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ANALYSIS OF VOLTAGE STABILITY AND TRANSFER CAPABILITY ENHANCEMENT OF TRANSMISSION SYSTEM USING FACTS CONTROLLERS

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***Abstract* — Power flow control, in an existing long transmission line, plays a vital role in Power System area. This paper deals with shunt connected compensation (SVC and STATCOM) based FACTS device for the control of voltage and the power flow in long distance transmission line. The device proposed here is used in different locations such as source end of the transmission line, in between and load end of the transmission line. The paper also deals with resolving of the optimal location of shunt flexible a.c. transmission system (FACTS) devices for a long transmission line for voltage and power transfer improvement. The results also show that optimal location depends upon voltage magnitude and the line loading and system initial operating conditions. In this paper the two machine 4-bus test system were simulated using MATLAB Simulink environment**.

***Keyword* — Stability, simulation, power transfer, SVC.**

1. INTRODUCTION

The flexible AC transmission system (FACTS) has received much attention in the last two decades. It uses high-current power electronic devices for stability, voltage control, power flow etc. of a transmission system. Some forms of FACTS devices are already available for prototype installation [l, 2] and others are still under development. FACTS devices can be connected to a transmission line in various ways, such as in series, shunt or a combination of series and shunt. For example, static VAr compensator (SVC) and static synchronous compensator (STATCOM) are connected in shunt; static synchronous series compensator (SSSC) and thyristor-controlled series capacitor (TCSC) are connected in series; thyristor controlled phase shifting transformer (TCPST) and unified power flow controller (UPFC) are connected in a series and shunt combination. The terms and definitions of various FACTS devices are described in a recent IEEE article [3]. FACTS devices are very effective and capable of increasing the power transfer capability of a line, if the thermal limit permits, while maintaining the same degree of stability [4-7].

This paper investigates the effects of considering the actual line model on the power transfer capability and stabilily when a shunt FACTS device is connected to the line. Today's power systems are widely interconnected to take advantage of diversity of loads, availability of resources and fuel prices, in order to supply electricity to the loads at minimum cost with a required reliability. Transmission is often an alternative to new generation and less transmission capability means a requirement for more generation resources. The cost as well as difficulties encountered in building new transmission lines, limits the transfer of available power. In many cases economic energy or reserve sharing is constrained by the transmission capacity. Flexible a.c. transmission system (FACTS) technology opens up new opportunities for controlling power flow and enhancing the usable capacity of present transmission lines. [1] FACTS devices control the interrelated parameters that govern the operation of a transmission system, thus enabling the line to carry power close to its thermal rating.

It has been observed that shunt FACTS devices give maximum benefit from their stabilized voltage support when sited at the optimal location of the transmission line. The proof of maximum increase in power transfer capability is based on a simplified model of the line that neglects the resistance and capacitance, which is a reasonable assumption for short transmission lines. However, for long transmission lines, when the accurate model of the line is considered, the results may deviate significantly from those found for the simplified model especially with respect to stability improvement [9, 10].

2. POWER SYSTEM STABILITY

2.1 Definition of stability of a System

The stability of a system is defined as the tendency and ability of the power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium [2].

Let a system be in some equilibrium state. If upon an occurrence of a disturbance and the system is still able to achieve the equilibrium position, it is considered to be stable. The system is also considered to be stable if it converges to another equilibrium position in the proximity of initial equilibrium point. If the physical state of the system differs such that certain physical variable increases with respect to time, the system is considered to be unstable [21].

$$|S_{Li}| \leq S_{Gi}^{max}$$

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$0 \le V_{FDi} \le V_{FDi}^{max}$

Therefore, the system is said to remain stable when the forces tending to hold the machines in synchronism with one another are enough to overcome the disturbances. The system stability that is of most concern is the characteristic and the behavior of the power system after a disturbance [26-27].

2.1. Need for power system stability

The power system industry is a field where there are constant changes. Power industries are restructured to cater to more users at lower prices and efficient power. Power systems are multifaceted as they become inter-connected. As the number of users increases, the load demand also increases linearly. Since concern for stability limits the transfer capability of the system, there is a need to ensure stability and reliability of the power system due to economic reasons.

Different types of power system stability have been classified into rotor angle stability, frequency stability and voltage stability [7].

3. Problem Formulation

If the problem formulation for total power transfer capability with FACTS devices including transmission power loss is used to determine the maximum power that can be transferred from a specific set of generators in source area to loads in sink area within real and reactive power generation limits, line flow limits, voltage limits, stability limits, and FACTS devices operation limits. Two categories of FACTS devices are included: SVC and STATCOM, used to enhance the loadability of the transmission line. SVC and STATCOM are used to control bus voltage, reactive power injection, stability control, oscillations damping and unbalanced compensation. [21].

The equations for system flow and stability are given as:

$$P_{Gi} - P_{Di} + P_L + P_{FDi}(V_{FDi}) + \sum_{j=1}^{N} V_i V_j Y_{ij} \cos(\theta_{ij} - \delta_i + \delta_j) = 0$$

$$Q_{Gi} - Q_{Di} + Q_L + Q_{FDi}(V_{FDi}) + \sum_{j=1}^{N} V_i V_j Y_{ij} \sin(\theta_{ij} - \delta_i + \delta_j) = 0$$

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}$$

$$Q_{Gi}^{min} \le Q_{Gi} \le P_{Gi}^{max}$$

$$V_i^{min} \le V_i \le V_i^{max}$$

$$Q_{FDi}^{min} \le Q_{FDi} \le P_{FDi}^{max}$$

Where,

PGi, QGi : real and reactive power generations at bus i ,

PDi, QDi : real and reactive loads at bus i ,

Vi , Vj : voltage magnitudes at bus i and j ,

$P_{FDi}(V_{FDi}, \alpha_{FDi})$: injected real power of FACTS device at bus i ,

$Q_{FDi}(V_{FDi}, \alpha_{FDi})$: injected reactive power of FACTS device at bus i ,

SLi : ith line or transformer loading,

N: total number of buses,

δ_i, δ_j : Voltage angles of bus i and j ,

Y_{ij} : Magnitude of the ijth element in bus admittance matrix,

θ_{ij} : angle of the ijth element in bus admittance matrix,

And the equations for power transmission are given as:

$$P = \frac{V_s V_r}{XL} \sin(\delta_s - \delta_r) = \frac{V^2}{X_L} \sin\delta$$

$$Q = \frac{V_s V_r}{X_L}[1 - \cos(\delta_s - \delta_r)] = \frac{V^2}{X_L}(1 - \cos\delta)$$

$$\delta = (\delta_s - \delta_r)$$

$$|V_s| = |V_r| = |V|$$

Where,

P: Active power in p.u.

Q: Reactive power in p.u.

Vs: Sending end voltage in p.u.

Vr : Receiving end voltage in p.u.

XL: Line reactance in p.u.

δs Voltage angle at sending end

δr Voltage angle at receiving end.

4. Facts Devices In Power Systems

Shunt compensation is used to influence the natural electrical characteristics of the transmission lines by generating the reactive power. There are two distinctly different approaches to controllable VAr generation. The first group employs reactive impedances with thyristor switches as controlled-elements (e.g. SVC); while the second group uses self-commutated static converters as controlled voltage sources (e.g. STATCOM). Extensive

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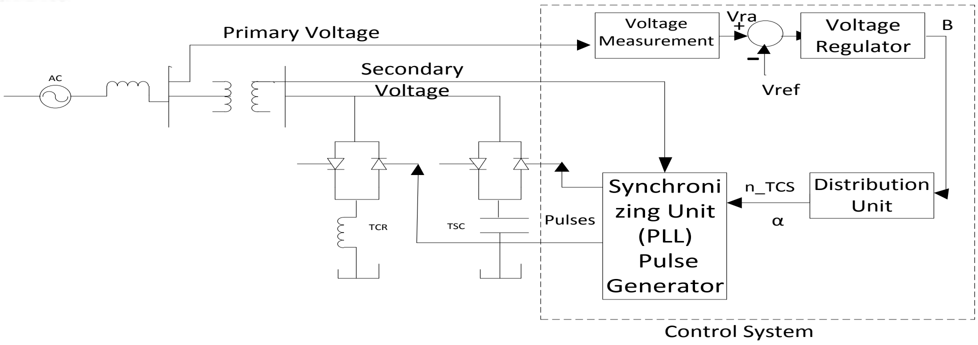


Fig:2 Single-line diagram of an svc and its control system block diagram

Elaborations on FACTS devices can be found in the literature [11, 12].

4.1**Static VAr Compensator (SVC)**

SVC is basically a shunt connected static VAr generator whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific power system variables. Figure 2 shows the single-line diagram of an SVC and a simplified block diagram of its control system. [13] The control system consists of the following main components:

* A measurement system measuring the positive-sequence voltage to be controlled.
* A voltage regulator that uses the voltage error (difference between the measured voltage Vm and the reference voltage Vref) to determine the SVC susceptance needed to keep the system voltage constant.
* A distribution unit that determines the Thyristor Switched Capacitors (TSCs) that must be switched in and out, and computes the firing angle of Thyristor Controlled Reactors (TCRs).

5. FOUR-BUS TEST SYSTEM

5.1. **Description of the transmission system**

The single line diagram shown below represents (four bus systems) a simple 400 kV transmission system. This system which has been made in ring mode consisting of buses (B1 to B4) connected to each other through three phase transmission lines L1, L2-1, L2-2 and L3 with the length of 280, 150, 150 and 150 km respectively. And the four loads are connected of 250MW, 100MW, 50MW and 2500+j1000 MVA as shown in Fig.4 System has been supplied by two power plants with the phase-to-phase voltage equal to 11 kv. Active and reactive powers injected by power plants 1 and 2 to the power system are presented in per unit by using base parameters Sb=2100 MVA and Vb=400KV, the power plants 1 (M1) and plants 2 (M2) generated 2100 MVA and 1400 MVA in per unit, respectively.

To maintain system stability with respect to loading, the transmission line is series/shunt compensated at its center by different FACTS such as SVC, and STATCOM. The two machines are equipped with a hydraulic turbine and governor (HTG), excitation system, and power system stabilizer (PSS).

Two Turbine and Regulators subsystems, the HTG and the excitation system are implemented, Two types of stabilizers can be connected on the excitation system: a generatic model using the acceleration power (Pa= difference between mechanical power Pm and output electrical power Peo) and a Multiband stabilizer using the Speed deviation (dw). These two stabilizers are standard models of the powerlib/Machines library. Manual Switch allow you to select the type of stabilizer used for both machines or put the PSS out of service. The dynamic load is connected at bus B3. We can use it to program different types of faults on the 400 kV systems and observe the impact of the FACTS on system stability and power transfer capability.

To comence the simulation in steady-state, the machines and the regulators have been previously initialized by means of the Load Flow and Machine Initialization utility of the powergui block. Load flow with machine M1 defined as a PV generation bus (V=11000 V, P=1600 MW) and machine M2 defined as a swing bus (V=11000 V, 0 degrees). After the load flow has been solved, the reference mechanical powers and reference voltages for the two machines have been automatically updated in the two constant blocks connected at the HTG and excitation system inputs: Pref1=0.761905 pu (1600 MW), Vref1=1.0 pu; Pref2=0.750827 pu (1051 MW), Vref2=1.01 pu.

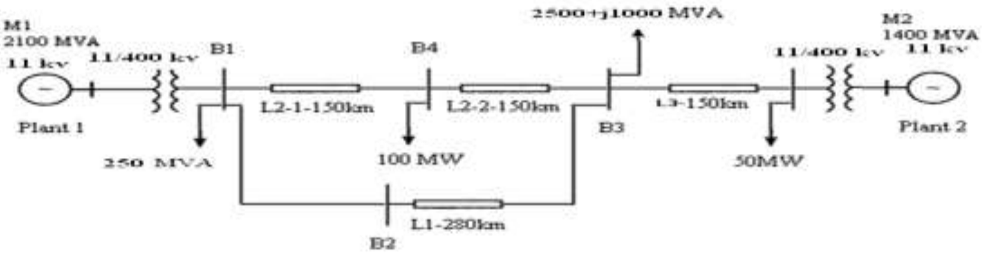


Fig.3The single line diagram of 4-bus 400 kV transmission test system

6. Simulation And Results

6.1.System analysis with-out FACTS

First trace on the Machines scope shows the rotor angle difference d_theta1_2 between the two machines. Power transfer is maximum when this angle reaches 90 degrees. It is a good signal for system stability. If d_theta1_2 exceeds 90 degrees for a long period of time, the machines will be out of synchronism and the system becomes unstable. Machine speeds are represented by the second trace. It can be observed that machine 1 speed increases during the fault because during that period its mechanical power is higher than its electrical power. If the system is simulated for a long period of time (in seconds), it is also seen that the machine speeds oscillate together at a low frequency (Hz). The displayed waveforms are shown below. Here considering dynamic loading effect on bus-3 as shown in simulation fig. 5.

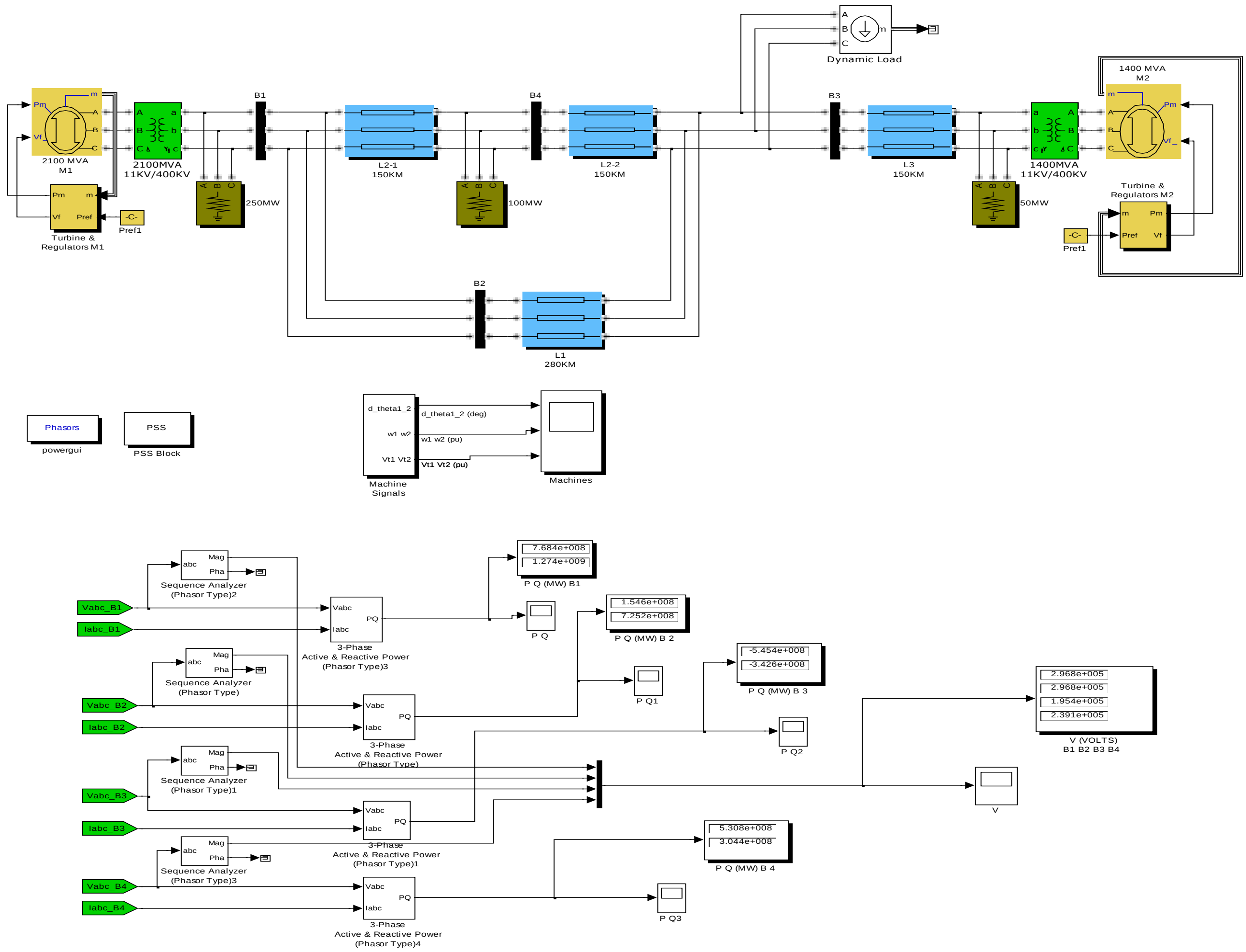
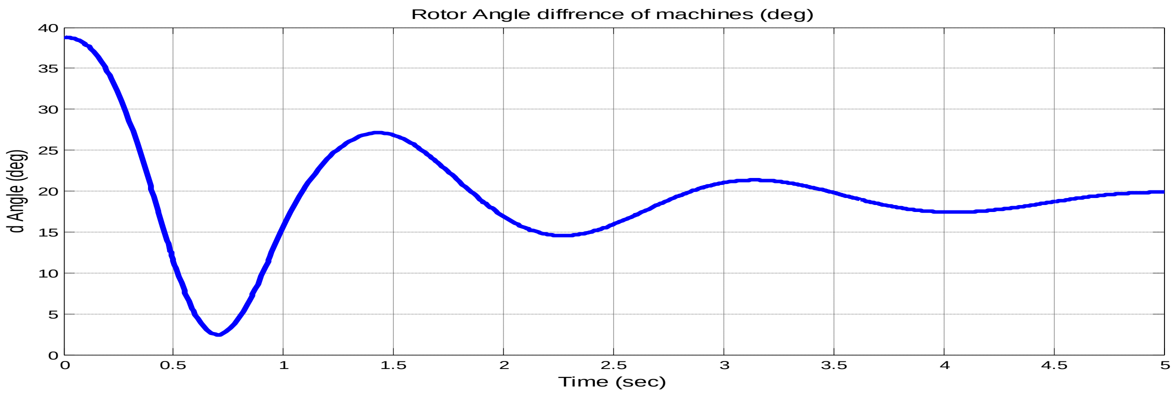
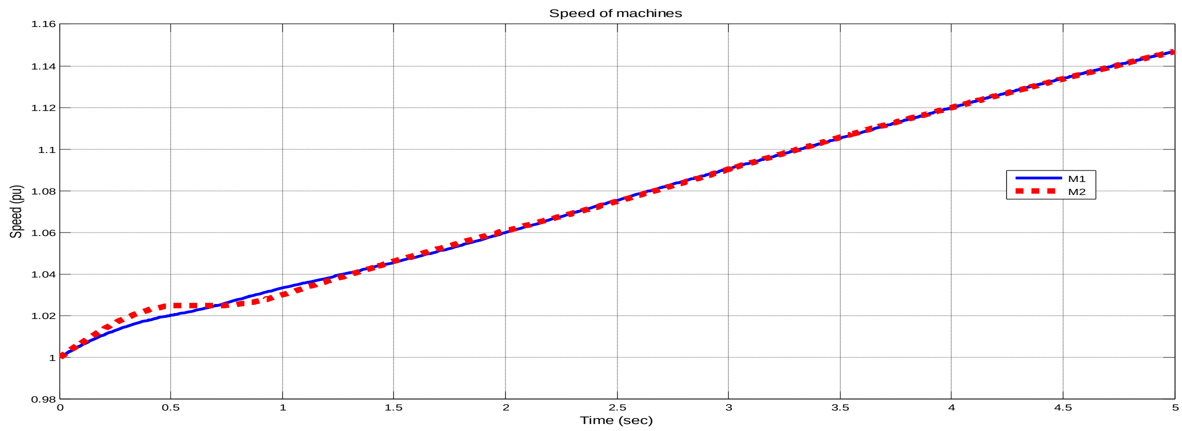


Fig.5 Simulation of test system with-out FACT Device.

The simulation results for test system with-out FACT are given below. The data for different parameters are given in table 1.



(a)



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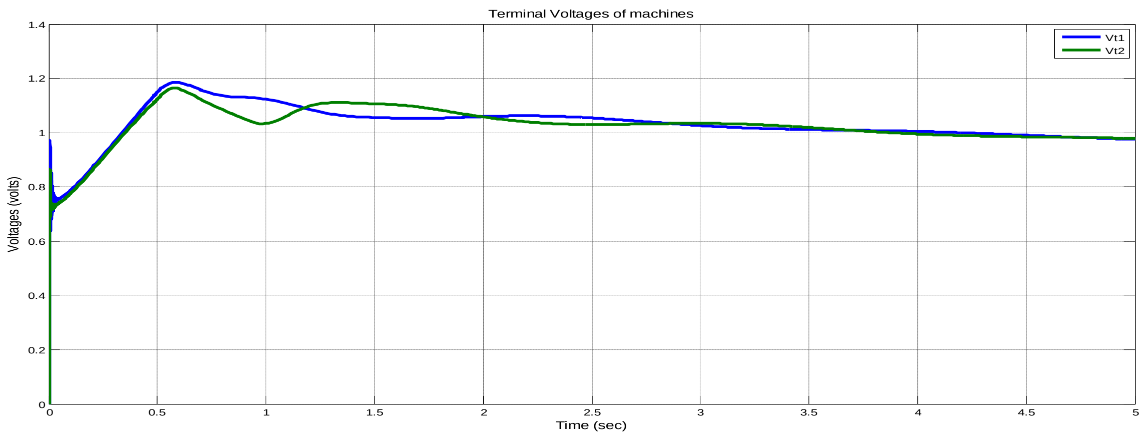

(c)

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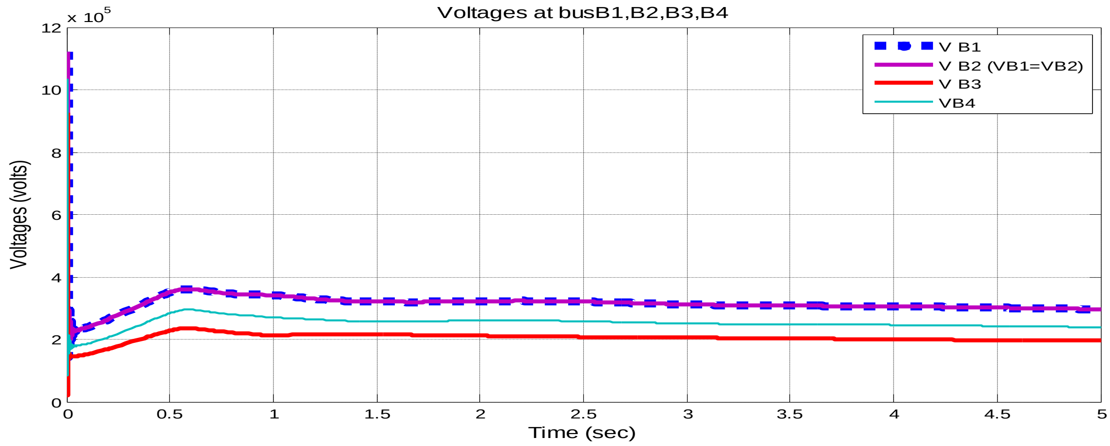
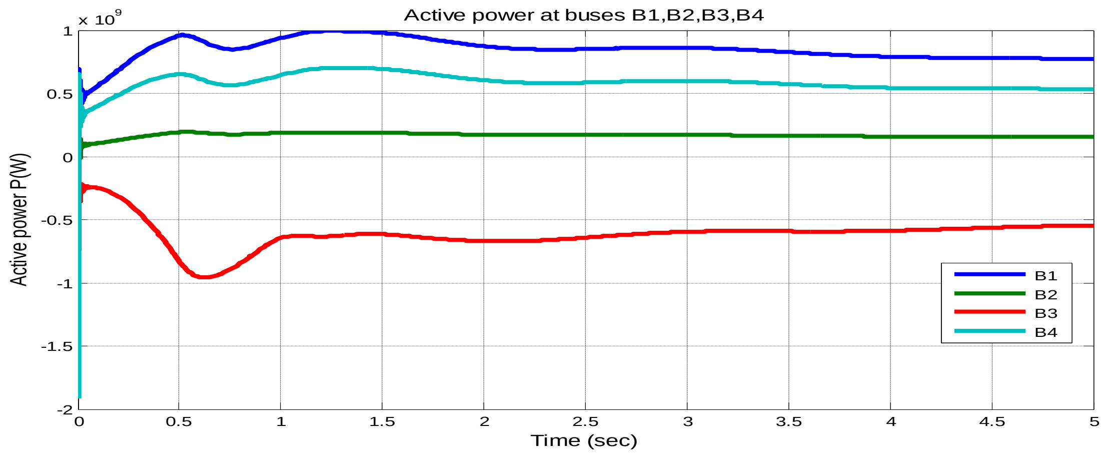
Fig.6 Waveforms for characteristics of machine (a) Rotor angle difference, (b) Speed of machines, (c) Terminal voltages of machines.



(a)



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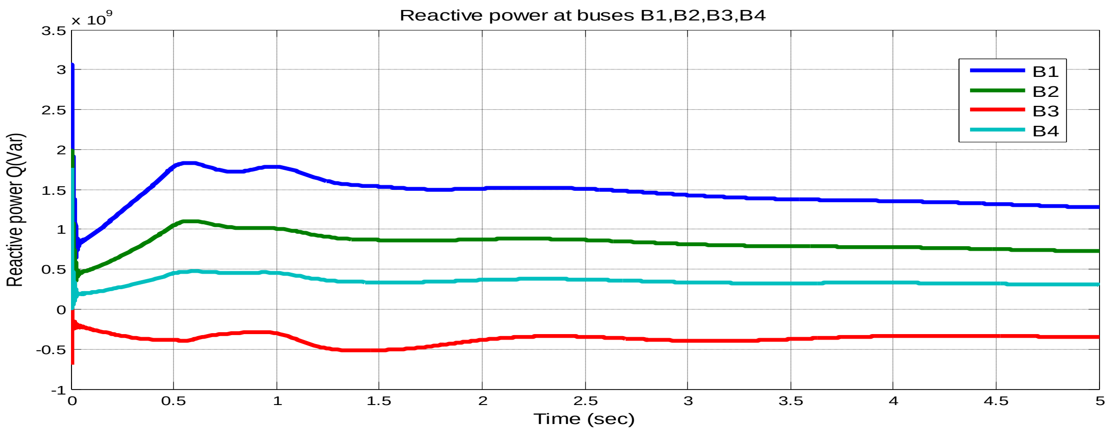

(c)

Fig.7 Profiles at buses B1, B2, B3, B4 with-out FACT Device, (a) Voltage, (b) Active Power, (c) Reactive Power.

Table-1 Active, Reactive power & voltages with-out FACTS

Bus	P (MW)	Q (Mvar)	S (MVA)	V (kv)
B1	768.4	1274	1487.79	296.8
B2	154.6	725.2	741.496	296.8
B3	-545.4	-342.6	664.08	195.4
B4	530.8	304.4	611.89	239.1

6.2 Impact of SVC

Here observe the impact of the SVC for stabilizing the network during a severe contingency. First put the two PSS in service. Verify that the SVC is in fixed susceptance mode with Bref = 0. The rating of the SVC is +/-1000 MVA, Start the simulation. In order not to pursue unnecessary simulation, the Simulink Stop block is used to stop the simulation when the angle difference reaches 3*360 degrees. Now open the SVC block menu and change the SVC mode of operation to Voltage regulation. The SVC will now try to support the voltage by injecting reactive power on the line when the voltage is lower than the reference voltage (1.0 pu). The selected SVC reference voltage corresponds to the bus voltage with the SVC out of service. In steady state the SVC will therefore be floating and waiting for voltage compensation when voltage departs from its reference set point. Let we installed SVC at bus 3, because the voltage at bus-3 is lower as seen with-out FACT analysis.

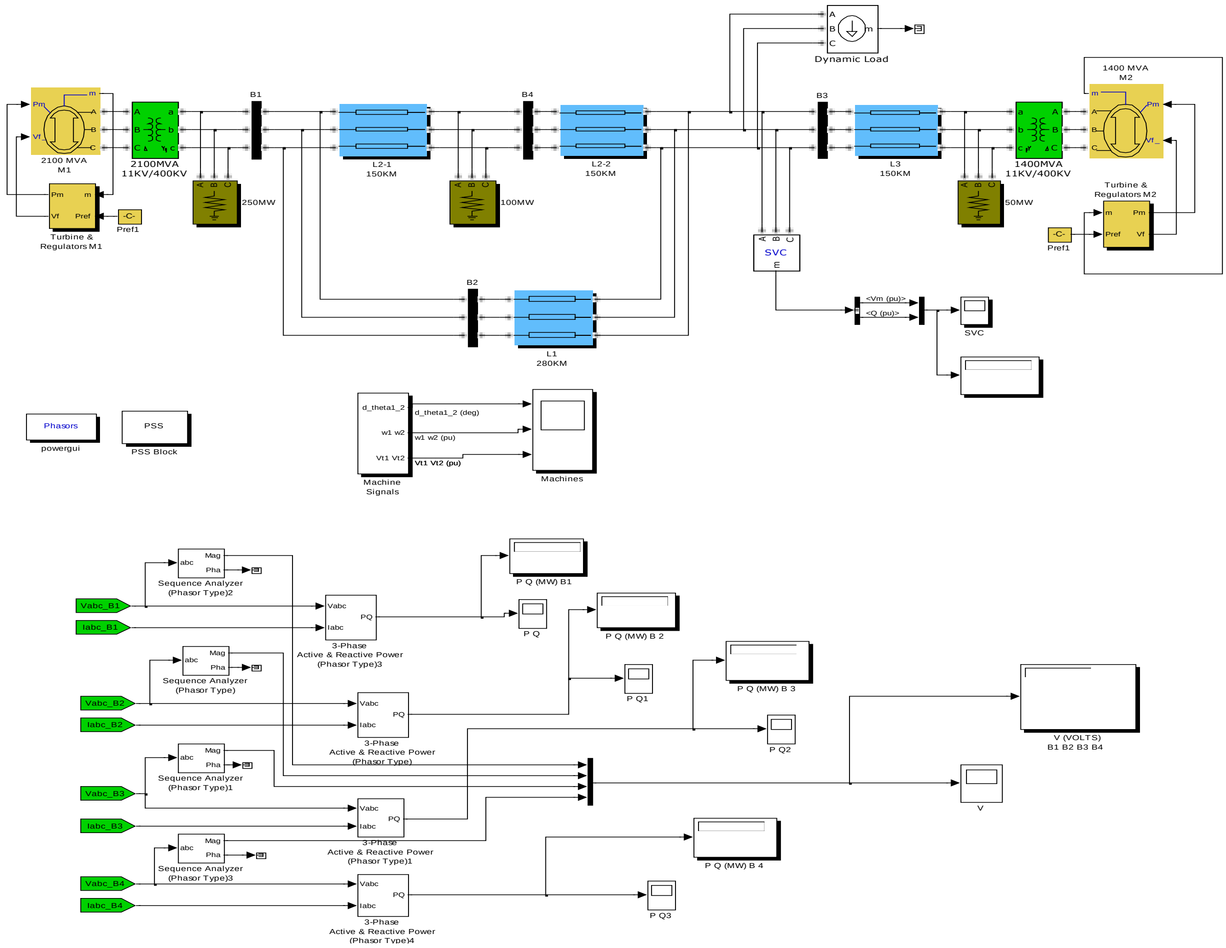

Fig.8 Simulation of test system with SVC

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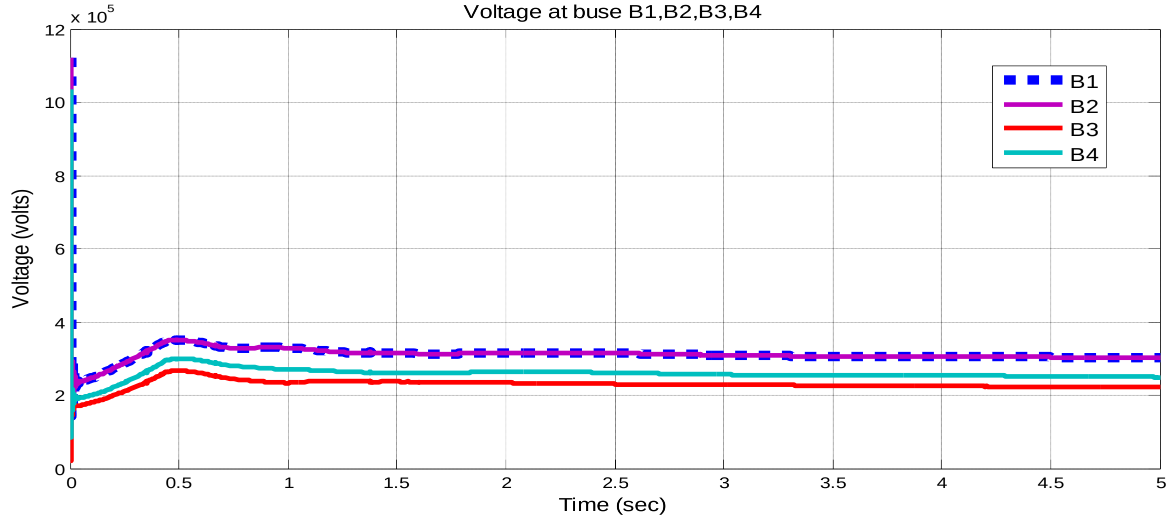
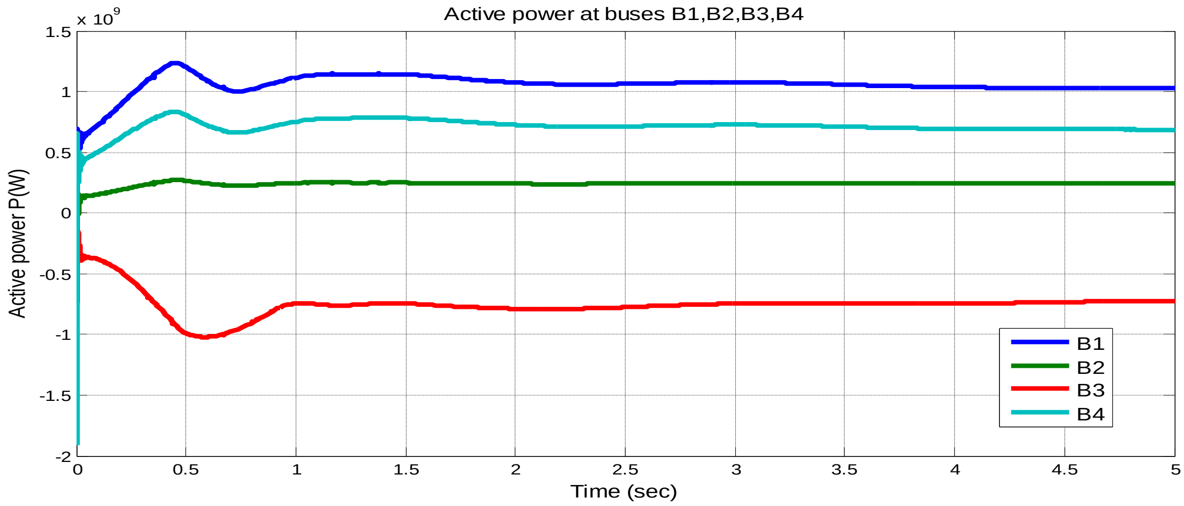
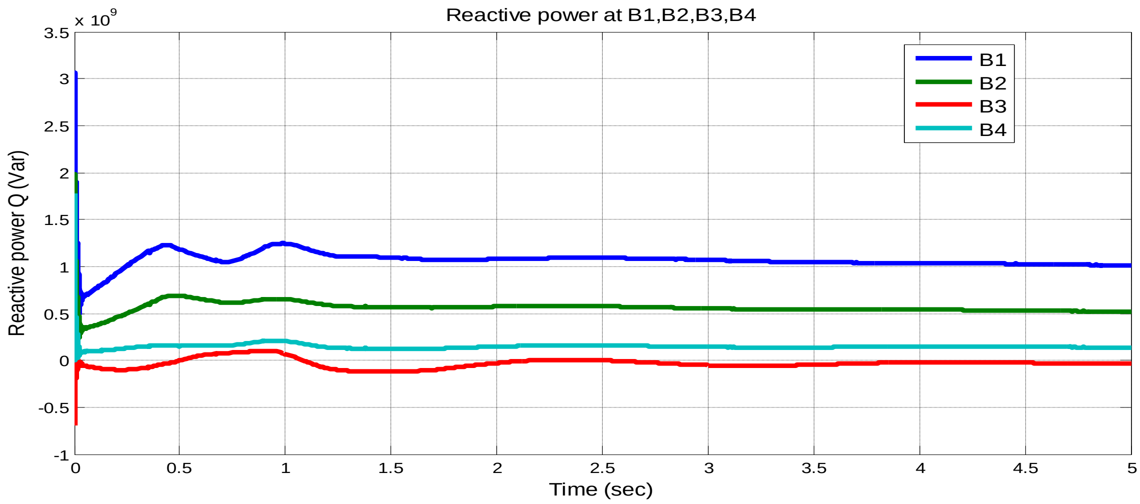
The simulation results for test system with SVC are given below. The data for different parameters are given in table 2.



(a)



(b)



(c)

Fig. 9 Profiles at buses B1, B2, B3, B4 with SVC, (a) Voltage, (b) Active Power, (c) Reactive Power

Table-2 Active, Reactive power & voltages with SVC

Bus	P (MW)	Q (Mvar)	S (MVA)	V (k volts)	SVC data	
					V (pu)	Q (pu)
B1	1028	1010	1441.14	301.5	-	-
B2	243	518.7	572.799	301.5	-	-
B3	-723.7	-37.3	724.66	221.8	0.6792	0.2416
B4	685.8	137.2	699.39	249.5	-	-

7. CONCLUSION

This paper deals with applications of the SVC. The detailed models of the SVC is implemented and tested in MATLAB/simulink environment. The models are applicable for voltage stability analysis, and cover broader range of power transfer capability.

The effects of FACTS (SVC) installed in power transmission path are analyzed in this thesis, and the conclusions are as follow:

(1) The FACTS can improve voltage stability limit observably, and FACTS give better performance for power transfer capability for 4-bus system transmission capacity increased 67.27 MVA (SVC).

(2) The power losses in system with-out FACT is more as compared when used FACTS devices. The loading capacity with SVC is increased, the reactive power compensated form -342.6 MVAR (no FACTS) to -37.3 MVAR (SVC), and voltage injected from 195.4(no FACTS) to 221.8 kv (SVC), at bus-3 for 4-bus system.

(3) The STATCOM give superior performance than SVC for reactive power, voltages and power transfer capability for both 4-bus and 6-bus system.

(4) Similarly the performance enhancement of 6-bus test system can be analyses for compensate reactive power, voltage injected and increased power transfer capability.

(5) As has been discussed above (1)-(4) it has been observed system performance improved by introducing the FACTS Devices, the best performance has been obtained by introducing FACTS devices such as SVC which compensate reactive power (MVAR), voltage injected (kv) and increased power transfer capability (MVA). It's concluded that by introducing FACTS device system performance, voltage stability and transmission capability improves considerably.

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