Impact of SSSC control modes on small signal stability and transient stability

By

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DEPARTMENT OF ELECTRICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

MAY 2014

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Major Project Report

Submitted in partial fulfillment of the requirements for the degree of

Master of Technology

In

Electrical Engineering

(Electrical Power System)

By

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Undertaking For Originality of the Work

I, **Nirav Bhatt(Roll No:12MEEE03)**,give undertaking that the Major Project entitled **"Impact of SSSC control modes on small signal stability and transient stability"** submitted by me,towards the partial fulfillment of the requirement for the degree of Master of Technology in Electrical Power System,Electrical Engineering,under Institute of Technology, Nirma University,Ahmedabad is the original work carried out by me and I give assurance that no attempt of plagiarism has been made.I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere,it will result in severe disciplinary action.

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CERTIFICATE

This is to certify that the Major Project Report entitled **"Impact of SSSC control modes on small signal stability and transient stability"** submitted by **Mr.Nirav B.Bhatt(Roll No: 12MEEE03)** towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering) in the field of Electrical Power System of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Abstract

In todays era the demand of electricity has increased and power system has been modernized. So the network of transmission lines interconnecting the generating stations to the main load points becomes complex. In order to carry the high demand of consumers it is required to have stable transmission system. Transient stability improvement is one of the important aspects in modern power system. There is SSSC designed to stabilize the interconnected power system.

SSSC is designed to stabilize the frequency of oscillation in an interconnected power system. As a series compensator, SSSC can control the magnitude of the compensation in two ways, which are called the constant reactance mode and the constant quadrature voltage mode. In the constant reactance mode, the voltage, injected by SSSC, is proportional to the line current. In the constant quadrature voltage mode, the injected voltage of the SSSC is a constant that is in quadrature to the line current.

This study presents the method of improving Voltage and Transient stability of power system using a SSSC. The mathematical model of power system equipped with a SSSC is systematically derived. The presented mathematical model is applied to design control strategy of a SSSC. The simulation results are tested on a Single Machine Infinite bus system. The effect of gain control of a SSSC on stability improvement is also investigated.

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Chapter 1

Introduction

Due to the deregulation policies the electric utilities are operating in an increasingly competitive market. At the same time, economic and environmental pressures force electric companies to enhance the power transfer capability of the existing transmission lines instead of constructing new ones. The development of new technologies, such as flexible AC transmission system (FACTS) controllers, has made it possible that electric utilities deal with above issues. Besides allowing a better utilization of existing power systems capacity, FACTS controllers can control network parameters, such as terminal voltage, line impedance, and phase angle, to improve both the steady state and dynamic performance of the system

In the context of FACTS technology, there are two controllers which can be used to provide series reactive compensation: the thyristor controlled series capacitor (TCSC) and the static synchronous series compensator (SSSC). To supply or absorb reactive power, a TCSC requires fully-rated capacitor or reactor bank. Practical and theoretical studies dealing with the usage of the TCSC to achieve better system performance are well reported in paper instead of using capacitor and reactor banks, a SSSC employs self-commutated voltage-source switching converters to synthesize a three-phase voltage in quadrature with the line current and so accomplishes specific compensation objectives . In steady-state applications, the main interest is to use the SSSC for controlling either impedance line or power flow (active and/or reactive) in transmission lines, whereas for dynamic control, the SSSC is mainly recommended for damping electromechanical oscillations. Thus, the SSSC control system may be comprised by a compensation control loop, to accomplish its steady-state function, and by a fast response control, to act during electromechanical transients. In order to fully understand and correctly employ the SSSC controller, both compensation and stability controls should be jointly investigated. Nevertheless, most of the previous studies deals with the SSSC controls in a separate way.Here the suitable model to study the SSSC control functions in steady state is presented. Studies of usingSSSC-for improvementof the dynamic behavior of the system are reported in [8][10]. In this work, the steady-state and dynamic SSSC controls are jointly considered in a simple power system. Impacts of different operation modes of the SSSC on small-signal and transient stability are investigated. The stability analysis and the design of the SSSC controllers for power flow control and for damping power system oscillations are based on nodal analysis, non-linear simulations, pole placement technique, and time and frequency response techniques.

1.1 Objective

The main objective of this project is to improve the stability of the power system by using the Static Synchronous Series compensator(SSSC).The 9 bus system with 3 synchronous generator will be developed and SSSC will be used in the system. With the help of different fault the effect on the system will be observed.

1.1.1 Outline of Thesis

a. Chapter-1 includes Introduction.

b. Chapter-2 includes introduction of the FACTs devices

c. Chapter-3 includes literature review of this project. Project related Paper and its description include onthese chapter.

d. Chapter-4 includes the Transient and Small signal stability in detail.

e. Chapter-5 includes the simulation results of the models.

1.2 Small signal stability analysis

1.2.1 Case (A)

The SSSC operates in the constant voltage injection mode. figure shows the active power deviation in lines 1 to 2, 2 to 4, and 2 to 3. Note that, in this case, the final value of power flow in line 2 to 4 is bigger than in line 2 to 3 to 4. This occurs because

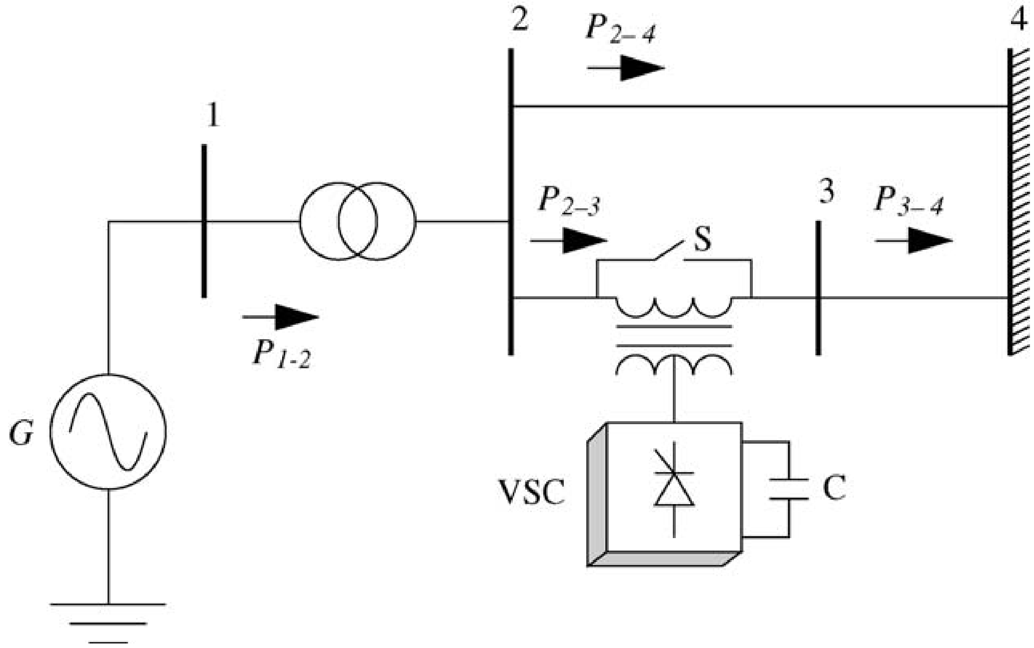


Figure 1.1: Test system with SSSC

after disturbance the effective impedance of line 2 to 3 to 4 is bigger than the impedance of line 2 to 4 as Vs is kept constant at its pre-disturbance value. The electromechanical mode, at both pre-disturbance and post-disturbance operation point, is given in Table 1.

1.2.2 Case (B)

The SSSC operates in the constant impedance emulation mode. The electromechanical mode is given in Table 1 showing that this control mode provides better damping and synchronizing torques than the constant voltage injection mode.

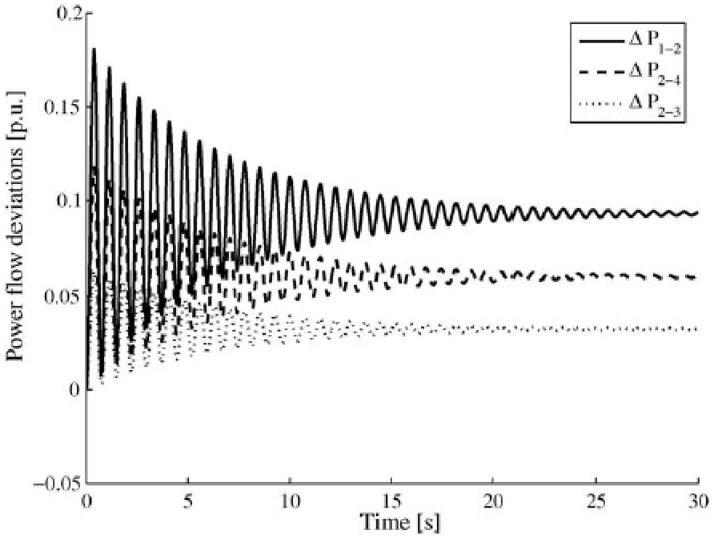


Figure 1.2: Powerflow deviation

Fig. shows the behavior of power flow deviations. Note that, in this case, the generated power step change power 1 to 2 is equally shared between the two circuits of the transmission corridor, since the value of impedance of the two lines (2 to 3 to 4 and 2 to 4) is the same at any instant, as determined by the compensation control loop.

Table 1
Electromechanical mode, Cases A, B, C, and D

Case	Pre-disturbance	Post-disturbance
A	-0.355 ± 8.45	-0.154 ± 8.48
B	-0.384 ± 9.02	-0.180 ± 9.07
C	-0.374 ± 8.42	-0.133 ± 8.45
D	-0.381 ± 8.47	-0.267 ± 8.47

Figure 1.3: Table 1

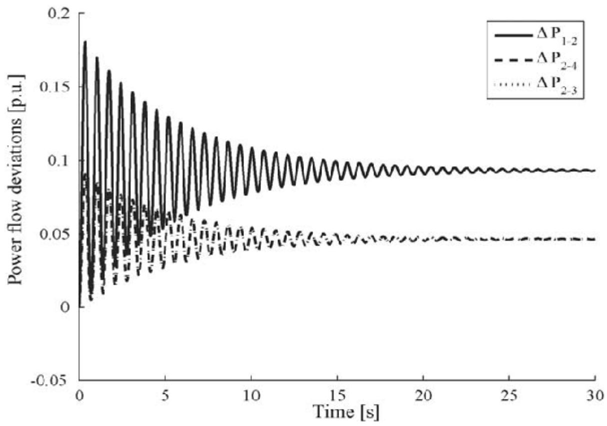
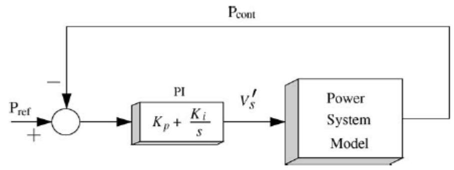


Figure 1.4: Power flow deviation

1.2.3 Case (C)

The SSSC operates in the constant power control mode. The SSSC control system diagram is depicted in figure. The control strategy chosen acts to keep the active power flowin line 2 to 3 at a specified value (Pcont =P2 to 3). The PI controller designwas based on pole placement technique. The gains Ki and Kp were selected so as to achieve minimal impact on the electromechanical mode (see Table 1). Figure shows the line 2 to 4 absorbing all of the increased active power generation (102 to 3 returns to its scheduled pre-disturbance value trough PI controller action. Note that the PI has a slow action and so the power line scheduling is accomplished over a period of about 25 s.



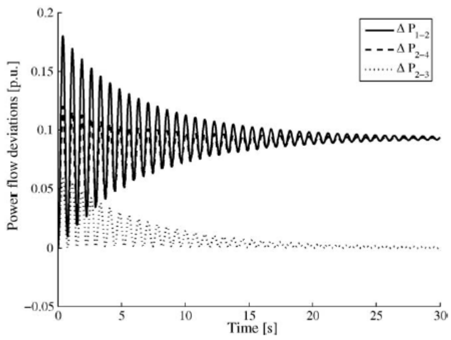


Figure 1.5: power flow deviation

1.2.4 Case (D)

The SSSC operates in the constant power control mode acting to keep constant the active power flow in line 2 to 4 (Pcont = P2 to 3 to P1 to 2) so that the compensated line 2 to 3 absorbs all of the increased active power generation as shown in Fig. As it can be verified in Table 1, at both pre-disturbance and postdisturbance operation points the synchronizing torque is higher in Case B. The damping torque at the post-disturbance operation point is lower in Case C, whereas it is higher in Case D. This is a consequence of the PI action. To maintain the power flow at its scheduled value, Vs has to be decreased in Case C and increased in Case D. Hence, the post-disturbance value of figure. voltage magnitude of the SSSC is lower in Case C and, conversely, it is higher in Case D. The SSSC voltage response for each case are presented in figure. In all cases so far investigated, the electromechanical mode is poorly damped (¡ 5disappear only after a very long time (more than 20 s). In Cases E and F is investigated the effectiveness of the SSSC for power flowcontrol and for system oscillation damping. Then, besides a PI controller, the SSSC has to be equipped with a

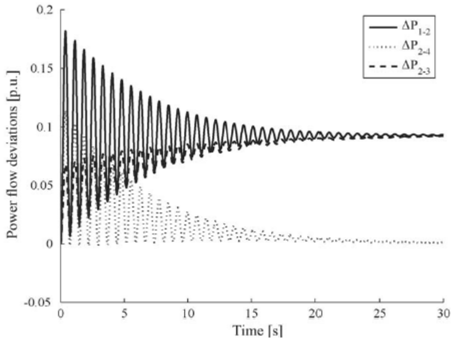


Figure 1.6: power flow deviation

POD stabilizer adequately designed.

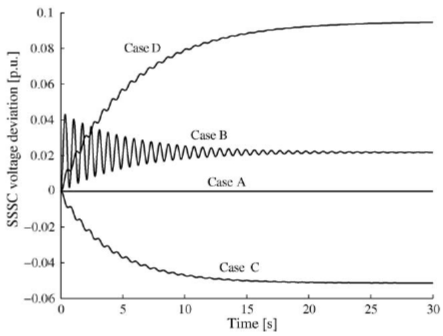


Figure 1.7: SSSC voltage deviation

The PI is used to keep constant the power flow in the compensated line, as in Case C. Figure shows the SSSCcontrol diagram that includes both PI andPOD-controllers. As mentioned before, two candidates as input signals of the POD are considered: active power in line 1 to 2 (P1 to 2) and current magnitude in line 1 to 2 (I1 to 2) Since the SSSC is placed close to bus 2, P1 to 2 and I1 to 2 are local signals.

Chapter 2

Facts Devices

Each of the above mentioned FACTS devices have their own characteristic and limitations. They are represented by different models and mathematical equations depending on the issue under consideration and the time frame involved. This section gives a brief introduction to each of these devices.

2.1 Static Var Compensator

Static VAR Compensator (SVC) is a shunt connected static Var generator/load, whose output is adjusted according the required capacitive or inductive current. The basic structure of SVC is shown in below figure. It can be seen that the model of an SVC is represented by a controllable reactor and fixed capacitors. Through a suitable co-ordination of the capacitors and the controlled reactor, the bus reactive power injected (or absorbed) by the SVC can be continually varied in order to control the voltage or to maintain the desirable power flow in the transmission network either over normal operating or under disturbances conditions . For steady state analysis, SVC is represented as a controllable susceptance. It contains the equivalent of automatic voltage regulator system to set and maintain a target voltage level. Steady state characteristic of SVC in figure shows below that there are upper and lower limits for SVC susceptance.

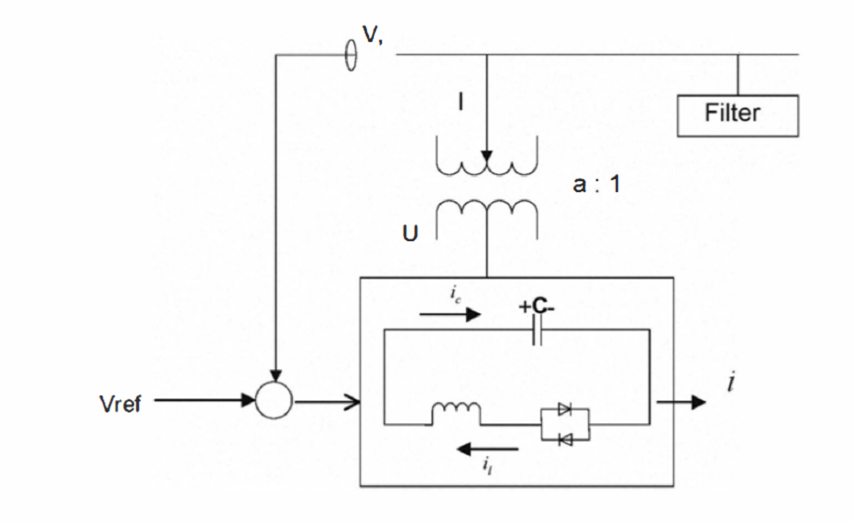


Figure 2.1: Static Var compensator

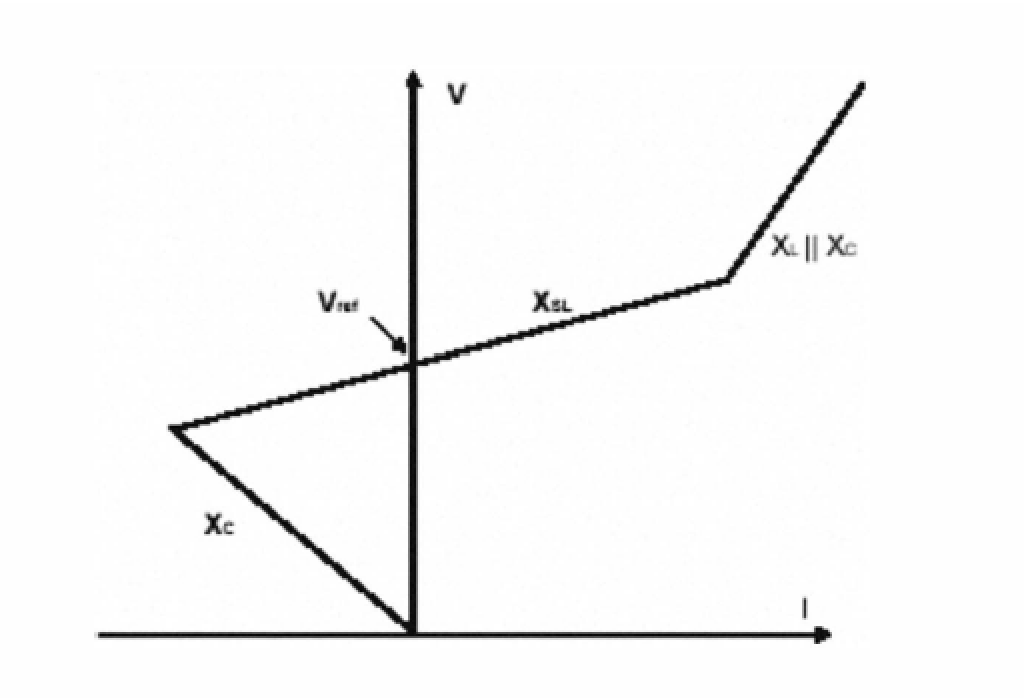


Figure 2.2: Characteristics of the SVC

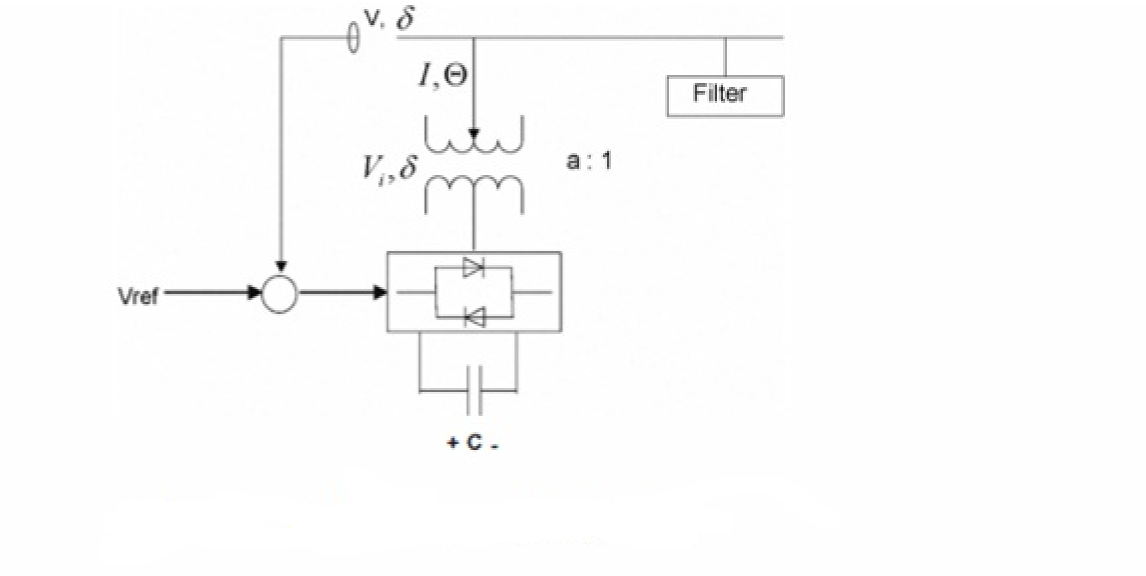


Figure 2.3: Static Synchronous Compensator

2.2 Static Synchronous Compensator

STATCOM is a Voltage-Source Inverter (VSI), which converts a DC input voltage into AC output voltage in order to compensate the active and reactive power needed by the system. Figures show the basic structure and terminal characteristic of STATCOM, respectively. It can be seen from figure(fig.2.3) that STATCOM is a shunt-connected device, which controls the voltage at the connected bus to the reference value by adjusting voltage and angle of internal voltage source. From figure, it is clear that STATCOM exhibits constant current characteristics when the voltage is low/high under/over the limit. This allows STATCOM to deliver constant reactive power at the limits compared to SVC.

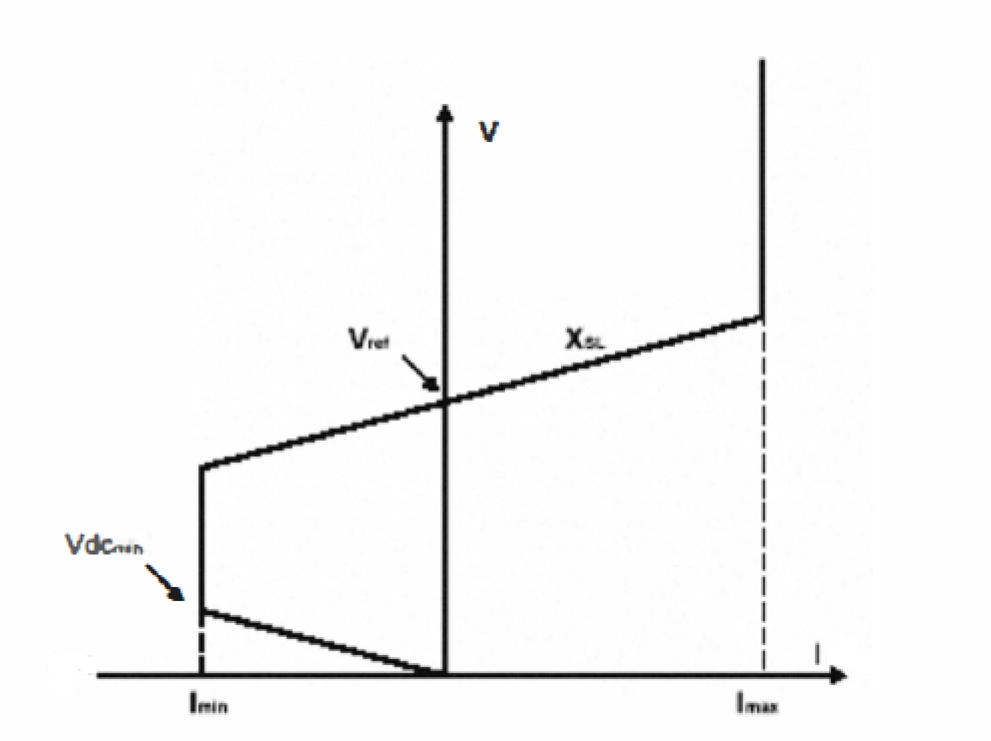


Figure 2.4: Characteristics of the STATCOM

2.3 Thyristor Controlled Series Capacitor

TCSC device uses Thyristor-Controlled Reactor (TCR) in parallel with capacitor segments of series capacitor bank. The basic structure of this device is shown in figure and it can be seen that the combination of TCR and capacitor allows the capacitive reactance to be smoothly controlled over a wide range. The value of susceptance (Be) of the line can be controlled according to a specific controlled variable hence controlling the voltage. Figure 2.6 gives the impedance characteristics of TCSC with the firing angle.

2.4 Static Synchronous Series Compensator

SSSC is based on a solid-state synchronous voltage source employing an appropriate DC to AC inverter, which can be used for series compensation of transmission lines. The SSSC is based on a DC capacitor fed Voltage Source Inverter (VSI) that generates a three-phase voltage at fundamental frequency,

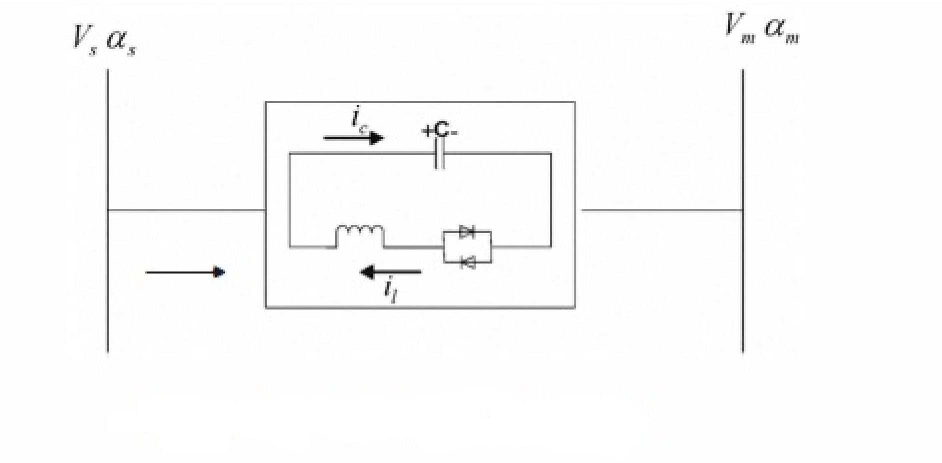


Figure 2.5: Thyristor Controlled Series Capacitor

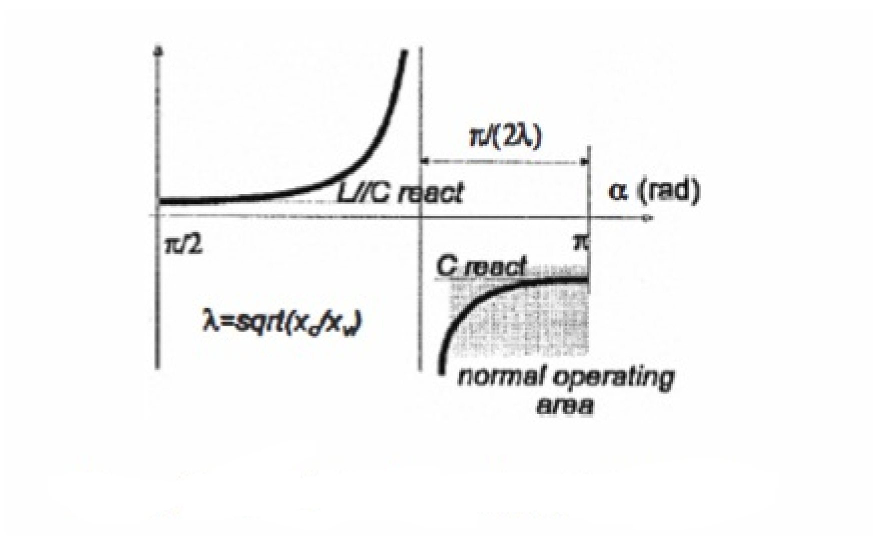


Figure 2.6: Characteristics of the TCSC

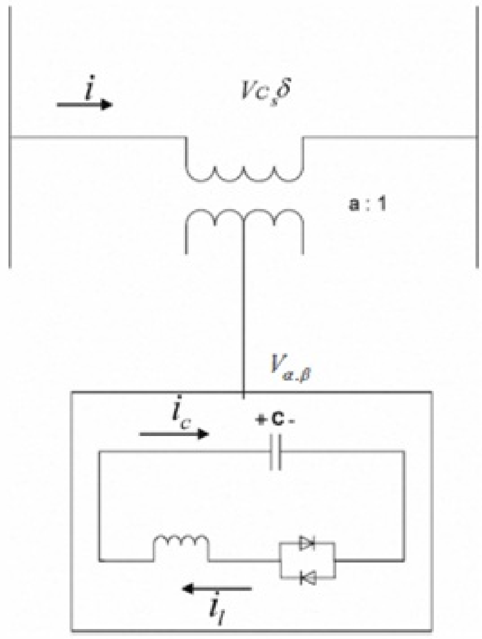


Figure 2.7: Static Synchronous Series Compensator

which is then injected in a transmission line through a transformer connected in series with line. The main control objective of the SSSC is to directly control the current, and indirectly the power, flowing through the line by controlling the reactive power exchange between the SSSC and the AC system. Figure 2.7 shows the representing model of SSSC and state variables and figure shows its operational characteristics .

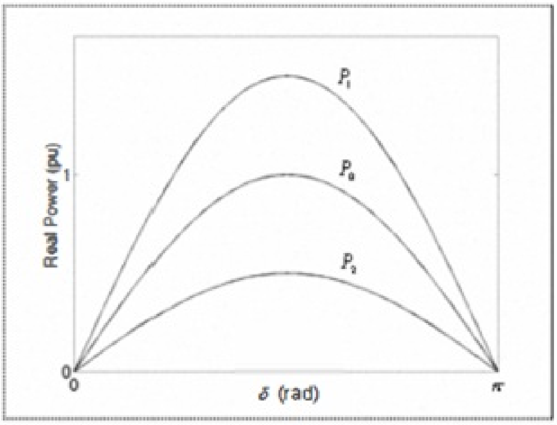


Figure 2.8: Characteristics of the SSSC

Chapter 3

Literature survey

3.1 Torsional oscillation studies in an SSSC compensated power system

In this paper a power flow controller is designed for a 48-step static synchronous series compensator (SSSC). Torsional characteristics of an SSSC compensated power system are studied and compared to a fixed capacitor compensated power system. The effects of dc link capacitor of the SSSC on torsional modes are studied. An integral state feedback controller is proposed to improve the torsional characteristics of the SSSC. The torsional characteristics are studied through eigenvalue analysis and the results are validated through PSCAD:EMTDC simulation studies. Series capacitive compensation in ac transmission systems can yield several benefits such as increased power transfer capability and enhancement of transient stability. However, the extent to which a transmission line can be compensated with conventional series capacitance is often severely restricted by concerns for the destructive effects of subsynchronous resonance (SSR). A rapidly controllable series compensator, however, has the potential to avoid or damp out SSR, thereby enabling the full steady-state benefit of series compensation to be realised. Furthermore, a controllable series capacitor would also enable fast control of the power transmitted by the line during transient power swings, thus allowing the transmission system to be safely operated much closer to its theoretical stability limit

3.2 Digital distance protection of transmission lines in the presence of SSSC

In this paper the impact of Static Synchronous Series Compensator (SSSC) on the impedance calculated by distance relay is investigated. Analytical results are presented and verified by detailed simulations. Six different phase to phase and phase to ground measuring units of the distance relay are simulated to resemble the behavior of the relay. It is shown in this paper that zero sequence of the injected voltage by 48 pulse SSSC converter has the most impact on the apparent impedance seen by the phase to ground fault measuring unit and cause under reaching of distance relay. It can be concluded from the results that SSSC located in the middle of the transmission line cause to divide trip characteristics of distance relay into two separate parts. It is also shown that the over-reaching operation of distance relay might happen in some cases in the presence of SSSC. All the detailed simulations are carried out in MATLAB/Simulink environment.

3.3 Operation, Modeling, Control and Applications of Static Synchronous Compensator

Flexible ac transmission systems (FACTS) controller can provide better control than conventional control and achieve fast control response time. Static synchronous compensator (STATCOM) is one of the key flexible ac transmission systems (FACTS) devices based on voltage source converter (VSC) technology. The controller can provide both capacitive and inductive compensation and is able to control output current over the rated maximum capacitive or inductive range independent of the ac system voltage. This paper presents a study of modeling, operation and control fundamentals of the STATCOM.

3.4 Improving Power System Transient Stability with Static Synchronous Series Compensator

Modern power system consists of the complicated network of transmission lines and carries heavy demand. Thus they cause stability problem. One of the major interests of power utilities is the improvement of power system transient behavior. Approach: Static Synchronous Series Compensator (SSSC) is a power electronic based device that has the capability of controlling the power flow through a line. This study applies the SSSC to improve transient stability of power system. To verify the effect of the SSSC on transient stability, the mathematical model and control strategy of a SSSC is presented. The SSSC is represented by variable voltage injection with associate transformer leakage reactance and the voltage source. The series voltage injection model of SSSC is modeled into power flow equation and thus it is used to determine its control strategy. This study uses machine speed deviation to control it. The swing curves of the three phase faulted power system without and with a SSSC is tested and compared in various cases. Results: The swing curve of system without a SSSC gets increases monotonically and thus the system can be considered as unstable whereas the swing curves of system with a SSSC can be considered as stable. Conclusion: SSSSC can improve transient stability of power system.

3.5 Reduction of Over Line Current in Power System from Short Circuit Effect Using Static Synchronous Series Compensator

Problem statement: One of the major problems in power system is the over line current from short circuit effect. It may cause in the electrical apparatus outages. Approach: Static Synchronous Series Compensator (SSSC) is a power electronic based device that has the capability of controlling the line current. This study applies the SSSC to decrease the over line current in power system during dynamic state. To verify the effect of the SSSC on over line current reduction, the mathematical model of power system equipped with a SSSC is presented. The variation curve of line current of the faulted system with without SSSSC and with a SSSC is tested and compared in various cases. Results: The line current of the system without a SSSC is continuously oscillation and the maximum value is much more than the system with a SSSC. Conclusion: SSSC can decrease over line current in power system from short circuit effect.

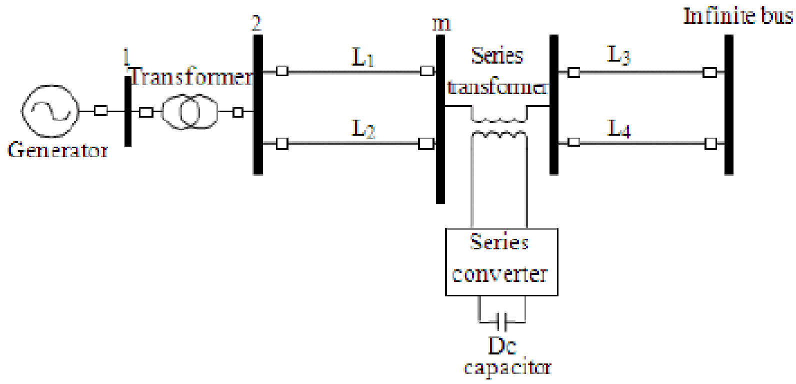


Figure 3.1: Single machine infinite bus system with a SSSC

Chapter 4

Small Signal Stability And Transient Stability

4.1 smallsignal stability

Small signal stability is the ability of the power sysytem to maintain synchronism under small disturbances. Such distrbances occur continually on the system because of small variations in loads and generation. The disturbances are considered sufficiently small for linearization of the system equations to be permissible for purposes of analysis. Instability that may result can be of two forms(1)steady increase in rotor due to lack of sufficient synchronizing torque, or (2) rotor oscillations of increasing amplitude due to lack of sufficient damping torque. The nature of system response to small disturbances depends on a number of factors including the initial operating,the transmission system strength, and the type of generator excitation controls used. For a generator connected radially to a large power system,in the ansence of automatic voltage regulators the instability is due to lack of sufficient synchronizing torque. This results in instability through a non-oscillatory mode as shown fig.

Intoday's practical power systems, small signal stability is largely a problem of insufficient damping of oscillations. The stability of the following types of oscillations is of concern.

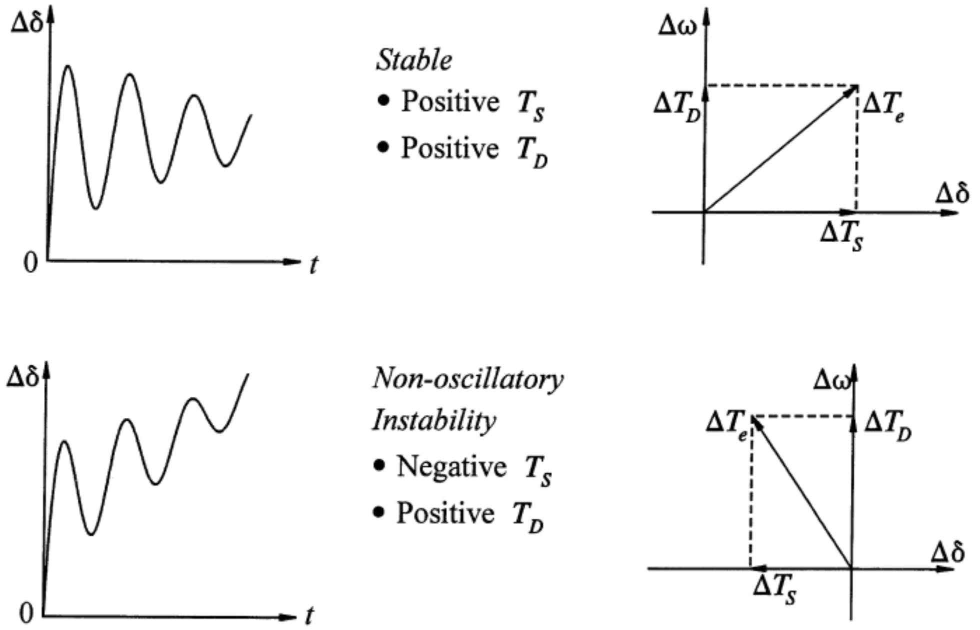


Figure 4.1: With constant field voltage

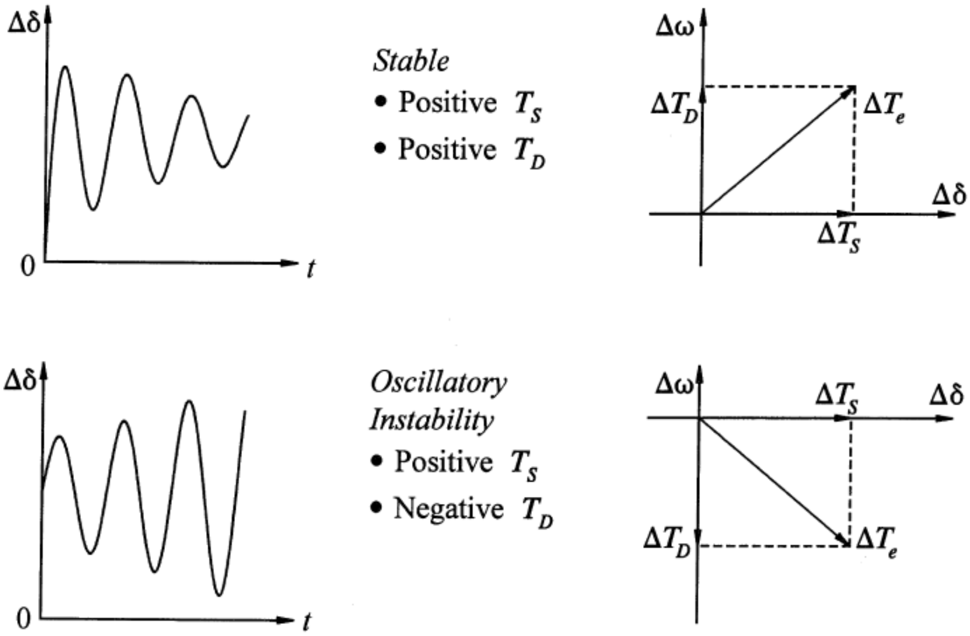


Figure 4.2: With excitation contorl

4.1.1 Local Modes

Local modes are associated with the swinging of units at a generating station with respect to the rest of the power system. The term local is used because the oscillations are localized at one station or a small part of the power system.

4.1.2 Interarea Modes

Interarea modes are associated with the swinging of many machines in one part of the system against machines in other parts. They are caused by two or more groups of closely coupled machines being interconnected by weak ties.

4.1.3 Control Modes

Control modes are associated with generating units and other controls. Poorly tuned exciters, speed governors, HVDC converters and static var compensators are the usual causes of instabilityof these modes.

4.1.4 Torsional Modes

Torsional modes are associated with thwe turbine-generator shaft sysytem rotational components. Instability of torsional modes may be causeed by interaction with excitation controls, spped governors, HVDC control,and series-capacitor-compensated lines.

4.2 Transient Stability

Transient stabilty is the ability of the power system to maintain synchronism when subjected to a severe transient disturbance. The resulting system response involves large excursions of generator rotor angles and is influenced by the nonlinear power-angle excursions of generator rotor angles and is influenced by the nonliner power-angle relationship. Stability depends on both the initial operating state of the system and the severity of the disturbance. Usually

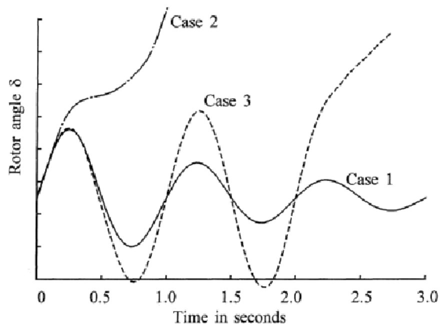


Figure 4.3: Rotor angle response to a transient disturbance

,the system is altered so that the post-disturbance steady-state operation differs from that prior to the disturbance. Disturbances of widely varying degrees of severity and probability of occurrence can occur on the system. The system is , however,designed and operated so as to be stable for a selected set of contingencies. The contingencies usually considered are short-circuits of different types:phase-to-ground ,phase-to-phase-to-ground, or three phase. They areusually assumed to occur on transmission lines ,but occasionally bus or transformer faults are also considered. The fault is assumed to be cleared by the opening of apporopriate breakers to isolate the faulted element. In some cases,high-speed reclosure may be assumed. Figures illustrates the behaviour of a synchronous machine for stable and unstable situations.

4.3 Electrical Faults in Power System

Electrical power system has a dynamic and complex behavior. Different types of faults can interrupt the healty operation of the power system. Some of the major Electrical faults are phase faults include phase to phase faults and phase to ground faults and three phase faults. Other Electrical faults are of not major significance but still are considered, Open circuit faults occurs due to the parting of the overheadline or failure operation of the circuit breaker, Interturn fault occurs due to the overvoltage or insulation breakdown, Electrical Faults result in the overloads due to passing the current throught the conductor which is above the permissible value and faults due to real power deficit occurs due to mismatch in the power generated and consumed and results in the frequency deviation and collapse of grid.

4.3.1 Phase Faults

Electrical Phase faults are characterised as:

1 Phase to Ground Fault

2 Phase to Phase Fault

3 Phase - Phase to Ground Fault

4 Three Phase Fault

4.3.2 Phase to Ground Fault

In this type of Electrical fault all the three sequence components (positive, negative and zero sequence components) are present and are equal to each other. In case of isolated neutral connection to the generator, there will be no return path for the current. So for such fault, fault current is zero.

4.3.3 Phase to Phase fault

These are unsymmetrical faults as these faults give rise to unsymmetrical currents (Current differ in magnitude and phase in the three phases of power system).In case of Phase to Phase fault positive and negative sequence component of current are present, they are equal in magnitude but opposition in phase. zero sequence components are absent.

4.3.4 Phase - Phase to Ground Fault

These faults are of unsymmetrical nature. In this type of faults negative and zero sequence faults are in opposition with positve sequence cmponents.

4.3.5 Three Phase Fault

This type of faults are called symmetrical fault. This type of faults occur very rarely but they are more severe. In this faults negative and zero sequence component currents are absent and positive sequence currents are present.

Chapter 5

Simulation Results

From the standpoint of output voltage control, converters may be categorized as directly and indirectly controlled. For directly controlled converters both the angular position and the magnitude of the output voltage are controllable by appropriate valve (on and off) gating. For indirectly controlled converters only the angular position of the output voltage is controllable by valve gating; the magnitude remains proportional to the dc terminal voltage. The control method of maintaining a quadrature relationship between the instantaneous converter-voltage and line current vectors, to provide reactive series compensation and handle SSR, can be implemented with an indirectly controlled converter. The method of maintaining a single frequency synchronous (i.e. fundamental) output independent of dc terminal voltage variation requires a directly controlled converter. Although high power directly controlled converters are more difficult and costly to implement than indirectly controlled converters (because their greater control flexibility is usually associated with some penalty in terms of increased losses, greater circuit complexity, and/or increased harmonic content in the output),nevertheless they can be realized to meet practical utility requirements.

In this paper, the SSSC is used to damp power oscillation on a power grid following a three-phase fault and L-L-G fault which is more severe. The power grid consists of two power generation substations and one major load centre at bus B3. The first power generation substation M1 has a rating of 2100 MVA,

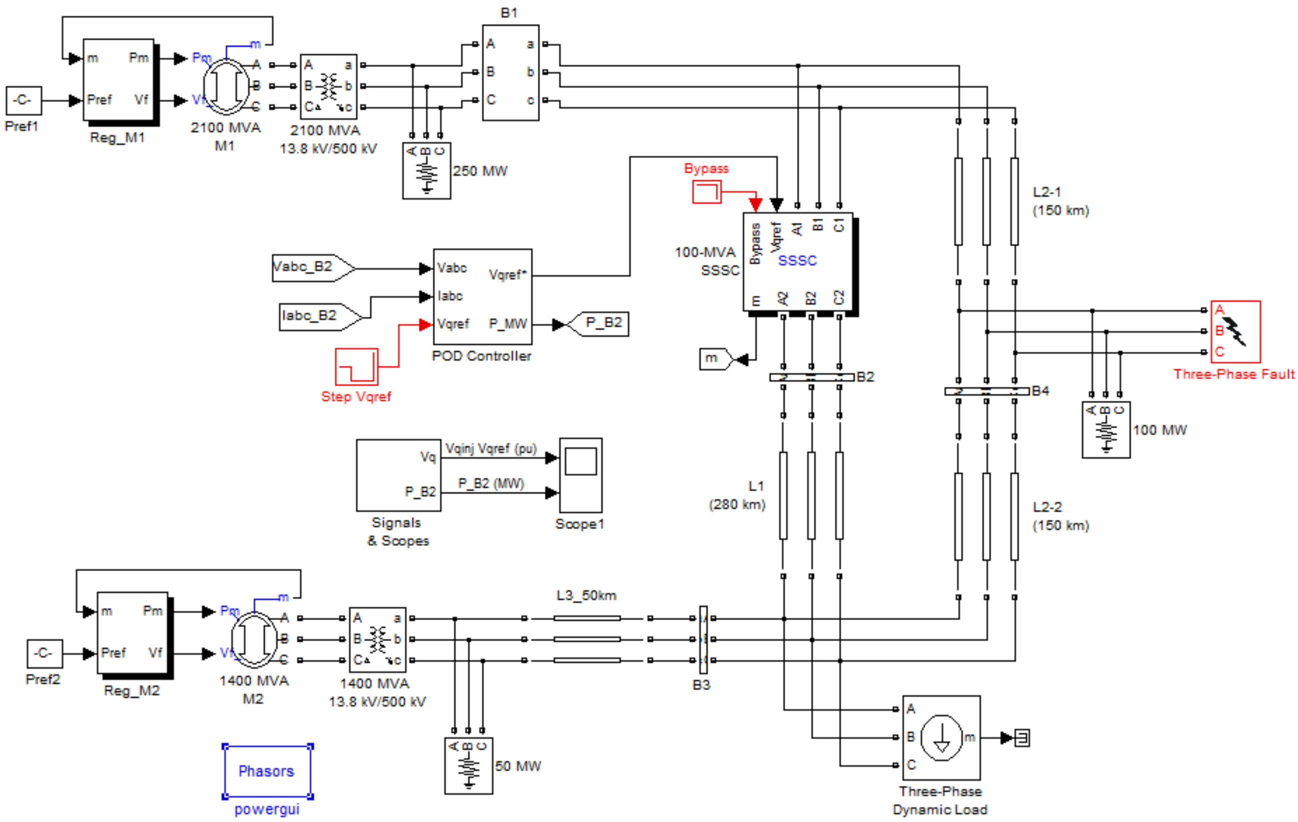


Figure 5.1: Static Synchronous Series Compensator (SSSC) used for power oscillation damping

representing 6 machines of 350 MVA and the other one M2 has a rating of 1400 MVA, representing 4machines of 350 MVA.

The load centre of approximately 2200 MW is modelled using a dynamic load model where the active and 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, L2 and L3. L1 is 280-km long and L2 is split in two segments of 150 km each in order to simulate a three-phase fault and L-L-G fault (using a fault breaker).

The generation substation M2 is also connected to the load by a 50-km line (L4). 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 L4 (measured at B3). The SSSC, located at bus B1, is in series with line L1.

5.1 SSSC Dynamic Responses

Initially Vqref is set to 0pu; at t = 3s, Vqref is set to -0.08pu (SSSC inductive); then at t = 9s, Vqref is set to 0.08pu (SSSC capacitive). Also, the fault breaker will not operate during the simulation. In below Fig.6, the first graph shows the active power flow P at B2 on line L1, measured at bus B2. The second graph shows the Vqref signal along with the measured injected voltage by the SSSC. The third graph shows the Id current of SSSC and fourth graph shows the magnitude of Vq.
We see on the transmitted power (P at B2signal) so, we reduce the "Maximum rate of change for Vqref(pu/s)" from 3 to 0.08. A 70 MVAr 30 kV SSSC is inserted in the test system between Bus 1and Bus 2, in series with the transmission line with higher impedance.

5.2 LLG fault without POD controller

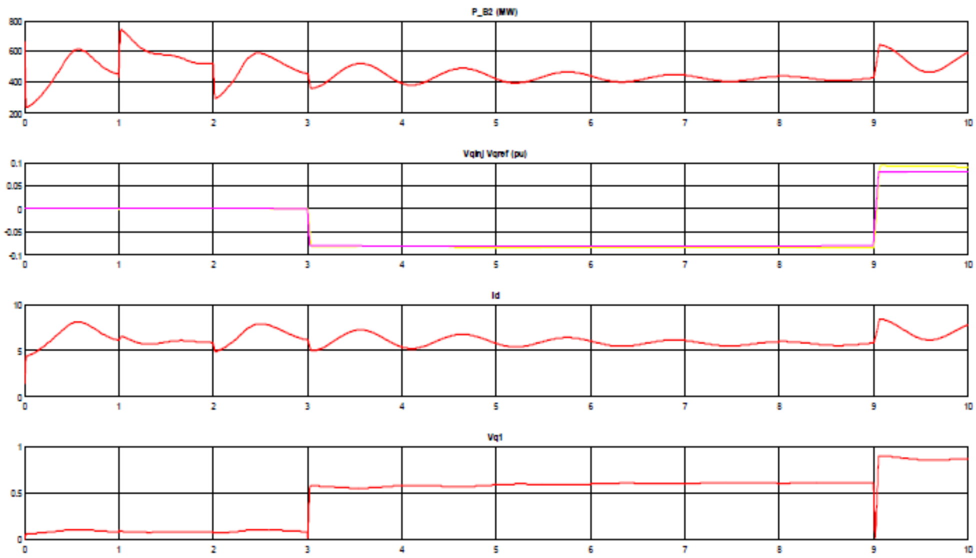


Figure 5.2: LLG fault without POD controller

5.3 LLG fault with POD controller

The simulation of a two-machine power system model with Static synchronous series compensator (SSSC) based damping controllers in the presence of a three-phase short circuit fault and two- phase ground fault are considered. The results show that the power system oscillations are damped out very quickly with the help of SSSC based damping controllers in few seconds.

The studies, which include detailed techniques of twelve-pulse and PWM controlled SSSC, are conducted and the control circuits are presented. The SSSC operating conditions and constraints are compared to the operating conditions of other FACTS devices, showing that the SSSC offers several advantages over others.

The dc voltage pre-set value in PWM-based controllers has to be carefully selected. As the modulation ratio lies between zero and one, the dc voltage should not be lower than the maximum of the requested SSSC output phase voltage in order to obtain proper control. On the other hand, if the dc side voltage

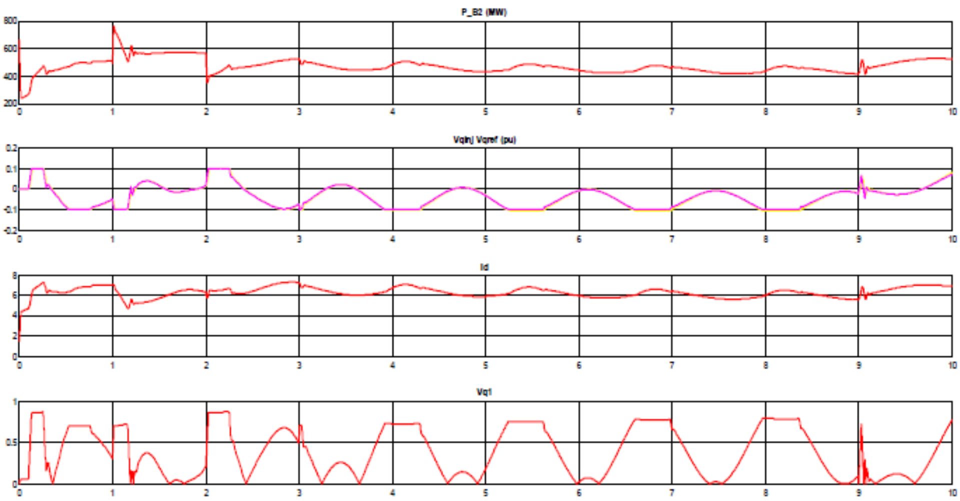


Figure 5.3: LLG fault with POD controller

is too high, the rating of both the GTO valves and dc capacitor has to be increased, which means higher installation costs. Not only that, a higher dc side voltage means a lower amplitude modulation ratio and the lower modulation ratio results in higher harmonic distortion.

Phase control allows the dc voltage to change according to the power system conditions, which is clearly advantageous, but it requires a more complicated controller and special and costly series transformers. The results show that the use of SSSC is having improved dynamic response and at the same time faster than other conventional controllers. Moreover, this approach is also simple and easy to be realized in power systems.

5.4 9 bus system

Simulation has been done for three machine , nine bus system.And Static Synchronous Series Compensator(SSSC) used for the improve the stability of the system.SSSC controlled by the Power Oscillation Damping controller(POD).In this simulation different fault are created and observed the waveform with SSSC and without SSSC.

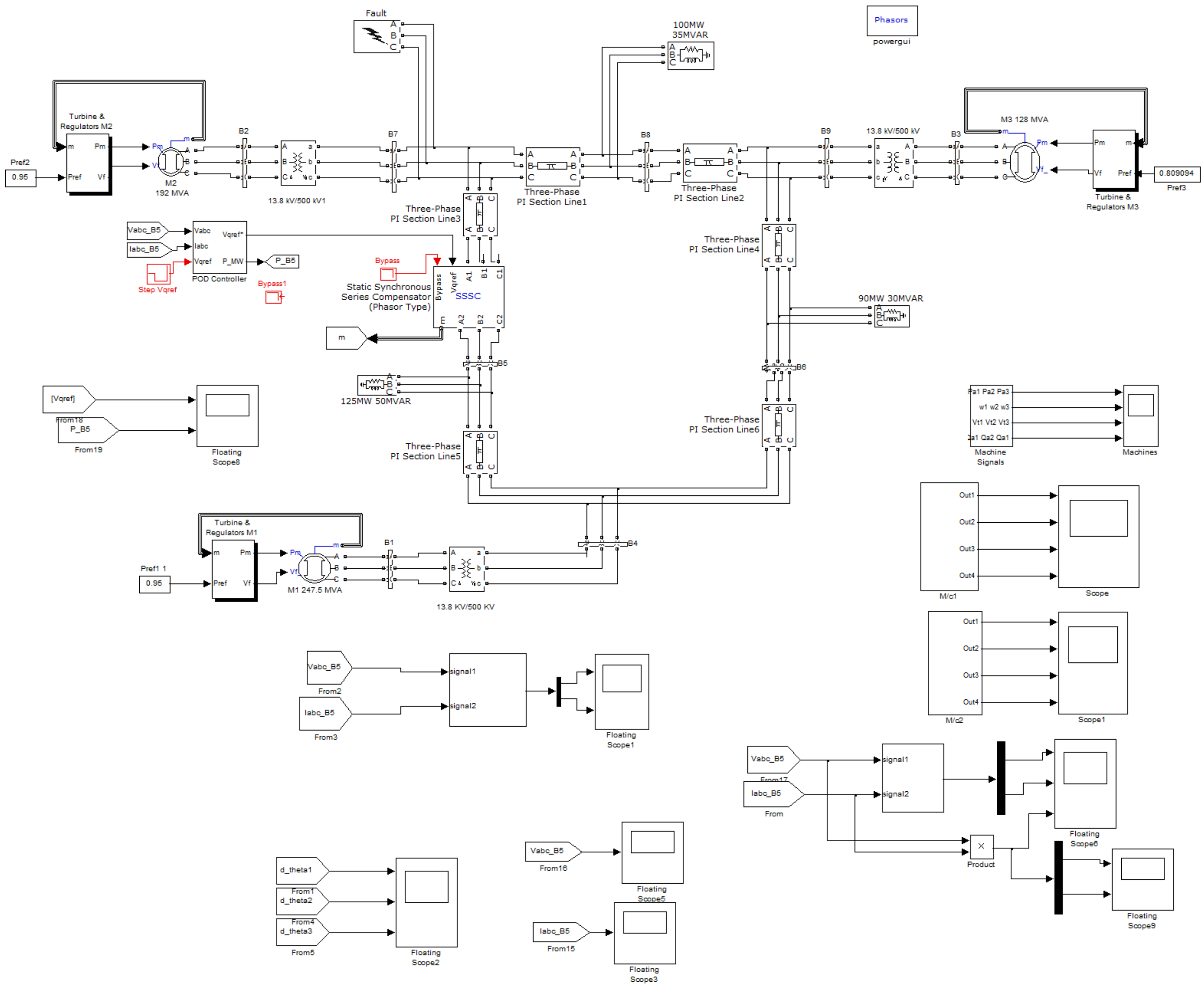


Figure 5.4: 9 bus system

5.5 LG fault without SSSC

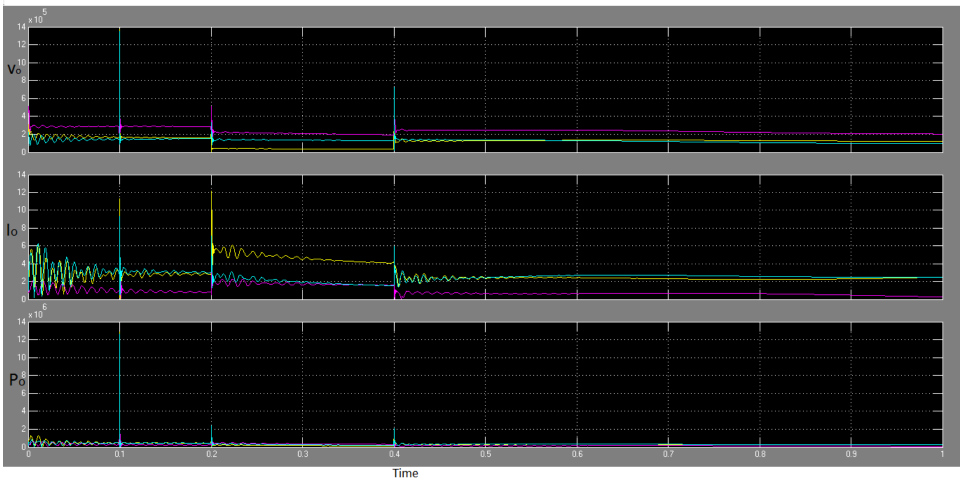


Figure 5.5: Wave form of voltage ,current and power without SSSC

5.6 LG fault with SSSC

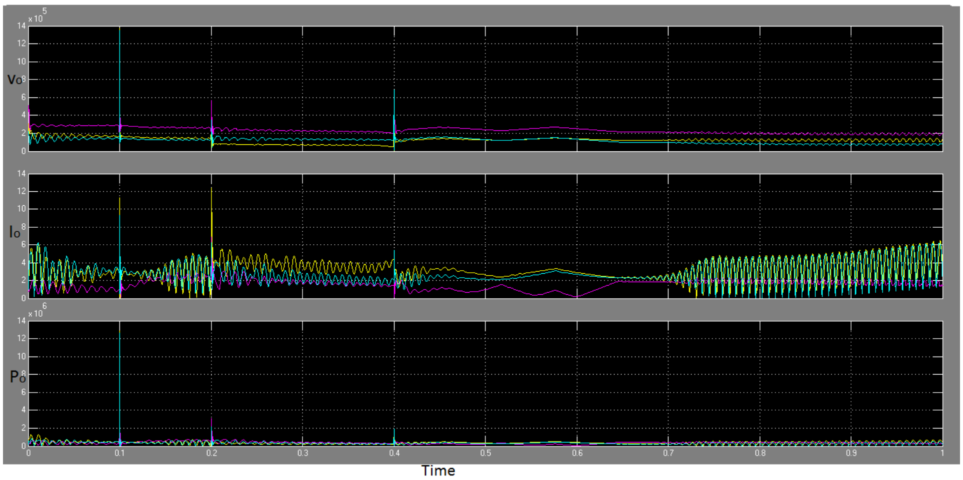


Figure 5.6: Wave form of voltage ,current and power with SSSC

5.7 LLG fault without SSSC

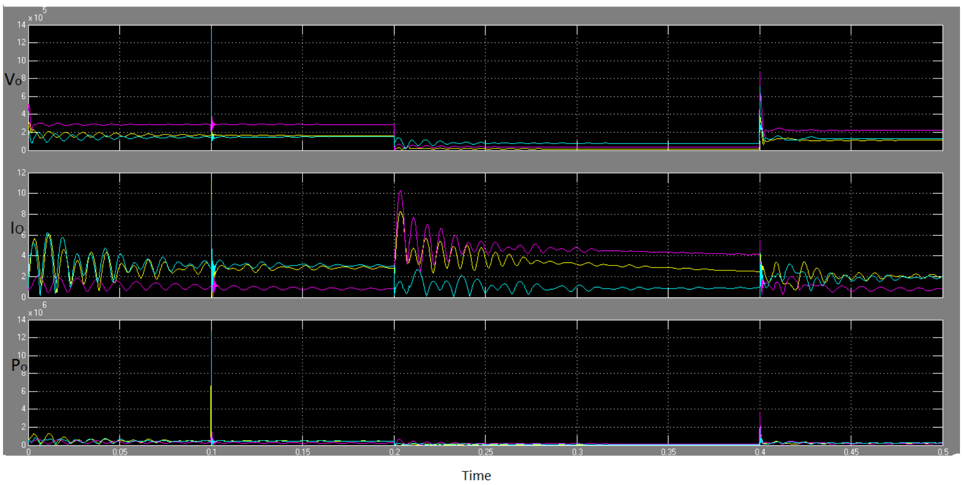


Figure 5.7: Wave form of voltage ,current and power without SSSC

5.8 LLG fault with SSSC

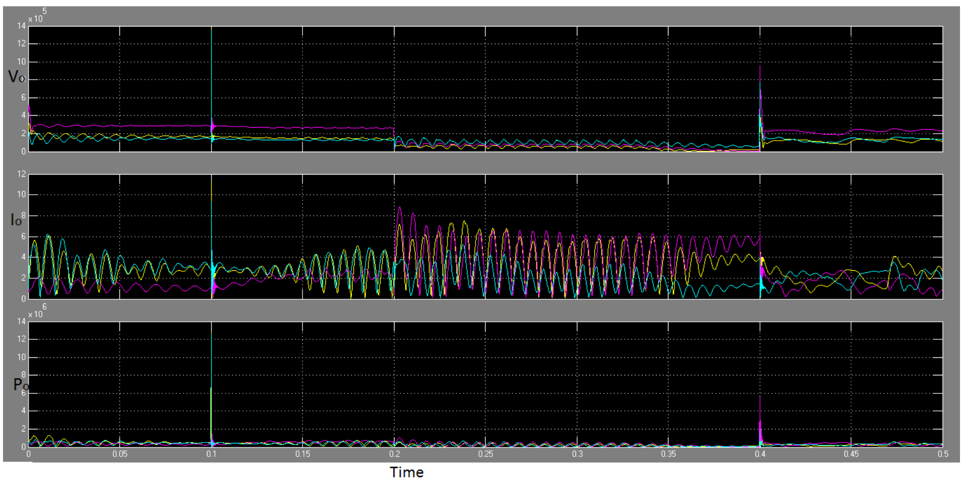


Figure 5.8: Wave form of voltage ,current and power with SSSC

5.9 LLL fault without SSSC

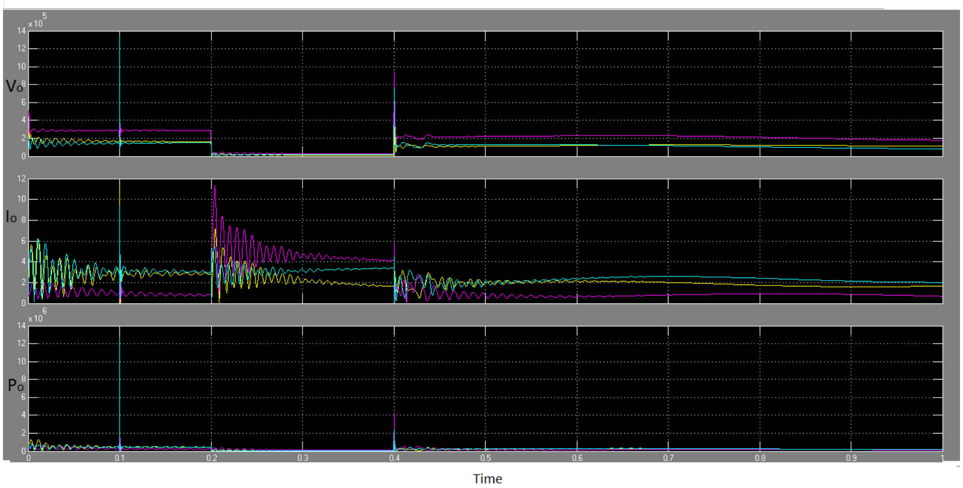


Figure 5.9: Wave form of voltage ,current and power without SSSC

5.10 LLL fault with SSSC

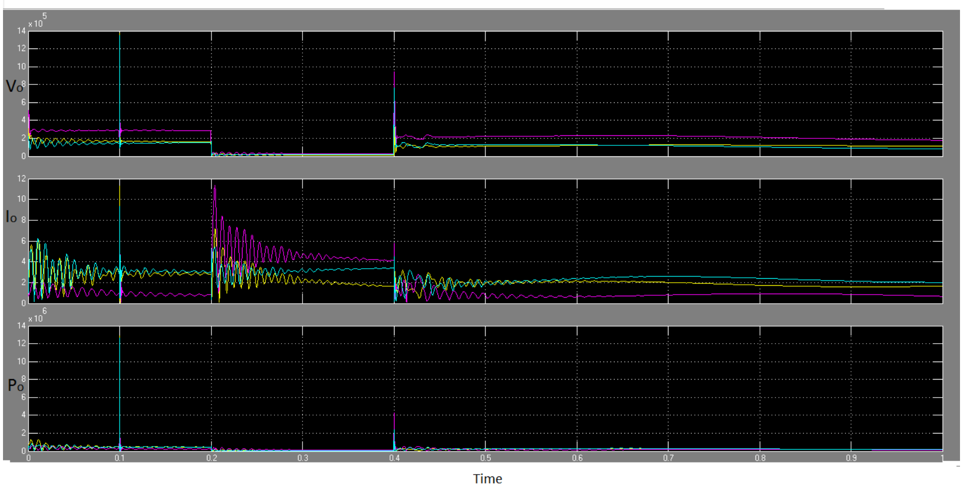


Figure 5.10: Wave form of voltage ,current and power with SSSC

5.11 PSAT tool box

The maintenance and availability of the power system can be considerd a major aspect of investigation. The encouragement to the planning of HV lines, the valuet of power that transfer per km on HV line and the amount of power transaction as seen from economic side is much responsible for concern towards congestion phenomena in power system. The idea for solving this problem is the use of FACTS devices especially the use of Synchronous Series Compensators (SSSC). In this paper the study of SSSC with its various modes of operation is investigated. Finally by help of modeling of a power system in MATLAB/PSAT toolbox, and by installing SSSC in transmission link, its use as power flow controller and voltage injection is seen. Conclusion is made on different results to see the benefit of SSSC in power system.

5.11.1 9bus system without SSSC

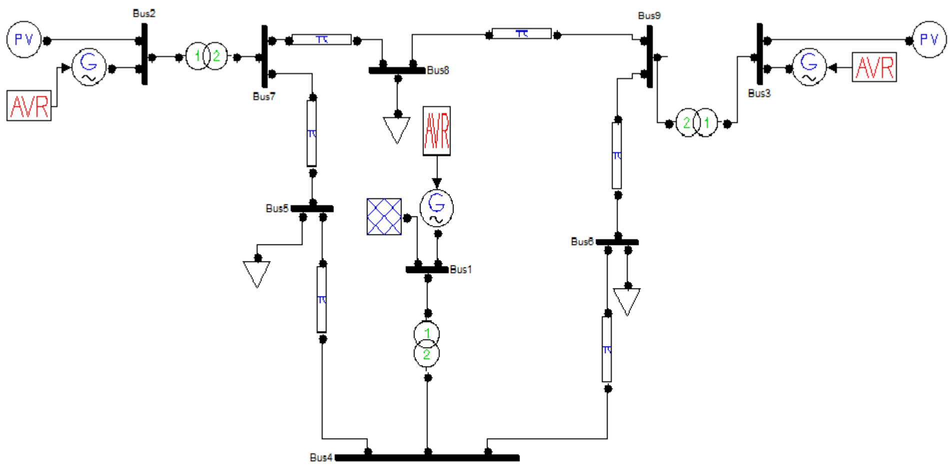


Figure 5.11: 9 bus system

5.11.2 Model block of single line diagram

Using the concept of the control system a power system is taken to implement the application of SSSC. The two modes i.e. the power flow control and the voltage injection mode are simulated in PSAT toolbox to see the effect of SSSC on a power system. Investigation is carried out to verify the utility of FACT device. Figure 3 illustrates application study the steady-state and dynamic performance of a SSSC used to relieve power congestion and improve power flow in a transmission system. The load flow analysis and the single line diagram simulation are done on power flow simulator.This software helps to calculateat each bus and the each transmission lines of the system. A SSSC is used to control the power flow in a test power transmission system. The system, connected in a loop configuration, consists essentially of nine buses (B1 to B9) interconnected through three transmission lines (L1, L2, L3,L4,L5,L6) and three 18 kV/230 kV transformer banks with power rated equals to 100 MVA. Three Specifications of synchronous machines connected to buses 1,2,3 on the 16.5,18,13.8 kV buses respectively that generate a total loads of 1500 MW which their data are presented in Table 3. Each plant model includes a speed regulator, an excitation system as well as a Power System Stabilizer (PSS). In normal operation, most of the 1200 MW generation capacity of power plant2 is exported to the 18 kV equivalents through transformers connected between buses.

5.12 Stability Analysis

From the below figure analysis of satbility is done.From the eigen value analysis we findout the stability of the system. Below figure shows the eigenvalue analysis from the software and from that system stable or unstable is findout.

POWER FLOW REPORT

P S A T 2.1.6

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File: C:\Users\Dell\Desktop\bhatt_mdl
Date: 05-Dec-2013 10:01:59

NETWORK STATISTICS

Buses:	9
Lines:	6
Transformers:	3
Generators:	3
Loads:	3

SOLUTION STATISTICS

Number of Iterations:	5
Maximum P mismatch [p.u.]	2.3476
Maximum Q mismatch [p.u.]	140.0025
Power rate [MVA]	100

POWER FLOW RESULTS

Bus	V [p.u.]	phase [rad]	P gen [p.u.]	Q gen [p.u.]	P load [p.u.]	Q load [p.u.]
Bus1	1.04	0	-0.44444	-0.0613	0	0
Bus2	1.025	-132760624.2	0.07259	0.04277	0	0
Bus3	1.025	-175889543.8	-0.25324	0.23072	0	0
Bus4	5.076	-117938830.1	2.3476	-57.0938	0	0
Bus5	1.1336	-132760120.3	1.9012	-3.132	1.25	0.5
Bus6	2.8882	-132760589.9	1.7735	140.0025	5.2137	173.7896
Bus7	0.93882	-132760581.1	-0.16535	-2.9484	0	0
Bus8	0	-132760558.3	0	0	0	0
Bus9	4.4652	-129792029.0	1.2445	-88.0572	0	0

Figure 5.12: power flow results

STATE VARIABLES

delta_Syn_1	2.6246
omega_Syn_1	1
e1q_Syn_1	1.0288
e1d_Syn_1	0.043
e2q_Syn_1	1.0326
e2d_Syn_1	0.03856
delta_Syn_2	-0.04002
omega_Syn_2	1
e1q_Syn_2	1.0363
e1d_Syn_2	0
e2q_Syn_2	1.0306
e2d_Syn_2	0.0872
delta_Syn_3	-2.383
omega_Syn_3	1
e1q_Syn_3	1.0492
e1d_Syn_3	-0.18223
e2q_Syn_3	1.0536
e2d_Syn_3	-0.1804
vm_Exc_1	1.025
vr1_Exc_1	-3.7308
vr2_Exc_1	-0.26382
vf_Exc_1	1.0643
vm_Exc_2	1.025
vr1_Exc_2	0.01637
vr2_Exc_2	-0.61183
vf_Exc_2	1.3596
vm_Exc_3	1.04
vr1_Exc_3	0.0119
vr2_Exc_3	-0.46488
vf_Exc_3	1.0331

OTHER ALGEBRAIC VARIABLES

vf_Syn_1	1.0643
pm_Syn_1	0.07259
p_Syn_1	0.07259
q_Syn_1	0.04277
vf_Syn_2	1.0331
pm_Syn_2	-0.44444
p_Syn_2	-0.44444
q_Syn_2	-0.0613
vf_Syn_3	1.3596
pm_Syn_3	-0.25324
p_Syn_3	-0.25324
q_Syn_3	0.23072
vref_Exc_1	1.0277
vref_Exc_2	1.025
vref_Exc_3	1.04

Figure 5.13: state variables

LINE FLOWS

From Bus	To Bus	Line	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
Bus5	Bus4	1	0.55552	-0.55712	0.00397	-28.7732
Bus7	Bus8	2	0.00077	-0.88512	0.00077	-0.88512
Bus8	Bus9	3	0	0	0.00125	-31.295
Bus7	Bus5	4	-0.09354	-2.0895	0.00218	-5.1644
Bus9	Bus6	5	0.99005	-58.145	0.00087	-82.9418
Bus6	Bus4	6	-2.451	-8.9903	0.0037	-40.0121
Bus2	Bus7	7	0.07259	0.04277	0	0.06894
Bus3	Bus9	8	-0.25324	0.23072	0	1.6136
Bus1	Bus4	9	-0.44444	-0.0613	0	2.0829

LINE FLOWS

From Bus	To Bus	Line	P Flow [p.u.]	Q Flow [p.u.]	P Loss [p.u.]	Q Loss [p.u.]
Bus4	Bus5	1	-0.55155	-28.2161	0.00397	-28.7732
Bus8	Bus7	2	0	0	0.00077	-0.88512
Bus9	Bus8	3	0.00125	-31.295	0.00125	-31.295
Bus5	Bus7	4	0.09571	-3.0749	0.00218	-5.1644
Bus6	Bus9	5	-0.98918	-24.7968	0.00087	-82.9418
Bus4	Bus6	6	2.4547	-31.0218	0.0037	-40.0121
Bus7	Bus2	7	-0.07259	0.02618	0	0.06894
Bus9	Bus3	8	0.25324	1.3828	0	1.6136
Bus4	Bus1	9	0.44444	2.1442	0	2.0829

GLOBAL SUMMARY REPORT

TOTAL GENERATION

REAL POWER [p.u.]	6.4764
REACTIVE POWER [p.u.]	-11.0167

TOTAL LOAD

REAL POWER [p.u.]	6.4637
REACTIVE POWER [p.u.]	174.2896

TOTAL LOSSES

REAL POWER [p.u.]	0.01273
REACTIVE POWER [p.u.]	-185.3063

Figure 5.14: Line flows

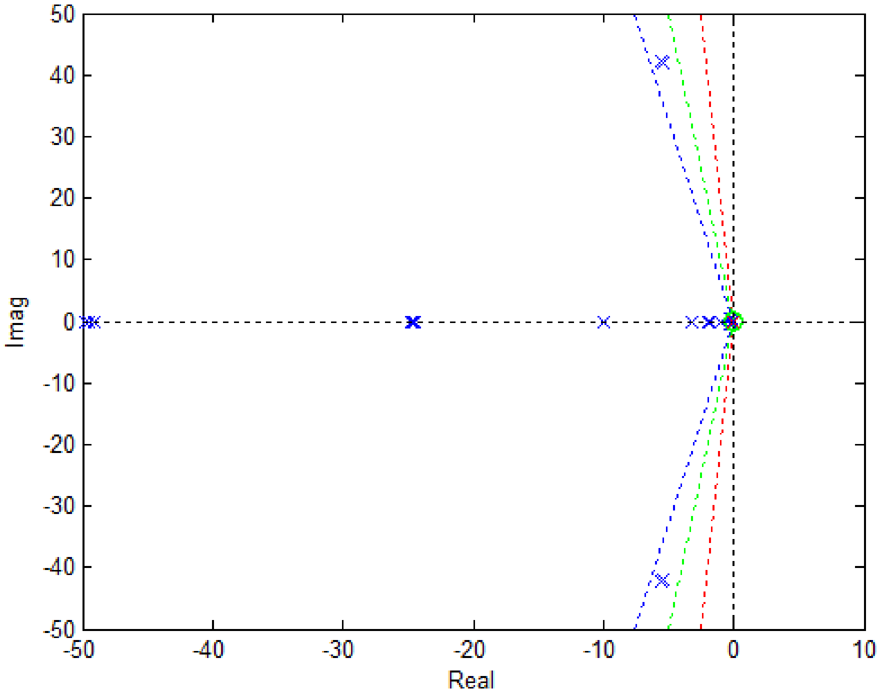

Figure 5.15: Stability analysis

5.12.1 9bus system with SSSC

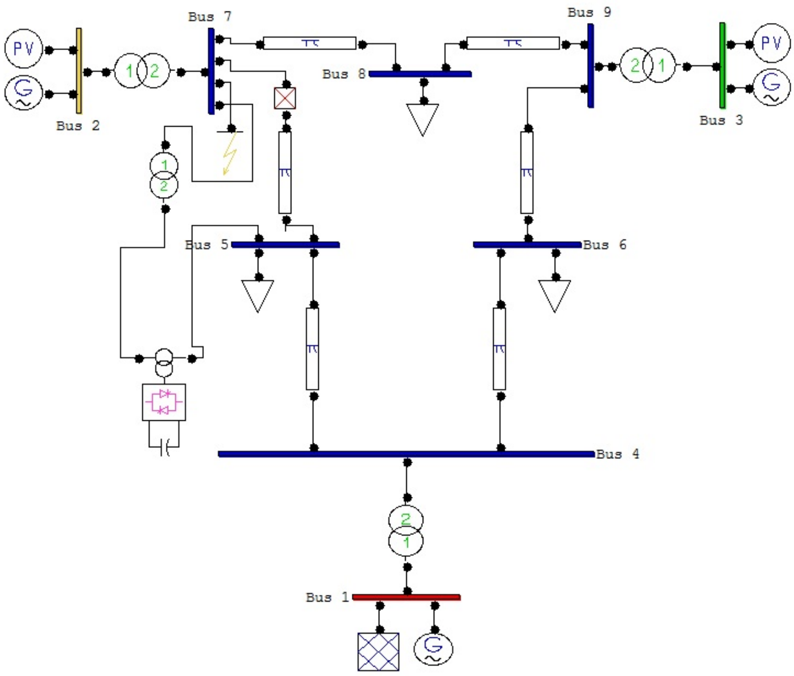

Figure 5.16: 9 bus system

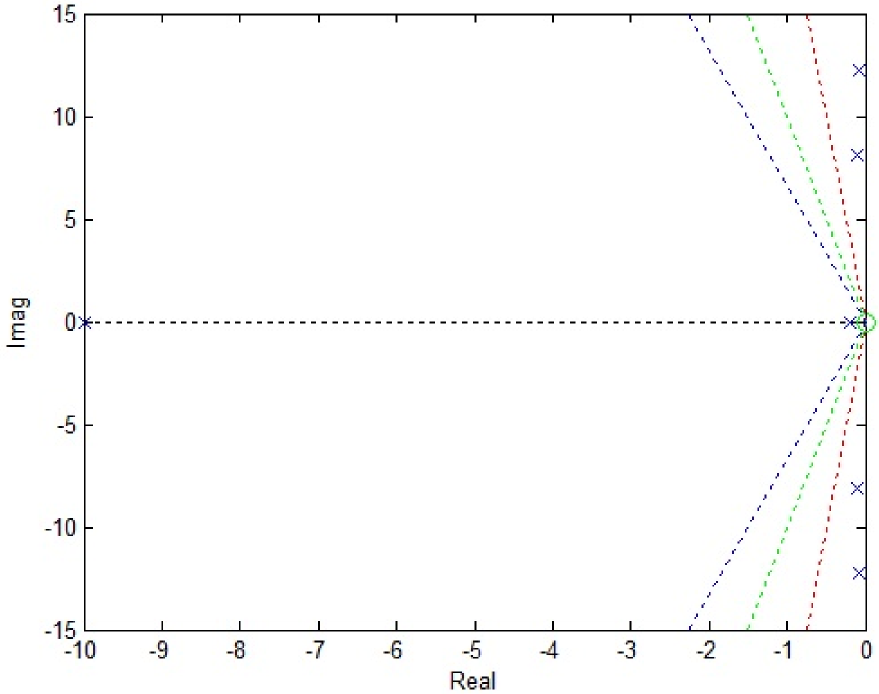

Figure 5.17: Stability analysis

Chapter 6

Advantage of SSSC

(1) Power Factor correction through continous voltage injection.

(2) Load balancing.

(3) Cover the capacitive and inductive demand.

(4) Power flow control.

(5) Reduce harmonic distortion.

Chapter 7

Conclusion

In this work, the effect of control system of SSSC on the small signal stability and transient stability of 9 bus ,3 synchronous machine system is observed . Also,the active power in the line and magnitudes of currents are compared as input signal to the power oscillation damping controller(POD controller).Therefore, it can be concluded that, when the SSSC works on reactive series compensation, the constant quadrature voltage mode is the more useful method to increase the damping torque, synchronizing torque, and transient stability limit .

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