

## Impact of Static Synchronous Compensator on Performance of Distance Protection of Transmission Lines

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**ABSTRACT** - The effect of static synchronous compensator (STATCOM) installed at transmission line on the performance of distance protection is investigated in this paper. The paper explores an apparent impedance calculation procedure for transmission line incorporating STATCOM based on the power frequency sequence circuits. A detailed model of 6 pulses STATCOM and its control and a mho relay model are proposed and integrated into the transmission system. The paper investigates distance protection operation of transmission lines with STATCOM connected at the midpoint during several operation conditions. Installation of STATCOM in the midpoint to control the reactive power flow affects the operation accuracy of distance relays. The simulation results of distance relays for the protection of transmission line incorporating STATCOM are presented. The analytical calculations show the impact of STATCOM on the distance protection relays during the different faults conditions. The study is carried-out using PSCAD/EMTC software.

**Keywords:** STATCOM, Distance Relay, Voltage Source Converter, Flexible Ac Transmission Line and Transmission Line Protection

**المستخلص:** تعرضت هذه الورقة الى دراسة تأثير المعوض المتزامن الثابت (STATCOM) مثبت في منتصف خط النقل على أداء الحماية المسافية. هذه الورقة تم حسب المعاوقة الظاهرية لخط نقل مدرج معه المعوض المتزامن الثابت استنادا إلى دوائر تتابع تردد القدرة. إقتراح النموذج التفصيلي للمعوض المتزامن الثابت 6 نبضات وطريقة السيطرة عليها وكذلك نمودجا لمرحلة mho ودمجها في نظام خط نقل. الورقة تحقق في عمل الحماية المسافية لخطوط النقل مع وجود المعوض المتزامن الثابت في منتصف خط النقل خلال ظروف تشغيل متعددة. تركيب المعوض المتزامن الثابت في منتصف خط النقل للتحكم في تدفق القدرة الرد فعلية يؤثر على دقة عمل المرحلات المسافية. عرضت نتائج المحاكاة المرحلات المسافية لحماية خط النقل مع وجود المعوض المتزامن الثابت. الحسابات التحليلية أظهرت تأثير المعوض المتزامن الثابت على مرحلات الحماية المسافية لأعطال مختلفة. أجريتهذه الدراسة باستخدام برامج محاكاة (EMTC. /PSCAD)

### INTRODUCTION

The dramatically increase of electrical power demand required significant modification in conventional power system. This is in order to cover the continuous growth in electrical power consumption with reliable and stable interconnected network. The introduction of flexible ac transmission system (FACTS) based on power electronic devices in electrical power system increase system controllability, line capacities, and provides precious functionalities such as reactive power compensation, voltage control and power oscillations damping [1-3]. The FACTS family includes a lot of devices which

can be connected in parallel, series or combination connection such as STATCOM, thyristor-controlled series compensation (TCSC), thyristor-switched series compensation (TSSC), Unified power flow controller (UPFC) and Static voltage compensator (SVC) [4-5].

The most used FACTS-device is the SVC or the version with Voltage Source Converter called static VAR compensator (STATCOM). The STATCOM is used to control reactive power flows, improve power quality and enhance system stability. The STATCOM reactive power injected/ or absorbed into/ or by power system change system parameters (such as line

impedance, line current and power angle). In distance protection due to presence of STATCOM in a fault loop, the voltage and current signals at relay point are changed in both steady and transient state and affect distance protection performance [6].

Distance protection relays have been widely applied for line protection due to their simple operating principle based on calculating the fault impedance and comparing it with the setting relay impedance. Since most of transmission lines use shunt STATCOMs to increase power transfer capability, it is important to study the effect of STATCOM on distance relays operation. In the literature there are several studies investigating the effect of series and shunt FACTS devices on the performance of distance protection relays [7-9].

This paper explores the impact of STATCOM installed at midpoint of transmission line on the performance of distance relay under various circumstances. The study is carried-out using PSCAD/EMTC during different fault conditions.

### STATCOM CONCEPT

STATCOM or Static Synchronous Compensator is a shunt device employs converters and use semiconductor switching devices which can be switched ON and OFF at any time like IGBT, GTO, and IGCT. In STATCOM the converter is controlled using a Pulse Width Modulation (PWM) switching strategy that allows independent control of the magnitude and phase angle of the ac-side voltage. This makes it possible to control the real and reactive power independently, in this case, the current can be made to lead or lag the ac voltage, and so the converter can consume or supply reactive power to the connected ac network and control the line voltage [10].

The schematic diagram of a STATCOM is shown in Figure 1. The reactive power flows between the VSC converter and the ac network can be expressed as presented in equation 1 [11-12]:

$$Q = \frac{V_c V_s \cos(\delta_c - \delta_s)}{X_t} - \frac{V_c^2}{X_t} \quad (1)$$

where,  $V_c$ ,  $V_s$ ,  $\delta_c$  and  $\delta_s$  are converter voltage, the point of common coupling voltage, converter

voltage phase angle and the point of common coupling voltage angle phase, respectively.

The reactive power exchange between the converter and the AC system can be controlled by varying the amplitude of converter voltage ( $V_c$ ) according to (1):

1. If  $V_c > V_s$ , then a lagging current results and the STATCOM acts as an inductor consumer.
2. If the amplitudes are equal no reactive power exchange takes place.
3. If  $V_c < V_s$ , then a leading current results and the STATCOM acts as a capacitor supplier.

The main advantage of STATCOM compared to ordinary static VAR compensator (SVC) and its ability to provide more capacitive reactive power during faults, or when the system voltage drops abnormally is shown in  $V-I$  characteristic in Figure 2 [13]. The STATCOM can provide full capacitive output current at any system voltage, practically down to zero.

### Effects of Stacom on Distance Relay Protection

The basic principles of distance relay protection is based on dividing the voltage at the relaying point by the measured current. The apparent impedance is compared with the reach point impedance to decide whether the fault is internal or external. Distance protection comprises of instantaneous directional Zone1 and one or more time delayed zones. The reach point is usually up to 85% of the protected line impedance for Zone1 protection, the remaining 15% is safety margin ensures that there is no risk of Zone1 protection over-reaching the protected line due to errors caused owing to any reason [13]. While the reach setting of Zone2 protection is 120% of the protected line impedance.

Zone3 reach should be set to at least 1.2 times the impedance presented to the relay for a fault at the remote end of the second line. The distance relay is modeled in the simulator as six Mho Distance elements with a positive sequence voltage polarization, three elements for phase loops and three elements for the phase-ground loops as shown in Figure 3. The relay calculates the apparent impedances of the fault loops which then are compared against impedance

limits that are determined by the relay settings as illustrated in the logic diagram of Figure 3. Equations 2 and 3 show the apparent impedance for single-phase-to-ground and three phase faults<sup>[13-14]</sup>.

**Ground Fault**

$$Z = \frac{V_{XG}}{I_X + \frac{Z_o - Z_l}{Z_l} I_{res}} = \frac{V_{XG}}{I_X + KI_{res}} \quad (2)$$

**Phase Fault**

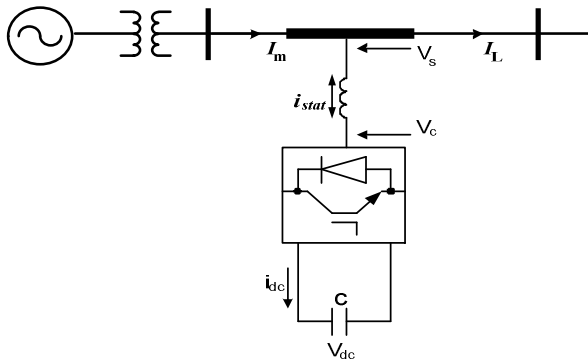
$$Z = \frac{V_{AG} - V_{BG}}{I_A - I_B} = \frac{V_{AG} - V_{CG}}{I_A - I_C} = \frac{V_{CG} - V_{AG}}{I_C - I_A} \quad (3)$$

Where  $V_{XG}$  is Line-to-ground voltage ( $V_{AG}$ ,  $V_{BG}$ ,  $V_{CG}$ ),  $I_x$  is Line current ( $I_A$ ,  $I_B$ ,  $I_C$ ) and  $Z$  is the calculated impedance.

The reactive power injected by STATCOM into power system cause significant changes in magnitude of the current flowing in the transmission line and hence affects the calculated impedance seen by the relay. The current ( $I_m$ ) in Figure 1 which is seen by the distance relay located at the beginning of the transmission line is defined as in equation 4.

$$I_m = I_{statcom} + I_L \quad (4)$$

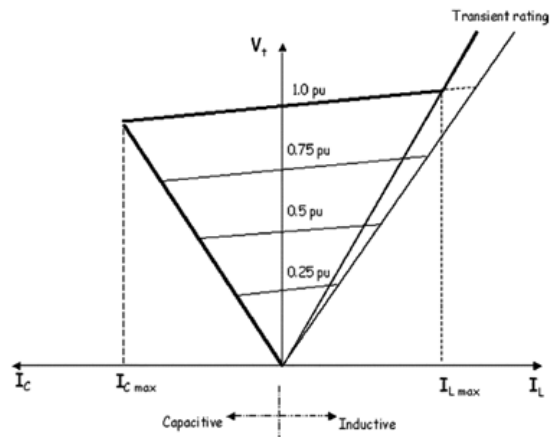
where,  $I_m$  is current from generation side,  $I_L$  load side current and  $I_{statcom}$  is STATCOM current.



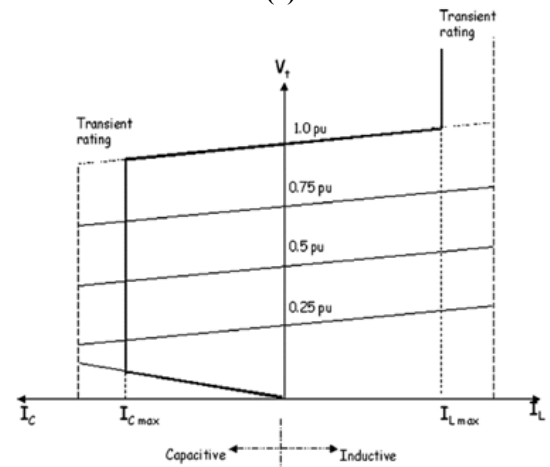
**Figure1: The schematic diagram of a STATCOM**

According to (4) the measured current at beginning of the line decreases when STATCOM injects current into the system and increases when STATCOM draws current from the system. The distance relay operation is affected when shunt FACT devices is installed,

for example a fault at point in transmission line without STATCOM will activate the distance relay, while the same fault when STATCOM is insulated will not activate the relay. The error in the apparent impedance introduced as a result of the STATCOM and the fault resistance in phase to ground and phase to phase faults are given as:



**(a)**



**(b)**

**Figure2: V-I characteristic (a) of the SVC (b) of STATCOM**

$$Z = \frac{V_{XG}}{I_X + \frac{Z_o - Z_l}{Z_l} I_{res}} + Z_{error} = \frac{V_{XG}}{I_X + KI_{res}} + Z_{error} \quad (5)$$



studies are demonstrated including line to ground, phase to phase, and three-phase to ground faults inside and outside the protected zone of the distance relay. In order to include STATCOM in the loop of the impedance seen by distance relay the fault is applied beyond the STATCOM. The distance relay operation is examined in all cases when the transmission line is equipped with and without STATCOM.

**Case 1: Single Phase to Ground Fault**

Figure 4 shows phase A to ground fault occurs at 337.5km (%75) from relay location (beyond the STATCOM and inside zone1) with the STATCOM injecting current into the point of common coupling in order to control the line voltage.

The apparent impedance trajectories of the transmission line with and without connecting STATCOM together with the distance relay characteristic is shown in Figure 5.

Figure5 depicts that the apparent impedance of the transmission line when the STATCOM injects current into system is larger than that for the system without STATCOM, therefore the fault is under reach. Figure 6 shows that the relay will not respond to the fault in both cases when the fault is applied at %90 of the line length because the fault is out of its zone setting.

**Case 2: Phase to Phase Fault (A-B)**

Figure 7 shows the apparent impedance seen by distance relay during an A-B phase fault with and without the STATCOM. In this case, the relay measures line voltage ( $V_{BC}$ ) and line current ( $I_{BC}$ ) to calculate the apparent impedance according to equation 3. The fault is applied at distance of 337.5km (%75 of line length) from the relay point. The relay sends the tripping signal correctly when the system operates without STATCOM as shown in Figure 7a. However, the relay may not sends the tripping signal correctly when the STATCOM is connected into the system as shown in Figure 7b.

Figure 8 depicts the apparent impedance of the transmission line when the fault is applied at %90 of the line length with the STATCOM injecting current to the system the relay will not

respond to the fault in both cases because it is out of its zone setting (%80).

**Case 3: Three phase to Ground Fault**

In the three-phase to ground fault inside zone1 the apparent impedance seen by the distance relay at the sending-end for both cases is illustrated in Figure9. Figure9 shows that the relay operates in both cases but the apparent impedance seen by the relay is larger when the STATCOM is connected into the system. Figure 10 illustrates that the relay will not operate when the fault is applying outside zone 1 at the distance of %90 of the line length.

All the results are obtained when the simulation is running at a load angle  $40^\circ$  and the STATCOM is injected current into the system. The result may change if the load angle is varied and the STATCOM is drawn current from the system.

Table 1 shows results for different load angle ( $40^\circ$ ,  $50^\circ$  and  $70^\circ$ ) and different fault types for the fault applied in inside (%75) and outside (%90) the protected zone. In 75% of transmission the distance relay sends no trip signal for phase to ground faults, but sends incorrect trip signal for phase to phase faults and phase to phase to ground faults.

For A-B fault the distance relay select A-G fault trip and for BC-G fault the distance relay select B-G fault trip. In 90% of transmission line the distance relay receive no trip signal because the faults are out of zone.

**Table 1: Under-reaching effect when STATCOM is injecting current (0 for no trip signal, x for wrong selection and 1 there is trip signal).**

Fault location	Fault type	Angle Order		
		40	50	70
%75	A-G	0	0	0
	A-B	x	x	x
	BC-G	x	x	x
	ABC-G	1	1	1
%90	A-G	0	0	0
	A-B	0	0	0
	BC-G	0	0	0
	ABC-G	0	0	0

### CONCLUSIONS

Installation of STATCOM at the midpoint of the transmission line affects the performance of the distance protection if the fault occurs beyond the STATCOM. The injected/ or drawn current by STATCOM results in an error in impedance measurement and may cause under/over reach and delaying response. The relay may trip for external fault if the STATCOM is absorbing reactive power from the system and may not respond for internal fault if the STATCOM is injecting reactive power into the system. It is vital to implement techniques to mitigate the impact of STATCOM on transmission line protection such as modifying the input voltage and current at the relays to compensate the STATCOM current effects.

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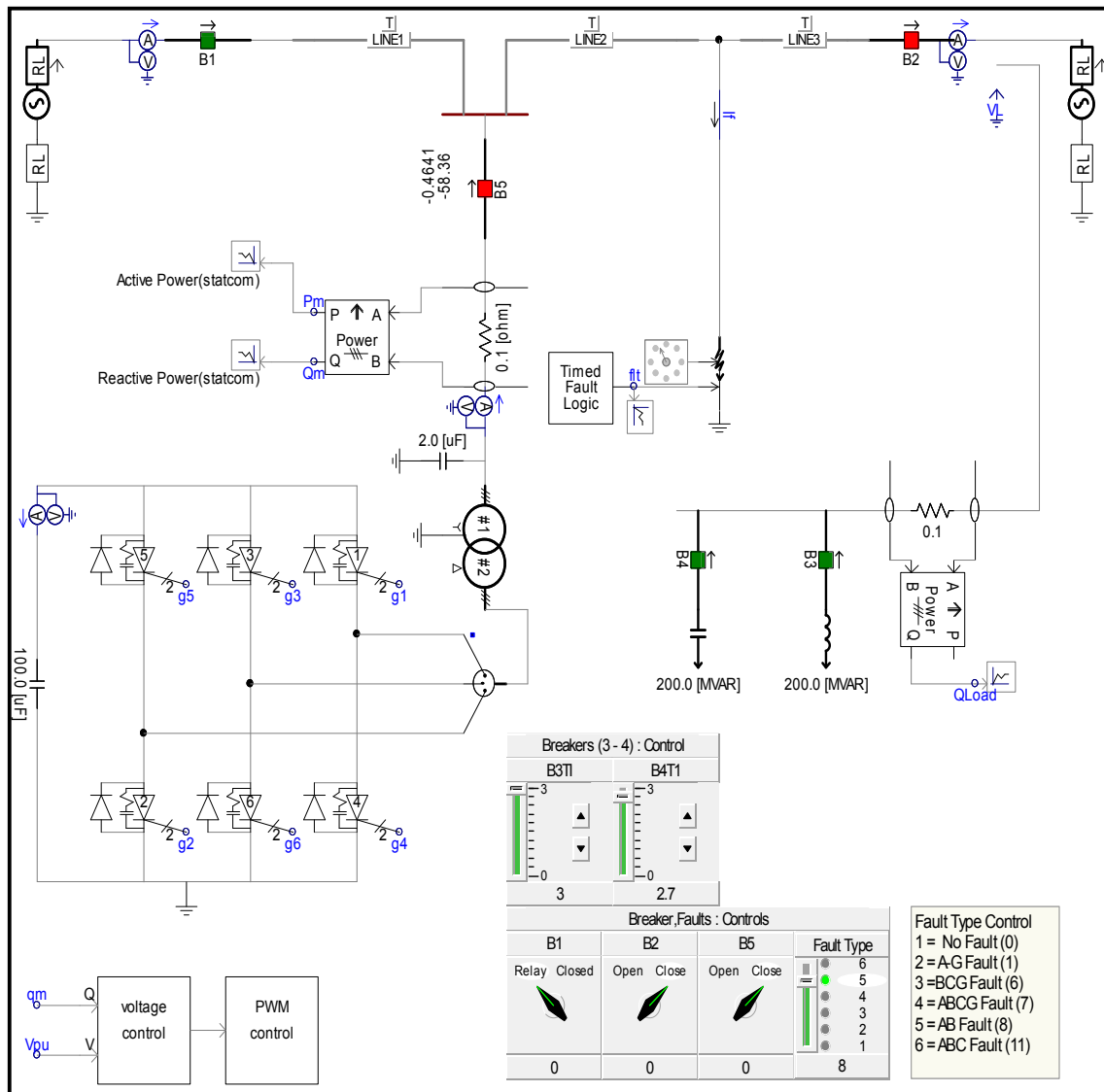


Figure 4: Test system lay-out.

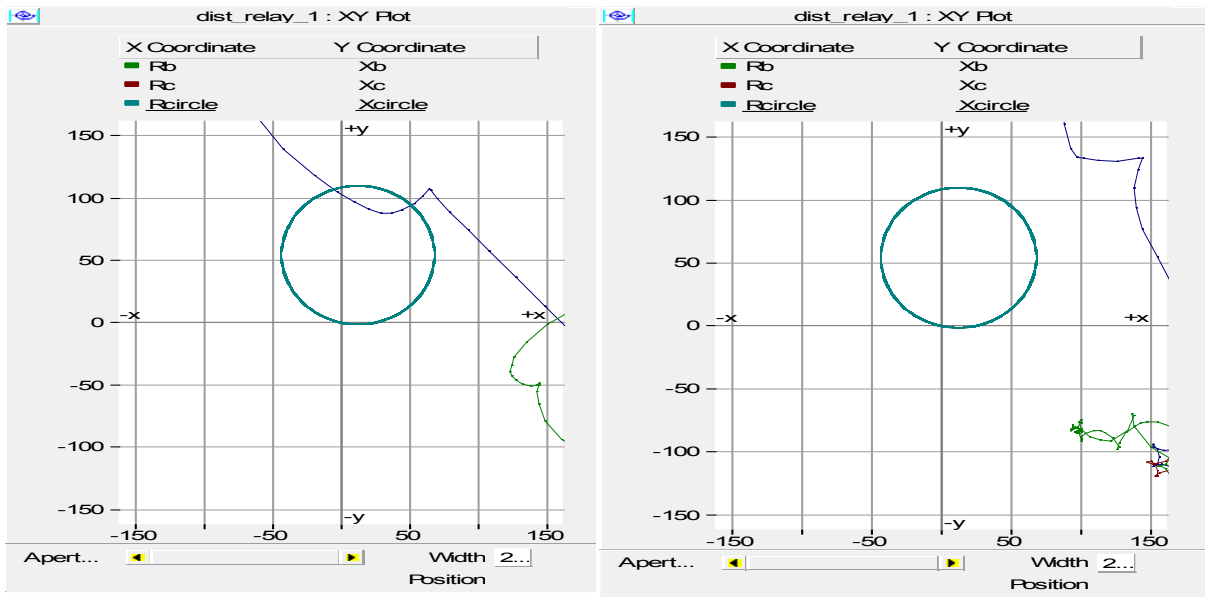


Figure 5: Phase A to ground fault at %75 length (a) without STATCOM (b) with STATCOM.

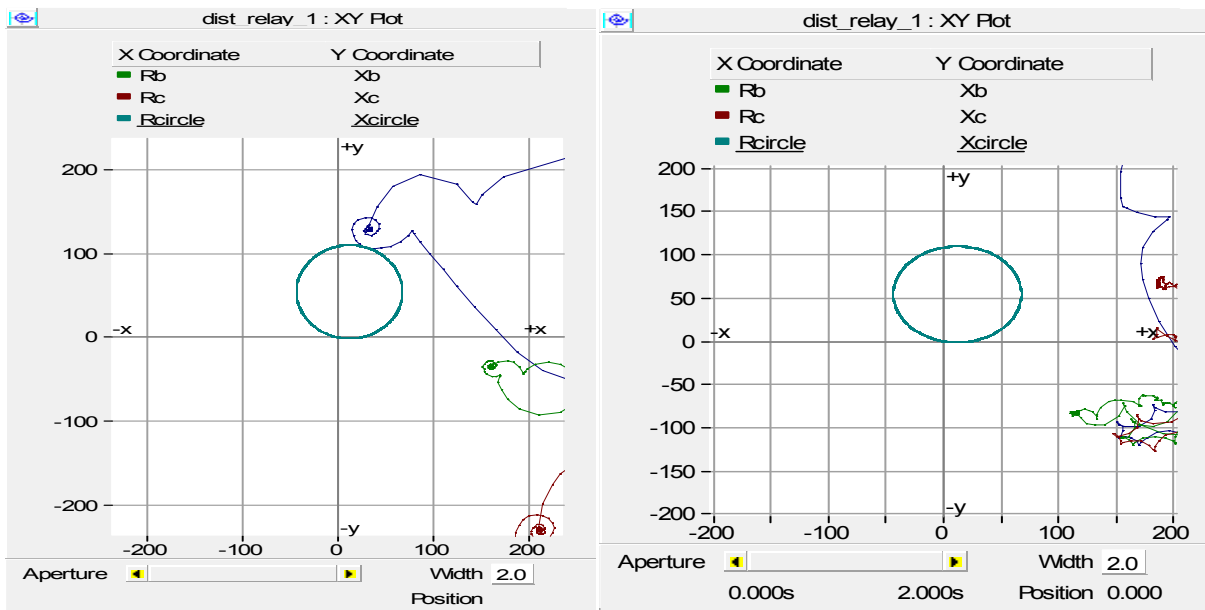
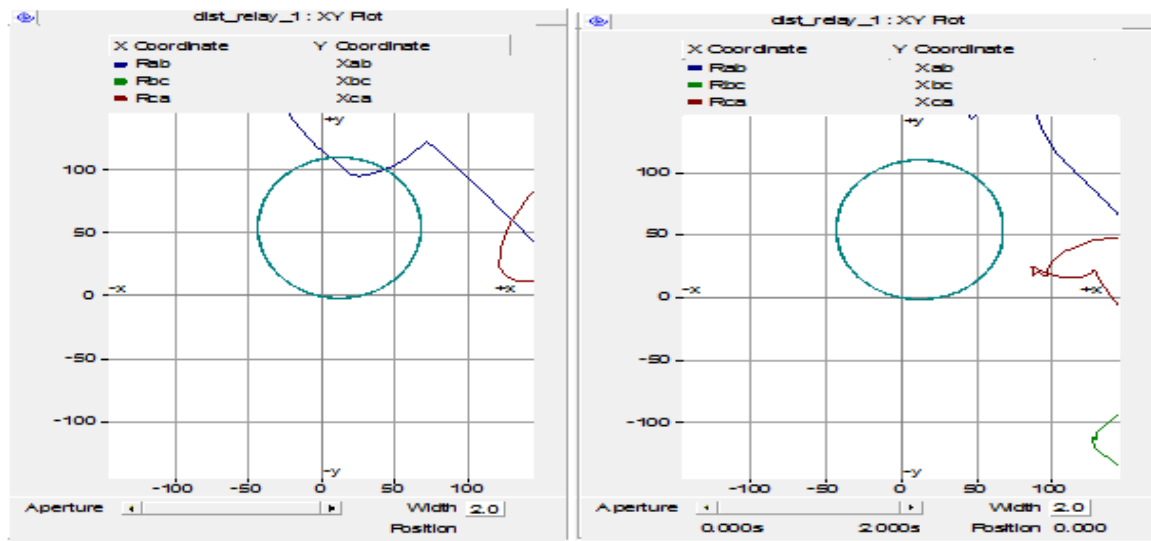
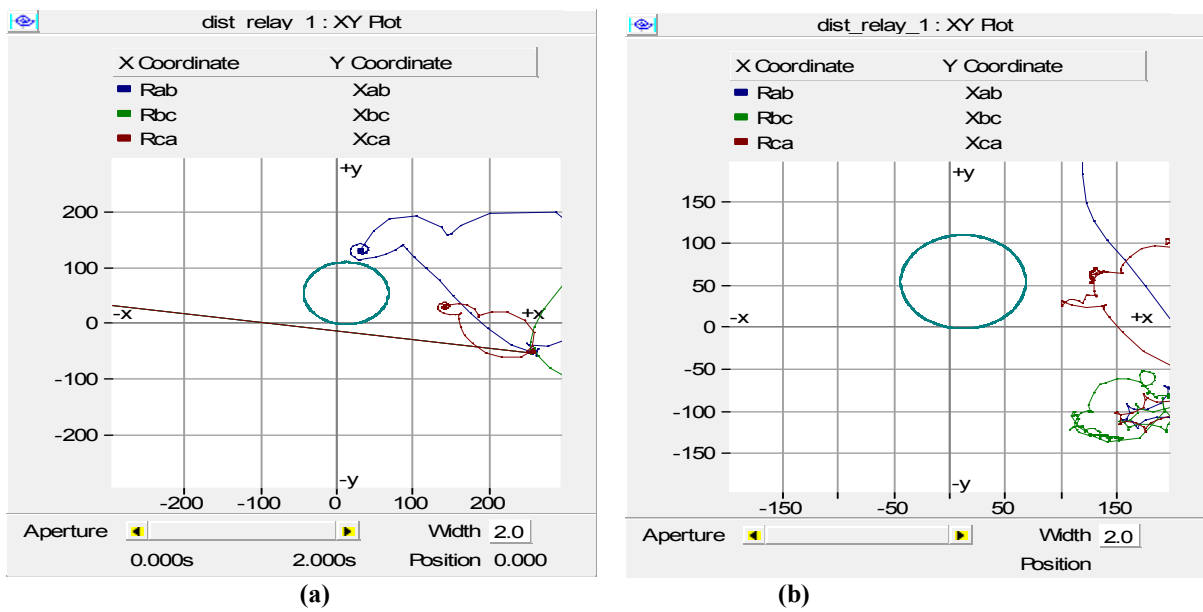


Figure 6: Phase A to ground fault at %90 length (a) without STATCOM (b) with STATCOM





(a) (b)  
 Figure 7: Phase to phase (A-B) fault at %75 length (a) without STATCOM (b) with STATCOM



(a) (b)  
 Figure 8: Phase to phase fault A-B at %90 length (a) without STATCOM (b) with STATCOM

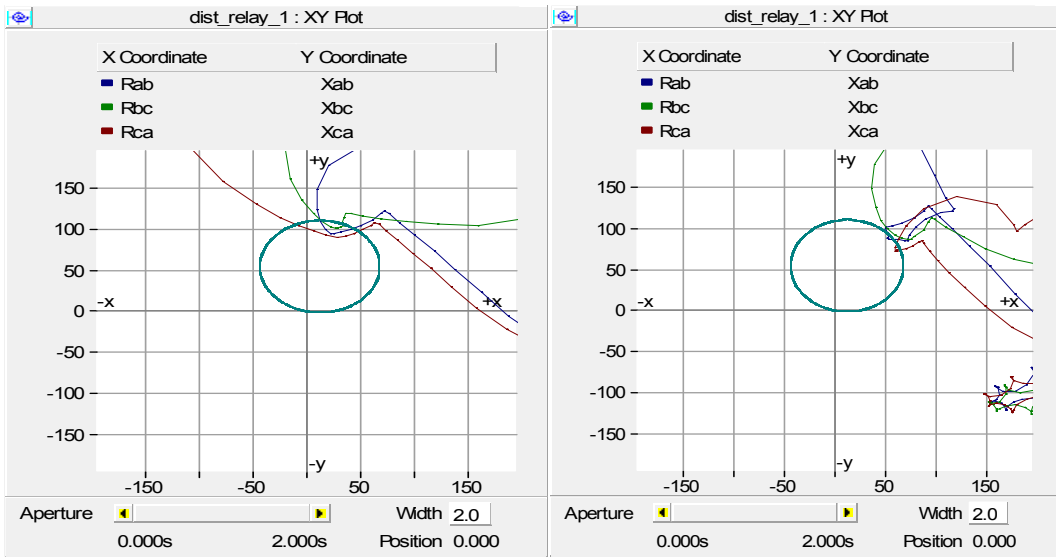


Figure9: Three phase to ground fault at % 75 lengths (a) without STATCOM (b) with STATCOM

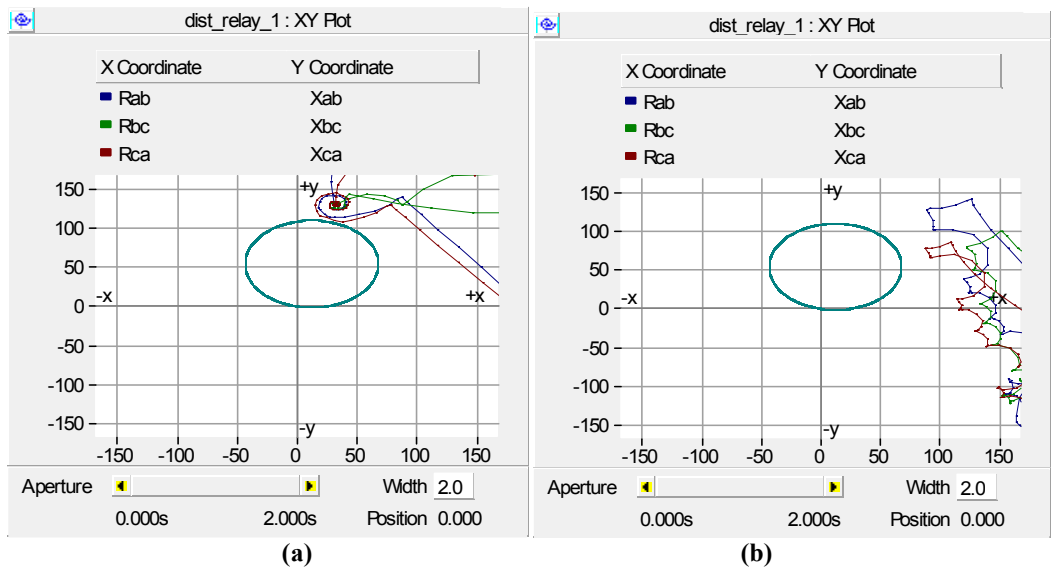


Figure 10: Three phase to ground fault at %90 length (a) without STATCOM (b) with STATCOM