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The effect of STATCOM controller on the opration of Distance relay under selected fault conditions for a part of the Libyan network

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Abstract— Flexible AC Transmission Systems (FACTS) devices can impact the performance of existing protective system components (specifically distance relays) due to the fact that FACTS change power system quantities Distance relay may mal-operate when FACTS devices are connected since they cause some of the tripping characteristics to change. In this paper, the effect of the most selected errors on the operation of the distance protection system was studied, in the presence of STATCOM compensators on a part of the Libyan network (southern Libyan). And to complete this, the Neplan program approved by the Libyan Electricity Company was used, and it was reached the results are discussed.

Keywords— Distance relays, Power system protection, FACTS controllers, STATCOM.

I. INTRODUCTION

The Libyan electrical power system is fed by many power plants, through a 220KV and 400KV high voltage grid systems, which is covered all Libyan areas. This large grid is Protected by protective devices. One of these devices is distance relay that is installed on transmission line.

Interlocking FACTS controllers/devices in transmission and distribution lines opens up new challenges in line protection as they change the voltage and current signals at the relay point in both steady state and transient conditions. Consequently, the operation of distance relays, In the presence of FACTS devices affects. the voltage and current values in both steady and transient state as well as the impedance seen by distance relay will be affected. Many researchers investigated the FACTS devices impact on performances of distance relays.

the apparent impedance calculation for single line to ground fault based on symmetrical components of voltages and currents at relay location. Their simulation results have shown the impact Static Synchronous Shunt Compensator (STATCOM) on measured impedance for single line to ground and double line fault with capacitive and inductive compensation. They found that the apparent impedance will increase when the STATCOM generates reactive power and decrease if the STATCOM consumes reactive power, and when the fault location increased, the error in measuring impedance and the influence ratio of STATCON will increase. Effects of two types of shunt controller FACTS devices, namely the static synchronous shunt compensator and static VAR compensator, is presented in [1] shunt controllers were presented as shunt reactance to calculate the transmission line impedance and they used artificial neural network for detecting and classifying the faults. SVC and STATCOM can cause under-reach and incorrect phase selection. Also, this work discussed the over-reach phenomena caused by employing STATCOM in weak systems only. The results showed the distance relay is not the best relay in a mid-point STATCOM connected transmission line. In addition, STATCOM caused incorrect phase selection and increased the operation time of distance relay. were reported in[2] new setting rule of the zones of distance relay to mitigate STATCOM effects when it's connected in a mid-point. The suggested setting rules are based on the simulation results to mitigate the error in impedance measurement. Different setting rules for under-reach and over-reach are proposed in this work is presented in [3].

Several reasons and events in our daily lives can cause a fault to occur in power system. However, the most common factors are well recognized and are usually classified into two classes based on the causing factors, are called natural factor and human factors. These factors affect the performance of distance relay that is connected on transmission line, also the distance relay performance is affected by interconnecting new devices (FACTS) in the protected transmission line. It is very important 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, the review of the past research comprehensive literature review is not given covering for effect of fault types on operation distance relay when STATCOM was installed This paper presents a study on the performance of lines, and distance protection relays when integrated within protect compensated transmission STATCOM [3, 4,and 5].

II. FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

Flexible alternating current transmission systems (FACTS) technology opens up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. Series controllers affect directly on the voltage, current, and power flow, therefore using series-connected for controlling current/power flow and damping oscillations is much useful than shunt connected. Shunt controllers is the best FACTS controller for voltage control and voltage oscillations around the point of connection. The series controllers can be used for some shunt applications and vice versa. Regulating voltage at substation bus using shunt controller is more effective while compensating voltage drop in transmission system by injecting voltage in series is lower cost. In multiline transmission system, we can connect a separate series controller in each line or connect as shunt controller at the substation. The series controller connection needs to have smaller MVA rating than Shunt controller. Also, any type of shunt controllers does not control the power flow in transmission system. Because of these reasons, companied shunt and series controller is the best to control all of operational parameters of transmission system such as line impedance, voltage magnitude and phase [6]. In this paper was selected types of compensators (STATCOM) from FACTS Family.

III. STATIC SYNCHRONOUS COMPENSATOR(STATCOM)

A Static synchronous generator operates as a shunt-connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage.

Static Synchronous Compensator (STATCOM) is one of the key FACTS devices. Based on a voltage converter, STATCOM regulates system voltage by absorbing or generating reactive power. Unlike a thyristor-based static variable compensator (SVC), the output current of the STATCOM (inductive or capacitive) can be controlled regardless of AC system voltage [7]. The STATCOM has superior performance during low voltage condition as the reactive current can be maintained constant. (In a SVC, the capacitive reactive current drops linearly with the voltage at the limit of capacitive susceptance). It is even possible to increase the reactive current in a STATCOM under transient conditions if the devices are rated for the transient overload.

Figure.1 shows the Static Synchronous Compensator (STATCOM) based on:

(a)voltage sourced

(b) current-sourced converter.

The possibility of generating controllable reactive power directly, without the use of ac capacitors or reactors by various switching power converters was disclosed by Gyugi in 1976 [8]. Functionality, from the standpoint of reactive power generation, their operation is similar to that of an ideal synchronous machine whose reactive power output is varied by excitation control. Like the mechanically powered machine these converters can also exchange real power with the AC system if supplied from an appropriate, usually DC energy source. Because of these similarities with a rotating synchronous generator, they are termed Static Synchronous Generator (SSG). When SSG is operated without an energy source and with appropriate controls to function as shunt-connected reactive compensator, it is termed, analogously to the rotating synchronous compensator (condenser) a Static Synchronous Compensator (STATCOM) or Static Synchronous Condenser (STATCON).

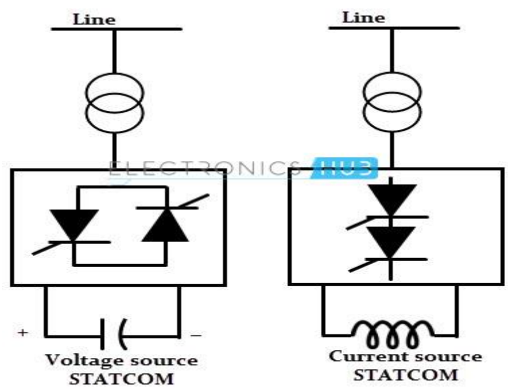

Fig.1 Static Synchronous Compensator (STATCOM) based on (a)voltage sourced

IV. DISTANCE RELAY PROTECTION

The basic principles of distance relay protection are 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 wither 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 [9]. While the reach setting of Zone2 protection is 150% 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 (SIEMENS 7SA511) Distance elements with a positive sequence voltage polarization, three elements for phase loops and three elements for the phase-ground loops 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 (.2). Equations (1) and (2) show the apparent impedance for single-phase-to-ground and three phase faults [9,10].

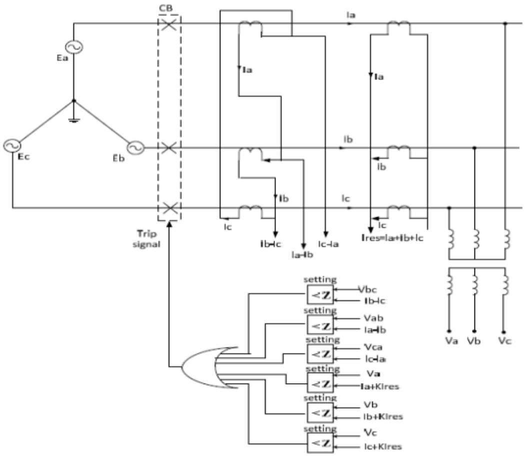

Fig (2): The logic diagram Distance protectional-out of service

The measured fault impedance is compared with the known line impedance. If the measured fault impedance is smaller than the set line impedance, a fault is detected and a trip signal sent to the circuit-breaker. This means that the distance protection in its simplest form operates by measuring the voltage and current at the relay location. No additional information is required for this basic distance protection, and the protection does not have to depend on any additional equipment or transmission signal. Because of inaccuracies in distance measurement, which are the result of measurement errors, transformation errors and inaccuracies in line impedance, in practice it is impossible to set the protection to 100% of the line length. A security limit (10 % -15 %) from the end of the line must be determined for the so-called under-reaching zone (1st zone) in order to ensure protection selectivity due to

internal and external faults, which can be seen in Figure (3). The rest of the line is covered by an over-reaching zone (2nd zone) which, in order to ensure selectivity, must have a time delay with respect to the protection of the neighboring line. In the case of an electro-mechanical protection, this difference in time is 400-500 ms, and 250-300 ms in the case of analog static and numerical protection. This time delay includes the operating time of the circuit breaker, delay of the distance measuring elements as well as the security limit.

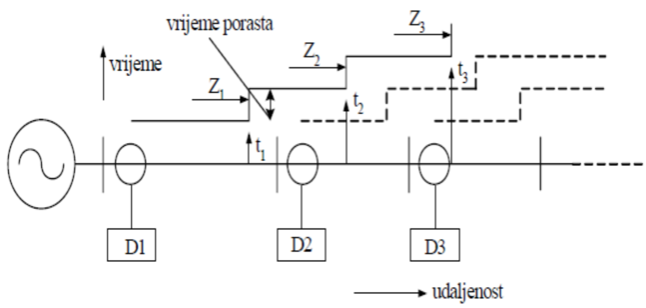

Fig. (3). Distance protection principle, division of the distance grades

Ground Fault

$$Z = \frac{V_{XG}}{I_X + \frac{Z_0 - Z_1}{Z_1} I_{res}} = \frac{V_{XG}}{I_X + K I_{res}} \quad (1)$$

Phase Fault

$$Z = \frac{V_{AG} - V_{BG}}{I_A - I_B} = \frac{V_{AG} - V_{CG}}{I_A - I_C} = \frac{V_{CG} - V_{AG}}{I_C - I_A} \quad (2)$$

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 impendence seen by the relay. The current (I_m) in Figure (4) which is seen by the distance relay located at the beginning of the transmission line is defined as:

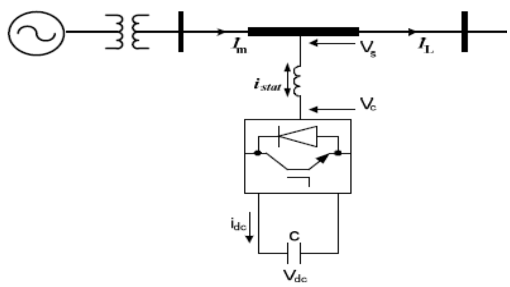

Fig (4): The schematic diagram of a STATCOM

$$I_m = I_{statcom} + I_L \quad (3)$$

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

According to (3) 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 FACTS 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:

$$Z = \frac{V_{XG}}{I_X + \frac{Z_0 - Z_1}{Z_1} I_{res}} + Z_{error} = \frac{V_{XG}}{I_X + K I_{res}} + Z_{error} \quad (4)$$

$$Z = \frac{V_{AG} - V_{BG}}{I_A - I_B} + Z_{error} = \frac{V_{AG} - V_{CG}}{I_A - I_C} + Z_{error} = \frac{V_{CG} - V_{AG}}{I_C - I_A} + Z_{error} \quad (5)$$

where K=(Z_0-Z_l)/Z_l and Z_{error} is the error measured impedance when the STATCOM is connected. The error in apparent impedance is due to the shunt-FACTS and proportional to the fault location and the ratio of the current in the shunt FACTS device and the relay.

The distance relay will see higher impedance when the STATCOM injects reactive power into system, and this leads to under reach condition. While the relay will see smaller impedance when the STATCOM absorbs reactive power from the system, in this case the relay considering fault at a closer location than the actual fault location and results in over reach condition.

V. Simulation Results

The Libyan electrical power system is fed by many power plants, through a 220kv and 400kv high voltage grid systems, which is covered all Libyan areas. This large grid is protected by protective devices. One of these devices is distance relay that is installed on transmission line. In this research the distance relay type (SIEMENS 7SA511) Compound on transmission line (SIBHA – FIJEJ 220kv) as shown in Figure (5) it will be taken as case study from side SIBHA substation (220KV) and will be simulate by Neplan software.

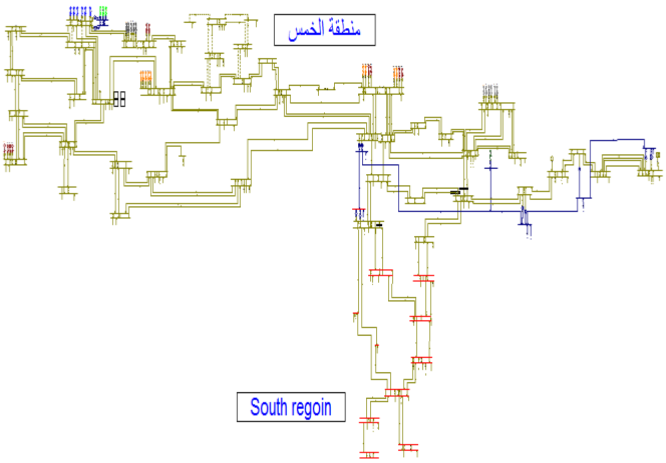

Fig (5). Test system under study

Table 1.1: Voltages in steady state operation. Run without FACTS voltage in the test system

Substation	V%	Substation	V%
AWAINAT	86.8	**SBHA**	90.7
TRAGEN	88.8	**SMNO**	91.8
UBARI	89.1	**SHATE**	92.2
FJAJ	89.9	**WRL**	94.3
SBHA WISTE	90.5	**GM&HON**	95

Table 1.1 shows a significant drop in under study that means, it requires some support to prevent the whole system from blackout to do that, STATCOM is Recommended.

Analysis the effect of fault types on the operation of distance relay in different Zones. In this section a distance relay type (SIEMENS7SA511) is fixed on (SIBHA- FAJEJ 220 KV) The simulation result is given in Figure (6)

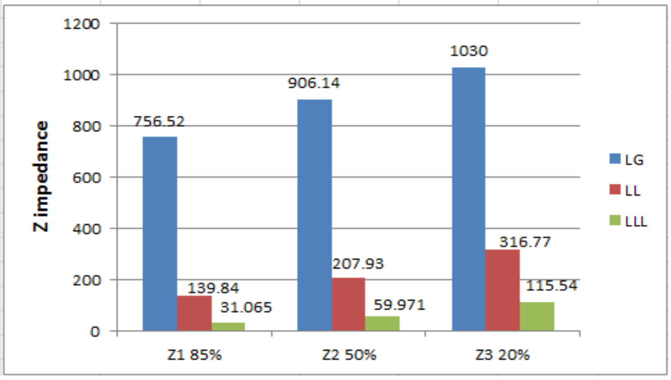

Fig. (6) . measured impedance values for different zones

A. *With STATCOM controller*

The STATCOM controller is connected to zone1 as described in previous section and different fault types is applied at different zones and the simulation results is shown in Figure (7).

Figure (7) presents the different measured impedance values as seen by distance relay with STATCOM for different fault types and for different zones.

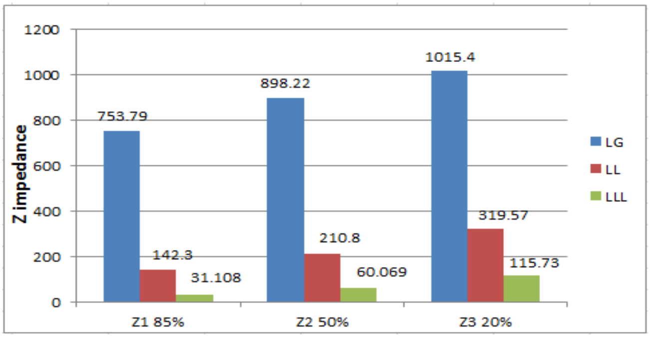

Fig (7) measured impedance in presence STATCOM for different zones

While the Figure (8) shows current values is due to faults at all zones as seen by distance protection combined on SBHA1 220KV.

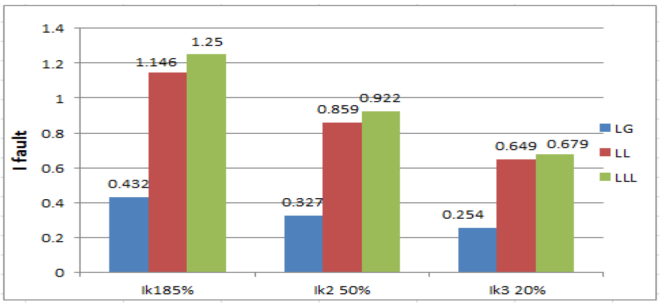

Fig (8) current values in presence STATCOM for different zones

B. Transient analysis with STATCOM in case of LG fault

In this section the STATCOM is connected to zone1 and the different fault are applied at different zones, the simulation results is given below:

when a LG fault is at 0 sec of the distance relay in zone1, the simulation result is presented in Figure (9), and from Figure one can notice that, the voltage before fault occurs is 0.98989pu, and the time of fault occur the voltage drops to 0.989pu.

Also, when a LG fault is at 0.25 sec of the distance relay in zone2, the simulation result is presented in Figure (10), and from Figure one can notice that, the voltage before fault occurs is 0.99pu, and the time of fault occur the voltage drops to 0.9705pu.

In addition, when a LG fault is at 1.2 sec of the distance relay in zone3, the simulation result is presented in Figure (11), and from Figure one can notice that, the voltage before fault occurs is 0.99pu, and the time of fault occur the voltage drops to 0.9766pu.

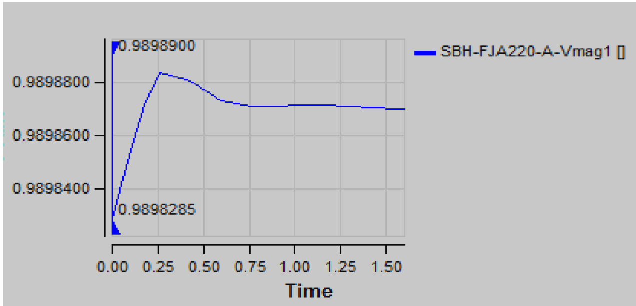

Fig (9) line voltage as result of LG fault at zone1

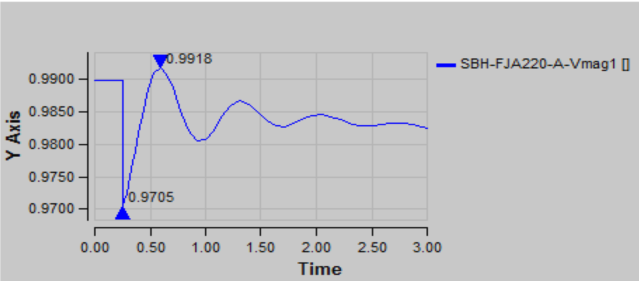

Fig (10) line voltage as result of LG fault at zone2

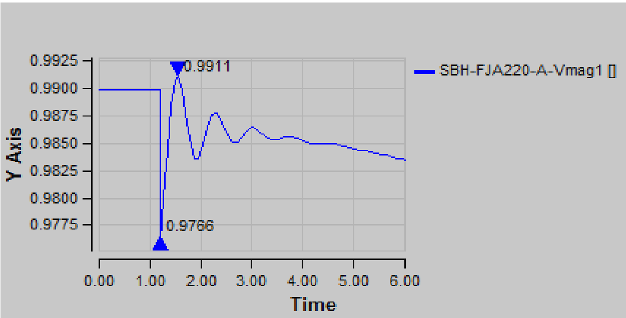

Fig (11) line voltage as result of LG fault at zone3

C. Thirdly Transient analysis with STATCOM in case of LL fault

In this section the STATCOM is connected to zone1 and the different fault are applied at different zones, the simulation results is given below:

when a LL fault is at 0 sec of the distance relay in zone1, the simulation result is presented in Figure (12), and from Figure one can notice that, the voltage before fault occurs is 0.98989pu, and the time of fault occur the voltage drops to 0.9893pu.

Also, when a LL fault is at 0.25 sec of the distance relay in zone2, the simulation result is presented in Figure (13), and from Figure one can notice that, the voltage before fault occurs is 0.990pu, and the time of fault occur the voltage drops to 0.861pu.

In addition, when a LL fault is at 1.2 sec of the distance relay in zone3, the simulation result is presented in Figure (14), and from Figure one can notice that, the voltage before fault occurs is 0.996pu, and the time of fault occur the voltage drops to 0.910pu

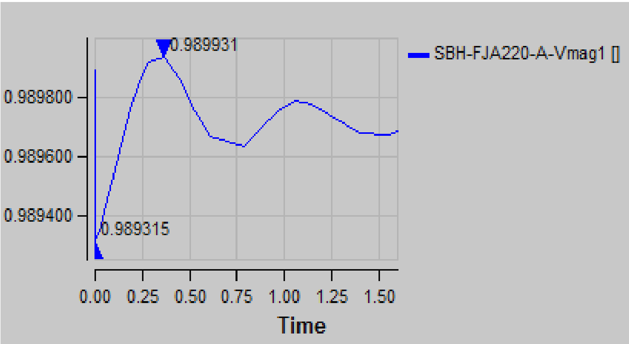

Fig (12) line voltage as result of LL fault at zone1

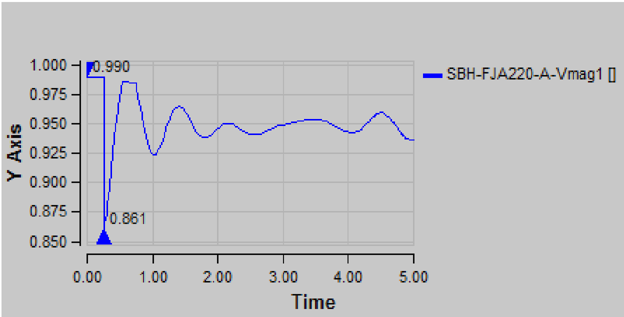

Fig (13) line voltage as result of LL fault at zone2

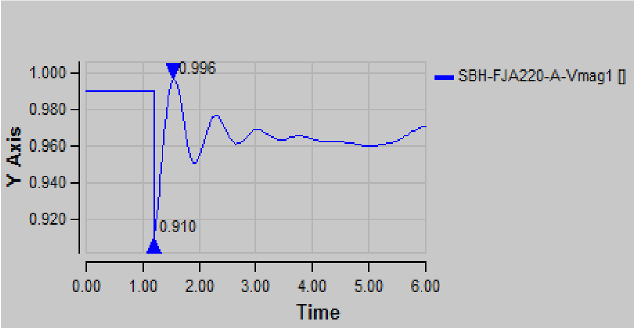

Fig (14) line voltage as result of LL fault at zone3

D. Transient analysis with STATCOM in case of LLL fault

In this section, the STATCOM is connected to zone1 and the different fault are applied at different zones, the simulation results is given below:

when a LLL fault is at 0 sec of the distance relay in zone1, the simulation result is presented in Figure (15), and from Figure one can notice that, the voltage before fault occurs is 0.990pu, and the time of fault occur the voltage drops to 0.980pu.

Also, when a LLL fault is at 0.25 sec of the distance relay in zone2, the simulation result is presented in Figure (16), and from Figure one can notice that, the voltage before fault occurs is 0.990pu, and the time of fault occur the voltage drops to 0.629pu.

In addition, when a LLL fault is at 1.2 sec of the distance relay in zone3, the simulation result is presented in Figure (17), and from Figure one can notice that, the voltage before fault occurs is 0.990pu, and the time of fault occur the voltage drops to 0.801pu

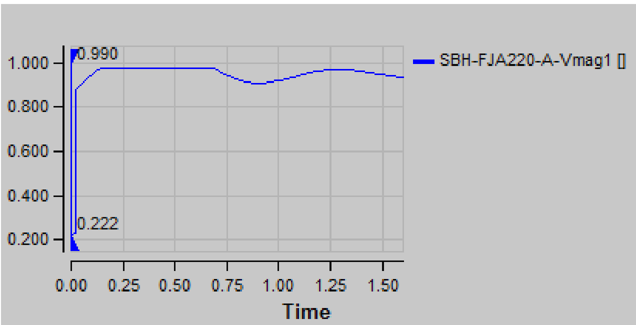

Fig (15) line voltage as result of LLL fault at zone1

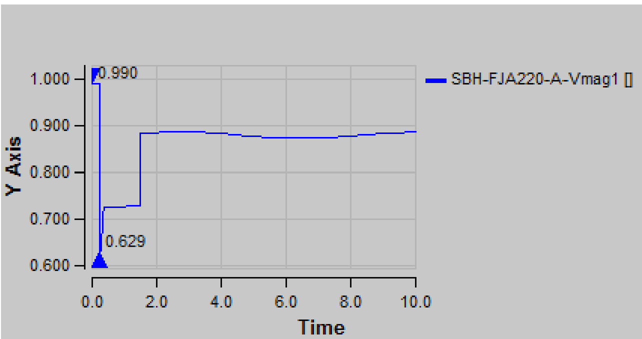

Fig (16) line voltage as result of LLL fault at zone2

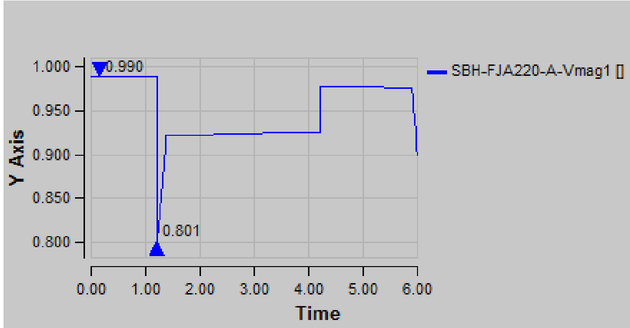

Fig (17) line voltage as result of LLL fault at zone3

VI. CONCLUSION

The effect (STATCOM) controller on the performance of distance relays is investigated detailed modeling of distance relay using Neplan/SIMULINK environment is presented. Different fault types and locations with FACTS controllers' and operation modes are simulated.

The simulation results have shown the ability to detect and classify any fault type and high level of accuracy to determine fault location The simulation results shows that, when the fault occurs between the relay and (STATCOM) location, the apparent impedance will not change and it will be equal to actual impedance regardless of the types and operation modes of STATCOM controller. Also, in case of(single line to ground fault) with (STATCOM) the distance relay will not operate (under-reach) for both capacitive and inductive operation modes. The apparent impedance seen by distance relay is much larger than actual impedance in different zones due to the zero sequence component. Whereas, in the case of the three phase faults, there is no difference in the impedance measurement of the distance protection device in the different zones in steady state and with STATCOM. In addition, in all fault case studies, the error in the measured impedance seen by distance relay increases as the fault location varies from STATCOM location to the end of the relay reach line

VII. RECOMMENDATION

In general, the effect of STATCOM on distance relay performance especially in most common fault type (Single Line to Ground. And phase to phase). The typical distance relay is not the best protective relay for FACTS compensated transmission line. Concerning recommendation for future work, I would like to suggest the following:

1- The proposed work can be extended by applying similar techniques to the transmission lines compensated by other FACTS devices such as Interline Power Flow Controller (IPFC) and SSSC compensator.

2- Regular routine test should be carried out to ensure the integrity of relay scheme as faulty protective devices such as circuit breakers, control cable discontinuity, faulty control knob, circuit breaker pole discordance etc. may also constitute fault and thus affect the integrity of the protection scheme and may lead to loss of supply of electrical energy

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