Digital Implementation of an Auto-Reclose Protection Scheme for a Distribution System

Sikho Ntshiba and Senthil Krishnamurthy
Deptment of. Electrical, Electronic and Computer Engineering
Center for SubStation, Automation and Energy Management Systems (CSAEMS)
Cape Peninsula University of Technology
Cape Town, South Africa
sntshiba0@gmail.com and krishnamurthys@cput.ac.za

Abstract— The distribution system is an important component of the power system since it distributes energy and collects income. Unavoidably, the distribution system is prone to fault conditions. When these fault conditions arise, the power lines of the distribution system are interrupted, and consumers are left without energy for hours, depending on the sort of network failure. Among the distribution system's customers are hospitals, residential areas, industry, agriculture, and schools. When users are deprived of service, power providers lose revenue and struggle to meet reliability requirements. When electric utilities fail to deliver energy in compliance with the contract's conditions, they are subject to fines. Traditionally, electric companies identified disruptions using a problem call system, in which a customer suffering a power loss would contact the company and report the outage. Field operators would be dispatched from control centers to restore electricity. This strategy leads in customers being without power supply during outages for an extended period of time. As a result, this study devised an auto-reclose technique for reconfiguring the 22kV distribution system in the event of a fault. in utilizing the DIgSILENT software. The designed auto-reclose technique is simulated and tested in the DIgSILENT simulation environment.

Keywords—Auto-reclose scheme, network reconfiguration, overcurrent protection.

I. INTRODUCTION

Reclosers are essential in a distribution network. They are strategically placed on a distribution system feeder. When a fault is detected, reclosers detect, interrupt, and reclose power circuits. Reclosers are graded or coordinated with other field devices to reduce the number of power outages.

The overcurrent and auto-reclose applications were investigated in the first part of the literature study as follows. In a power system, distribution system faults occur more frequently than in other sectors, resulting in service interruption to customers [1]. When these fault conditions occur, they disrupt the distribution system's electrical lines, leaving customers without electricity. Enhancing service dependability while lowering associated costs is a primary objective for power utilities in order to increase customer satisfaction and retention [2]. Rapid response and dependability are required of the protective system. A variety of devices have been used to protect the distribution system network, including overcurrent relays, reclosers, sectionalizers, and fuses [3]. Automatic reclosers must be deliberately situated and configured to isolate problematic network segments and restore power to healthy network segments in order to improve service reliability..

Different researchers proposed auto-reclose function using different software's. In [4] a new auto-recloser framework on Matlab Simulink is proposed. Ref [5] proposed adaptive single pole auto-recloser algorithm to discriminate permanent and temporary faults using EMTP software. Author's [6] implemented a smart PC based auto-recloser using Labview. Literature review was conducted to ascertain the difficulties associated with power restoration. [7] investigates a problem diagnosis scheme for grounded or unground distribution system architectures. This approach detects, classifies, and locates fault states using an artificial neural network (ANN). In 1998, [8] proposed a PC-based system for demonstrating the use of artificial intelligence to diagnose and restore electricity to an interconnected distribution system. To restore power, the intelligence technique makes advantage of the post-fault network's status, tripped breakers, main protection alert, and conventional event. To restore electricity in a radial distribution network, Ref [9] devised a fault detection, isolation, and restoration strategy employing a radial distribution network. [10] proposes a service restoration genetic algorithm for the distribution system that prioritizes the most critical loads and identifies the least-cost restoration plan that maximizes restored loads while minimizing the projected number of switching operations. Ref [11] described a communication-based recloser method that, by using the recloser deadtime, decreases the restoration time in smart distribution systems. The theoretical features of fault detection, isolation, and restoration in a distribution system are discussed in [12]. The article discusses the technological, environmental, and economic problems associated with distribution system self-healing. In ref [13], a hybrid technique for recloser and sectionalizer in distribution systems was presented, taking into account protection coordination, fault type, and equipment malfunctioning.

The second part of the literature looked into various ways for isolating fault conditions and restoring service. A 22kV distribution network is modeled in the DIgSILENT software environment in this paper, and the simulation results are analyzed. The simulation examines the performance and coordination of overcurrent protective reclosing relays. The findings of the simulation are utilized to determine the pick-up settings for the auto-recloser method. The overcurrent relaying system's performance is investigated by simulating fault conditions in various areas of the distribution network. The auto-reclose function, as well as network reconfiguration, are investigated and examined.

The first section of this paper highlights the challenges of distribution and the importance of reclosers. The principles of operation of reclosers are described in Section 2. The findings of the considered distribution network's modeling, simulation, and analysis are presented in Section III. CT selection and overcurrent protection settings are covered in Section IV. Section V discusses the simulation results for overcurrent and auto-reclose scheme and section VI and VII provides paper's conclusion and future work.

II. THE PRINCIPLE OF OPERATION OF AUTO-RECLOSERS

According to IEEE Std C37.104-2012, the primary parameters and settings for auto-reclose schemes include the number of reclosing tries, deadtime, reclamation time, auto reclosing reset time, and reclosing lockout [14].

A. *Number of reclosing attempts*

The number of reclosing efforts is a predefined number of attempts made by the recloser to correct a problem over a certain period of time. There are no hard and fast rules for determining the number of reclosing procedures, but some elements must be considered. According to reference [15], these factors include circuit breaker constraints and system conditions.

B. *Deadtime*

The time period between the circuit's interruption and re-establishment upon reclosing. Before attempting to auto-reclose a circuit breaker that tripped due to a fault, several critical variables must be considered. These parameters include system stability and synchronization, load type, circuit breaker characteristics, protection reset time, and deionization of faults. While the objective is to swiftly restore supply to consumers, auto-reclosing attempts without allowing sufficient time for the dielectric to re-establish its strength result in a failed reclose attempt. If sufficient time is not allowed for the gas to disperse, the ionized gas channels generated by the fault arc will resume conducting after the auto-reclose. The time required for deionization is dependent on the voltage, the distance between conductors, the amount of the fault current, and the meteorological conditions [16]. The time delay required to deionize the air at the fault point can be computed using equation 1 [14]. "t" denotes the time period in cycles, whereas ",V-LL." denotes the rated line voltage in Kilo volts.

$$t = 10.5 + \frac{V_{L-L}}{34.5} \qquad (1)$$

Table 1 summarizes the usual recloser deadtime periods prescribed by IEEE Std C37.104-2012 at the distribution system level.

Table 1: Distribution system recloser deadtime intervals

Deadtime interval	Typical time setting range in seconds
The initial trip to first reclose	0-5
Second trip to second reclose	10-20
Third trip to third reclose	10-30

This article uses three seconds, ten seconds, and ten seconds for the initial reclose, the second reclose trip, and the third reclose trip, respectively.

C. *Reclaim time*

The recovery time is dependent on the type of protection utilized and the circuit breaker's spring winding time, as stated in IEEE Std. C37.104-2012. Reclaim time is the time required for the counting mechanism to return to its initial position following one or more counting operations. The reset time in an auto-reclosing device is the amount of time that must pass after a completed closing operation, measured immediately from the contact made by the closing contacts, before the reclosing device commences a new reclosing sequence, in the case that the fault persists.

D. *Autoreclosing reset time and autoreclosing lockout*

The reset time refers to the amount of time required for a reclosing relay to reset following a successful auto-reclosure. After the reset time delay ends, if auto reclosing is successful, the reclosing relay returns to its reset state. The reset time delay may be selected based on the type of the issue and the anticipated clearing time. A longer reset delay prevents excessive tripping and auto-reclosing in the event of intermittent problems. A delay less than the time interval between intermitted faults allows the reclosing to reset, so preventing lockout. Excessive operations are prevented by lengthening the reset time on the reclosing relay, however this may result in unwanted lockout operations.

When automatic reclosing attempts fail, the reclosing relay enters a lockout condition, preventing the circuit breaker from being closed automatically. After a predetermined number of fully unsuccessful tries to re-energize the line, auto-reclose is disabled. Lockout conditions prevent persistent faults from causing harm to the device and the entire distribution system.

The DIgSILENT software's EMT defines the auto-reclose sequence procedure as given in steps 1 to 11 below. Based on the SEL-351 relay operation duration, the fault is simulated and cleared. The deadtime is defined in accordance with IEEE Std C37.104-2012.

- Step 1: Identify the first fault state.
- Step 2: Define clearing a fault condition depending on how long the relay would have to run to clear that specific fault state.
- Step 3: Establish the first deadtime interval.
- Step 4: Create a second set of fault circumstances.
- Step 5: Specify how to clear the fault condition.
- Step 6: Establish the second deadtime interval.
- Step 7: Establish the third fault condition.
- Step 8: Specify how the fault situation should be cleared.
- Step 9: Establish the third deadtime interval.
- Step 10: Define a fault and clear the fault.
- Step 11: Specify the lockout state.

III. DISTRIBUTION NETWORK MODELING , SIMULATION AND RESULTS

This section describes the considered distribution network and its data, modeling, simulation and results.

A. *Discription of the four bus radial distribution network and power system data*

The performance of the auto reclose function was investigated in this paper using a four-bus radial distribution network as a case study (see Figure 1). Table 2 contains network data. Six overhead lines and six lump loads are connected to the network via two parallel 66kV to 22kV transformers. A typical open point separates the two radial lines (NOP). It is worth noting that the load flows are carried out with both transformers operational and the tap changer set to tap two. The reason for setting the tap changer to tap two is that this is the tap position that can supply the entire load from both feeders A and B with the NOP open, or from either feeder A or B with the NOP closed, without changing the voltage profile.

Table 2: Distribution network data

Power system components	Ratings
Transformer 1	HV 66kV/LV 22kV
Transformer 2	HV 66kV/LV 22kV
Load 1	1.2MW at 0.95 pF
Load 2	0.9MW at 0.95 pF
Load 3	0.9MW at 0.95 pF
Load 4	1.4MW at 0.95 pF
Load 5	0.75MW at 0.95 pF
Load 6	0.75MW at 0.95 pF

The following three configurations are tested with reference to the network diagram with load flow depicted in Fig.1 and detailed simulation results presented in Table 3 with scenarios 1 to 3 as follows:

1. When the NOP is open and both Feeder circuit breakers (CB) (A and B) are closed
2. When the NOP is closed, the feeder B circuit breaker is open, and the whole distribution system network is fed by feeder A.
3. When the NOP is closed, the circuit breaker at feeder A is open and feeder B supplies the full distribution system network.

B. Load flow and short circuit study simulation results

This section describes the distribution system network power flow and short circuit simulation results. Normally, the distribution system under investigation is operated with two transformers in service. When one transformer fails due to a malfunction or maintenance, the second transformer should be capable of supplying the distribution system's whole load. The following table summarizes the load flow investigations for the three situations considered. Which are as follows: a) The NOP is open, but the CBs A and B are closed; b) Feeder A feeds the network with the NOP closed; and c) Feeder B feeds the network with the NOP closed. Table 3 provide the simulation results summary of the three scenarios. These results include p.u voltage profile on each busbar, loading of transformers and each load.

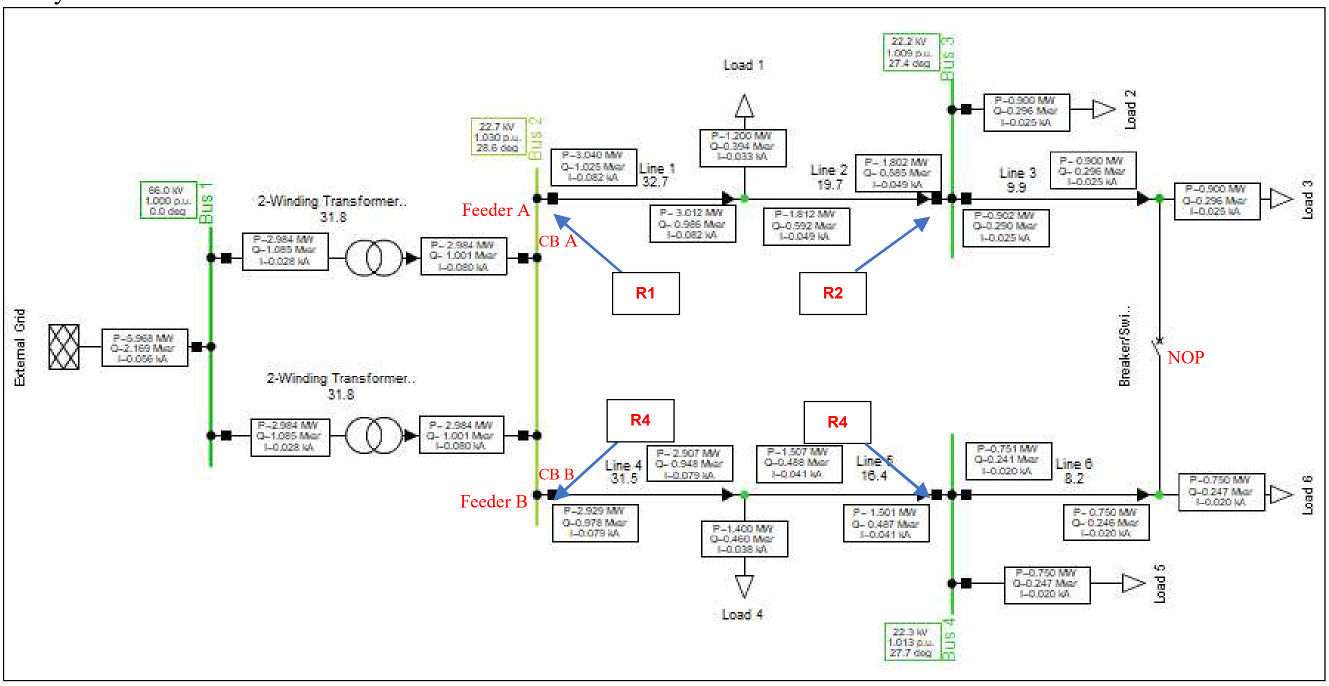

Fig.1: Single line diagram of the network, when NOP is open and CB's A and B closed

Table 3: Summary of the three simulation results

Power System components	Scenario 1	Scenario 2	Scenario 3
	Voltage in p.u		
Bus 1 (Slack Bus)	1	1	1
Bus 2 (PV Bus)	1.03	1.028	1.029
Bus 3 (PQ Bus)	1.009	0.978	0.965
Bus 4 (PQ Bus)	1.013	0.954	0.987
	Transformer summary		
Transformer 1 Transformer 2	2.98MW 1.08Mvar 0.94 PF 0.03kA 31.75% loading	3.08MW 1.26Mvar 0.92 PF 0.03kA 33.26% loading	3.05MW 1.22Mvar 0.93 PF 0.03kA 32.87% loading
	Load summary		
Load 1	1.2MW 0.394Mvar 0.95 PF 0.033kA	1.2MW 0.394Mvar 0.95 PF 0.033kA	1.2MW 0.394Mvar 0.95 PF 0.035kA
Load 2 Load 3	0.9MW 0.3Mvar 0.95 PF 0.025kA	0.9MW 0.3Mvar 0.95 PF 0.03kA	0.9MW 0.3Mvar 0.95 PF 0.03kA
Load 4	1.4MW 0.46Mvar 0.95 PF 0.038kA	1.4MW 0.46Mvar 0.95 PF 0.041kA	1.4MW 0.46Mvar 0.95PF 0.038kA
Load 5 Load 6	0.75MW 0.25Mvar 0.95 PF 0.02kA	0.75MW 0.25Mvar 0.95 PF 0.02kA	0.75MW 0.25Mvar 0.95 PF 0.02kA

On the considered distribution network, a short circuit analysis is performed. Consideration is given to three-phase and single-phase phase short circuits. Table 4 summarizes the short circuit results for feeders A both upstream and downstream. The fault current results provide an accurate representation of the short circuit currents at their fault current locations, which correspond to the positions of the protection relays. The fault analyses were carried out at the outgoing and downstream ends of feeder A, where R1 and R2 are located. Table 4 shows the fault current and apparent power at the various places.

Table 4: Short circuit simulation results for upstream and downstream of feeder A and B of the distribution network

Fault type	Fault location	S (MVA)	I (kA)
Single-phase to ground fault	Feeder A (Line 1 at 1%)	73.8	5.81
Three-phase fault	Feeder A (Line 1 at 1%)	186.21	4.89
Single-phase to ground fault	Feeder A (Line 3 at 1%)	12.73	1.0
Three-phase fault	Feeder A (Line 3 at 1%)	64.02	1.68

IV. Selection of CT and Overcurrent Protection Settings

The CT ratio should be large enough that the CT secondary current does not exceed twenty times the rated current when the primary fault current is maximum symmetrical [17]. The CT ratio chosen is 300:1. The maximum load current feasible in the examined distribution system network is attained when Feeder A supplies the entire distribution system with 168A. Due to the fact that this current is smaller than the CT primary current, it complies with the IEEE standard IEEE Std C37.110.

The overcurrent protection configuration settings are provided in Table 5. These are the parameters for Feeder A, relay 1, and relay 2. This paper will examine only feeder A, and the same will be true for feeder B. In feeder A, the maximum fault current is 5.81kA. When the maximum fault current is multiplied by the CT ratio (5.81kA/300 = 19.37A), the result is less than 20 times the rated CT secondary current.

For protective relay applications to distribution lines, the pickup currents were determined using IEEE Standard C37.110-1996. Phase overcurrent protection elements in accordance with ANSI codes 50, 51, and 67 detect single-phase and three-phase overcurrent. The earth fault protection element, which has the ANSI codes 50N, 51N, 50G, and 51G, detects an earth fault. When the fault current exceeds the relay threshold setting, the Protection feature is activated.
The automatic recloser operating time is defined by IEC 60255 and IEEE C37.112 and is given in Equation 2.

$$T_p = TMS \times \frac{0.14}{\left(\frac{I}{I_s}\right)^{0.02} - 1} \quad (2)$$

Where:
T_p is the operating time of a relay
TMS is the multiplier setting
I is the current detected by the relay
I_s is current setting

Table 5: Configuration of the R1 and R2 realys, as well as the residual overcurrent element

Protection device name	Branch	Stage (Phase /Residual)	Characteristic curve	I Pick up primary	I Pick up Secondary With CT ratio 300:1	Time dial	Direction
Relay 1	Line 1	51P	IEC Normal inverse	168×1.5= 252A	0.84A	0.13s	Non-Directional
		67P1	IEC Definite time	3900A	13A	0s	
		51G	IEC Normal inverse	252×0.25 = 63A	0.21A	0.17s	
Relay 2	Line 2	51P	IEC Normal inverse	135×1.5= 202.5A	0.68A	0.05s	

V. Overcurrent and Auto-Reclose Simulation Results

In this section a three-phase short circuit on feeder A between R1 and R2 studied and analyzed. The goal of this study case is to use the EMT simulation to explore the SEL-351 overcurrent relay's characteristics and auto-reclose function on DigSILENT software.

Between busbar 2 and busbar 3 (Line 1-Line 2) of feeder A, a three-phase short circuit is simulated. When a momentary fault occurs on this segment of the line, power is expected to be restored after the SEL-351 relay is reclosed (relay R1). When a three-phase permanent fault occurs at this section of the line, relay R1 is expected to auto-close three times, and if the fault persists, relay R1 is expected to lockout, send an open signal to SEL-351 (relay R2) downstream at busbar 3, and send a close signal to the NOP to back feed the section of the line between busbar 3 (Line 3) and NOP.
In DigSILENT, an EMT simulation was run for 25.5 seconds to emulate the auto-reclose function described above. With reference to Fig 2, At 0.1 seconds, a three-phase fault was introduced in the segment of the line, which was cleared after 0.385 seconds. Because the initial recloser occurred after 3 seconds, the entire Feeder A line was dead for 3 seconds. Feeder A is subjected to a 10-second dead period. The fault was still simulated, and after 0.385 seconds, a second reclose happened, and the fault was cleared. Feeder A is subjected to a 10-second dead period. After 0.385 seconds, the fault was still simulated and cleared. It is evidence that the problem is permanent after three reclosure efforts, and the relay will trip and lockout. Table 6 contains a summary of the auto-reclose sequence.

Table 6: Feeder A auto-reclose procedure for a three-phase fault between relays R1 and R2 (between Line 1-Line 2)

Recloser operation modes	Dead Time	Fault current	Fault initiated	Fault cleared	Fault duration
Recloser first attempt	-	2.229 kA	0.1s	0.485s	0.385s
Recloser second attempt	3s	2.232 kA	3.485s	3.87s	0.385s
Recloser third attempt	10s	2.233 kA	13.87s	14.255s	0.385s
Recloser fourth attempt	10s	2.134 kA	24.255s	24.255	0.385s

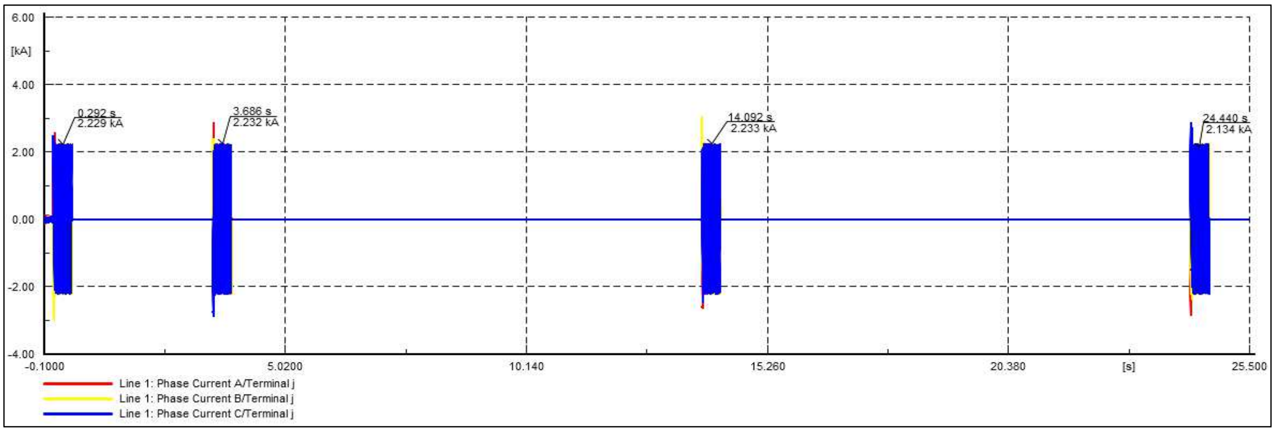

Fig.2: Auto-reclose results for three-phase fault between R1 and R2

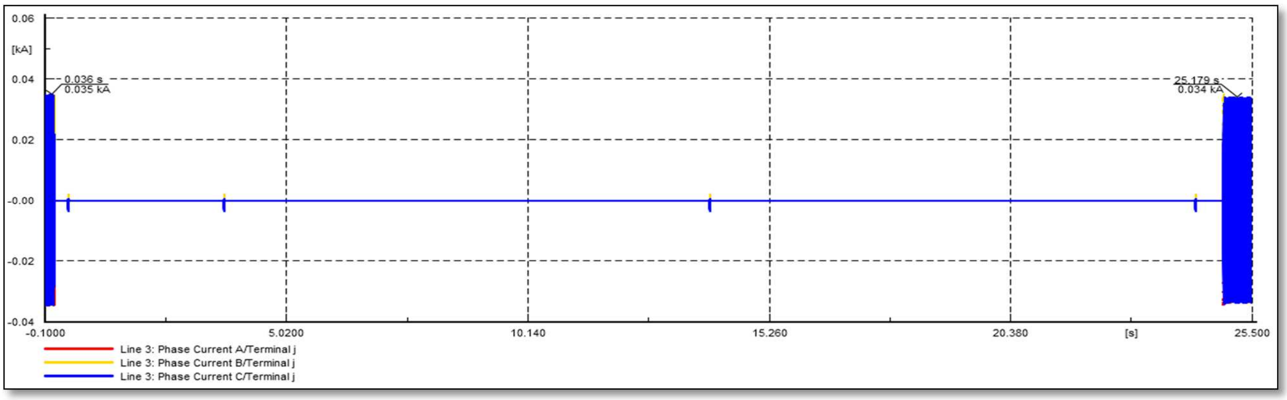

Fig.3: Back feed for the line segment between busbar 3 and NOP (line 3)

Fig.2 depicts the usual load current before the fault was introduced between 0 and 0.1 seconds, as well as the three attempts at reclosing till the lockout state. Fig.3 depicts a three-phase current for line 3 when the permanent fault between busbars 2 and 3 occurred (between R2 and NOP). As illustrated in Fig.3, a normal load current of 0.035kA flowed between 0 and 0.1 seconds. When the fault was introduced at 0.1 seconds, R1 locked out and R2 opened, the NOP closed, and line 3 was again supplied via the NOP by feeder B, the auto-reclose cycle occurred. After the auto-reclose cycle was completed and the faulty section was separated, the normal load current was flowing on line 3 to supply load 2 and load 3, as illustrated in Fig.3 The resultant power flow is depicted in Fig.4 after the faulty section of the line between busbar 2 and busbar 3 was disconnected. Electricity is passed from feeder B to line 3, through the NOP, to provide power to loads 2 and 3. The overcurrent curve used to examine the performance of relay R1 is shown in Fig.. The inverse time overcurrent element (51P1) operated at 0.385 seconds due to a fault of 2536.76A, as shown in figure 5. The definite time element (67P1) was not triggered, and its operating time was 9999.999 seconds.

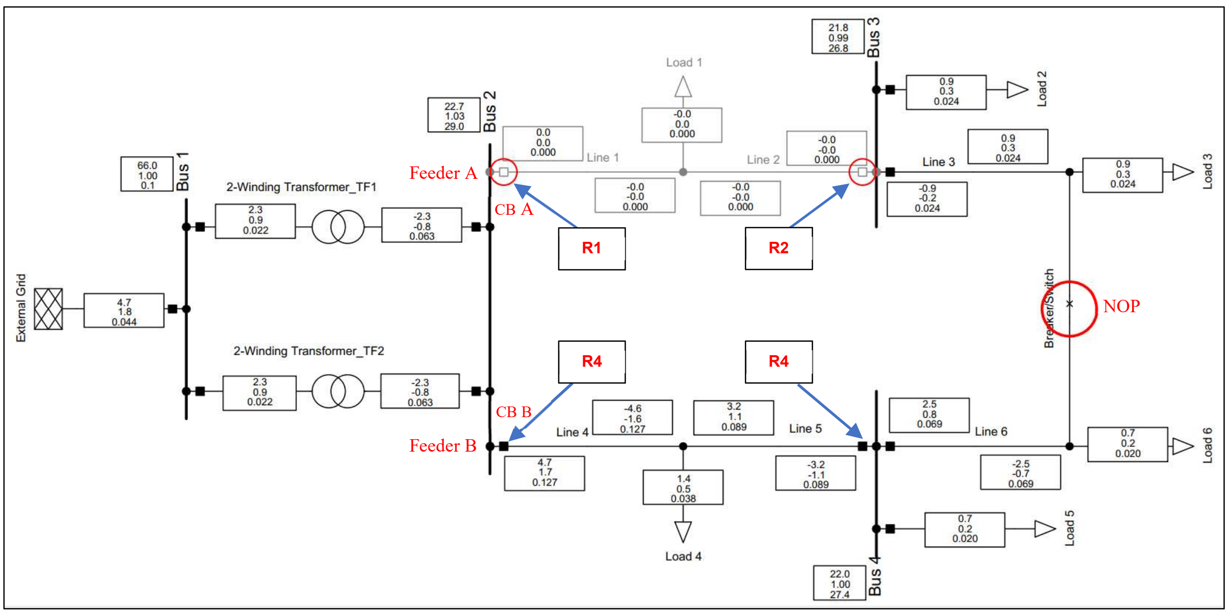

Fig.4: Power flow after isolating line busbars 2 and 3

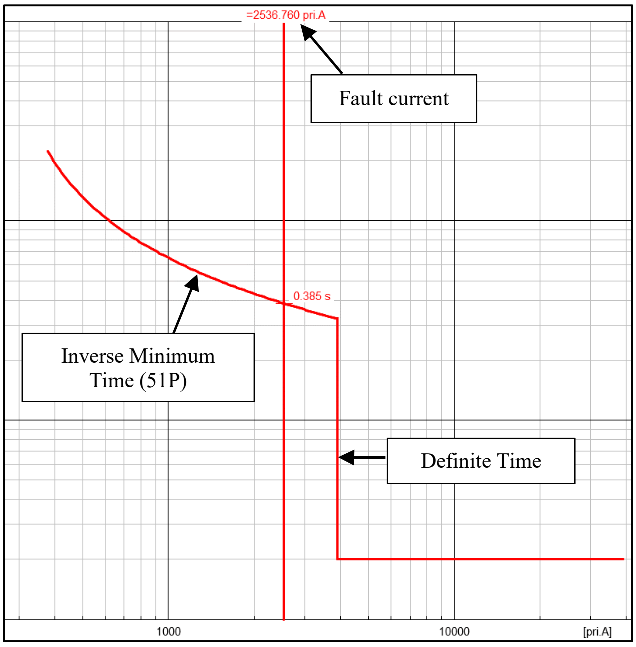

Fig.5: R1 overcurrent response for a three-phase fault on the line between busbars 2 and 3

VI. CONCLUSION

The auto-reclose overcurrent protection solution for industrial distribution networks was presented in this paper. The recloser overcurrent relays use both current and time discriminations for upstream and downstream coordination. According to the simulation results, when the outgoing feeder fails, the downstream segment of the network can be immediately back-fed by the healthy feeder. According to the simulation findings presented in this research, both transient and permanent phase faults in the network are evaluated for overcurrent relay performance for the recloser functions. The ground fault scenario is investigated for a persistent issue in the network while considering human and animal safety. The relay performance was satisfactory in both three-phase and ground fault conditions, and it satisfied the protective time stamp requirements.

VII. FUTURE WORK

The author intends to concentrate on technologically oriented solutions for automatic reconfiguration of the distribution network using IEC61850 standard-based reclosers features. The authors' previous work on IEC61850 application to motor protection and capacitor bank protection can be found in references [18] and [19]. The key knowledge gained from those references will help the researchers in the design of a completely automatic recloser system for a distribution system.

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