Power system performance analysis with STATCOM along with distance protection scheme

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Abstract: Distance protection scheme used conventionally over lines for faults detection requires adaptability to the system variation. This paper develops an approach using shunt connected flexible AC transmission systems (FACTS) based devices. The STATCOM is used as integrated part of power system with fault detection using distance relay characteristics. Simulation is developed on PSCAD and results are generated and validated. It is observed that under system transients are minimized with distance protection scheme connected system due to presence of STATCOM.

Key words: Distance protection, STATCOM, Relay Characteristics, FACTS.

1 Introduction: In present time the issues related to energy crisis, environment safety, space availability and generation plus operating cost causes multiple challenges in the development of generation facilities and new types of transmission lines installation and requires robust type changes in the traditional practices in power system applications. Utilization of power system by novel devices for example Flexible AC Transmission Systems is imperative and very needful. Power flow calculation over line depends on line impedance, magnitude and phase between the sending and receiving end parameters. Variable capacitors and static phase shifters generally added to create variation in the power flow by changing the network parameters and helps in improving power transfer capabilities and reducing investment cost. It supports to find solutions for the limitations created by modern generation and transmission demands. The objective of this paper is development of comparative models to analyse benefits of allocation strategy of STATCOM for line protection with the distance protection scheme that will lead to minimize the transients over the generation.

In this work accurate control coordination is required in between the system devices and it is tough to bring the controls application of system devices to work together. The STATCOM in this work is found to be capable of influencing the system in a very fast and effective manner on adding distance protection scheme and helped in improving the system stability and system reliability. Additional concern is also given in this paper on analysis of power flows, reactive power and voltage/current stability. [1, 2]

Power electronics introduced a new era in power systems control. Many control devices are in uses which are known as Flexible AC Transmission System i.e. FACTS [3]. Near about Eleven such electronic devices are available [4] able to change in a fast, effectively for improved the performance.[5, 6 and 7]. Two types are observed Loop flow, shown in Figure 1: unwanted power flow at the utilities end formed across at interconnection in closed loop.

In power systems with parallel flow (figure 1) shows power interchange between utilities loads at A and B and affects the whole network and causes problems

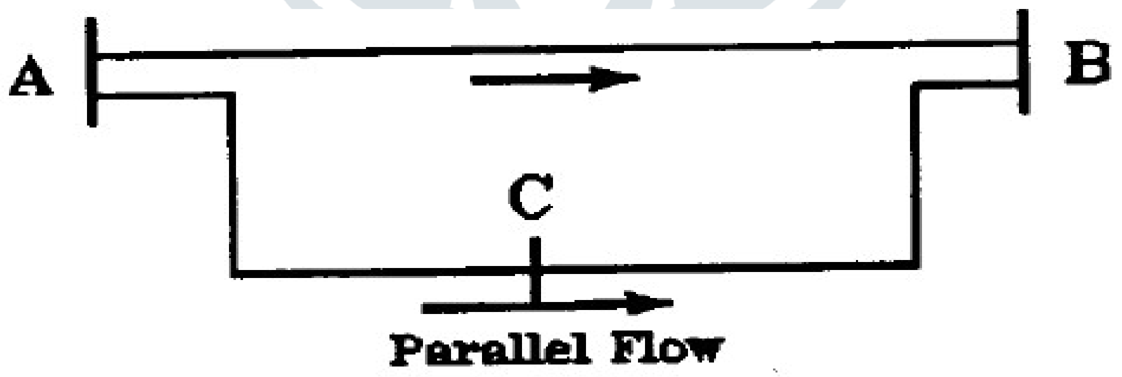


Figure 1: Power System with Parallel Flow

The concept is key point for use of FACTS in power system network parameters controls and helps to eliminate several problems due to loop (parallel) flows and its inclusion causes reduction of operation and transmission costs, increase of security and increase of transmission capabilities. This flexibility, however, comes with a price with systematic control and coordination that can bring all devices to work together.

FACTS Devices: FACTS devices helps in to control the lines and enhance the transmission power by monitoring line characteristics and parameters with compatibility to load changes and variations. Reactors at shunt-connected scheme help to reduce the issues of overvoltage at low load condition and shunt-connected capacitors control voltage for loads at large values in magnitude. Shunt compensation prevent voltage instability and minimize transient and provides an efficient oscillations damping. Traditionally switched reactors and capacitor used for shunt compensation, voltage regulation, limiting the power and voltage signal fluctuations, and system stability with lower satisfactory level because such devices was slow hence fast monitoring was incorporated to perform these operations more efficiently [8].Overview of such devices is given below:

TCSC comprises a series capacitor in parallel with a Thyristor Controlled Reactor (TCR) Ls. A metal oxide varistor (MOV) type nonlinear resistor connected to series capacitor to limit over voltage across capacitor. A circuit breaker is added with the TCSC to bypass the fault. A current limiting inductor, L_d, is also present in circuit to limit the capacitor current [9].

UPFC devices are used in series of line with transformer as intermediate equipment. The active power received from line via a transformer. They generates/absorbs the reactive power as per the control operations due to switching action obtained from converters [10].

TCPST are similar to UPFC but the reactive power receiving from series by the TCPST device is taken through transmission line and forwarded through the transformer connected in shunt[10].

Traditionally power flow was controlled by line reactance using fixed or thyristor-controlled series capacitors (TCSC) or inductors. Another way of power flow control is by dynamic impedance compensation system [11], solid state switching converters. Static Synchronous Series Compensator (SSSC) is a solid-state voltage source inverter that injects voltage of variable magnitude, in series of power line. This voltage is in quadrature to the line current. This injected voltage emulates an inductive or a capacitive reactance in series with the transmission line influences the electric power flow in the power lines [12].

The Static synchronous Compensator known as STATCOM used as shunt-connected source of both lead/lag action control based reactive power signals. A Reactive Power variation is performed by the voltage regulator to give a constant voltage at the connected power network. STATCOM is solid-state switching converter produces real and reactive power when provided by energy-storage device over the input side. It is analogous of synchronous machine that balance the sinusoidal voltages signal with no inertia and internally generation capability of reactive (capacitive and inductive) power [8].

Static VAr Compensator (SVC) generates or absorbs reactive power at middle connection power transmission line branch. SVC control voltage to improve all the power transfer quality. They do not generate /receive the power signals but affects voltage control indirectly by acting in capacitive component mode and absorb power by acting as inductive component [13].

Controlling of power flow by TCSC and TCPST is very common [14]. They inject a series voltage to line and adjust the line reactance or the phase shift. Recent advances made it possible to implement the switching of voltage source converters schemes. SSSC , STATCOM , UPFC etc. has provided flexibility with optimal power flow control and helps for active and reactive power flow through series and a shunt reactive compensation [14- 15].

These modern FACTS device during fault loop affects the steady state and transient components in power signals at the relay point. Apparent impedance calculations accounted for the variable voltage and its angle and shunt current and admittance is also observed in the device [16].The fault resistance, arc magnitude and condition of the apparent impedance influences greatly by the location and parameters of FACTS device during fault. Impedance observed through the relay is lower/higher than the actual then the distance relay undergoes through over-reach or under-reach. Hence systematic relay setting on distance protection is required to remove over-reach or under-reach problems in systems [17-22]. On-line corrections and adaptive setting of the trip boundaries is demonstrated in some recent works [18-20]. This paper demonstrates the work on PSCAD tool that helps to analyse the performance of STATCOM with and without distance protection using apparent impedance calculation that justifies transient minimization by simulation results.

2 Overview of STATCOM:

Among the different FACTS devices SVC control the voltage at point of connection by controlling susceptance through adjustment of reactive power [23], [24]. They have capability to rapidly vary reactive parameters change system conditions [25], [26]. Gate turn off devices (GTOs) supported advanced static var systems (SVS). The static synchronous compensator like STATCOM, SSC etc. are advanced SVS. STATCOM has 3 phase groups of many GTO and capacitor and a monitoring. The work in this paper investigates the midpoint STATCOM performance of impedance parametric protection using the relays in ABC-G fault conditions. First of all mathematical equations for typical interconnection are described. PSCAD is used with single line diagram for 115kV source supply simulated to collect result on distance relaying scheme in fault with and without connection of the controlled protection scheme. [27].

Figure 2 shows developed power system with a STATCOM connected at the line is modelled by two pi-sections and the protection relay on sending bus is provided. The STATCOM resultant reactive power value varies with the power transfer. All types of faults simulation and the fault impedance can be changed as desired.

A. STATCOM has many utilities in transmission. The STATCOM operate with reactive power to supervise the voltage. STATCOM acts as controlled-current-source with response to conditions by acting in service untill reactive current does not exceed to given limits shown in Fig. 2.

$$I_\gamma = \left(\left(Zs' + \frac{Z_L}{2} \right)^{-1} \left(V_\gamma^{-1}(E'_S + E'_R) - 2 \right) - 2Y'_c \right) V_\gamma. \tag{1}$$

The value of current "I y " is automatically adjusted to changes in load angle "delta ," in such a way as to keep the midpoint voltage "V y " constant. STATCOM provides the desired reactive power generation and absorption entirely by means of electronic processing of the voltage and current waveforms in a voltage source converter (VSC). Fig. 2 shows the V-I characteristics of a STATCOM. The STATCOM is able to independently control its output current over the rated maximum capacitive or inductive range irrespective of the amount of ac-system voltage. Unlike the SVC

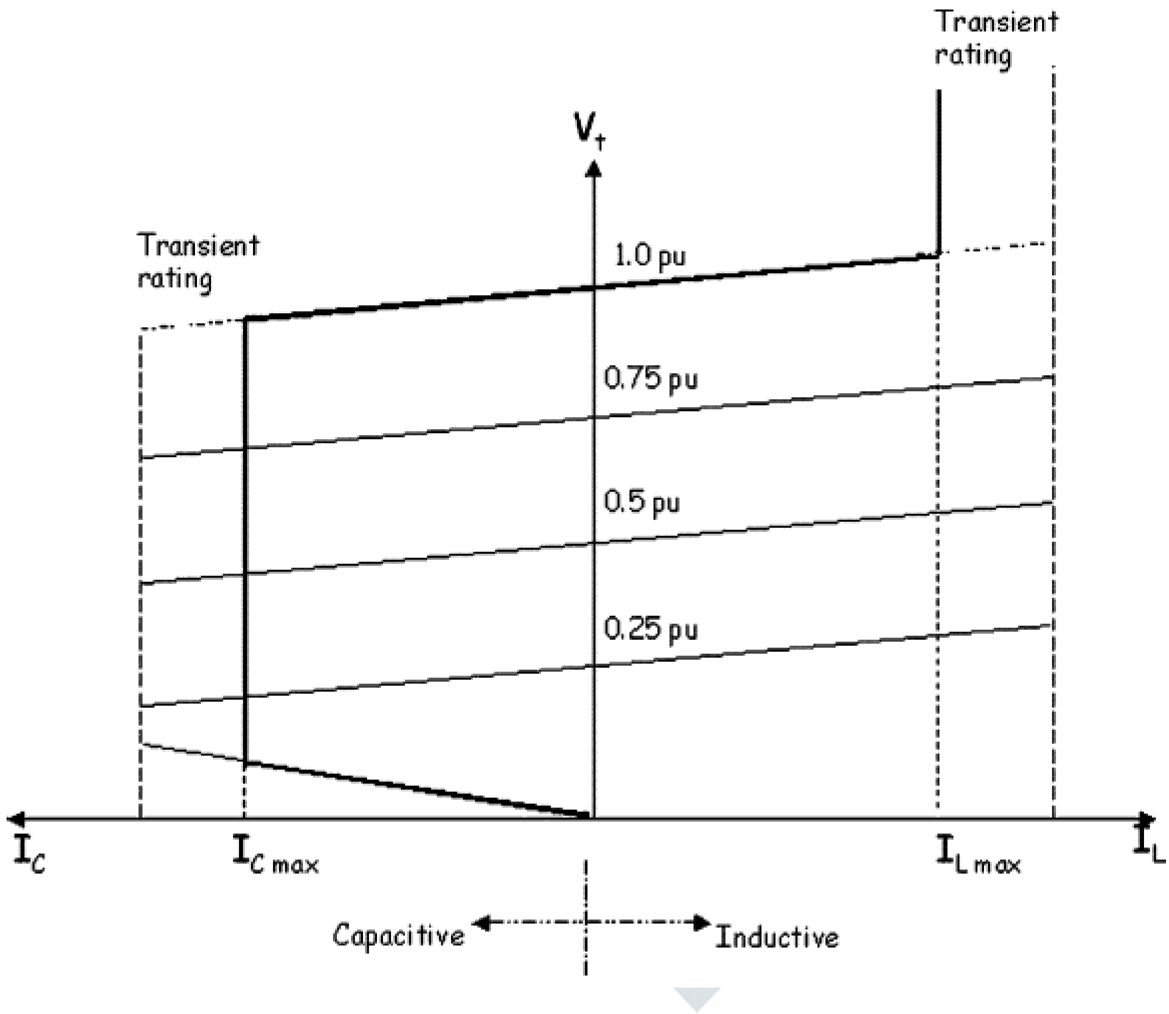


Figure 2: V-I characteristics of a STATCOM

The STATCOM can provide full capacitive reactive current independent of the system voltage up to to a system voltage of 0.15 pu [28]–[30]. This would mean that the capacitive reactance of a STATCOM could go to a very low value.

STATCOM Specifications

1) STATCOM is 6-pulse GTO-based voltage-source inverter, 100 MVA, 115 kV rated voltage. PWM switching frequency(,fs=60) Hz.

2) Coupling Power Transformers: Y- delta, 100 MVA, 115/25 kV and 0.1 pu

3 System Modelling:

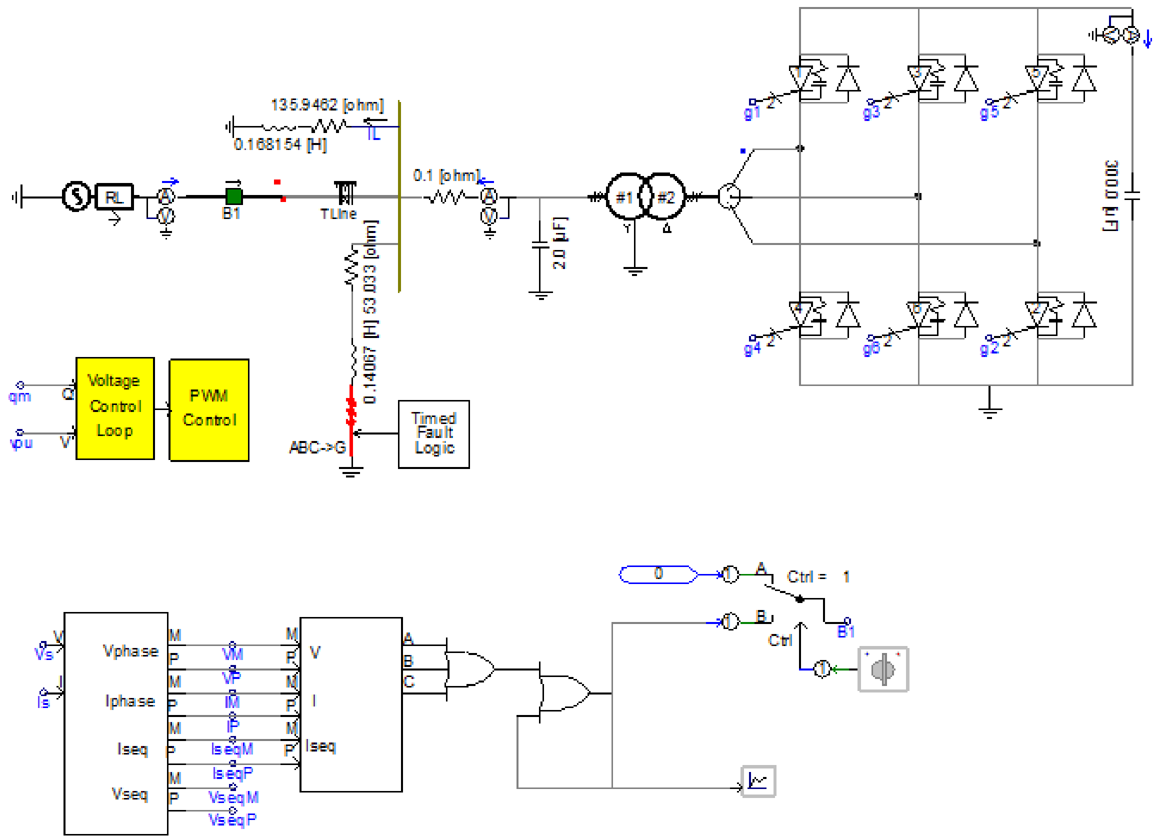
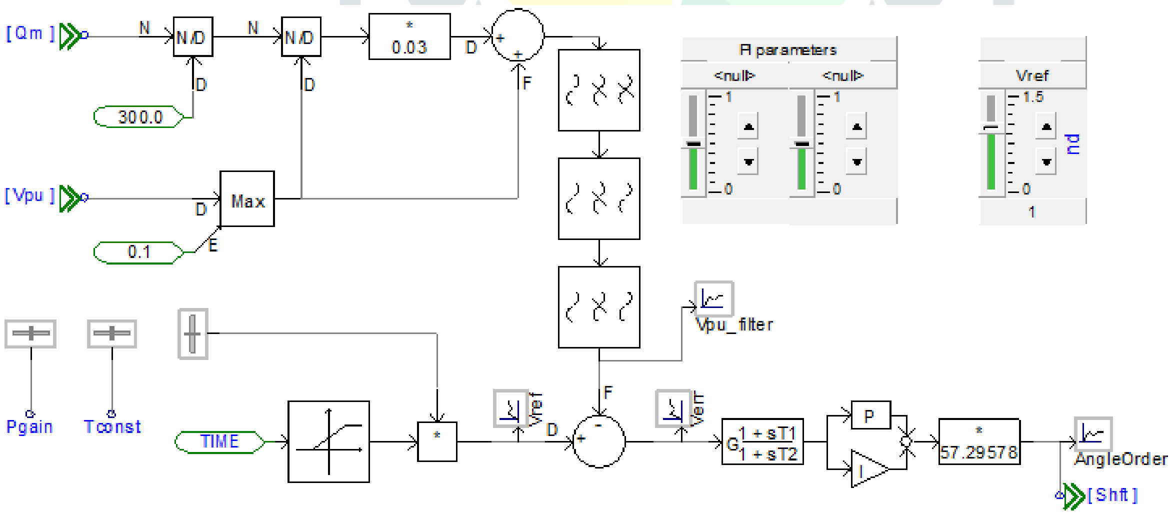


Figure 3a: Power system model with STATCOM and distance protection scheme.



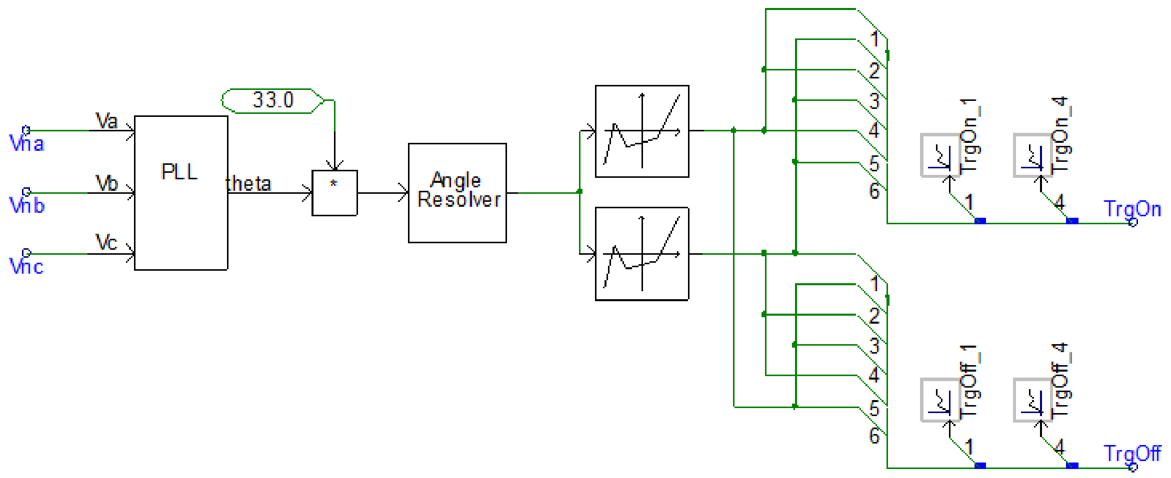


Figure 3b: Controller diagram for generating firing pulses.

4 Results and Discussions:

In this work a STATCOM is connected with a power system source end bus of 115kV 3phase supply. A fault is given at 1.5sec for duration of 0.5 sec. Two models are developed on PSCAD/EMTDC software for analysis of power signals during and after the fault. Case 1 involves the power system with the STATCOM without distance protection scheme and case 2 involves power system with the STATCOM with distance protection scheme. The results are generated and explained for both cases in upcoming section.

Case 1: Without distance protection -

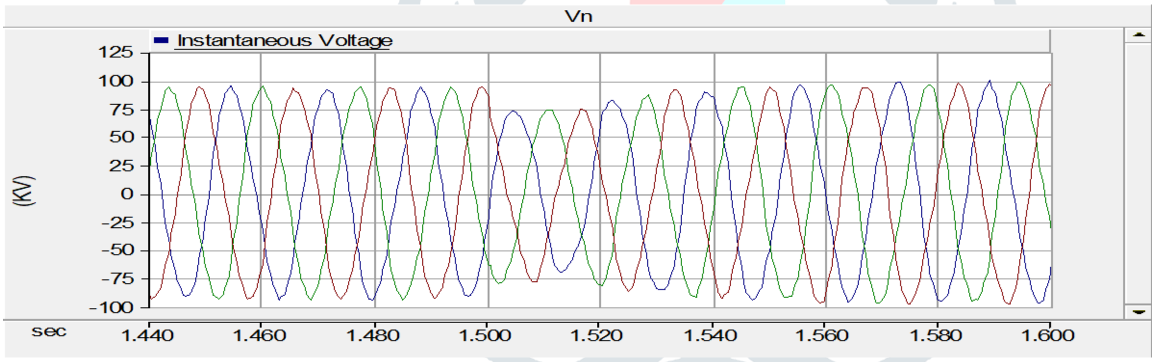


Figure 4.1a: Instantaneous voltage at source bus with STATCOM and without distance protection before and during fault.

The STATCOM is connected at source bus through a coupling transformer and fault is simulated. Instantaneous voltage is measured for 3phase supply before, during fault and after fault clearance. Figure 4.1a shows the measured voltage at source bus side connected voltmeter. After the fault the voltage is dropped and as the fault is removed the voltage increased and reaches to the steady state.

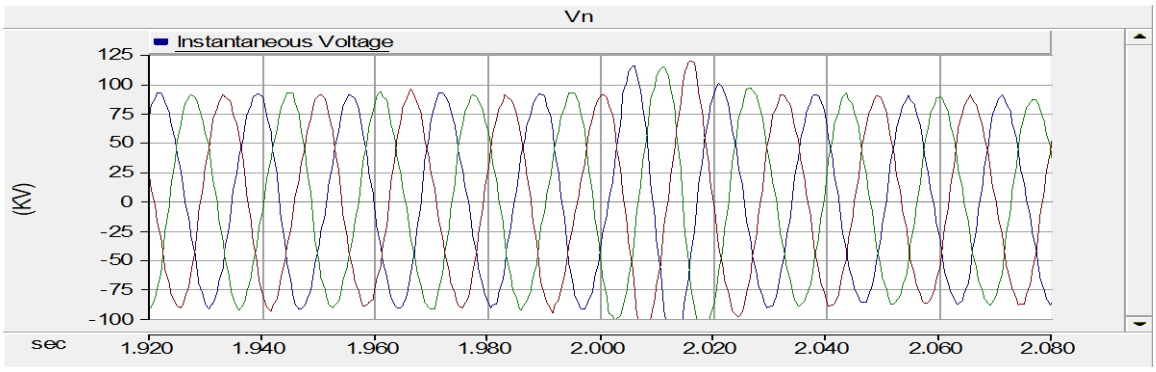


Figure 4.1b: Instantaneous voltage at source bus with STATCOM and without distance protection after fault clearance.

Instantaneous voltage is measured for 3phase supply after fault clearance is shown in Figure 4.1 b shows the measured voltage at source bus side connected voltmeter. After the fault the voltage is dropped and as the fault is removed the voltage increased and reaches to the steady state. After 2sec peak overshoot is observed and the transient time is also recorded.

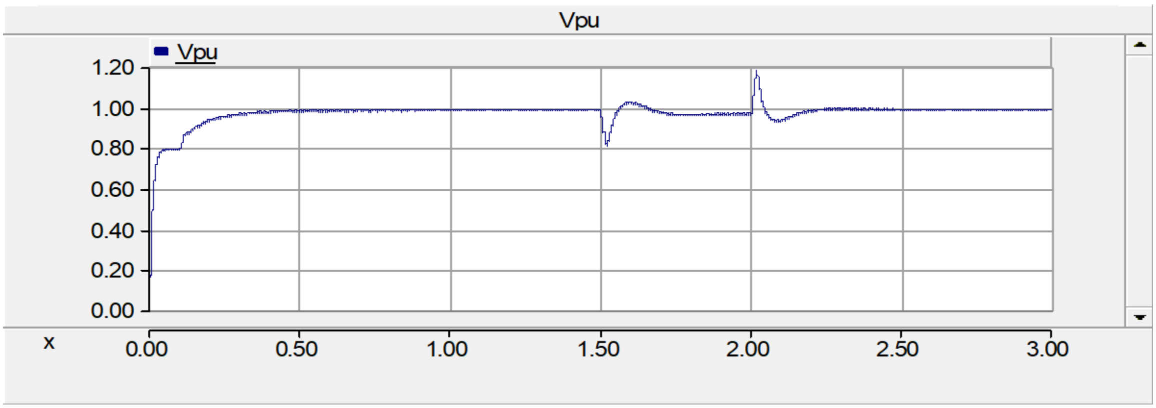


Figure 4.1c :Voltage magnitude at source bus with STATCOM and without distance protection .

Instantaneous voltage magnitude is also shown supply before, during fault and after fault clearance from 0 to 3sec simulation time and shown in Figure 4.1c.It shows the measured voltage at source bus side connected voltmeter. After the fault at 1.5 sec the voltage is dropped and as the fault is removed at 2.0sec the voltage increased and reaches to the steady state.

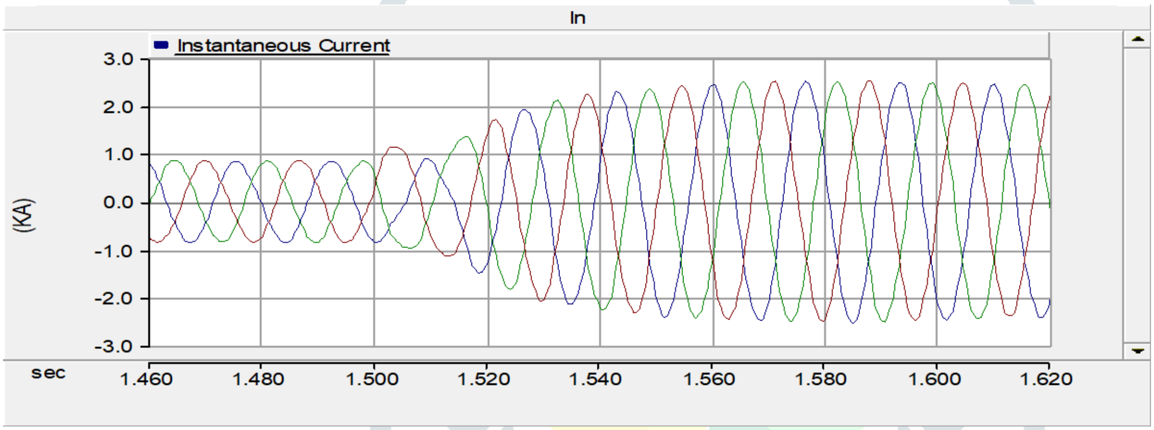


Figure 4.2a : Instantaneous current at source bus with STATCOM and without distance protection before and during fault.

Instantaneous current is also measured before, during fault and after fault clearance. Figure 4.2a shows the measured current. After the fault the current is increased at 1.5 second and within fault duration reached to steady state.

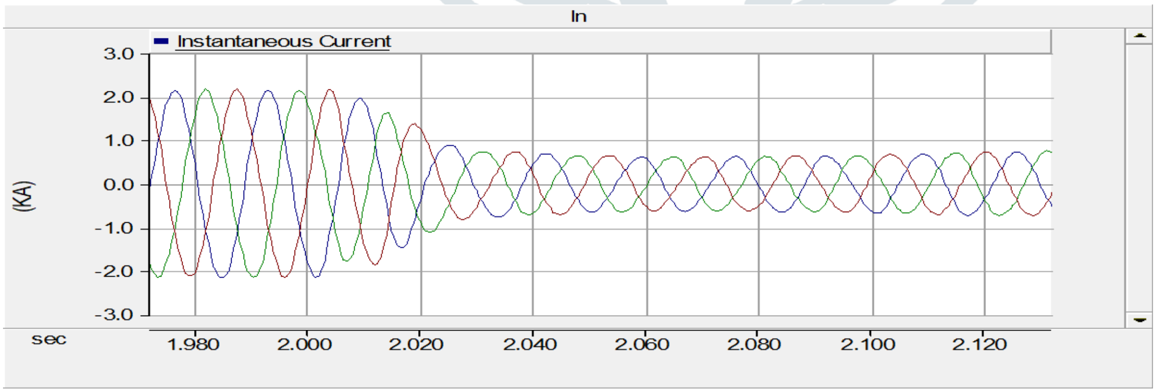


Figure 4.2b : Instantaneous current at source bus with STATCOM and without distance protection before and during fault.

Instantaneous current after fault clearance is shown in Figure 4.2 b after the fault is removed at 2.0 sec the current is dropped and reaches to the steady state.

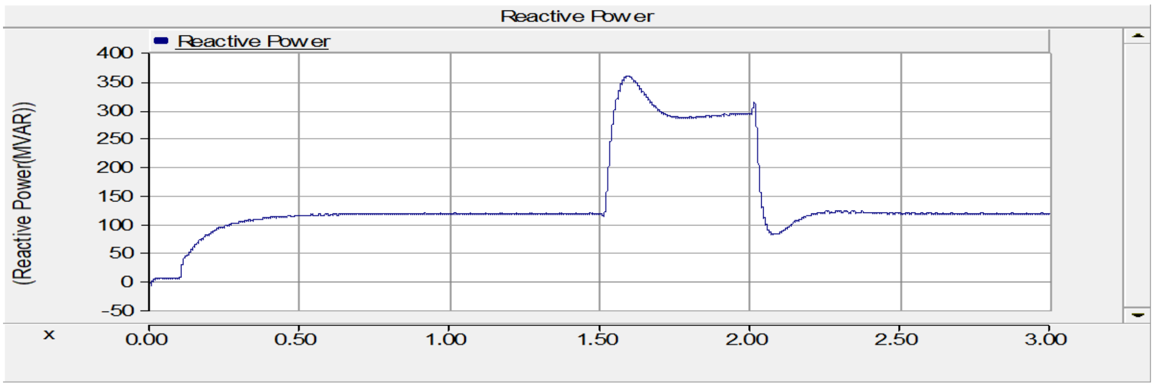


Figure 4.2 c : Reactive power at source bus with STATCOM and without distance protection before and during fault.

Reactive power magnitude is also shown before, during fault and after fault clearance from 0 to 3sec (see Figure 4.2c).It shows the measured reactive power after the fault at 1.5 sec is abruptly increased and as the fault is removed at 2 sec it decreases and reaches to the steady state.

Case 2: With distance protection-

In this case the result are generated for the case when a distance protection scheme is provided by the measurement of fault impedance value using mho circle by adding the breaker 1 at the source end the line is disconnected by sending trip signal to breaker.

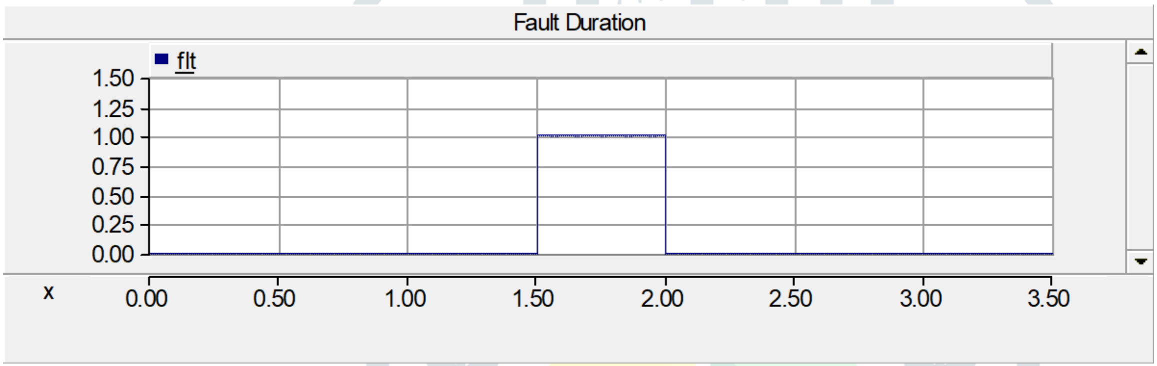


Figure 4.3 a: Fault Signal generated for 0.5sec.

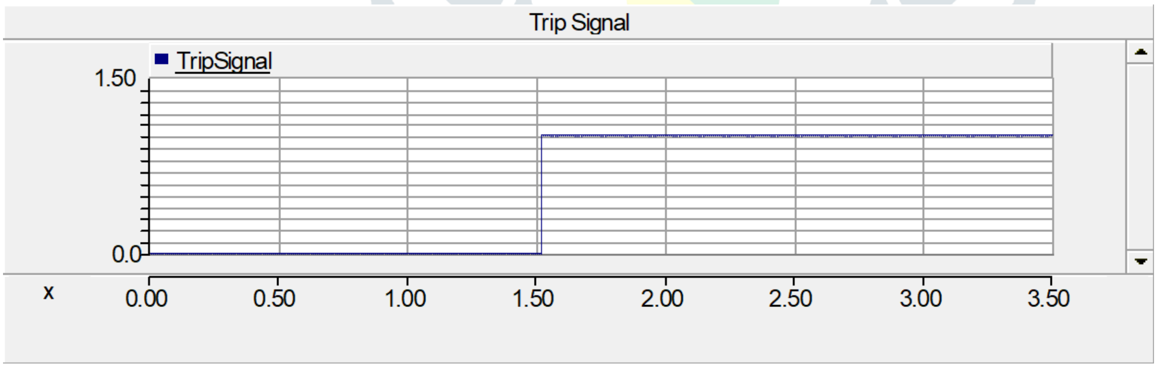


Figure 4.3b: Trip signal generated by protection scheme.

Figure 4.3 shows the occurrence time of the fault. A pulse is given to the fault block at the load terminal. The fault occurrence time is from 1.5sec to 2sec and fault duration is 0.5sec.As the fault occurred the voltage and current signals sense the change in line impedance through mho circle and sends the trip signal to the breaker. The generation of trip signal just after fault occurrence i.e. 1.5sec is shown in figure 4.3b.

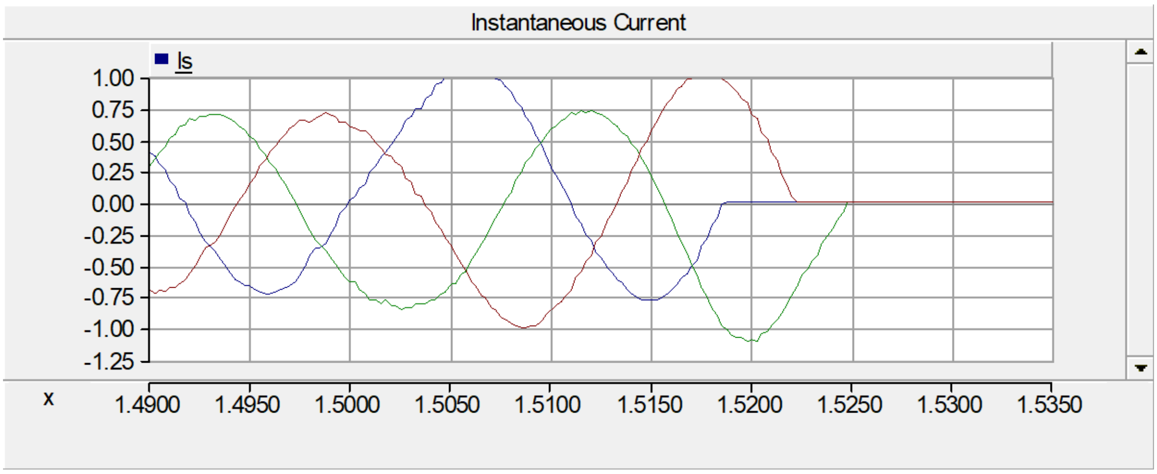


Figure 4.4a: Instantaneous current at source bus with STATCOM and with distance protection before and during fault.

The STATCOM is connected at source bus through a coupling transformer along with the breaker at the source. Fault is simulated and instantaneous current is measured Figure 4.3a shows the measured voltage at source bus side connected voltmeter. After the fault the current is dropped to zero due to instant removal of line from the source by the breaker.

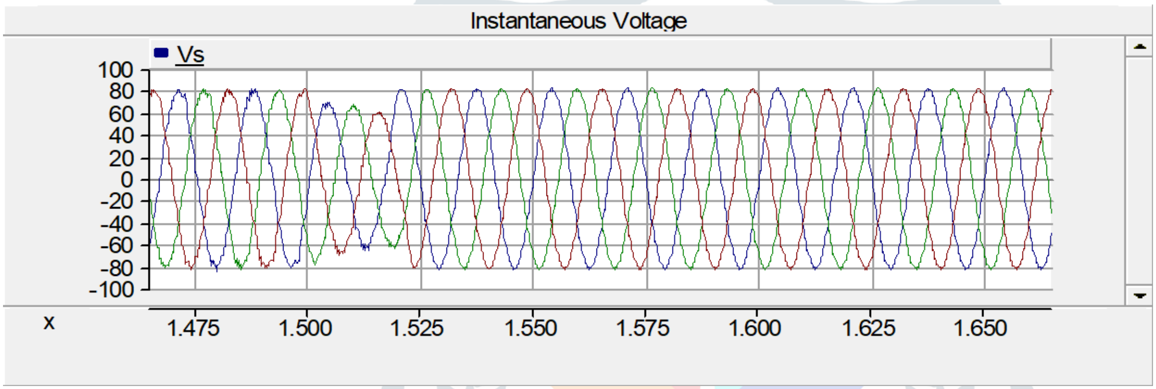


Figure 4.5a: Instantaneous voltage at source bus with STATCOM and with distance protection before and during fault.

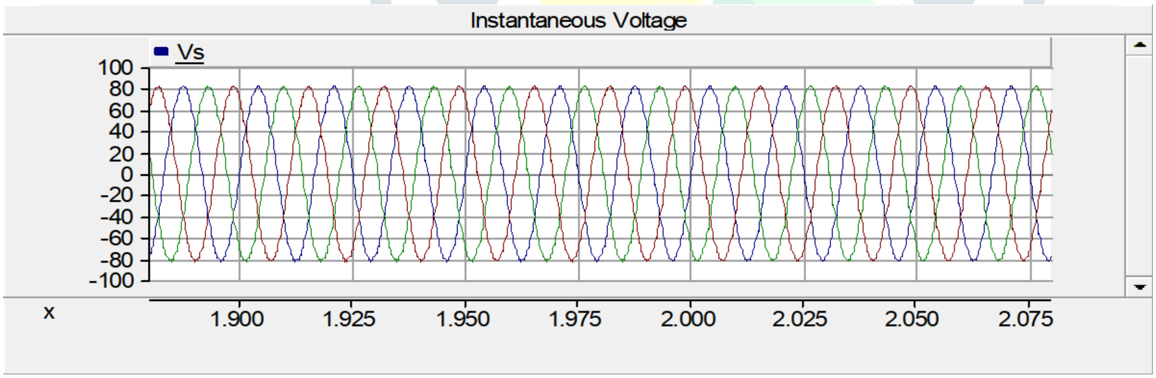


Figure 4.5b: Instantaneous voltage at source bus with STATCOM and with distance protection after fault clearance.

Instantaneous voltage is measured for 3phase supply after fault clearance is shown in Figure 4.5 b shows the measured voltage at source bus side connected voltmeter. After the fault the voltage is constant and as the fault is removed the voltage remains unchanged at the steady state. After 2sec no peak overshoot is observed and no transient is recorded due to instant removal of line.

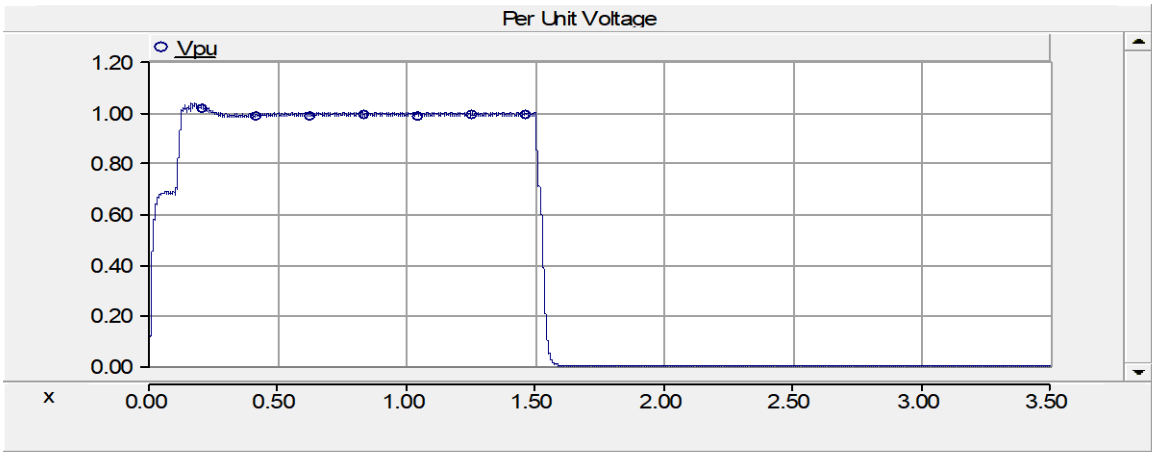


Figure 4.5 c: Voltage magnitude at source bus with STATCOM and with distance protection.

Instantaneous voltage magnitude is also shown supply before, during fault and after fault clearance from 0 to 3.5sec simulation time and shown in Figure 4.5c.It shows the measured voltage at source bus side connected voltmeter. After the fault at 1.5 sec the voltage is dropped and as the fault is removed at 2.0sec the voltage remains zero as the breaker has disconnected the line.

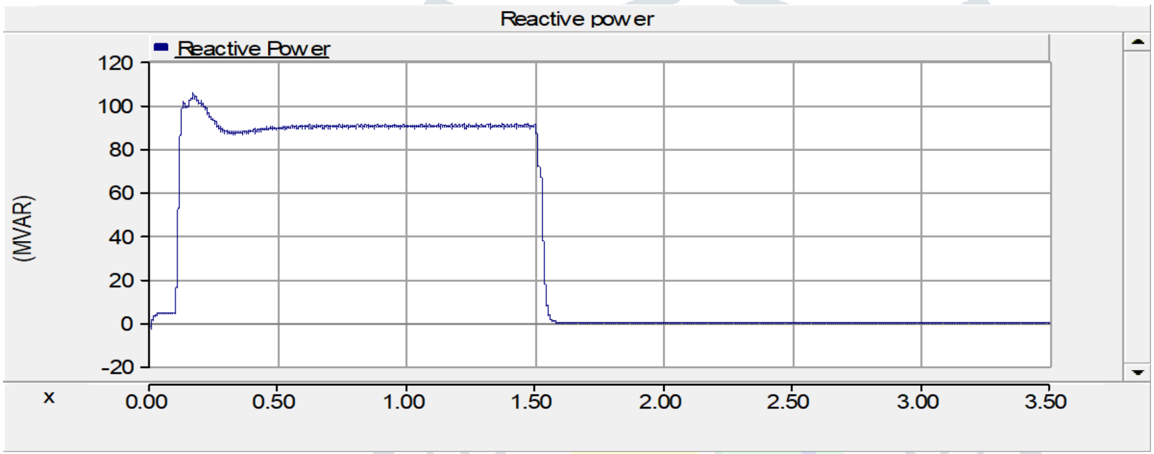


Figure 4.6: Reactive power at source bus with STATCOM and with distance protection before and during fault.

Reactive power magnitude is also shown before, during fault and after fault clearance from 0 to 3sec (see Figure 4.6).It shows the measured reactive power after the fault at 1.5 sec is becoming zero due to isolation of the line. All the results of plots discussed are analysed for different instances of fault are tabulated below.

Table 1:Instantaneous Voltage				
Sr. no	STATCOM Without distance protection		STATCOM With distance protection	
	Time	Value	Time	Value
1	t<1.5sec	94 KV	t<1.5sec	82 KV
2	1.5 sec <t < 2 sec	73 KV	1.5 sec <t < 2 sec	78 KV
3	t>2 sec	119 KV	t>2 sec	82 KV
4	Settling Time	0.12 sec	Settling Time	0.025 sec
Table 1:Instantaneous Current				
Sr. no	STATCOM Without distance protection		STATCOM With distance protection	
	Time	Value	Time	Value
1	t<1.5sec	0.860 KA	t<1.5sec	0.75 KA
2	1.5 sec <t < 2 sec	2.510 KA	1.5 sec <t < 2 sec	1.095 KA
3	t>2 sec	0.88 KA	t>2 sec	0
4	Settling Time	0.2 sec	Settling Time	0.025 sec

Table 2: Analysis of Voltage (pu) with and without distance protection in presence of STACOM.

Table 1:Per Unit Voltage				
Sr. no	STATCOM Without distance protection		STATCOM With distance protection	
	Time	Value	Time	Value
1	t<1.5sec	0.99	t<1.5sec	0.99
2	1.5 sec <t < 2 sec	1.025	1.5 sec <t < 2 sec	0.514
3	t>2 sec	1.21	t>2 sec	0.0010

4	Settling Time	0.24 sec	Settling Time	0.1 sec

Table 3: Analysis of Voltage (pu) with and without distance protection in presence of STACOM.

Sr. no	STATCOM Without distance protection		STATCOM With distance protection	
	Time	Value	Time	Value
1	t<1.5sec	118(MVAR)	t<1.5sec	90.35(MVAR)
2	1.5 sec <t < 2 sec	359.60(MVAR)	1.5 sec <t < 2 sec	31.50(MVAR)
3	t>2 sec	122(MVAR)	t>2 sec	0
4	Settling Time	0.0320 sec	Settling Time	0.12 sec

5 Conclusions:

The proposed work focus on distance relay based protection scheme for frequent occurring ABC-G (3phase line to ground) fault with shunt-FACTS as STATCOM. Observations were made in presence of STATCOM without and with distance protection schemes. It is observed that the trip action has impact due to coupling transformer connection due to variation in impedance. The observed results are justified in terms of overshoot and settling time of current and voltage transients. It is observed that the current and voltage overshoots and settling time are reduced on adding distance protection. The reactive power is also observed to be reduced.

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