Scientific Journal of Impact Factor (SJIF): 4.72

e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 4, Issue 6, June -2017

Series Compensated Transmission Line Protection using PSCAD

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Abstract – *In order to meet the high demand for power transmission capacity, some power companies have installed series capacitor on power transmission line. The introduction of the capacitance in series with the line reactance allows reduction in line impedance, thus resulting increased power transmission capability. It provides the benefits of increased system capacity, reduced system losses and voltage regulation. The paper presents series compensated transmission line model by using PSCAD. Results are tested with different fault locations for compensated and without compensated transmission line. Performance of the developed method ensures that the proposed scheme gives the apparent effects when compensation is going to be added in the line.*

Keywords – *series compensation; PSCAD; mho relay; zone setting; impedance calculation*

I. INTRODUCTION

In a current scenario, the per-capita consumption of power is symbolizes the development of any country. This has resulted in a many times increase in power demand. This drives power system engineers to generate and transmit maximum limit which is possible power through transmission line that is up to thermal limits, which leads to installation of compensation devices in transmission line. However, this inclusion of compensation cause changes in system parameter that is in its impedance seen from the relay point, current and voltage inversion, introduction of sub-harmonic frequency components, etc. This need changes in existing protection concepts.

Series Compensation lines used series capacitor to cancel a portion of the inductive reactance of the line, and thereby improving the power transferring capability of the transmission line.

To utilize the whole capacity of the series capacitor installation in a utility network, it is essential to understand the impact of series compensation on protection to design appropriate ways with necessary changes. Compensation in a transmission system is normally introduced for extra high voltage transmission line, which usually employs distance relay (Mho relay) for the protection purpose. A distance relay works on real time calculation of impedance of the line with real time measurements aided with types of fault information. Therefore, the position of fault with respect to the compensator (zone of fault) is required for a distance relay to accomplish its overall decision. Faulty phase selection also increases system stability and availability by allowing single pole tripping. This will improve the behavior of transient stability and reduces switching overvoltage in the system.

It is very difficult task to handle series compensated line during various abnormalities with relay settings. The introduction of the series capacitance in the lines adds many complexities to the effective performance of distance relay [1]. The relay will try to look at the ratio of voltage and current to determine the distance to fault in order to decide if the fault is in its own zone or out of its protection zone. If it is known that the capacitor is always going to be part of fault loop, then reach setting of relay is possible [2].

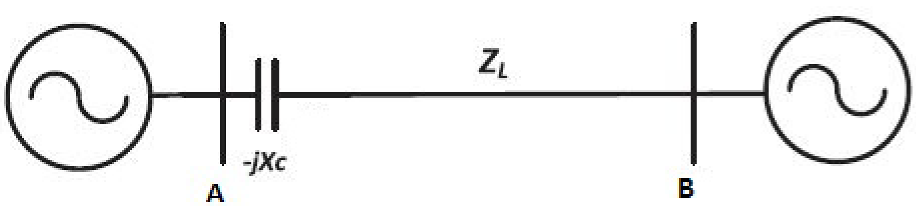


Figure 1. Series Compensated Transmission Line

There are some advantages of series compensation when it is used in EHV transmission line given below:

1. The lower line impedance improves system stability.
2. Improves regulation of voltage.
3. Adding series compensation provides a formula of controlling the division of load among several lines.
4. As loading Increase in a line it will improves the utilization of the transmission system.

There are some disadvantages also as follows:

1. Increase in fault current.
2. Mal-operation of distance relay if the degree of compensation and location is not proper.
3. High recovery voltage of lines across the CB contacts and is harmful.

Series compensation is generally stated as a percentage of the line inductive reactance, which is referred to as the "degree of compensation". Thus, we speak of a line that is 50% or 60% compensated, meaning that 50% or 60% of the inductive reactance respectively, is being installed as series capacitive reactance.

SC at line end most suitable. It may cause a mho relay to measure a negative reactance for a close-in fault, which the distance element shows to be a fault behind the relay.

When SC come into the picture the operation of the distance relay becomes complicated due to change in line reactance. So it will highly uncertain during various types of other faults. Over and under reaching, V & I inversion takes place.

II. IMPEDANCE CALCULATION AND ZONE SETTINGS

Table 1.Transmission Line Parameters

Line Length	300 km
Voltage	230 KV
System Frequency	50 Hz
Positive sequence R	0.036294×10^{-3}[ohm/m]
Positive sequence X_L	0.5031×10^{-3}[ohm/m]
Positive sequence X_C	288.288[Mohm-m]
Zero sequence R	0.037958×10^{-3}[ohm/m]
Zero sequence X_L	1.3277×10^{-3}[ohm/m]
Zero sequence X_C	446.428[Mohm-m]

Here the transmission line of 300 km is considered. Load is connected at receiving end side bus that is 150 MW 25 MVAR. Time to apply fault is 1 sec. Duration of fault is 0.3 sec. Simulation run time is 3 sec. Voltage input time constant is 0.05 sec. Source positive impedance is 1.43+j6.21 [ohm].

Bergeron model is used in this simulation. It is single frequency model that is all calculated parameters, such as characteristic impedance Z_o are calculated at the specified frequency. Usually 50/60 Hz is taken for Ac transmission.
It can be used for transient simulation in time domain, only results at specified steady state frequency are meaningful.

Distance relays are designed to protect power systems against four basic types of faults L- G, LL-G, LL and three phase fault. In order to detect any of above faults each one of the zones of distance relays require six units. Three units for detecting faults between the phases and the remaining three units for detecting phase to earth faults. The setting of distance relays is always calculated on the basis of the positive sequence impedance. Table 2 indicates fault impedance calculation formulae for all of the fault types.

Table 2. Fault Impedance Calculation on Different Faults

Distance Element	Formula
Phase A	$Z_A=V_A/(I_A+3KI_O)$
Phase B	$Z_B=V_B/(I_B+3KI_O)$
Phase C	$Z_C=V_C/(I_C+3KI_O)$
Phase A- Phase B	$Z_{AB}=V_{AB}/(I_A-I_B)$
Phase B- Phase C	$Z_{BC}=V_{BC}/(I_B-I_C)$
Phase C- Phase A	$Z_{CA}=V_{CA}/(I_C-I_A)$

Where, k= (Z0-Z1)/Z1, Z0 and Z1 are zero sequence and positive sequence impedances.

When the distance of the transmission line is set to 300Km, the constant for ground impedance is calculated as:

Z1 = (0.0362X10-3 + j0.5031X10-3) (300km)

$= 267.7\angle\ 69.44^{o}\ \Omega$

Z0 = (0.0379X10-3 +j1.3277X10-3) (300km)

$= 414.01\ \angle\ 74.06^{o}\ \Omega$

Therefore:

$K = (Z_0 - Z_1)/\ Z1$

$= 0.6\ \angle\ -4.5^{o}$

Here two zones are taken for simulation study. The reach for Zone 1 is 80% of 150 km means it gives protection upto 120 km line length. The reach for Zone 2 is 150% of 150 km means it gives protection upto 225 km line length.

R = 0.0362Ω X_L = 0.5031Ω

$\Theta = \tan^{-1}\frac{X_L}{R}$

$= \tan^{-1}\frac{0.5031}{0.0362}$

$= 85.88^{0}$

Zone 1 (80% of 150km) **Zone 2 (150% of 150km)**

R=4.344Ω X_L=60.372Ω R=8.145Ω X_L=113.19Ω

$Z = \sqrt{R^2 + {X_L}^2} Z = \sqrt{R^2 + {X_L}^2}$

Z = 60.52 Z = 139.48

$r = \frac{Z}{2} = 30.26 \quad r = \frac{Z}{2} = 69.74$

$X = r\cos\Theta = 2.174 \quad X = r\cos\Theta = 4.993$

$Y = r\sin\Theta = 30.18 Y = r\sin\Theta = 69.5$

III. RESULTS AND DISCUSSION

A. CASE 1

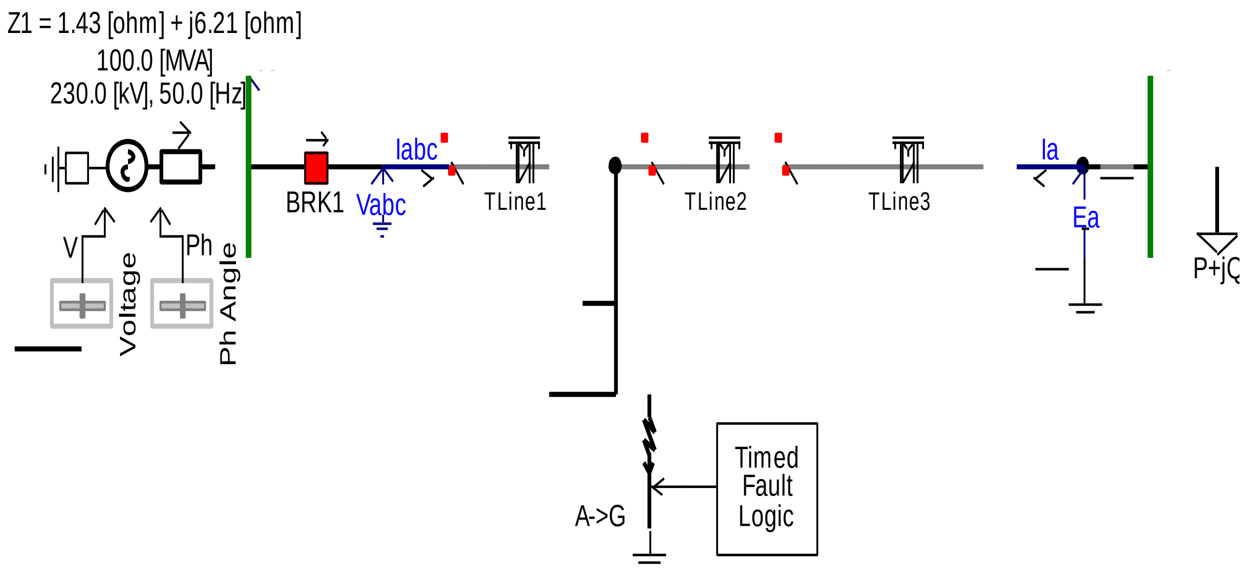
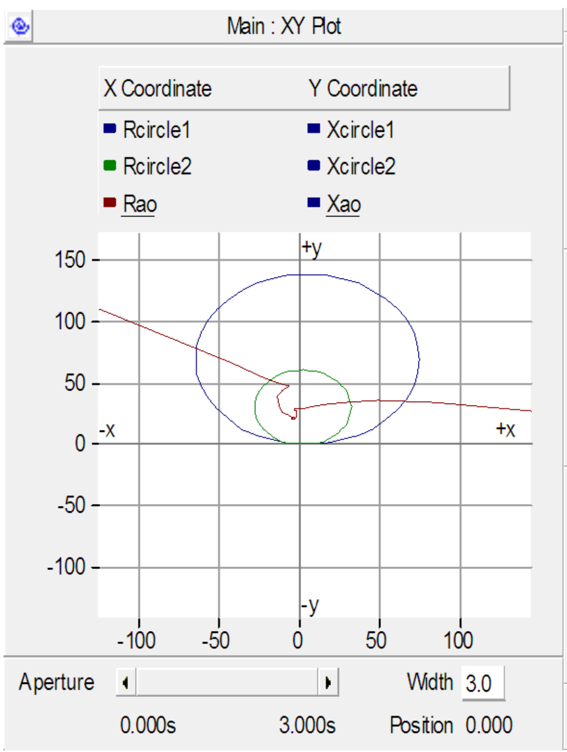


Figure 2.Transmission line model for fault at 75 km (without compensation)

The transmission line model contains total length of the 300Km. In this the Bergeron type Transmission line is considered. The results of the Mho relay are obtained by dividing the whole Line in the three zones. The test is performed on the following model in PSCAD Software Tool.



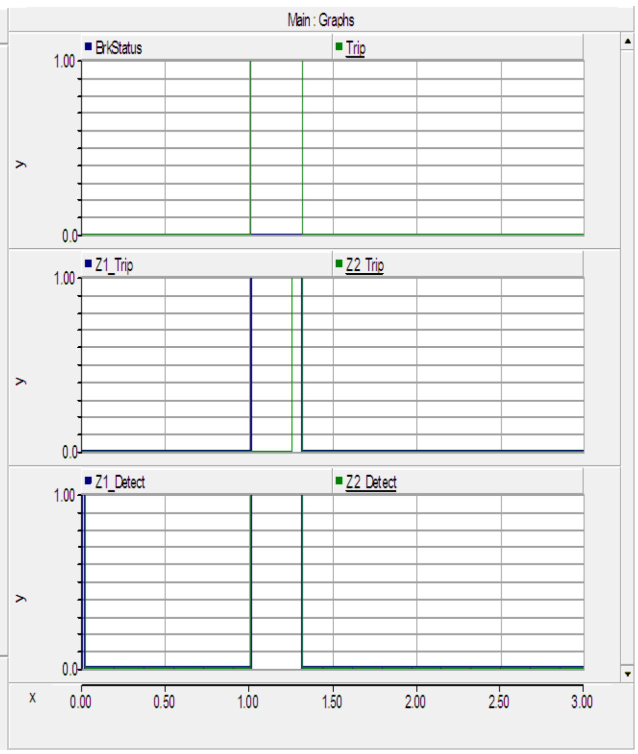


Figure 3.R-X plot for fault at 75 kmFigure 4. Trip signalfor AG fault at 75 km

The above transmission line model analyze the simulation result with fault location 75 km and fault remains in the system for duration of 0.3 sec. Figure 3 shows the R-X diagram of the above transmission line model. From the R-X diagram, we can easily observe that relay operates in first zone as the fault location is 75 km. Figure 4 shows the trip signal for zone 1 as fault is at 75 km.

B. CASE 2

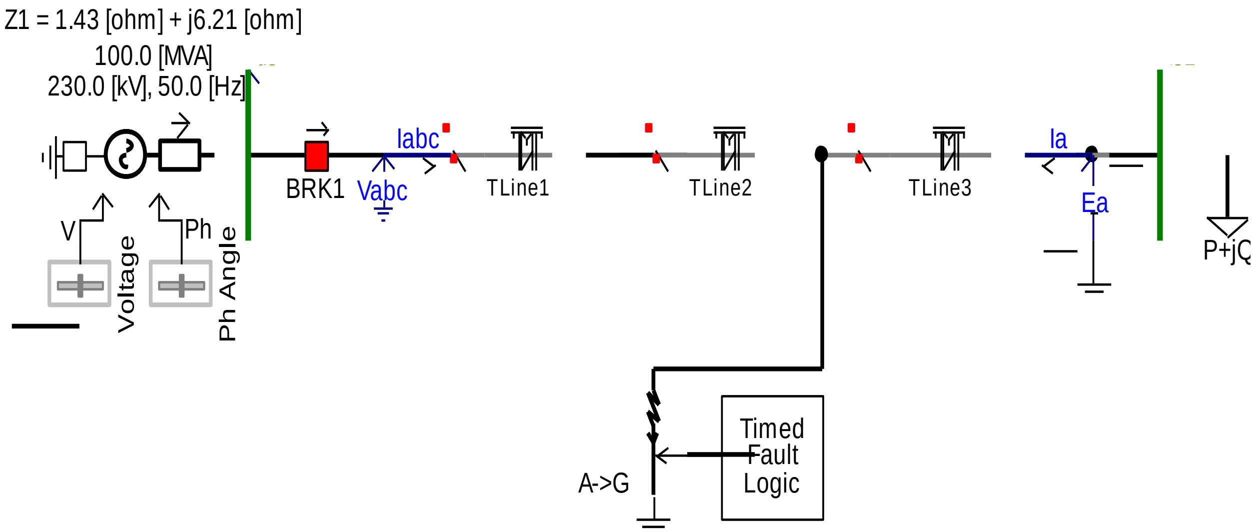
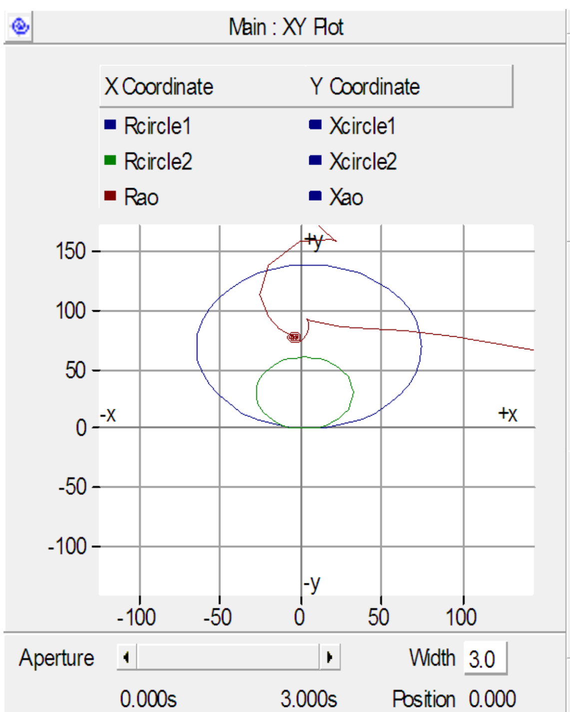


Figure 5. Transmission line model for fault at 150 km (without compensation)



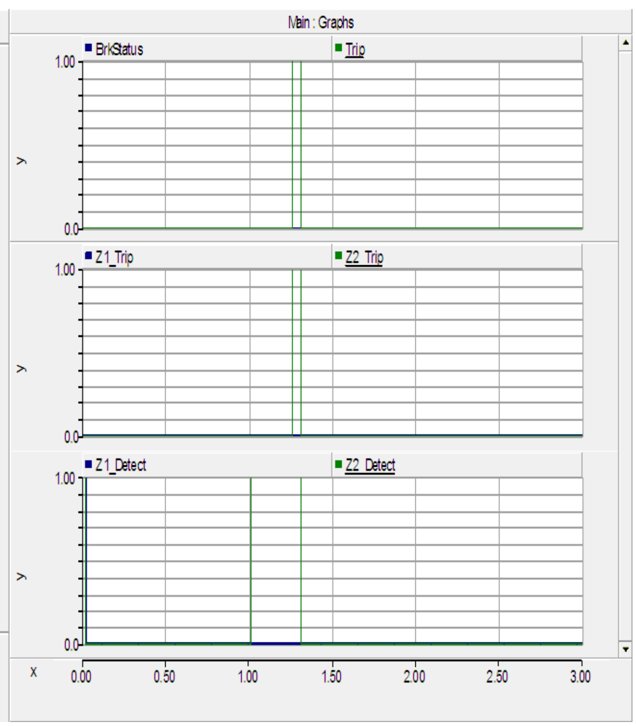


Figure 6.R-X plot for fault at 150 km *Figure 7.Trip signal for AG fault at 150 km*

Figure 6 shows the R-X diagram for the fault location at 150 km. From R-X diagram, we can observe that the relay operates in second zone. Figure 7 shows the trip signal for zone-2 as fault is at 150 km.

C. CASE 3

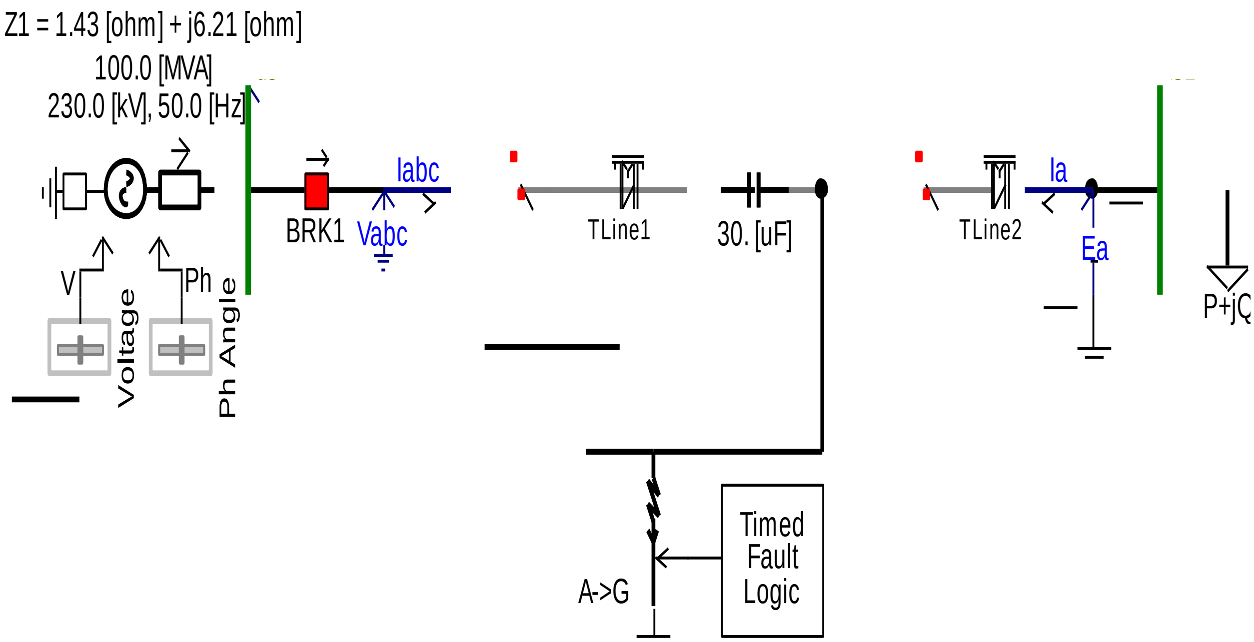
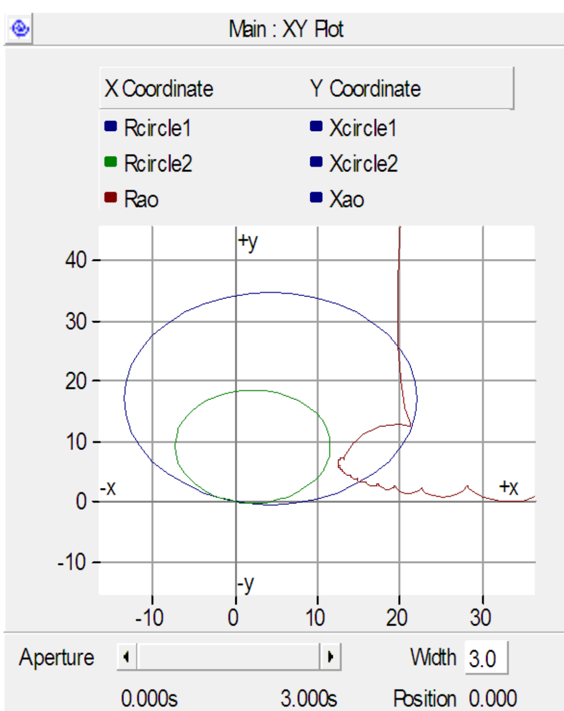


Figure 8. Transmission line model for fault at 150 km (with compensation)

Figure 8 shows the transmission line model with the fault location at 150 km for AG (line to ground) fault. Here, we have provided the fix capacitor of value 30 μF. Zones are classified according to the compensation settings. Figure 9 shows the setting of the mho circle with compensation.



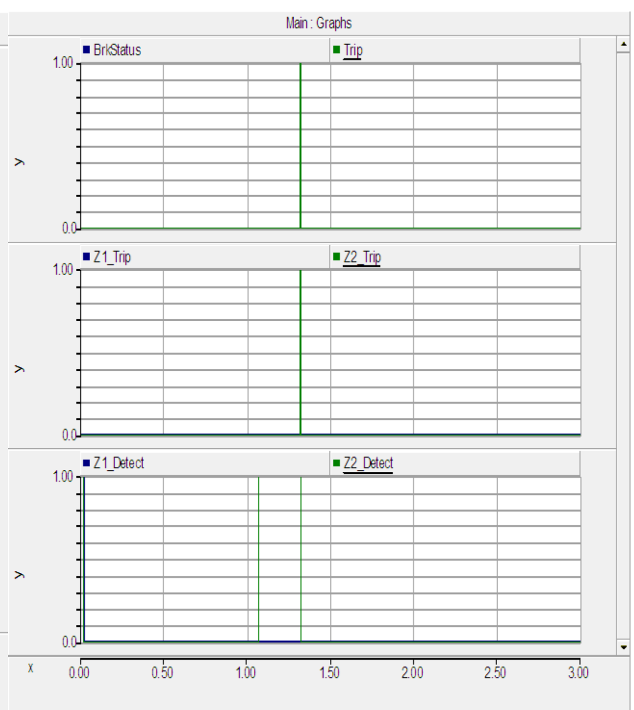


Figure 9.R-X plot for fault at 150 km

Figure 10. Trip signal for AG fault at 150 km

Figure 9 shows the R-X diagram of above transmission system. This model shows that the relay operates in zone-2 as fault location is 150 km. The trip signal for zone-2 is shown in figure 10. Here because of compensation setting, the fault impedance reduces. So we can implement relay compensation setting for mho relay for proper zone operation.

IV. CONCLUSION

Here, the fault detection of transmission line is done with the usage of PSCAD simulation. In this project, the simulation study is analysed for AG fault with various fault locations. The R-X plot shows that the mho relay adapts its characteristic to trip itself in their respective zones. It is operated for the provided compensation level and according to the information received on the system condition. We have analysed the results for the series compensated transmission line. The insertion of a series capacitor into the transmission line increases power transfer capability. It improves the stability margin and gives the better voltage regulation. Results show that because of the compensation setting, the line impedance will get reduced and MHO relay operates satisfactorily in its zone.

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