ADVANCE DISTANCE PROTECTION OF TRANSMISSION LINE IN PRESENCE OF SHUNT COMPENSATOR

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Abstract-*Transmission line have a great impact on transfer of large amount of power to distribution sector which is further supplied to different types loads. In recent times to improve the transmission line rated voltage FACTS device are used on large scale. Shunt FACT device have great impact on distance relay tripping characteristics. The impact of shunt compensator is more pronounced on the apparent impedance seen by the phase to ground fault. The mal-operationof the distance relay for the transmission line with shunt compensator at various locations is studied.The simulation resultsshow that the under-reaching and over-reaching is more severe with shunt compensator at mid-point of thetransmission line. The impact of shunt compensator on the relay tripping boundaries is also mentioned in this paper.*

The proposed scheme calculates the apparent impedance by measuring the corrected voltage and current phasors and compared with the set value. ATP/EMTP software is used on two machine system to establish the claims.

Key Words:*Facts, Distance relay, Shunt compensation.*

1. INTRODUCTION

The protection of the transmission line is an important aspect when we consider the stability of the power system as it is used to transfer bulk power from one area to other. The distance protection of the transmission line gives reliable and the fast decision making capability to detect fault in the zone of protection and provides the information about trip or no trip [1]. Distance Relaying belongs to the principle of ratio comparison. The ratio is between voltage and current, which in turn produces impedance. The impedance is proportional to the distance in transmission lines, hence the distance relaying designation for the principle. This principle is primarily used or protection of high voltage transmission lines.

The static VAR compensator (SVC) and static synchronous compensator (STATCOM) are important shunt FACTS devices and are widely used all over the world. They maintain constant line voltage at the point of connection in a transmission line and are preferably connected in themiddle of the line because voltage sag is maximal in the middle. Both devices inject current at the point of connection. The SVC is a parallel combination of a thyristor-controlled reactor (TCR) and thyristor switch capacitor (TSC). The STATCOM is a voltage source convertor (VSC) based device, so it has better control and can supply a constant current over the complete voltage profile. Shunt FACTS devices supply or absorb current into the connecting bus. According to the direction of current injection into the transmission line, the distance relayshows under-reaching or over-reaching effects [4]. The goal of distance protection is to calculate the impedance between the relay and fault point. If a FACTS device is located between a relay and fault point, it inserts equivalent impedance in the fault loop, and the relay is thereforenot able to calculate the correct faultimpedance, which leads to accuracy, security, and reliability problems.

The impact of STATCOM on the steady state performance of a self-polarized mho distance relay for midpoint compensated lines under different loading conditions arediscussed in [6]. The adverse effect of the shunt-connected FACTS devices on the performance of the distance commercial relays is analyzed in [7]. The channel aided distance protection scheme with various blocking algorithms for mitigation of adverse effect of shunt-connected FACTS devices at mid-point is presented in [8].

In this paper we consider the transmission line with midpoint compensation (SVC/STATCOM) and the compensator is considered in steady state.

2. SHUNT FACT DEVICES

There are mainly three types of FACTS devices: (1) series, (2)shunt, and (3) composite (combination of series and shunt).The basic purpose of all FACTS devices is to enhance power transfer capability and improve stability of a power system. Application and operation of the mentioned FACTS devices are different. Series devices are connected in series with the transmission line, and they improve the power transmission capability of a transmission line by reducing line impedance.

Shunt devices are used to improve voltage regulation. In the middle of transmission line, voltage sag is maximal, so shunt devices are connected in the middle of a line. Composite FACTS devices (UPFC) are a combination of series

and shunt devices, so they have the property of both devices [1, 2]. All FACTS devices affect the performance of the distance relay differently. There are mainly two types of shunt FACTS devices: (1) SVC and (2) STATCOM. Both devices affect the distance relay performance according to their characteristics. The working principles and their impact on distance protection are explained.

2.1 SVC and STATCOM

The SVC and STATCOM regulate voltage at the connectingbus by injecting a current in quadrature to the driving line voltage and in phase with line current. Current injected by the SVC into the connecting bus linearly varies with the line voltage at that point; *i.e.*, it works as a variable current source over the operating characteristic, as shown in Figure 1(a).
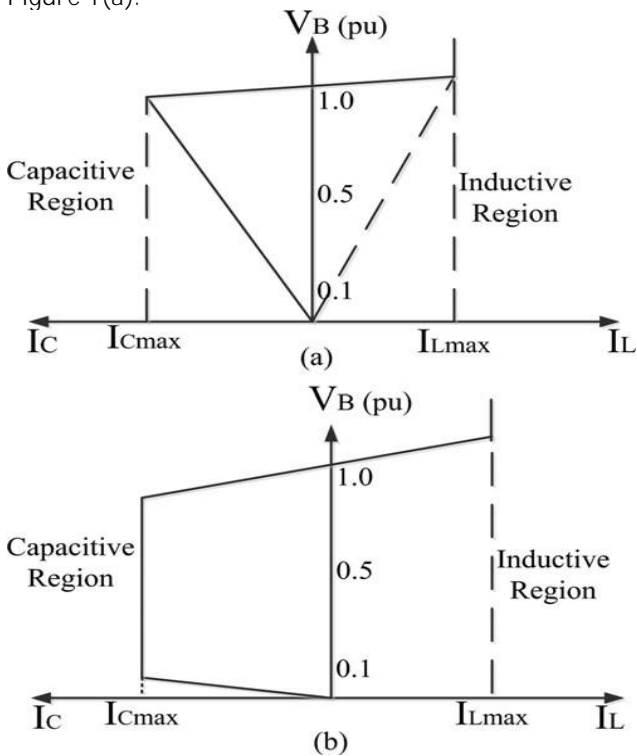

Figure 1.Operating voltage-current (V-I) characteristic of shunt FACTS devices.

The STATCOM is a VSC-based device that injects constant current into the line, acting as a constant current sourceover the operating characteristic, as shown in Figure 1(b).

Both devices work in two modes of operation: (1) capacitive mode and (2) inductivemode. In case of heavy loads, the line voltage drops below the reference or permissible value, and the shunt FACTS device works in capacitive mode and supplies current into the bus, hence injecting reactive power to the system. In this case, net impedance of the transmission line increases,and the distance relay shows under-reaching effects. In case of light loads or capacitive load conditions, the line voltage increases due to the Ferranti effect, and the shunt FACTS device works

in inductive mode, taking current from the system and absorbing reactive power from the system. So in inductive mode, net line impedance reduces; hence, the relay show over-reaching effects. The amount of impedance added or subtracted by the shunt FACTS devices in capacitive or inductive mode, respectively, is a function of current injected by the device [1, 2].

3.DISTANCE RELAY

In the protection of transmission line, the use of distance relays has found to be the most feasible and effective as compared to the other type of protection such as over current relay. There are some parameters in transmission line such as line resistance, source impedance, types of faults, fault location etc. which affects the current measured by relay. This leads to unsatisfactory performance of over current relay. On the other hand distance relay being actuated by two quantities comparatively gives much better performance by taking care of all such factors.

There are three types of distance relays namely reactance relay, impedance relay and mho relay. But performance of these relays gets affected by factors like power swing, arc resistance. The quadrilateral distance relay is quite better option for the protection of transmission line as it covers minimum area in R-X diagram and it is closer to ideal distance relay characteristic [10] When a short-circuit fault occurs on a transmission line, distance relays gives protection and trips the circuit breaker by disconnecting the faulty portion from the healthy section.[11]

The setting of distance relays should ensure that the relay is not going to operate when not necessary and will operate, only when **it's necessary. Distance relays** effectively measures the impedance between the relay location and the fault. If the resistance of the fault is low, the impedance is proportional to the distance from the relay to the fault. A distance relay is designed to only operate for faults occurring between the relay location and the selected reach point and remains stable for all faults outside this zone.

4. EFFECTS OF SHUNT COMPENSATOR ON DISTANCE RELAY CHARACTERISTICS

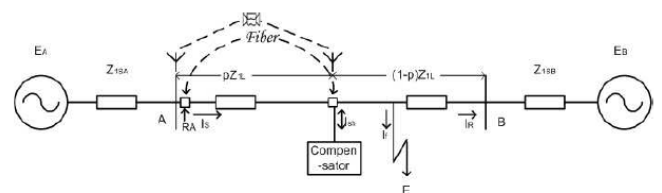

Figure 2.Single line diagram of test system

The impacts of the installation of Shunt compensator on a transmission line have been tested for a practical system, a 400 kV Iranian transmission line with a length of 300 km [5].

4.1 Shunt compensator at Near End

Fig. 4, shows the effect of the variation of Y_{SHUNT} on the measured impedance at the relaying point. Here Y_{SHUNT} takes the values 1.0 (red curve), 0.5 (green curve), 0.0 (blue curve), 0.5 (magenta curve), and 1.0 (cementa curve) in pu. The positive values are related to the inductive mode, while the negative values corresponding the capacitive mode, and the magnitude of zero represents the compensator inactive mode.
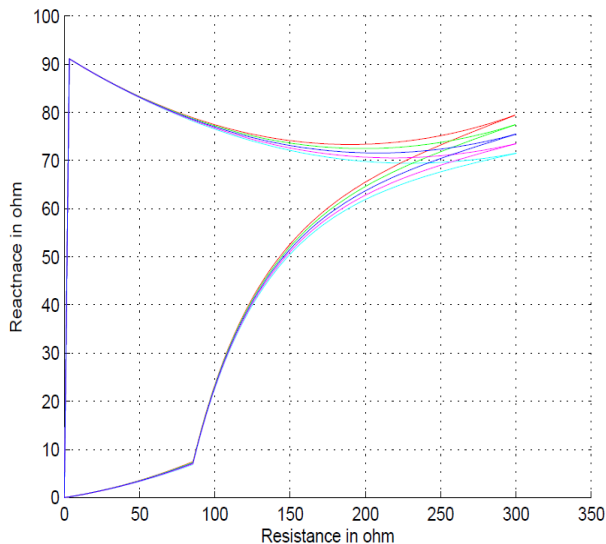

Figure 4. Tripping characteristic with Shunt compensation at near end

Comparing the tripping characteristics without Shunt compensator and that of in the presence of inactive compensator at the near end, it can be seen that the tripping characteristic is not changed due to the presence of inactive compensator on the line. It can be seen that as Shunt compensator admittance varies from the inductive to the capacitive mode, the measured reactance increases while the measured resistance variation is not considerable, only slight decreasing can be seen. In the case of the low fault resistance, the measured impedance at the relaying point is almost unchanged.

4.2 Shunt compensator at Mid-Point

Fig. 5 shows the effect of the variation of Y_{SHUNT} on the measured impedance at the relaying point. Here Y_{SHUNT} is equal to 1.0, 0.5, 0.0, 0.5, and 1.0 pu and curve colors are same as mentions previous. As mentioned, in this case shunt compensator is not in the fault loop for the faults on the near half of the line, while for the faults on the far half; Shunt compensator is included in the loop. Therefore tripping characteristic divides into two parts, Fig. 5. The lower part is related to the near half of the line, while the upper part is corresponding to the far half of the line.

In the case of inactive Shunt compensator, the upper boundary of the lower part and the lower boundary of the upper part are placed on each other. In other words, in the case of inactive compensator there is no space between two parts and on the other hand, there is no overlapping between two parts. Comparing the tripping characteristic

without compensator and that of in the presence of inactive compensator at the mid-point, it can be seen that the tripping characteristic is not changed due to the presence of inactive compensator on the line.
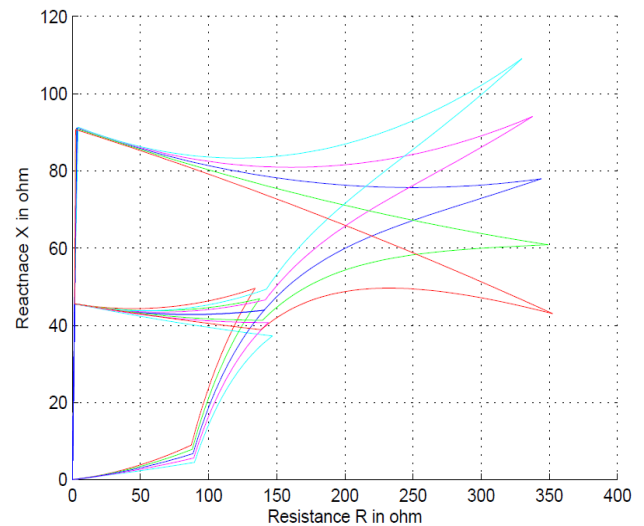

Figure 5. Tripping characteristic with Shunt compensation at mid-point

4.3 Shunt compensator at Far End

Fig. 6, shows the effect of the variation of Y_{SHUNT} on the measured impedance at the relaying point. Here Y_{SHUNT} also takes the values 1.0, 0.5, 0.0, 0.5, and 1.0 pu. Comparing the tripping characteristic without compensator and that of in the presence of inactive compensator at the far end, it can be seen that the tripping characteristic is not changed due to the presence of inactive compensator on the line, and similar to previous cases two characteristics are the same. It can be seen that as Shunt compensator admittance varies from the inductive to the capacitive mode, the measured reactance decreases while the measured resistance varies not considerably, only a slight increasing could be observed. In the case of the low fault resistance, the measured impedance at the relaying point is almost unchanged. The changes of the tripping characteristic due to Shunt compensator at the far end are somehow opposite of that of for the Shunt compensator at the near end.
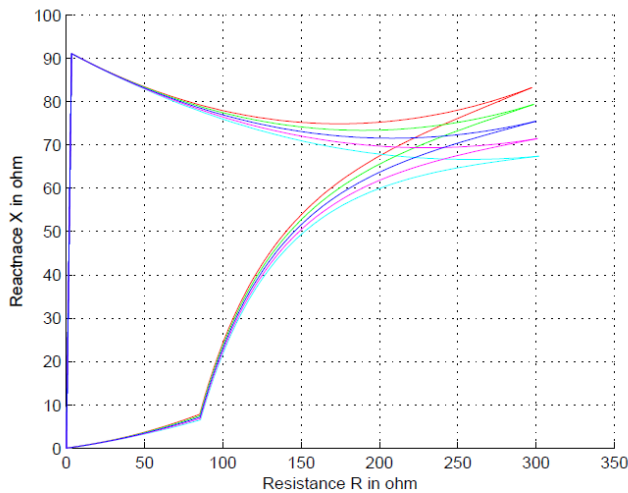
Figure 6. Tripping characteristic with Shunt compensation at far end

5. PROPOSED SCHEME

Consider the two machine system connected with transmission line with static shunt compensator connected at the mid-point as shown in Fig.2. For line to ground fault on a-phase, the impedance measured by the distance relay "R" is given as [9]. When shunt compensator is connected at the mid-point of the transmission line as shown in Fig. 2 and if fault F occur on phase-A at distance p, the apparent impedance measured by the distance relay located at bus-A [3] is given as:

$$Zseen = pZ_{1L} + (p-0.5)\, Z_{1L}\frac{Ish}{Irelay} + R_f\frac{If}{Irelay} \quad (1)$$

Where $Irelay = I_a + mI_{ao}$

where Z_{1L} is the positive sequence impedance of line, Ish and If are the compensator current and fault current, p is per unit length of line, Rf is the fault resistance. When there is fault resistance is zero the equation (1) can be rewritten as:

$$Zseen = pZ_{1L} + (p-0.5)\, Z_{1L}\frac{Ish}{Irelay} \quad (2)$$

It is clearly seen that, when compensator is present in power system, it injects or absorbs the reactive power. The nature of the current injected is inductive or capacitive, it depends on the power system operational condition and structural condition.

$$Ia = I_f + I_{sha} \quad (3)$$

$$Ia = I_{fa} \quad (4)$$

$$Verra = Zseriesa \times mIsha \quad (5)$$

$$Vanew = Va + Verra \quad (6)$$

where $Zseriesa$ is the series impedance of source EA. When shunt compensator is present in the fault loop, the sending end current of phase-A is given by equation (3) and when compensator is not present in the fault loop it is given by equation (4) by neglecting the line charging currents.

We can conclude that when shunt compensator is not present in the fault loop the distance relay does not mal-operate to locate the fault point while, when it is present in the fault loop the distance relay under-reach or over-reach the fault point due to the current injected or absorbed by the compensator. Now, if we have the synchronized measurement which gives the information of the compensator terminal voltage and current injected or absorbed by it and the appropriate communication link is present between the compensator terminal and relaying bus-A, it is possible to correct voltage and current at relaying bus-A and hence the apparent impedance measured by the distance relay of phase-A as:

$$Zappnew = \frac{Vanew}{(Ia + Isha) + mIa0} \quad (7)$$

The main issue is the nature of the compensator injected current, it is observed that when shunt compensator is working in the inductive mode nature of the current is positive and when shunt compensator is working in the capacitive mode the nature of the current is negative with the direction of the current shown in Fig. 2.

5.1 Proposed Algorithm

Fig. 7, shows the relaying algorithm for proposed scheme. Algorithm starts with the setting of the distance relay for the first zone of protection of transmission line followed by the sending of command for the synchronization of the measurement at the relaying bus and the compensator terminal. The voltage and current samples synchronously measure at the terminal of the compensator transmitted to the relaying bus via fiber optic or fast communication link.

The phasors are estimated using the Discrete Fourier Transform (DFT) using sampled data obtained at the relaying bus. The proposed corrections in the voltage and current are carried out using estimated phasors at the relaying bus. The apparent impedance is calculated using the corrected voltage and current phasors and compared with the set value. The decision to trip or not to trip is issued when the calculated impedance is equal or less than the set value.

6. SIMULATION AND RESULTS

To evaluate the performance of the proposed scheme, the following methodology has been used:

a. Simulate power system [3] response to disturbances (e.g., faults) using EMTP. ATP [3] software has been used for simulations.

b. Samples obtained from the EMTP simulation are fed to a MATLAB program which implements the proposed advance distance protection scheme. Full-cycle recursive DFT is used to estimate the phasors [3, 9].
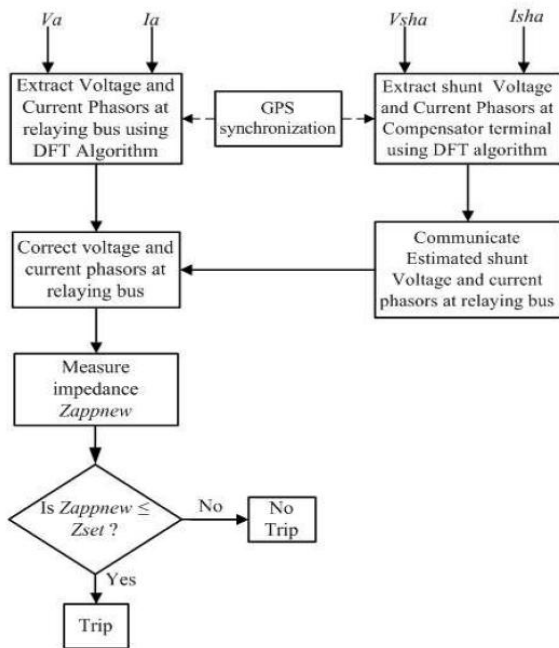
Figure 7.Algorithm of proposed scheme

6.1 Shunt compensation at 25% of line

Fig.8, shows the impedance trajectories for the mid-point shunt compensated(Inductive) transmission line for SLG fault on phase-A at 25 % of the line without faultresistance. It can be observedthat the setting of the distance relay is for 80 % of line length for first zone and fault is beforethe shunt compensator. The shunt compensator is not in the fault loop and hence it does nothave any effect on impedance measured by the distance relay. It can be observed that theimpedance trajectories of line without compensation, with compensation and with proposed schemehave the matching operating points.
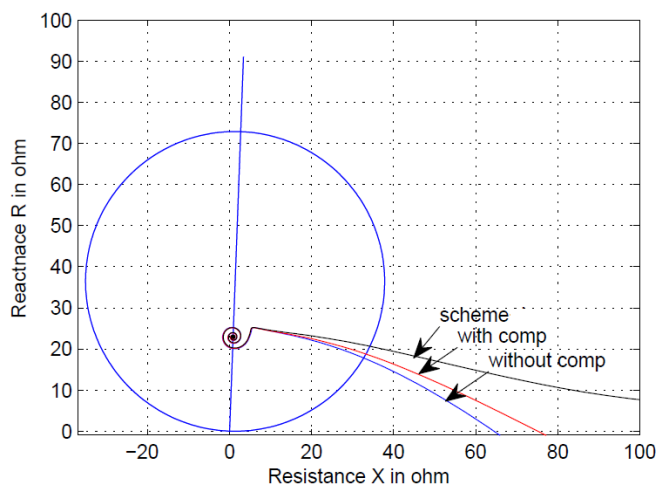

Figure   8.Impedancetrajectories   with   inductive compensation for fault at 25% of line without fault resistance for line without compensation, withcompensation and compensation with proposed scheme

Fig. 9, shows the impedance trajectories for phase-A to ground fault at 25 % of theline length with 10 - fault resistance for the mid-point compensated (Inductive) transmissionline. In presence of fault impedance the measured impedance is affected by the structural andoperational conditions. It is observed that proposed scheme work effectively in such conditionsalso. Same results are observed for the faults before the shunt compensator supplying capacitivecompensation connected at the mid-point of the transmission line.
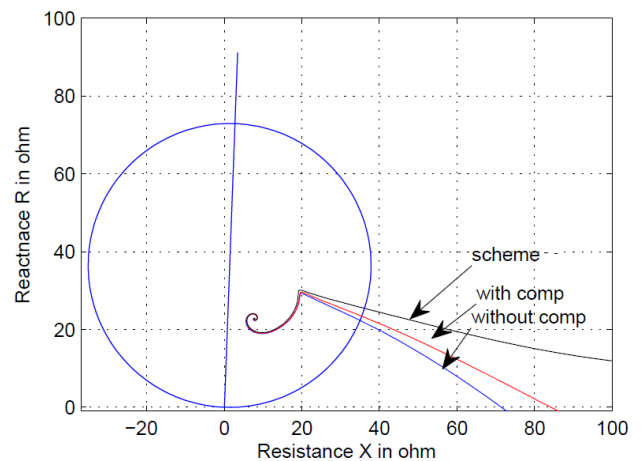

Figure   9.Impedance   trajectories   with   inductive compensation for 25% fault with 10Ω fault resistancefor line without   compensation,   withcompensation   and compensation with proposed scheme

6.2 Shunt compensation at 80% of line

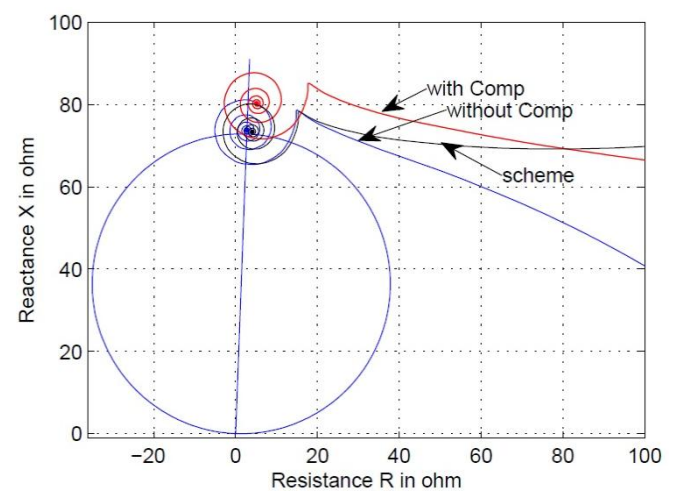
Figure   10.Impedancetrajectories   with   inductive compensation for fault at 80% of line without fault resistance for line without compensation, withcompensation and compensation with proposed scheme

Fig.10 shows the impedance trajectories for the mid-point shunt compensated(Inductive) line for phase-A to ground fault at 80 % of the line length with zero fault resistance.Fig. 11. Shows the impedance trajectories for the

mid-point shunt compensated(Inductive) line for phase-A to ground fault at 80 % of the line length with 10Ω fault resistance.
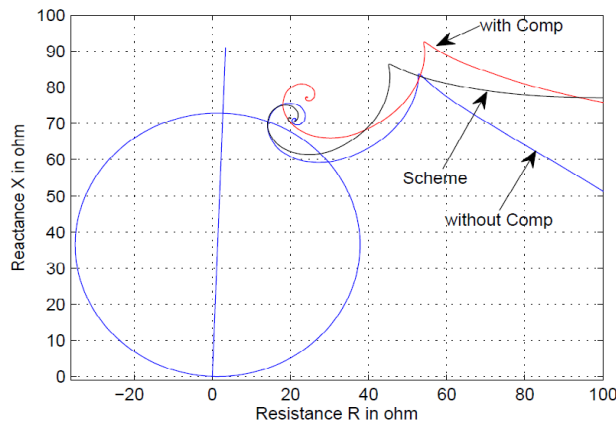

Figure 11.Impedancetrajectories with inductive **compensation for fault at 80% of line with 10Ω fault** resistance for line without compensation, withcompensation and compensation with proposed scheme

It is observed, that the operating points fortrajectories without compensation and compensation with proposed scheme settle very close to eachother indicating the robustness of the proposed scheme. The distance relays do not mal-operateand locate the fault very accurately giving the correct trip decision for in-zone fault.
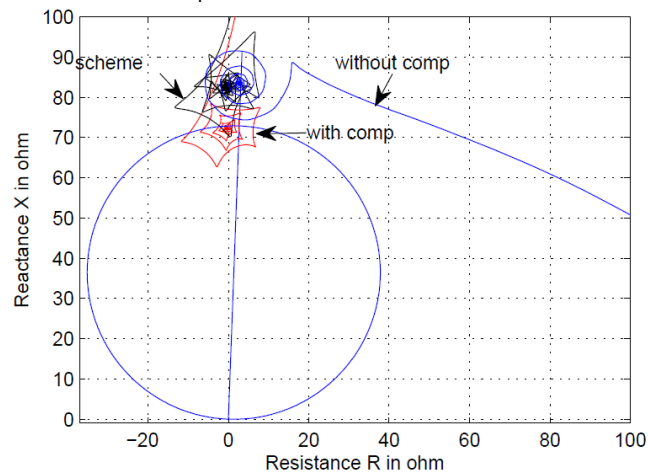
6.3 Shunt compensation at 90% of line

Figure 12.Impedancetrajectories with capacitivecompensation for fault at 90% of line without fault resistance for line without compensation, withcompensation and compensation with proposed scheme

Fig.12, shows the impedance trajectories for the mid-point shunt compensated(Capacitive) transmission line for SLG fault on phase-A at 90 % of the line without fault resistance. It can be observed that the setting of the distance relay is for 80%of line length for first zone butdue to compensation and its inclusion in the fault loop, distance

relay locate the out of zone faultin the zone of protection. Hence, distance relay over-reach to locate the fault and mal-operationis observed due to capacitive shunt compensation. It can be observed, that the operating pointsfor trajectories without compensation and compensation with scheme settle very near to eachother indicating the robustness of the proposed scheme. The distance relay do not mal-operateand locate the fault very accurately giving the correct trip decision for out-zone fault.
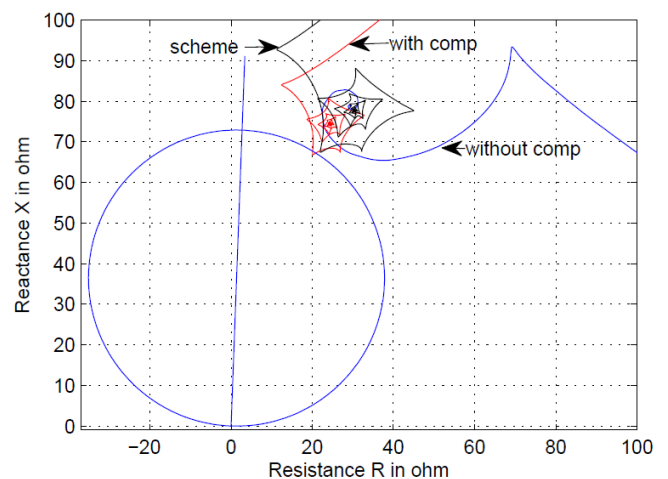

Figure 13. Impedancetrajectories with capacitivecompensation for fault at 90% of line with 10Ω fault resistance for line without compensation, withcompensation and compensation with proposed scheme

7. CONCLUSIONS

The results obtained conspicuously shows that the measured impedance shows an aberrantpath than that of the actual impedance of the line between fault point and the relaying pointin presence of mid-point shunt compensation device. The mal-operation of distance relayis observed in the form of under-reaching and over-reaching the fault point with mid-pointcompensation. When compensating device is working in the inductive mode the distancerelay under-reach the fault point while when compensating device supplying the capacitivecompensation distance relay over-reach the fault point.To mitigate the issues involved with the distance relay with mid-point shunt compensation,advance distance relaying scheme is proposed using the synchronized measurement.

From simulation results it has been observed that the proposed scheme work betterand locate the fault with high accuracy. Hence, advance distance protection scheme with midpointcompensated transmission line gives reliable and secure operation of power system.

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