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Impact of STATCOM on Distance Relay Operation for Various Types of Faults

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ABSTRACT:Flexible AC Transmission (FACT) devices are normally used to to enhance controllability and increase power transfer capability of the grid. However, in power systems grids, presence of FACT devices such as STATCOM (Static Synchronous Compensator) usually affects the operation of some sub-systems such as distance relays. It is very important that the distance relays do not mal-operate under system fault conditions as this will result in the loss of stability or the security of the system. As STATCOM devices have fast response and their functional characteristics and control system introduce dynamic changes during fault conditions in a transmission line it is important that distance relays perform correctly irrespective of such dynamic changes introduced during fault. This paper presents a complete analysis of distance relay operation in the presence of STATCOM for all types of faults. It has been found from the simulation results that the operation of distance relays prone to either under-reach or over-reach when a STATCOM installed at the mid-point within the protection zone of the relay.

Keywords: FACT devices, Distance protection, STATCOM, Power system grid faults, PSCAD.

I. INTRODUCTION

The measured impedance at the relaying point is the basis of the distance protection operation. There are several factors affecting the measured impedance at the relaying point as presented in[1, 2]. Some of these factors are related to the power system parameters prior to the fault instance, which can be categorized into two groups. First group is the structural conditions, represented by the short circuit levels at the transmission line ends, whereas the second group are the operational conditions, represented by the line load angle and the voltage magnitude ratio at the line ends. In the recent years FACTS devices are introduced to the power systems to increase the transmitting capacity of the lines and provide the optimum utilization of the system capability[3, 4]. However, in the presence of FACTS devices such as STATCOM in particular, the conventional distance characteristic such as Mho and Quadrilateral are greatly subjected to mal-operation in the form of over-reaching or under-reaching the fault point[5, 6]. Generally three installation positions are considered for the STATCOM[6]; at the near end bus, at the mid-point of the line and at the remote end bus. In the case of ends buses, STATCOM is not present in the fault loop and therefore not affecting the distance relay operation.When STATCOM is installed at the mid-point, if the fault locates between the relaying point and the mid-point, the STATCOM is not present in the fault loop, otherwise STATCOM would be included in the fault loop. When STATCOM is not present in the fault loop for zero fault resistance, the measured impedance is equal to the actual impedance of the line section between the relaying and fault points. On the other hand, when STATCOM is within the fault loop, even in the case of zero fault resistance, the measured impedance would be deviated from its actual value. Therefore, the conventional distance relays are exposed to the mal-operation, in the form of over-reaching or under-reaching. In this case, the effect of STATCOM on the protective zones should be considered accurately[7, 8]. Thus, it is essential to study effects of FACTS devices on the protective systems, especially the distance protection, which is the main protective device at EHV (Extra High Voltage) level.

This paper presents a detailed analysis of the impact of STATCOM employed in a transmission system on the performance of distance relay using PSCAD package. At first a briefreview of the effects of a STATCOM connected at the midpoint of a transmission line on the performance of distance protection relays is presented. Followed by a detailed simulation study for various types of faults applied on a transmission line protected by distance relay.

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II. ANALYSIS OF A TRANSMISSION LINE WITH A STATCOM

Fig. 1 shows a distance relay protecting a long transmission line with a STATCOM installed at the mid-point.The STATCOM is controlled to compensate the voltage at the mid-point of the transmission line. Fig. 2 illustrates the V-I characteristics of a STATCOM. As it can be seen, a STATCOM can provide both capacitive and inductive compensation and is able to control its output current over the rated maximum capacitive or inductive range independent of the ac system voltage[9]. This feature is the main advantage of the STATCOM over other FACTS devices such as Static VAR Compensator (SVC) [6]. SVC can supply only diminishing output current with decreasing system voltage as determined by its maximum equivalent admittance[10, 11]. This also means that the maximum capacitive or inductive reactance generated by STATCOM decreases linearly with voltage with constant current.

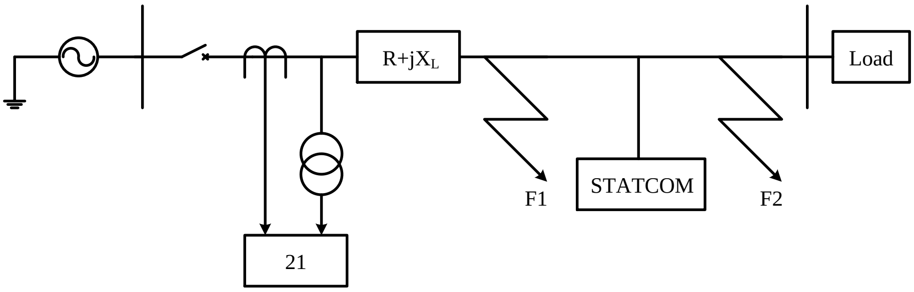

Fig. 1 Distance relay in a transmission system with a STATCOM at the midpoint

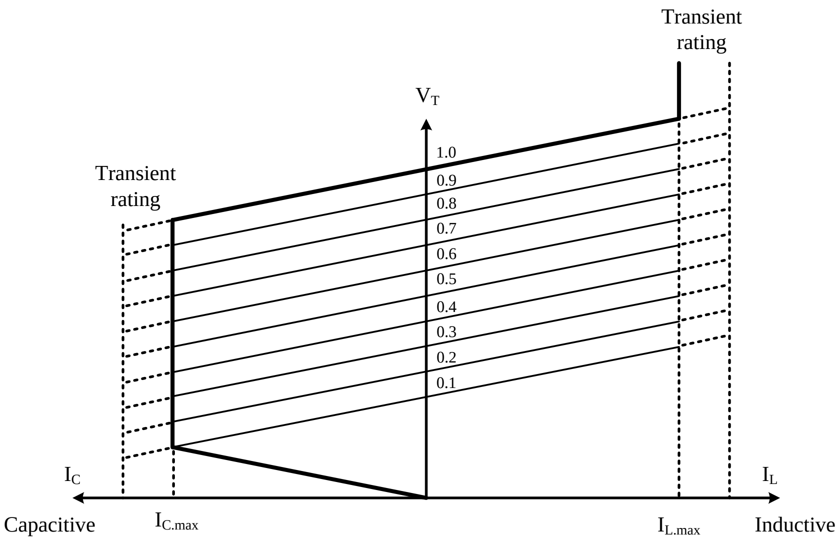

Fig. 2 V-I Characteristics of STATCOM

A fault at F_1 in front of the STATCOM will not affect the relay performance. The impedance Z calculated by the traditional distance protection relay using the measured voltage and current, in terms of the reach setting, can be expressed as in (1). The impedance Z_1 is the zone impedance which normally set in terms of the positive sequence impedance of the transmission line. The rest of the relationship is essential to ensure that the relay operates correctly for all the earth faults, and compensating for the cross coupling effects with the adjacent lines.

$$Z = Z_1 + \left[\left(\frac{I_{res}}{I_p}\right).Z_{res}\right] + \left[\left(\frac{I_{mut}}{I_p}\right).Z_{mut}\right] \tag{1}$$

where,

Z_1 is the positive sequence impedance reach setting

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$I_p$is the current in the faulted phase
$I_{res} = (I_a+I_b+I_c)$ is the residual current
$I_{mut}$is the residual current in the parallel line
$Z_{res} = (Z_0+Z_1)/3$ is the residual impedance, which includes the earth impedance.
$Z_{mut}$is the mutual compensating impedance

For any fault behind the STATCOM (at point F_2) the STATCOM is in the front of the fault. At these conditions, STATCOM injects a current in quadrature with the line voltage feeding the fault and boosting the voltage at the mid-point, which is seen as additional impedance by the relay. This impedance can be either inductive or capacitive, depending on the mode of operation of the STATCOM prior to the fault. In this situation the relationship of (1) does not apply and therefore the apparent impedance calculated by the distance relay is different from the actual fault impedance. This scenario leads to possible under-reach or over-reach of the measuring elements of the distance relay. Hence the relay must be provided with some form of compensation to eliminate the under-reach or the over-reach as given by,

$$Z' = Z + Z_{compensating} \tag{2}$$

where$Z_{compensating}$is the additional impedance required to compensate the effects of STATCOM.

III. SIMULATION STUDY FOR VARIOUS FAULTS

A model of a transmission line with a STATCOM installed at the mid-point using PSCAD package is shown in Fig. 3. PSCAD is a graphical user interface, providing a very flexible interface to the electromagnetic transient simulation software Electomagnetic Transients Program (EMTDC). EMTDC is the library of power system component models and a procedure which constitutes the simulation software packages are referred to as "PSCAD/EMTDC" and the combination allows the engineers to set up and run a wide variety of power system simulation[12]. The simulations are performed for various types of faults (single-phase to ground, two phase and three-phase faults) applied inside the protected zone of the distance relay. Based on the developed model, STATCOM is included in the loop of impedance seen by the distance relay as presented in the following sub-sections.

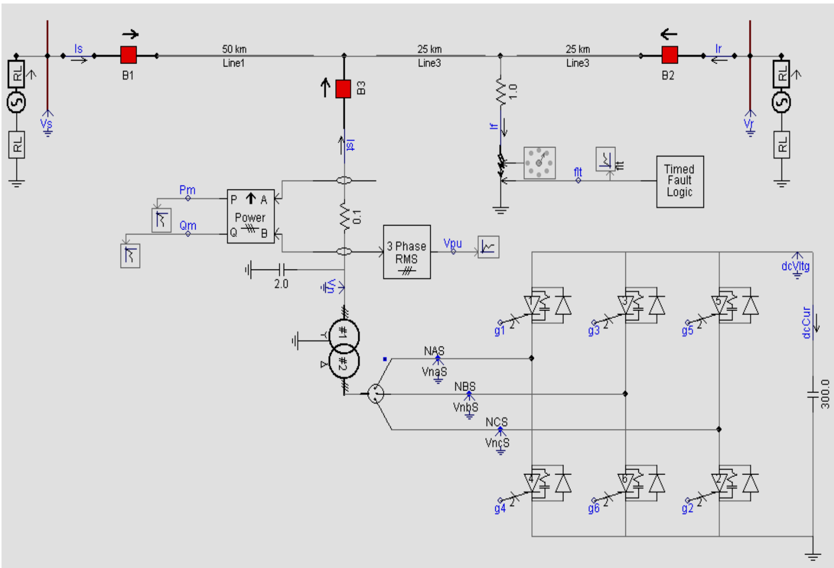
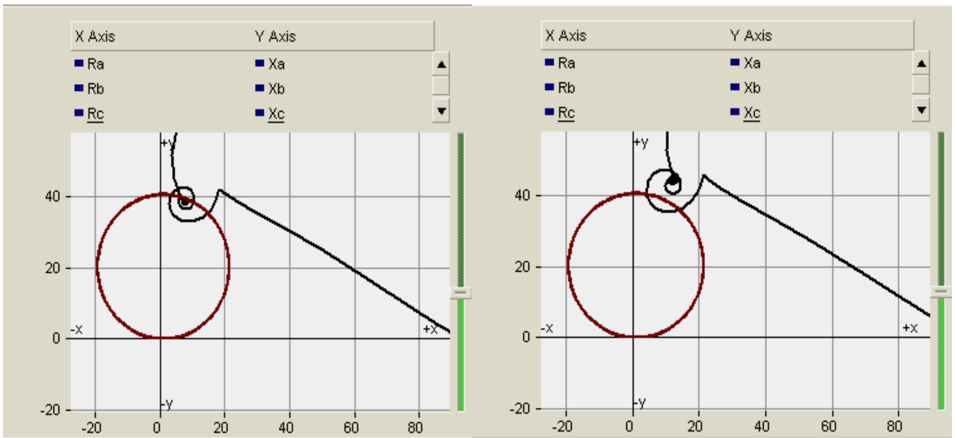


Fig. 3A transmission line with STATCOM at the mid-point modelled by PSCAD

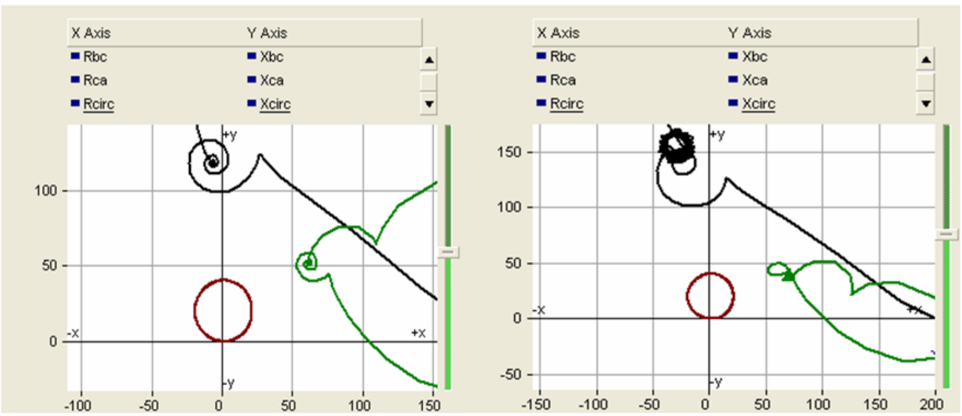
A. *Phase to Ground (A-G) Fault*

In the system shown in Fig. 3, phase-A to ground fault occurs at a distance of 75 kilometers on the right side of STATCOM. The setting value in terms of the desired voltage for STATCOM is 1.0pu. The apparent impedance trajectories of the system with and without STATCOM together with the distance relay mho characteristic are shown in Fig. 4. It can be seen that the apparent impedance of the transmission system with STATCOM is greater than that for the system without STATCOM. The protection zone of the distance relay will thus decrease i.e. it will underreach[13, 14]. Fig. 5 shows the results of simulation of the other units calculation of line-line impedance during A-ground fault for both conditions (with/ without STATCOM). It is clear that only the impedance of the faulted phases will be calculated by relay and the trajectories of the apparent impedance of other units do not cross the Mho circle for this fault condition.



(a) (b)

Fig. 4Apparent impedance seen by the relay during A-ground fault (a) without STATCOM (b) with STATCOM



(a) (b)

Fig. 5Line-line elements of distance relay during A-ground fault (a) without STATCOM (b) with STATCOM

When the fault is on the right side of STATCOM, both the apparent resistance and reactance of the system with STATCOM are larger than that for the system without STATCOM. This can be explained by thethe I_{sh}/I_{relay} (influence ratio). Because of the reactive power injection by STATCOM, the voltage at the STATCOM connecting point is higher compared to the system without STATCOM; in other words, the distance seen by the relay is farther than its real distance. This increase in the apparent impedance would lead to the under-reaching of distance relay. When the STATCOM is installed in the middle of the transmission line, and the original distance relay's reach is set of 80% then, the reach point $N_{new}$for the system with STATCOM can be derived from following,

$$50\%\,Z_1 + (N_{new} - 50\%)\left(1 + \frac{I_{sh}}{I_{relay}}\right)Z_1 = 80\%\,Z_1 \qquad (3)$$

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$$N_{new} = 50\% + \frac{30\%}{1 + \frac{I_{sh}}{I_{relay}}} \quad (4)$$

where I_{sh} is the shunt current injected by the STATCOM and $I_{relay}$is the relaying current.

The setting of STATCOM has a big impact on the apparent impedance[15]. According to different system conditions, STATCOM may have different setting values for desired voltage, and this setting will also affect the performance of the distance relay. The next study is conducted for the apparent impedance and during a single phase to ground fault when the STATCOM settings are 1.2, 1.0 and 0.8 pu respectively.As seen fromFig. 6, 7 and 8, both the apparent resistance and reactance seen by the distance relay for a single phase to ground fault will increase with the increase of STATCOM setting reference voltage. This can be explained by the different reactive power injection. When the setting voltage is high during the fault, to keep the higher desired voltage, STATCOM will inject more reactive power; in other words, the reactive current injection of STATCOM $I_{sh}$is high; this will increase the influence ratio and accordingly increases the apparent impedance seen by the distance relay.

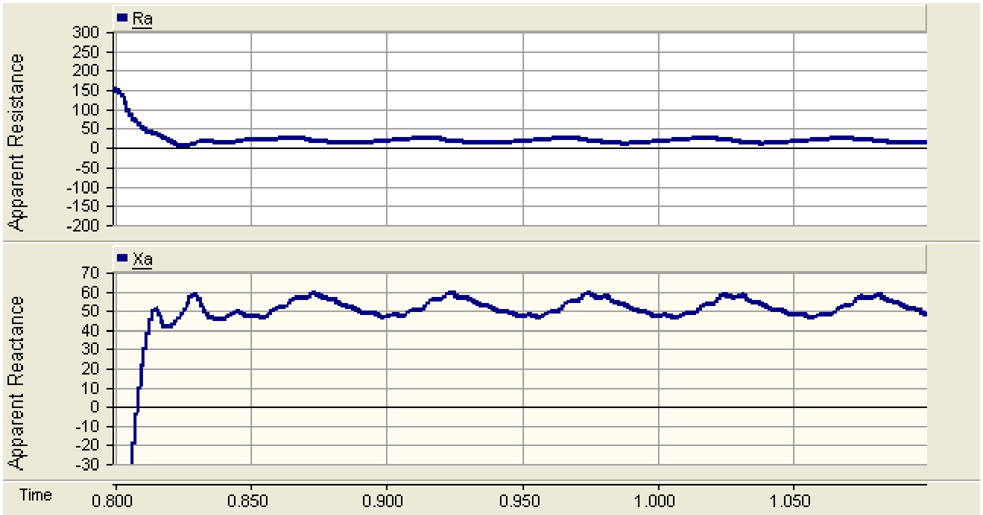

Fig. 6(a) Apparent resistance (b) Apparent reactance; when the setting of STATCOM is 1.2 pu.

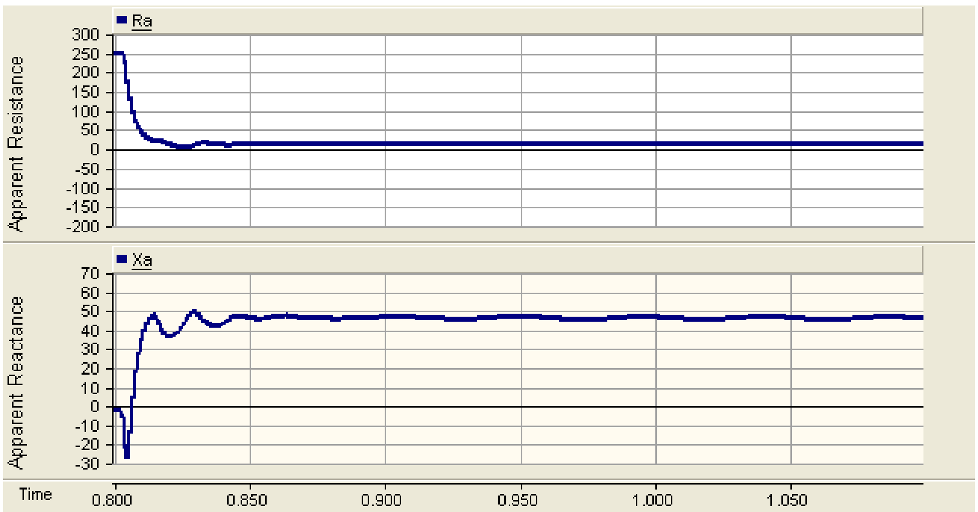

Fig. 7(a) Apparent resistance (b) Apparent reactance; when the setting of STATCO is 1.0 pu.

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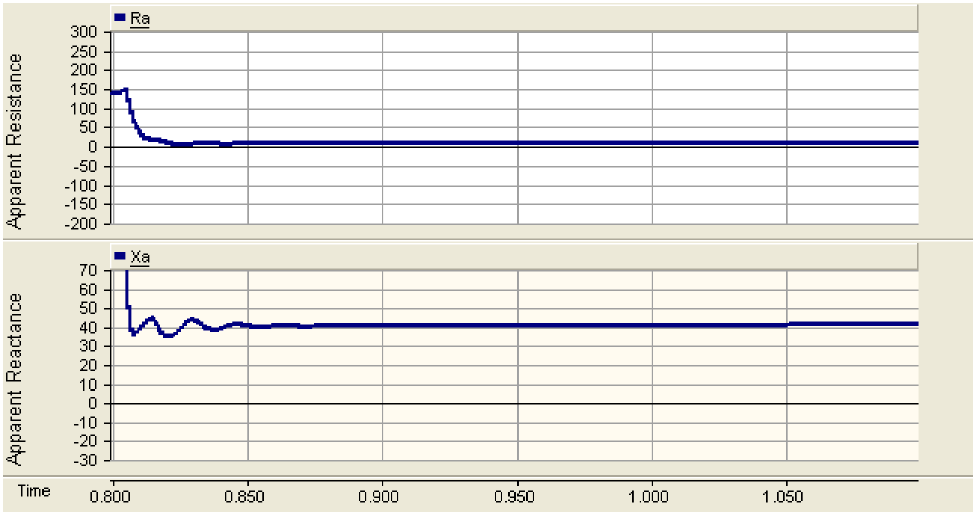
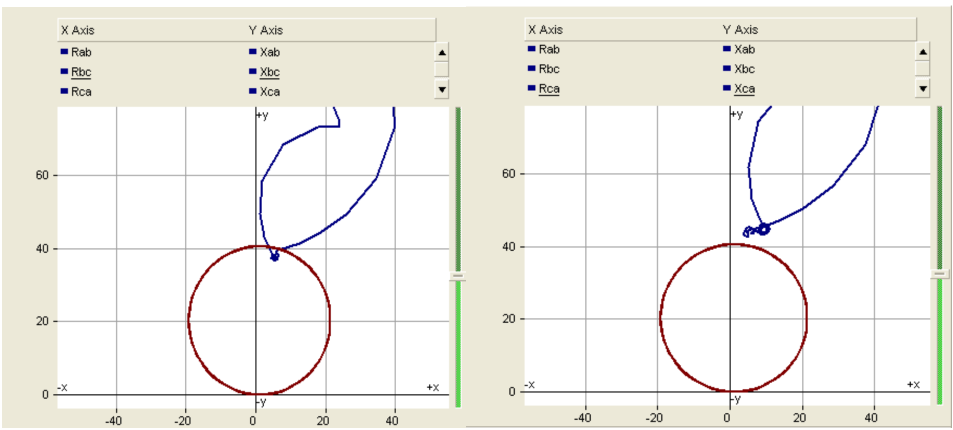


Fig. 8(a) Apparent resistance (b) Apparent reactance; when the setting of STATCOM is 0.8 pu.

It is worth mentioning that for certain conditions, when the system capacity is high and the STATCOM voltage setting value is low, if a single phase-ground fault occurs outside zone 1, the STATCOM connecting point voltage may be higher than the setting value, in this case the STATCOM will absorb reactive power in the system, the current I_{sh}will become inductive, the influence ratio $\boldsymbol{I_{sh}/I_{relay}}$will become negative rather than positive and the apparent impedance seen by the distance relay will decrease compared to the system without STATCOM. This may lead to over-reaching of distance relay, and this is clearly undesirable.

B. Phase to Phase (B-C) Fault

For a phase to phase fault, the relay voltage input is line-to-line voltage and the current is delta line current. Fig. 9 show the apparent impedance seen by distance relay during a B-C phases fault. The relay voltage is $V_{BC}$and relay current is I_{BC}. The fault is located in75km from relay point and the STATCOM setting value is 1.0pu. As can be seen from Fig. 9, during a phase to phase fault, because of the STATCOM, the apparent reactance increases, but unlike the single phase to ground fault, the apparent resistance decreases and hence the distance relay can not operate properly[14]. This is clearly shown in the figure that the apparent impedance trajectory has been moved upward only.



(a) (b)

Fig. 9 Apparent impedance seen by distance relay during B-C fault (a) without STATCOM (b) with STATCOM

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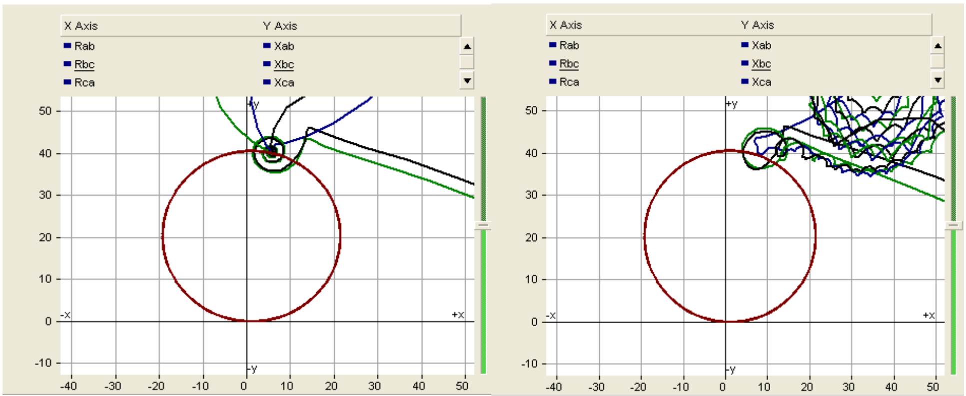
C. Three-Phase (ABC) Fault

The same system has been simulated for the three-phase faults and the apparent impedance seen by the distance relay located at the sending-end for the cases with and without STATCOM which is the fault applied inside the protection zone of the relay. The effect of the STATCOM under fault condition for the cases with the STATCOM disconnected as well as STATCOM connected are illustrated in Fig.10a and b. It can be seen that in the presence of STATCOM the apparent impedance trajectory has been shifted outward the Mho circle.



(a) (b)

Fig. 10 Apparent impedance seen by distance relay during Three-phase fault (a) without STATCOM (b) with STATCOM

IV. CONCLUSIONS

The impact of STACOM on the distance relay operation for various types of faults has beed presented in this paper. The analysis is carried out for a STATCOM installed at the mid-point based on simulation study using PSCAD package. It was found from the simulation results that STATCOM does affect the performance of the distance relay under fault conditions. It has shown that when STATCOM located at the mid-point of the transmission line, the conventional distance relays are exposed to the mal-operation, in the form of over-reaching or under-reaching. In this case, the effect of STATCOM on the protective zones should be considered.It has been found that the apparent impedance is influenced by the level of reactive power injected by the STATCOM resulting in either under reaching or over reaching of the distance relay. Since deviation of the measured impedance is not constant, because of the varying parameters of STATCOM, adaptive methods should be utilized. The distance relay wills under-reach when the STATCOM supplies the reactive power, and will over-reach when the STATCOM consumes the reactive power. The setting of STATCOM has a big impact on the apparent impedance. The higher the voltage setting is, the larger the apparent impedance will be.

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BIOGRAPHY

Ali Abdolkhani graduated from Dezfool University, Iran, with B.E. degree in electrical engineering in 2000. After completing his B.E. he worked in the industry for about 6 years in Iran. He received his M.T. degree from the College Of Engineering/University of Pune (COEP), India, in electrical engineering in 2008. He is currently working towards his Ph.D. with the power electronics group of the University Of Auckland, New Zealand. His research interest lies in IPT (InductivePower Transfer) technologies and mainly focused on Contactless Slipring Systems (CSS) for rotary applications. Beside the academic, Ali is working with the team of PowerByProxiLtd. (www.powerbyproxi.com) on various types of wireless power transfer systems.

Peyman S. Banaghirigraduated from Dezfool University, Iran, with B.E. degree in electrical engineering in 2000. After completing his B.E. since then he is working in the industry relevant to his field at regional distribution systems center in Iran (RDC). He is currently working towards his Master degreein power management (Electrical Engineering) at Amir Kabir University of technology, Tehran polytechnic, Iran. His research lies in renewable energy and power marketing.

Farzad A. Rocky graduated from Dezfool University, Iran, with B.E. degree in electrical engineering in 2000. Besides the academic, Farzad has been working in the industry relevant to his field at the oil and energy company in Iran since 1991. He is currently working towards his Master degree at Islamic Azad University, Kish international branch in Iran.