Modeling and Simulation of Distance Protection for Transmission Lines with Different Grounding Methods

ABDALLAH. R. ALZYOUD , EYAD ZAROUR ,FAKHRI JARRAR, AKRAM ARAR
Electrical Engineering Department, Faculty For Engineering Technology
Al-Balqa Applied University
Amman-JORDAN/P.O.Box 15008 code 11134
JORDAN

Abstract: - Distance protection is one of the most important methods used in protection of transmission and distribution lines. It can detect and determine the location of all faults. Operation of distance relays depends on the correct measurement of the current and voltage signals; the voltage and current phasors must be measured very accurately to avoid errors in distance measurement.

The most common fault of the transmission and distribution lines is the single phase to the ground fault, the fault current is related to the grounding method. Therefore, the measurement of the impedance seen by the distance relay in the event of ground fault depends on the method of grounding and on the effect of the arc resistance. Distance relay is designed to measure impedance for ground fault (L-G fault), considering the effect of grounding methods using MATLAB simulation and the coordination of 3-stepped distance zones. In this paper simulation models of the electric power system with real technical specifications are introduced using MATLAB/Simulink and NEPLAN software, where the distance protection for the transmission line with different grounding methods are used.

Voltage and current waves are illustrated under various faults. The simulation models enable investigation of the earth fault under different methods of grounding. The performance of distance protection is studied taking into consideration the arc resistances and the load encroachment. The obtained results show that the protection schemes are very effective for all types of faults. Arc fault resistance influences the operation of distance relays, thus causing it to give inaccurate impedance measurement resulting to under-reach condition, so it should be considered.

Key-Words: - Distance Relay: Grounding: Earth Fault: Modelling: compensation factor:
Received: June 6, 2021. Revised: August 12, 2022. Accepted: September 20, 2022. Published: October 26, 2022.

1. Introduction

It is important to focus on transmission and distribution lines, which are the most important parts of electrical power systems, and they are the most exposed components to faults, so the focus will be on protection systems related to transmission lines, and one of the most important methods used in protection systems is a distance protection as it can determine the location of the fault which is very important in the transmission and distribution lines,[1,2]

The operation of distance relays depends on the correct measurement of the current and voltage signals, and these values must be measured very accurately in order to avoid errors in impedance measurements [4].

The protection circuits of electrical power network have almost ended with important stage of development, when the majority of them were transformed, or partially developed from electromagnetic means of protection and control to the electronic hardware system. Nowadays, the trend in this field of industry is the implementation of programmable protection systems that can easily interface with the primary transducers from one side and the dispatch control center from the other side [2,3].

Distance protection involves the electrical measurement of distance along a transmission line to the fault point. There is uniform distribution of the impedance of the transmission line along the length of the transmission line. The impedance from the relay to the fault point is proportional to the distance from the relay to the fault point. Therefore, this is the basis of the principle of distance relay. Unlike over-current protection, distance relay protection gives a good way of having selectivity, speed of operation and discrimination by allowing trip operation up to a particular measure of distance. In distance protection, three sets of distance protection zones or more are set up to provide backup protection. Fault coverage of over-current protection is affected by source impedance and voltage variations, but fault coverage of distance protection is less affected by source impedance variation. Authors in [5] investigated and concluded that the basis of network protection in transmission lines is the distance protection.

Relative source impedances and system conditions do not easily affect distance protection. According to [6], distance relay characteristics are of various types which includes mho, quadrilateral, reactance, admittance, polarized-mho, offset mho etc. Authors in[7-9] researched on distance relay modelling and simulation for performance testing using MATLAB/SIMULINK tool using MHO distance characteristics and analyzed the relay for one-phase to ground and three phase faults at the transmission line and found that the relay operated correctly but when a fault resistance was introduced at the line , the relay under-reached. Furthermore, it was found that power system networks regularly encounter short circuits such as trees falling on lines and other abnormal conditions that make current leave the intended path to flow through another path. Because of this short circuit, heavy current flows in the power system equipment thereby causing damage to them.

These researchers further explained that since power system is regarded as large capital investment because most of its equipment are very costly, there must be security and reliability of supply for the entire power system to be optimally utilized as power system always encounter faults despite how well it was designed. The brain of any protective system is the protective relay while transducers help to sense network abnormalities and then relate it to the protective relay. Circuit breakers receives trip signal from the protective relay to isolate faulty parts from healthy part. In this paper we implemented admittance type distance relay model with three zones of protection using MATLAB/SIMULINK and NEPLAN . Model simulation for single phase to ground faults for a network with different earthing methods with faults at various locations of transmission line was investigated. Values of three phase currents and voltages from VTs/CTs are inputs for impedance measurement. These three phase voltages and currents require filtering to clear off the harmonics which may be present due to arcing of the fault.

Sampling of filtered signals at required/selected sampling frequency is done before being used by distance relay. The relay then compares the setting impedance with the impedance measured to ascertain if the fault is within or outside the protected zone. Single phase to ground fault at different zones with fault resistance and without fault resistance to examine relay performance was considered using modified CIGRE system.

For transmission lines protection, choosing a suitable relay type and relay's setting is essential. We may make the fault analysis and the test by the simulation software, and according to the actual system requirement, choose the suitable protective relay, but for reliability and security considerations, the massive simulations tests are usually undertaken. This is a quite numerous and diverse job; therefore, having a superior simulated environment is important {Modeling and Testing of a Digital Distance Relay Using MATLAB/SIMULINK}.

The most common fault of the transmission line is the single phase to earth fault, which is related to the grounding method [3]. Therefore, the measurement of the impedance seen by the distance relay in the event of ground fault depends on the method of grounding and the effect of the arc resistance on the performance of the distance relay.

Distance relay is designed to measure impedance for ground fault (LG fault), considering the effect of grounding methods (K0 compensation) using MATLAB simulation and the coordination of 3-stepped distance zones [2].

In this paper simulation models of the electric power system with real technical specifications are introduced using MATLAB/Simulink and NEPLAN/Simulink, where the distance protection for the transmission line with different grounding is used. The grounding method determines the amount of fault current through neutral and the voltage of healthy phases. Voltage and current waves are illustrated under various faults [3].

The simulation models enable the detailed investigation of the earth fault under different methods of grounding. The performance of distance protection is studied taking into consideration the arc resistances and the load encroachment. The obtained results show that the protection schemes are very effective for all types of faults.

According to [10], distance relays measure the line impedance from the position of the relay up to the fault point. This measured impedance is proportional to the line length from the position of the relay to the fault point.

2. Grounding Methods

The method of grounding has a small influence during normal operation of the system but becomes important and effective when an earth fault occurs to an overhead line (OHL) or an underground cable (UGC).[11]

The selection of system grounding method requires deep analysis. The correct grounding solution may be obtained through a great amount of calculations and simulations of the network during fault. The different grounding methods, in common use are:

a) Solidly or direct grounding (effective grounding).

b) Unearthed or Isolated neutral (floating neutral point).

c) High impedance (resistance) grounding.

d) Low impedance (resistance) grounding.

e) Resonant or Petersen Coil grounding (compensated grounding).

A fault on a power system is an abnormal condition that involves failure risks of power system equipment. Generally, two types of failures can occur. The first is an insulation failure that results in a short circuit fault.

The second is a failure that results in an interruption of current flow. Short circuit faults can occur between phases, or between phases and earth, or both. When the system is grounded by a low resistance or directly (solidly) grounded, the fault current will be very large.

The characteristics of earth-fault current depend on the method of neutral point grounding as shown in this paper. Many researchers in the past few years discussed the correlation between different types of neutral grounding and earth-fault, including fault localization and detection in MV networks.

In [11]-[14], the authors compared between different types of neutral grounding.

Voltages and currents have non- sinusoidal evolution during the fault occurrence and clearance periods because of a component called dead-beat or free component as discussed in [15].

Analysis of overvoltages generated by SLG faults in Petersen coil grounded MV networks is presented in [16,17].

The paper presents fault simulation models implemented in MATLAB®/ SIMULINK®, and NEPLAN software. The created models allow for detailed investigation of different factors including the method of grounding the neutral point on the performance of distance protection.

3.Distance protection with a three-step characteristic

Distance protection is a widely used protective scheme for the protection of high and extra high voltage (EHV) Transmission and sub-transmission lines. Figure 1 shows a three-step time characteristics of distance relay.

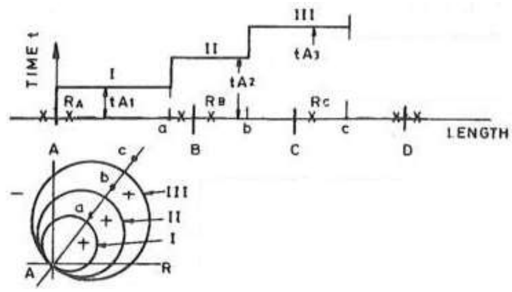

Fig.1 three-step time characteristics of distance relay.

This scheme employs several distance relays which measure the impedance or some components of the line impedance at the relay location.

All the forms of this protection consist of a few common elements performing definite typical function [3,4].

The protection system includes the following elements:

-Voltage and current transformers.

-Starting element (Z3) brings the protection into action on occurrence of a fault. This element measures the impedance (distance) at the third zone of protection.

-Distance element (Z2). This element measures the distance of the second zone of protection.

-Distance element (Z1) measures the distance of the first zone of protection.

-Time delay elements t1, t2 and t3 create a time lag with which the protection operates according to the behavior of the distance elements.

-Power directional element (PDR) prevents the protection to operate when the fault power flows toward the bus bars of a substation.

-Logic gates.

If a fault occurs within the first zone ,the distance element of the first zone (Z1) operates with a high speed to form a path for disconnecting the line with a fault in the second zone ,distance element(Z1) does not operate as the impedance across its terminals is greater than the operating impedance setting of the first zone (Zr>Z1).In this case the distance element (Z2) of the second zone is brought into action and it actuates the timer (t2).After the setting time expires, a tripping signal is sent to disconnect the line . When a fault is in the third zone ,but external to the second zone , elements (Z1 and Z2)do not operate as impedances at their terminals exceed the operating impedance settings .Timer (t3) actuated by the starting element (Z3), operates after time (t3) expires , and a tripping signal is sent to the circuit breaker .

In the illustrated system, the distance relays have three zones. Where zone 1 is set to protect about 90% of the line length and to operate with no intentional time delay. Zone 2 is set for 100% of the protected line plus about 50% of the shortest adjacent line, and is set to operate with time delay T2 .Zone 3 is set to reach 100% of the impedance of the first two lines and 25% of the third line , and to operate the zone 3 element with time delay T3. Figure 2 shows the distance relay algorithm flow chart.

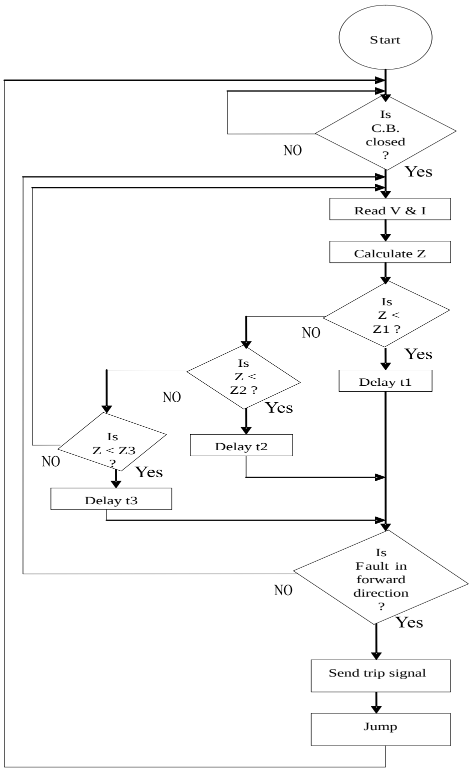

Fig. 2: Relay Algorithm Flow Chart

4. The System Under Study

A CIGRE modified network with a load of (330kW, 126.9KVAR) at each bus is used as a case study. The network is depicted in Fig 3 , and table (1) shows the parameters of the studied network.

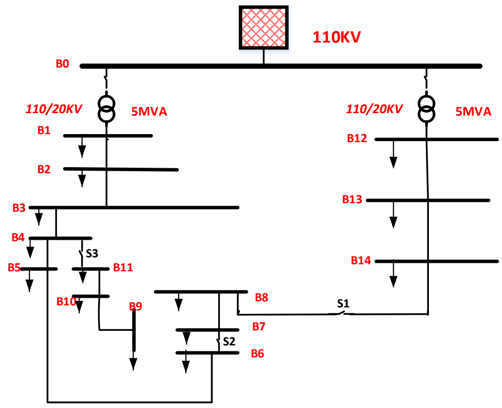

Figure 3: A CIGRE modified single line diagram

Table :1 Parameters for the studied system

Line segment	Z+ (Ω/km)	Z0 (Ω/km)	Length (km)
L1-2	0.501+j0.716	0.817+j1.598	120
L2-3	0.501+j0.716	0.817+j1.598	116.36
L3-4	0.501+j0.716	0.817+j1.598	73.4
L4-5	0.501+j0.716	0.817+j1.598	83
L5-6	0.501+j0.716	0.817+j1.598	124
L6-7	0.501+j0.716	0.817+j1.598	40
L7-8	0.501+j0.716	0.817+j1.598	25
L8-9	0.501+j0.716	0.817+j1.598	90
L9-10	0.501+j0.716	0.817+j1.598	60
L10-11	0.501+j0.716	0.817+j1.598	55
L11-4	0.501+j0.716	0.817+j1.598	100
L12-13	0.501+j0.366	0.658+j1.611	30
L13-14	0.501+j0.366	0.658+j1.611	30
L14-8	0.501+j0.366	0.658+j1.611	20
L3-8	0.501+j0.716	0.817+j1.598	140

The Single line diagram of case study system which is consists of a source ,transformer and three lines is shown in Fig.4.

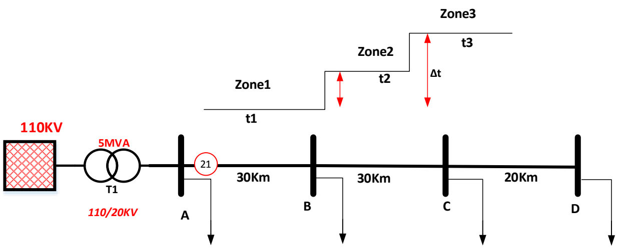

Figure 4 A single line diagram of the studied network with distance protection

The system is protected by three step distance protection with three zones,

- Zone 1: this is set to protect 80% of the line length AB.
- Zone 2: this is set to protect 100% of the line length AB, plus at least 50% of the shortest adjacent line BC and operates with time delay t2.
- Zone 3: this is set to protect 100% of the two lines AB, BC, plus about 25% of the third line CD and operates with time delay t3.

The calculations related to the line used to design the distance protection will now be performed, and the values of the impedances seen by the distance relay for each zone will be calculated as follows (See Fig (5))

$AB\ section = 30\ km,\quad BC\ section = 30\ km,\ CD\ section = 20\ km$

$Total\ length = 80\ km$

$R1 = 0.501\ \Omega/km\ ,\ L1 = 2.28\ mH/km$

$R0 = 0.658\ \Omega/km\ , L0 = 5.13\ mH/km$

$Z1 = 0.501 + 0.716j\ \Omega/km$

$Z0 = 0.658 + 1.61j\ \Omega/km$

$$Zset(1) = Z1 * 0.8 \quad (1)$$

$$= (0.501 + 0.7161j) * 30 * 0.8$$

$Zset(1) = 12\ \Omega$

$$Zset(2) = (Z1 * L1) + (Z1 * L2 * 0.5) \quad (2)$$

$Zset(2) = 39\ \Omega$

$$Zset(3) = (Z1 * L1) + (Z1 * L2) + (Z1 * L3 * 0.2) \quad (3)$$

$Zset(3) = 56\ \Omega$

5. Simulation Results

Investigation of single line to ground faults on the studied system are presented for all different cases of neutral point grounding.

In this section, the 3-zone distance relay is designed using MATLAB Simulink as shown in figure 5., then the line to ground fault is applied to different zone. Using the compensation factor, measuring the ground fault current, and displaying the system waves before, during, and after the fault.

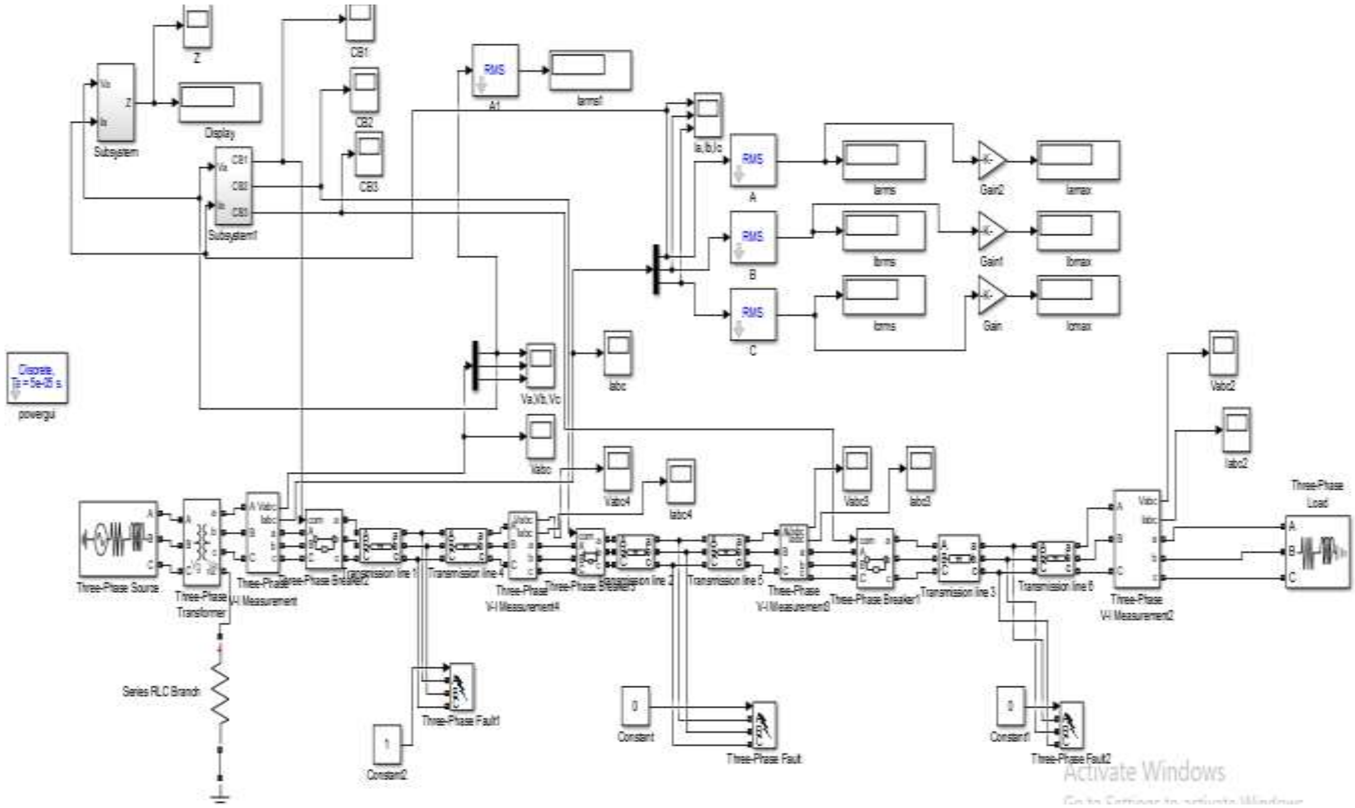

Fig. 5: MATLAB Simulink for the studied system

Figure 6 shows the block diagram of the distance protection relay for ground fault.

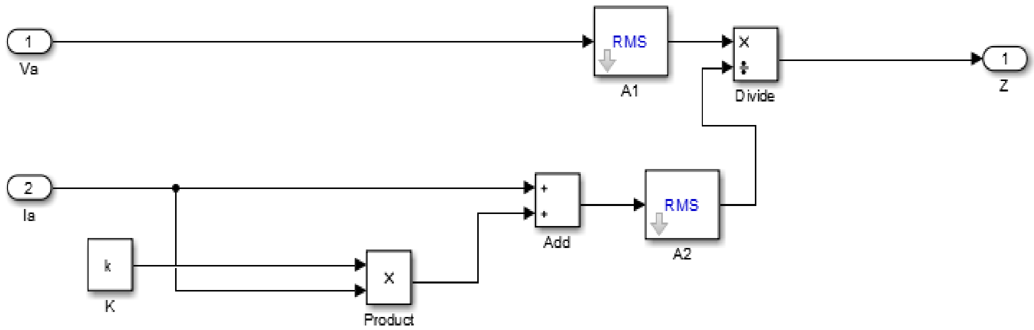

Figure 6: block diagram of the distance protection relay for ground fault

To compensate the zero-sequence impedance of the line we introduce the compensation factor (Ko) which is determined by:

$$Ko = \frac{(Zo - Z1)}{3Z1} \qquad (4)$$

$$Z1 = \frac{Va}{Ia + (Ko * Ia)} \qquad (5)$$

Where: Zo - Zero Sequence impedance

Z1 - Positive Sequence impedance

Va - Phase Voltage

Ia- phase current

Figure 7 shows the block diagram of the distance protection relay for ground fault to provide Coordination of three zones (stepped 3-zones characteristic).[9]

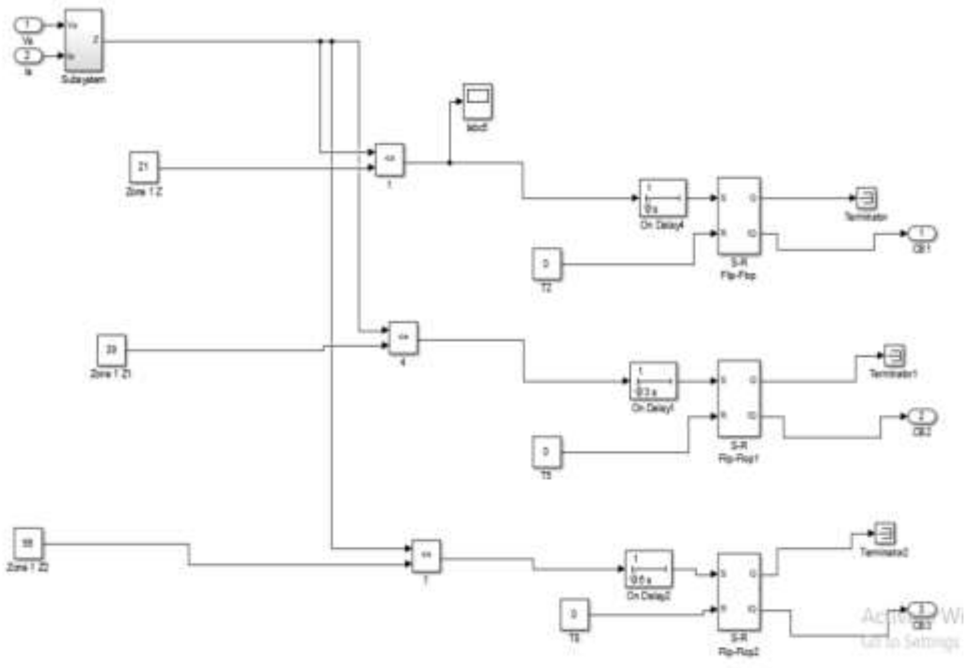

Fig. 7

Trip signals (figures 8-10):

1)The signal sent to the CB1 under the occurrence of LG fault in zone1

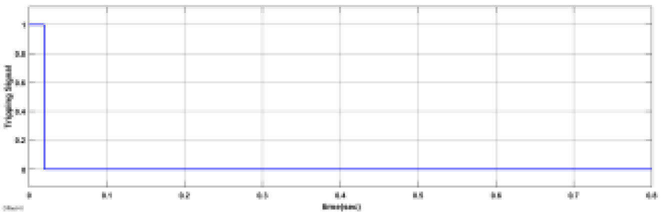

Fig. 8

2)The signal sent to the CB1 under the occurrence of LG fault in zone2.

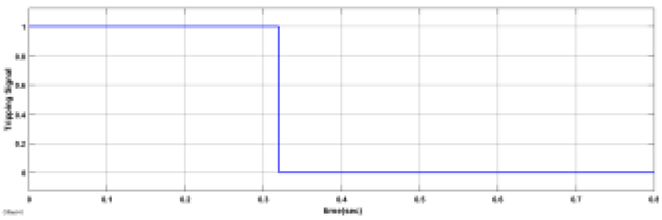

Fig. 9

3)The signal sent to the CB1 under the occurrence of LG fault in zone3.

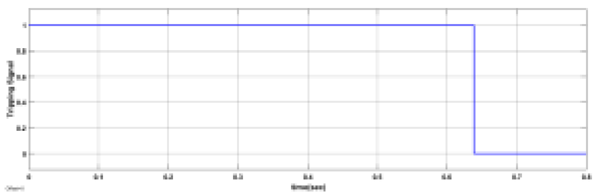

Fig. 10

The fault currents waves are displayed for each zone after the circuit breaker is opened (Figure 11-13)

1) Current waves of CB for LG fault in zone1

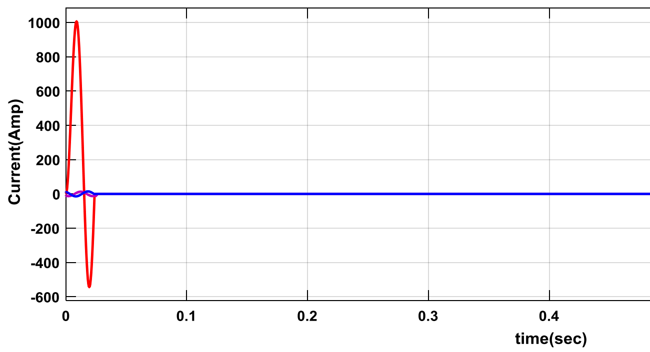

Figure 11

2) Current waves of CB for LG fault in zone2

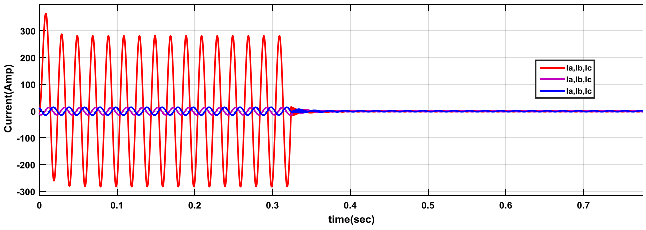

Fig. 12

3) Current waves of CB for LG fault in zone3

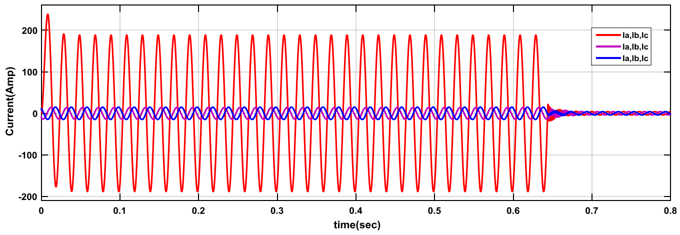

Fig. 13

Table 2: Results of Distance protection Performance for Different Fault Location.

Earthing methods	Compensating Factor (k)	Location of LG fault	Tripping CB
Solidly	0.35	Zone (1)	CB1
Resistance Earthing Re = 10 Ω	0.4	Zone (1)	CB1
Resistance Earthing Re = 100 Ω	1.53	Zone (1)	CB1
Isolated (R = 10000 Ω)	143.3	Zone (1)	CB1
Reactance Earthing L = 0.01 H	0.36	Zone (1)	CB1
Reactance Earthing L = 0.1 H	0.791	Zone (1)	CB1
Reactance Earthing L = 1 H	4.84	Zone (1)	CB1
Solidly	0.35	Zone (2)	CB2
Resistance Earthing Re = 10 Ω	0.4	Zone (2)	CB2
Resistance Earthing Re = 100 Ω	1.53	Zone (2)	CB1
Isolated (R = 10000 Ω)	143.3	Zone (2)	CB1
Reactance Earthing L = 0.01 H	0.36	Zone (2)	CB2
Reactance Earthing L = 0.1 H	0.79	Zone (2)	CB2
Reactance Earthing L = 1 H	4.84	Zone (2)	CB1
Solidly	0.35	Zone (3)	CB3
Resistance Earthing Re = 10 Ω	0.4	Zone (3)	CB3

Resistance Earthing Re = 100 Ω	1.53	Zone (3)	CB2
Isolated (R = 10000 Ω)	143.3	Zone (3)	CB1
Reactance Earthing L = 0.01 H	0.36	Zone (3)	CB3
Reactance Earthing L = 0.1 H	0.79	Zone (3)	CB3
Reactance Earthing L = 1 H	4.84	Zone (3)	CB1

The single line diagram of the studied network is simulated using NEPLAN software as shown in figure 14. A NEPLAN Electricity is a software tool used to analyze, plan, optimize and simulate networks. The user-friendly graphical interface allows the user to perform study cases very efficiently. The customizable software has a modular concept and covers all electrical aspects in transmission, distribution, generation / industrial networks. Besides steady state calculations, power quality and optimization aspects and protection design.

By NEPLAN simulator, a L-G fault is applied to each of the three zones at different locations of each line and the characteristics of the distance protection relay are investigated under the effects of arc resistance on distance relay and its response.

Initially, the system will be displayed in its steady state, which shows a transmission line divided into three zones protected by distance relays and the operation of the main distance relay against earth fault in each zone as shown in Figure 14.

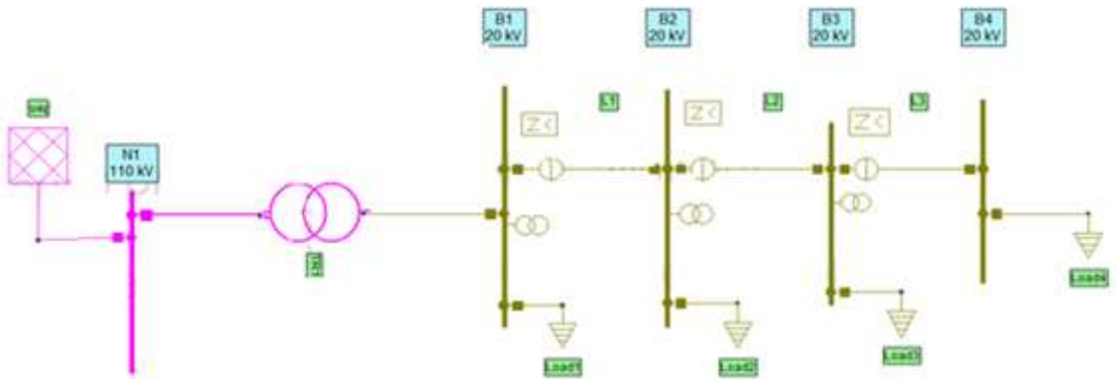

Fig. 14

Before applying faults and studying the properties of the protection relay, the special coordination of this divided line into 3-zones will be presented, this coordination is called three stepped characteristic of distance relay shown in Figure 15. This characteristic represents the tripping time of each zone as a function of impedance or length of that line.

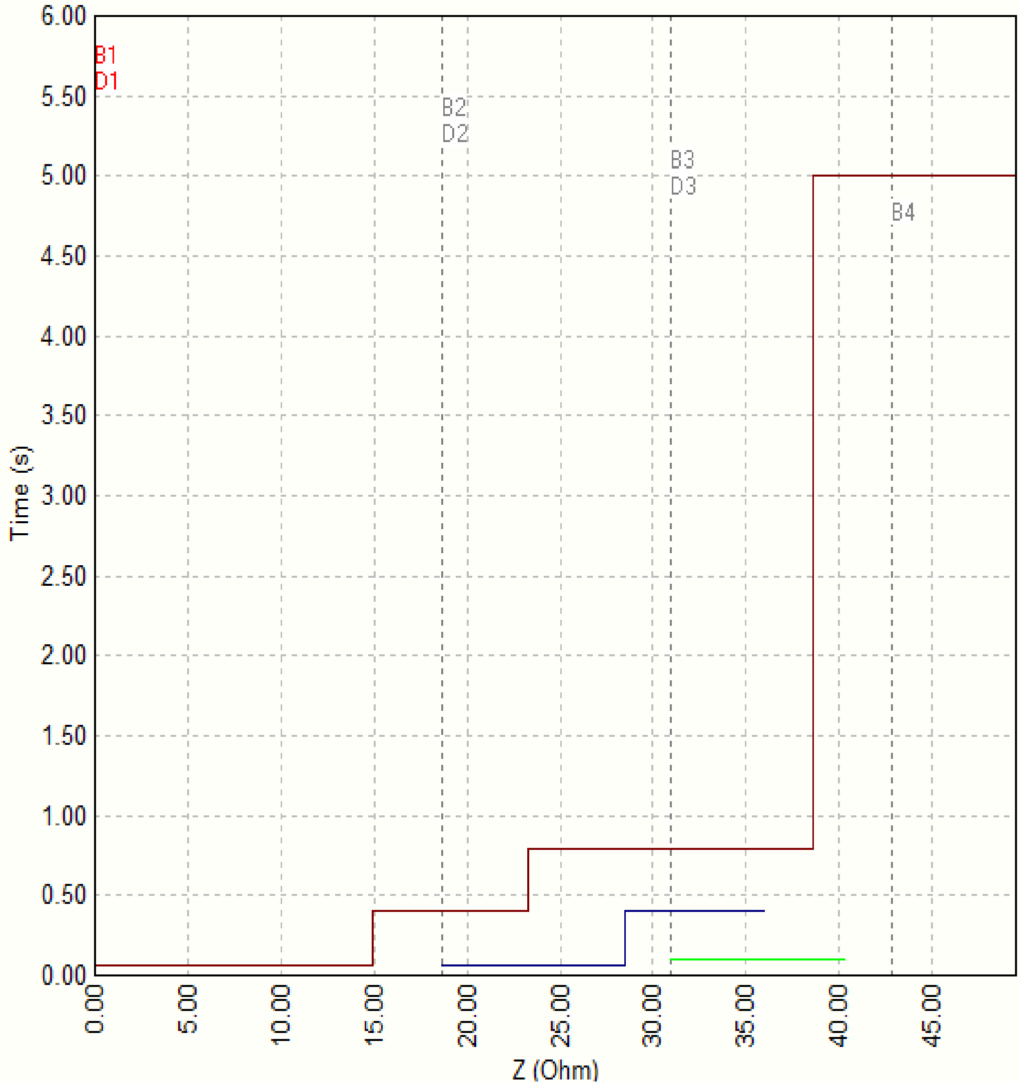

Fig. 14

An earth fault (phase to earth fault) is applied to all zones in a sequence and to the different locations of the line in each zone ,and the characteristics of the distance relay after the fault has occurred is illustrated.

The faulted line will be presented as a yellow line as shown in figures (15-17).

a) Single line to ground fault in zone 1

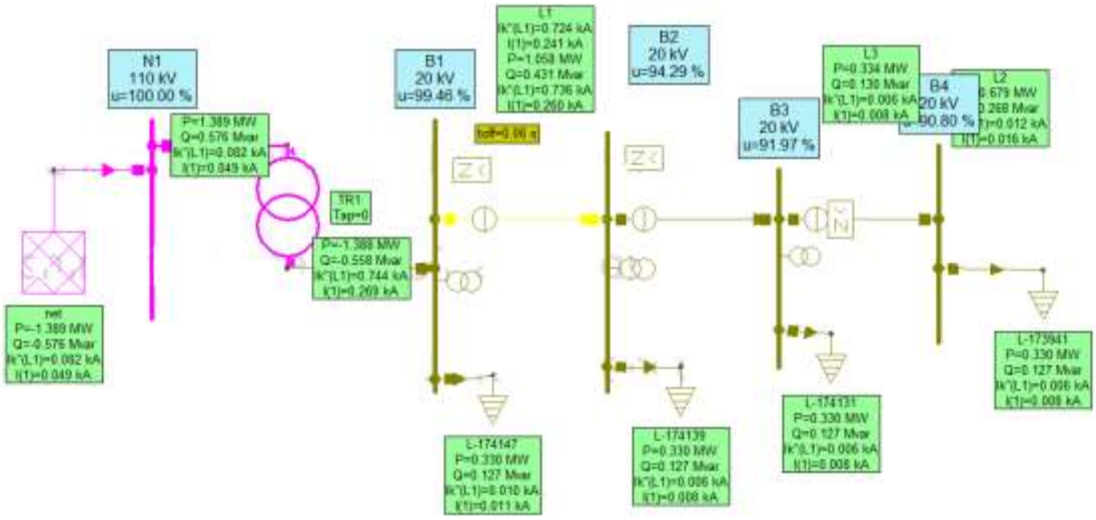

Fig. 15

b) Single line to ground fault in zone 2

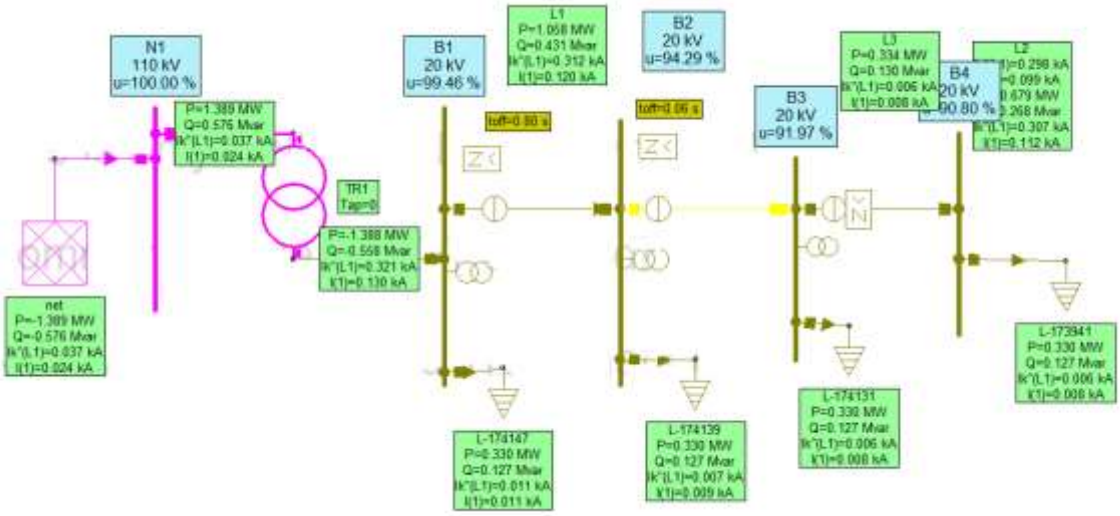

Fig. 16

c)Single line to ground fault in zone 3

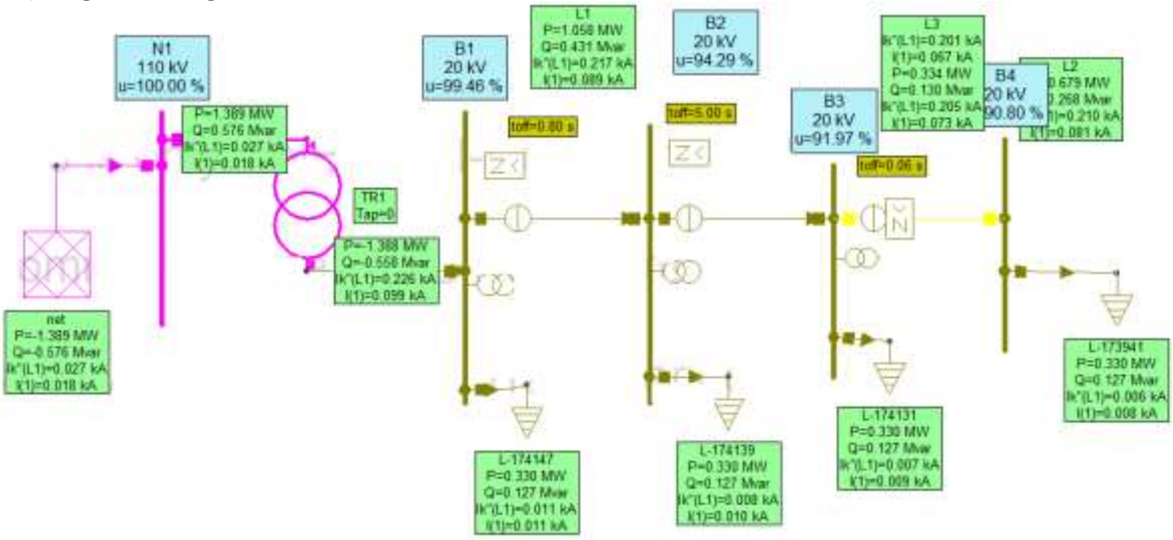

Fig. 17

The results, which are the characteristics of the distance relays, are displayed on the R-X plane of the ground fault at different lengths, with the presence and absence of arc resistance and with load variation (load encroachment) as shown in figures (18-20) below .

a)Line to ground fault on 50% of the length of line 1

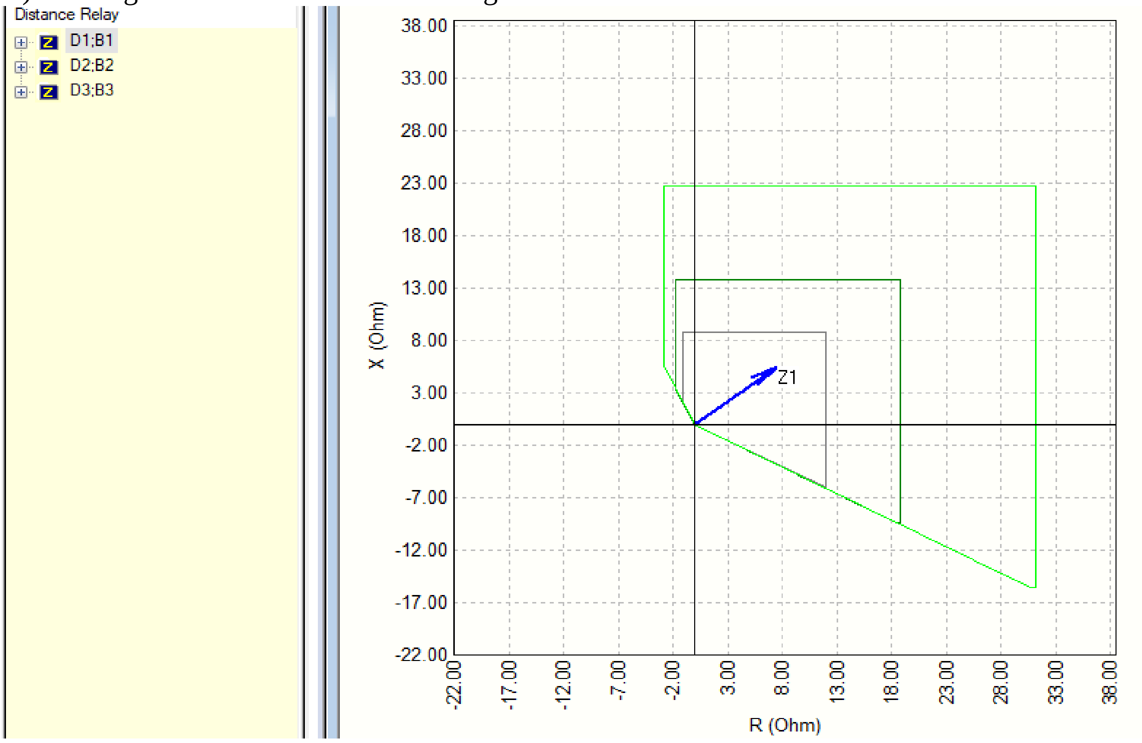

Fig. 18

b)Line to ground fault on 50% of the length of line 2

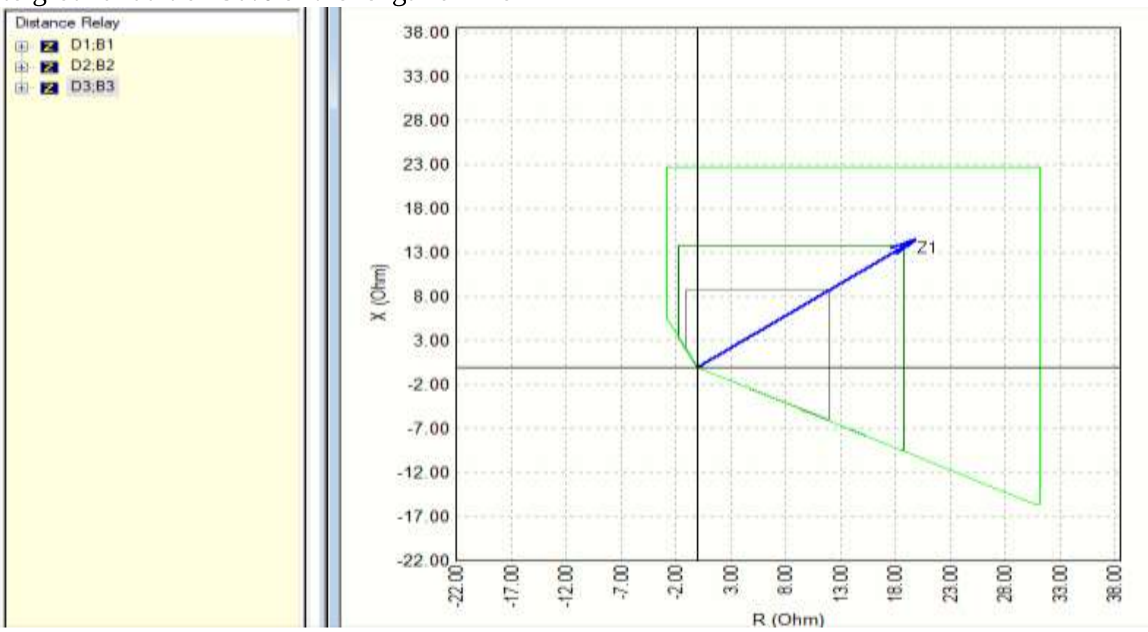

Fig. 18

c)Line to ground fault on 50% of the length of line 3

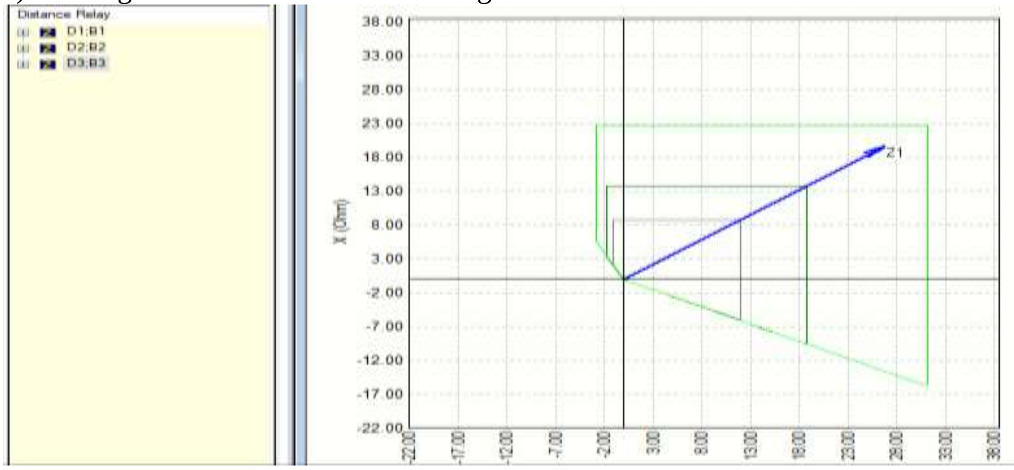

Fig. 19

Figure 20 shows the load encroachment characteristics, the relay characteristics should not enter the load zone.

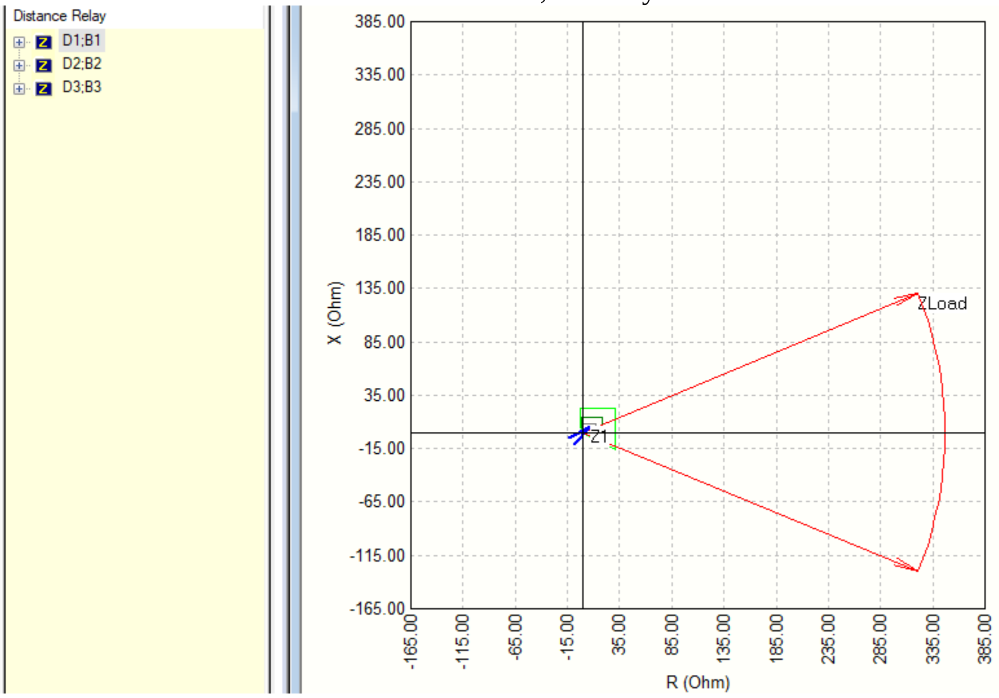

Fig. 20

Figure 21 shows the effect of arc resistance on the measured impedance seen by the distance protection.

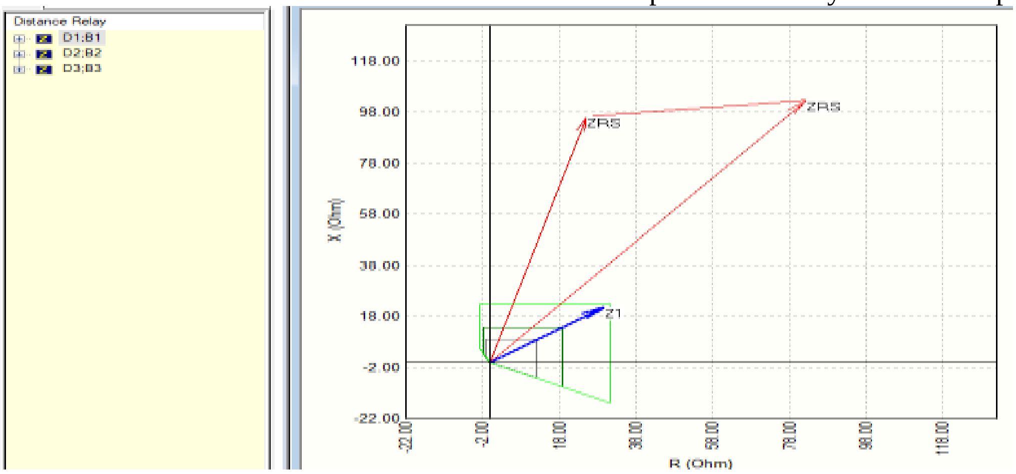

Fig. 21

6. Conclusion

An earth fault current is a current that flows to earth and has a magnitude that depends on the method of system earthing (high currents in Solidly earthed systems and very low currents in high impedance and isolated earthing systems), overcurrent protection cannot correctly determine the location of fault.

Considering the zero-sequence compensation factor for earth fault current measurement in three stepped distance protection can accurately determine the location of fault, the measured impedance by the relay does not depend on the earthing methods.

It is noted that the resistance of the fault arc can take the fault impedance outside the relay's tripping characteristic, so that it does not detect this condition. The effect of arc resistance is most significant on short lines where the reach of the relay setting is small. It can be a problem if the fault occurs near the end of the reach.

It is noted that when setting a distance relay, especially zone 3, which has the longest reach, that its characteristic does not encroach on the load area, as unnecessary tripping will may occur.

The simulated results by MATLAB Simulink and NEPLAN Software match the theory solutions.

7. Reference

[1] Abdullah Hamed Ahmed , Ahmed Jasim Sultan. (2019). A New Approach Of Mho Distance Relay For Transmission Line. IOP Conf. Series: Materials Science And Engineering, 1-15.

[2] Arora, Kiran Sahu And T. G. (2014). Numerical Three Stepped Distance Relay. International Journal Of Engineering Research & Technology (IJERT), 540-544.

[3] Abdallah R.Alzyoud, M.A.Salahat "Using Programmable Logic Controllers (Plcs) To Realize Distance Protection " Published In WSEAS International Conference Proceedings + Journal ,Corfu Island ,Greece ,August ,2005.

[4]Mr.Ajaysingh T.Chandan, Mr.K.Venkata Rama Mohan, Mr.Santhosh Kompelli, Mr.Arvind R.Singh. (2015). Advance Distance Protection Of Transmission Line In Presence Of Shunt Compensator. International Research Journal of Engineering and Technology (IRJET), 751-757.

[5] G. Ziegler, "Numerical Distance Protection Principles and Applications", Wiley and Sons, ISBN 3-89578-266-1, 2006.

[6] Muhd Hafizi Idris, Surya Hardia, and Mohd Zamri Hasana, "Teaching Distance Relay Using Matlab/Simulink Graphical User Interface" Maylaysian Technical Universities Conference on Engineering & Technology 2012.

[7] G. Omar, H. Elfetori and A. Hawai, "Implementation and Evaluation of a SIMULINK Model of a Distance Relay in MATLAB/SIMULINK", 2013.

[8] Purra Sai Kiran,P. Ramchander. (2015). Modeling and Performance Analysis of Mho-Relay in. International Journal & Magazine of Engineering,, 400-405.

[9] Shraddha A.Kohale, Dr.S.B.Warkad. (2017). Modelling & Simulation of Numerical MHO Relay. International Journal for Research in Applied Science & Engineering Technology (IJRASET), 1392-1398.

[10] Muhd Hafizi Idris, Mohd Saufi Ahmad, Ahmad Zaidi Abdullah, Surya Hardi, "Adaptive Mho Type Distance Relaying Scheme with Fault Resistance Compensation" IEEE 7th International Power ngineering and Optimization Conference, Langkawi, 2013.

[11] Muhammad Tami AI-Hajri, "Neutral Ground Resistor Monitoring Schemes," IEEE International Symposium on Electrical Insulation, Indianapolis; USA, September 19-22; 2004.

[12] Jeff Roberts, Hector J Altuve, and DaqingHou, "Review of Ground Fault Protection Methods for Grounded, Ungrounded,and Compensated Distribution Systems," Schweitzer Engineering

Laboratories, 2001.

[13] Till Welfonder and Volker Leitloff, "Location Strategies and Evaluation of Detection Algorithms for Earth Faults in Compensated MV Distribution Systems," IEEE Transactions on Power Delivery; 15 (4), 2000.

[14] D Griffel, Y Harmand, V Leitloff, and J Bergeal, "A New Deal for Safety and Quality on MV Networks," IEEE Transactions on Power Delivery; 12 (4):1428-1433,1997.

[15] DumitruToader, Stefan Haragus, ConstantinBlaj, and Iulia Cata, "Numerical Simulation of Single Phase Faults in Medium Voltage Electrical Networks," University of Timisoara, Romania, 2010.

[16] Cerretti, A. ; Gatta, F.M. ; Geri, A. ; Lauria, S. ; Maccioni, M. ;Valtorta, G., "Temporary overvoltages due to ground faults in MV networks," IEEE PowerTech, 2009, Bucharest , pp. 1 – 8,

2009.

[17] Abdallah R Al-Zyoud, A Alwadie, A Elmitwally, A Basheer Investigation of Earth Fault Characteristics Under Different Neutral Grounding Methods .International Review on Modelling and Simulations (IREMOS) 8 (3), pp.323-330,2015