MARKET BASED POWER QUALITY IMPROVEMENT USING SERIES FACTS CONTROLLER SIMULATION

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ABSTRACT

Day by day energy consumption is increasing. Also power demand based on market need required to control by proper control system. For this purpose series FACTS controller are more suitable device. It is an urgent need to increase power generation and hence increase in power transmission capability. There is an increasing demand of power flow control in power systems of the future and FACTS devices are the most suitable devices to control power flow. However cost and reliability are the main issues that create hurdles in widespread application of FACTS Devices. Distributed-series FACTS Controller gives an opportunity to realize cost effective power flow control.
These papers present the MATLAB Simulink model of series FACTS controller with complete MATLAB simulation models and parameter details for designing FACTS controller for future researchers.

Keyword: - *SSSC, TCSC, Series FACTS controller, MATLAB.*

1. INTRODUCTION

Day by day power demand is increasing. To fulfil increased demand, it is an urgent need to increase power generation and hence increase in power transmission capability. With increasing load demand, hence increase in power generation and transmission, power system becomes more and more complex, as a result, in some cases Transmission Line becomes overloaded (above thermal limit) and in other cases it becomes under loaded though its thermal limit capacity is not reached. It may lead to uncontrolled power flows; and excessive reactive power in the system, thus the full potential of transmission interconnections is not utilized. There is a need to shift a power from overloaded line to other parallel path. Accordingly new transmission line erection is needed. But it is costly and difficult due to land acquisition problem, environmental problems etc. and it is time consuming also. The possible solution is to optimize the utilization of the existing network and to boost the transmitted power upto the thermal limit of the network.

2. SERIES FACTS CONTROLLER

2.1. TCSC

The basic conceptual TCSC module comprises a series capacitor, *C*, in parallel with a thyristor-controlled reactor, *LS*, as shown in Figure 2. However, a practical TCSC module also includes protective equipment normally installed with series capacitors, as shown in Figure 3. A metal-oxide varistor (MOV), essentially a nonlinear resistor, is connected across the series capacitor to prevent the occurrence of high-capacitor over- voltages.

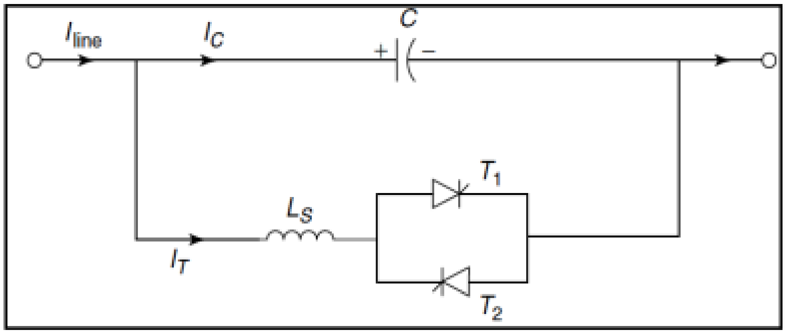

Fig.2:- TCSC basic module

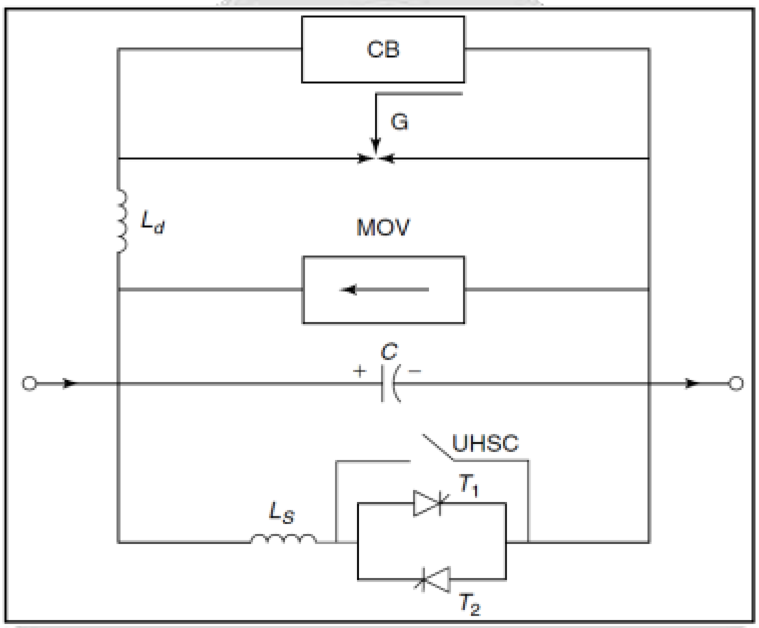

Fig.2:- TCSC practical module

Not only does the MOV limit the voltage across the capacitor, but it allows the capacitor to remain in circuit even during fault conditions and helps improve the transient stability.

Also installed across the capacitor is a circuit breaker, CB, for controlling its insertion in the line. In addition, the CB bypasses the capacitor if severe fault or equipment-malfunction events occur. A current-limiting inductor, *Ld*, is incorporated in the circuit to restrict both the magnitude and the frequency of the capacitor current during the capacitor-bypass operation.

If the TCSC valves are required to operate in the fully "on" mode for prolonged durations, the conduction losses are minimized by installing an ultra–high-speed contact (UHSC) across the valve. This metallic contact offers a virtually lossless feature similar to that of circuit breakers and is capable of handling many switching operations. The metallic contact is closed shortly after the thyristor valve is turned on, and it is opened shortly before the valve is turned off. During a sudden overload of the valve, and also during fault conditions, the metallic contact is closed to alleviate the stress on the valve.

2.2. SSSC

A series capacitor compensates the transmission-line inductance by presenting a lagging quadrature voltage with respect to the transmission-line current. This voltage acts in opposition to the leading quadrature voltage appearing across the transmission-line inductance, which has a net effect of reducing the line inductance. Similar is the operation of an SSSC that also injects a quadrature voltage, *VC*, in proportion to the line current but is lagging in phase:

$$\overline{V_C} = -jkX\overline{I_L} \qquad (10.24)$$

The current in a line compensated at its midpoint by the SSSC is expressed as;

$$I_L = \frac{2V \sin \delta/2}{X} + \frac{V_C}{X} \qquad (10.25)$$

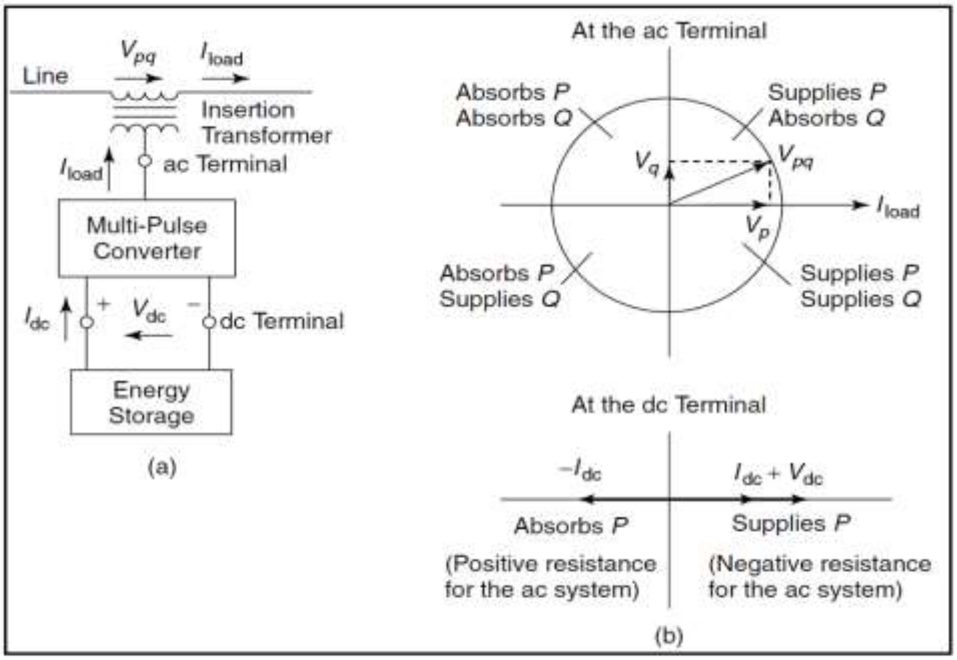

Fig.3:- (a) Generalized series-connected synchronous-voltage source employing a multi-pulse converter with an energy-storage device; (b) the different operating modes for real- and reactive-power exchange.

Where, *V*= the magnitude of voltage (assumed to be the same) at the two ends of the transmission line

δ = the angular difference across the line

A series-compensation scheme using the SSSC is depicted in figure 3. Normally, the SSSC-output voltage lags behind the line current by 90 degree to provide effective series compensation. In addition, the SSSC can be gated to produce an output voltage that leads the line current by 90 degree, which provides additional inductive reactance in the line. This feature can be used for damping power swings and, if the converter has adequate rating, for limiting short-circuit currents. A typical SSSC controller connected in a transmission line is shown in Figure 4. This controller comprises a VSC in which its coupling transformer is connected in series with the transmission line.

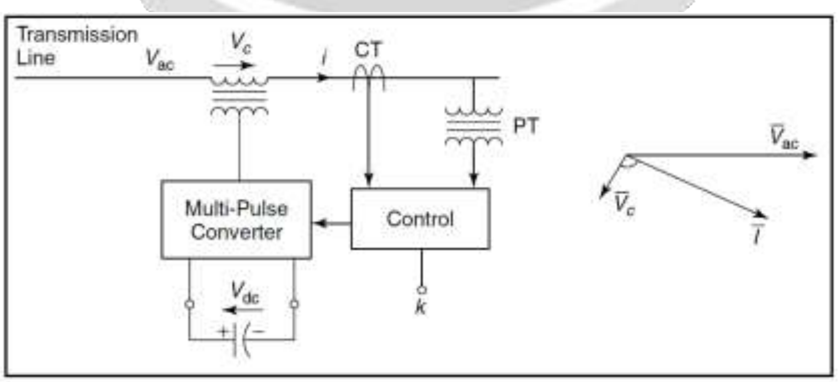

Fig.4:- A synchronous-voltage source employing a multi-phase dc/ ac converter that is operated as a series-capacitive compensator.

3. MATLAB SIMULATION MODEL & RESULTS

3.1. TCSC Detail Model

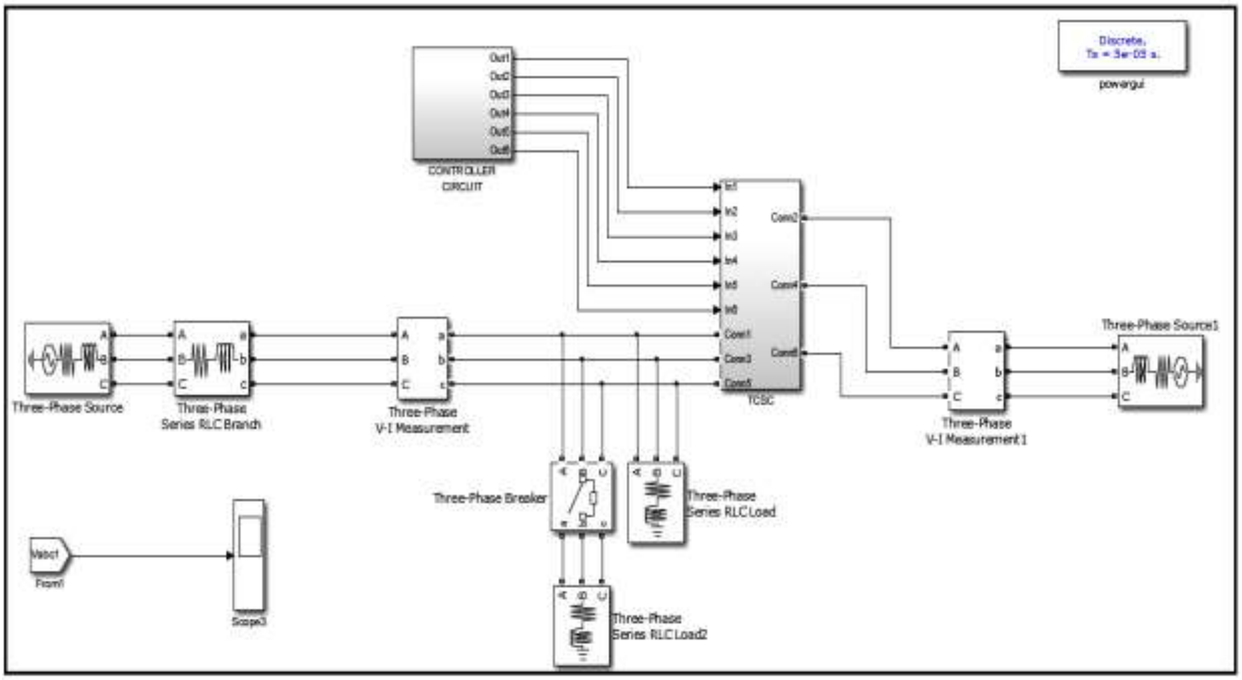

Fig.5:- MATLAB Simulation detail model of power system with TCSC

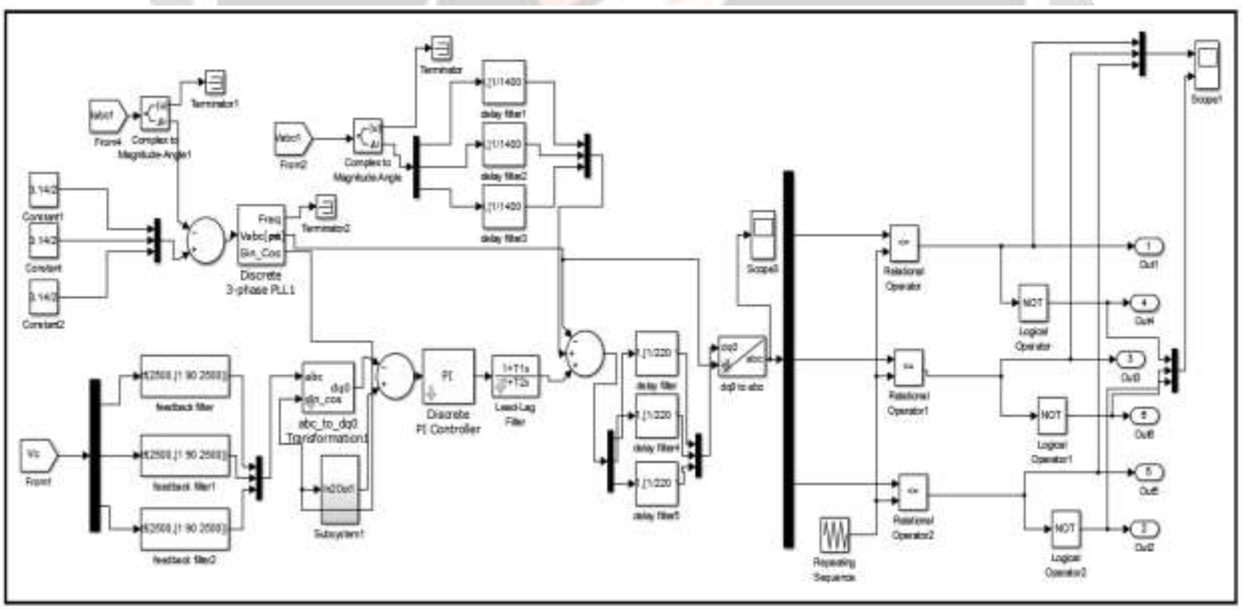

Fig.6:- MATLAB simulation model for TCSC controller subsystem

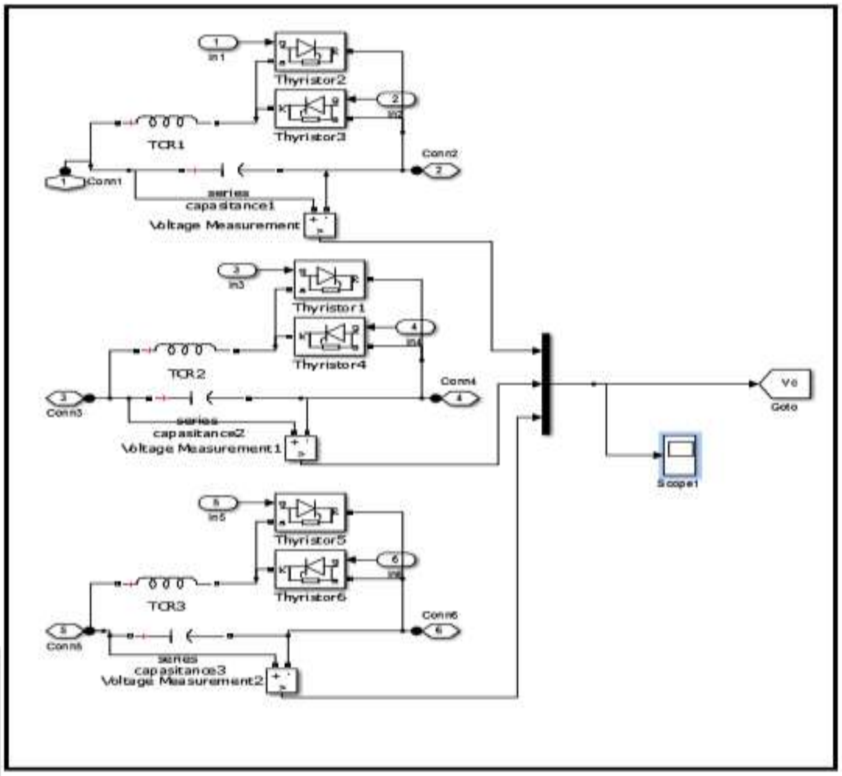

Fig.7:- MATLAB simulation model for TCSC subsystem

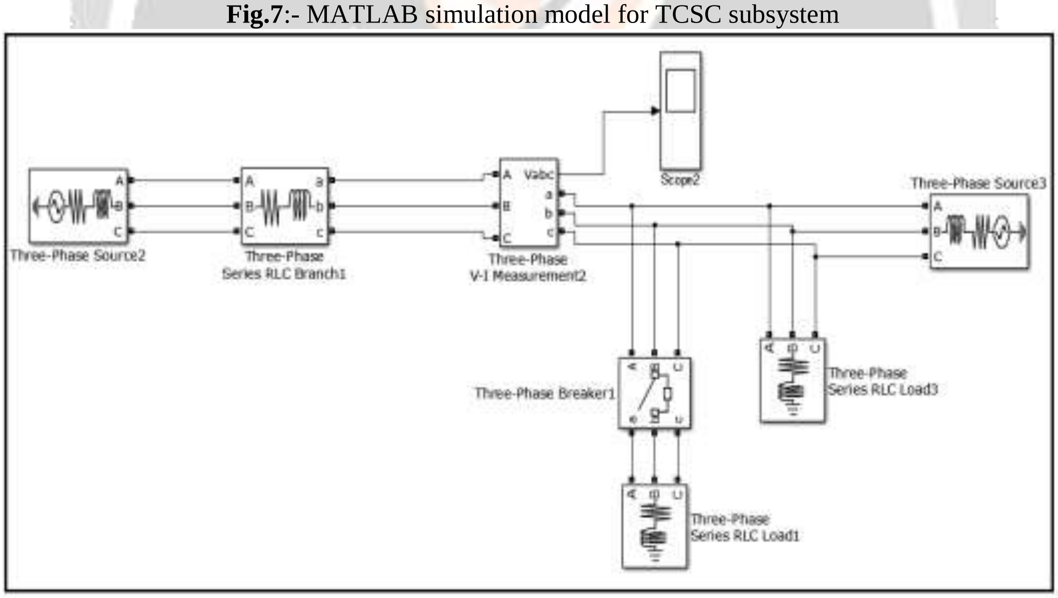

Fig.8:- MATLAB simulation model of power system without TCSC

3.2. TCSC Detail model parameter

Table 1:- TCSC detail model parameter specification

Sr. No.	Name of simulation block	Parameter specification
1.	Three phase voltage source	Phase to phase rms voltage = 539 KV; Frequency = 60Hz; Three phase short circuit level at base voltage = 100 MVA;

		Base voltage = 539 KV; X/R ratio = 7.
2.	Three phase series RLC branch	Branch type = Series RL; Resistance R = 6.0852; Inductance L = 0.4323.
3.	Three phase breaker	Initial status of breaker = open; Transition time = 0.3sec to 0.6 sec; Breaker resistance Ron = 0.001Ohm; Snubber resistance Rp =1MOhm
4.	Three phase RLC load2	Nominal phase to phase voltage (Vn) = 539 KV; Nominal frequency fn=60Hz; Active power=50 MW; Inductive reactive power QL=50 MVAR; capacitive reactive power QC= 0VAR.
5.	Three phase RLC load	Nominal phase to phase voltage (Vn) = 539 KV; Nominal frequency fn=60Hz; Active power=50 MW; Inductive reactive power QL=30 MVAR; capacitive reactive power QC= 0VAR.
6.	Three phase voltage source 1	Phase to phase rms voltage = 477.8 KV; Frequency = 60Hz; Three phase short circuit level at base voltage = 100 MVA; Base voltage = 477.8 KV; X/R ratio = 7.
7.	TCSC Subsystem	Thysristor data : Resistance Ron = 0.001 Ohm; Inductance Lon = 0 H; Forward voltage = 0.8 V; Snubber resistance Rs = 500 Ohm; Snubber Capacitance Cs = 250 nF. Inductance branch L = 0.043 H.

3.3. TCSC simulation results

3.3.1. Voltage profile without TCSC

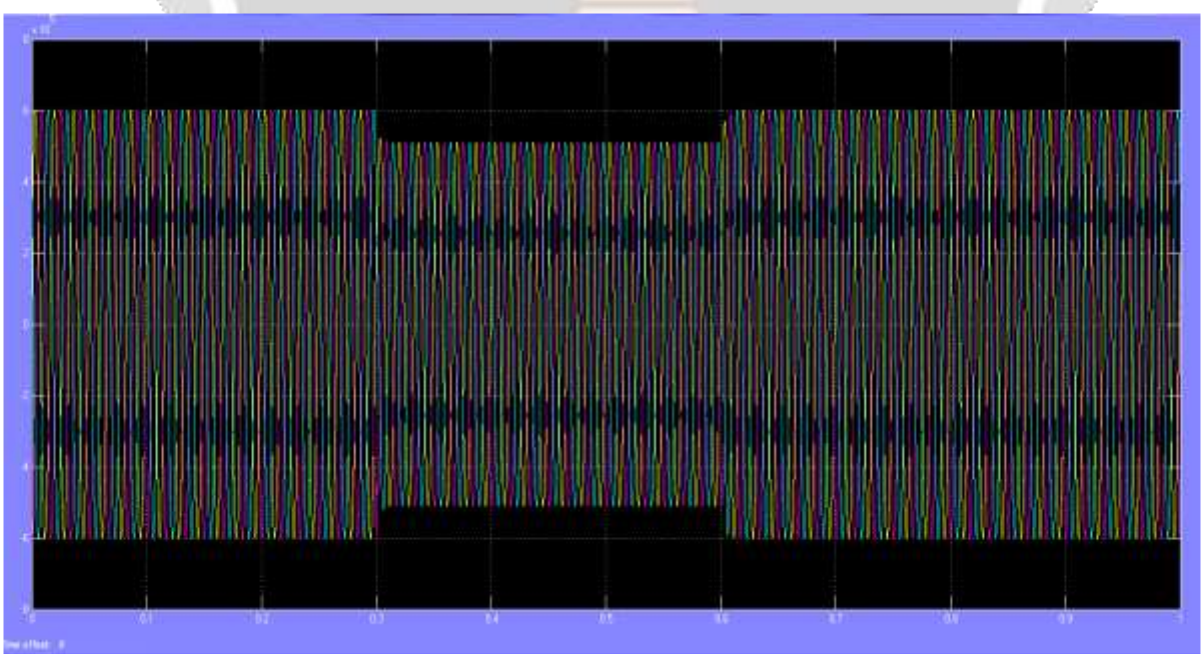

Fig.9:- Voltage of power system without TCSC

3.2.2. Voltage profile with TCSC

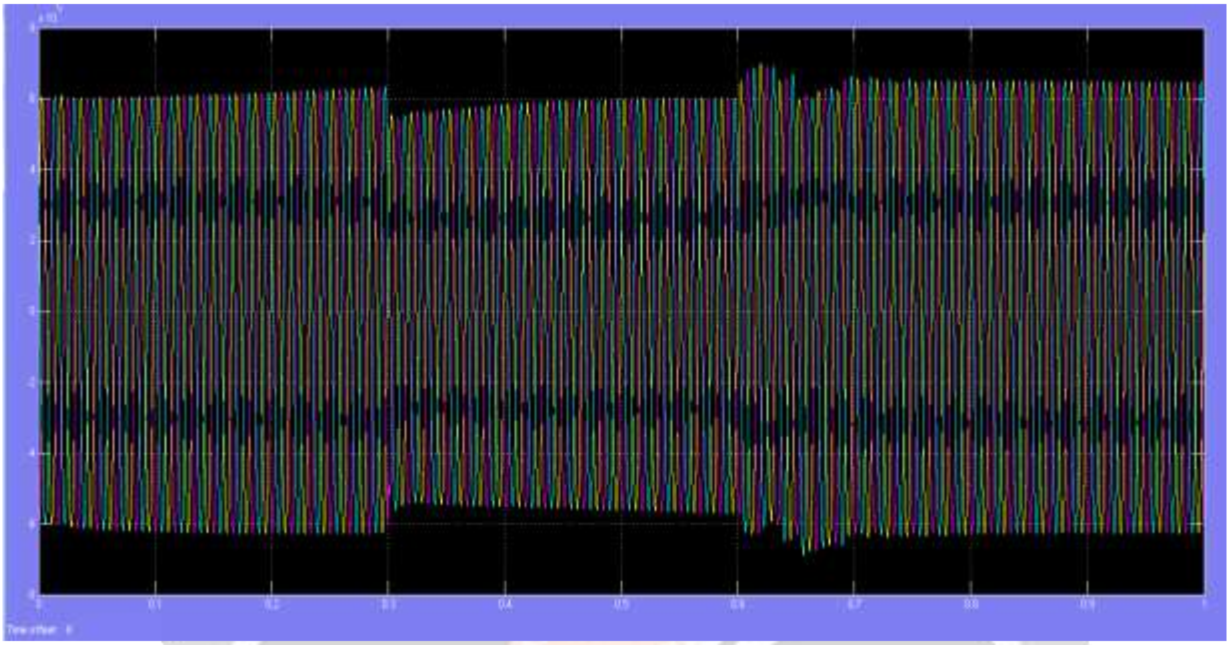

Fig.10:- Voltage of power system with TCSC

3.4. SSSC Model

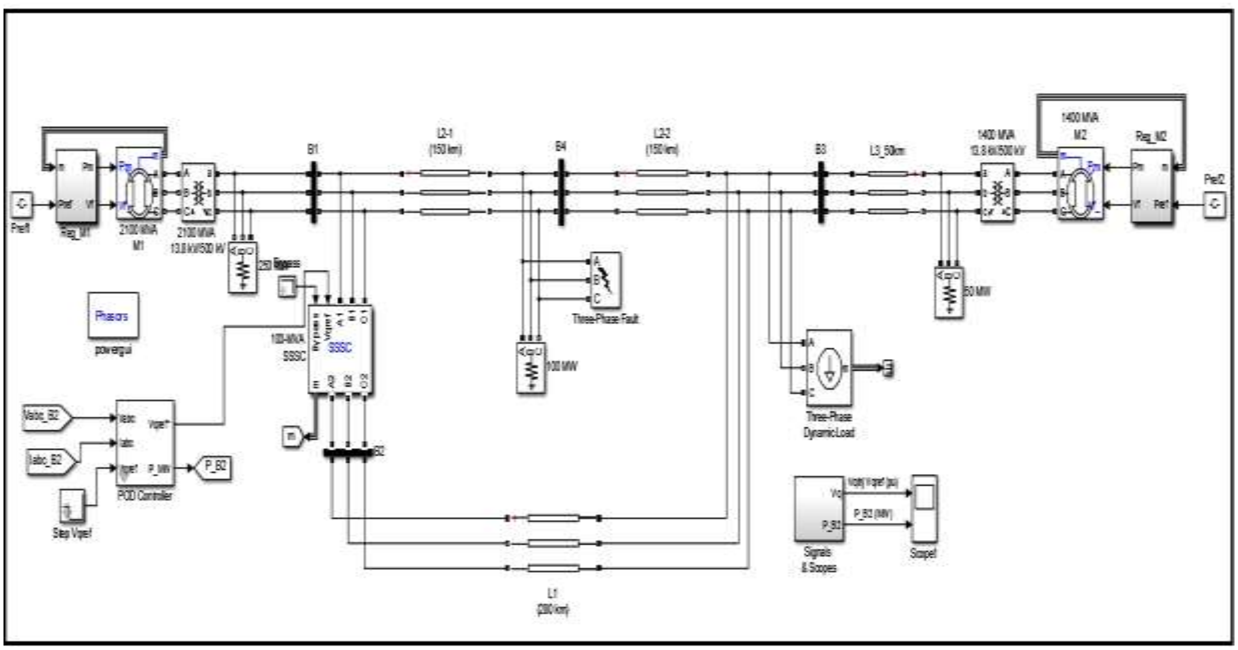

Fig.11:- Complete MATLAB simulation model of SSSC coupled power system.

The Static Synchronous Series Compensator (SSSC), one of the key FACTS devices, consists of a voltage-sourced converter and a transformer connected in series with a transmission line. The SSSC injects a voltage of variable magnitude in quadrature with the line current, thereby emulating an inductive or capacitive reactance. This emulated variable reactance in series with the line can then influence the transmitted electric power. The SSSC is used to damp power oscillation on a power grid following a three-phase fault.

The power grid consists of two power generation substations and one major load center at bus B3. The first power generation substation (M1) has a rating of 2100 MVA, representing 6 machines of 350 MVA and the other one (M2) has a rating of 1400 MVA, representing 4 machines of 350 MVA. The load center of approximately 2200 MW is modeled using a dynamic load model where the active & reactive power absorbed by the load is a function of the system voltage. The generation substation M1 is connected to this load by two transmission lines L1 and L2. L1 is 280-km long and L2 is split in two segments of 150 km in order to simulate a three-phase fault (using a fault breaker) at the midpoint of the line. The generation substation M2 is also connected to the load bya 50-km line (L3). When the SSSC is bypass, the power flow towards this major load is as follows: 664 MW flow on L1 (measured at bus B2), 563 MW flow on L2 (measured at B4) and 990 MW flow on L3 (measured at B3).
The SSSC, located at bus B1, is in series with line L1. It has a rating of 100MVA and is capable of injecting up to 10% of the nominal system voltage. This SSSC is a phasor model of a typical three-level PWM SSSC. If you open the SSSC dialog box and select "Display Power data", you will see that our model represents a SSSC having a DC link nominal voltage of 40 kV with an equivalent capacitance of 375 uF. On the AC side, its total equivalent impedance is 0.16 pu on 100 MVA. This impedance represents the transformer leakage reactance and the phase reactor of the IGBT bridge of an actual PWM SSSC.The SSSC injected voltage reference is normally set by a POD (Power Oscillation Damping) controller whose output is connected to the Vqref input of the SSSC. The POD controller consists of an active power measurement system, a general gain, a low-pass filter, a washout high-pass filter, a lead compensator, and an output limiter. The inputs to the POD controller are the bus voltage at B2 and the current flowing in L1.

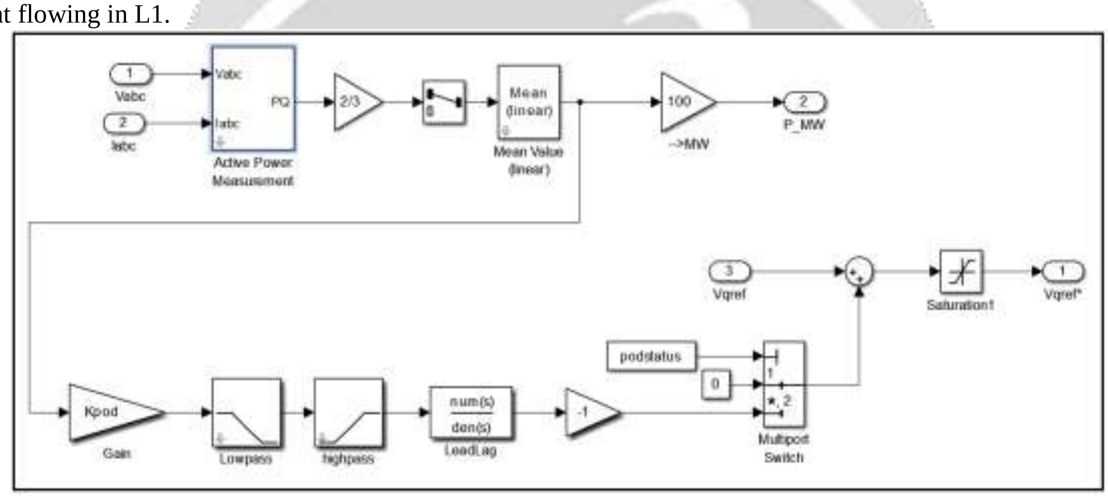

Fig.12:- POD controller subsystem model for SSSC control.

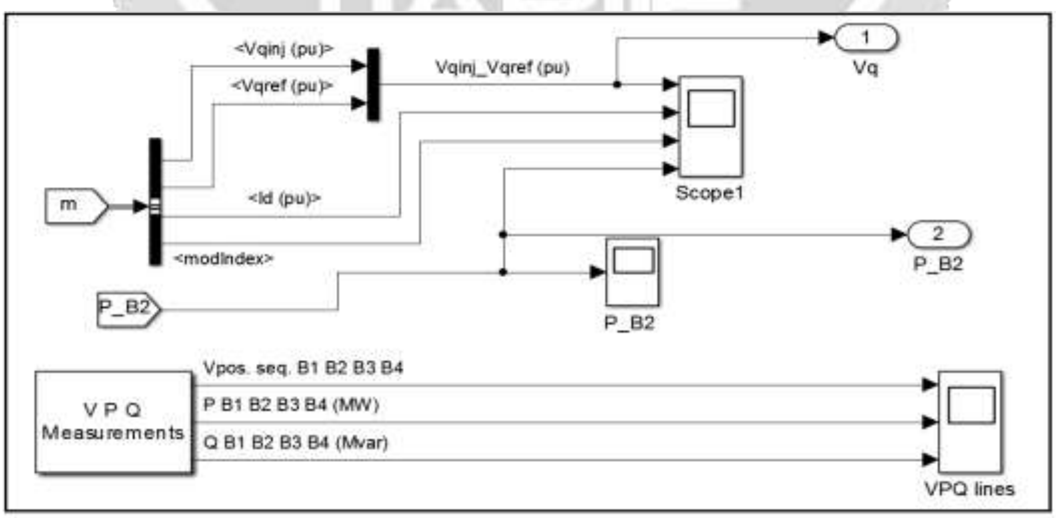

Fig.13:- Scope subsystem model for power system parameter and result observation.

3.5. SSSC model parameter

Table 2:- SSSC model parameter specification

Sr. No.	Name of simulation block	Parameter specification
1.	Synchronous machine (M1)	Nominal power = 2100 MW; Line to line voltage = 13800 V; Frequency = 60; Xd = 1.305 pu; Xd' = 0.296 pu ; Xd" = 0.252 pu ;Xq = 0.474 pu ; Xq" = 0.243 pu; Xl = 0.18 pu ; d axis time constant = short circuit; q axis time constant = open circuit; Td' = 1.01Sec ; Td" = 0.053Sec ; Tqo" = 0.1sec; Stator resistance Rs = 2.8544 * 10^{-3} pu; Inertia coefficient H = 3.7 sec; Friction factor F = 0 pu; Pole pair =32.
2.	2100 MVA Three phase transformer	Nominal power = 2100 MVA; Frequency=60Hz; Winding 1 (primery) =12.8 KV; R_1= 0.002pu, L_1=0.0 pu; Winding 2(Secondery) = 500 KV; R_1= 0.002 pu, L_1=0.12 pu; Magnetizing resistance R_m=500 pu; Magnetizing inductance =500 pu.
3.	250 MW resistive load	Nominal phase to phase voltage (Vn) = 500KV; Nominal frequency fn=60Hz; Active power=250 MW; Inductive reactive power QL=0KVAR; capacitive reactive power QC=0 MVAR.
4.	Transmission line 150Km (L2-1)	Frequency for RLC specification = 60Hz; Positive sequence resistance r1= 0.01273 Ohm/Km; Zero sequence resistance r0 = 0.3864 Ohm/Km ;Positive sequence inductance L1= 0.9337mH/Km; Zero sequence inductance L0= 4.1264 mH/Km ; Positive sequence capacitor C1= 12.74nF/Km; Zero sequence capacitor C0= 7.751nF/Km; Line length = 150Km.
5.	100 MW resistive load	Nominal phase to phase voltage (Vn) = 500KV; Nominal frequency fn=60Hz; Active power=100 MW; Inductive reactive power QL=0KVAR; capacitive reactive power QC=0 MVAR.
6.	Transmission line 150Km (L2-2)	Frequency for RLC specification = 60Hz; Positive sequence resistance r1= 0.01273 Ohm/Km; Zero sequence resistance r0 = 0.3864 Ohm/Km ;Positive sequence inductance L1= 0.9337mH/Km; Zero sequence inductance L0= 4.1264 mH/Km ; Positive sequence capacitor C1= 12.74nF/Km; Zero sequence capacitor C0= 7.751nF/Km; Line length = 150Km.
7.	Three phase dynamic load	Nominal line – line voltage = 500 KV; Frequency = 50 Hz; Active and reactive power at initial voltage Po = 2.2×10^9 W; Qo = 1×10^8 VAR; Initial positive sequence voltage Vo = 1.00208 pu with phase angle 20.9514 degree.
8.	Transmission line 150Km (L3_50km)	Frequency for RLC specification = 60Hz; Positive sequence resistance r1= 0.01273 Ohm/Km; Zero sequence resistance r0 = 0.3864 Ohm/Km ;Positive sequence inductance L1= 0.9337mH/Km; Zero sequence inductance L0= 4.1264 mH/Km ; Positive sequence capacitor C1= 12.74nF/Km; Zero sequence capacitor C0= 7.751nF/Km; Line length = 50Km.
9.	50 MW resistive load	Nominal phase to phase voltage (Vn) = 500KV; Nominal frequency fn=60Hz; Active power=50 MW; Inductive reactive power QL=0KVAR; capacitive reactive power QC=0 MVAR.
10.	1400 MVA Three phase transformer	Nominal power = 1400 MVA; Frequency=60Hz; Winding 1 (primery) =13.8 KV; R_1= 0.002pu, L_1=0.0 pu; Winding

		2(Secondery) = 500 KV; R_1= 0.002 pu, L_1=0.12 pu; Magnetizing resistance R_m=500 pu; Magnetizing inductance =500 pu.
11.	Synchronous machine (M1)	Nominal power = 1400 MW; Line to line voltage = 13800 V; Frequency = 60; Xd = 1.305 pu; Xd' = 0.296 pu ; Xd" = 0.252 pu ;Xq = 0.474 pu ; Xq" = 0.243 pu; Xl = 0.18 pu ; d axis time constant = short circuit; q axis time constant = open circuit; Td' = 1.01Sec ; Td" = 0.053Sec ; Tqo" = 0.1sec; Stator resistance Rs = 2.8544 * 10^{-3} pu; Inertia coefficient H = 3.7 sec; Friction factor F = 0 pu; Pole pair =32.
12.	SSSC phasor model	Control parameter: Maximum rate of change for Vqref = 3 pu/sec; Injected voltage regulator gain Kp = 0.03; Ki =1.5; Vdc regulator gain Kp= 0.1×10^{-3}; Ki = 20×10^{-3}. Power data: System nominal volatage = 500 KV; frequency = 60 Hz; Series convertor rating Snom = 100MVA; Maximum injected voltage = 1 pu; Series convertor impedance R = 0.16 pu; L = 0.16 pu; DC link nominal voltage = 40000 V; DC link total equivalent capacitance = 375 micro F.

3.5. SSSC MATLAB simulation result

3.5.1. SSSC dynamics response

In the "Step Vqref" block (the red timer block connected to the "Vqref" input of the POD Controller).This block should be programmed to modify the reference voltage Vqref as follows: Initially Vqref is set to 0 pu; at t=2 s, Vqref is set to -0.08 pu (SSSC inductive); then at t=6 s, Vqref is set to 0.08 pu (SSSC capacitive). Double-click on the POD Controller block and set the POD status parameter to "off". This will disable the POD controller. Also, make sure that the fault breaker will not operate during the simulation (the parameters "Switching of phase A, B and C" should not be selected).

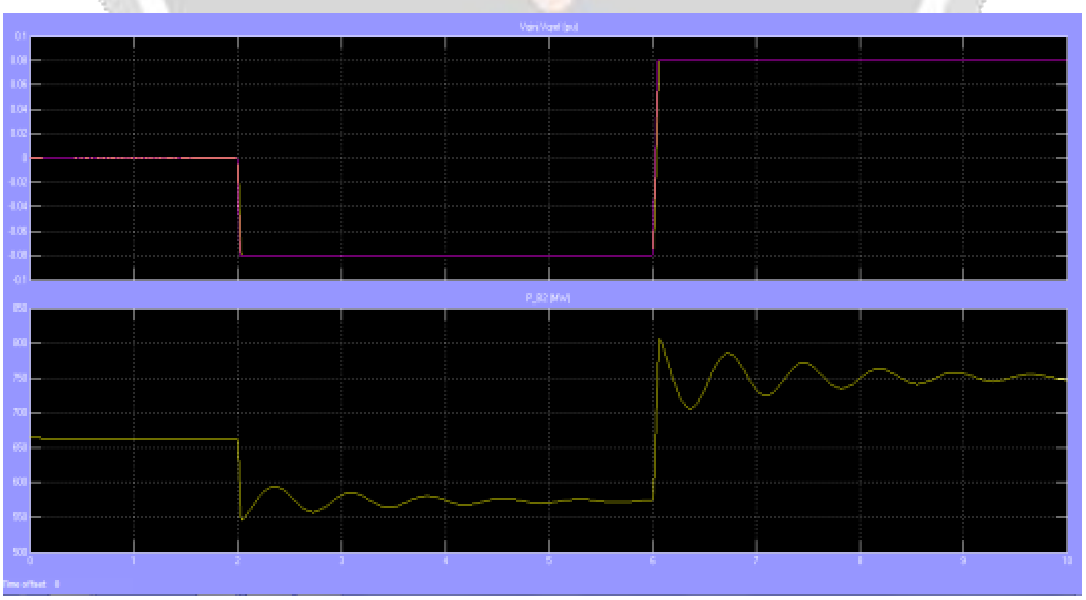

Fig.14:- SSSC dynamic response when maximum rate of change of Vqref = 3pu/sec.

At the Scope1, graph displays the Vqref signal (magenta trace) along with the measured injected voltage by the SSSC. The second graph displays the active power flow (P_B2) on line L1, measured at bus B2. We can see that the SSSC regulator follows very well the reference signal Vqref. Depending on the injected voltage, the power flow on line varies from 575 to 750 MW. In a real system the reference signal Vqref would typically be changed muchmore gradually in order to avoid the oscillation we see on the transmitted power (P_B2 signal). Double-click on the SSSC block and select "Display Control parameters".

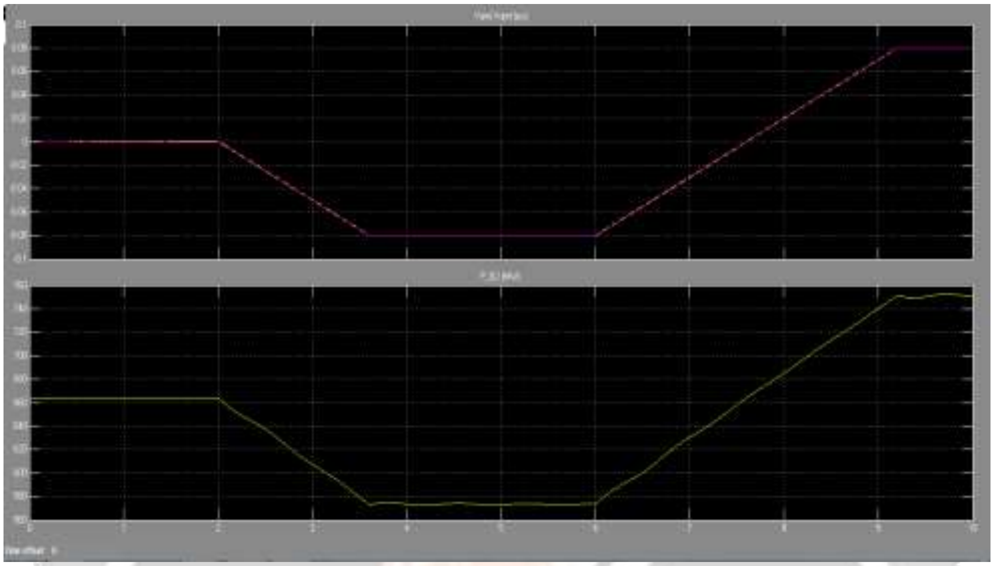

Fig.15:- SSSC dynamic response when maximum rate of change of Vqref = 0.05pu/sec.

Modify the "Maximum rate of change for Vqref (pu/s)" parameter from 3 to 0.05. The power oscillation on the active power should now be very small show in figure.

3.5.2. SSSC damping power oscillation response

In this section we compare the operation of our SSSC with and without POD control. Set the "Step Vqref" block and multiply by 1000 the time vector in order to disable the Vqref variations. Set on the fault breaker and select the parameters "Switching of phase A, B and C" to simulate a three-phase fault. The transition times should be set as follows: [20/60 30/60]+1; this means that the fault will be applied at 1.33 s and will last for 10 cycles. It was observed that, the power oscillation on the L1 line (second graph on Scope1) following the three-phase fault.

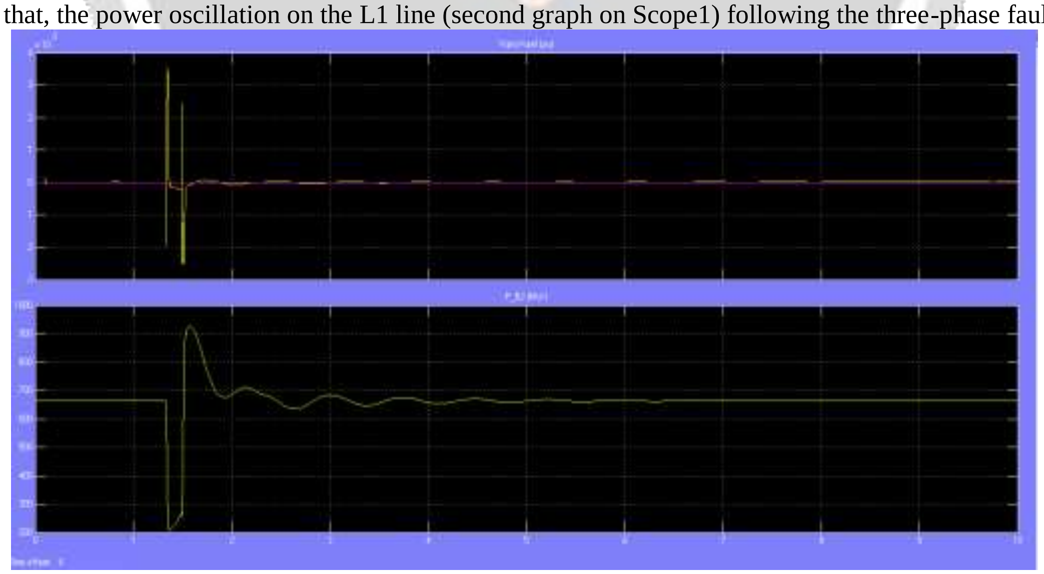

Fig.16:- SSSC dynamic response for damped out oscillation without POD controller.

Now, consider second simulation with the POD controller in operation. Set on the POD Controller block and set the POD status parameter to "on". Looking again at the second graph on Scope1 (P_B2 signal), we can see that the SSSC with a POD controller is a very effective tool to damp power oscillation.

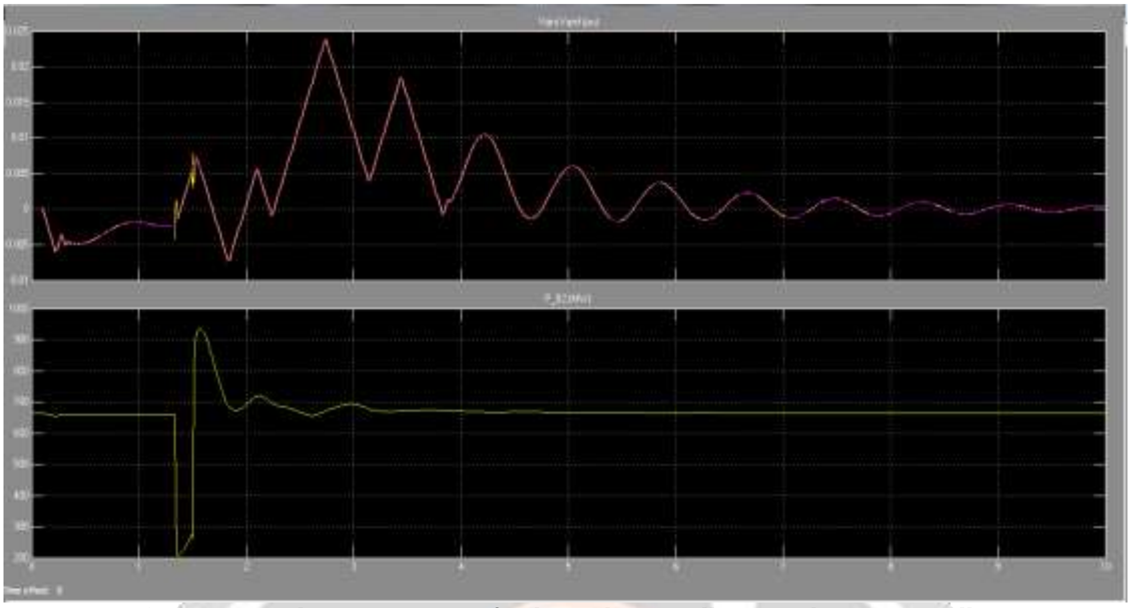

Fig.17:- SSSC dynamic response for damped out oscillation with POD controller.

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