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# Distance algorithm for Transmission Line with Mid-Point Connected STATCOM

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**Abstract -** *This paper presents an adaptive zone selection algorithm for the transmission line with midpoint connected STATCOM. The objective of this paper is to investigate the performance of transmission line distance protection with shunt connected FACT device (STATCOM). The impact of STATCOM on distance protection is investigated for different types of fault, different fault resistances and load angles. The studied power system and STATCOM with their associate elements and controllers are modelled using EMTDC/PSCAD software. Numerous number of fault scenarios are simulated and the strength of the proposed adaptive zone setting method is verified.*

***Key Words***: Flexible ac transmission system (FACTS), Power system protection, distance relay, midpoint static synchronous compensator (STATCOM), adaptive zone.

## 1. INTRODUCTION

The use of FACTS controllers increases the power transfer capability, improves the voltage stability, enhances the transient stability and damps the sub-synchronous oscillation [1-4]. FACTS devices enhances the power transfer capability by fully utilizing the existing transmission assets. The impact of FACTS controllers on transmission system is significant as they consist of high speed switching device that can handle power of megawatt level and modern control schemes. Among the various FACTS controllers, Static Synchronous Compensators (STATCOMs) are device that support the reactive power at the point of the connection to maintain the voltage profile and boost up the power transfer capability. This study investigates the challenges to distance protection of transmission line equipped with STATCOM.

In this work a 230 kV-50 Hz, three phase power system as shown in Fig. 1. The instrument transformers are connected at bus M. The current transformer (CT) and CCVT are having ratios of 1000:1 A and 230 kV: 115 V respectively. The line between bus M and N is 300 km. Distributed parameter line model is considered. The sampling rate is maintained at 1 kHz. The system is simulated in EMTDC/PSCAD environment.

## 2. Modelling of 100 MVA, 12 pulse STATCOM

### 2.1 STATCOM controller model

The single line diagram of 100 MVA, 12 pulse voltage source converter (VSC) based STATCOM connected to the transmission line is shown in fig. 1. STATCOM generates three phase controllable voltage output similar to system frequency. The dc input to the STATCOM is provided by the capacitor. The function of the coupling capacitor is to connect the ac power system with the STATCOM at point of the connection. The reactive and real power flow exchange between the ac system and STATCOM can be varied just by varying the output of the converter. The STATCOM midpoint reference voltage and its characteristic slope are set to 1 p. u. and 3% respectively.

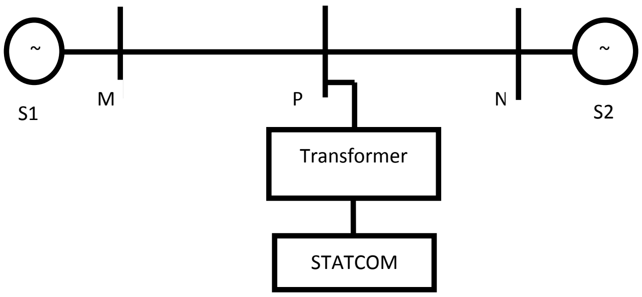

Fig.1. Power system model with

A pulse width modulation (PWM) control scheme is adopted in this study to generate balanced three phase firing signals i.e. all the three phases signals are $120^0$ apart from each other.

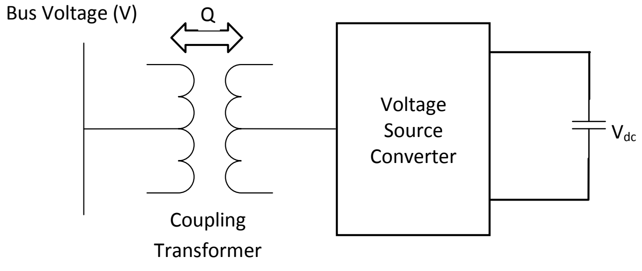

Fig. 2. Basic Structure of STATCOM

### 2.2 STATCOM voltage controller model

The STATCOM voltage controller regulates transmission line voltage at the point of connection by injecting or absorbing the reactive power. The schematic block diagram of the STATCOM controller is shown in the fig. 3. The voltage controller consists of positive sequence component block, quadrature current block, PI controllers and phase locked loop (PLL) block. The positive sequence of the midpoint voltage using the three phase voltage is computed by positive sequence component block, this measured voltage ($V_{mes}$) is compared with the reference voltage ($V_{ref}$) to produce desired change in the voltage simply called error voltage ($V_{error}$). Now, the erroneous voltage signal is fed to a proportional integral controller-1 (PI-1) whose function is to regulate the voltage and produces the change in angle between the reference and measured voltage. However, this can be achieved by two sub processes. The output of the PI controller-1 produces the reference quadrature current ($I_{qref}$) which is compared with the measured quadrature current ($I_{qmes}$) produced by the quadrature current computation block. The error of both the current ($I_{qerror}$) again fed to PI controller-2 to produce the desired phase shift (α). The error in α indicates the variation of the DC capacitor voltage in order to vary the reactive power between converter and ac power system. A step response voltage signal is used to tune the PI controllers in order to produce the desire outputs.

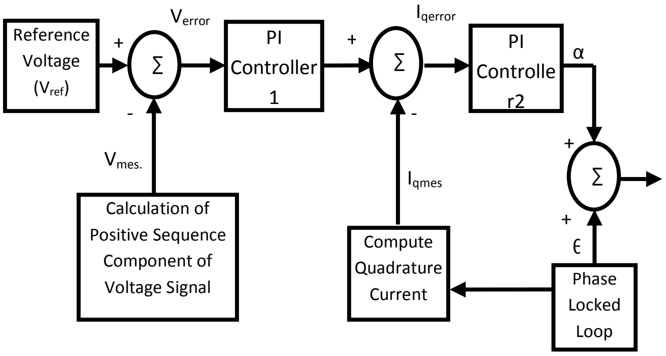

Fig. 3. STATCOM controller

## 3. Apparent Impedance Calculation With STATCOM

In this segment mathematical representation of the apparent impedance seen by the relay in presence of the midpoint connected STATCOM is formulated. The equivalent network of system shown in fig. 1. is represented in fig. 4.

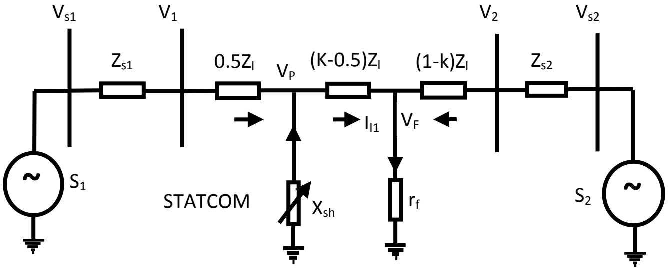

Fig. 4. Equivalent faulted circuit

where,

$V_{s1}$, $V_{s2}$ = Equivalent voltages of two source S1and S2

$Z_{s1}$, $Z_{s2}$ = Equivalent source impedances of two source S1and S2

$I_{s1}$, $I_{s2}$ = Currents from two source S1and S2 end

$r_f$ = Fault resistance in ohm

$i_f$ = Fault current in ampere

Xsh = Equivalent reactance of STATCOM

$I_{sh}$ = STATCOM injected current in ampere

$V_F$ = Fault voltage

k = Fault location in percentage (%)

$Z_l$ = Transmission line impedance in ohm

1, 2 = Source end buses

$V_1$, $V_2$ = Source end bus voltages

$Z_{app}$ = $Z_r$= Apparent or relay impedance seen by the relay at the point of connection

The mathematical representation of the impedance seen by the relay following to a single line to ground (SLG) and three phase fault is shown below

### 3.1 Single Line to Ground Fault (SLG)

Fault occurs beyond the STATCOM (k ≥ 50%), the voltage seen by the relay can be formulated as (1)

$$V_1^{012}=0.5Z_l^x I_{s1}^x+(K-0.5)Z_l^x\left(I_{sh}^x+I_{s1}^x\right)+i_F r_F \tag{1}$$

where,

x; suffix represents the sequence component

$V_1$ = Voltage at relay point

$Z_l$ = Transmission line impedance

$I_{s1}$ = relay current

$I_{sh}$ = STATCOM injected current

$I_f$ = fault current

$r_f$ = fault resistance

The apparent impedance of relay is given by (2)

$$Z_r=\frac{V_r}{I_r}=\frac{V_1}{I_1} \tag{2}$$

By simply adding the three sequence components of corresponding voltage and current signals, the relay voltage and current (Vr and Ir) is given by (3)

$$V_r=kZ_L^1\left[I_{s1}+kI_s^0\right]+(K-0.5)Z_l^1\left(I_{sh}+mI_{sh}^0\right)+i_f r_f \tag{3}$$

where,

$i_f=I_{s1}+I_{s2}+I_{sh}$ represents the total fault current

$m=\frac{Z_l^0-Z_l^1}{Z_l^1}$ = compensation factor

In this work, the relay is connected at bus '1', positive and negative sequence impedances are assumed to be equal. In eqn. (2) the relay current is calculated as $I_r = I_{s1}+kI_{s1}^0$. The relay impedance is shown in (4)

$$Z_r = kZ_l^1 + (k-0.5)Z_l^1\left(\frac{I_{sh} + kI_{sh}^0}{I_{relay}}\right) + R_F\left(\frac{i_f}{I_{relay}}\right) \tag{4}$$

Where $I_{sh0}$ is the zero sequence component of current injected by the STATCOM. But, its effect is not considered to be significant as one side of the coupling transformer is delta connected and can be neglected. So, eqn (4) can be written as

$$Z_{app.} = Z_r = kZ_l^1 + (k-0.5)Z_l^1\left(\frac{I_{sh}}{I_{relay}}\right) + r_F\left(\frac{i_f}{I_{relay}}\right) \tag{5}$$

## 3.2 Three Phase Fault

Following a three phase fault at k ≥ 50% of the transmission line, the apparent impedance seen by the relay can derived and finally given in (6)

$$Z_{app.} = Z_r = kZ_l^1 + (k-0.5)Z_l^1\left(\frac{I_{sh}}{I_{s1}}\right) + r_F\left(\frac{i_f}{I_{s1}}\right) \tag{6}$$

# 4. PROPOSED ADAPTIVE METHOD

Distance relay issues trip signal based on the comparison of setting impedance and apparent impedance values. In normal operating condition both the impedances are equal. Considering the setting impedance value to be 85% of line, the apparent impedance can be written as:

$$Z_{app.} = Z_r = 0.85Z_l^1 \tag{7}$$

Comparing eqs. (6) and (7)

$$Z_{app.} = Z_r = kZ_l^1 + (k-0.5)Z_l^1\left(\frac{I_{sh}}{I_r}\right) \tag{8}$$

Solving eq. (8), final equation for new setting zone is given by

$$Z_n = 0.5 + Z_l^1\left(\frac{0.35}{1+\varphi}\right) \tag{9}$$

where,

$$\phi = \left(\frac{Z_{comp}}{Z_l}\right) = \left(\frac{I_{sh}}{I_r}\right) = \text{compensation factor} \tag{10}$$

Ish = current injected by STATCOM, Irelay = relay current at bus M, $Z_{comp}$ = compensated impedance and $Z_l$ = transmission line impedance.

# 5. PERFORMANCE OF THE PROPOSED TECHNIQUE

## 5.1. Single Line to Ground (SLG) Fault

### 5.1.1. During Underreach

Underreach occurs due to capacitive mode operation of STATCOM as a result of which the net impedance seen by the relay increases. Therefore, the conventional relay doesn't trip for a fault near the boundary of zone 1. Fig. 5(a) shows impedance trajectory for system with and without STATCOM. Conventional relays for the transmission line without STATCOM operates correctly and with STATCOM it maloperates. However, with new adaptive zone setting this maloperation can be prevented. Single line to ground fault is created at remote end (255 km) of the transmission line with STATCOM connected at the midpoint.

### 5.1.1.1. Performance for different fault locations

Faults occurring at the boundary of zone 1 hinders the performance of the relay. However, for an in-zone fault the relay should operate correctly with adaptive zone setting. Single line to ground fault is created at 255 km from relay location with fault resistance of 1Ω and load angle of $20^0$. The corresponding results with and without STATCOM is shown in Fig. 5(b).

### 5.1.1.2. Performance for different fault resistance

In this section performance of the proposed method is analyzed for different fault resistance values. Single line to ground fault is created near the zone 1 reach. Fig. 5(c) shows the impedance trajectory with and without STATCOM. The fault resistance and load angle is set to 30Ω and $30^0$ respectively.

### 5.1.1.3. Performance for different load angle

To investigate the impact of variation in load angle and performance of proposed method during such system condition, single line to ground fault is created at remote end of the transmission line. In this section load angle of $50^0$ and a low fault resistance of Rf =0.01Ω is considered. From this analysis it has been found that increasing the load angle of the system the relay calculated impedance is increased. The corresponding result is shown in Fig. 5(d).

### 5.1.2. During Overreach

Overreach occurs when the STATCOM is operated in inductive mode. The primary causes are when STATCOM compensates a weak system and the reference voltage is less than 1 p. u. To observe the relay overreach condition reference voltage of 0.85 p. u. is considered. Single line to ground fault is created a remote end (260 km) of the transmission line with midpoint connected STATCOM and proposed adaptive method is applied with different power system scenarios to mitigate the condition of overreach. Relay measured impedance without STATCOM is correct while with STATCOM for an out of section fault the impedance trajectory enters into the Zone-1.

However, proposed technique evaluates the new zone for which the relay operation is accurate. The corresponding result is shown in Fig. 6(a).

### 5.1.2.1. Performance for different fault locations

To examine the performance of the proposed adaptive method a single line to ground fault is created at 200 km from the relay location. The case is simulated with fault resistance $R_f$ = 1Ω and load angle of $30^0$. The proposed algorithm not only operates correctly for out of section faults but also operate correctly for an in-zone fault. The corresponding result is shown in Fig. 6(b).

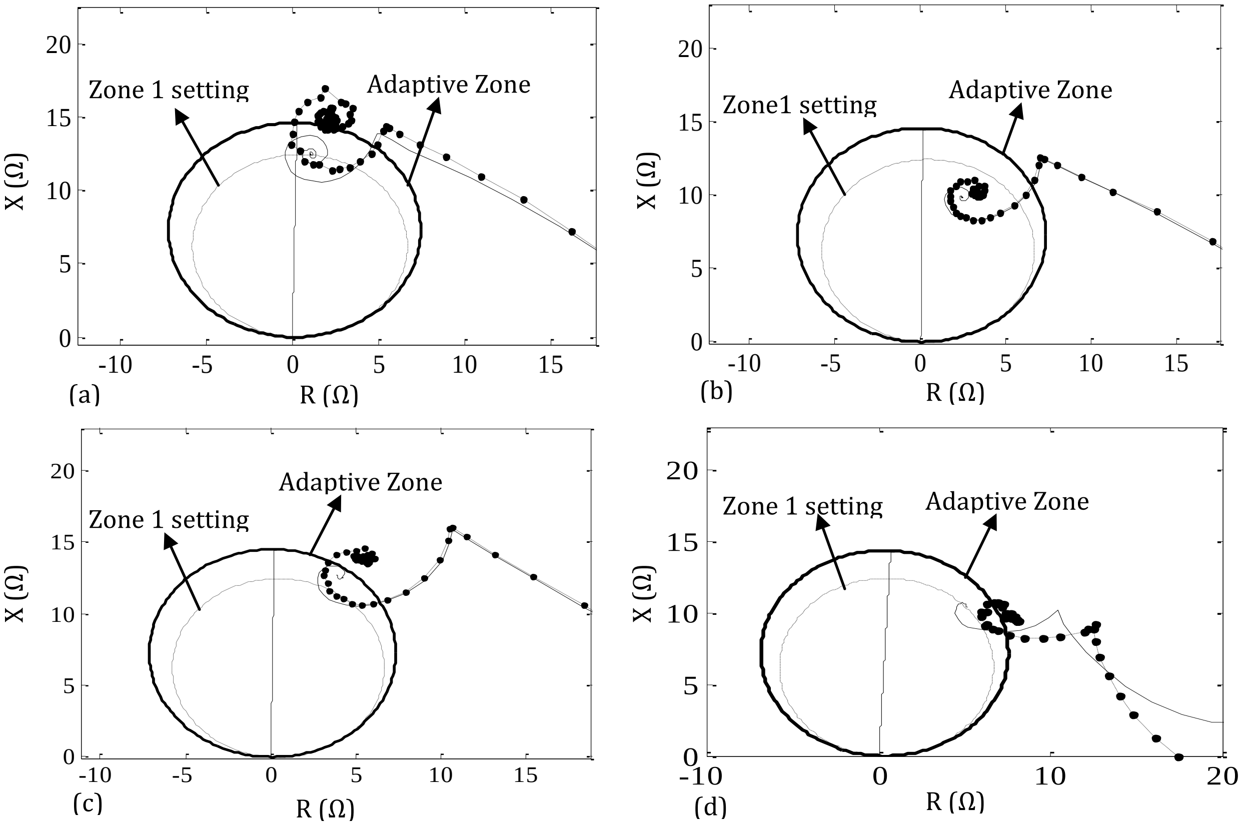

Fig.5. Adaptive Mho relay for LG fault (a) load angle $20^0$ and Rf =1 Ω, (b) load angle $10^0$ and Rf =10 Ω, (c) load angle $30^0$ and Rf =30 Ω, (d) load angle $50^0$ and Rf =50 Ω

### 5.1.2.2. Performance for different fault resistance

The performance of proposed algorithm is evaluated for different fault resistances. Single line to ground fault is created at remote end of the transmission line (beyond Zone-1) with a high fault resistance of Rf = 30Ω and load angle of $30^0$. Fig. 6(c) shows the impedance seen by relay with conventional zone-1 setting, which leads to maloperation. However, operation of the relay is correct with proposed adaptive zone.

### 5.1.2.3. Performance for different load angle

To investigate the impact of variation in load angle and performance of proposed method during such system condition, single line to ground fault is created at remote end of the transmission line. In this section load angle of $50^0$ and a low fault resistance of $R_f$ =0.01Ω is considered. Henceforth, it has been found that by increasing the load angle of system the relay calculated impedance also increases. The corresponding result is shown in Fig. 6(d).

## 5.2. Line to Line (LL) Fault

### 5.2.1. During Underreach

Performance of proposed adaptive zone based distance algorithm is evaluated for several line to line fault scenarios, assuming the capacitive mode operation of the STATCOM. Line to Line faults (phase A to Phase B) are created at distance 255 km (boundary of the zone 1 reach), considering variations in fault resistance (0.01 Ω to 30 Ω).

The proposed adaptive relay is also tested during the variation of load angle ($10^0$ to $50^0$). The corresponding results with various fault resistance and load angle are shown in Fig.6. It is observed that the conventional distance relay doesn't operate correctly with mid-point connected STATCOM whereas proposed adaptive zone based distance relay correctly operates.

During the STATCOM infeed, LL fault at the boundary of the zone 1 leads to maloperation of distance relay (underreach effect). However, proposed algorithm computes a new adaptive zone for which relay operation is correct, shown in Fig. 7(a). Fig. 7(b) shows the accuracy of the proposed method for an in-zone fault (at 200 km). Functionality of the proposed method is also verified for low to high fault

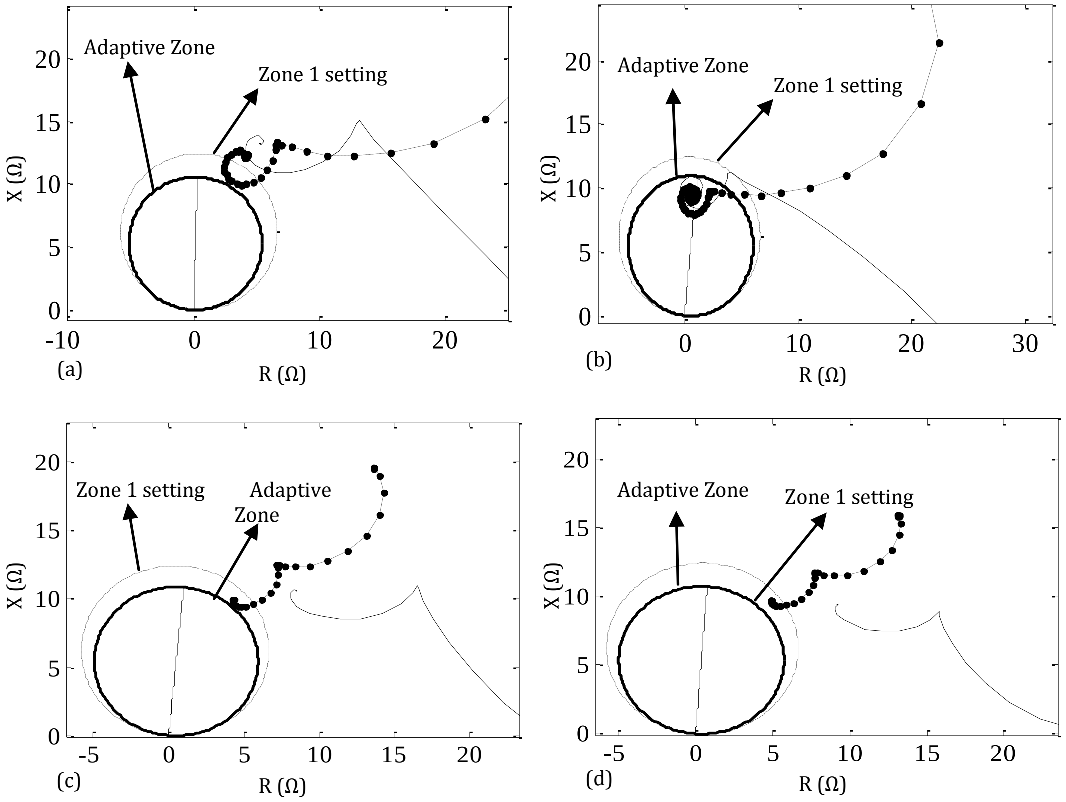

Fig.7. Adaptive Mho relay for LG fault (a) load angle 20° and $R_f$ =1 Ω, (b) load angle 10° and $R_f$ =10 Ω, (c) load angle 30° and $R_f$ =30 Ω, (d) load angle 50° and $R_f$ =50 Ω

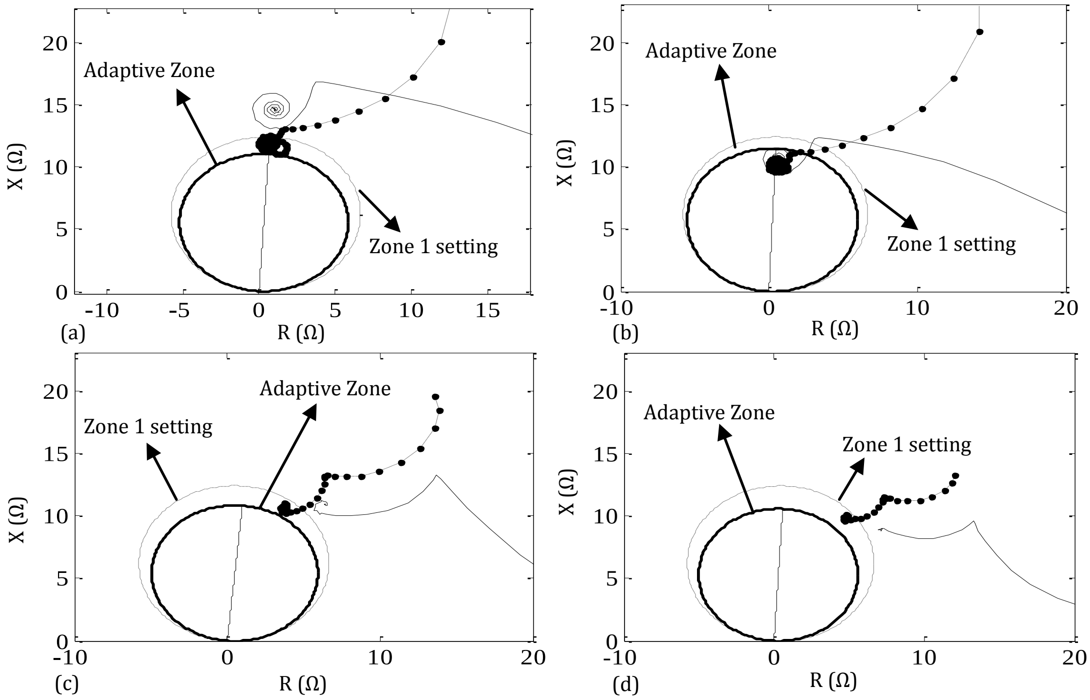

Fig.8. Adaptive Mho relay for LL fault (a) load angle 20° and $R_f$ =1 Ω, (b) load angle 10° and $R_f$ =10 Ω, (c) load angle 30° and $R_f$ =30 Ω, (d) load angle 50° and $R_f$ =50 Ω

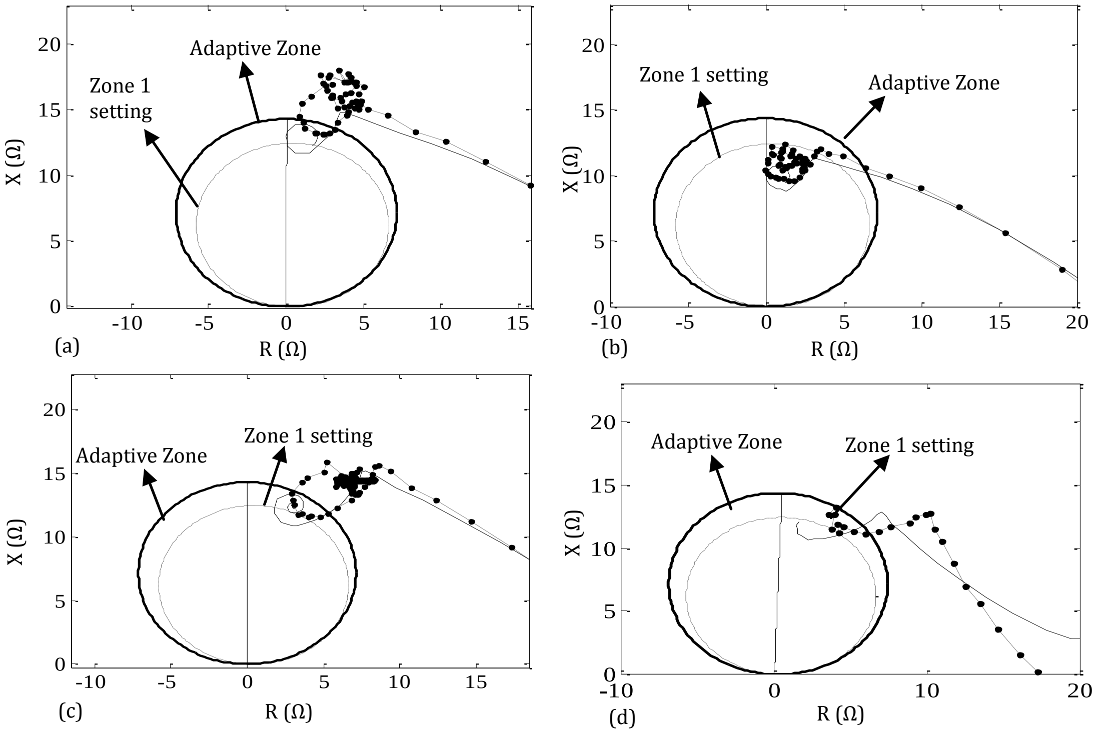

Fig.9. Adaptive Mho relay for LLL fault (a) load angle 20° and $R_f$ =1 Ω, (b) load angle 10° and $R_f$ =10 Ω, (c) load angle 30° and $R_f$ =30 Ω, (d) load angle 50° and $R_f$ =60 Ω

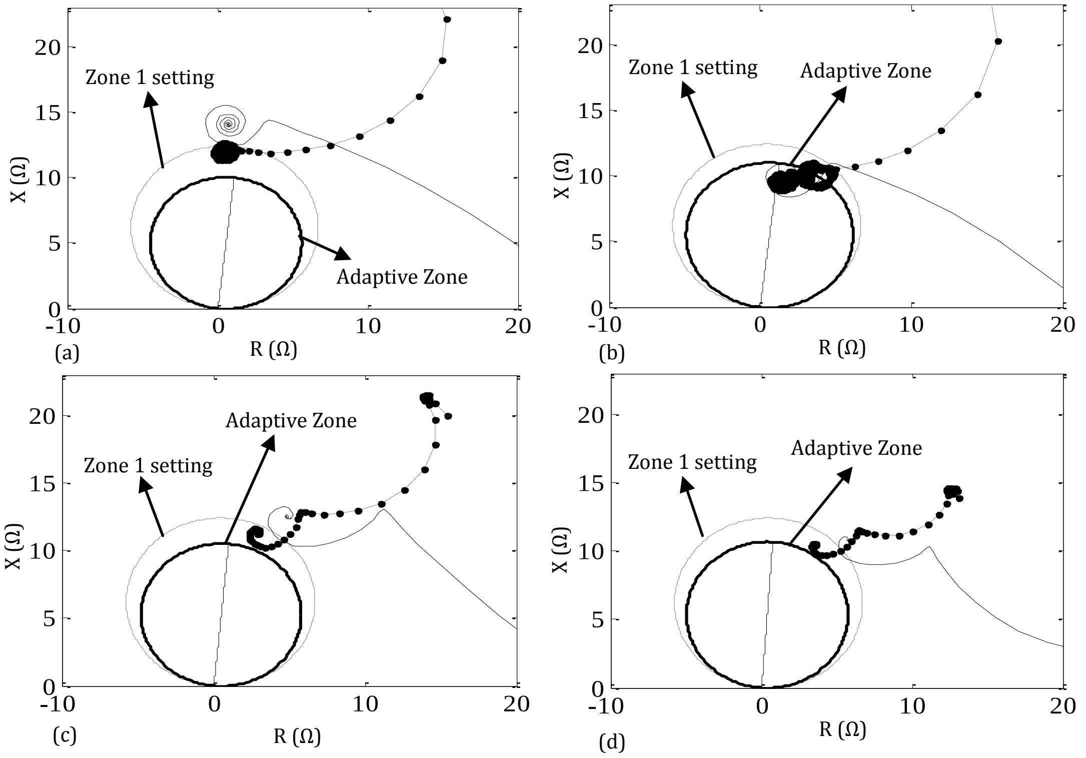

Fig.10. Adaptive Mho relay for LLL fault (a) load angle 20° and $R_f$ =1 Ω, (b) load angle 10° and $R_f$ =10 Ω, (c) load angle 30° and $R_f$ =30 Ω, (d) load angle 50° and $R_f$ =60 Ω

resistance of 0.01 Ω, 10 Ω and 30 Ω and for different load angle of $10^0$, $20^0$ and $50^0$ shown in Fig. 7(c) and Fig. 7(d).

### 5.2.2. During Overreach

To examine the performance of proposed method, Line to Line fault (Phase A to Phase B) is created outside the zone 1 (260 km) from relay location. The STACOM is set to be operated in an inductive mode. For an out of section fault, due to presence of midpoint connected STATCOM the conventional distance relay recognizes it as an in zone fault and maloperates. However, with proposed algorithm the relay calculates new zone setting for which the relay operates correctly. The corresponding result is shown in Fig. 8(a).

To validate the efficiency of proposed method various system conditions with different fault resistances and load angle have been simulated on power system. Fig. 8 (b) shows, the impedance trajectory corresponding to an inzone fault (200 km from bus M) with load angle $10^0$ and Rf =10 Ω. It can be concluded from Fig. 8 (b) that both the distance relay operates correctly for an inzone fault.

To study the impact of fault resistance and load angle on midpoint connected STATCOM, Line to Line faults are created beyond zone 1 setting with fault resistance of 50 Ω and 30 Ω and load angles of $30^0$ and $50^0$. With conventional zone 1 setting relay maloperates as the fault resistance increases. However, proposed technique computes the new setting zone for which the operation of relay is correct and reliable. The corresponding results are shown in Fig. 8(c). Now, the load angle and fault resistance is incremented to $50^0$ and 50 Ω respectively and simulated. As earlier discussed apparent impedance increases with increase in load angle. Faults beyond the zone 1 cause overreach and the conventional relay maloperates. In Fig. 8(d), impedance trajectory enters into the trip region of the conventional distance relay characteristics even though the fault is out of zone 1 limit. However, the operation of the conventional distance relay is reliable when STATCOM is out of service. In order to mitigate this problem the proposed adaptive algorithm computes the new setting zone.

From Fig. 8(d), it is observed that the impedance trajectory lies outside for new setting zone. Therefore, proposed algorithm successfully mitigates the overreach issue associated with midpoint connected STATCOM.

## 5.3. Triple Line Fault (LLL)

### 5.3.1. During Underreach

To illustrate the performance of proposed method, LLL faults are created at boundary of zone 1 reach (255 km). Fault resistances are varied within the range of 0.01Ω to a higher value of 60 Ω. Different load angles are taken into the consideration to evaluate the strength of the proposed technique.

It is observed that both conventional and proposed relay operates correctly for in-zone faults. However, faults near the boundary causes maloperation of the conventional relay for different scenarios but, proposed method is highly reliable, accurate in operation and is efficient in mitigating the underreach effect. The efficiency of the proposed method as compared to conventional relaying algorithm is shown in Fig. 9.

### 5.3.2. During Overreach

In this section, performance of proposed method is analyzed for triple line (LLL) fault. LLL faults are created beyond the zone 1 setting of the distance relay connected at bus M. During simulation, efficiency of proposed technique and impact of various system parameters on distance relaying are investigated. Fault resistance is varied from a lower value of 0.01Ω to a higher value of 60 Ω. The load angle is varied within the range of $10^0$-$50^0$.

It is observed that proposed adaptive zone selection algorithm operates correctly for all the scenarios. For an in-zone fault (200 km) the conventional MHO relay and proposed method operates correctly as shown in Fig. 10 (b). On the other hand, for out of section faults the trajectory enters into the trip region of conventional MHO relay characteristic in presence of STATCOM. This effect remains same for different load angles and fault resistances. However, proposed method is capable of mitigating this problem with different power system conditions.

## 6. CONCLUSIONS

This paper addresses the impacts of midpoint connected STATCOM on distance protection and also reports the limitation of conventional distance relay. This paper proposes a new adaptive zone selection algorithm based on the calculation of compensating impedance. However, this compensating impedance is calculated depending upon the current injected or absorbed by the STATCOM. Simulation and analysis of the proposed method is performed in EMTDC/PSCAD environment. Proposed algorithm is tested under different fault conditions, with wide variation in fault resistances and load angles. Both underreach and overreach effects are analyzed and the related issues can be mitigated using proposed adaptive zone algorithm. From the results and analysis it can be concluded that proposed technique is accurate, highly reliable, robust, secure and fast in operation. It can be installed with the conventional distance relay for midpoint connected STATCOM and for any shunt connected FACTS devices.

## REFERENCES

[1] N. G. Hingorani and L. Gyugyi, Understanding FACTS: Concepts & Technology of Flexible AC Transmission Systems. New York: Wiley, 1999.

[2] E. Larsen et al., Basic aspect of applying SVCs to series-compensated AC transmission lines, IEEE Trans. Power Del., (5) (July) (1990) 689–686.

[3] L. Gyugyi, Converter-based FACTS Controllers, IEE Colloquium on Flexible AC Transmission Systems - The FACTS, 23 Nov. 1998, Pages: 1/1-111 , Ref. No. 1998/500.