Implementation of a Distance Protection Scheme using Real-Time Digital Simulator

Dr. S. Krishnamurthy and C.W Van Wyk

Abstract— Electrical protection plays an important role in the transmission of electricity. This is due to the mere fact that human control can cause disruption in transmitting the electricity to the end-user. Distance protection, which forms part of electrical protection, is one of the most important types of protection to ensure the continuity of supply to the end-users. Proper electrical protection measures are required to avoid the damages on the overhead line equipment and to maintain continuity of the supply to the end users. The paper investigates problem formulation, algorithms, and methods used in the distance protection scheme development. This paper determines the relay configuration settings and describes how to implement the distance protection into the power system network by using the Real-Time Digital Simulator (RTDS). The power system network is modelled in the RSCAD Software and the operation of the distance relay is analysed with the help of the three zones R-X diagram. A 230 kV, 180 km transmission line is used to implement and test the MHO type distance protection scheme. The results are validated for different types of fault events on the various sections of the power system network.

***Index Terms*— Power system, Electrical protection, Distance relay, Transmission systems, R-X diagram and Real-Time Digital Simulator.**

1 INTRODUCTION

Transmission lines play an essential role in the distribution of electrical power to the customers and it can provide a connection between the generation and the load. Transmission lines operate at voltage levels from 66 kV to 765 kV and should be tightly interconnected for reliable operation. Factors like deregulated market environment, economics, proper way of clearing the events and green energy requirements have pushed the electrical utilities to operate the transmission line voltages close to their operating limits [1]. If the transmission line fault is not detected and isolated quickly, it will cascade in the power system causing widespread outages. To detect the transmission line faults, power utilities used the distance protection scheme. It plays a critical role in the protection of transmission lines and is the most widely used method for transmission line protection. Its main goal is to detect and isolate faults as soon as possible.

The authors gratefully acknowledge the authorities of Cape Peninsula University of Technology, South Africa for the facilities offered to carry out this work. The research work is funded by the National research foundation (NRF) THRIP grant TP2011061100004 "CSAEMS Development and Growth".

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To ensure the disturbance does not affect the healthy sections on the transmission line. The great advantage of the distance protection scheme provides main and back-up protection of the power transmission lines [3]. The protection schemes used in transmission lines are designed to identify the location of faults and isolate only the faulted section. [1]. The key challenge of the transmission line protection schemes are reliable to detect and isolate the faults and to provide security to the power system.

The mal-operation of the zone 3 distance protection scheme is illustrated with the help of the North American blackout occurred on 14th August 2003, about 4:10 p.m. Eastern Daylight Time (EDT). It resulted in the loss of more than 70,000 megawatts (MW) of electrical load in parts of Ohio, Michigan, New York, Pennsylvania, New Jersey, Connecticut, Massachusetts, Vermont, and the Canadian provinces of Ontario and Quebec. It is estimated that about 50 million people were affected [4]. The cause of the North American black-out was due to tripping of the distance relay on Zone 3. It changes the zone 3 apparent impedance and the relay characteristics is analysed with the help of the R-X diagram.

This paper modelled a distance relay in RTDS which provides a better GUI to the user and its solutions are in real-time. The operation of the distance relay is implemented and analysed in Real-Time. This paper presents the configuration setting and implementation of a MHO type distance relay in the RSCAD Software environment. Symmetrical and unsymmetrical events are introduced into the power system network and the distance relay characteristics for the Zone 1, zone 2 and Zone 3 are analysed with the help of the R-X diagram. Thus the aim of this paper is to investigate the existing distance protection methods and to develop a distance protection scheme, which to be implemented in the RTDS.

This paper has five sections and is organized as follows: section 1 introduces the background of the distance protection scheme. Section 2 describes the considered power system network and its implementation in the RSCAD software environment. Section 3 describes the distance relay algorithm and flowchart for the zone coordination of the distance protection scheme. Section 4 describes the implementation and validation of the distance protection scheme for the different case studies. Section 5 provides the conclusion and future work.

2 IMPLEMENTATION OF THE POWER SYSTEM NETWORK IN RSCAD SOFTWARE ENVIRONMENT

The power system network is implemented in the RSCAD software environment. The RTDS is used to study the complex power systems networks with High Voltage Alternating Current (HVAC) and High Voltage Direct Current (HVDC). The RTDS Simulator is a fully digital electromagnetic transient power system simulator that operates in real-time, Fig. 1. The system's graphical user interface, proprietary software and mathematical algorithms can simulate and analyse any complex modern power systems [5].

Fig. 1.The Real-Time Digital Simulator

RSCAD represents a family of software tools consisting of individual modules that accomplish the different tasks involved in operating the simulator [5]. RSCAD has the ability to organize and share simulation projects and cases, assemble circuit diagrams using predefined or user-defined power and control system component models, automate or interact with operation of the simulator, and analyse and post-process the simulation results.

2.1 Transmission line model in the RSCAD software environment

Fig. 2 shows the three zone distance protection scheme. Each zone has its own reach and over-reach relay setting and the zones must coordinate each other with respect to the location of the events on the network.

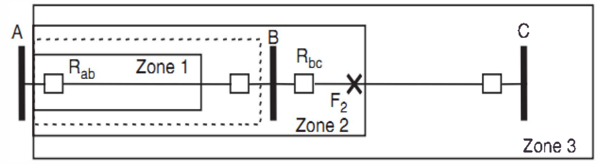

Fig. 2. Three zone distance protection scheme

The total length of the line is 180 km and it is divided into two sections. Line section 1 is 100 km and line section 2 is 80 km long. The power system network is modelled in RSCAD software and is shown in Figure 3. It has one generator (G1), four buses (Bus 1 is used as a slack bus), and 2 transmission lines. The power transmission line voltage and current signals are measured using a Current Transformer (CT) and a Potential Transformer (PT). The CT and PT measure the line currents and voltages respectively and send these signals to the distance relay model. The distance relay calculates the impedance according to the event type and location of the event on the network. It sends a trip to the respective zones, if the measured impedance is less than the setting impedance of the corresponding zone. Symmetrical and unsymmetrical faults are introduced on bus 3, Fig. 3.

2.2 T-Line file model in the RSCAD software enviornment

The input to the T-Line file in the the RSCAD software is RLC data. Fig. 4 shows the implementstion of the transmission line parameters in the T-Line file of the RSCAD software. The transmission line data entered in the T-Line file is directly linked to the transmission lines modelled in the RSCAD draft. The total positive, negative and zero sequence resistances and inductive reactances of the two transmission lines are calculated using Equations (1) and (2). The negative sequence reactances are assumed to be the same as the postive sequence reactances and the effect of the positive and zero sequence shunt capacitive reactances are neglected in the considered case study. A detailed summary of the power system data is given in Table I.

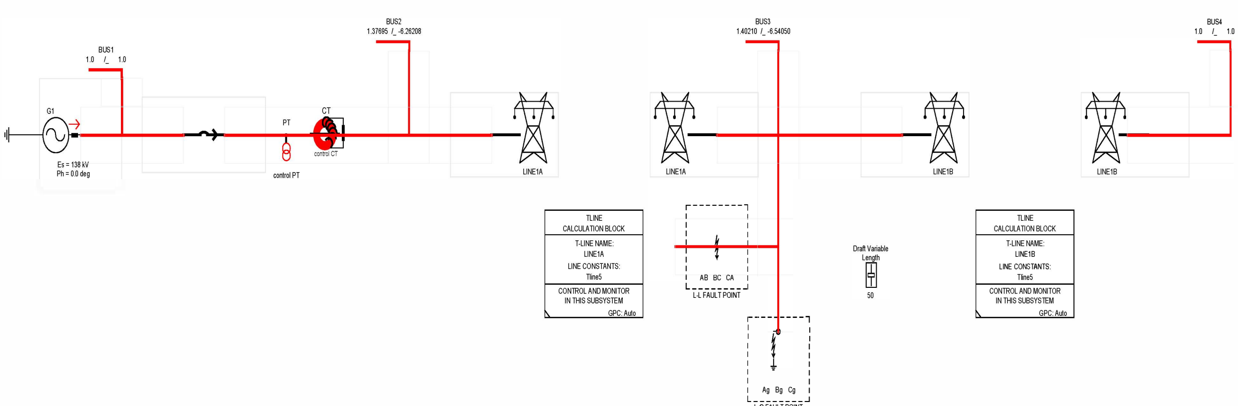

Fig. 1. Power system network in the RSCAD software environment

Table I: Power system data

S. No	Parameters		Value	Unit
1	Generator (G_1) Voltage		230	kV
2	Nominal frequency		50	Hz
3	PT	Number of turns on the primary side	230000	
		Number of turns on the secondary side	230	
4	CT turns ratio		1000	
5	Line 1	Line length	100	km
		Positive sequence impedance	6 + j20	Ω
		Negative sequence impedance	60 + j60	Ω
6	Line 2	Line length	80	km
		Positive sequence impedance	4.8 + j18	Ω
		Negative sequence impedance	48+j54	Ω

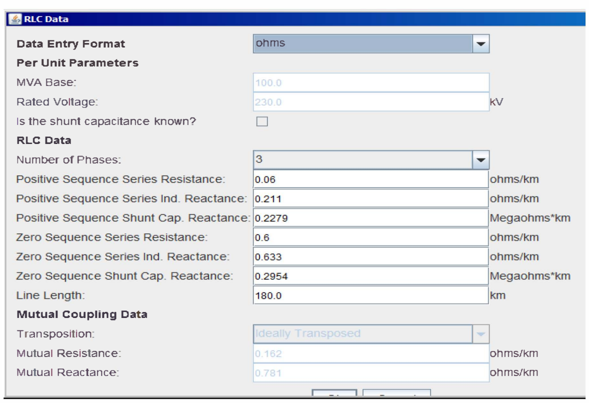

Fig. 4. RLC Data in the T-Line file of the RSCAD Model

$$Z_{tot,(actual)} = Z_{L1} + Z_{L2} \tag{1}$$

Where

Z_{L1} = Impedance of the line section 1

Z_{L2} = Impedance of the line section 2

$$Z_1 = Z_2 = \frac{Z_{tot}}{Total\ line\ length} \tag{2}$$

Where

Z_1 = Positive sequence impedance

Z_2 = Negative sequence impedance

Total line length = 180km

The positive and negative sequence impedance calculations for the considerded case study is given in the Appendix and those values are used in the RLC data of the T-Line file of the RSCAD as shown in Fig. 4.

2.3 Description of the distance relay model in the RSCAD software environment

The distance relay in the RSCAD software environment is shown in Fig. 5. The distance relay has 6 input signals (3-phase voltages and currents). The positive sequence memory voltage is created inside the relay and its input is available for compensation of the mutual coupling. The distance elements are directly supervised by a directional and a phase selection element. The distance measuring zones for the phase to ground will be compensated. The positive, negative, and zero sequence voltages and currents are used for the sequence impedance calculations and it can be monitored in the runtime or either it can be imported into the draft as an input to other control components [5].

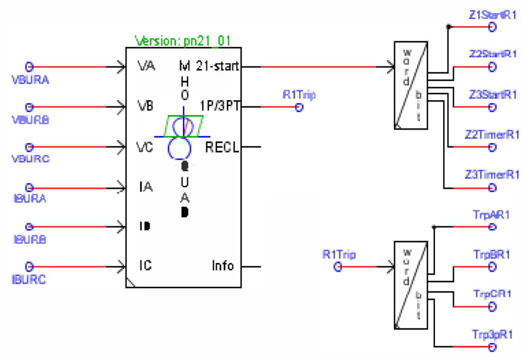

Fig. 2. Distance relay configuration in the RSCAD environment

The two output terminal signals of the distance relays are named as 21-start- and 1P/3PT. The 21-start has 5 elements. They are:

i. Z1StartR1
ii. Z2StartR1
iii. Z3StartR1
iv. Z2TimerR1
v. Z3TimerR1

Where

Z1StartR1 – Starting element of the trip signal for Zone 1
Z2StartR1– Starting element of the trip signal for Zone 2
Z3StartR1 – Starting element of the trip signal for Zone 3
Z2TimerR1- Time delay to start the trip signal for Zone 2
Z3TimerR1- Time delay to start the trip signal for Zone 3

All these signals are monitored in the run-time window of the RSCAD software. The characteristic of the Zone 1 is instantaneous. To avoid the cascaded tripping Zone 2 and Zone 3 as the time delays. Only Zone 3 has reverse reach in the RSCAD distance relay software environment. The R-X diagram is considered to validate the zone operations of the distance relay according to the type and location of the events in the network.

The 1P/3P signal is used to trip the contact of the circuit breakers. The measured impedance of the distance relay is shown in the R-X diagram. It is called as the fault impedance. Table II provides the summary of the equations used to calculate the different types of events on the network. The R-X diagram is used to validate the measured impedance against the setting one.

2.4 Design and description of the event control logic in the RSCAD environment

The aim of the designed and implemented event control logic in the RSCAD software is to introduce, test and analyse the operation of the various types of faults (L-L and L-G) into the power system network as shown in the Fig. 7. The event control logic plays a critical role in ensuring that the relay operates according to the type and location of the events on the transmission line. The designed event control logic in the RSCAD software consists of various control components.

The description of the event control logic as follows: when the fault button is pressed it produces a 0.1ms pulse signal. The control circuit has an if-else component, which has two input signals, node voltage N1 and constant zero. It has an output 1, for the positive node voltage signals. The output of the If-else component is connected to the positive edge detector component. The S-R flip-flop has two inputs such as positive edge detector and fault components respectively. The S-R flip-flop initiates the 1st falling edge detector with a time delay (tToStart1) introduced by the point-on-wave component. The 2nd falling edge detector initiated by the output signal of the 1st falling edge detector and its output has a time delay initiated by the fault duration slider. The output of the 2nd falling edge detector is a time constant. This constant is multiplied with the type of events. It means particular type of the event is introduced in the power transmission line for small time duration in the considered case study. The time duration with respect to the different type of event is designed in the control logic as shown in Fig. 7. The duration of the fault is determined by the fault duration slider in the Runtime Window of the RSCAD software.

Table II. Summary of the impedance formulae according to the type of events

Event type	Impedance formula
AG	$\frac{E_A}{(I_A + 3kI_0)}$
BG	$\frac{E_B}{(I_B + 3kI_0)}$
CG	$\frac{E_C}{(I_C + 3kI_0)}$
AB and ABG	$\frac{(E_A - E_B)}{(I_A - I_B)}$
BC and BCG	$\frac{(E_B - E_C)}{(I_B - I_C)}$
CA and CAG	$\frac{(E_C - E_A)}{(I_C - I_A)}$

Note: The compensation factor 'K' is calculated automatically in the RSCAD Software environment.

3 DISTANCE RELAY ALGORITHM

Distance relays are also known as impedance relays. They are used to calculate line impedances by measuring the voltage and currents on the power transmission lines [6]. The Mho type distance relay is used in this research work. It compares the setting impedance with the measured one, with respect to the type and location of the events on the line. The distance relay issues a trip signal, if the setting impedance is less than the measured one. The characteristics of the R-X diagram helps to identify whether the events lie inside or outside the zones. The flow chart of the distance relay algorithm is shown in Fig. 6.

The distance relay uses the voltage and current signals from the PT's and CT's and calculates the fault impedance according to the type and location of the events. If the measured fault impedance is less than the Zone 1 reach impedance, then the fault falls within Zone 1 and its characteristic is analysed with the help of the R-X diagram. For Zone 1 fault, the distance relay issues a trip signal to the Circuit Breaker (CB) instantaneously without time delay. If the fault impedance is greater than the Zone 1 reach and less than the Zone 2. The distance relay issues a trip signal to the CB after a time delay of 400ms. If the fault impedance is greater than the Zone 2 reach, then the Zone 3 issues a trip signal to the CB after a time delay of 700ms.

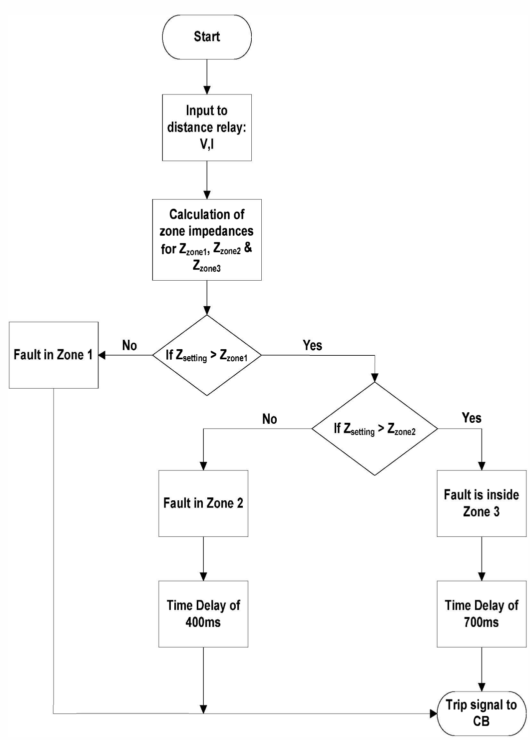

Fig. 6. Flowchart for the distance protection scheme zone operation and its coordination

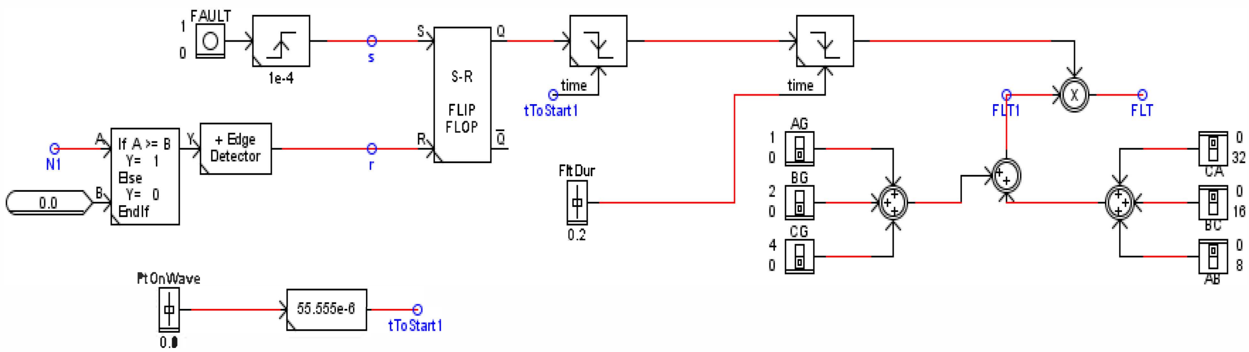

Fig.7. Designed and implemented the event control logic in the RSCAD environment

4 CASE STUDY: SIMULATION, TESTING AND VALIDATION OF THE DISTANCE RELAY OPERATION

The power system network considered in the case study is 230kV, 180km transmission line as shown in Fig. 3. The transmission line is no loaded in the considered case study. The distance relay is integrated into the power system network with the help of the RSCAD control components as shown in Fig. 5. Different types and locations of events are considered to test, validate, and analyse the operation of the distance relay in the RSCAD software environment. The results for the three-phase short circuits are shown in this paper. The measured impedance for the zone 3 is given in Table III. The case study for zone the 3 distance relay is not showed in this paper. Table III provides measured zone reach impedances for all three zones. In addition to that the RSCAD simulation results are verified with the hands-on calculation. Three-Phase fault at 40km of the power transmission line.

Table III: The measured line impedances for different location and types of the events (L-G, L-L and L-L-G)

Line impedance in (Ω)		
Zones		
Zone 1 (40km)	Zone 2 (100km)	Zone 3 (180km)
$2.39 + j8$	$6 + j20$	$10.8 + j38$

4.1 Three-Phase fault at 40km of the power transmission line

Case study 1 investigates a three-phase fault at 40km of the power transmission line. The fault duration was set to 0.35s, which ensures that the fault in the power system for that time stamp falls within Zone 1.

Fig. 8a shows that the operation of the CB which has the time stamps of 0.2 and 0.55 seconds for opening and closing of the contact of the breakers for three-phase short circuit at 40km of the power transmission line. The magnitude of the fault current is 1.56 kA. Fig. 8b shows the R-X diagram for a three-phase short-circuit and the measured fault impedance on the Zone 1 is shown in the R-X diagram.

4.2 Three-Phase fault at 100km of the power transmission line

Case study 2 investigates a three-phase event at 100km of the power transmission line. The fault duration was set to 0.6s, which ensures that the fault in the power system for that time stamp falls within Zone 2. Figure 9a shows the operation of the distance relay and the relay characteristics is analysed with the help of the R-X diagram. Figure 9b shows the operation of the CB which has a time stamps of 0.2 and 0.8 seconds for opening and closing of the contacts of the breakers for a three-phase short circuit at 100km of the power transmission line. The magnitude of the fault current is 1.485kA, which is close to the hands-on calculation.

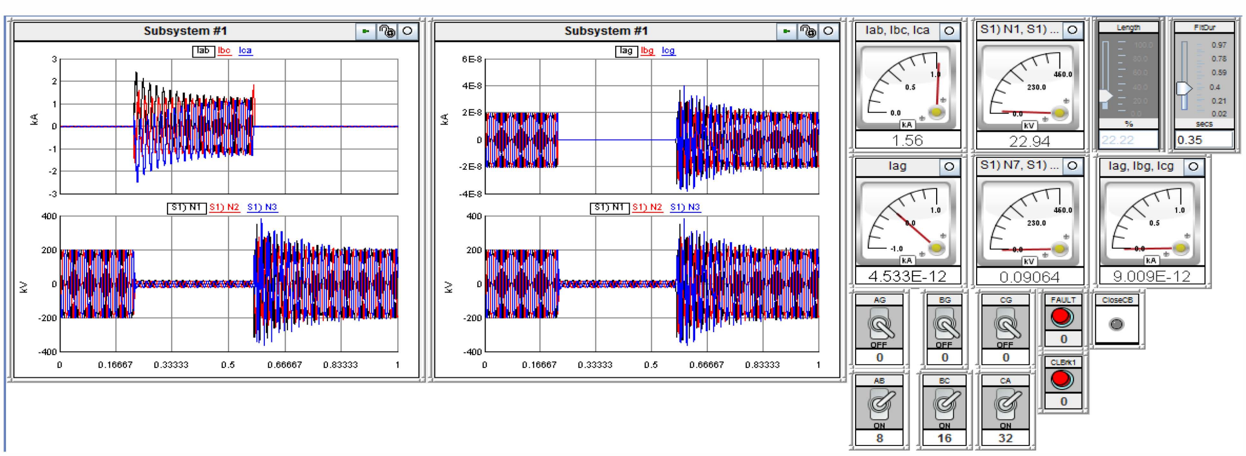

Fig. 3a. Simulation results for a three-phase short-circuit at 40km of the power transmission Line

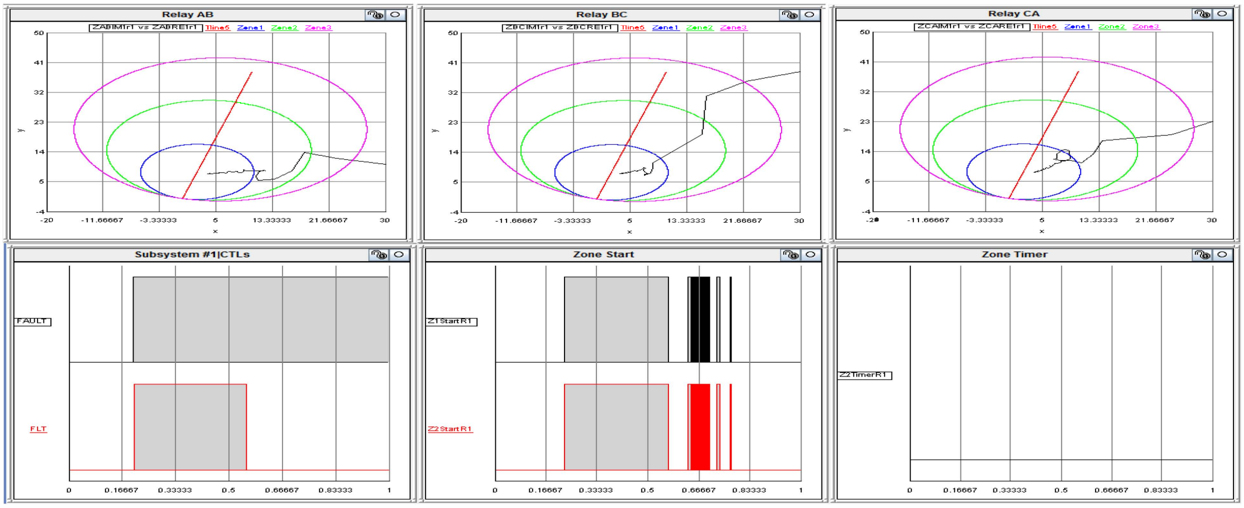

Fig. 8b. R-X and timer diagram for a three-phase short-circuit at 40km of the power transmission Line

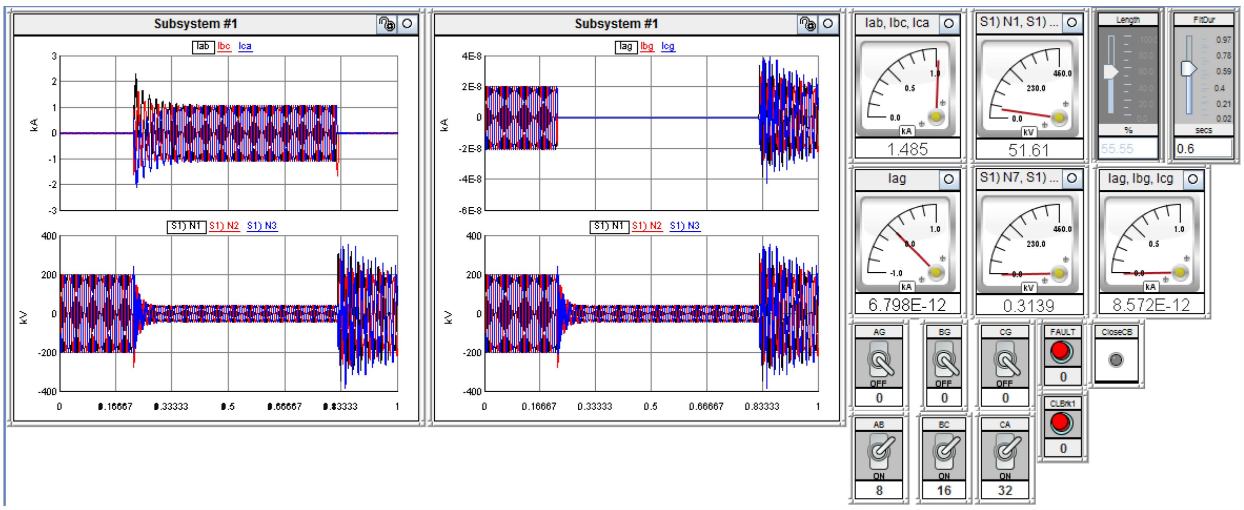

Fig. 9a. Simulation results for a three-phase short-circuit at 100km of the power transmission Line

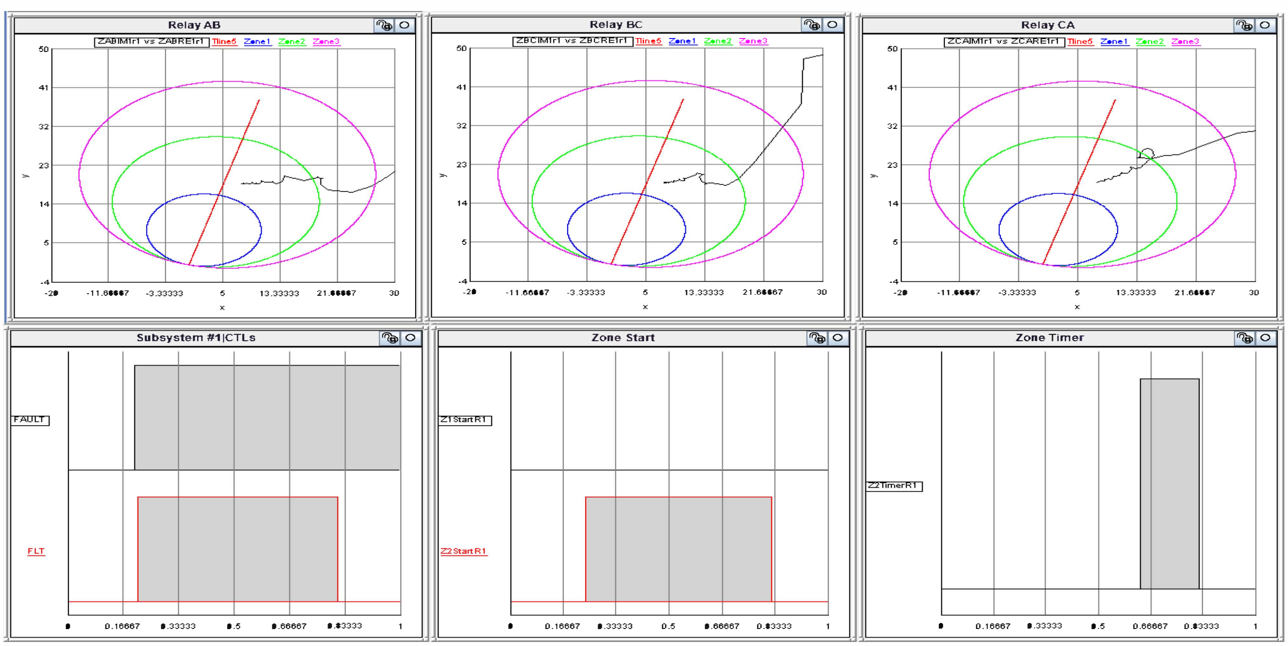

Fig. 9b. R-X and timer diagram for a three-phase short-circuit at 100km of the power transmission Line

5 CONCLUSION

Electrical protection plays an important role in transmission of electricity. This is due to the mere fact that many factors beyond the human control can cause disruption in transmitting the electricity to the end-user. These factors can be trees falling on transmission lines, strong winds, vandalism, etc. Thus, various methods have been put into place to ensure continuity of supply in the event of a fault and to protect the electrical equipment by isolating the faulty section from the healthy part of the network within minimum time stamp. Distance protection forms part of the transmission line protection schemes. This paper presents the configuration setting and implementation of a MHO type distance relay in the RSCAD Software environment. Symmetrical and unsymmetrical events are introduced into the power system network and the distance relay characteristics are analysed with the help of the R-X diagram.

The simulation results show that the distance relay modelled in the RSCAD software is capable to issue the trip signal and the contacts of the circuit breakers are open and closed with respect to the type and location of the events. These setting are designed by the user with the help of the control components available in the RSCAD software environment. The event control design is shown in Figure 6. Most of the authors used MATLAB/SIMULINK to model the distance relay in non-real-time. This paper modelled a distance relay in RTDS which provides a better GUI to the user and its solutions are in real-time. The operation of the distance relay is implemented and analysed in Real-Time. This research work outcome will be used in the Protection Course to teach the distance relay model to undergraduate students at the University level.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the authorities of Cape Peninsula University of Technology, South Africa for the facilities offered to carry out this work. The research work is funded by the National research foundation (NRF) THRIP grant TP2011061100004 “CSAEMS development and growth”.

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APPENDIX

The Positive and zero sequence impedance are calculated using Equations (1) and (2). The detalied claculation used in the considered case study is given below:

A. POSITIVE SEQUENCE IMPEDANCE

$$Z_{tot(1)}(\text{actual}) = Z_{L1} + Z_{L2}$$

$$= (6 + j20) + (4.8 + j18)$$

$$= (10.8 + j38)\Omega$$

$$Z_1 = \frac{(10.8 + j38)}{180\text{km}}$$

$$Z_1 = (0.06 + j0.211)\Omega / \text{km}$$

B. ZERO SEQUENCE IMPEDANCE

$$Z_{tot(zero)}(\text{actual}) = Z_{L1} + Z_{L2}$$

$$= (60 + j60) + (48 + j54)$$

$$= (108 + j114)\Omega$$

$$Z_{zero} = \frac{(108 + j114)}{180\text{km}}$$

$$= (0.6 + j0.633)\Omega / \text{km}$$

The calculated positive and negative sequence impedances are used in the RLC data of the T-Line file of the RSCAD as shown in Fig. 4.

BIOGRAPHY

Dr. S. Krishnamurthy has BE and ME in Power System Engineering from Annamalai University, India and DTech in Electrical from Cape Peninsula University of Technology, South Africa. He has been a lecturer at the SJECT, Tanzania and Lord Venkateswara and E.S. College of Engineering, India. Since 2011 he has been working as a Lecturer at the department of Electrical, Electronic and Computer Engineering, Cape Peninsula University of Technology, South Africa.

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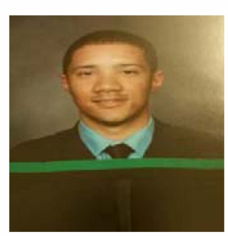

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