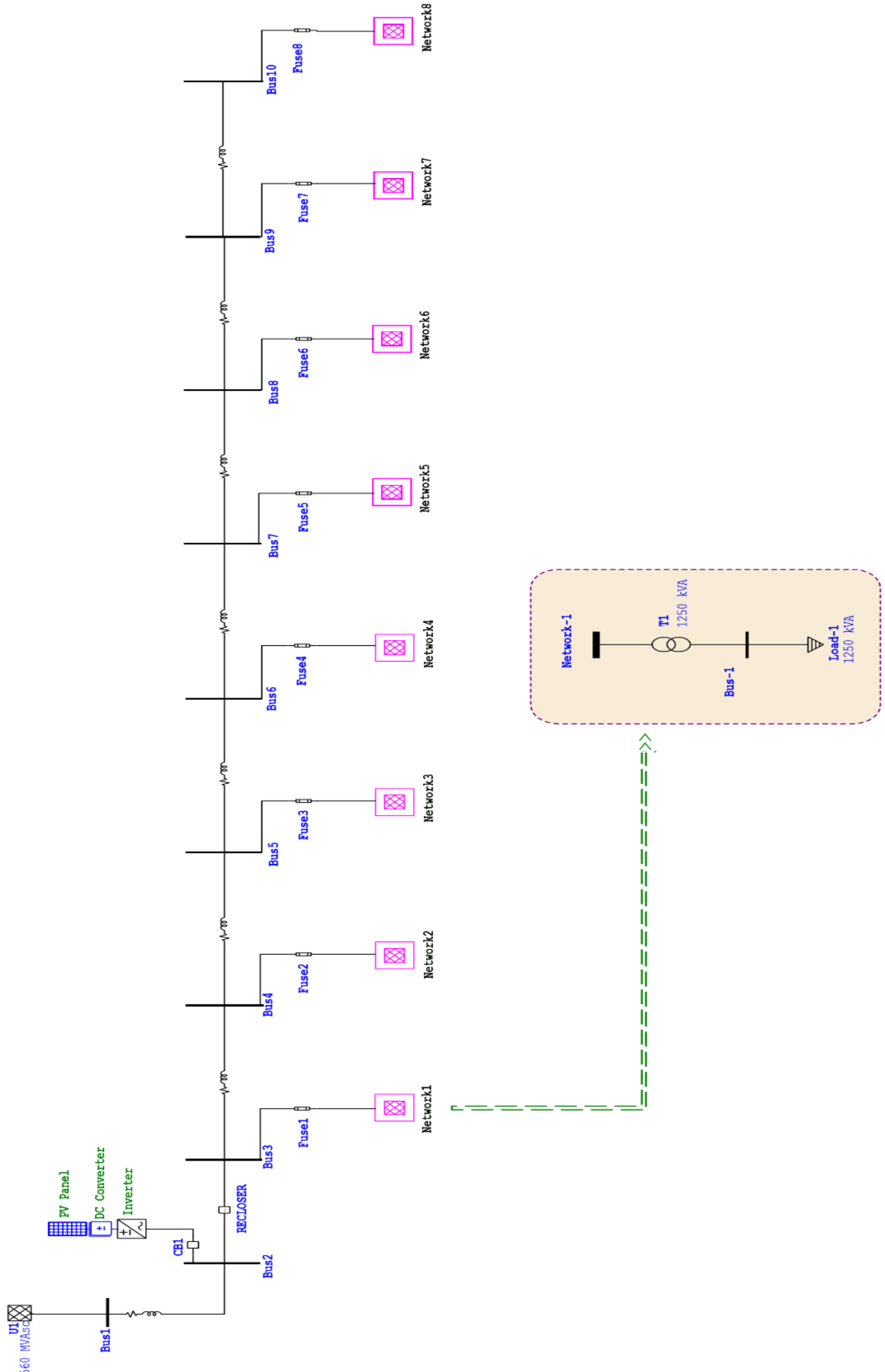

Fig. 2. Single-Line Diagram of Investigated Distribution Network in ETAP Environment.

When there is no PV in the grid, the fault current through the grid is equal to 982 amps due to the fault created in the Fuse4 protection zone. The operation time of the reclosers according to the predefined protection curve is 136 milliseconds. After the reclosers had operated their fast curve twice, the fuse blew due to the residual fault at 648 milliseconds, breaking the circuit.

$$t_{Recloser} \leq 0.75\times t_{Fuse} \quad (1)$$

It can be seen that the coordination is well maintained, as the time of 136 ms is less than the 75% fuse melting time (648 ms), 487 ms. In this situation, the protection characteristic curve of reclosers and fuse 4 of the tested network is shown in Figure 3.

In the event of a fault in the area protected by fuse 4, the operation of two protective devices is shown.

For a penetration factor of 25% of the photovoltaic source, the fault current passing through the feeder was equal to 1054 amps, for which the operating time of the arresters and the fuse is equal to 134 ms and 365 ms, respectively.

After applying the proposed method in controlling the output current of the PV source, in case of an error corresponding to the voltage of the connection point of that source to the network, the fault current passing through the protection equipment is controlled and coordinates them.

Table (1) shows the effect of the proposed method on the operation time of fuses and reclosers in the presence of a distributed generation source. The coefficients of the presence of scattered production sources, coordination between two protection devices, recloser, and fuse, based on the fuse protection scheme, well maintaining the worst conditions of the presence of PV sources, the margin of coordination between reclosers and fuse can be seen in Fig. 4.

At the highest penetration coefficient and the protection characteristics of the two devices are presented in Fig. 5. Also the good effect of the proposed method can be seen.

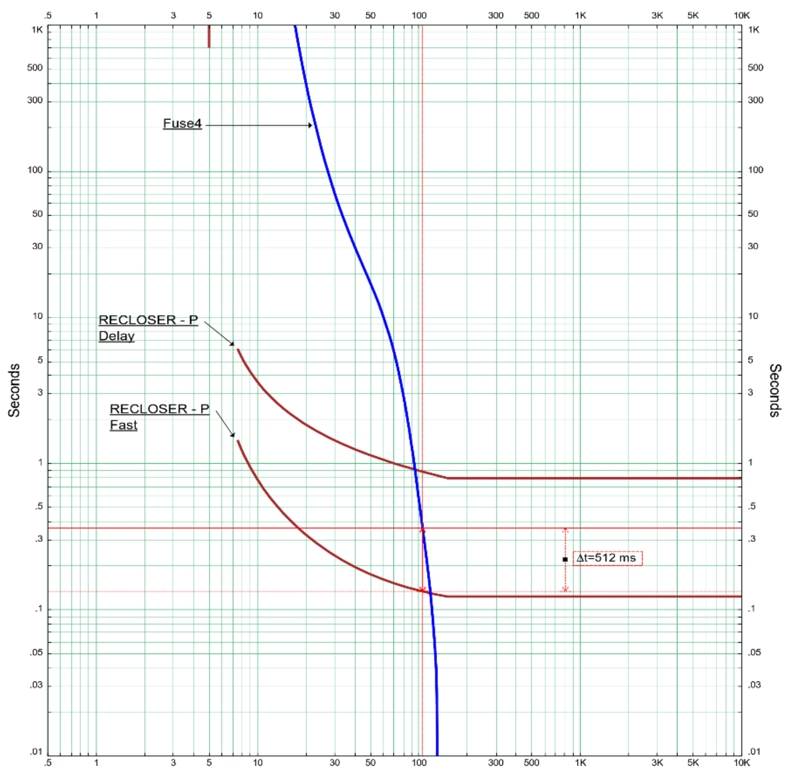

Fig. 3. Protection curves for fuses and reclosers.

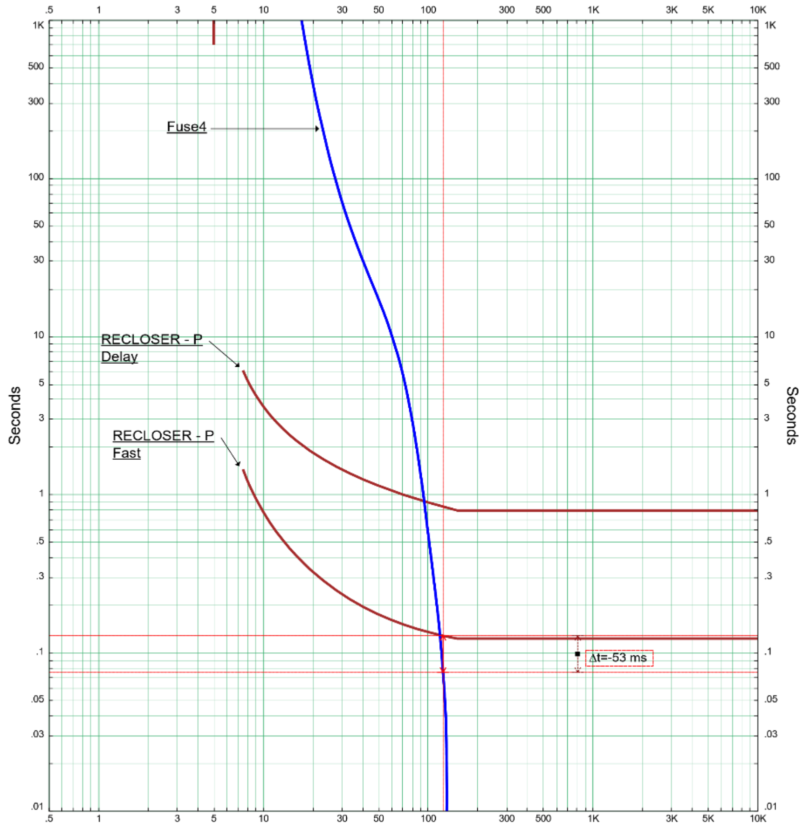

Fig. 4. The PV source's presence with the highest penetration coefficient according to the initial design.

Table 1. ***Operation durations of fuses and reclosers considering dispersed production sources following the implementation of the suggested approach.***

PV (%)	Δt (ms)	$t_{Recloser}$ (ms)	t_{fuse4} (ms)	$I_{Recloser}$ (Amp)	I_{fuse4} (Amp)
100	16.75	130	196	1130	1130
75	61.5	131	257	1096	1096
50	125.75	132	344	1059	1059
25	217.5	134	469	1021	1021
0	350.75	135	648	982	982

5. CONCLUTION

Advancements in technology have instigated profound transformations in power networks, particularly within distribution networks. Consequently, the enhancement of electrical networks can give rise to intricate issues warranting investigation. The power distribution network's protection system holds paramount significance and can encounter challenges stemming from distributed generation sources, including alterations in network protection configurations. This study employs current control through a distributed source inverter.

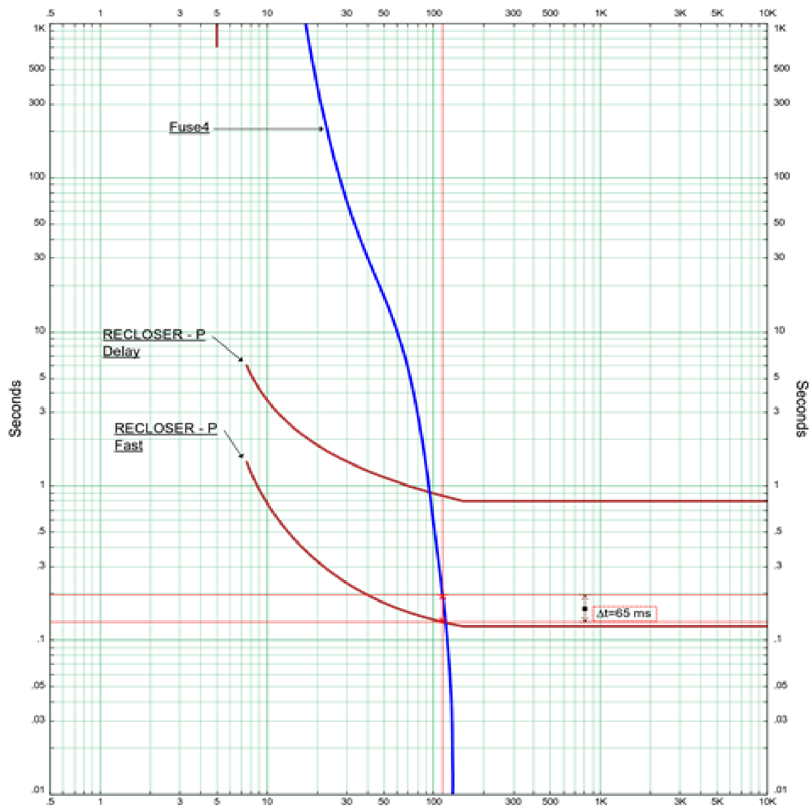

Fig. 5. The existence of the PV source with the utmost penetration coefficient, as per the newly proposed control method.

It outlines the design and coordination of a fuse-reclosers protection scheme within a 20 kV distribution network. This endeavor delves into both the coordination of protection for dispersed production sources and the quandaries posed by escalating penetration rates. The simulation is executed using ETAP software, elucidating the study's insights and outcomes.

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