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IMPROVEMENT OF ELECTRIC POWER SYSTEM DYNAMICS BY MEANS OF STATIC SYNCHRONOUS COMPENSATOR

Omar Farrok[1], M.G. Rabbani[2] and Md. Rabiul Islam[2]

ABSTRACT

The application of static synchronous compensator (STATCOM) is presented in this paper which is one of the key shunt controllers in flexible alternating current transmission system (FACTS) to control the transmission line voltage, improve the power factor and enhance the power transmission. 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 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. From the simulation of different cases it is found that the STATCOM is capable enough to control the transmission line voltage, control the reactive power, maintain unity power factor and improve the power transmission capability with shorter response time while operating at a low switching frequency. The proposed STATCOM has been simulated using the MATLAB / Simulink package.

Key words: *FACTS, PID controller, PWM technique, STATCOM, VSC*

INTRODUCTION

FACTS controller injects voltage in series and/or current in parallel to the transmission line to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle, and the damping of oscillations at various frequencies below the rated frequency. 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 mainly on voltage source converter. 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 (Yang *et al*., 2005; Fawzi, 2007; P. F. Puleston *et al*., 2007).

Theoretically, FACTS controllers can be realized by either a VSC or a current source converter (CSC) (N. G. Hingorani, 2000; L. T. Moran *et al.*, 1989); 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 (L. Gyugyi, 1994; L. Gyugyi *et al*., 1995; P. W. Lehn, 1998; C. D. Schauder, 1993; K. K. Sen, 1999). 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,

[1]Department of Electrical & Electronic Engineering, AUST, Rajshahi-6204, Bangladesh;
[2]Department of Electrical and Electronic Engineering, RUET, Rajshahi-6204, Bangladesh

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.

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. In principle, all shunt controllers inject current into the system at the point of connection. Even a 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 (Yankui *et al*., 2006). Different shunt compensators are shown in Figure 1(a). 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 (M. S. El–Moursi, 2006). The STATCOM connected to a transmission line with the VSC topology 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(b). 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(c). 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(d).

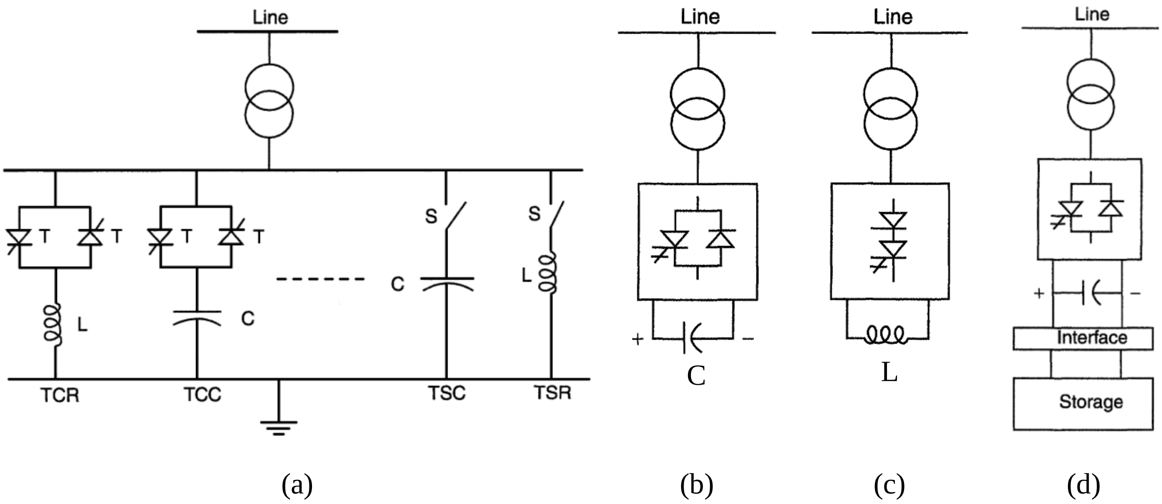

Figure 1. Different shunt compensators

The shunt converter can be controlled in two different modes one is 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 (Tavakoli *et al*., 2005). 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 (Shivkumar *et al*., 2005; Ricardo *et al.*, 2005). In steady state operation, the voltage V_2 generated by the VSC is in phase with V_1, only reactive power is flowing. Let us assumed that the line voltage is V_1 and the voltage of the VSC is V_2. 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

$$P = \frac{V_1 V_2 \sin\delta}{X} \quad \text{------------------------------------} \; (1)$$

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

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.

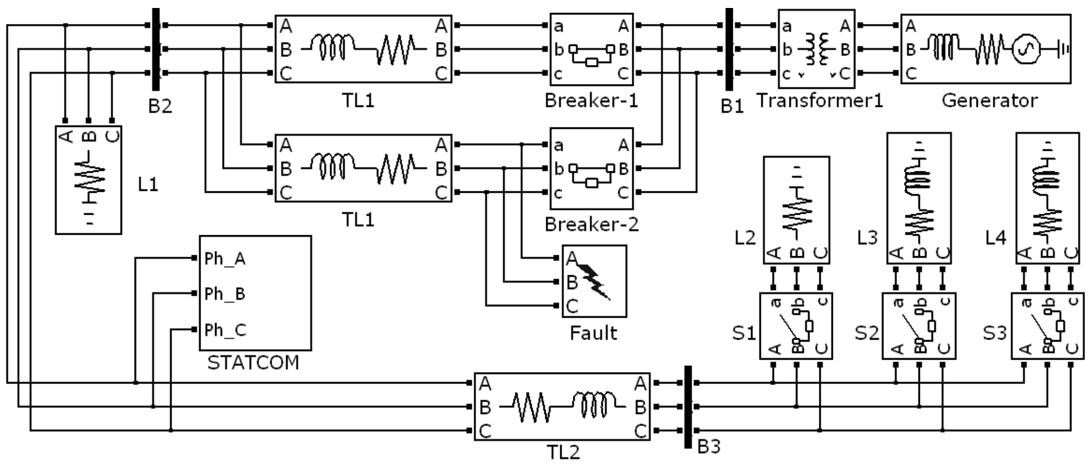

Figure 2 Simulation model of the power system

The basic block diagram of the STATCOM is illustrated in Figure 3. B1, B2 and B3 represent three GTO / Diode double arm bridges. Mux-1, Mux-2 and Mux-3 represent three multiplexers. 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. So three phase converter constructed with three single phase converter 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 GTO / Diode bridges (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.

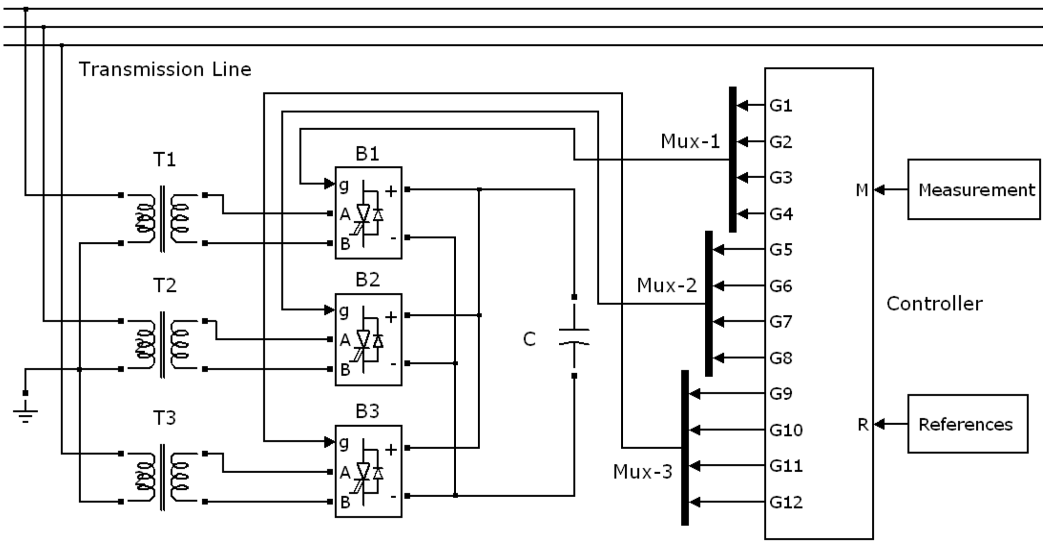

Figure 3 Block diagram of the STATCOM connected to a transmission line

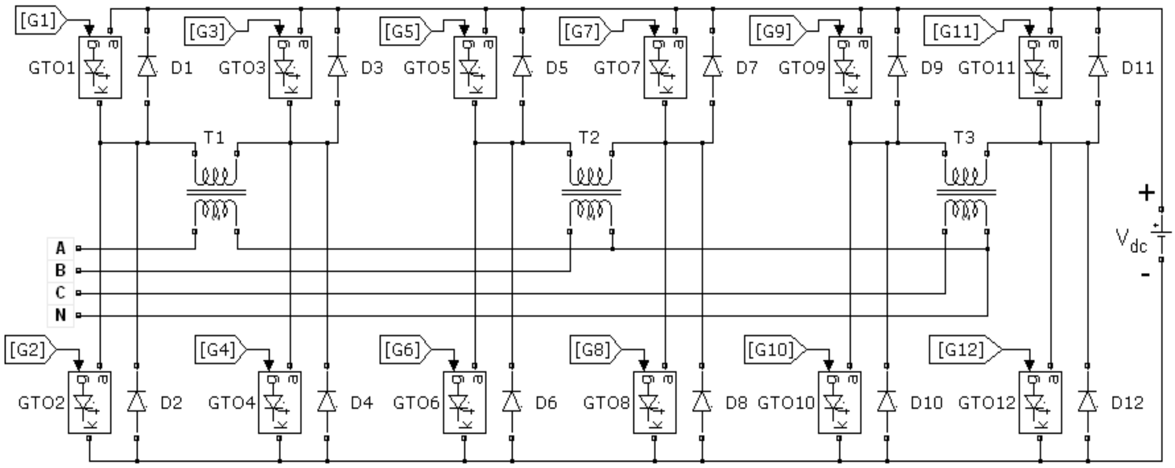

Figure 4. Circuit diagram of GTO / Diode bridges

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 (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 (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. As the shunt converter can be controlled in two different modes, therefore, when it is operated as VAR control mode to improve power factor in that case the reference value of the reactive power should be set zero; on the other hand when it is used in automatic voltage control mode the reference value should be set to same as the transmission line voltage.

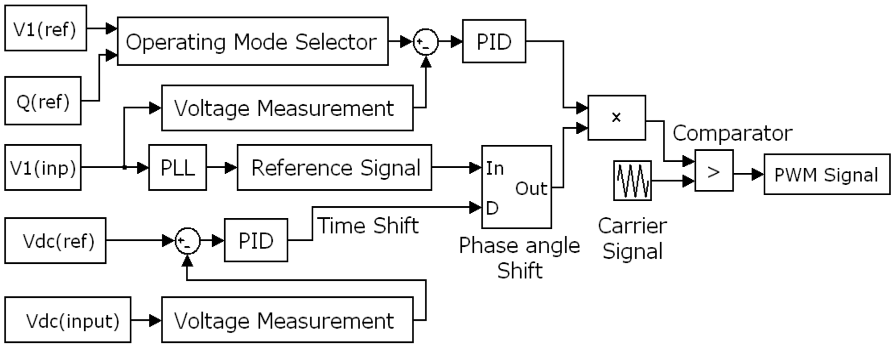

Figure 5. Block diagram of the STATCOM controller

SIMULATION RESULTS

Case 1: In this case study the STATCOM works as a reactive power controller (var controller). The load L1 is always connected; L2 and L3 are connected at t=0 second, L4 is connected at t=0.25 second. The start time of this simulation is t=0 second and the end time is t=0.4 second. Figure 6 shows real and reactive power flow through the bus B2 when the shunt compensator is not connected. Figure 7 shows the same when the shunt compensator is connected. The STATCOM controller neutralizes the reactive power successfully. The apparent power flowing through B2 and PF correction are shown in Figure 8 and 9 respectively.

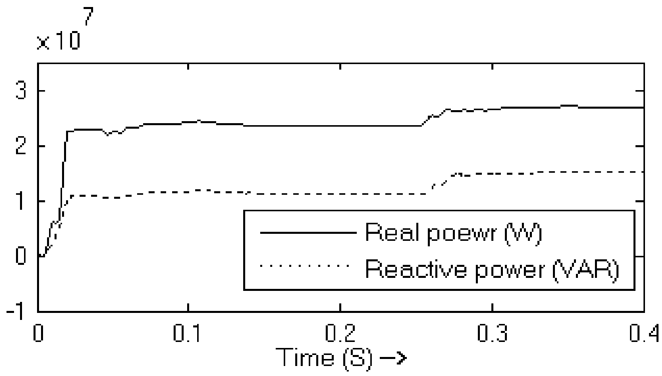

Figure 6. Real and reactive power flow through B2 without FACTS controller

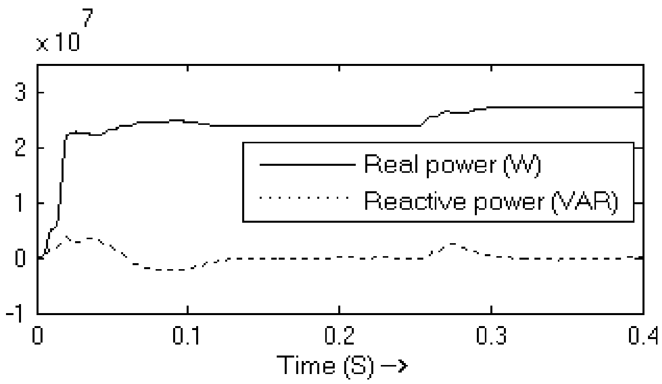

Figure 7. Real and reactive power flow through B2 with FACTS controller

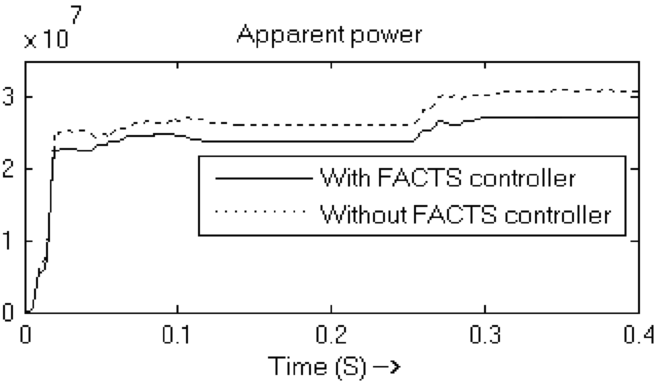

Figure 8. Apparent power flow through B2

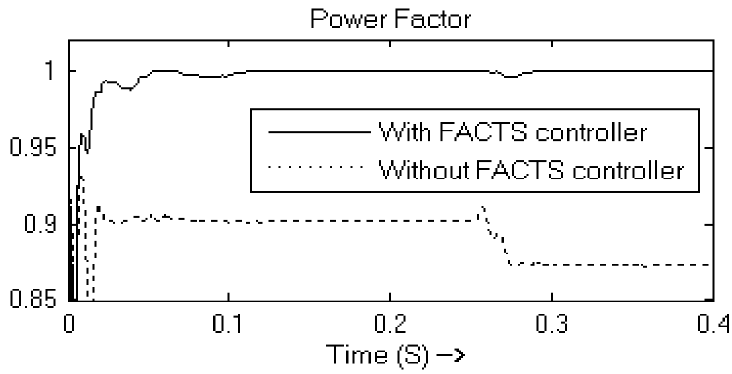

Figure 9. Power factor improvement

The phase shifting and dc link voltage are shown in Figure 10 and 11 respectively. The modulation index is required to control due to generate or absorb the required amount of reactive power which is shown in Figure 12 Figure 13 shows control of time delay by another PID controller which cause phase shift control to maintain constant dc voltage.

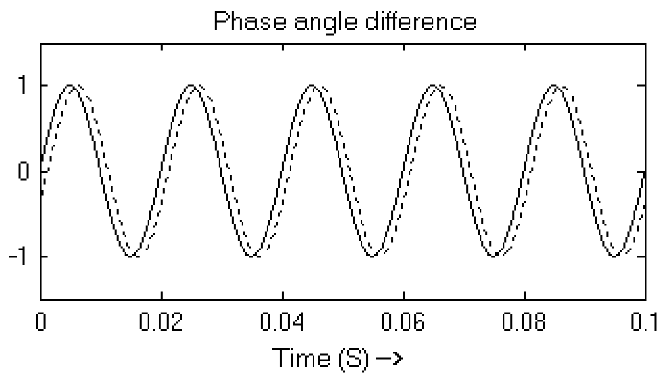

Figure 10. Phase angle difference of STATCOM

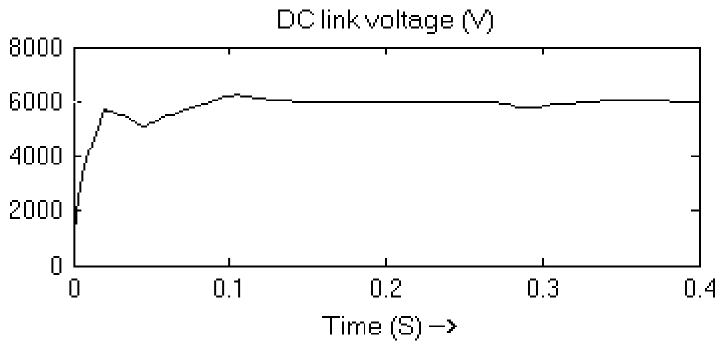

Figure 11. Control of DC link voltage

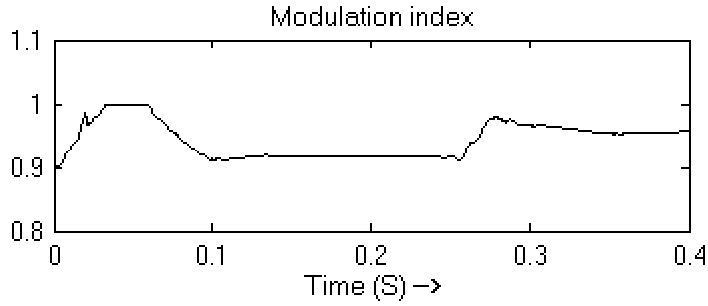

Figure 12. Control of modulation index

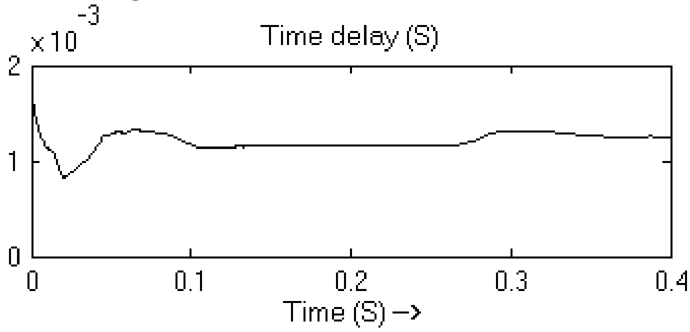

Figure 13. Control of time delay

Case 2: In this case study the STATCOM works as an automatic voltage controller. 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 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 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 and 18 represents the modulation index and phase angle control to maintain constant transmission line voltage and V_{dc} respectively for the case-2. The control strategy of the STATCOM controller is shown in Figure 19 by a flow chart.

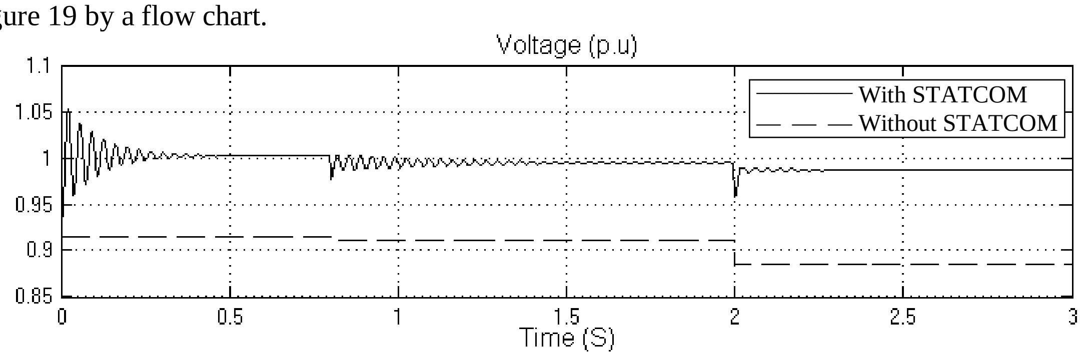

Figure 14. Transmission line voltage at B1

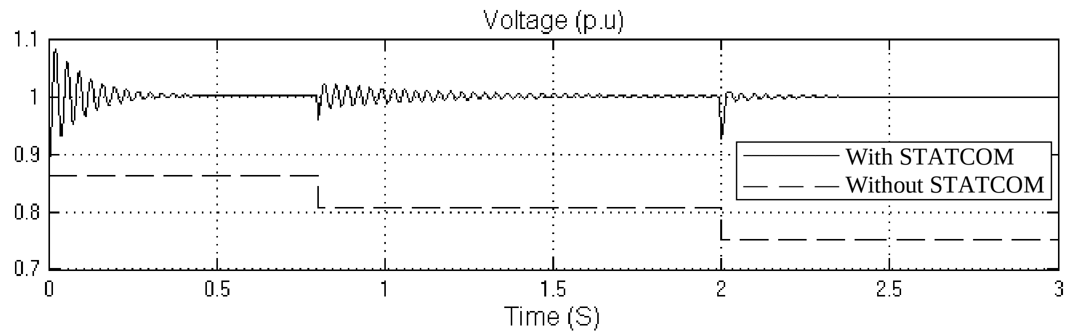

Figure 15. Transmission line voltage at B2

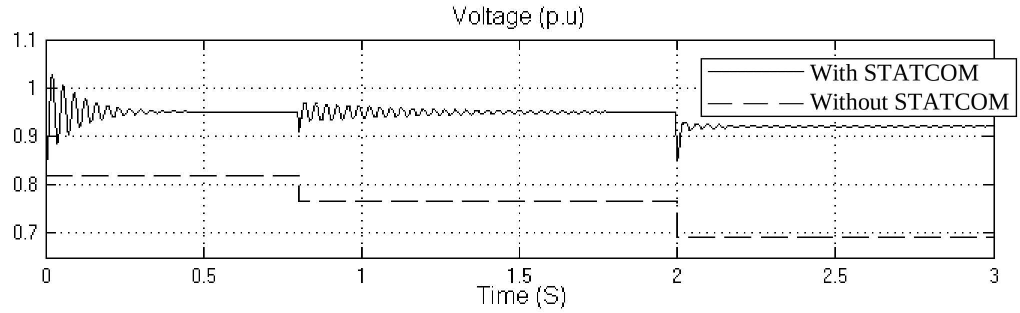

Figure 16. Transmission line voltage at B3.

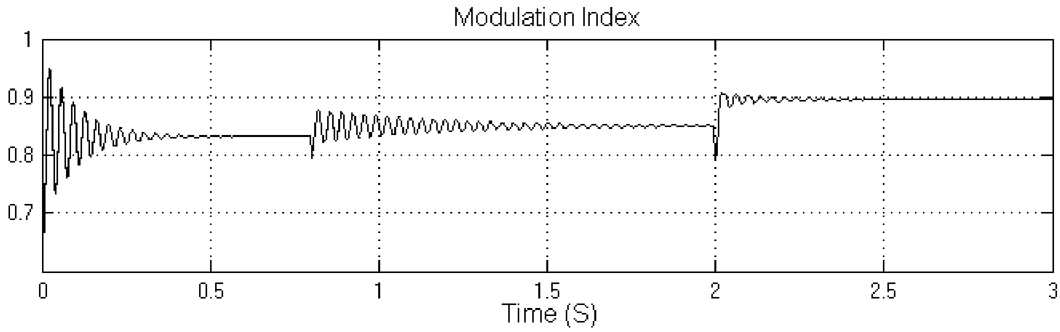

Figure 17. Control of the modulation index.

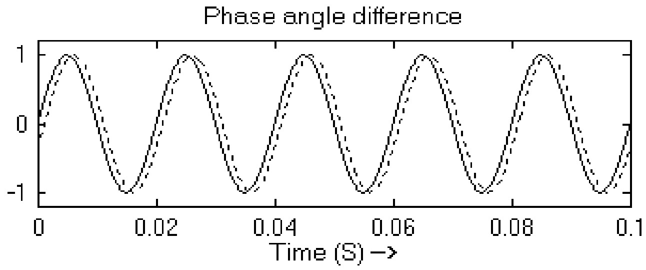

Figure 18. Control of phase angle.

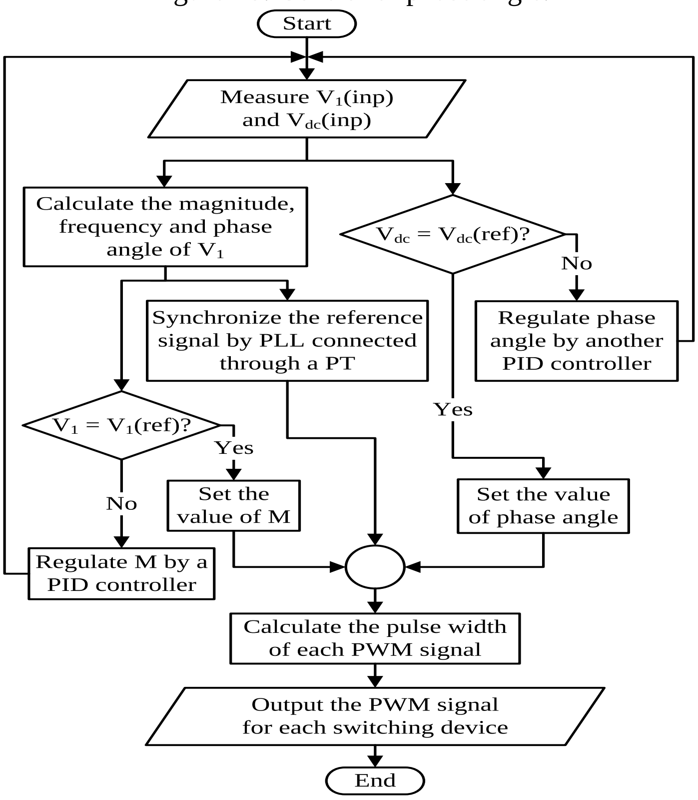

Figure 19 Flow chart of the STATCOM controller.

CONCLUSION

Although the STATCOM performs the same function as the static var compensator (SVC), at voltage lower than the normal voltage regulation range, the STATCOM can generate more reactive power than the SVC. This is due to the fact that the maximum capacitive power generated by a SVC is proportional to the square of the system voltage while the maximum capacitive power generated by a STATCOM decreases linearly with voltage. This ability to provide more capacitive reactive power during a fault is one important advantage of the STATCOM over the SVC. In addition, the STATCOM normally exhibits a faster response than the SVC because the STATCOM has no delay associated with the thyristor firing as in the SVC. The simulation results show that the STATCOM is capable enough to control the transmission line voltage, improve the power factor and enhance the power transmission capability. The simulation result also prove that the STATCOM with the proposed switching scheme functions successfully as the real time voltage and var controller and it improves the dynamic stability with a wide range of control the reactive power. There are several methods for tuning a PID loop. Manual tuning, Ziegler-Nichols, software tools and Cohen-Coon methods are very popular. Among them Ziegler-Nichols method is chosen at first and then manual tuning is chosen for fine tuning.

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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
Parameters of PID controller: Sampling time=0.01 mS; K_p= 10, K_i= 500, K_d=0.02