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Design and Simulation of an Efficient STATCOM Controller to Improve Electric Power System Dynamics

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Abstract – *This paper presents the design and simulation of a static synchronous compensator (STATCOM) controller which is one of the key shunt controllers in flexible alternating current transmission system (FACTS) to control the transmission line voltage and can be used in power systems to enhance the power transmission capacity and extend the transient stability margin. In this paper, the STATCOM based on the voltage source converter (VSC) topology is proposed as it is conventionally realized by a VSC that can generate a controllable current directly at its output terminals. The performance and behavior of the STATCOM is simulated at different cases which result in excellent current and voltage waveforms as well as short response time while operating at a low switching frequency. The transmission system is divided into two portions; one is consisted of two sets of three phase transmission lines in parallel and another is consisted of a three phase transmission line. When the STATCOM is not installed, interruption of either three phase line due to a fault decreases the transmission line voltage as the line impedance increases to double before the interruption. Different bus voltages at different cases are simulated and it is observed that installing the STATCOM makes it possible to control the transmission line voltage. The proposed STATCOM has been simulated using the MATLAB/Simulink package*

Keywords – FACTS, PID controller, PWM technique, STATCOM, VSC.

1. INTRODUCTION

Due to deregulation, environmental legislations and cost of construction, it is becoming increasingly difficult to build new transmission lines. Thus it is essential to fully utilize the capacities of the existing transmission systems. FACTS controllers are proving to be very effective in using the full transmission capacity while increasing operational efficiency and maintaining reliability of power systems. These controllers are based on power electronic devices and have fast response time. Advanced FACTS controllers are based on voltage source converter mainly. As an important member of the FACTS controllers' family, STATCOM has been at the center of attention and the subject of active research for many years. STATCOM is a shunt connected device that is used to provide reactive power compensation to a transmission line. STATCOM can enhance the power transmission capability and thus extend the steady-state stability limit through regulation of the line voltage at the point of connection. STATCOM can also be used to introduce damping during power system transients and thus extend the transient stability margin when controlled properly [1]-[3].

Theoretically, FACTS controllers can be realized by either a VSC or a current source converter (CSC) [4], [5]; but practically more than 10 years ago, the focus of all the published work on STATCOM except a few has been on using VSC topology because CSC is more complex than a VSC in both power and control circuits. Filter capacitors are used at the ac terminals of a CSC to improve the quality of the output ac current waveforms. This adds to the overall cost of the converter. Furthermore, filter capacitors resonate with the ac-side inductances. As a result, some of the harmonic components present in the output current might be amplified, causing high harmonic distortion in the ac-side current. Besides, conventional bi-level switching scheme cannot be used in CSC. Unless a switch of sufficient reverse voltage withstanding capability such as Gate Turn Off Thyristor (GTO) is used, a diode has to be placed in series with each of the switches in CSC. This almost doubles the conduction losses compared with the case of VSC. The dc-side energy-storage element in CSC topology is an inductor, whereas that in VSC topology is a capacitor. The power loss of an inductor is expected to be larger than that of a capacitor. Thus, the efficiency of a CSC is expected to be lower than that of a VSC [6]-[9].

In this paper, the STATCOM controller is represented as block diagram in the MATLAB/Simulink environment that presents electronic model of the original control circuit. PID controller is used to control the desired parameter. Basically there are four loop tuning methods for a PID controller; these are Manual Tuning, Ziegler–Nichols, Software Tools and Cohen-Coon method. Ziegler–Nichols method is chosen for loop tuning primarily and then manual tuning is applied to the PID controller by trial and error method to increase its performance. Generally there are four

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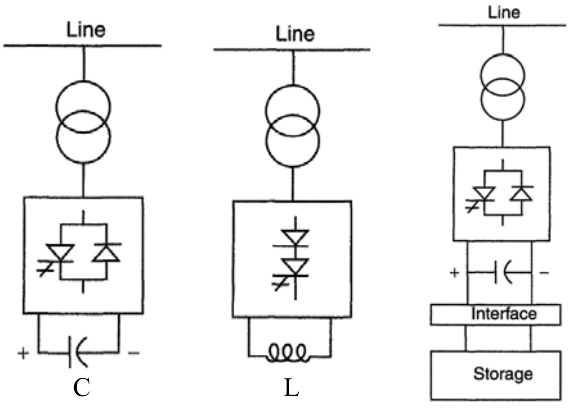
different control strategies for a controller, direct control, decoupling control, cross control and matrix control. Direct control method is used in the controller. Two PID controllers are simultaneously used, one is used to control phase shift and another is used to control modulation index.

2. PRINCIPLE OF OPERATION

STATCOM can be defined as a static synchronous generator operated as a shunt-connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage. The shunt controllers may be variable impedance, variable source, or a combination of these [10]. The STATCOM connected to a transmission line is shown in Figure 1. The VSC is represented in symbolic form by a box with a gate turn off device paralleled by a reverse diode and a dc capacitor as its voltage source as shown in Figure 1(a). The CSC is represented by a box with a gate turn off device with a diode in series and a direct current (dc) reactor as its current source as shown in Figure 1(b). The VSC represented in symbolic form by a box with a gate turn off device paralleled by a reverse diode and a dc capacitor with storage connected by an interface is shown in Figure 1(c).



(a) (b) (c)

Fig. 1. Static synchronous compensator.

In principle, all shunt controllers inject current into the system at the point of connection. Even variable shunt impedance connected to the line voltage causes a variable current flow and hence represents injection of current into the line. As long as the injected current is in phase quadrature with the line voltage, the shunt controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well [11]. The shunt controller is like a current source, which draws from or injects current into the line. The shunt controller is therefore a good way to control voltage at and around the point of connection through injection of reactive current (leading or lagging), alone or a combination of active and reactive current for a more effective voltage control and damping of voltage oscillations [12].

The shunt converter can be controlled in two different modes one is reactive volt-ampere (VAR) control mode another is automatic voltage control mode. In case of VAR control mode the reference input is an inductive or capacitive VAR request. The shunt inverter control translates the var reference into a corresponding shunt current request and adjusts gating of the inverter to establish the desired current [13]. For this mode of control a feedback signal representing the dc bus voltage is also required. In case of automatic voltage control mode the shunt converter reactive current is automatically regulated to maintain the transmission line voltage at the point of connection to a reference value. For this mode of control, voltage feedback signals are obtained from the sending end bus feeding the shunt coupling transformer [14], [15]. Let us assume that the voltage across the secondary coil of the shunt transformer is V_1 and the generated voltage of the VSC is V_2. In steady state operation, the voltage V_2 is in phase with V_1, only reactive power is flowing. If V_2 is lower than V_1, Q is flowing from V_1 to V_2; e. g. STATCOM is absorbing reactive power. On the reverse, if V_2 is higher than V_1, Q is flowing from V_2 to V_1; that means STATCOM is generating reactive power. The amount of real and reactive power which is represented by P and Q respectively are given by:

$$P=\frac{V_1V_2\sin\delta}{X} \tag{1}$$

$$Q=\frac{V_1(V_1-V_2\cos\delta)}{X} \tag{2}$$

where X is the equivalent reactance of the shunt transformer and δ is the angle of V_1 with respect to V_2.

3. SIMULATION SETUP

Figure 2 shows the simulation model including a power system with a transmission line and some loads. The STATCOM is installed at bus B2 which can be treated as nearly midpoint of the sending end and the receiving end.

Different loads are connected at the bus B2 and B3. The transmission system is divided into two portions; one is consisted of two sets of three phase transmission lines in parallel represented by TL1 and another is consisted of a three phase transmission line represented by TL2. All loads including the TL1 are connected by three phase breakers which can connect or disconnect the related portion of the circuit at any time executed by the program.

The basic block diagram of the STATCOM is illustrated in Figure 3. B1, B2 and B3 represent three GTO/Diode double arm bridges. Conventionally shunt controllers are constructed of three phase converters or inverters but it is possible to replace the three single phase converters with a three phase converter. The three phase converter constructed with three single phase converter produces less switching ripples than the conventional three phase converter [16].

So, three phase converter constructed with three single phase converters is used. T1, T2, and T3 represent the transformer coils of phase A, B, and C respectively that form a three phase transformer connected to shunt converter. A capacitor (C) which acts as a voltage source is used. The original circuit diagram of each GTO/Diode bridge (B1, B2, and B3) is shown in Figure 4. Each bridge consists of four GTO and four diodes where the GTO and diode are connected in antiparallel way. So, four different control pulses are required to control each of the bridges. Therefore to apply firing pulses to three different bridges properly total twelve different pulses are required to control. For each GTO/Diode bridge, a 4-input multiplexer is used.

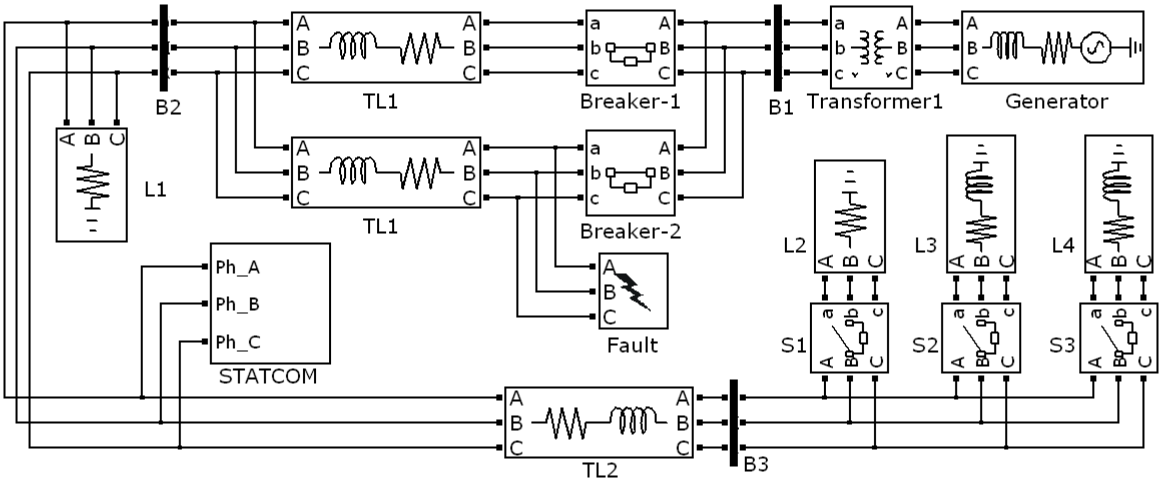


Fig. 2. STATCOM connected to the simulation model of the power system.

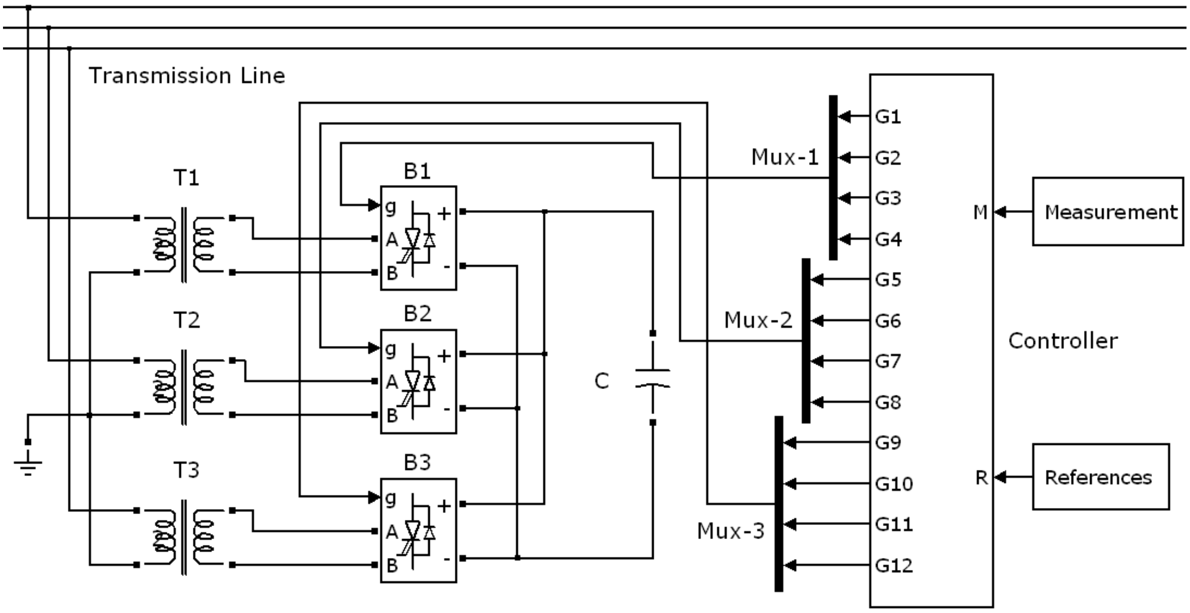


Fig. 3. Block diagram representation of the STATCOM.

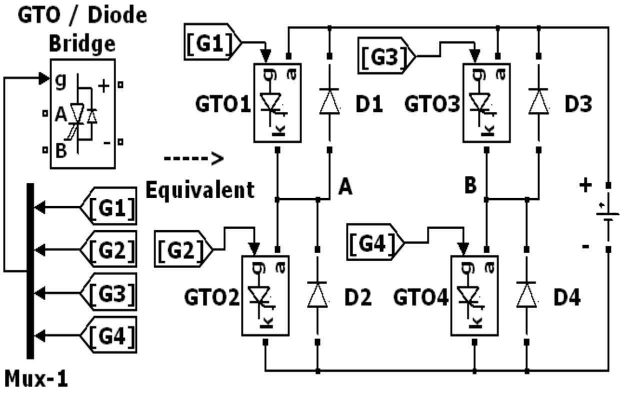


Fig. 4. A GTO/diode bridge equivalent circuit.

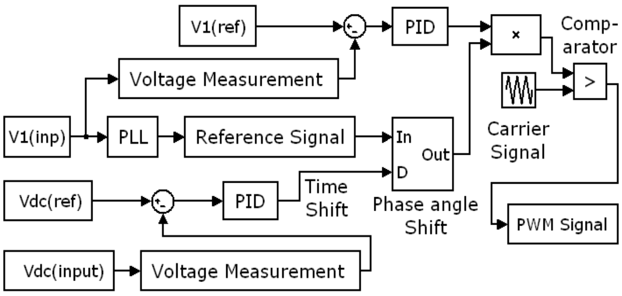


Fig. 5. Block diagram of the STATCOM controller.

4. CONTROL STRATEGY

The shunt converter is operated in such a way as to demand this dc terminal power from the line keeping the voltage across the storage capacitor V_{dc} constant. So, the net real power absorbed from the line by the STATCOM is equal only to the losses of the converters and their transformers according to Equation 1. The remaining capacity of this shunt converter can be used to exchange reactive power with the line so to provide VAR compensation at the connection point. The reactive power which can be found from Equation 2 is electronically provided by the shunt converter, and the active power is transmitted to the dc terminals. The shunt converter reactive current is automatically regulated to maintain the transmission line voltage at the point of connection to a reference value. For this mode of control, voltage feedback signals are obtained from the sending end bus feeding the shunt coupling transformer. The block diagram of the STATCOM control technique is illustrated in Figure 5.

The line voltage and dc link voltage across capacitor are measured to calculate the amount of reactive power to regulate the line voltage as in this case STATCOM acts as a voltage regulator. The controller is consisted of 12 GTO with additional components. The controller controls the signal from G1 to G12 which are sinusoidal pulse width modulated signals. In the Figure 5 only one pulse width modulated signal generation technique is shown, another 11 signal can be generated similarly.

5. SIMULATION RESULTS

Case 1: When the load L1 and L2 is connected at t=0 second, L2 is connected at t=0.6 second and L3 is connected at t=1.2 second. The start time of this simulation is t=0 second and the end time is t=3 second. Figure 6, 7, and 8 shows real and reactive power flow through the bus B1, B2, and B3.

Figure 9, 10, and 11 shows the Transmission line voltages at the bus B1, B2, and B3 in per unit (p. u.). The dotted line represents the voltage in p. u. when STATCOM is not used. The solid line represents the voltage in p.u. when STATCOM is installed. As it is installed at bus B2 the voltage is controlled successfully. Though STATCOM is not installed at bus B1 the voltage at bus B1 is 1 p.u. because the supply voltage is 1 p.u. The dc link voltage (V_{dc}) across the capacitor tends to change during operation. In steady state the voltage V_2 has to be phase shifted slightly behind V_1 in order to compensate for transformer and VSC losses and to keep the capacitor charged and due to maintain the constant dc voltage. The dc link voltage is shown in Figure 12. The modulation index is required to change due to generate or absorb the required amount of reactive power. To maintain constant transmission line voltage at B2 the modulation index is controlled by PID controller which is shown in Figure 13.

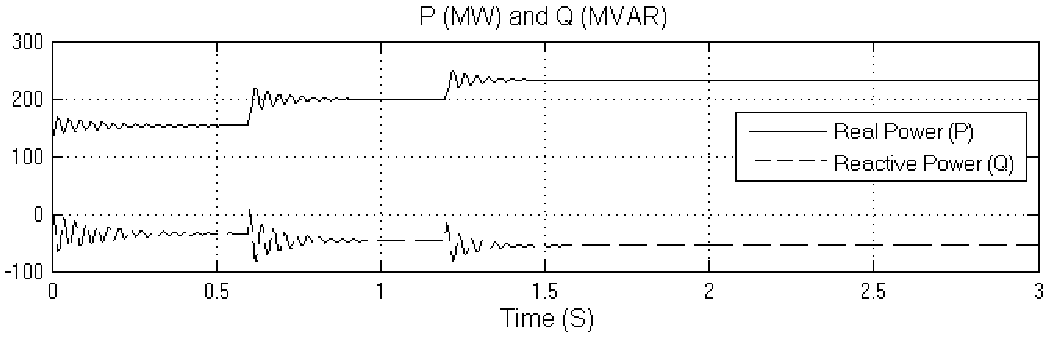


Fig. 6. Real and reactive power flow through B1.

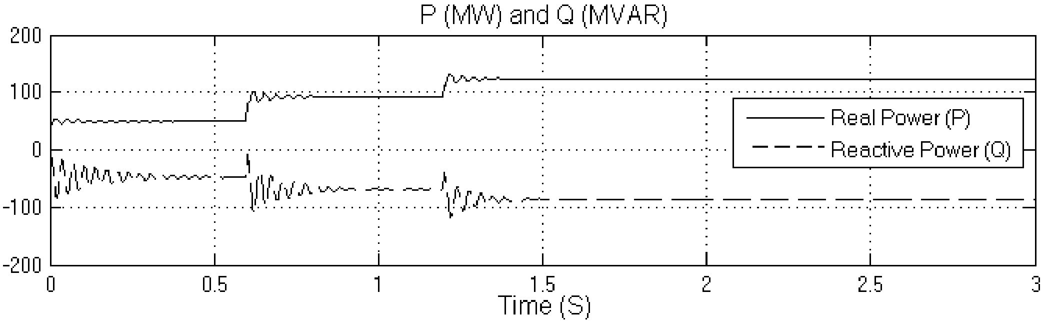


Fig. 7. Real and reactive power flow through B2.

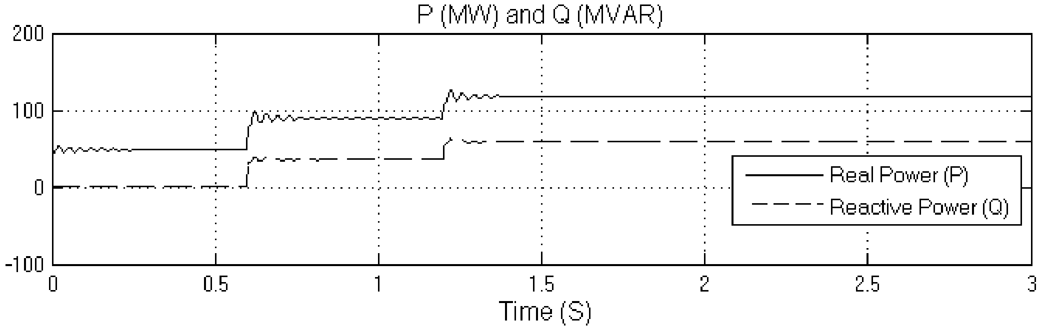


Fig. 8. Real and reactive power flow through B3.

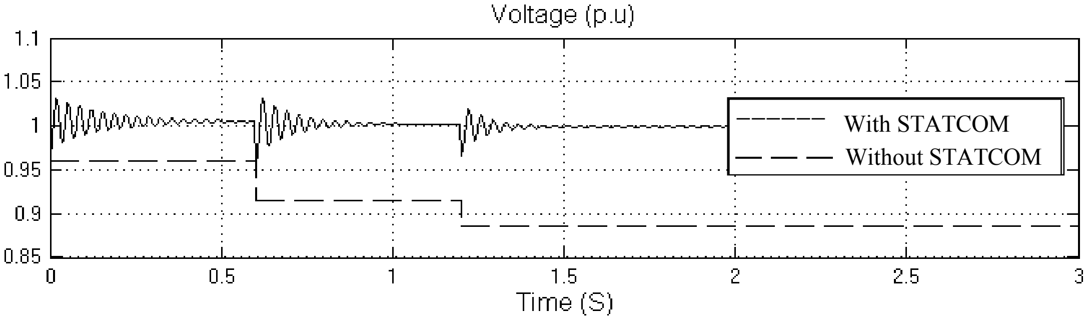


Fig. 9. Transmission line voltage at B1.

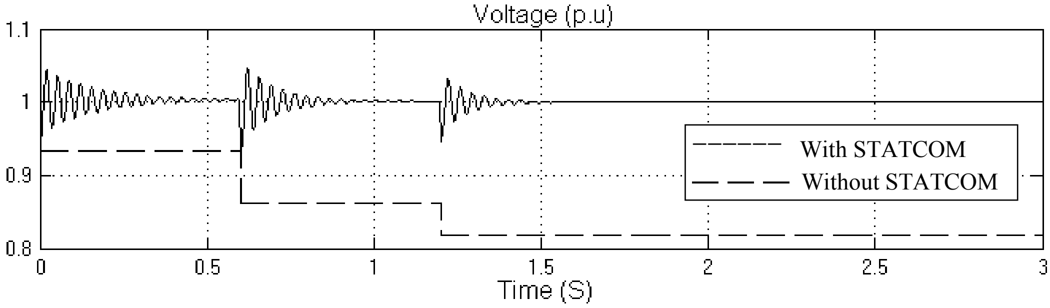


Fig. 10. Transmission line voltage at B2.

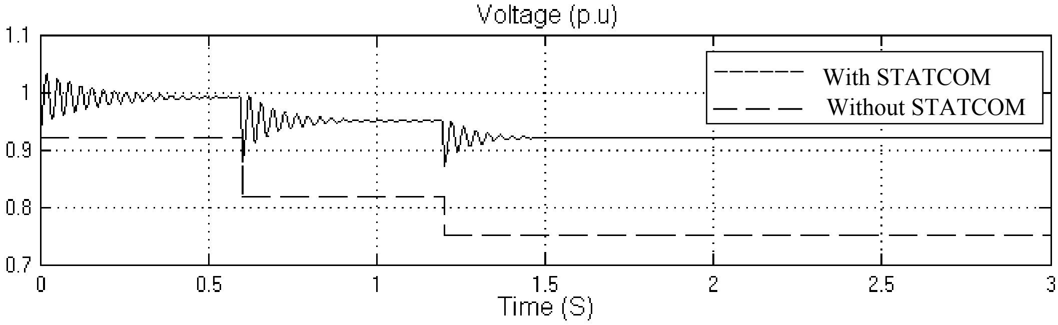


Fig. 11. Transmission line voltage at B3.

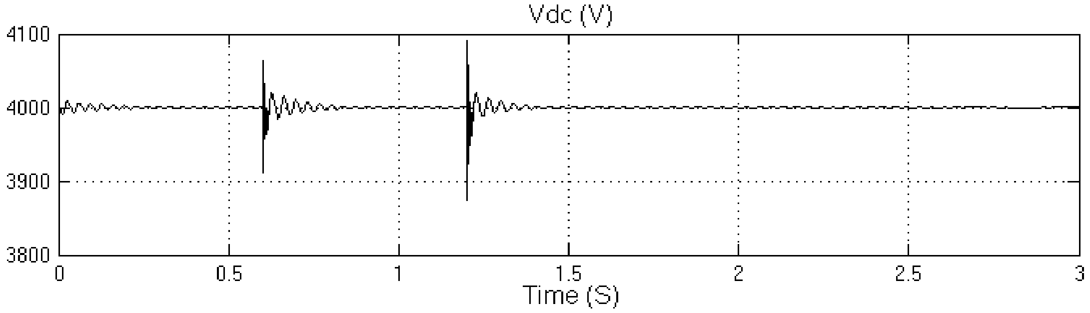


Fig. 12. DC link voltage.

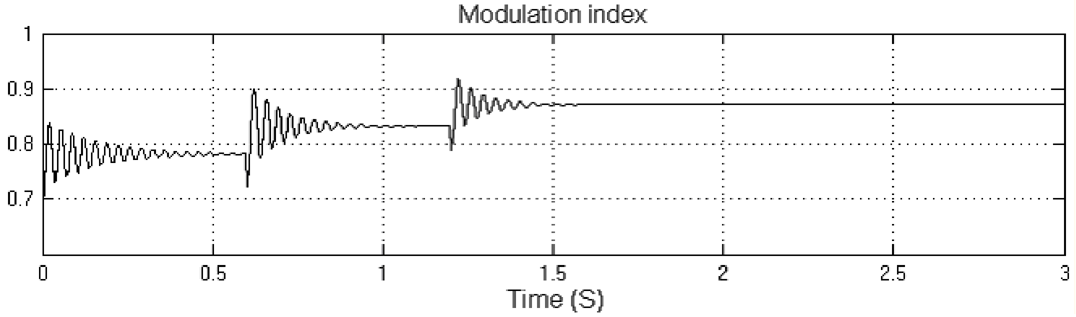


Fig. 13. Control of the modulation index.

Case 2: When a fault occurs at t=0.8 second at TL1 consisting of two sets of three phase transmission lines in parallel according to Figure 2, the breaker-2 disconnects the faulty section from the rest of the system. Therefore the line impedance becomes double before the interruption. The load L1, L2 and L3 are closed at t=0 second and load L4 is closed at t=2 second. The start time of this simulation is t=0 second and the end time is t=3 second. Figure 14, 15 and 16 shows the transmission line voltages at bus B1, B2 and B3. The original scales of Figures 9 to 11 and Figures 14 to 16 along y axis (voltage in p. u.) are 0 to 1.1 but all the scales are zoomed so that the voltage oscillations can be seen clearly. The dotted line represents the voltage in p.u. when STATCOM is not used. The solid line represents the voltage in p.u. when STATCOM is installed. Figure 17 represents the modulation index to control the amount of reactive power of the transmission line for the case-2.

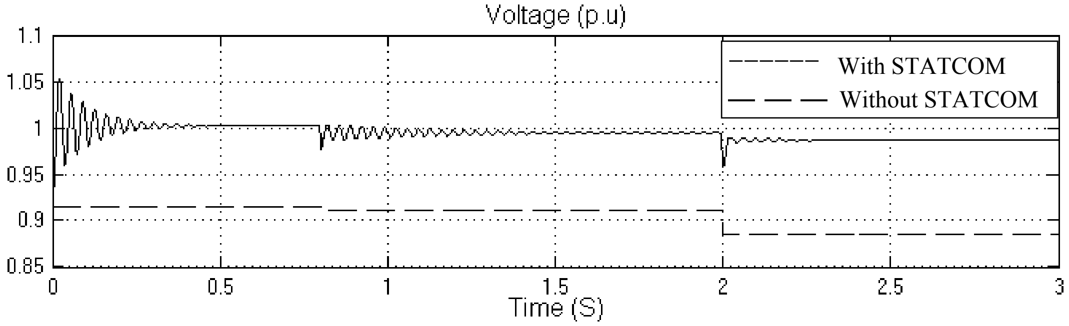


Fig. 14. Transmission line voltage at B1.

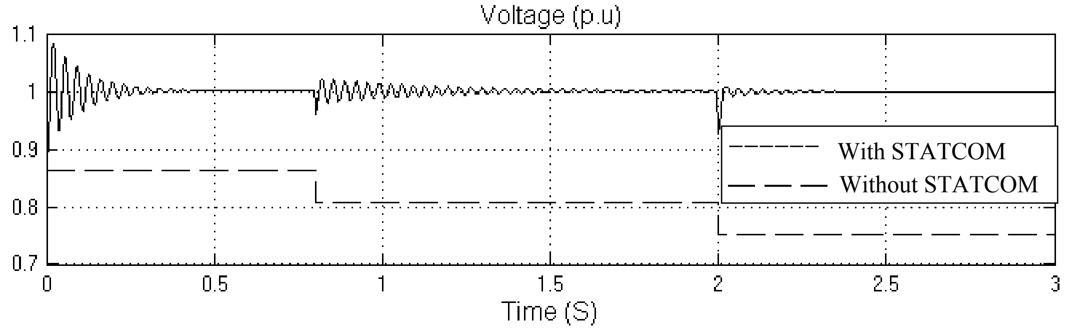


Fig. 15. Transmission line voltage at B2.

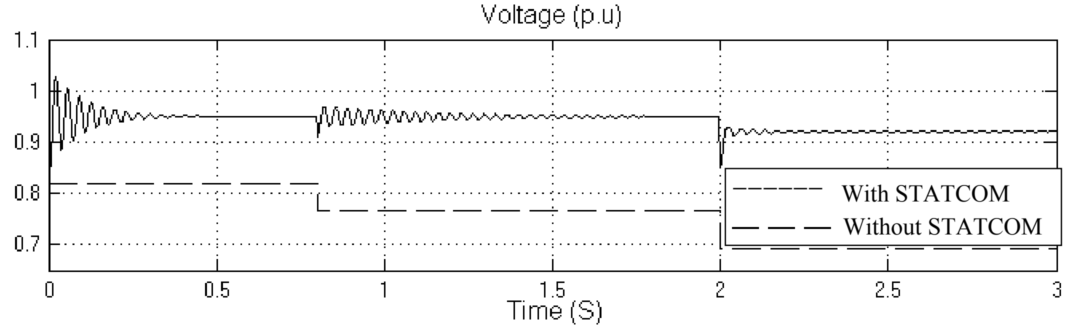


Fig. 16. Transmission line voltage at B3.

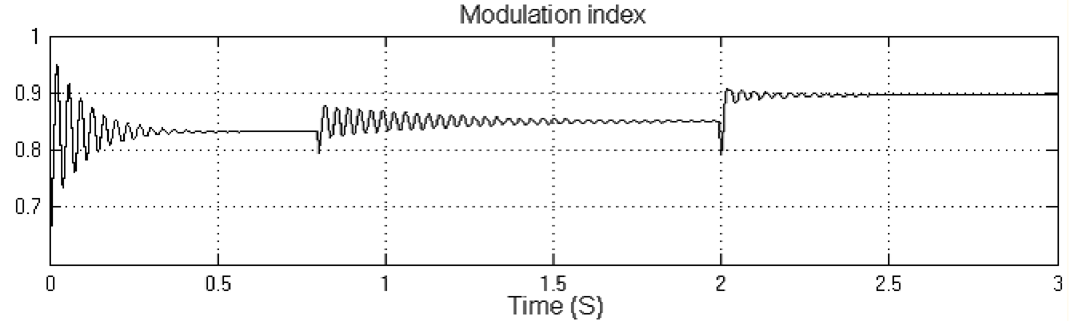


Fig. 17. Control of the modulation index.

6. CONCLUSION

The simulation results show that the STATCOM is capable enough to control the transmission line voltage though the same controller can be used in var control mode. V_{dc} is regulated by controlling proper phase shift and transmission line voltage is regulated by varying the modulation index. Two Single input single output (SISO) closed loop systems are used. The response of the controller is very fast due to apply direct control method. For any type of balanced and unbalanced fault like, simultaneous short circuit fault across all three phases, single line to ground fault, line to line fault and double line to ground fault represented by “Fault” block the circuit breaker isolates the faulty section. The simulation results also prove that the STATCOM with the proposed switching scheme functions successfully as the real time voltage controller and it improves the dynamic stability with a wide range of control the reactive power. From the simulation results it may seem that each case the magnitude of voltage oscillation is high because each figure is zoomed along y axis to observe the oscillation clearly but in original scale the oscillation is very low. Three single phase converters are used rather than three phase converter to reduce switching ripples. Bangladeshi national grid is modeled as transmission line in this paper.

REFERENCES

[1] Ye, Y., Kazerani, M., and Quintana, V.H., 2005. Current-source converter based STATCOM: modeling and control. *IEEE Transactions on Power Delivery* 20(2): 795-800.

[2] Jowder F.A., 2007. Improvement of synchronizing power and damping power by means of SSSC and STATCOM: A comparative study. *Electric Power Systems Research* 77(8): 1112-1117.

[3] Puleston, P.F., González, S.A. and Valenciaga, F., 2007. A STATCOM based variable structure control for power system oscillations damping. *International Journal of Electrical Power & Energy Systems* 29(3): 241-250.

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

[5] Moran, P.D., Ziogas, L.T., Joos, G. and Hingorani, N.G., 1989. Analysis and design of a three-phase current source solid-state var compensator. *IEEE Transactions on Industrial Application* 25(2): 356-365.

[6] Gyugyi, L., 1994. Dynamic compensation of AC transmission lines by solid-state synchronous voltage sources. *IEEE Transactions on Power Delivery* 9(2): 904-911.

[7] Gyugyi, L., Schauder, C.D., Williams, S.L., Reitman, T.R., Torgerson, D.R., and Edris, A., 1995. The unified power flow controller: A new approach to power transmission control. *IEEE transactions on power delivery* 10(2): 1085-1097.

[8] Lehn, P.W. and M.R. Iravani, 1998. Experimental evaluation of STATCOM closed loop dynamics. *IEEE Transactions on Power Delivery* 13(4): 1378-1384.

[9] Schauder, C.D. and H. Mehta, 1993. Vector analysis and control of advanced static VAR compensators. *IEE Proceedings* 140(4): 299-306.

[10] Sen, K.K., 1999. STATCOM—STATic synchronous COMPensator: Theory, modeling, and applications. In *Proceedings IEEE Power Engineering Society Winter Meeting*, 1177-1183.

[11] Yankui, Z., Yan, Z., Bei, W. and Jian, Z., 2006. Power injection model of STATCOM with control and operating limit for power flow and voltage stability analysis. *Electric Power Systems Research* 76(12): 1003-1010.

[12] El-Moursi, M.S. and A.M. Sharaf, 2006. Novel reactive power controllers for the STATCOM and SSSC. *Electric Power Systems Research* 76(4): 228-241.

[13] Tavakoli Bina, M., Eskandari, M.D. and Panahlou, M., 2005. Design and installation of a ±250 kVAr D-STATCOM for a distribution substation. *Electric Power Systems Research* 73(3): 383-391.

[14] Iyer, S., Ghosh, A. and Joshi, A., 2005. Inverter topologies for DSTATCOM applications-a simulation study. *Electric Power Systems Research* 75(2-3): 161-170.

[15] Ricardo D.M., Juan M.R. and Rubén T.O., 2005. Three-phase multi-pulse converter StatCom analysis. *International Journal of Electrical Power & Energy Systems* 27(1): 39-51.

[16] Fujita, H., Akagi, H. and Watanabe, Y., 2006. Dynamic control and performance of a unified power flow controller for stabilizing an AC transmission system. *IEEE Transactions on Power Electronics* 21(4): 1013-1020.

APPENDIX

Shunt Controller:
Voltage rating: 132 kV
Rated power: 200 MVA
DC link voltage: 4000 V
DC link capacitor: 1000 μF

Transmission line (TL1 and TL2):
Length: TL1=60 km, TL2=40 km
Model: Short transmission line
Resistance: 0.101 ohm/km
Reactance: 0.38 mH/km
Transmission line voltage: 132 kV

Generator:
Type: Y, Grounded neutral
System frequency: 50 Hz
Voltage rating: 11 kV (phase-phase)
Power rating: 300 MVA

Transformer1:
Voltage ratio: 11 kV/132 kV
Type: Y-Y
Rated power: 300 MVA
Resistance: 0.004 p.u.
Reactance: 0.08 p.u.

Loads:
L1: P=100 MW
L2: P=50 MW
L3: P=50 MW
Q=40 MVAR
L4: P=40 MW
Q=30 MVAR