Impact of Static Synchronous Compensator (STATCOM) on Performance of Distance Relay

A. Salemnia, M. Khederzadeh, *Senior Member, IEEE* and A. Ghorbani

***Abstract*-- In this paper impact of static synchronous compensator (STATCOM) on performance of distance relay is investigated both with analytic and simulation methods. At the first step the complete model of STATCOM with a 48-pulsed voltage source converter and its control circuit are described. At the next step, using analytic computations, the impact of STATCOM on the impedance calculated by the relay is investigated. Finally the impact of different factors like settings of STATCOM, type of faults, the place in which faults are occurred, load angle and the level of system short circuit on the relay impedance are examined using simulations in MATLAB/Simulink environment.**

***Index Terms*—Static Synchronous Compensator(STATCOM), Distance relay.**

I. Introduction

IT has been obvious that with a suitable parallel compensation of reactive power, transferable power increases in steady-state condition and voltage profile along the line is controlled. STATCOM is a static synchronous generator which is used for parallel compensating of reactive power and, its inductive or capacitive current can be controlled independent of system AC voltage. STATCOM produces a set of three-phase voltages which are controllable with AC power system frequency. Each output voltage couples and synchronizes with its counterpart voltage in AC system using a relating reactance which is provided by coupling generator's phase leakage inductance [1].

Distance relay is widely used in protecting transmission lines which is based on calculation of impedance existed between the relay and the place in which fault is occurred [2]. Presence STATCOM in fault loop influences the transient and steady-state voltages and currents of the system. When a fault occurs in the transmission system, severe voltage falling in the system occurs and as a result, STATCOM reacts to improve the voltage (i.e. recovering the system voltage to its setting voltage) by injecting some capacitive current to the network. The injected current interferes with the distance relay and causes some side-effects. Some previously studied effects have been investigated in [3], [4]. The effect of shunt and series FACTS devices are discussed in the aforementioned works using both analytical study and computer simulations. A comprehensive study of the impact of TCSC on performance of the distance relay in different working conditions is accomplished in [5]. In [6], impact of STATCOM on performance of distance relay is considered in which steady-state model of STATCOM is used in the simulations. The impact of shunt compensators such as SVC and STATCOM on distance protection is investigated in [7]. The results obtained in [8], scrutinizes the impact of UPFC on the distance protection which is related to STATCOM and the shunt part of UPFC. The studies done in [9], deals with the effect of the place in which STATCOM is installed on tripping characteristics of distance relay. In all the studies done in [6-9], effects of other factors such as STATCOM DC capacitor value and I_{qref} limiter in control circuit, haven't been considered in spite of the fact that these two factors play a significant role in STATCOM performance. In [8], it is claimed that the setting value of STATCOM influences the impedance calculated by the distance relay; however it is shown in this paper that the impact of STATCOM setting on the calculated impedance by the relay is negligible. Complete model of STATCOM is used in the simulations. 48-pulse voltage source converter is used in the simulation based on the fact that this kind of converter is popular in practice. Control circuit used in this paper is more practical because the STATCOM current limiter, which is used in unbalanced systems, is considered in the simulations. The impacts of some other important factors like fault location, fault type, STATCOM setting, system Short Circuit Level (SCL), system load angle and the structure of STATCOM control circuit on performance of distance relay are also considered in this paper.

II. System and STATCOM Model

The studied system and the model of STATCOM are described. STATCOM controller is also designed in this section.

A. System Model

The Single-line schematic diagram of the system under study, with the equivalent circuit of STATCOM in the mid-point of the line1 with the positive and zero sequence networks are shown in Fig. 3(the negative sequence is similar to the positive one and is omitted). The two systems are connected with 500 kV transmission lines with Short Circuit Level of 8000 MVA which the angle difference between them is $\delta = 30^{\circ}$. The positive and negative sequence line

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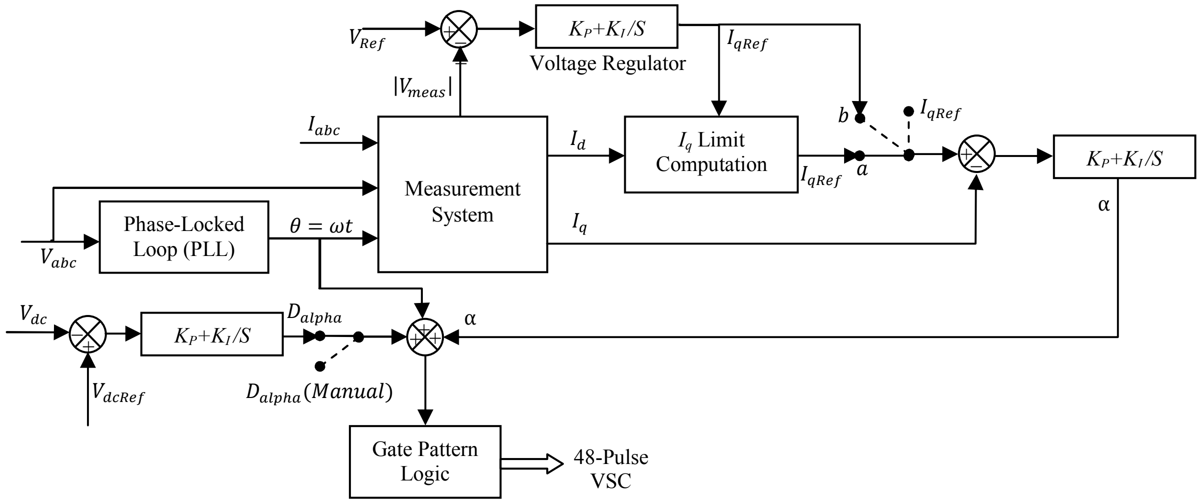

Fig. 1. Control block diagram of STATCOM

impedance is 0.0201+j0.2868 ohm/km, and the zero sequence transmission line impedance is 0.1065+j0.8671 ohm/km [10].

B. STATCOM Model with it's Control Circuit

In this paper 48-pulsed voltage source converter (VSC) is used to model the 200MVA STATCOM. In order to model the 48-pulsed VSC, four three-level converter are used which are connected to mid-point of line1 through four zig-zag 15kV/500kV transformers [1], [11]. STATCOM control circuit is shown in Fig. 1. In the Fig. 1, control inputs are AC system 3-phase voltage V_{abc}, output current of STATCOM, I_{abc}, reactive current reference I_{qRef}, reference voltage V_{Ref} (if the goal was controlling output voltage) and DC voltage reference V_{DCRef}. This DC voltage reference determines the real power the converter must absorb from the ac system in order to supply its internal losses [1]. STATCOM output current is separated to two different component, reactive current component I_q and active current component I_d. Reactive component of the current I_q is compared with reactive current reference I_{qRef}. The resulting error between the two signals after an appropriate amplification results in the α angle. This angle defines the necessary phase shift between the output voltage of the converter and the AC system voltage needed for charging (or discharging) the storage capacitor to the DC voltage level required. So, the α angle is added to θ angle to form the $\alpha + \theta$ angle which represents the desired synchronizing signal for the converter to satisfy the reactive current reference [1]. Considering the control circuit, when an unbalancy occurs in ac system (like a fault), STATCOM compensates for all three phases. This is due to its control circuit in which all three output voltages are controlled simultaneously; that is, single-phase voltage control is not applied. This operating mode provides the best VA utilization of the converter and generally the lowest harmonic generation obtainable under normal system condition’ with a given method of waveform synthesis employed [1].

Two different working states are defined for STATCOM:

1. Voltage regulating mode:

In this mode the output voltage is specified by an external controller (operator) and, STATCOM maintains its output voltage in the value of reference voltage (V_{Ref}) by absorbing or injecting reactive power. The value of I_{qRef} is obtained by the voltage regulator (Fig. 1).

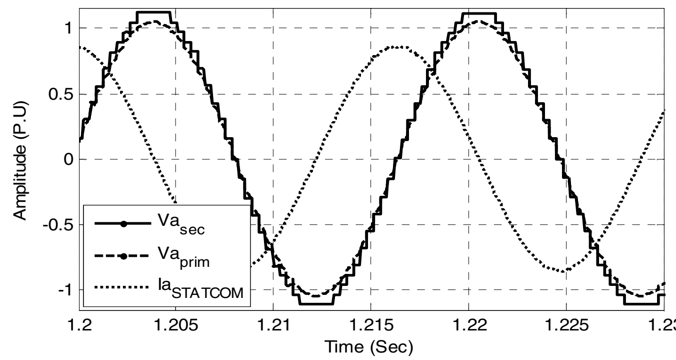

Fig. 2. 48-pulse converter output voltage (V_{asec}), AC system voltage (V_{aprim}), and output current of STATCOM ($I_{aSTACOM}$).

2. Reactive power regulating mode:

In this mode, STATCOM reactive power is hold in a fixed value and, I_{qRef} is offered directly by an external controller (Fig. 1).

For example the output of the 48-pulsed converter is shown in Fig. 2, in which V_{Ref}=1.05. Using load flow analysis, the voltage in the middle of line1, when the STATCOM is unloaded, is obtained 0.98 p.u. Therefore, reactive power must be injected by STATCOM in the middle of the line to bring the voltage to 1.05 p.u. In other words, capacitive current is to be injected to the system which is demonstrated in the Fig. 2 (Notice that when the STATCOM is operating in capacitive mode, the 48-pulse secondary voltage generated by inverters is higher than the primary voltage and in phase with primary voltage. Current is leading voltage by 90°; the STATCOM is therefore generating reactive power).

III. Analytical Study

The Single line schematic diagram of the system under study, with the STATCOM model is shown in Fig. 3. For the shown system, the midpoint of the line is the best place for being compensated because the voltage decrease during the

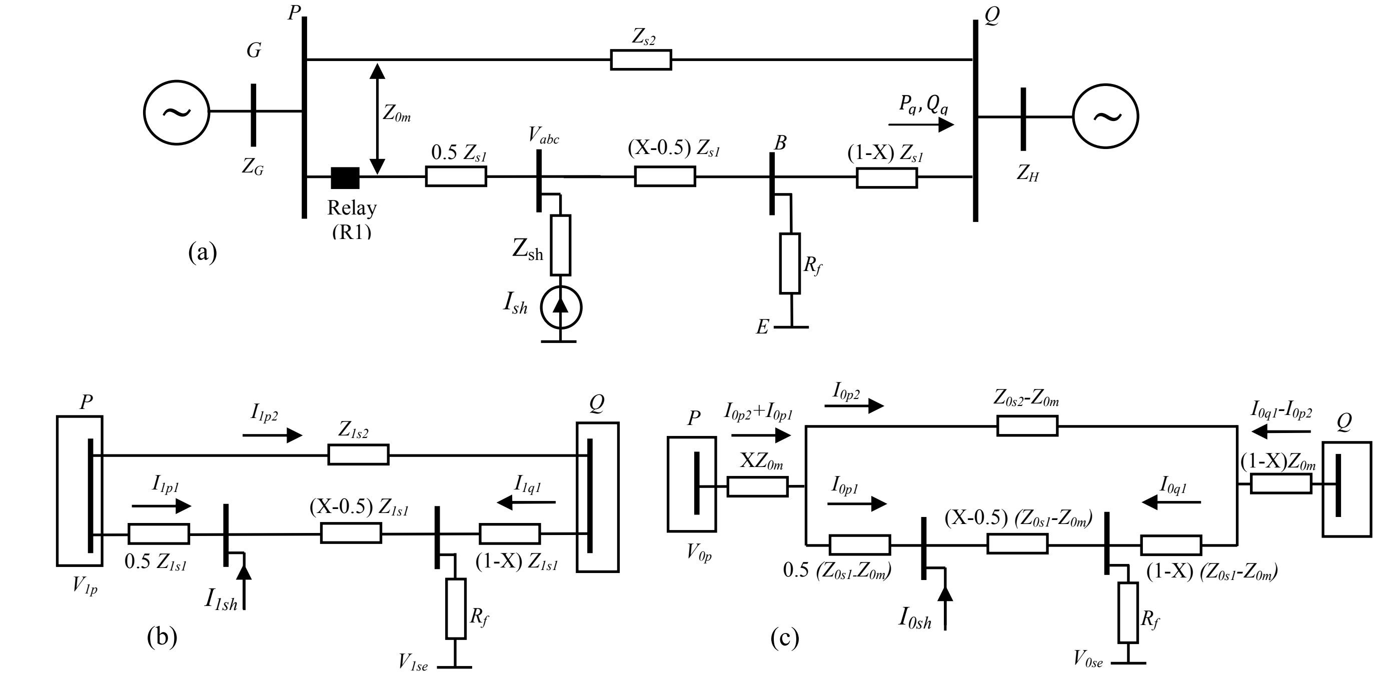

Fig. 3. Transmission system with equivalent circuit of STATCOM(a); positive sequence network(b); zero sequence network(c).

compensation has its maximum value in the midpoint [1]. It is supposed that a fault has been occurred at point *B* where its distance to R1 relay is *X*. As explained earlier the direction of the STATCOM current is considered injective to the system. Some definitions are used in the investigations:

V_p: is phase voltage at relay location at bus *P*;

I_{p1}: is phase current through faulty line at relay location at bus *P*;

I_{p2}: is phase current through sound line at relay location at bus *P*;

V_{0p}, V_{1p}, V_{2p}: are sequence phase voltages at relay location at bus *P*;

I_{0p1}, I_{1p1}, I_{2p1}: are sequence phase currents through faulty line at relay location at bus *P*;

I_{0p2}, I_{1p2}, I_{2p2}: are sequence phase currents through sound line at relay location at bus *P*;

I_{0q1}, I_{1q1}, I_{2q1}: are sequence phase currents through faulty line at bus *Q*;

I_{0sh}, I_{1sh}, I_{2sh}: are sequence phase currents of the STATCOM;

V_{0se}, V_{1se}, V_{2se}: are sequence phase voltages at fault location *E*;

R_f : is fault resistance;

Z_{0s1}, Z_{1s1}, Z_{2s1}: are sequence impedances of the faulty line and Z_{1s1}=Z_{2s1}.

Z_{0s2}, Z_{1s2}, Z_{2s2}: are sequence impedances of the sound line and Z_{1s2}=Z_{2s2}.

Z_{0m}: is the zero sequence mutual impedance between the faulty and sound lines.

Z_{0G}, Z_{1G}, Z_{2G}, Z_{0H}, Z_{1H}, Z_{2H}: are sequence impedance of generators *G* and *H* respectively [12].

Considering the positive sequence shown in Fig. 3, it can be written:

$$V_{1p} = xZ_{1s1}I_{1p1} + (x-0.5)Z_{1s1}I_{1sh} + R_f(I_{1p1} + I_{1sh} + I_{1q1}) + V_{1se} \quad (1)$$

$$V_{1p} = Z_{1s2}I_{1p2} + (1-x)Z_{1s1}I_{1q1} + R_f(I_{1p1} + I_{1sh} + I_{1q1}) + V_{1se} \quad (2)$$

By eliminating the term V_{1se}, from 1 and 2, the following equation is obtained:

$$I_{1q1} = \frac{x}{1-x}I_{1p1} + \frac{(x-0.5)}{(1-x)}I_{1sh} - \frac{k_1}{1-x}I_{1p2} \quad (3)$$

Where:

$$k_1 = Z_{1s2}/Z_{1s1} \quad (4)$$

By substituting (3), in (1), the following equation is obtained:

$$V_{1p} = xZ_{1s1}I_{1p1} + (x-0.5)Z_{1s1}I_{1sh} + R_f\left(\frac{1}{1-x}I_{1p1} + \frac{0.5}{1-x}I_{1sh} - \frac{k_1}{1-x}I_{1p2}\right) + V_{1se} \quad (5)$$

In the same way for negative sequence:

$$V_{2p} = xZ_{1s1}I_{2p1} + (x-0.5)Z_{1s1}I_{2sh} + R_f\left(\frac{1}{1-x}I_{2p1} + \frac{0.5}{1-x}I_{2sh} - \frac{k_1}{1-x}I_{2p2}\right) + V_{2se} \quad (6)$$

Similar to for zero sequence:

$$V_{0p} = xZ_{0m}I_{0p2} + xZ_{0s1}I_{0p1} + (x-0.5)(Z_{0s1} - Z_{0m})I_{0sh} + V_{0se} + R_f\left(\frac{1}{1-x}I_{0p1} + \frac{0.5}{1-x}I_{0sh} - \frac{k_0}{1-x}I_{0p2}\right) + V_{0se} \quad (7)$$

Where:

$$k_0 = (Z_{0s2} - Z_{0m})/(Z_{0s1} - Z_{0m}) \quad (8)$$

For the parallel lines with identical parameters, $k_l = k_0 = 1$. For an A-G fault, the boundary condition is:

$$V_{0se} + V_{1se} + V_{2se} = 0 \quad (9)$$

From (2), (6), (7) and (9), the voltage at the relay point can be derived as:

$$V_p = x\big(Z_{1s1}I_{p1} + (Z_{0s1} - Z_{1s1})I_{0p1} + Z_{0m}I_{0p2}\big) + \frac{R_f}{(1-x)}\big(I_{p1} - k_1 I_{p2} + (k_1 - k_0)I_{0p2}\big) + \Delta V \quad (10)$$

Where:

$$V_{0p1} + V_{1p1} + V_{2p1} = V_p \quad (11)$$
$$I_{0p1} + I_{1p1} + I_{2p1} = I_{p1}$$
$$I_{0p2} + I_{1p2} + I_{2p2} = I_{p2}$$

And:

$$\Delta V = (x - 0.5)Z_{1s1}I_{sh} + (x - 0.5)(Z_{0s1} - Z_{1s1} - Z_{0m})I_{0sh} + R_f\frac{0.5}{(1-x)}I_{sh} \quad (12)$$

In the transmission system without STATCOM, for a single phase-to-ground fault, the apparent impedance of distance relay can be calculated using the following equation:

$$Z = \frac{V_p}{I_{p1} + ((Z_{0s1} - Z_{1s1})/Z_{1s1})I_{0p1}} = \frac{V_p}{I_{Relay}} \quad (13)$$

When the STATCOM is in the middle of line1, V_p in (13) will be as in (10). Therefore, the impedance value calculated by the relay when STATCOM is installed can be obtained as:

$$Z = xZ_{1s1} + xZ_{0m}\frac{I_{0p2}}{I_{Relay}} + \frac{R_f}{(1-x)I_{Relay}}\big(I_{p1} - k_1 I_{p2} + (k_1 - k_0)I_{0p2}\big) + \Delta Z \quad (14)$$

Where:

$$\Delta Z = (x - 0.5)Z_{1s1}\frac{I_{sh}}{I_{Relay}} + (x - 0.5)(Z_{0s1} - Z_{1s1} - Z_{0m})\frac{I_{0sh}}{I_{Relay}} + R_f\frac{0.5}{(1-x)}\frac{I_{sh}}{I_{Relay}} \quad (15)$$

It can be inferred from the (15) that the STATCOM cause to increase the value of apparent impedance calculated by the relay under the condition that during the fault the value of voltage decrease was in a level in which the system voltage would be lower than V_{Ref} of the STATCOM to compel the STATCOM to inject reactive power. This condition is a practical one and occurs frequently in practice.

IV. Relay Modeling

A procedure for designing a fault impedance estimation algorithm for distance protection is discussed in this section. Positive, negative and zero sequence networks of the system experiencing the fault from the relay located near bus *P* and various shunt fault conditions were used to derive the performance (16) where in (16) and the coefficients S_1, S_2, and S_0, are listed in Table 1 (a=-0.5+j0.866 and a^2=-0.5-j0.866) [13]. Also note that e_r is the error term in the estimation of the distance due to fault resistance and STATCOM.

$$X = \frac{S_1V_{1p} + S_2V_{2p} + S_0V_{0p}}{S_1I_{1p1}Z_{1s1} + S_2I_{2p1}Z_{1s1} + S_0(I_{0p1}Z_{0s1} + I_{0p2}Z_{0m})} + e_r \quad (16)$$

A digital distance relaying algorithm proposed by the authors use the phasor estimates, sequence components of phasors and fault classification scheme [14], before calculating fault distance where its basic modules are shown Fig. 4. The measured voltages and currents at the relay point are sampled at 32 samples per cycle.

The simulation results are analyzed in the next section. Impact of the place in which fault occurs is considered in the all sections.

V. Simulation Results

A. Impact of System Short Circuit Level (SCL)

Impact of compensator on the calculations done by distance relay is significant for weak systems. In other words, line voltages for weak systems are weaker in comparison with strong systems. For example, the impedance calculated by R1 relay for a A-G fault occurred in 150km from R1 relay, for the system with SCL=1500MVA and V_{Ref}=1 is shown in Fig.5.

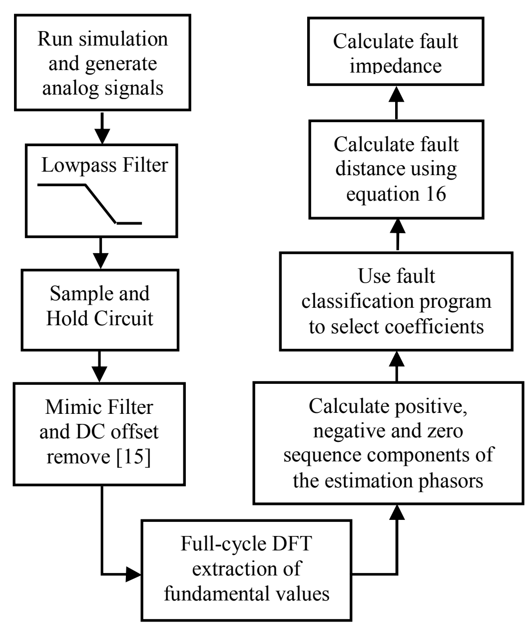

Fig. 4. Basic modules of distance relaying.

TABLE I
FAULT TYPE COEFFICIENT OF EQUATION 20

Fault type	*Equation 20* S_1	S_2	S_0
A-G	1	1	1
B-G	a^2	a	1
A-B	1	$-a$	0
A-B-G	a	0	-1

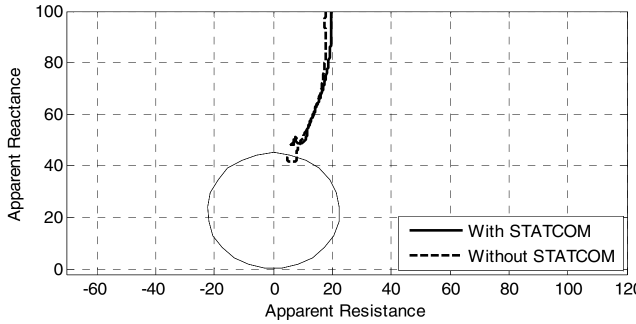

Fig. 5. Apparent impedance seen by the relay (A-G fault and with/without STATCOM (fault distance =150 km)).

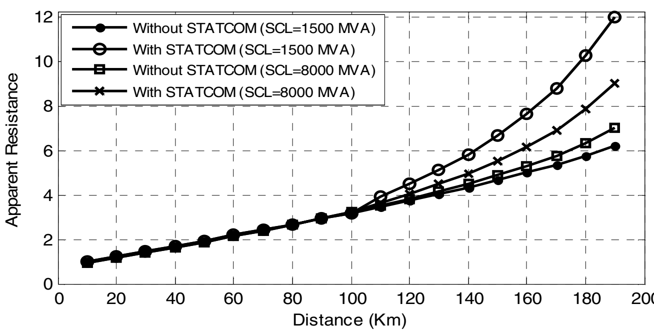

Fig. 6. Apparent resistance with different fault location (A-G fault and with/without STATCOM and different system SCL).

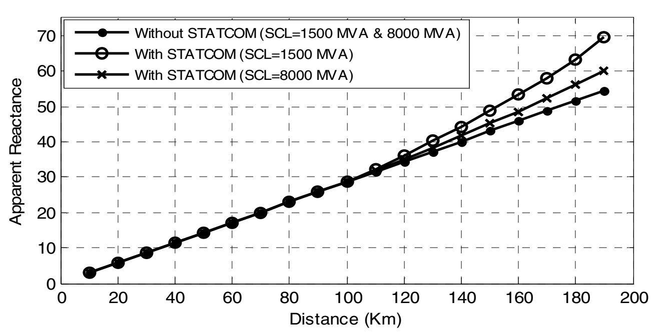

Fig. 7. Apparent reactance with different fault location (A-G fault and with/without STATCOM and different system SCL).

As expected, STATCOM has increased the values of apparent resistance and apparent reactance. This increase in the apparent impedance cause the relay to see the fault beyond the place it really is and as a result the relay will not react to the occurred fault. To study the impact of the fault location, apparent resistance and apparent reactance for different fault location and for system with SCL=1500 and 8000 MVA are shown in figures 6 and 7, respectively. As expected, impact of STATCOM on the system with SCL=8000 MVA is less than the one with SCL=1500 MVA. For the faults occurred in a distance less than 100km (in the left side of the STATCOM) STATCOM is not within the fault loop and therefore, hasn't any impact on the impedance. It is also observed that the farther the distance the more the impact on the calculated impedance [7].

B. Impact of Load angle

Like the previous section, the simulation result for different fault locations of A-G fault and V_{Ref}=1 for the system with

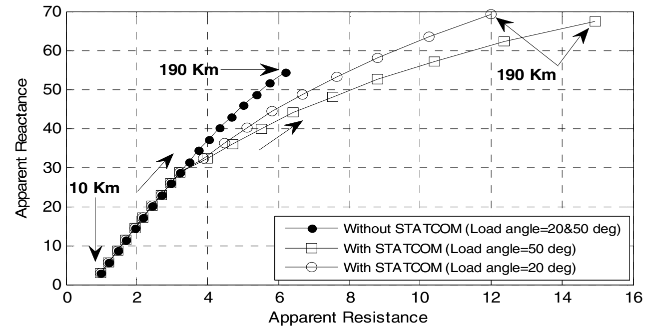

Fig. 8. Apparent impedance seen by the relay for different fault location (A-G fault and with/without STATCOM and different load angle).

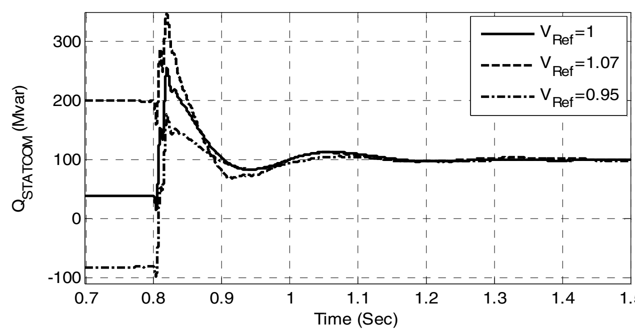

Fig. 9. STATCOM reactive power injection with different STATCOM setting.

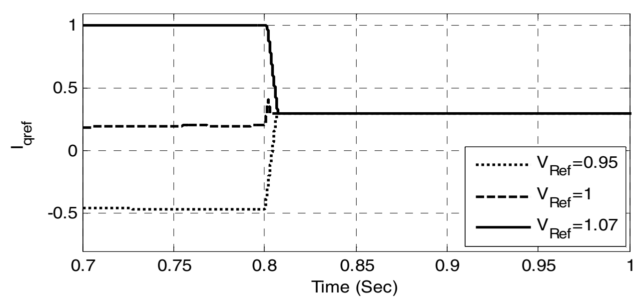

Fig. 10. I_{qref} with different STATCOM setting.

SCL=1500MVA is shown in Fig. 8. From the results obtained from Fig. 8, it can be observed that by increasing load angle the value of R/X in the calculated impedance by the relay is going to be increased.

C. Impact of STATCOM Setting

Depending on the system condition, STATCOM may have different settings. When a fault transition occurs in system, the system voltage during the fault decreases significantly and therefore, the system voltage is below V_{Ref} during the fault. STATCOM has to produce reactive power to compensate the voltage, independent of its setting. The simulation results for three different STATCOM settings containing V_{Ref} = 0.95, 1, 1.07 p.u., for an A-G fault occurred in a place 150km away from R1 relay, are shown in figures 9 and 10. As shown in Fig. 9, before the fault occurrence at t=0.8 sec, when V_{Ref} =1.07 p.u the STATCOM has injected its maximum rated VA (200MVA) to the network and as a result the system voltage only increased to 1.054. This is the reason that I_{qref} has limited in its maximum value (1 p.u.). It can observed from Fig. 9 that, after the A-G fault, STATCOM produces reactive power

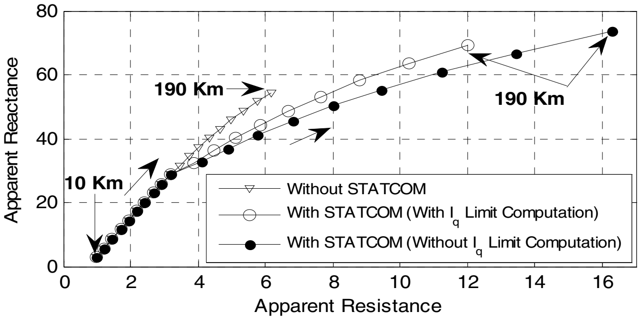

Fig. 11. Apparent impedance seen by the relay for different fault location (A-G fault and with/without STATCOM).

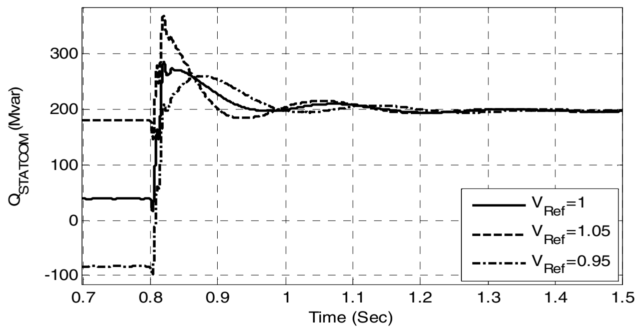

Fig. 12. STATCOM reactive power injection with different STATCOM setting.

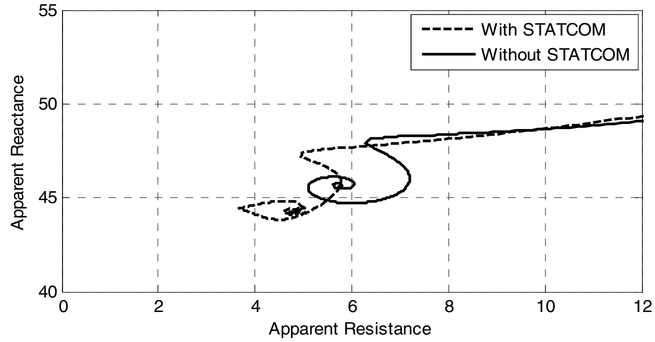

Fig. 13. Apparent impedance seen by the relay (A-G fault and with/without STATCOM (fault distance =150 km)).

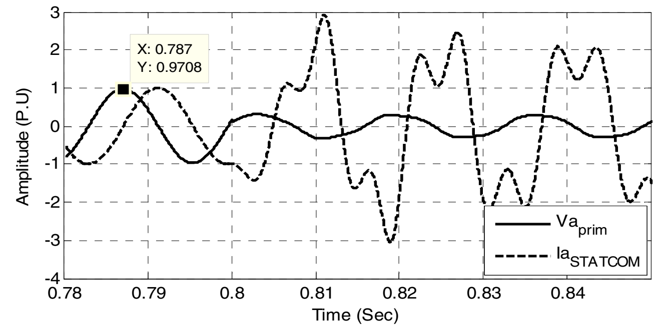

Fig. 14. AC system voltage (V_{aprim}) and output current of STATCOM ($I_{aSTACOM}$).

in all three conditions. however; there might be an issue about the injected reactive power, why STATCOM refused to inject its maximum power (200MVA) to the network and, it injected only about 100MVA in all three working conditions? It can be justified by I_{qref} signal. As shown in Fig. 10, after the fault, the value of I_{qref} has been 0.3 p.u (instead of 1 p.u). The reason is the block named Iq limit computation in the STATCOM controller diagram (Fig. 1) which has a feedback from I_d. In normal working condition, I_d has a very low value. After the fault occurrence its value increases due to the asymmetry caused in the system. On the other hand $\sqrt{I_d{}^2 + I_q{}^2}$ must be lower than a specific value (which is considered 1.05 in this paper). Therefore, the I_{qref} limiter limits the I_{qref} value considering the calculated I_{qref} and the value of I_d. During the fault, the value of I_d increases and, it isn't controllable. Conversely I_{qref} is controllable and, therefore to satisfy $\sqrt{I_d{}^2 + I_q{}^2} < 1.05$ condition, I_{qref} has been limited instead of becoming 1 p.u. (the minimum of this signal is considered 0.3 in this paper). Consequently, STATCOM has a similar impact in all three settings.

D. Impact of STATCOM I_{qref} Limit Computer

In this section like most of the researches [6-9], it is supposed that the STATCOM hasn't any I_{qref} limiter in its control circuit represented in Fig. 1. In other words it is supposed that output of the voltage regulator goes directly into the current regulation section. Like the studies in the previous sections, the value of calculated impedance by R1 relay for the system with SCL=1500MVA, A-G fault and different fault locations is shown in Fig. 11. It can be seen from the figure that, without the limiter, STATCOM has a more impact and, this is obvious because after the fault occurrence, STATCOM injects 200MVA to compensate the voltage. Therefore, its impact on the impedance calculated by R1 relay will be more than the condition of having a I_{qref} limiter. The aforementioned impact is greater for the systems with a lower SCL.

In this section the impact of STATCOM setting when the I_{qref} limiter isn't in the circuit is considered. STATCOM reactive power for three different STATCOM settings containing V_{Ref}= 0.95, 1, 1.07 p.u., for a A-G fault occurred in a place 150km away from R1 relay, is shown in Fig. 12. It can be observed that STATCOM injects 200MVA reactive power to the network independent of its setting. Therefore, the STATCOM setting hasn't a significant impact on the calculated impedance because it injects a unique (its maximum value) amount of reactive power in all settings.

There is a condition in which STATCOM causes the relay to see the fault closer than it really is. It happens when STATCOM absorbs reactive power from the system. If the system voltage was above the reference voltage after the fault STATCOM has to absorb reactive power to compensate the voltage exceeds. To such a condition, the system SCL must be a high value and conversely, the reference voltage (V_{Ref}) must be a low value.

The simulation results for the system with SCL=20000 MVA and V_{Ref}=0.8 for a A-G fault occurred 160km away from R1 relay, are shown in figures 13 and 14. As shown in Fig. 14, STATCOM absorb inductive current even after the fault occurrence.

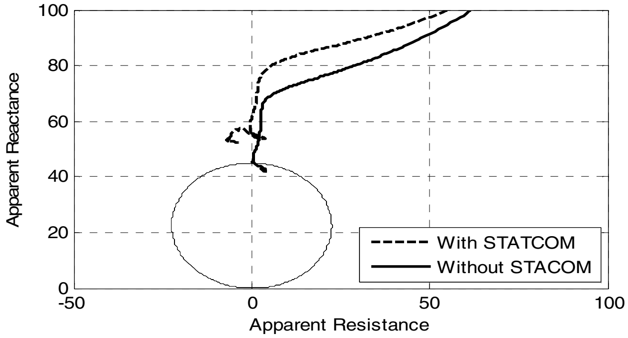

Fig. 15. Apparent impedance seen by the relay (A-B fault and with/without STATCOM (fault distance =150 km)).

E. The Effect Phase to phase fault

In this section, the impedance calculated by R1 relay for two phase faults A-B is investigated. For an A-B fault, the boundary condition is:

$$V_{1se} = aV_{2se} \quad (17)$$

By substituting (17), in (5) and (6), the following equation is obtained:

$$V_{1p} - aV_{2p} = xZ_{1s1}(I_{1p1} - aI_{2p1}) + (x - 0.5)Z_{1s1}(I_{1sh} - aI_{2sh}) + \frac{R_f}{1 - x}\left((I_{1p1} - aI_{2p1}) + 0.5(I_{1sh} - aI_{2sh}) + K_1(aI_{2p2} - I_{1p2})\right) \quad (18)$$

In the transmission system without STATCOM, for a A-B fault, the apparent impedance of distance relay can be calculated using the following equation:

$$Z = \frac{V_{1p} - aV_{2p}}{I_{1p1} - aI_{2p1}} = \frac{V_{1p} - aV_{2p}}{I_{Relay}} \quad (19)$$

When the STATCOM is in the middle of line1, $V_{1p} - aV_{2p}$ in (19) will be as in (18). Therefore, the impedance value calculated by the relay when STATCOM is installed can be obtained as:

$$Z = xZ_{1s1} + (x - 0.5)Z_{1s1}\frac{(I_{1sh} - aI_{2sh})}{I_{Relay}} + \frac{R_f}{(1 - x)I_{Relay}}\left((I_{1p1} - aI_{2p1}) + 0.5(I_{1sh} - aI_{2sh}) + K_1(aI_{2p2} - I_{1p2})\right) \quad (20)$$

For a A-B fault occurred in 150km away from R1 relay, the calculated impedance is demonstrated in Fig. 15. Like the previous sections, impact of the fault location is investigated. The impedance calculated by R1 relay for different distances of the fault, is shown in Fig. 16. It can be observed that impact of STATCOM is greater for A-B fault than the one for A-G fault and during a phase to phase fault, the apparent reactance increases but the apparent resistance decrease. Like the A-G fault, impact of STATCOM is greater for the systems with lower SCL.

There some special cases in which STATCOM cause the both the phase-to-phase element and the single phase-to-ground relay elements will see the fault as an internal fault.

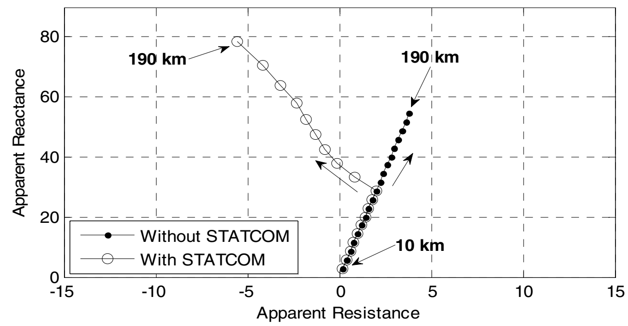

Fig. 16. Apparent impedance seen by the relay for different fault location (A-B fault and with/without STATCOM and system SCL=8000 MVA).

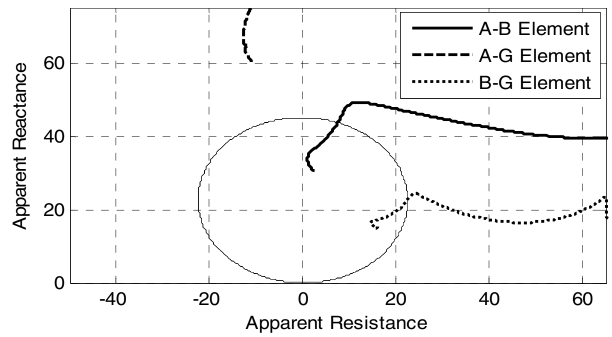

Fig. 17. Apparent impedance seen by the different relay elements (A-B fault and with/without STATCOM (fault distance =105 km)).

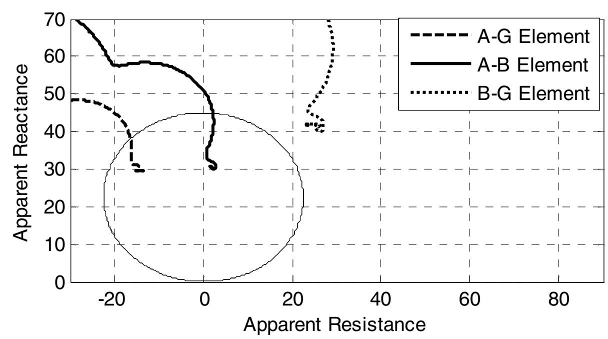

Fig. 18. Apparent impedance seen by the different relay elements (A-B fault and with/without STATCOM (fault distance =105 km)).

For example for the system with SCL=15000MVA and $\delta = 80^{\circ}$ when a A-B fault is occurred in a place 105km away from R1 relay, B-G factor wrongly recognizes a fault within the protected region which is demonstrated in Fig. 17 and for the system with SCL=20000MVA and $\delta = -80^{\circ}$ when a A-B fault is occurred in a place 105km away from R1 relay, A-G factor wrongly recognizes a fault within the protected region which is demonstrated in Fig. 18.

VI. CONCLUSION

In this paper, impact of STATCOM on performance of distance relay has been investigated. The obtained results are summarized here:

1. If during the A-G fault the system voltage positive sequence at the place where STATCOM is installed, was less than $V_{Ref,}$ STATCOM cause to increase the resistance and reactance of apparent impedance, calculated by the relay, by injecting reactive power to

the network.

2. Impact of STATCOM is greater for farther faults.
3. The more the load angle the more the value of R/X calculated by the relay.
4. STATCOM setting (V_{Ref}) hasn't any significant impact on the impedance calculated by the relay.
5. Existence of the I_{qref} limiter in the STATCOM control circuit cause to decrease the impact of STATCOM on distance protection.
6. When SCL of the system was high and V_{Ref} was low in an order in which value of the system positive sequence was greater than V_{Ref} during the fault, STATCOM absorb reactive power and cause to decrease the apparent impedance.
7. For A-B fault like A-G fault, STATCOM cause to increase the apparent reactance but conversely A-G fault the apparent resistance decrease .

VII. References

[1] A. N. G. Hingorani and L. Gyugyi, *Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems*, New York: IEEE Press, 2000.

[2] , *Power System Protection*, Vol. 2. Edited by The Electricity Training Association.

[3] M. Khederzadeh, "The impact of FACTS device on digital multifunctional protective relays," in Proc. *IEEE/PES Transmission and Distribution Conf. and Exhib. 2002*: *Asia Pacific*, vol. 3, Oct. 6–10, 2002, pp. 2043–2048.

[4] P. K. Dash, A. K. Pradhan, G. Panda, and A. C. Liew, "Digital protection of power transmission lines in the presence of series connected FACTS devise," in *Proc. IEEE Power Engineering Soc. Winter Meeting*, vol. 3, Jan. 23–27, 2000, pp. 1967–1972.

[5] M. Khederzadeh, and T. S. Sidhu, "Impact of TCSC on the protection of transmission Lines," *IEEE Trans. Power Delivery*, vol. 21, no. 1, pp. 80–87, Jan. 2006.

[6] K. El-Arroudi, G. Joos, and D. T. McGillis, "Operation of Impedance Protection Relays with the STATCOM," *IEEE Trans. Power Delivery*, vol. 17, no. 2, pp. 381–387, Apr. 2002.

[7] T. S. Sidhu, R. K. Varma, Pradeep Kumar Gangadharan, "Performance of Distance Relays on Shunt—FACTS Compensated Transmission Lines," *IEEE Trans. Power Delivery*, vol. 20, no. 3, pp. 1837–1845, Jul. 2005.

[8] X. Zhou, H. Wang, R. K. Aggarwal, and P. Beaumont, "Performance Evaluation of a Distance Relay as Applied to a Transmission System With UPFC," *IEEE Trans. Power Delivery*, vol. 21, no. 3, pp. 1137–1147, Jul. 2006.

[9] A. Kazemi, S. Jamali, and H. Shateri, "Effects of STATCOM on Distance Relay Tripping Characteristic," *IEEE/PES Transmission and Distribution Conference & Exhibition*: Asia and Pacific Dalian, China, 2005.

[10] P. K. Dash, A. K. Pradhan, Ganapati Panda, and A. C. Liew, "Adaptive Relay Setting for Flexible AC Transmission Systems (FACTS)," *IEEE Trans. Power Delivery*, vol. 15, no. 1, pp. 38–43, Jan. 2000.

[11] M. S. El-Moursi and A. M. Sharaf, "Novel Controllers for the 48-Pulse VSC STATCOM and SSSC for Voltage Regulation and Reactive Power Compensation," *IEEE Trans. Power Syst*, vol. 20, no. 4, pp. 1985–1997, Nov. 2005.

[12] Y. Liao and S.Elangovan, "Digital distance relaying algorithm for first-zone protection for parallel transmission lines," *IEE Proc.-Gener. Transm. Distrib*, vol. 145, no. 5, pp. 53-536, Sep 1998.

[13] D. L. Waikar, S. Elangovan, and A. C. Liew, "Fault Impedance Estimation Algorithm for Digital Distance Relaying," *IEEE Trans. Power Delivery*, vol. 9, no. 3, pp. 1375–1383, Jul. 1994

[14] M. S. Sachdev, and S. R. Kolla, "A polyphase digital distance relay," *Transactions of the Engineering and Operating Division, Canadian Electrical Association*, vol. 26, part 4, no 87-SP-170, pp. 1-19, Mar. 1987.

[15] G. Benmouyal, "Removal of DC-offset in current waveforms using digital mimic filtering," *IEEE Trans. Power Delivery*, vol. 10, no. 2, pp. 621–630, Apr. 1995.