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Mal-Operation of Mho Relay In Transmission Line Due To Presence of TCSC

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***Abstract:** Distance protection is simple and it provides fast response to clear the fault. Distance protection is also providing primary and remote backup function depending upon distance of transmission line. Distance protection uses various relays like mho relay/admittance relay, impedance relay and reactance relay. In power transmission system, Flexible AC Transmission System (FACTS) controllers are used to increase power transfer capability and reactive power control, but distance relay get affected due to presence of FACTS devices. This may create the stability issues, security and it may affect on voltage profile. The changes in impedance level would affect the accuracy of distance protection. This paper represents the effect of TCSC on operation of mho relay in transmission line. The work presented here emphasis on the interaction of TCSC on distance protection and their performances under different condition i.e., load angle variation, variation of SCL, different fault location. Design and control performance of MHO relay during normal operation as well as during variation in different condition is verified by using PSCAD simulation software.*

***Keywords** : Distance protection, MHO characteristic, FACTS devices, TCSC, PSCAD software.*

I. INTRODUCTION

Transmission lines are crucial parts of distribution system as they provide path for flow of power through it. It provides the mobility to HV and LT customers to provide power in any direction and at any location. It operates at different voltage levels, and is preferably interconnected for reliable operation. Factors like increase in load demand, de-regulated market, economics are forced to operate the transmission line closer to its stability limit [1-2]. Transmission lines have a convenient way if there is any kind of fault in the system detected then only that part of the system can isolated from the whole system. And rest can perform those operations smoothly. It is the challenge to the transmission line to detect and isolate the fault compromise the security of the system. The three phase transmission line is protected by three step distance protection.

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It works based on three separate single phase impedance vectors. Loadability of a transmission line is defined as the transmission line is operated under specified limits. The factors like thermal rating of conductor, voltage regulation and stability consideration are affect loadability of short, medium and long transmission line correspondingly [3]. Now days, FACTS devices are used in transmission line to improve the power transfer capability of a transmission line. The lines are designed for a particular power but now a day the demand or the load is increased day by day. There are two methods to improve the power transfer capability either reconstruct the infrastructure or used FACTS devices. It is economical to use FACTS devices instead to modifying the transmission lines.

Many papers represent their results on analysis of fault location of distance relay in presence of series and shunt FACTS devices on line [4-9]. The behavior of distance relay is analyze using the sequence component with SVC which is connected at mid-point of line. It represents the relay characteristic impedance using measured impedance at the relaying point in presence of SVC. It conclude that at lower compensation settling factor of distance protection is less and at higher compensation settling factor is increased [5-6].The impact of STATCOM on distance relay is analyses by taking result at different load levels. The apparent impedance is inclined by the level of reactive power injected by the STATCOM result in either under-reaching or overreaching of distance relay [7].The transmission line of medium length is being compensated by SSSC. The inclusion of SSSC in the fault loop affects the components of current and voltage [8]. UPFC has the advantage that it can control line impedance, Voltage magnitude and phase. The operation of UPFC during fault from its control function is an important issue that affects the dynamic performance of power system and distance protection [9].

TCSC is used as it has capability to control the amount of compensation of a transmission line and its ability to damp the oscillations of SSR (sub synchronous resonance). Hence TCSC is used to improve the power transfer capability of a transmission line. It consists of reactor (L), thyristor valve and fixed capacitor (FC),. It provides active power control through transmission line [10-11]. It can be modeled as a variable reactance (both capacitive and inductive) where the net reactance (X_{net}) offered by TCSC depends on the conduction angle of thyristors [12]. Section II represent "Distance protection: and setting zone". Section III represents "Impact of TCSC on apparent impedance". Section IV represent "Calculation of apparent impedance in presence of TCSC" in this the effect of TCSC is analytically proven.

Section V represents "Simulation of test system" and finally section VI shows the result of simulation with and without TCSC by varying the load angle.

II. DISTANCE PROTECTION: PRINCIPLE AND SETTLING ZONE

Distance protection is an effective protection system offering considerable economic and technical advantages. The transmission line impedance is proportional to its length, for distance measurement it is apt to use a relay able of measuring the impedance of a line up to a predestined point. This relay is described as a distance relay and is deliberate to drive only for faults taking place between the relay location and the selected reach point thus giving discrimination for faults that may occur in different line segment. The apparent impedance is compared with the reach point impedance. If the measured impedance is less than the reach point impedance then the fault exists on the line between the relay and the reach point as shown in Fig. 1.

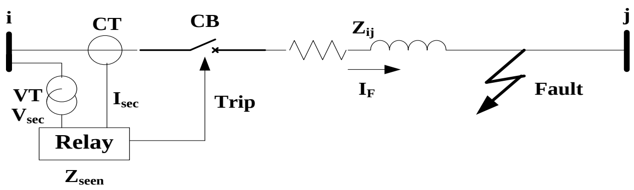

Fig. 1 Principle operation of distance protection

Distance relays are intended to protect power systems against phase fault and ground fault i.e., symmetrical and unsymmetrical faults. In order to identify any of the above faults, six units are required by each zone of distance relay, which is given in table 1 with fault impedance for all faults. Three units are required for detection of faults between the phases and the left over three units are used for detection of phase to earth faults. On the basis of the positive sequence impedance, the setting of distance relays is always calculated. The key pro of distance protection is that its fault coverage of the protected circuit is virtually independent of variations of source impedance which is dissimilar to phase and neutral over current protection.

Table 1.fault impedance calculation formula for all of the fault types

Distance unit	Formula
Phase A	$Z_A = V_A / (I_A + 3kI_0)$
Phase B	$Z_B = V_B / (I_B + 3kI_0)$
Phase C	$Z_C = V_C / (I_C + 3kI_0)$
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, $K = \frac{(Z_0 - Z_1)}{Z_1}$

Z_A, Z_B and Z_C are the impedance of phase A, phase B and Phase C respectively. Z_{AB} is the impedance between phase A and phase B. Z_{BC} is the impedance between phase B and phase C. Z_{CA} is the impedance between phase C and phase A. Z_0 and Z_1 are zero sequence and positive sequence impedance.

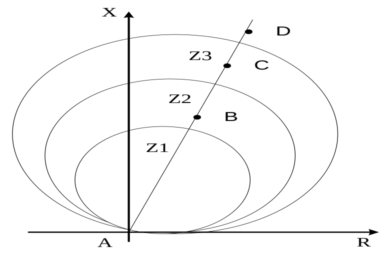

Fig. 2 Three zone protection of mho relay.

Generally long transmission line is protected by three stepped distance protection. First step provide instantaneous protection to zone1 and it does not having intentional time delay. Second step provide protection to zone2 with the time delay t_1 and third step provide instantaneous protection to zone3 with time delay t_2.Fig 2 shows the 3 zones of protection with the help of mho relay characteristics.

III. EFFECT OF TCSC ON APPARENT IMPEDANCE

TCSC is used to perk up the power transfer capability of existing transmission line. But due to its operational characteristics it effects on the distance protection of transmission line. The resonance is occurs in between the inductive and capacitive region. Occurrence of resonance in TCSC device is inevitable. However, only one resonant region, unambiguously one capacitive range and one inductive range, is allowed. During fault, TCSC may operate in three basic modes. In thyristor blocking mode Due to absence of gate pulses the TCSC effectively operate as FSC. In thyristor bypass mode, the thyristor conduct with conduction angle 180º and gate pulse applied across thyristor valve. Thyristor valve behaves like a parallel combination of capacitor-inductor combination. In steady state thyristor boost mode, the capacitive boost mode of operation is the common mode of operation, so a significant portion of the line inductance is compensated by the capacitive reactance accessible by TCSC [16].

IV. CALCULATION OF APPARENT IMPEDANCE IN ATTENDANCE OF TCSC

At the point of installation, distance relay is operated which is based on measured impedance. When the fault impedance is zero, the measured impedance depend on length of the line between relay and point at which fault occurred. Fig. 4 shows case of zero impedance. It states that measured impedance by the relay is equal to pz_{1l}. P is defining as the length of the line between relay point and point at which fault occurred in per unit. z_{1l} is the positive sequence impedance of relay. In attendance of fault impedance the equivalent impedance is in not equal to pZ_{1l} . Fig.3 shows the equivalent diagram for LG fault. Where Z_s is the source impedance, I_a is current at phase A and I_b is the current at phase B. R_f is the fault resistance. Consider Fig. (3) And (4), the apparent impedance measured by relay without TCSC is a calculated as,

$$Z_A = pZ_{1l} + \frac{3R_f}{C_{Ld} + 2C_1 + C_0(1+3K_0)} \tag{1}$$

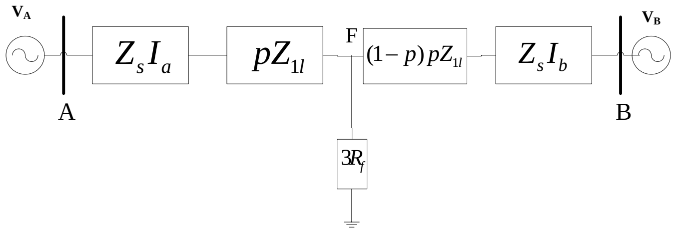

Fig. 3 Equivalent diagram for LG fault.

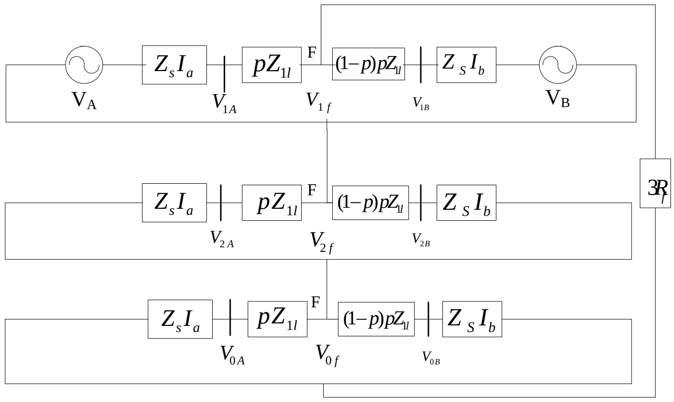

Fig. 4 Equivalent circuit for phase A in LG fault.

Where, Z_A is the apparent impedance, Z_{1A} and Z_{1B} are the positive sequence impedance at bus A and B, Z_{0A} and Z_{0B} are the zero sequence impedance at bus A and B respectively. Z_{1l} is the positive sequence impedance of relay, R_f is the fault resistance and Z_s is the source impedance, Z_{TCSC} is the impedance of TCSC, p is the length of line between relay point and the point at which fault occur which is in per unit and K is degree of compensation [13].

$$Z_{1A} = Z_s I_a + pZ_{1l} \quad (2)$$

$$Z_0 A = Z_s I_{0a} + pZ_{0l}$$
(3)

$$Z_{1B} = Z_s I_b + (1-p)pZ_{1l}$$
(4)

$$Z_{0B} = Z_s I_{0b} + (1-p)pZ_{0l}$$
(5)

$$Z = \frac{2Z_{1A}Z_{1B}}{Z_{1A}+Z_{1B}} + \frac{Z_{0A}Z_{0B}}{Z_{0A}+Z_{0B}} \quad (6)$$

$$K = \frac{1-he^{-j}}{Z_{1B}+Z_{1A}he^{-j}} \quad (7)$$

$$\frac{V_B}{V_A} = he^{-j} \quad (8)$$

$$C_1 = \frac{Z_{1B}}{Z_{1A}+Z_{0B}} \quad (9)$$

$$C_0 = \frac{Z_{0B}}{Z_{0A}+Z_{0B}} \quad (10)$$

$$C_{Ld} = \left(Z + 3R_f\right)K \quad (11)$$

$$K_0 = \frac{Z_{0l} - Z_{1l}}{3Z_{1l}} \quad (12)$$

Two cases are considered in presence of TCSC, the fault current passes through the TCSC is the first case and second case is fault current does not pass through the TCSC, the equation for this two cases are given below,

Case1: Fault current passes through the TCSC

This case is represented that, the equivalent impedance of TCSC is connected in series with line impedance. Therefore equations (6),(7) and (8) are customized as follows,

$$Z_A = Z_{TCSC} + pZ_{1l} + \frac{3R_f}{C_{Ld} + 2C_1 - C_0(1+3k_0)}$$
(13)

where,

$$Z_{1A} = Z_s I_a + Z_{TCSC} + pZ_{1l} \quad (14)$$

$$Z_{0A} = Z_s I_{0a} + Z_{TCSC} + pZ_{0l} \quad (15)$$

the impedance of TCSC are shown in Equation (14) and (15) i.e., Z_{TCSC} is added in the impedance of transmission line and it will create impact on distance protection of line.

Case2: Fault current doesn't pass through the TCSC

This case is represented that, equivalent impedance of TCSC is connected in series with the line impedance behind the fault point. Equations (9) and (10) are customized as follows,

$$Z_{1B} = Z_s I_b + Z_{TCSC} + (1-p)Z_{1l}$$
(16)

$$Z_{0B} = Z_s I_{0b} + Z_{TCSC} + (1-p)Z_{0l} \quad (17)$$

V. ANALYSIS OF TEST SYSTEM

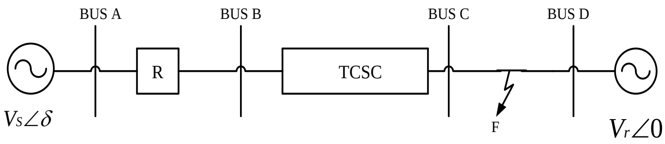

Fig. 3 Single line diagram of the test system.

Fig.5 shows single line diagram of the test system. The effect of the installation of TCSC has been tested for a test system. A 400kV transmission line with a length of 300km has been used for this study. By utilizing the PSCAD simulation software various sequence impedances of the line are evaluated according to its physical dimensions. The calculated impedances and the other parameters of the system are as following:

R, =0.01133 /km, X_1 =0.3037 /km, R=0.1535 /km, X = 1.1478 /km, Z_{SIA} = 8 85, Z=16 85, Zsos = 24 75.

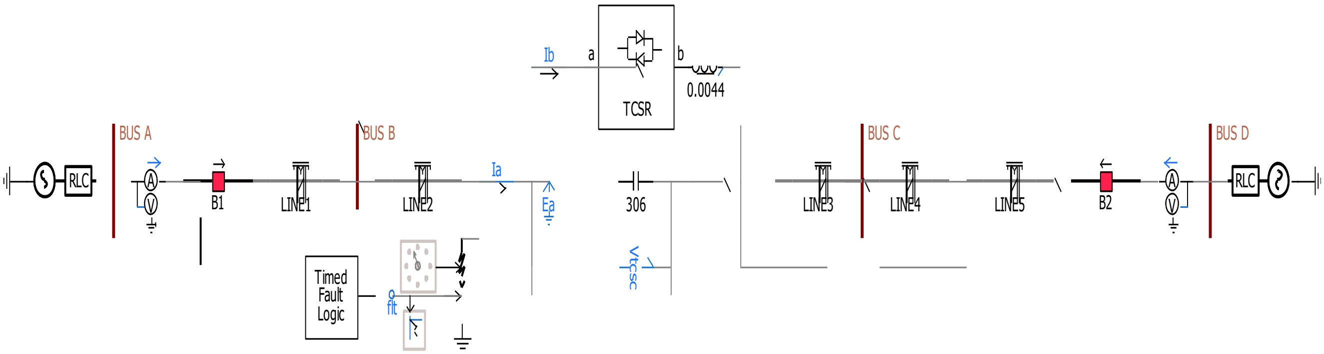

Fig. 4 Test system model of transmission line with TCSC in PSCAD

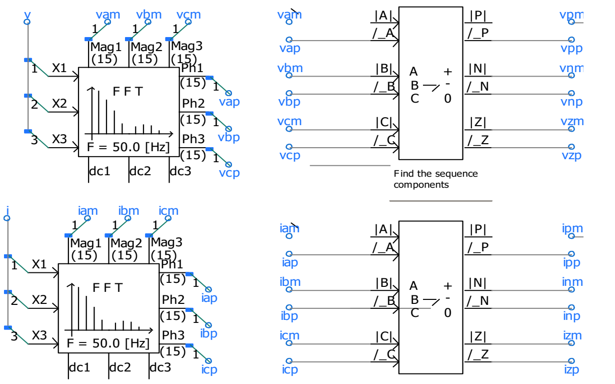

Fig. 5 Sub system of Fast Fourier Transform. and sequence analyzer.

The test system considered for the investigation is shown in Fig.6. The power systems consist of two substations and three phase transmission line of 400kV. The total line length from bus A to bus B is 300km. TCSC is used to improve the power transfer capability of transmission line. It is connected at the middle of the transmission line i.e., in between bus B and bus C and provide 50% compensation. Impact of TCSC location on the apparent impedance for faults before and after TCSC can be analyzing by using this test model. The mho relay is used for the protection of transmission line. The relay R_1 is connected at bus A is providing back up protection to zone 2 i.e., line BC and zone 3 i.e., line CD. The zone1, zone2 and zone3 setting of R_1 is 80%, 120% and 220% with impedance of 53.95Ω, 101.16Ω and 151.75Ω respectively. The test system is simulated in PSCAD simulation software.

In order to recognize the characteristics of voltage and current of the distance relay are sampled at a particular frequency in kHz and are make us to estimate the phasors using DFT. Fig.7 shows the sub system of fast Fourier transform block. The input to the block is voltage and current. It takes three voltage signals v_1, v_2, v_3 and separates the magnitude v_{am}, v_{bm}, v_{cm} and phasors v_{ap}, v_{bp}, v_{cp}. Three current signal i_1, i_2, i_3 separates its magnitude i_{am}, i_{bm}, i_{cm} and phasor i_{ap}, i_{bp}, i_{cp}.. It contains only positive and zero sequence positive sequence for LL fault and zero for LG fault. Once the phasors are obtain apparent impedance corresponding to each type of fault is derived. There are symmetrical and unsymmetrical fault out of which LG which is unsymmetrical fault is more severe than other faults hence we take results by considering LG fault.

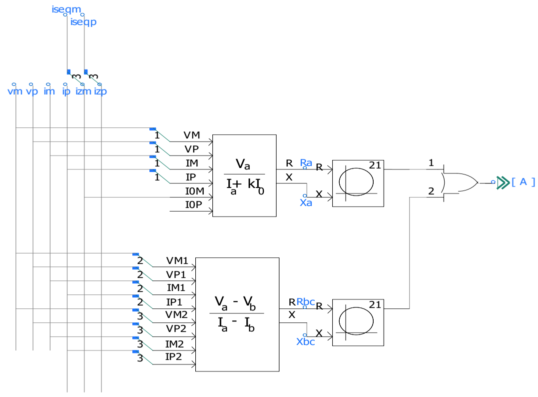

Fig.8 model of distance relay.

Fig.8 shows circuit of distance relay model in PSCAD. The 6 signals collect by FFT are given to distance relay. Distance relay check the value of apparent impedance, if impedance is less than set value of impedance (Z_{set}) i.e., $Z_{seen}<Z_{set}$ then fault is existed. If fault is exist then relay give the tripping command to the tripping circuitry. When a transmission line subjected to a fault, the voltage and current signals comprises decaying dc components, higher and lower order frequency components. The low pass anti-aliasing filters with proper cut-off frequency is used for to eliminate higher order frequency component, the drawback of anti-aliasing filter is it cannot eliminate decaying dc components and rejects lower order frequency components. Hence the performance of digital relay get affected.

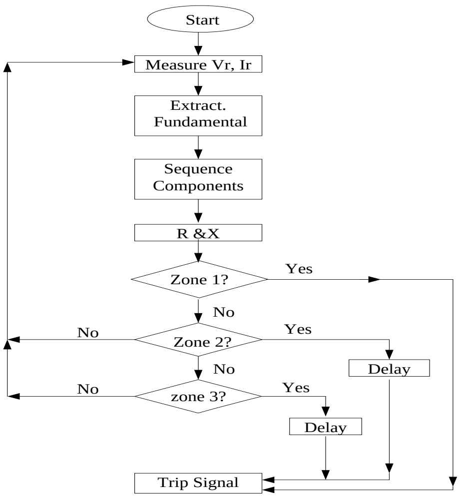

Fig. 9 MHO relay modeling algorithm

Therefore, the Discrete Fourier transform is used to remove the dc-offset components [17-18].

The Fast Fourier Transform is a fast algorithm for proficient computation of DFT. The number of arithmetic operations and memory required to compute the DFT are reduces with the help of FFT. Fig. 9 shows mho relay modeling algorithm, for extracting the fundamental frequency component, FFT block is used in PSCAD.

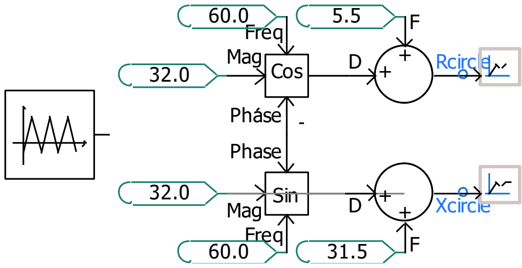

Fig. 10 settling of distance relay.

Relay 1 is set at 53.95 Ω and is only protect the 80% of protected line AB. Relay 2 is set at 101.16 Ω and is protect the 100 % of protected line AB + 50 % of the protected line BC. Relay 3 is set at 151.75 Ω and is protecting 100 % of protected line AB + 100 % of the protected line BC+25% of the protected line CD. 9

Effect of transmission line without TCSC

Fig. 11 shows the voltage and current waveform for the effect on transmission line without TCSC. The voltage and current waveforms are not distorted as the TCSC is not present in the line.

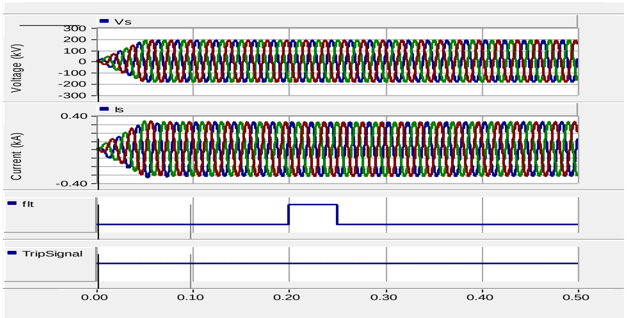

Fig. 11 Effect on transmission line without TCSC.

Effect on transmission line in presence of TCSC

8000MVA with TCSC

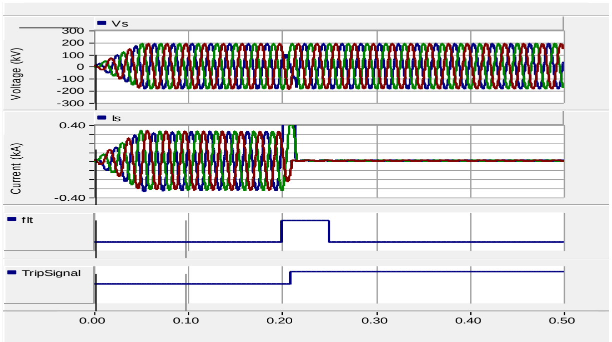

Fig. 12 effect on transmission line with TCSC.

Fig.12 shows waveforms for voltage and current. The fault is occurring at 0.20 hence the voltage and current waveform are distorted from 0.2sec. Relay give trip command to trip circuitry relay will open and isolate the faulty part from healthy part.

Case 1.LG fault at different distance from the relay location or (zone 2 result with and without TCSC)

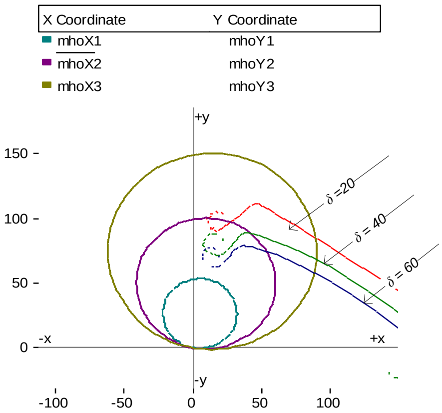

Fig. 13 Trajectory of apparent impedance of L-G measuring unit for different load angle variation (Legend: red =20o, Green=40o, blue=60o)

Fig. 13 shows the apparent impedance trajectory with or without TCSC in zone2. We create the LG fault in zone2 i.e., at 250km and impedance of fault is 89.90Ω. When TCSC is present due to inductive operation and capacitive operation the impedance is decreases or increases respectively. Due to which the mal operation of zone3 relay and zone1 relay occurs. The relay will under reach or over reach.

Case 2.LG fault at different distance from the relay location or (zone 3 result with and without TCSC)

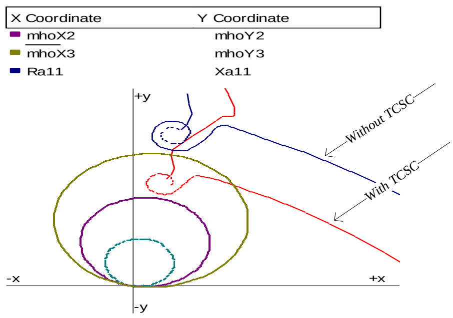

Fig. 14 Trajectory of apparent impedance LG measuring unit.

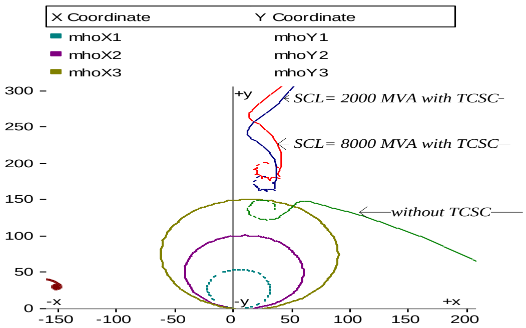

Fig.15 Trajectory of Apparent impedance of LG unit for different SCL's.(Legend: green=without TCSC, blue=SCL 2000MVA with TCSC, red = SCL 8000MVA with TCSC).

Fig.15 shows the apparent impedance trajectory with or without TCSC in zone2. We create the LG fault in zone3 i.e., at 265 km and impedance of fault is 120.02Ω.The attendance of TCSC in the fault loop and its injected inductive current force the relay to under reach.

This current impact on apparent impedance of line due to which the impedance seen by relay is out of zone3 of line this will cause the mal operation of relay in the form of under reach and over reach.

VI. CONCLUSION

The paper represents the mal operation of mho relay in transmission line due to presence of TCSC. Due to the presence of TCSC the distance relay will over reach and under reach depending apparent impedance. The test system is analyze in PSCAD and the results are taken for LG fault as chance of occur of LG fault are 85%.Two cases are considered to analyze the system, In first case, at variable load angle the relay is under reach or over reach depending on the value of load angle. In second case, the SCL values are varied due to which relay will cause the mal operation of mho relay.

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