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Teaching Distance Relay Using Matlab/Simulink Graphical User Interface

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Abstract

This paper describes the modeling of distance relay using Matlab/Simulink package. SimPowerSystem toolbox was used for detailed modeling of distance relay, transmission line and fault simulation. Inside the modeling, single line to ground (SLG) fault was choose to be the fault type and Mho type distance characteristic was choose to be as the protection scheme. A graphical user interface (GUI) was created using GUI package inside Matlab for the developed model. With the interactive environment of graphical user interface, the difficulties in teaching of distance relay for undergraduate students can be eliminated.

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Keywords: Distance Relay; Matlab/Simulink; Graphical User Interface; Single Line to Ground; Mho Distance Protection.

1. Introduction

The understandings of protection schemes are very important for electrical engineering students who take the power system subject. They must be prepared with enough knowledge and understandings before being ready to work in power utility or power related fields. Protection relays are among main components in power systems which can give very high impact on power system's stability and reliability. One of the protection relays used in power system is distance or impedance relay which is mainly used in transmission system. Distance relay can be used as main or backup protection. It can be used to protect the transmission line or power transformer. Nowadays, numerical distance relays have been used widely replacing the electromechanical and static distance relays. The understanding on the operation of distance relay is quite difficult compared to other protection relays because of its complex theories and philosophies. The difficulties in the understanding of distance relay occur when the students can't relate the theories they learned with the actual operation of distance relay. By using the graphical user interface, it is aimed to minimize this problem thus enhances their understanding.

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1.1 Distance Protection Scheme

Fig. 1 shows the basic distance protection scheme of a transmission line. The impedance measurement inputs are the values of three phase current and voltage phasors taken from the current transformer (CT) and voltage transformer (VT) respectively. Three phase current and voltage waveforms must be filtered first to eliminate the harmonic contents which may present due to arcing of the fault. The filtered waveforms then sampled at a selected sampling frequency before being used digitally inside distance relay. The relays compare the setting impedance with the measured impedance to determine if the fault is inside or outside the protected zone. They immediately release a trip signal when the impedance value is inside the zone 1 impedance circle of distance relay. [1].

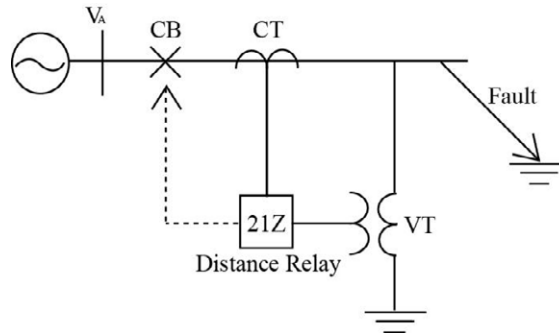


Fig. 1. Basic distance protection scheme.

There are many types of distance relay characteristic such as mho, quadrilateral, reactance, admittance, polarised-mho, offset mho etc. Every type of characteristics has different intended function and theories behind. In this simulation, Mho type distance relay was used as the distance protection scheme. Fig. 2 shows the characteristic of Mho type distance relay which is normally used to protect long transmission line or as backup protection where Z_n is the reach setting. The impedance measurement algorithms used depends on the fault type.

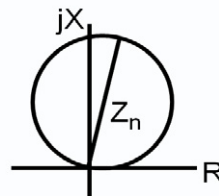


Fig. 2. Mho type distance characteristic.

1.2 Fault Calculation Algorithms

A fault in power system can be classified into symmetrical or unsymmetrical faults. Three phase fault is the only symmetrical fault where all phases are in contact with each other. The line to line (LL) fault, double line to ground (DLG) fault and single line to ground (SLG) fault are classified as unsymmetrical faults [2]. Basically, when a fault occurs at a transmission line, distance relay measures the impedance between the faulty phases in case of LL fault or between faulty phases and neutral conductor in case of ground faults. Table 1 show the different algorithm used to measure the fault impedance for different types of fault [3]. Distance relay will first determined the fault type by using internal phase selection feature and then determine which impedance measurement algorithm must be used.

Table 1. Fault Impedance Algorithm For Different Fault Types

Fault Type	Algorithm
AG	$V_A / (I_A + 3k_0 I_0)$
BG	$V_B / (I_B + 3k_0 I_0)$
CG	$V_C / (I_C + 3k_0 I_0)$
AB or ABG	$(V_A - V_B) / (I_A - I_B)$

BC or BCG	$(V_B - V_C)(I_B - I_C)$
CA or CAG	$(V_C - V_A)(I_C - I_A)$

Where;

A, B and C indicates faulty phases.

G indicates ground fault.

V_A , V_B and V_C indicate voltage phasors

I_A , I_B and I_C indicate current phasors

Z_0 = line zero-sequence impedance

Z_1 = line positive-sequence impedance

k_0 = residual compensation factor where $k_0 = (Z_0 - Z_1)/kZ_1$. k can be 1 or 3 depend on the relay design.

2. Modeling Transmission Line And Distance Relay

Matlab is powerful analysis software which has the capability of modeling power system components using SimPowerSystems toolbox inside Simulink package. In this toolbox, many available power systems components such as three-phase transformer, three-phase load, distributed parameters line, three-phase source, circuit breaker etc can be used for AC or DC applications [4]. All these components are ready to use where the users should only drag the components into model file and enter the parameter values.

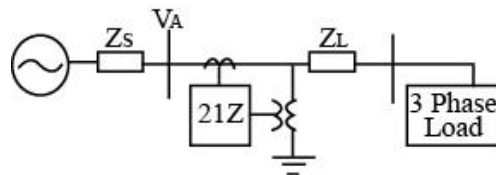


Fig. 3. One-line diagram of transmission line with three-phase load.

Fig. 3 shows the one-line diagram of a spur transmission line connecting to a three-phase load which was used in this modeling. The transmission line and load was modeled using distributed parameters line and three-phase load block sets respectively. Fig. 4 shows the developed model of transmission line and load. From Fig. 4, it can be seen that the transmission line was separated into two equal lines. The reason is to simulate a fault at a point along the transmission line where the first line simulate the fault distance from the substation terminal until fault point while the second line simulate the balance distance from fault point until the end of the transmission line. Table 2 shows the ‘default’ power system, transmission line and load data used in this simulation. However, the users have the capability to change these parameters using GUI which was developed after the modeling completed.

One of the great features of Simulink package is the developed model can be included in one block set only by creating the subsystem for the developed model. This feature minimizes the use of space inside the file for the case of complex system. Furthermore, the created subsystem block set also can be copied and pasted at any space or file thus eliminates the multiple building of the model. As shown in Fig. 5, the developed transmission line and load model in Fig. 4 has been changed into one single transmission line and load block set.

As discussed earlier, the fault impedance measurement requires the post-fault three phase current and voltage phasors. The three phase current and voltage waveforms extracted from the CT and VT respectively need to be filtered first which is done by the Low pass Filter block set. Then, the only remained fundamental voltage and current waveforms will be passed to Fast Fourier Transform (FFT) block set. The function of FFT block set is to extract the magnitudes and phase angles of fundamental three phase current and voltage phasors. The FFT block set performs a Fourier analysis of the input signal over a running window of one cycle of the fundamental frequency of the signal. These magnitudes and phase angles then are used by the SLG Fault Calculation block set to calculate the impedance of the faulted phase before the occurrence of fault until the fault is cleared. The outputs of this block set are the magnitudes and phase angles of impedance, the values of resistance and the values of reactance. All these data are calculated before the occurrence of fault until the fault is cleared.

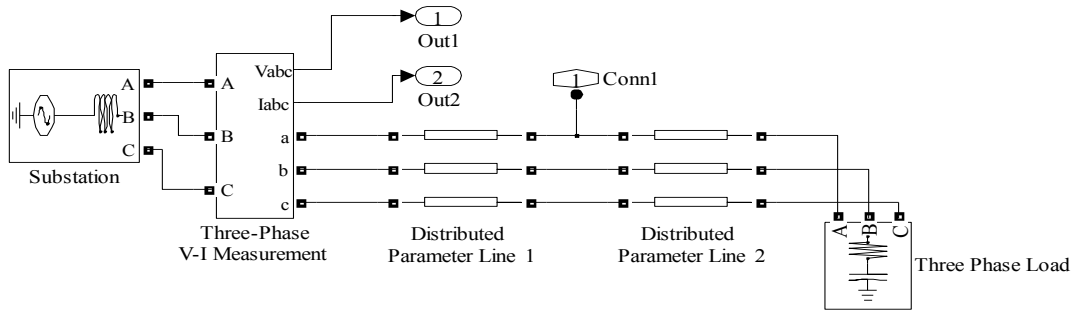


Fig. 4. Transmission line and load model.

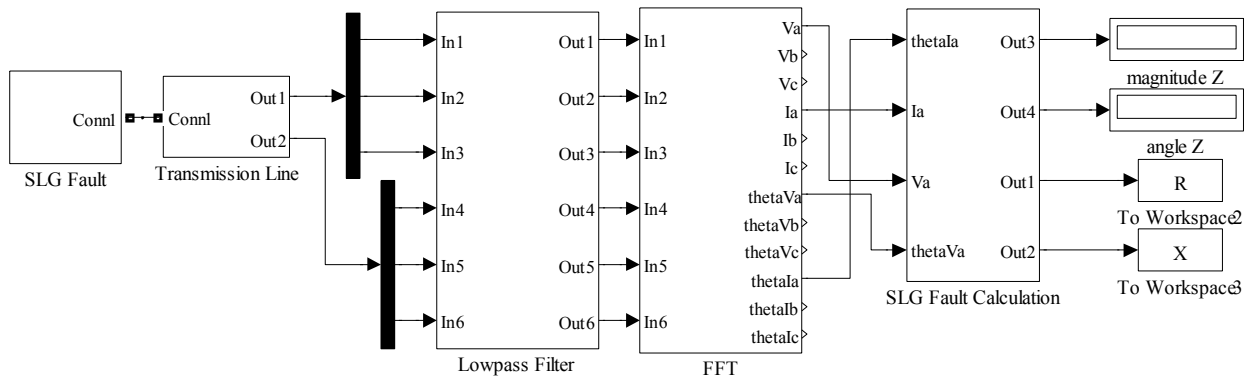


Fig. 5. Overall simulation model.

Table 2. Power System, Transmission Line And Load Data

Power system, transmission line and load data	Value	Unit
Power system		
Power system voltage	132,000	Volt
Phase angle of phase A	0	degree
Nominal frequency	50	Hz
3 phase short circuit level at base voltage	300,000,000	VA
Source X/R ratio	6	-
Transmission line		
Line length	50	km
Positive sequence resistance	0.01239	Ω/km
Zero sequence resistance	0.1239	Ω/km
Positive sequence inductance	0.00043386	H/km
Zero sequence inductance	0.00130157	H/km
Positive sequence capacitance	1e-9	F/km
Zero sequence capacitance	1e-9	F/km
3 phase load		
Active power	40,000,000	W
Inductive reactive power	0	Var
Capacitive reactive power	19,373,000	Var

3. Building Graphical User Interface

The final stage of the project is to develop the GUI for the finished model. After completed, this GUI will become as an education tool for the students in enhancing their understanding on distance relay characteristic. This GUI was developed using Matlab GUIDE Quick Start [5]. This GUIDE makes it easy for the user to develop the GUI for any type of applications. The saved GUI file is in figure form (.fig). Once saved for the first time, Matlab will automatically attach the GUI figure file with its associated M-file. This M-file contains the associated default coding for each elements put inside the GUI figure file. Then, the only left step is for the users to associate each element inside the GUI figure file with their intended functions or coding. The GUI figure file can be linked with parameters inside Simulink model using the 'callback' function. The callback function will call the intended parameters when the users want to change their default values and make appropriate action once the element for example the pushbutton is pushed. Fig. 6 shows the unsaved GUI figure file for the developed simulation model using GUIDE Quick Start. After saved and run, the GUI figure file is ready to be used as shown in Fig. 7.

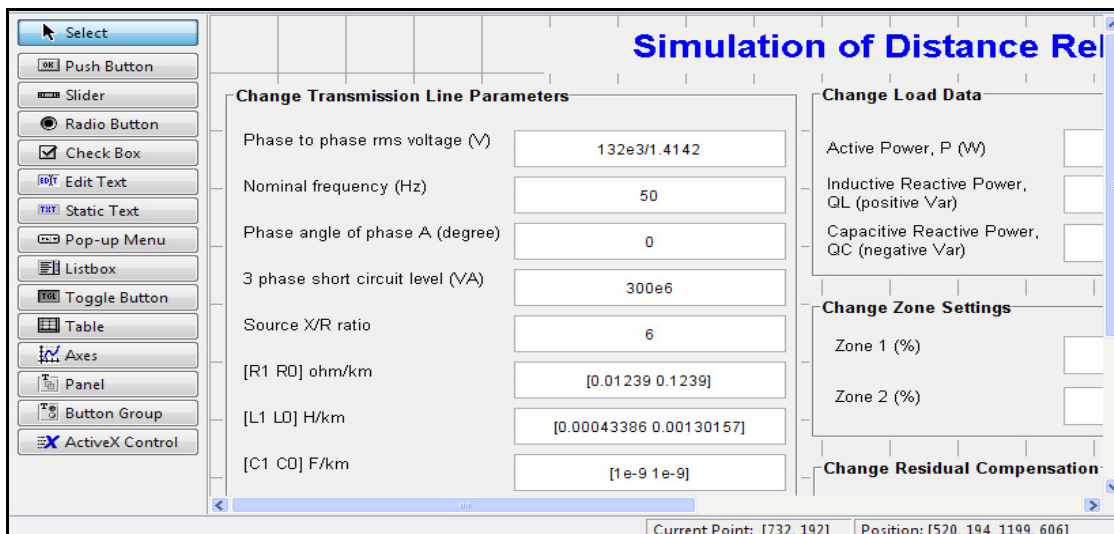


Fig. 6. Unsaved GUI figure file.

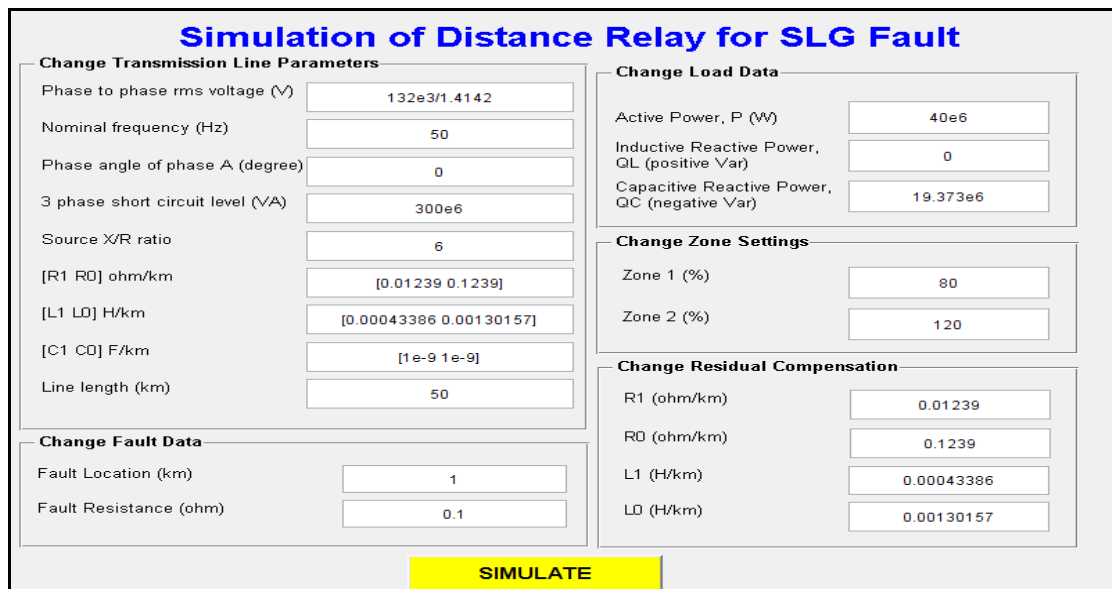


Fig.. 7. Completed GUI figure file for the developed model.

4. Sample GUI Applications

This section presents several sample applications using the developed GUI for the Mho type distance protection relay. By using this GUI, the students can study the effects of parameter changes on distance relay characteristic such as the effect of fault location and fault resistance. Fig. 8 & 9 show the fault impedance locus for fault at 20 km and 49 km from the substation terminal respectively. The setting for zone 1 and zone 2 is 80 percent and 120 percent of line length or equal to 40 km and 60 km respectively. It can be seen that the final point of fault impedance locus for fault at 20 km falls under zone 1 characteristic while it falls between zone 1 and zone 2 characteristics for fault at 49 km from substation terminal.

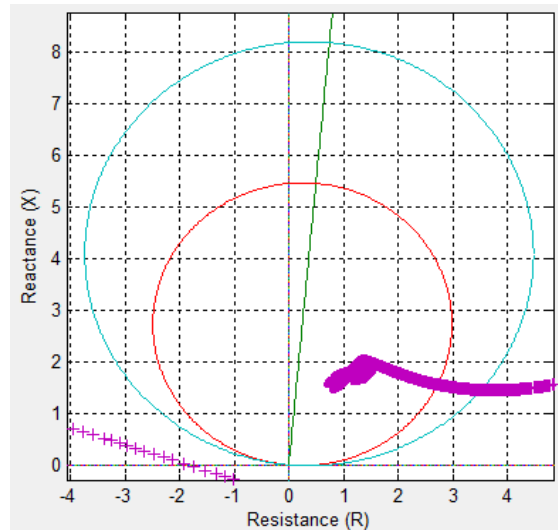


Fig. 8. Fault impedance locus for fault at 20 km from substation terminal.

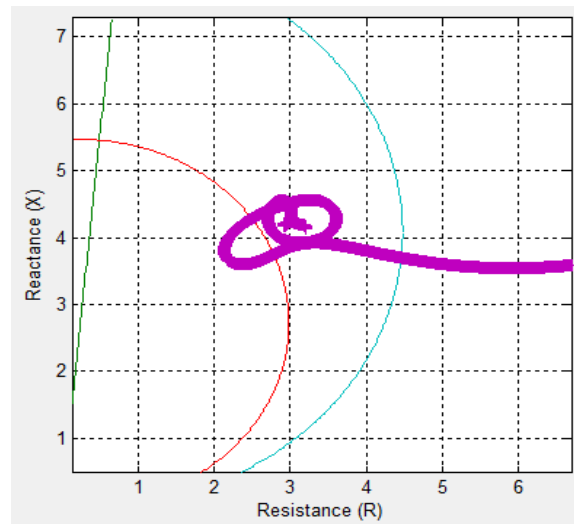


Fig. 9. Fault impedance locus for fault at 49 km from substation terminal.

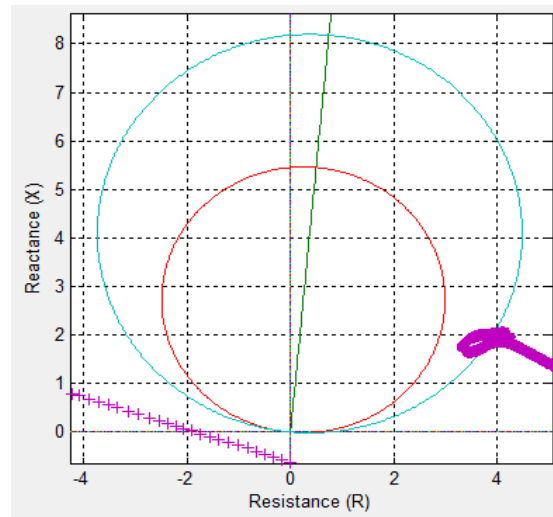


Fig. 10. Fault impedance locus for fault at 30 km from substation terminal with fault resistance 5 ohm.

Fig. 10 shows the effect of fault resistance on Mho type distance characteristic. The fault location is 30 km from substation terminal while the fault resistance value is 5 ohm. It can be seen that fault resistance has deviated the final point of fault impedance locus far away from zone 1 reach.

5. Conclusions

A Matlab GUI based distance relay was successfully developed and presented. The GUI provides a user-friendly interface to help students to enhance their understanding of distance protection scheme. The students are able of changing simulation parameters such as power system data, transmission line data, load data and fault data and observe their effects on fault impedance locus. For future enhancement, the model can be extended for other types of distance relay characteristic and fault types.

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