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Adverse Impact of STATCOM on the Performance of Distance Relay

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Abstract

FACTS devices like the Static synchronous Compensator (STATCOM), are mostly used to enhance the maximum power transfer capability of the transmission Line (TL) system. AMatlab simulation model of Distance Relay protection ofTL, with connected STATCOM at the mid-pointfor optimum power transfer is presented. The STATCOM's impact on the operation of the relay is assessed with the effects on the relay misoperation in the third zone of protection coverage, during fault conditions, in four different locations.Thewrong measured fault impedance by relay resulted to misoperation in zone 3 (under reach phenomena). The simulation result indicates a slight increase in the measured impedance of 1.33 Ω over the actually expected impedance setting (72.02 Ω) of the relayat 220 km protection coverage of zone 3 along the TL. This variation is about 4 km distance outside the expected distance protection coverage for fault in zone 3 as proven.

Keywords: *FACTS, STATCOM, distance relay, impedance, model*

1. Introduction

Power Energy demand is increasing rapidly,it requires more generation, distribution, and transmission lines [1]. Protection of transmission lines is an important aspect of system stability consideration as illustrated in [2]. Protection relay are among main components in power system that provide stability and reliability to power system. Distance relay can be used as main protection or backup devices to protect the transmission lines. It is widely applied for protection due to its simple operation under most circumstances and provide good protection capability in a case of faults [3]. There are many types of distance relays based on their different characteristic such as MHO numerical relay, quadrille etc. [4]. In this paper MHO type distance relay will be model, and simulated in order to determine the impact analysis of STATCOM device on distance relay operation performance during different fault conditions on the transmission line [5]. The distance relay impedance measurements algorithm depends on the fault location measurements of the three phase voltages and currents signal taken at the point of fault. This measured signal are taken with the application of voltage and current transformer (VT and CT), which delivered the input signals to the protection relay.

Faults in power system can be classified into two major categories: the symmetrical faults and unsymmetrical faults. The symmetrical faults occurs only when all the three phases are shorted with oneanother, but contrary faults condition to this scenario is classified as unsymmetrical faults [6]. When a fault occurs at the transmission line the distance relay measures the impedance at the fault location by calculating the ratio of voltage and the current measurements at the fault location with the aid of mathematical formulas as illustrated for different fault types in Table 1. The calculated fault impedance is then compared with the reference steady state impedance setting (actual impedance) of the system to enables trip decisions to be generated accordingly when necessary. The output from such decision is used to decide if the fault impedance is inside or outside the relay coverage zones of protection, it will then initiate a trip signal to the closest circuit breaker to operate, and clear the fault accordingly. But in case the fault is outside the coverage zones of protections, such relay will not respond to such faults, thereby leading to danger to lives, installations, and expected damages [7]. This is

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necessitated in order to keep the healthy section of the lines, to avoid unwarranted blackouts or damages to any equipment connected to transmission lines at the substation [8].

In order to secure an increase in the maximum power transfer capability of the system to provide optimum utilization of the transmission power line system, the FACTS devices are introduced for the power system dynamics enhancement [5]. Installation of the FACTS devices such as STATCOM on the transmission lines, enhances the transfer capability of the transmission power system lines, by providing maximum utilization of system facilities [1]. FACTS have some disadvantages with respect to the distance relay operation, due to the changes in the transmission line parameters. Consequently this affects the measured impedance by the distance relay during fault conditions as compared to the steady state set impedance for different fault types and locations [9]. Taking into consideration the coupling location of the connected STATCOM: if it is connected at the mid-point of the line for optimum power transfer, and the fault occurred before the STATCOM, the effect of the STATCOM is not felt by the distance protection relay coverage zones for such scenarios [10]. But, if the fault occurs after the STATCOM connection, still within the relay coverage zone 3, towards the far end terminal of the relay coverage zones. Then the effect on the distance protection relay operation is noticed, resulting to mis-operation of the distance relay to such fault. This is known as (under reach phenomena) [9].

Table 1. Fault Impedance Algorithm For Various Fault Types [12]

Fault type	Algorithm
AG	VA /(IA + 3 k0 I0)
BG	VB /(IB + 3 k0 I0)
CG	VC /(IC + 3 k0I0)
AC & ACG	(VA – VC)/(IA – IC)
AB & ABG	VA – VB)/(IA – IB)
BC & BCG	(VB – VC)/(IB – IC)
ABC &	(VA / IA) or (VB / IB) or (VC / IC)

A, B, C indicates the phase fault and G indicates the ground fault.
I_a, I_b, I_c are the phase currents
K = (Z0 - Z1) / 3Z1 Compensation Factor.
I0 = (Ia + Ib + Ic) / 3 zero sequence current.
Z0 Zero sequence impedance.
Z1 positive-sequence impedance

2. Research Method

A 400KV Libyan transmission line, with a transmission line length of 300 km is proposed for modelling as seen in a block diagram of Figure 1. The detail system configuration data as proposed is displayed in Table 2, 3 and 4. The STATCOM is connected at the midpoint of the transmission lines for optimum power transfer in this research work. Different fault types are simulated at different location on this modelled lines in Matlab software. This is followed by the modelling of a distance relay with the help of Matlab Simulink's blocks. The three faults type executions were performed in three different locations of the lines, under three different scenarios as: before compensation with faults within the three zones of coverage of the modelled relay. After compensation provision with the STATCOM device connected, and faults initiated before the STATCOM contribution to the line. Finally, when the fault is simulated at the far end of the compensated transmission line, within the zone 3 coverage of the distance relay.

Table 2. Source Data

Parameters	Data
Base Voltage	400 KV
Frequency	60 Hz
Phase to phase rms voltage V	400 KV
Positive sequence source resistance	0.8929 Ω
Positive sequence inductive	16.58mH

Table 3. Transmission Line Data

Line Parameters	Value
Positive sequence resistance	0.01165 Ω/km
Zero sequence resistance	0.2676 Ω/km
Positive sequence inductive	$0.8679e^{-3}$ H/km
Zero sequence inductive	$3.008e^{-3}$H/km
Positive sequence capacitive	$12.74e^{-9}$F/km
Zero sequence capacitive	$7.751e^{-9}$ F/km

Table 4. Three Phase Load Data

Parameters	Data
Transmission line length	300 KM
Nominal Phase to Phase Voltage	400 KV
Nominal Frequency	60 Hz
Active Power	210 M WATT
Inductive Reactive Power	150 M VAR
Capacitive Reactive Power	0 M VAR

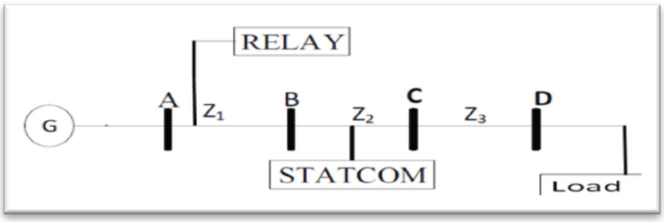

Figure 1. A transmission line with STATCOM at mid-point

MATLAB/SIMULINK is a very powerful tool applied for the modelling of the distance protection relay, the library contains all block components needed to model any type of relay and the necessary component parts as provided by Simulink tool box. Using MATLAB gives the flexibility to model each component part of the relay as a subsystems separately, within the scope of this study. All modelled subsystems are interconnected together to accomplish one relay model. The proposed model is made up of three component units as a subsystems individually.

2.1. Algorithm for Fault Calculation

In modelling a distance protection relay, the fault detection component unit of the transmission line is the first to be modelled, using the "IF" and "else" decision blocks [11]. This block contains three decision path connected to three output ports, which determines whether the fault present is a single phase to ground fault, double lines to ground fault or three phase to ground fault as displayed in Figure 2, 3 and 4 respectively. These blocks were built using enable subsystem block for activation of the system to receive an enable signal.

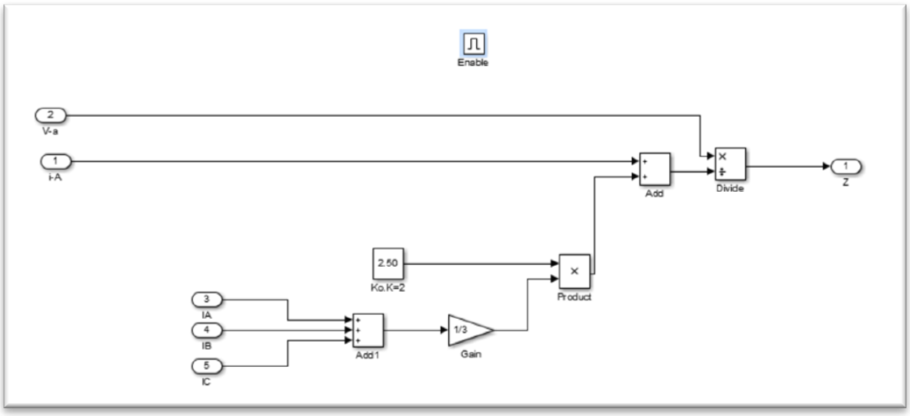

Figure 2. SL-G fault apparent impedance

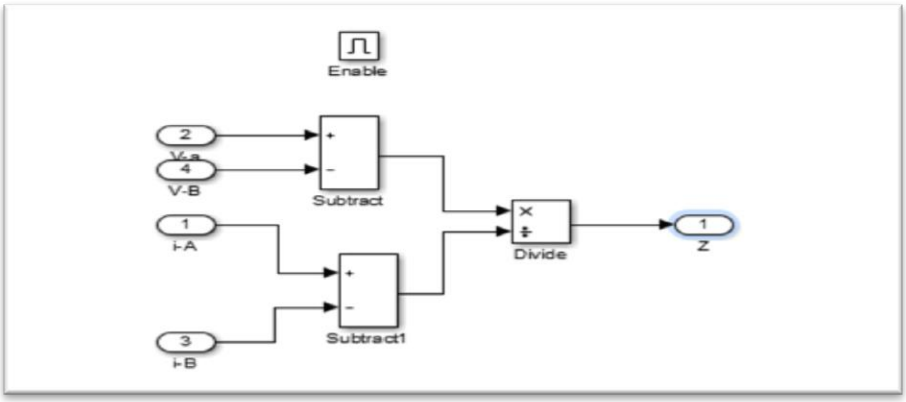

Figure 3. DL-G fault apparent impedance

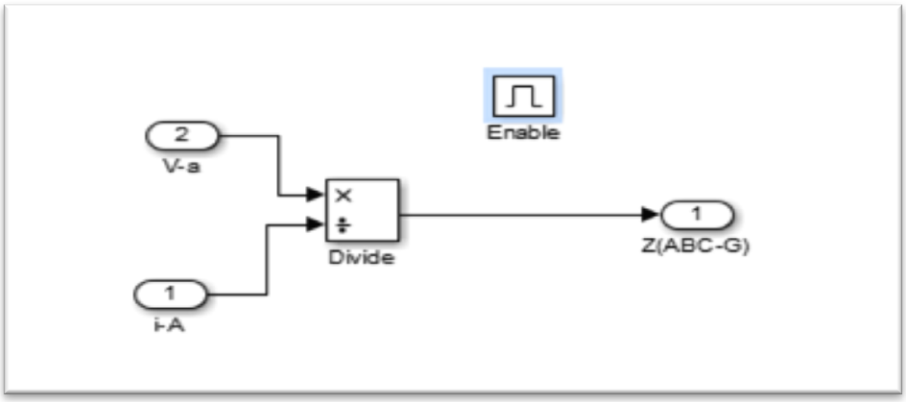

Figure 4. 3Ph fault apparent impedance

2.2. Apparent Impedance Measurements

The second unit part of the distance relay model is the apparent impedance measurements block, which include all impedances algorithms to calculate the impedance of each fault type as shown in Table 1.This is achieved by fault signal measurement of the voltage and current signals through the voltage and current transformer as an input interface to the distance protection relay [12] [13]. The signals output values from the fault detection and classification blocks, mandates which algorithm from Table 4 to be selected.

2.3. Detection Zone and Signal Tripping

The third unit of the modelling of the distance protection relay system is the detection zone, and signal tripping subsystem modelling designed to detect the fault zone location, based on the measured impedance value as shown in the Figure 5. The distance relay mho characteristic for each measured impedance is displayed in Figure 6. If the measured impedance is at the fault location is less than or equal to 26.2Ω, then the fault is located in zone 1 coverage area of the relay coverage as displayed in the characteristic impedance of Figure 6.

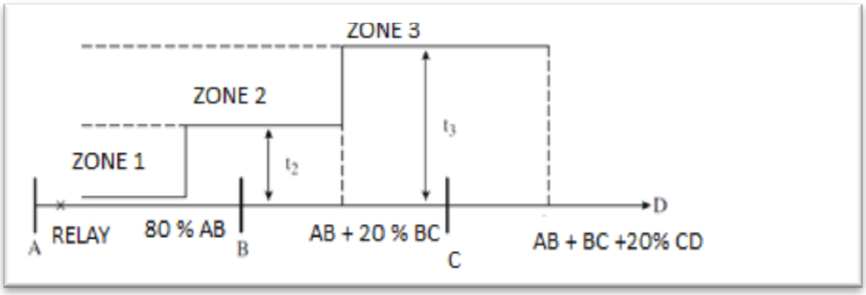

Figure 5. Zones of protection for distance relay

In addition, Table 5 displayed the calculated impedances based on the proposed model. If the measured impedance is greater than 0 Ω but less than 26 Ω, then the fault is in zone 1. Also, if the measured impedance at the fault location is greater than 26.2 Ω, but less than 39.28 Ω, then the fault is located in the zone 2 of the characteristic. Finally, if greater than 39.28 Ω, but less than 72.02 Ω, the fault is in zone 3 as summarized in Table 5. The complete modelled relay from the three subsystem is displayed in Figure 6.

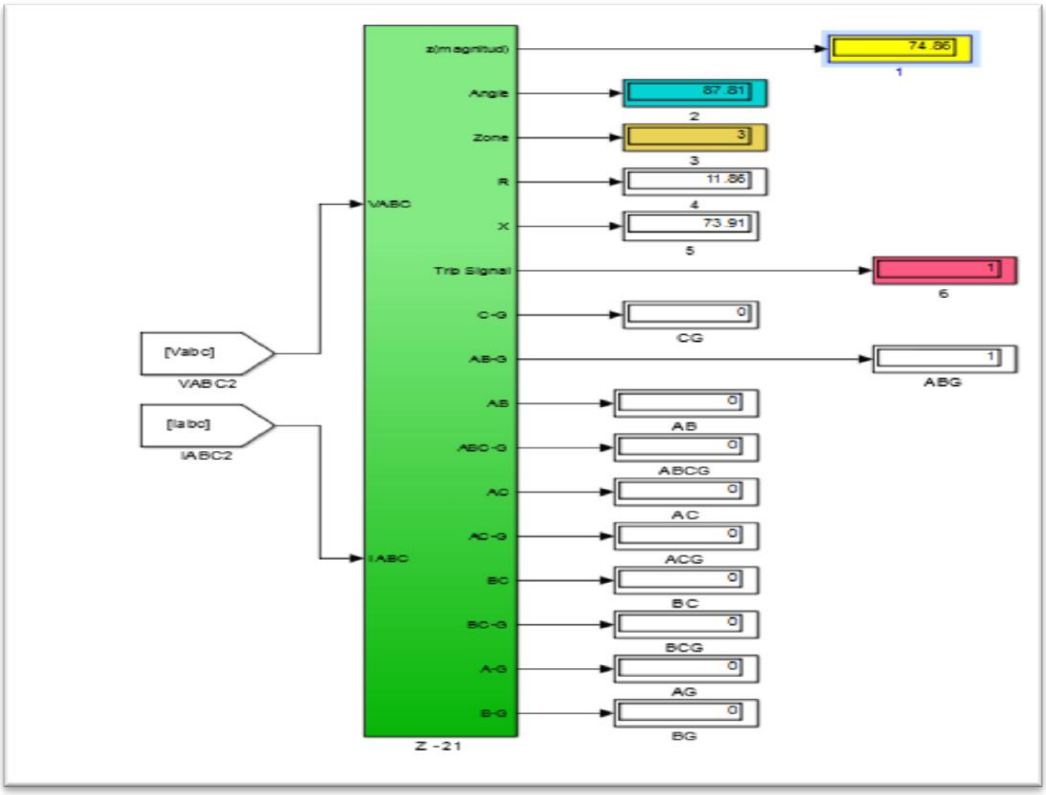

Figure 6. complete integrated model of distance relay

Table 5. Setting Point of Three Zones Distance Relay

Zones	Setting Point	Value Ω
Zone1	80%T L1	26.191 Ω
Zone2	100%T L1&20%TL2	39.288 Ω
Zone3	100%TLI1+100%TL2 &20%L3	72.020 Ω

2.4. Distance Relay Characteristic Shape

The distance protection relay output characteristic model of the fault impedance measurement is achieved through the writing of the matlab codes in an M-file function file to help understanding the behavior of distance relay response to fault as displayed in Figure 7 of the mho characteristic of the relay operational output [14].

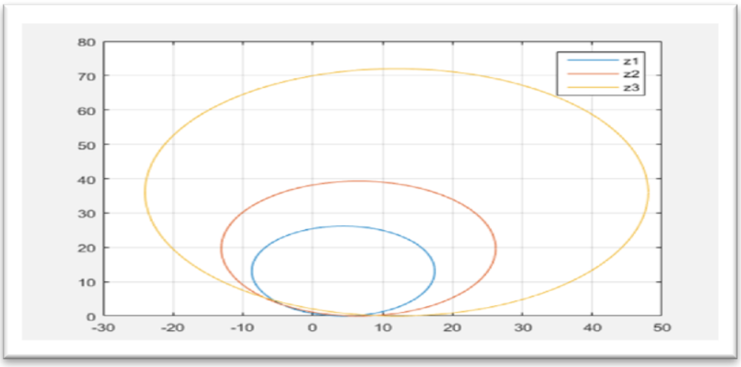

Figure 7. MHO distance relay characteristic

3. Results and Analysis

The complete model of a three phase 400KV, 260MVA, 60Hz, 300KM power transmission line, with three equal section of TL1, TL2 and TL3 is displayed in Figure 8. A 210MW and 150MVAR loads connected alongside with the modelled distance protection relay. obtained result from the connected modelled distance protection relay under three different fault types, at three selected locations within the relay protection coverage zone, without the connection of the STATCOM device is displayed in Table 6. The connected input to the modelled distance relay of Figure 6, is the measured voltage and current values at the fault location by the voltage and current transformers. The relay output labels as displayed in Figure 6, from the top to the bottom are: the measured impedance, phase angle, zone detection to show the zones of the fault location, the system measured resistance and reactance as stored in the work space for the implementation of the impedance trajectory paths. Furthermore, the relay tripping signal output binary logic signal of “1”or “0” coloured in red in the displayed Figure 8, with binary logic “1” indicating an initialization of a trip signal to the nearest circuit breaker to the fault, while binary logic “0” is for non- tripping signal.

The next simulation result obtained as displayed in the Table 6 is from the obtained relay measurement with the connected STATCOM device at the mid-point of the lines to regulate the system voltage for improved power transfer capability as seen in Figure 8.

Three different fault types were simulated from these models at four different locations with connected STATCOM and without. The obtained results under these two scenarios were compared as seen in Table 6. The result from the simulated phase to ground fault, at 60 KM from the near end of the transmission line with the relay protection coverage, displayed the mho trajectory of Figure 9. This indicate that the occurrence of fault between the relay and location of STATCOM, the apparent measured impedance will not change and it will be equal to actual set impedance of the line and the relay will operate normally to protect the line under this fault type.

The second result obtained under the three phase to ground fault at the end of the transmission line, at a distance of 220 KM, which lies in the zone 3 protection coverage area of the distance relay characteristic is displayed in Figure 10. The blue colour star indicator shows the measured fault impedance location on the zone 3 trajectory, without the presence of

STATCOM as shown in Figure 10. Furthermore, the red colour star indicator on the same Figure 10 displayed the measured fault impedance outside the zone 3 coverage of the distance protection relay, with voltage and current contributions from the connected STATCOM device at the midpoint of the transmission lines. This affect the normal operation of the relay because, the measured fault impedance calculated from the magnitude of the voltage and current is higherthat the actual setting of the relay for such location, which locate the fault impedance outside the zone 3 coverage trajectory slightly as seen in Figure 10. This is known as under reach phenomena and at this point the relay will mis-operate, because when the relay measures the fault impedance of the system, it will be located outside of its protection coverage boundary of 220 KM with a different of 4 KM as displayed in the comparison of Figure 11.

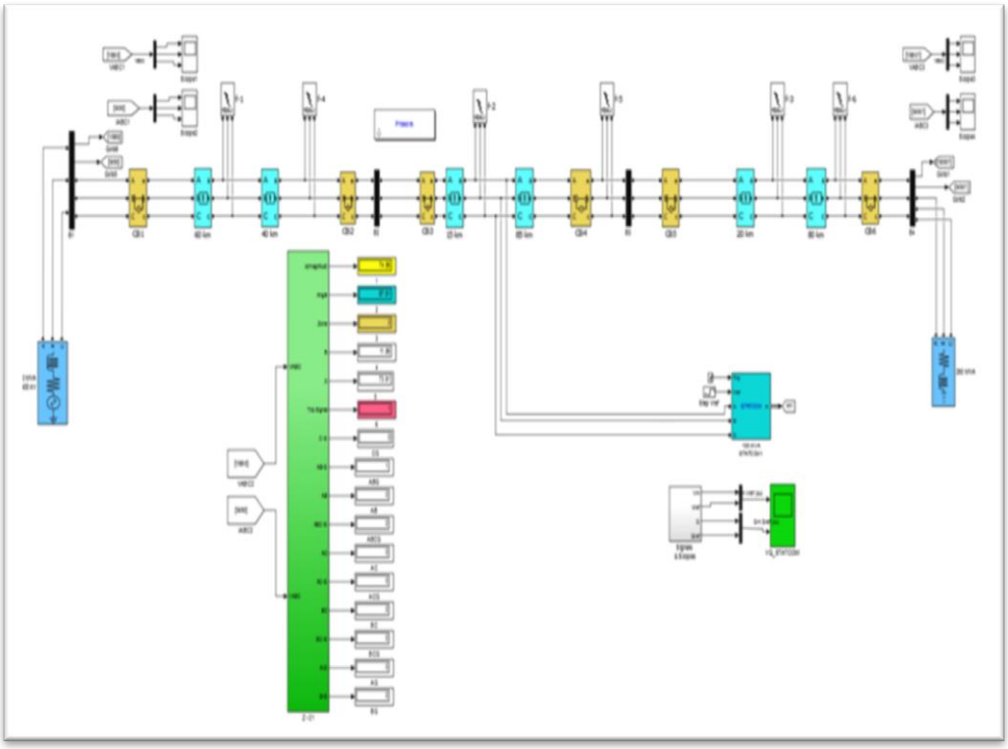

Figure 8. Power system simulation model with STATCOM installed

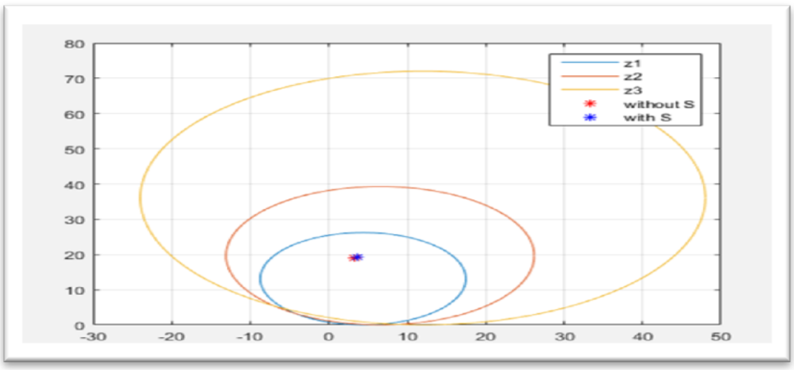

Figure 9. R- JX plot impedance locus for a fault at 60km (zone1)

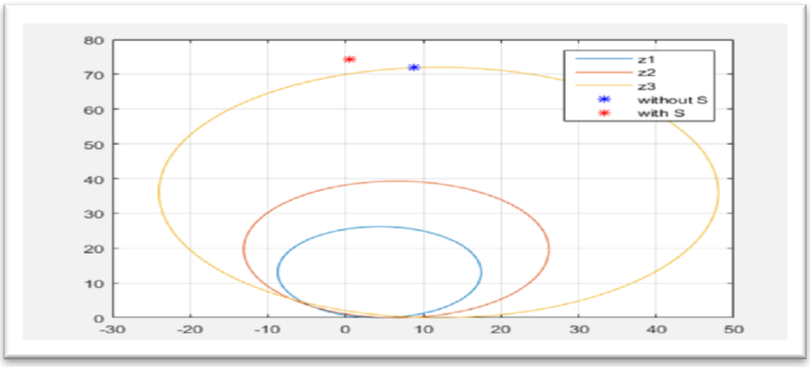

Figure 10. R-j X plot impedance locus for fault at 220 km zone3

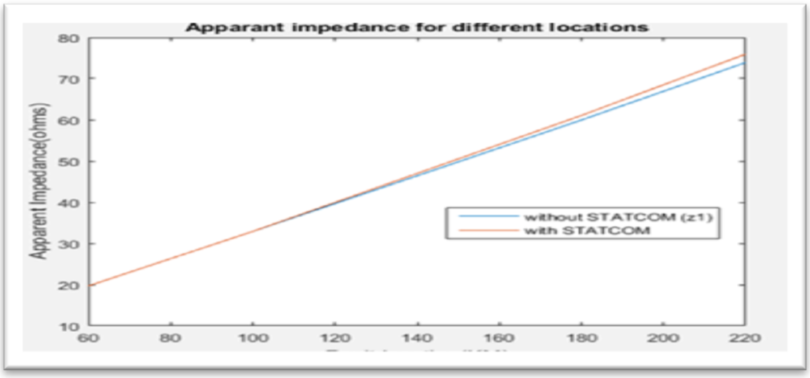

Figure 11. The measured apparent impedance

However the obtained result the from double line to ground fault is the same as seen in the three phase to ground fault in Table 6. It can be seen from the displayed result that the closer the fault location to the STATCOM point of connection on the line, the more is the impact felt by the distance protection relay, leading to the mis operation of the device to fault.The findings can be summarize according to the simulation results as follows: the STATCOM has great impact on distance protection relay operation performance when connected within the fault loop. Secondly, the distance protection relay discovered the apparent impedance greater than the impedance sitting of the relay in the case of capacitive compensation, and less than in the case of inductive compensation.Thirdly, generating reactive power to the system will cause under reach phenomena, while consuming reactive power causes over reach phenomena, finally the apparent impedance is directly proportional to the distance between the fault location and the location of STATCOM device.

Table 6. Distance Relay Measured Impedance for Different Types of Faults And Locations

Type of fault	Distance	Without STATCOM			With STATCOM			Calculated impedance
		R	X	Z∠θ	R	X	Z∠θ	
SL-G	60km	3.617	19.35	19.69∠84.64	5.705	19.02	19.86∠84.53	19.64∠87.96
	100km	3.393	32.61	32.78∠84.72	8.83	31.86	33.07∠84.55	32.70∠87.96
	180km	8.547	58.48	59.11∠81.97	7.954	59.03	59.56∠85.69	58.93∠87.96
	220km	5.54	71.11	71.43∠85.14	3.511	73.13	73.22∠84.78	72.03∠87.96
DL-G	60km	0.214	19.68	19.68∠87.95	0.215	19.68	19.68∠87.95	19.64∠87.96
	100km	0.519	32.91	32.91∠87.95	0.520	32.91	32.91∠87.95	32.70∠87.96
	180km	2.568	59.90	59.95∠87.92	2.570	59.90	59.95∠87.84	58.93∠87.96
	220km	4.50	72.71	72.85∠87.90	7.507	73.07	74.18∠87.78	72.03∠87.96
3PH-G	60km	0.214	19.68	19.68∠87.95	0.214	19.68	19.68∠87.95	19.64∠87.96
	100km	0.519	32.91	32.91∠87.95	0.519	32.91	32.91∠87.95	32.70∠87.96
	180km	2.568	59.90	59.95∠87.92	2.570	59.90	60.84∠87.92	58.93∠87.96
	220km	4.50	73.76	72.85∠87.90	6.99	73.85	74.18∠87.86	72.03∠87.96

4. Conclusion

Distance relay is designed and modeled by MATLAB SIMULINK and tested with and without connecting FACTS controllers under different fault types and locations. The results from the simulation illustrate the capability to detect and classify all fault types with high level of accuracy to determine fault location. The simulation results of the distance relay mis-operate by the effect of connected STATCOM at the mid-point of the line. The apparent impedance is impacted by the reactive power, been injected by STATCOM, resulting to an under reaching phenomena of the distance relay. But when the fault occurs between the relay and STATCOM, the system apparent impedance will be equal to the setting impedance and the STATCOM has no effect on the power system. Otherwise, when the STATCOM is connected in the fault zone, the impedance measured would be greater than the expected, which will cause the distance relay to mis-operate if it exceeds its boundary of 220 km as seen in this research work.

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