Under-reach correction of distance relay in transmission lines

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ABSTRACT

Conventional distance relaying in transmission line may seriously cause under-reaching or over-reaching when receiving side impedance are comparatively greater than sending side impedances and vice versa. These mal-operations become more severe especially in the case that the two networks connected to the ends of the protected lines have extraordinary different equivalent impedances. The protection zones of ground fault elements of distance relay can be modified adaptively in a quadratic function form with the present magnitude and power factor of load, based upon the user setting values. The behavior of a distance relay on a single circuit transmission line and double circuit transmission line is analyzed and simulated using EMTDC/PSCAD software. Transmission lines are modeled by using Bergeron model in PSCAD program for simulation purposes. A new non-iterative algorithm is proposed, which produces a secure decision to trip only the faulted phases during single line to ground fault, for under-reach correction in basic distance relaying scheme. PSCAD/EMTDC software is used to generate time series of phase current following a line to ground fault in the single and twin circuit parallel line model and is captured in COMTRADE file. This file serves as an input to the MATLAB based code of the proposed non-iterative algorithm.

I. INTRODUCTION

Purpose and Requirements of Protection Relaying

The purpose of power system protection is to minimize the consequences resulting from faults . Since the damage resulting from faults increases with the duration of faults, fast fault detection and clearing is imperative. Furthermore, protection schemes must be selective, i.e. they must remove the faulty device only, in order to minimize power delivery interruption.

Distance Relay in Power System

Distance relays are normally used to protect transmission lines [7]. They respond to the impedance between the relay location and the fault location. As the impedance per Km of transmission line is fairly constant, these relays respond to the distance to a fault on the transmission line. They detect faults in transmission systems and isolate abnormal or fault conditions by sending trip signals to associated circuit breaker.

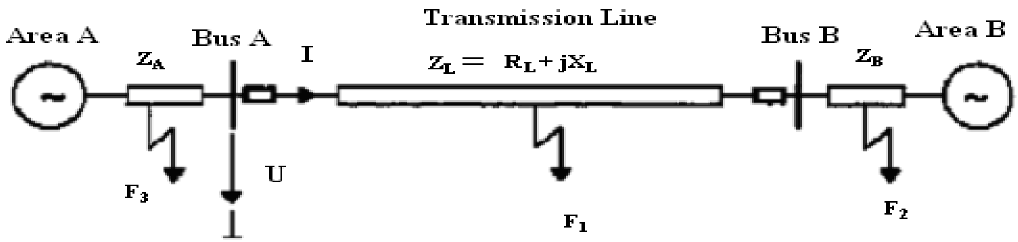


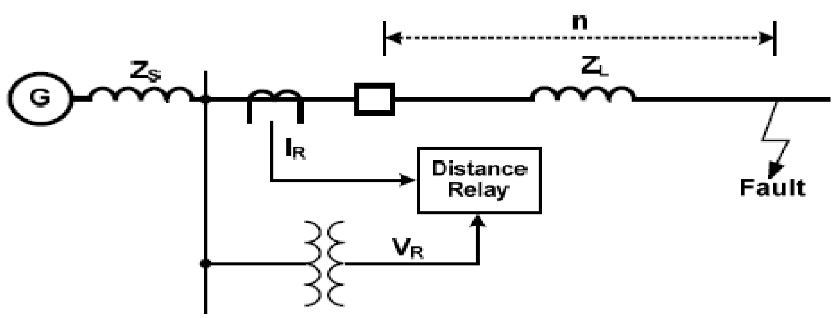
Fig. 1 Transmission line protected by distance protection.

A comparison of local signals (voltage and current) enables the relay to decide which zone contains the fault [5,15]. In this way, a distance assessment is made from the relay location to the fault location. Most of the relay characteristics that we use are quadrilateral and mho. Quadrilateral relay is suitable for protecting ground fault. Mho relay is very effective with detecting phase fault. Many problems affect the application of distance protection in a power system. These problems are outlined as follows]:

1 The transient of current and voltage signals at the occurrence of a fault.
2 The distance relay mal-operates during a power swing condition due to the reason that the apparent impedance in system may come inside the zone.
3 Discrimination between a healthy load and a system fault condition which the distance relay must be able to identify these condition to prevent mal-operation.
4 The fault resistance may create problems for distance measurements because the value of the fault resistance makes to distance relay produce error apparent impedance which may be difficult to forecast.

Operation of distance relay

The distance relay is connected with a power line through instrument transformers, as shown in Figure 2. Assuming that the fault occurs on the line at a distance of nZ_{1L} ohm from the relay, the voltage VR on the relay will be the $I_r nZ_L$ drop from the distance relay to the fault since the voltage at the fault is 0 V.



Therefore, the impedance of the distance relay is:

$$Z_R = \frac{V_R}{I_R} = \frac{I_R nZ_{1L}}{I_R} = nZ_{1L}$$

Under-Reach - Effect of Remote infeed

A distance relay is said to under-reach when the impedance presented to it is apparently greater than the impedance to the fault. Percentage under-reach is defined as:

$$[(Z_R - Z_F)/ Z_R] \times 100\%$$

where:
Z_R = intended relay reach (relay reach setting)
Z_F = effective reach

Over-Reach

A distance relay is said to over-reach when the apparent impedance presented to it is less than the impedance to the fault. Percentage over-reach is defined by the equation:

$$[(Z_F - Z_R)/ Z_R] \times 100\%$$

II. ALGORITHM DEVELOPED FOR UNDER-REACH CORRECTION IN TWIN CIRCUIT

Consider a twin circuit parallel line of type-1 network as shown in fig. 3. If Z_S is the self-impedance of a phase, and Z_P is the mutual impedance between two phases of the same circuit. The basic sequence impedances are given by the following equation:

$$Z_L^0 = Z_S + 2 Z_P$$

$$Z_L^+ = Z_S - Z_P \qquad (2)$$

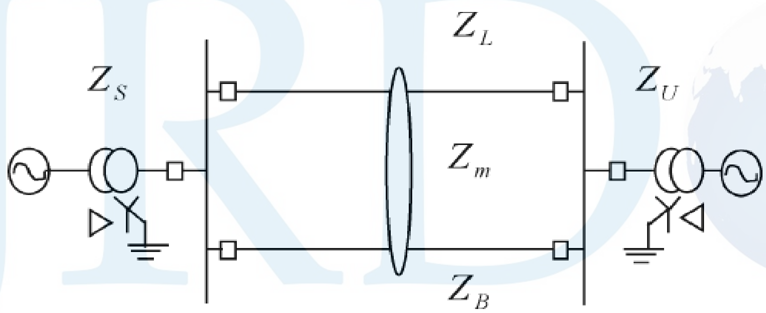


Fig. 3 Twin-circuit parallel line

Ignoring Inter-Circuit Mutual Coupling

When the inter-circuit mutual coupling of positive, negative and zero sequence circuits of parallel lines are neglected, the applicable equivalent circuits for the parallel for parallel combination are identical, only the circuit element values are different [1]. From the equivalent circuit shown in fig. 4, the equivalent impedance values of the lower part of the equivalent circuits after delta-star transformation are

$$Z_l^i = \frac{Z_S^i \, Z_U^i}{Z_S^i + Z_B^i + Z_U^i}$$

$$Z_j^i = \frac{Z_S^i \, Z_B^i}{Z_S^i + Z_B^i + Z_U^i} \qquad (3)$$

$$Z_k^i = \frac{Z_B^i \, Z_U^i}{Z_S^i + Z_B^i + Z_U^i}$$

Index I takes the symbol +, - or 0, depending on the sequence equivalent circuit.

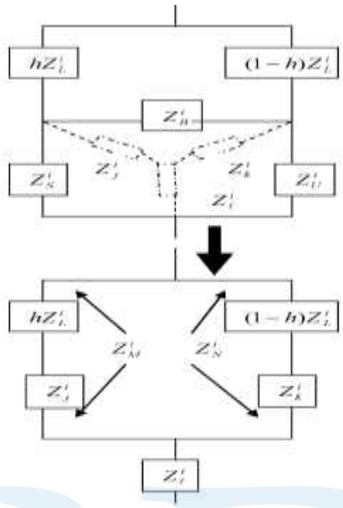


Fig. 4 Equivalent circuit without inter-circuit mutual coupling

Zero Sequence Impedance

$$Z^0 = Z_l^0 + \frac{Z_M^0 \, Z_N^0}{Z_M^0 + Z_N^0} \qquad (4)$$

In terms of the basic zero sequence impedance of the lines and the end sources, the zero sequence impedance of the parallel circuit

$$Z^0 = \frac{Z_S^0 \, Z_U^0}{Z_S^0 + Z_B^0 + Z_U^0} + \frac{\left\{h\, Z_L^0 + \frac{Z_S^0 \, Z_B^0}{Z_S^0 + Z_B^0 + Z_U^0}\right\} \text{x} \left\{(1-h)\, Z_L^0 + \frac{Z_B^0 \, Z_U^0}{Z_S^0 + Z_B^0 + Z_U^0}\right\}}{Z_L^0 + \frac{Z_S^0 \, Z_B^0 + Z_B^0 \, Z_U^0}{Z_S^0 + Z_B^0 + Z_U^0}}$$

After algebraic simplifications

$$Z^0 = - \frac{(Z_S^0 + Z_B^0 + Z_U^0)(Z_L^0)^2}{Z_L^0(Z_S^0 + Z_B^0 + Z_U^0) + Z_S^0 Z_B^0 + Z_B^0 Z_U^0} h^2$$

$$+ \frac{(Z_S^0 + Z_B^0 + Z_U^0)(Z_L^0)^2 + Z_L^0(Z_B^0 Z_U^0 - Z_B^0 Z_S^0)}{Z_L^0(Z_S^0 + Z_B^0 + Z_U^0) + Z_S^0 Z_B^0 + Z_B^0 Z_U^0} h$$

$$+ \frac{Z_S^0 Z_B^0 Z_U^0 + Z_L^0(Z_S^0 Z_B^0 + Z_S^0 Z_U^0)}{Z_L^0(Z_S^0 + Z_B^0 + Z_U^0) + Z_S^0 Z_B^0 + Z_B^0 Z_U^0}$$

$$Z^0 = - k_1 h^2 + k_2 h + k_3 \qquad (5)$$

Positive Sequence Impedance

$$Z^+ = Z_l^+ + \frac{Z_M^+ Z_N^+}{Z_M^+ + Z_N^+}$$

The positive sequence impedance of the parallel circuit in terms of the basic positive sequence impedance of the lines and the end sources

$$Z^+ = \frac{Z_S^+ Z_U^+}{Z_S^+ + Z_B^+ + Z_U^+} + \frac{\left\{h\, Z_L^+ + \frac{Z_S^+ Z_B^+}{Z_S^+ + Z_B^+ + Z_U^+}\right\} \text{x} \left\{(1-h)\, Z_L^+ + \frac{Z_B^+ Z_U^+}{Z_S^+ + Z_B^+ + Z_U^+}\right\}}{Z_L^+ + \frac{Z_S^+ Z_B^+ + Z_B^+ Z_U^+}{Z_S^+ + Z_B^+ + Z_U^+}}$$

After algebraic simplifications

$$Z^+ = -\frac{(Z_S^+ + Z_B^+ + Z_U^+)(Z_L^+)^2}{Z_L^+\left(Z_S^+ + Z_B^+ + Z_U^+\right) + Z_S^+ Z_B^+ + Z_B^+ Z_U^+} h^2 +$$

$$+ \frac{\left(Z_S^+ + Z_B^+ + Z_U^+\right)\left(Z_L^+\right)^2 + Z_L^+\left(Z_B^+ Z_U^+ - Z_B^+ Z_S^+\right)}{Z_L^+\left(Z_S^+ + Z_B^+ + Z_U^+\right) + Z_S^+ Z_B^+ + Z_B^+ Z_U^+} h$$

$$+ \frac{Z_S^+ Z_B^+ Z_U^+ + Z_L^+\left(Z_S^+ Z_B^+ + Z_S^+ Z_U^+\right)}{Z_L^+\left(Z_S^+ + Z_B^+ + Z_U^+\right) + Z_S^+ Z_B^+ + Z_B^+ Z_U^+}$$

$$Z^+ = -\, k_4 h^2 + k_5\, h + k_6 \qquad (6)$$

Negative Sequence Impedance

$$Z^- = Z_l^- + \frac{Z_M^- Z_N^-}{Z_M^- + Z_N^-}$$

Substitution of the values in terms of the basic negative sequence impedances of the lines and the algebraic simplifications there after, yields similar expression as in case of positive sequence impedance, except that the positive sequence values get replaced by the corresponding negative sequence values. The negative sequence impedance of the parallel circuit is

$$Z^- = -\, k_4 h^2 + k_5\, h + k_6 \qquad (7)$$

Where h is the fractional distance of the fault from the sending end in per unit.

III. SOFTWARE MODEL IN PSCAD/EMTDC

A typical 500 kV, 50 Hz and 65 km long single and identical twin circuit transmission line was chosen to model in PSCAD/EMTDC software. The single line diagram is illustrated in Figure 5.

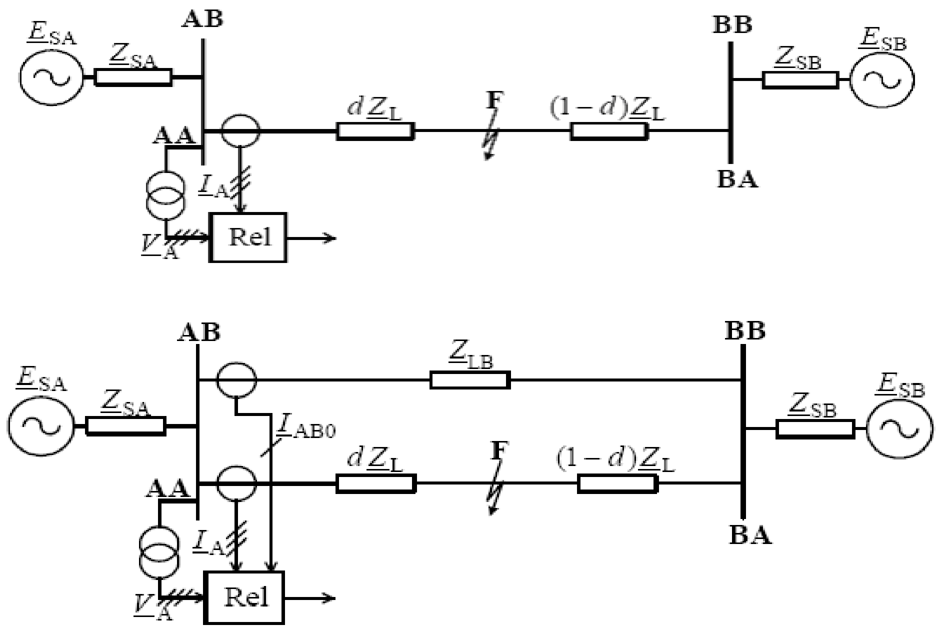


Fig.5 The single line diagram of 500 kV single and twin circuit line

Transmission lines are modeled by using PI section model in PSCAD software. It is illustrated in Figure 5. A set of simulation tests was carried in the test model of a power system shown in Figure 6 which is interfaced with the model of a relay implemented using the PSCAD/EMTDC models. The transmission system modeled contains of a total line length of 65 km.

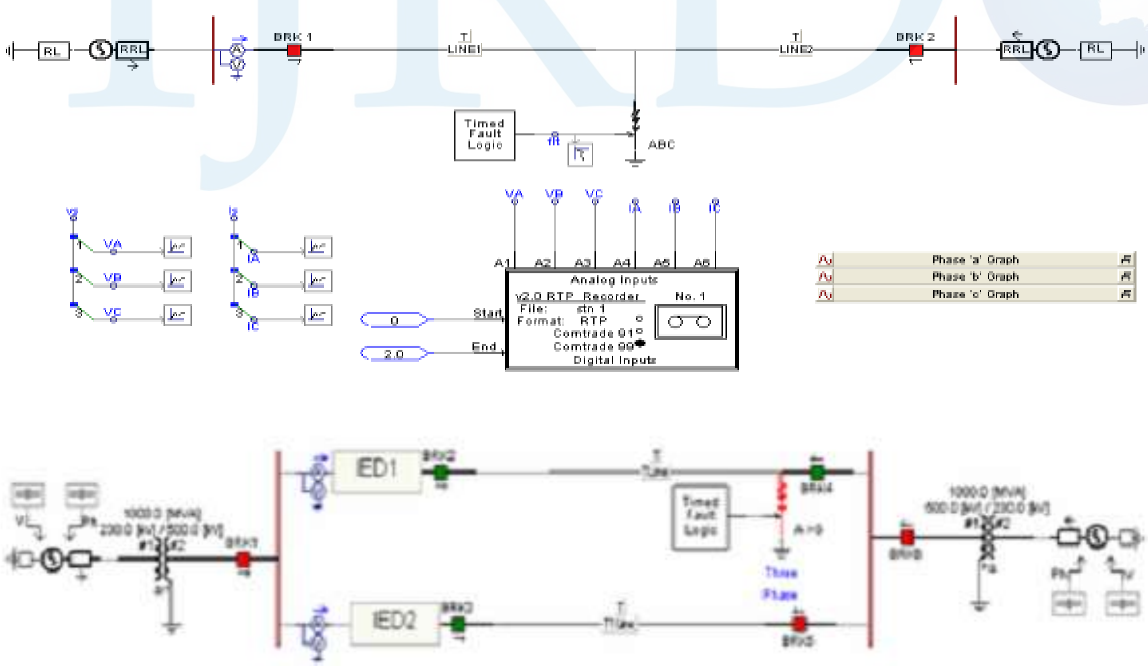


Fig. 6 PI section model for a transmission line

IV. CALCULATION OF IMPEDANCE SETTING VALUES FOR ZONES OF PROTECTION

In this research, protection zone 1 of the distance relay is calculated and modeled. However, protection zone 2 from nearby substations are calculated and modeled in order to present the remote trip. The calculation setting values are:

Distance Relay at CB1
Voltage = 500 kV
MVA = 100 MVA
Distance = 65.0 km
Z1 of line A = 65´(0.08 + j0.27) Ohm
= 5.2 + j17.75 Ohm
= 18.496 $\angle$73.67^{0}Ohm
= 18.496$\angle$73.67^0 Ohm
Zone setting for Mho relay at relay CB1.
Zone 1 reach setting = 80% of transmission line A
= 0.8 * (18.496$\angle$1.2858 rad) Ohm/Phase
= 14.7968$\angle$1.2858 Ohm/Phase
Set radius of the mho circle = 14.7968/2
= 7.3984 Ohm
Zone 2 sets to back up Mho relay at relay B1.

Zone 2 reach setting = 100% of line A + 20% next line (line B)
= [1 x (14.7968$\angle$1.2858) +0.2 x (14.7968$\angle$1.2858)] Ohm/Phase
= 17.7562$\angle$1.2858 Ohm/Phase
Set radius of the circle = 17.7562/2
= 8.8781 Ohm

V. SIMULATION RESULT:

Simulation Results for SLG Faults on Single Circuit Line

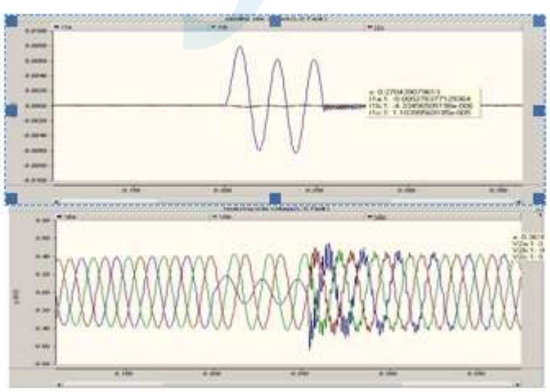


Fig. 6.1 Voltage and current signal seen by relay1 during SLG fault

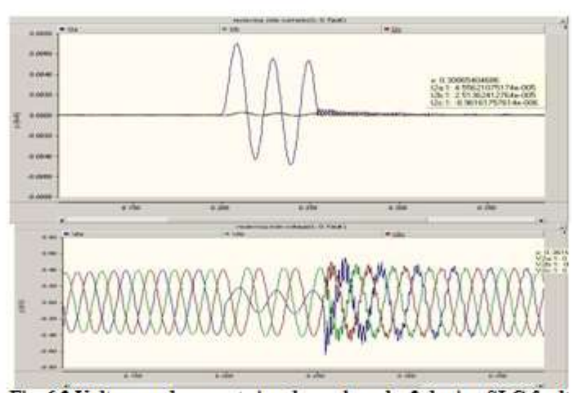


Fig. 6.2 Voltage and current signal seen by relay2 during SLG fault

Table1: Distance relay setting

% Fault Location (km)	75%	78%	85%
Actual impedance (Ω)	3.9+j13.3125	4.056+j13.845	4.42+j15.0875
Estimated impedance for real K0 (Ω)	4.94+j12.227	5.125+j12.72	5.564+j13.912

Estimated impedance for complex K0 (Ω)	3.885+j13.36	4.043+j13.924	4.394+j15.251
Relay trip signal	1 after 30 ms	1 after 60 ms	0

Simulation Results for SLG Faults on Double Circuit Line

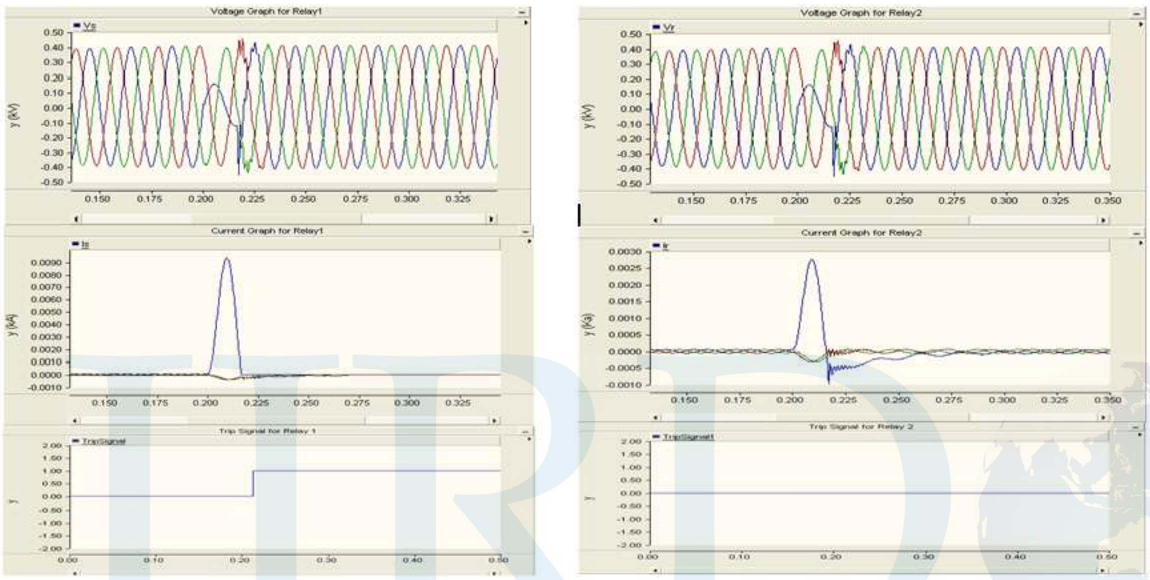


Fig 6.3 Voltage current and trip signal for relay1and relay 2 under SLG fault

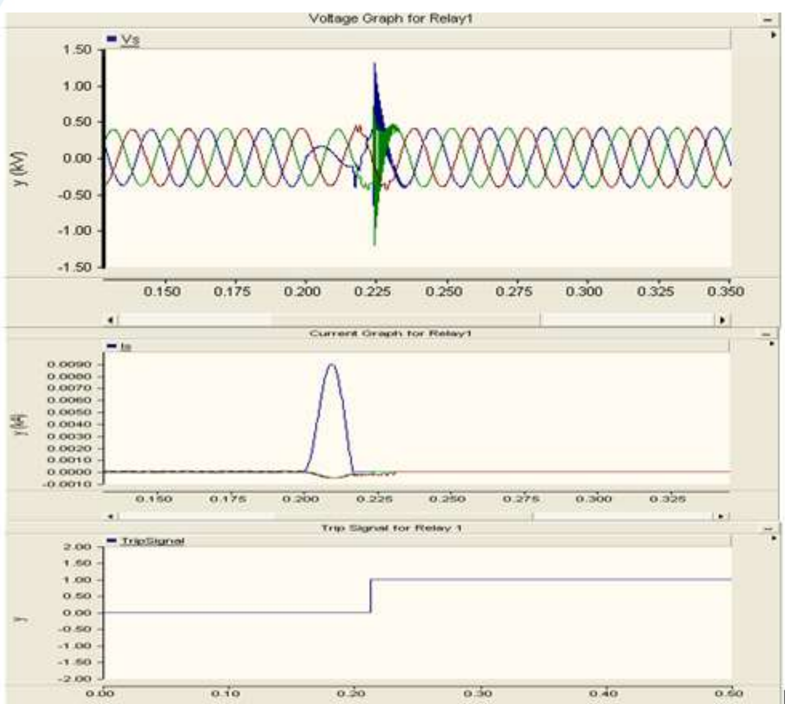


Fig 6.4 Voltage current and trip signal for relay1and relay 2 under SLG fault

VI. CONCLUSION:

The proposed algorithm perform well to eliminate under reach correction of distance relay in single line as well as double circuit transmission line. The result and simulation are verified and shown above. The only those relay are operated in which fault occur. No relay mal-operate when we use this algorithm.

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