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COMPARATIVE STUDY AND APPLICATIONS OF FACTS DEVICES IN POWER SYSTEM

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Abstract:-In this paper, "Comparative Study and Applications of FACTS Devices in Power System", has been carried out. In a power system network consisting of generators, transmission lines, transformers and load etc., STATCOM, SVC and UPFC are applied between two buses separately and their effects is analyzed as par applied system conditions. Power flow between different buses and voltage regulation of above FACTS devices is found out. Simulation of the system was carried out in Matlab environment.

Keywords: STATCOM, SVC and UPFC, Matlab simulation tool.

1.INTRODUCTION

Transmission lines in congested areas are often driven increased electric power consumption and trades. Thus, secure operation and reliable supply is endangered by the higher risks for faulted lines. FACTS devices are able to influence power flows and voltages to different degrees depending on the type of the device. If the reactive power of the load is changing rapidly, then a suitable fast response compensator is needed. Static VAR Compensator (SVC) thyristor control series compensator (TCSC) and thyristor control phase shift transformer (TCPST) is such a compensator which belongs to FACTS family. The ultimate objective of applying reactive shunt compensation in the line is to improve the voltage profile. The inclusion of the FATCS devices in the circuit improves the reactive power in the line. FACTS are successfully simulated and the results show the voltage profile improvement [1-6].

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. The Unified Power Flow Controller (UPFC) is a second generation FACTS device, which enables independent control of active and reactive power besides improving reliability and quality of the supply [7-14].

The power flow over a transmission line depends mainly on three important parameters, namely voltage magnitude of the buses (V), impedance of the transmission line (Z) and phase angle between buses (θ). The FACTS devices control one or more of the parameters to improve system performance by using placement and coordination of multiple FACTS controllers in large-scale emerging power system networks to also show that the achieve significant improvements in operating parameters of the power systems such as small signal stability, transient stability, damping of power system oscillations, security of the power system, less active power loss, voltage profile, congestion management, quality of the power system, efficiency of power system operations, power transfer capability through the lines, dynamic performances of power systems, and the loadability of the power system network also increased[14-19]. As FACTS devices are fabricated using solid state controllers, their response is fast and accurate. Thus these devices can be utilized to improve the voltage profile of the system by using coordinated control of FACTS controllers in multi-machine power systems in this work.

1.1 Static Var Compensator(SVC):-

A static var compensator is a static var generator whose output is varied so as to maintain or control specific parameters (e.g. voltage or reactive power of bus) of the electric power system.

In its simplest form it uses a thyristor controlled reactor (TCR) in conjunction with a fixed capacitor (FC) or thyristor switched capacitor (TSC). A pair of opposite poled thyristors is connected in series with a fixed inductor to form a TCR module while the thyristors are connected in series with a capacitor to form a TSC module. SVC can control the voltage magnitude at the required bus thereby improving the voltage profile of the system. The primary task of an SVC is to maintain the voltage of a particular bus by means of reactive power compensation (obtained by varying the firing angle of the thyristors)[3].

1.2 STATCOM:-

The Static Synchronous Compensator (STATCOM) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive). The variation of reactive power is performed by means of a Voltage Sourced Converter (VSC) connected on the secondary side of a coupling transformer. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize a voltage V2 from a DC voltage source. The principle of operation of the STATCOM is explained on the Figure 1. below showing the active and reactive power transfer between a source V1 and a source V2. In this figure, V1 represents the system voltage to be controlled and V1 is the voltage generated by the VSC [5].

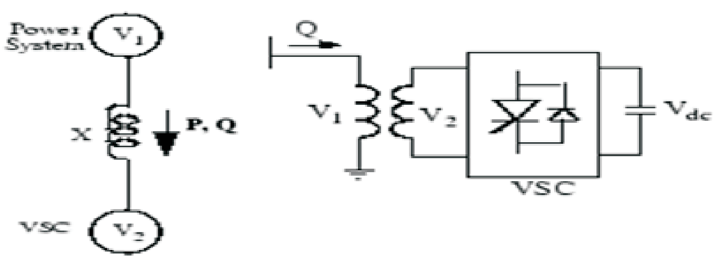

Figure 1. Operating principle of STATCOM

$$P = \frac{V_1 V_2}{X} \sin \delta \qquad ...(1)$$

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

Where,

V_1 = line to line voltage of source V_1
V_2 = line to line voltage of V_2
X = reactance of interconnection transformer and filter
δ = angle of V_1 with respect to V_2.

In steady state operation, the voltage V_2 generated by the VSC is in phase with V_1 (d=0), so that only reactive power is flowing (P=0). If V_2 is lower than V_1, Q is flowing from V_1 to V_2 (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 (STATCOM is generating reactive power). The amount of reactive power is given by,

$$Q = \frac{V_1 (V_1 - V_2)}{X} \qquad ...(3)$$

A capacitor connected on the DC side of the VSC acts as a DC voltage source. 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.

1.3 Unified Power Flow Controller (UPFC):-

A Unified Power Flow Controller (UPFC) is power electronics based system which can provide control of the transmission line impedance, phase angle and reactive power. The UPFC consists of two voltage sourced converters using gate turn off thyristors (GTO) which operate from a common dc-circuit consisting of a dc storage capacitor (Figure 2) [15].

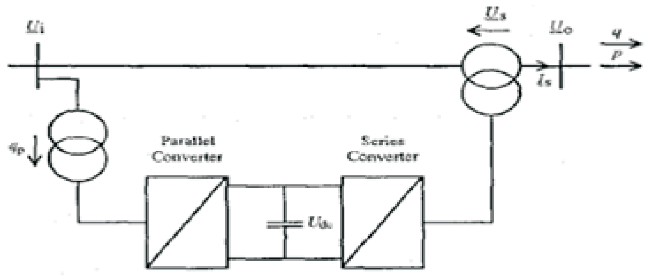

Figure2. Basic Scheme of a UPFC

2. MODELING AND SIMULATION RESULTS:-

2.1 Simulation model of SVC:-

In a 500 kV /230 kV transmission system , a SVC is used to regulate the voltage. The system, connected in a loop configuration, consists essentially of two 500 kV/230 kV transformer banks Tr1 and Tr2 and five buses (B1 to B5) interconnected through transmission lines (L1, L2, L3) and. Two power plants located on the 230-kV system generate a total of 1500 MW which is transmitted to a 500-kV 15000-MVA equivalent and to a 200-MW load connected at bus B3.

The plant models include an excitation system, a speed regulator as well as a power system stabilizer (PSS). A static var compensator (SVC) is used to regulate voltage. When system voltage is low the SVC generates reactive power (SVC capacitive).

When system voltage is high it absorbs reactive power (SVC inductive). The SVC is rated +200 Mvar capacitive and 100 Mvar inductive. The Static Var Compensator block is a phasor model representing the SVC static and dynamic characteristics at the system fundamental frequency.

To set the SVC control parameters select "Display Control parameters". The SVC is set in voltage regulation mode with a reference voltage Vref=1.0 pu. The voltage droop is 0.03 pu/ 200MVA, so that the voltage varies from 0.97 pu to 1.015 pu when the SVC current goes from fully capacitive to fully inductive.

The actual SVC positive-sequence voltage (V1) and susceptance (B1) are measured inside the 'Signal Processing' subsystem, using the complex voltages V_{abc} and complex currents Iabc returned by the Three-Phase V-I Measurement block.

Simulation model is shown in fig.3. It is the same power system network as used earlier. In this model a Vref signal is given to SVC and its reactive power compensation capability is tested. SVC acts as a voltage regulator. Voltage at SVC bus against applied V_{ref} signal is measured.

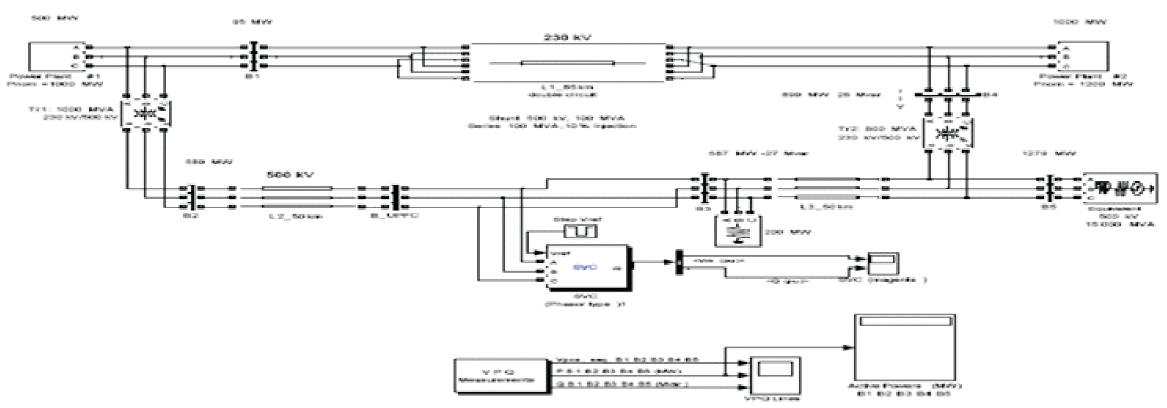

Figure 3. Simulation model of SVC

2.1.1 SVC Simulation results

SVC acts basically in Voltage Regulation and VAR control mode .For the selected power system network, result of Voltage Regulation mode has been found out.

Voltage Regulation

In the Figure 4 results of applied reference voltage and measured reference voltage at SVC Bus is shown. Here SVC shows its voltage regulation capability.

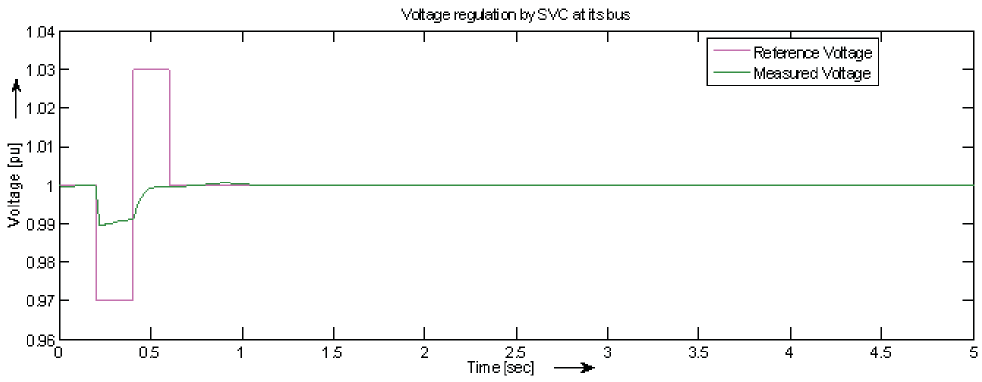

Figure 4 Reference Voltage and measured voltage at SVC Bus.

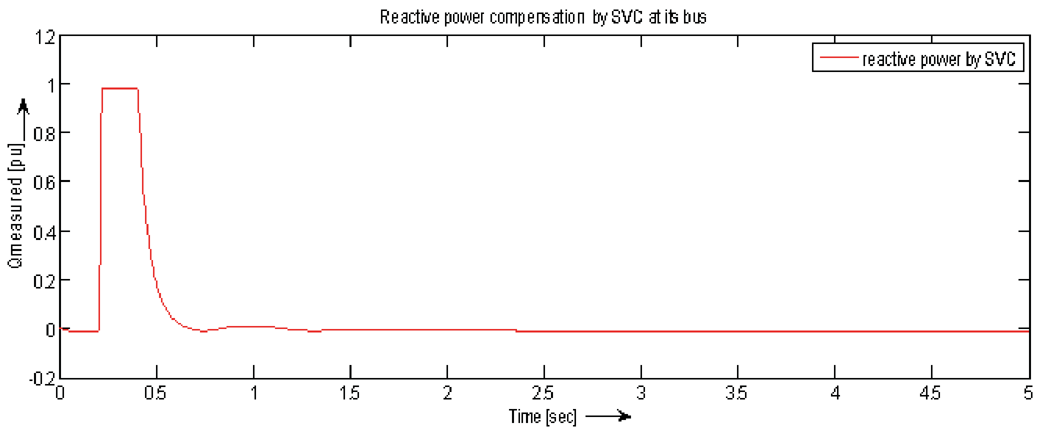

Figure 5. Reactive power supplied by SVC during voltage regulation

2.2 Simulation model of STATCOM

The Static Synchronous Compensator (STATCOM) is one of the key FACTS devices. Based on a voltage-sourced converter, the STATCOM regulates system voltage by absorbing or generating reactive power. Contrary to a thyristor-based Static Var Compensator (SVC), STATCOM output current (inductive or capacitive) can be controlled independent of the AC system voltage.

In a 500 kV /230 kV transmission system, a STATCOM is used to regulate the voltage. The system, connected in a loop configuration, consists essentially of two 500 kV/230 kV transformer banks Tr1 and Tr2 and five buses (B1 to B5) interconnected through transmission lines (L1, L2, L3) and. Two power plants located on the 230-kV system generate a total of 1500 MW which is transmitted to a 500-kV 15000-MVA equivalent and to a 200-MW load connected at bus B3. The plant models include an excitation system, a speed regulator as well as a power system stabilizer (PSS).

In this model, the STATCOM is located at the bus B_UPFC and has a rating of +/- 100MVA. This STATCOM is a phasor model of a typical three-level PWM STATCOM. In the STATCOM dialogue box set "Display Power data" at DC link nominal voltage of 40 kV with an equivalent capacitance of 375

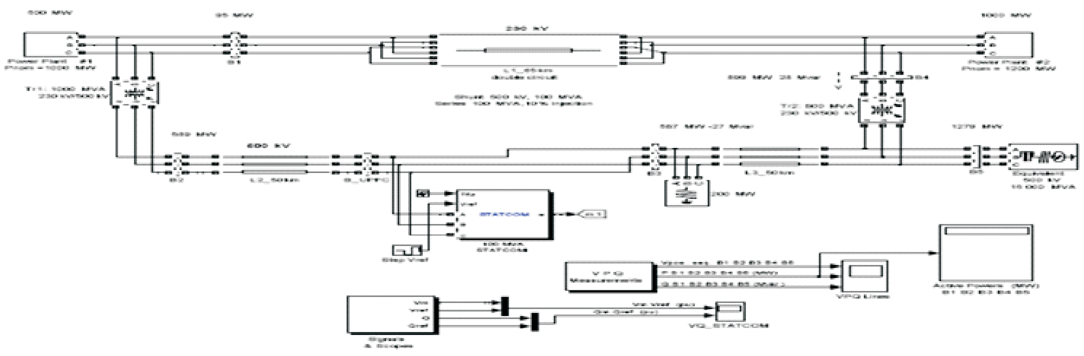

Figure 6 Simulation model of a STATCOM

2.2.1 STATCOM Simulation Results

Simulation results of STATCOM is found out by connecting it in parallel with Buses B_1,B_2,B_3,B_4 and B_5 one by one while reactive power load is connected at Bus B_2.

Voltage Regulation at Bus$_1$

Simulation results of STATCOM are shown in Figure 7 when it is connected to Bus B_1.

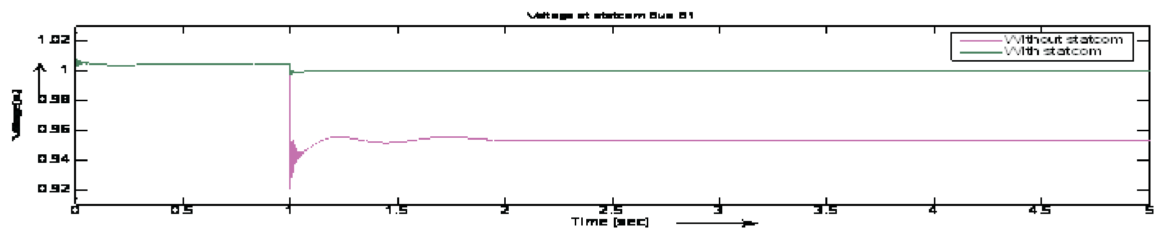

Figure 7 STATCOM connected at Bus B_1

Voltage Regulation at Bus B2

Simulation results of STATCOM are shown in Figure 8 when it is connected to Bus B_2.

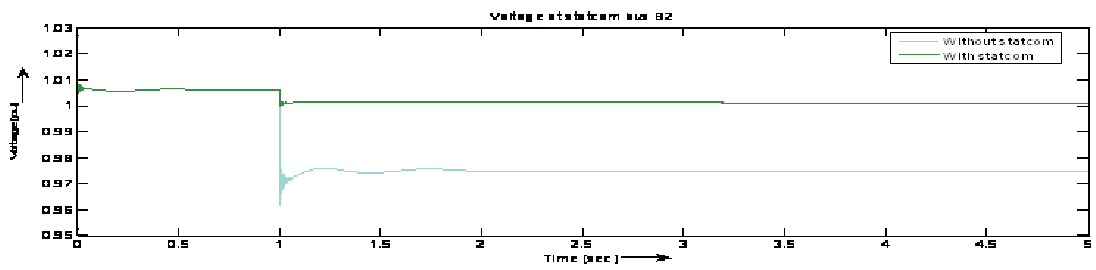

Figure 8 STATCOM connected at Bus B_2.

Voltage Regulation at Bus B_3.

Simulation results of STATCOM are shown in Figure 9 when it is connected to Bus B_3.

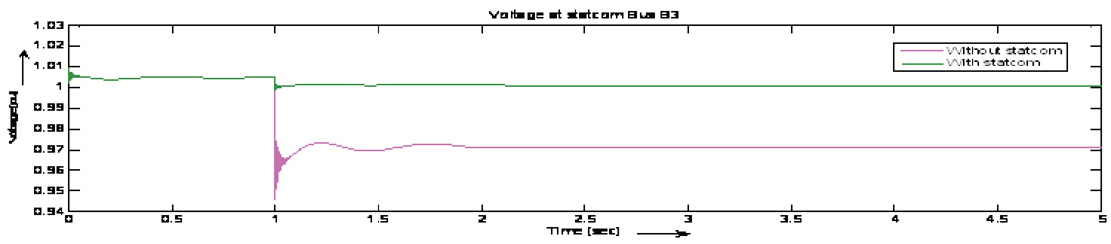

Figure 9 STATCOM connected at Bus B_3.

Voltage Regulation at Bus B_4

Simulation results of STATCOM are shown in fig 10 when it is connected to Bus B_4.

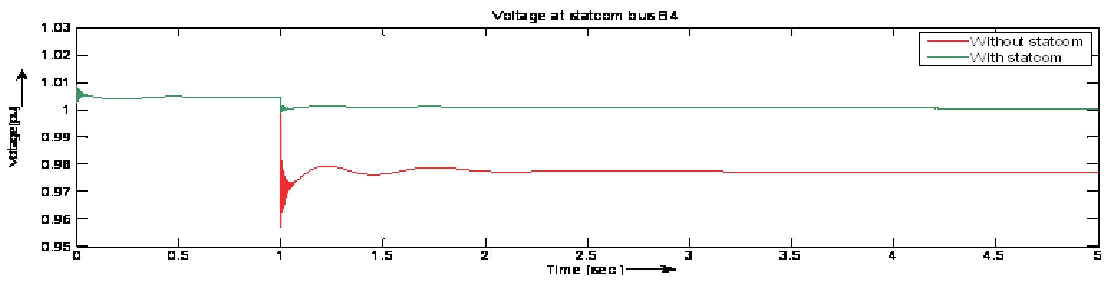

Figure 10 STATCOM connected at Bus B_4

Voltage Regulation at Bus B_5

Simulation results of STATCOM are shown in Figure 11 when it is connected to Bus B_5.

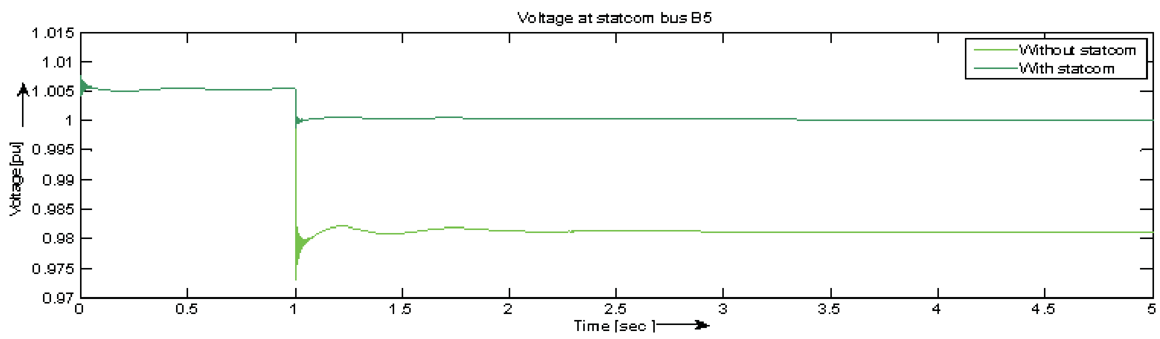

Figure 11 STATCOM connected at Bus B_5

2.3 Simulation model of UPFC

In a 500 kV /230 kV transmission system, a UPFC is used to control the power flow. The system, connected in a loop configuration, consists essentially of two 500 kV/230 kV transformer banks Tr1 and Tr2 and five buses (B1 to B5) interconnected through transmission lines (L1, L2, L3) and. Two power plants located on the 230-kV system generate a total of 1500 MW which is transmitted to a 500-kV 15000-MVA equivalent and to a 200-MW load connected at bus B3. The plant models include an excitation system, a speed regulator as well as a power system stabilizer (PSS). In normal operation, most of the 1200-MW generation capacity of power plant 2 is exported to the 500-kV equivalent through three 400-MVA transformers connected between buses B4 and B5. For this simulation model we are considering a contingency case where only two transformers out of three are available (Tr2= 2*400 MVA = 800 MVA).

Using the load flow option of the powergui block, the model has been initialized with plants 1 and 2 generating respectively 500 MW and 1000 MW and the UPFC out of service. The load flow shows that most of the power generated by plant 2 is transmitted through the 800-MVA transformer bank (899 MW out of 1000 MW), the rest (101 MW), circulating in the loop. Transformer Tr2 is therefore overloaded by 99 MVA. The simulation model illustrates how the UPFC can relieve this power congestion.

The UPFC located at the right end of line L2 is used to control the active and reactive powers at the 500-kV bus B3, as well as the voltage at bus B_UPFC. It consists of a phasor model of two 100-MVA, IGBT-based, converters (one connected in shunt and one connected in series and both interconnected through a DC bus on the DC side and to the AC power system, through coupling reactors and transformers). Parameters of the UPFC power components are given in the dialog box. The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87 kV) in series with line L2. Power flow at each bus is found out with UPFC in service and controlling the B3 active and reactive powers respectively at 687 MW and -37 Mvar. Simulation model is shown in Figure 4.4.

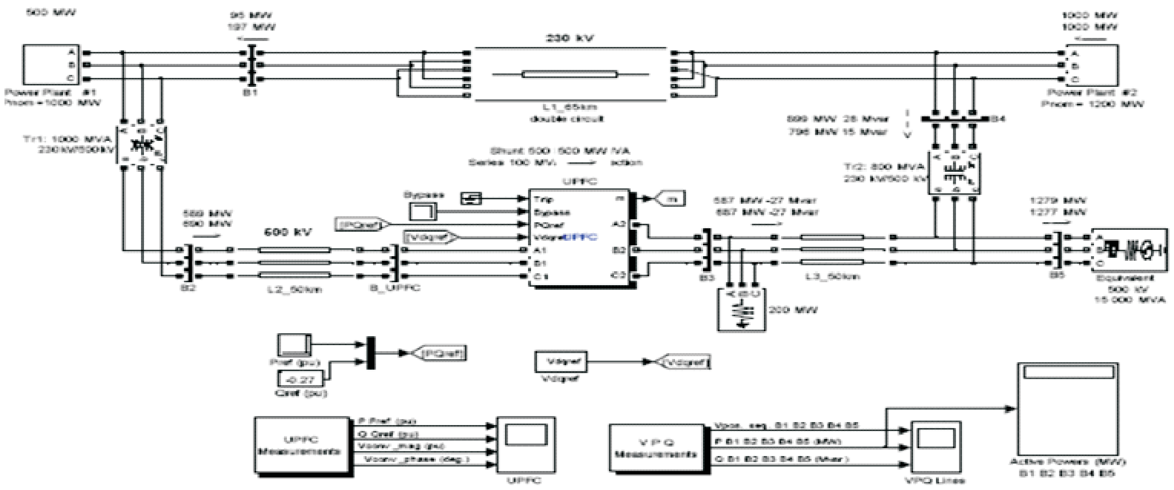

Figure 12 Simulation model of UPFC

2.3.1 Simulation results of UPFC

UPFC simulation results for change in active power demand, reactive power demand and corresponding value of magnitude and phase angle of injected voltage are found out.

Simulation results for step like changes in Active Power at UPFC Bus

Figure 13 shows step like change in reference active power and response of UPFC to meet this demand.

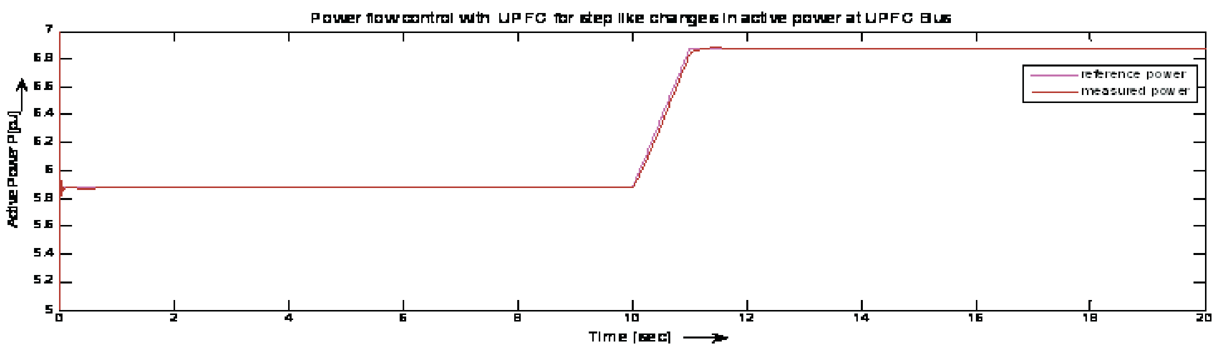

Figure 13 Reference active power with measured active power at UPFC Bus

Simulation results for step like changes in Reactive Power at UPFC Bus.

Figure 14 shows step like change in reference reactive power and response of UPFC to meet this demand.

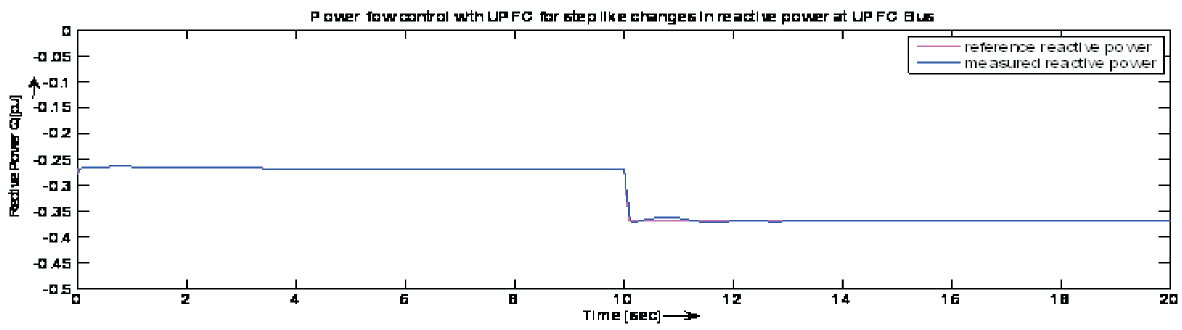

Figure 14 Reference reactive power with measured active power at UPFC Bus

Simulation results for UPFC injected Voltage Magnitude and phase angle.

Figure 15 and Figure 16 shows UPFC injected voltage magnitude and phase angle to meet the demand in active and reactive power.

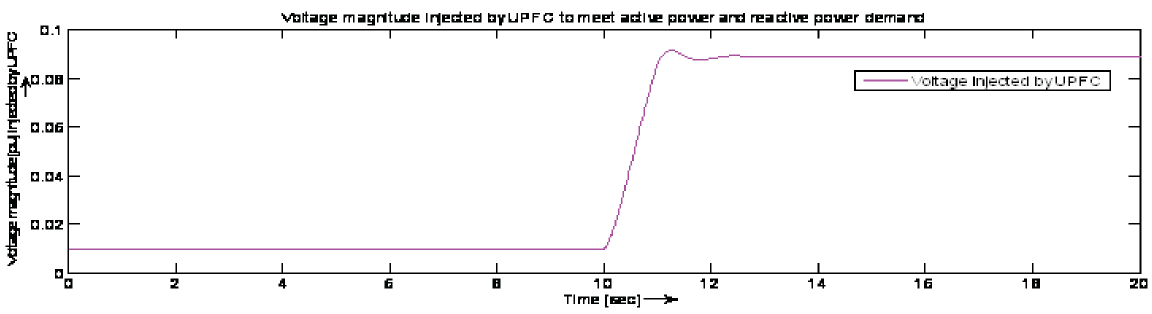

Figure 15 Voltage magnitude injected by UPFC

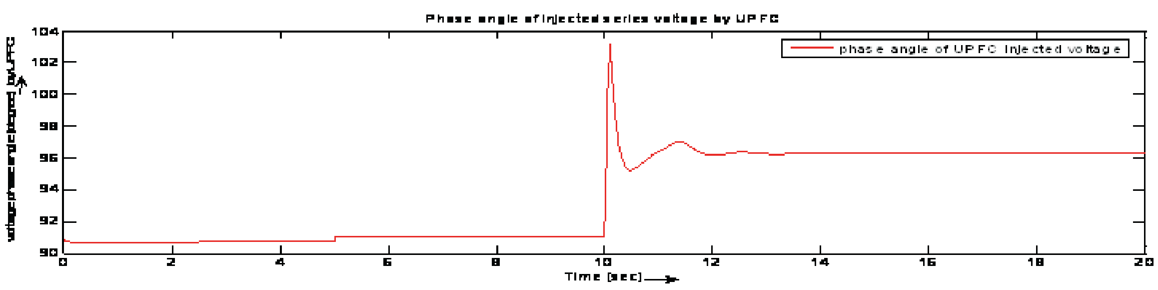

Figure 16 Phase angle of injected series voltage at UPFC Bus

3. CONCLUSION

UPFC can control active and reactive power flow in transmission lines. SVC and STATCOM improves system voltage stability. Voltage regulation mode of SVC and STATCOM is successfully simulated in MATLAB.

Simulation results are good and they are accepted. UPFC can control active power and reactive power independently. Series compensator of UPFC can be operated in power flow control mode and simultaneously shunt compensator may be operated in voltage regulation or var control mode. Similarly, simulations carried out showed that SVC and STATCOM provides excellent voltage regulation, power factor and active power regulation capabilities.

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