ANALYSIS OF VOLTAGE STABILITY IN TWO MACHINE SYSTEM WITH SVC USING MATLAB SIMULATION

Thesis submitted towards the partial fulfillment of the requirements of the degree

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in

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Submitted by

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CERTIFICATE

I hereby declare that the Thesis entitled "**ANALYSIS OF VOLTAGE STABILITY IN TWO MACHINE SYSTEM WITH SVC USING MATLAB SIMULATION** " is an authentic record of my own work carried out as the requirements for the award of the degree of M.E. (Power Systems & Electric Drives) at Thapar University, Patiala, under the guidance of **Ms. Manvir Kaur**, Lecturer, EIED.

The matter presented in this Thesis has not been submitted for the award of any other degree of this or any other university.

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ABSTRACT

Power system is a wide network and consists of generation, transmission and distribution. In the era of development, demand of electric power demand is increasing tremendously. For fulfilling this demand the generation capacity is increased, also restructuring in some countries add to the power system complexity the most effected components of power system with this advancement are transmission and distribution system, besides rotor angle stability correction of power factor and compensation of active and reactive power. Power system also concerns about the transients in voltage. Requirement of good power quality along with additional load make the compensating device a necessity in the modern era of power system. This modern world demand of electricity is increasing which in turns load the system due to need reactive power days. The reactive power is given by the FACTS devices. Facts devices used for many purposes in power system. The simulation of the model of transmission network along with compensating device SVC is being done in MATLAB. Simulation results for changing load with and without SVC are analyzed.

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CHAPTER 1

INTRODUCTION

1.1 Overview

In the recent year of development, demand of electric power is increasing tremendously. To meet the demand, the generation of electricity has been increasing by increasing the generating capacity . The power system is vary in size and structural components however they all have some basic characteristic.

- Are comprised of three phase ac system operating essentially at constant voltage.
- Use of synchronous machines for generation of electricity. Prime movers convert Primary source of energy (fossil, nuclear and hydraulic) to mechanical energy that is , in turn, converted to electrical energy by synchronous generators.
- Transmit the power over long distances to consumers spread over a wide area. This require a transmission system comprising subsystem operating at different voltage levels.

1.2 Power System

The power system is a network of electrical components used to supply, transmit and use electric power. The power system can be broadly divided into the generators that supply the power, the transmission system that carries the power from the generating centres to the load centres, sub transmission which steps down transmission voltage further and then distribution system that feeds the power to nearby homes and industries. For efficient and reliable operation of power systems, the control of voltage and reactive power should satisfy the following objectives:

- Voltages at the terminals of all equipment in the system are within acceptable limits. Both utility equipment and customer equipment are designed to operate at a certain voltage rating. Prolonged operation of the equipment at voltages outside the allowable range could adversely affect their performance and possibly cause them damage.
- System stability is enhanced to maximise utilisation of the distribution system.
- The reactive power flow is minimised so as to reduce RI^2 and XI^2 losses to a practical minimum. This ensures that the transmission system operates effi-ciently i.e. mainly for active power transfer.

1.2.1 Transmission

Transmission is the main part of power system which contains bulk of power. As the name suggest it is use to transmit the power to long distance. It forms the backbone of the integrated power system and operates at highest level (typically 230kV and above).It connects the generating station to grid. At the generating station the voltage is stepped up to transmit the power and by reducing losses. Transmission is done without earth wire. It mainly consists of only phase conductor so it is transmitted by delta connection. There are loses in transmission line. Transmission should be done in such a way to be minimum loses.

1.2.2 Sub-transmission

Sub-transmission is part of an electric power transmission system that runs at relatively lower voltages. It is uneconomical to connect all distribution substations to the high main transmission voltage, because the equipment is larger and more expensive. Only larger substations connect with this high voltage. It is stepped down and sent to smaller substations. Large industrial customers are commonly supplied directly from subtransmission system

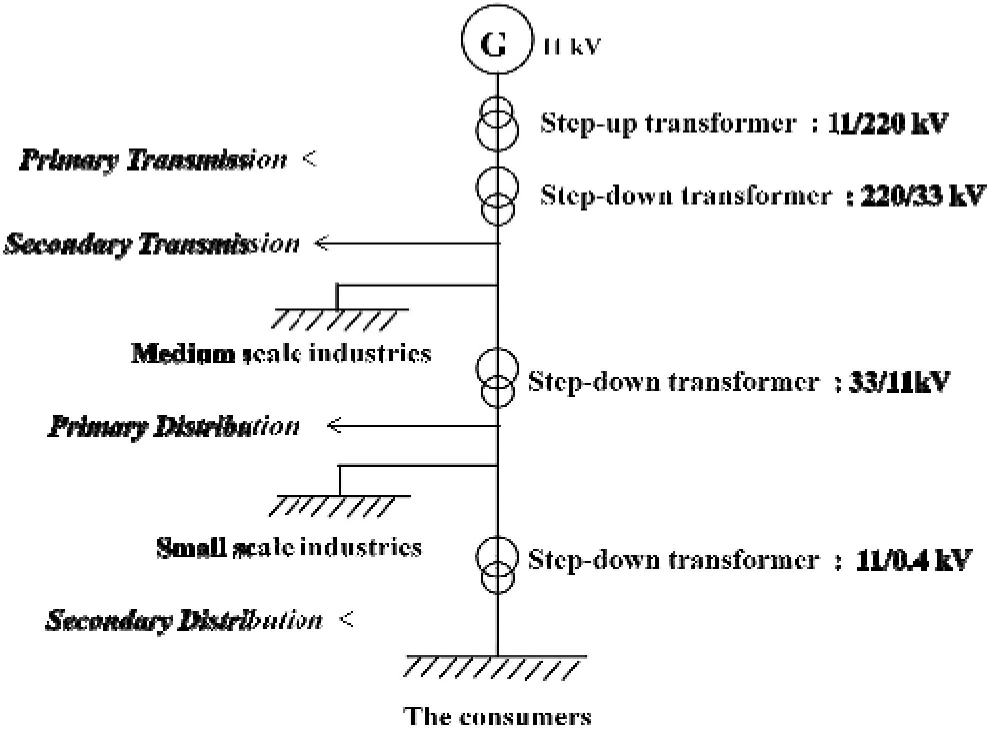

Fig.1.1 Layout of Power System

1.2.3 Distribution

Distribution is the final stage in the delivery of electricity to end users. It is divided into two categories.

- Primary distribution.
- Secondary distribution.

1.2.3.1 Primary Distribution

The primary distribution voltage is typically between 4.0 kV and 34.5 kV. Small industrial customers are supplied by primary feeders at this voltage level.

1.2.3.2 Secondary Distribution

Secondary distribution is the lowest voltage level in the power system. It supplies power to the residential customers and commercial customers at 120/240 V.

1.3 Power Quality

Power quality is one of the most neglected aspects in energy conservation. Power quality is the true indication of the how clean is the power present in the power distribution network. All the equipments transformer, motors, cables etc. are designed for certain operational parameters. It is estimated that by the use of good quality of power an industry could save almost 10-20% reduction in electricity bills along with other benefits such as enhanced life of plant and plant equipments.

1.4 Factors affecting quality of power system are:

- Harmonics
- Voltage fluctuations

1.4.1 Harmonics

The subject of harmonics is quite a complex one and is one of the primary causes of energy loses, plant equipment failure and malfunctioning .Nonlinear devices are responsible for distortion of sinusoidal wave due to this fundamental sinusoidal wave of 50 Hz frequency generate replicated sinusoidal wave with reduced amplitude at odd multiples such a 150 Hz (third harmonics) 250 Hz (fifth harmonics).

1.4.1.1Reduction of Harmonics

Reduction of harmonic distortion of a system can be accomplished with centralized or localized harmonic filters. Centralized filters include filtered automatic power factor correction units and active harmonic filters. Localized filtering can be accomplished by applying drive filters or active filters at the harmonic generating loads themselves.

1.4.2 Voltage Fluctuation

Voltage fluctuation is inherently present on the supply side of the distribution utility. Voltage fluctuations are changes or swings in the steady-state voltage above or below the designated input range for a piece of equipment. Fluctuations include both sags and swells. Causes of voltage fluctuation Large equipment start-up or shutdown, sudden change in load, improper wiring, or grounding, utility protection devices.

1.4.2.1Reduction of Voltage Fluctuation

Voltage fluctuation can be reduced by using synchronizing relay (transformers, compensation stages), switch-on damping resistors (short-term), thyristor switched capacitor batteries in an high-voltage network, flicker compensators based on thyristor modules or IGBT/IGCT converters.

1.5 Power System Stability

Power system stability can be broadly defined as that property of the power system that to remain in a state of equilibrium under normal operating condition and to regain acceptable state of equilibrium after being subjected to disturbance [1]. Synchronism among the different types of stabilities, steady- state stability involves slow or gradual changes in the operating condition, such as incremental changes in load or generation. At any point of time, a power system operating condition should be stable, meeting various operational criteria, and it should also be secure in the event of any credible contingency. Present day power systems are being operated closer to their stability limits due to economic and environmental constraints. Maintaining a stable and secure operation of a power system is therefore a very important and challenging issue. Voltage stability of a power system is to maintain steady acceptable voltage at all buses in the power system under normal operating condition after being subjected to a disturbance. A system enters a state of voltage instability when subjected to disturbance, increase in load demand or change in system condition causes a progressive and uncontrollable drop in voltage.

1.6 Power Quality Problems

Power distribution system must provide an uninterrupted supply to their consumer with a fixed magnitude level and frequency. But in actual practice there is no such standards for non linear loads which significantly affect the power quality of the load. As a result purity of the actual waveform should not be disturbed otherwise it creates problem in power system. A power voltage spike can damage valuable components. Power Quality problems encompass a wide range of disturbances such as voltage sags/swells, flicker, harmonics distortion.

- **Voltage Dip**: A voltage dip is used to refer to short-term reduction in voltage of less than half a second. According to internationally-adopted definitions (under European standard EN 50160), a voltage dip occurs when the power voltage drops to a level below 90% of standard voltage for no longer than a minute. However, most voltage dips last for less than one-tenth of a second before the standard voltage of the power supply is restored. A voltage dip is not a power interruption. During the occurrence of a voltage dip, the power supply is not interrupted.

- **Voltage Swell:** is defined by IEEE 1159 as the increase in the RMS voltage level to 110% - 180% of nominal, at the power frequency for durations of ½ cycle to one (1) minute. Voltage swell is basically the opposite of voltage sag or dip. Voltage swells are almost always caused by an abrupt reduction in load on a circuit with a poor or damaged voltage regulator, although they can also be caused by a damaged or loose neutral connection.

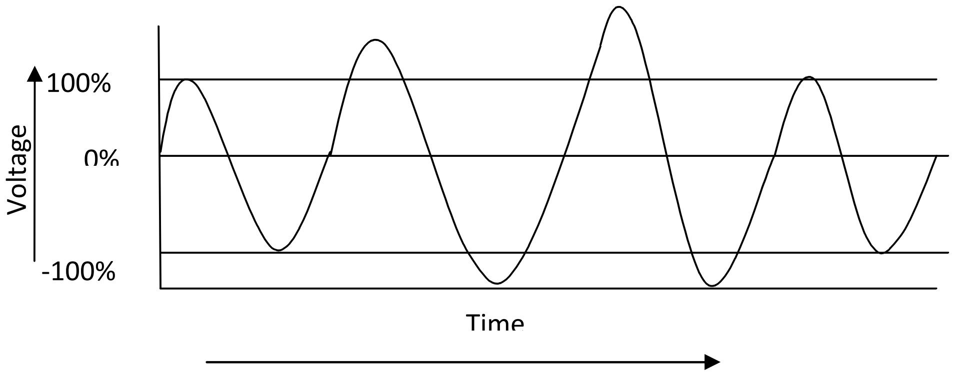

Fig 1.2 voltage swell versus time

- **Voltage Sag:** A Voltage sag is not a complete interruption of power; it is a temporary drop below 90 percent of the nominal voltage level. Most voltage sags do not go below 50 percent of the nominal voltage, and they normally last from 3 to 10 cycles—or 50 to 170 milliseconds.
- **Voltage transients**: They are temporary, undesirable voltages that appear on the power supply line. Transients are high over-voltage disturbances (up to 20KV) that last for a very short time.

1.6.1 Causes of Dips, Sags and Surges

- Rural location remote from power source.
- Unbalanced load on a three phase system.
- Switching of heavy loads.
- Long distance from a distribution transformer with interposed loads.
- Unreliable grid systems.
- Equipments not suitable for local supply.

1.6.2 Causes of Transients and Spike:

- Lightening.
- Arc welding.
- Switching on heavy or reactive equipments such as motors, transformers, motor drives.
- Electric grade switching.

1.7 Organization of thesis

- Chapter1 is the introduction of power system quality and power system problems.
- Chapter 2 is for voltage stability in the power system, problems and voltage stability analysis and their methodology.
- Chapter 3 is literature review of reference paper.
- Chapter 4 is problem formulation and their solution.
- Chapter 5 is conclusion and future Scope.

CHAPTER 2

VOLTAGE STABILITY

2.1 Concept of Voltage Stability

Beside rotor angle stability, or transient stability, power system stability also concerns about voltage stability. The voltage stability is the ability of power system to maintain steady acceptable voltages at all buses in the system at normal open conditions and after being subjected to a disturbance [2]. According to the definition of voltage instability. "Voltage instability stems from the attempt of load dynamics to restore power consumption beyond the capability of the combined transmission generation s system [3]. Voltage instability may, or may not lead to voltage collapse, which is defined by catastrophic result of a sequence of events leading to a low-voltage profile suddenly in a major part of the power system [3].When lacking of the reactive power transfer capability to the load, the power system may cause voltage instability. Therefore, any changes in the power system which affects the reactive power transfer such as dynamic loads, reactive power generation, disconnection of transmission lines, or switching off static compensators are factors relating to voltage instability. Classification of voltage stability helps analysis the problem, and identifies factors relating to voltage instability. Depending on time scale, Voltage stability is classified as short term and long term voltage stability. Short term voltage stability involves dynamics of fast acting load components like induction motors, electronically controller loads. The study period of interest is in order of several seconds. While long term voltage stability refers to slower acting equipments like tap changing transformers, generator current limiters. The study period of interest extends to several minutes [2].

2.2 Classification of Voltage Stability

Voltage stability classified into two categories**:**

- Large disturbance voltage stability.
- Small disturbance voltage stability.

2.2.1 Large Disturbance Voltage Stability

It is concerned with system ability to control voltages following large disturbance such as loss of load, loss of generation, system faults. This form of stability requires the examination of the dynamic performance of the system over a long period of time which is enough to capture the interaction of devices i.e. ULTC (under load tap changer), and generators field current limiter [2].

2.2.2 Small Disturbance Voltage Stability

It is concerned with system ability to control voltages following small perturbation, such as gradual change in load either increasing of load or decreasing of load. This form of stability can be effectively studied with steady state approach [2].

2.3 Element Effects Voltage Stability

2.3.1 Load Characteristic

Load characteristic could be critical in voltage stability analysis. This should include transformer ULTC (under load tap changer) action, reactive power compensation and voltage regulators in the sub transmission system.

2.3.2 Generators and their Excitation Control

For voltage stability analysis it may be necessarily to account for constant droop characteristic of the AVR rather than it assumes zero droop. If load compensation provided, its effect should be represented. Field currents and armature current limits should represent specifically rather than as fixed value of the maximum reactive power limit.

2.3.3 Automatic Generation Control (AGC)

For contingencies resulting in a significant mismatch between generation and load, the action of primary speed control and supplementary tie line bias frequency control can change system generation significantly.

2.3.4 Protection Control

These include generating unit and transmission network protection and controls. Examples are generators excitation protection, armature overcurrent protection, transmission line over current protection, capacitor bank controls, phase shifting regulators, and under voltage load shedding.

2.4 Analysis of Voltage Stability

2.4.1 Single Load, Infinite Bus System

The characteristics of voltage stability are illustrated by an infinite-bus system. In figure 2.1, infinite bus has constant voltage, E. The load is assumed have constant power factor $\cos\phi$. The line impedance is Z=R+jX.

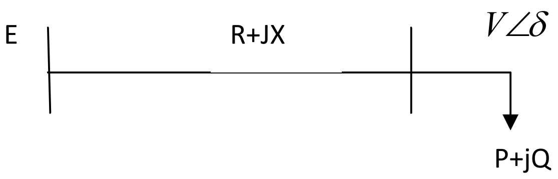

Fig2.1 Two Machine Model

The purpose is to calculate the load voltage V with different values of load. The voltage is calculated by solving the load flow equation:

$$\frac{V^*.(E-V)}{Z}=S^* \qquad \text{………………………2.1}$$

E is the voltage at infinite bus

Vis the voltage load, V=$V\angle\delta$

S is the load power demand S=P+jQ

Z is the line impedance Z= R+jX

$$\sqrt{\frac{E^2}{2}-QX\pm\sqrt{\frac{E^2}{4}-X^2P^2-XE^2Q}} \qquad \text{………………………2.2}$$

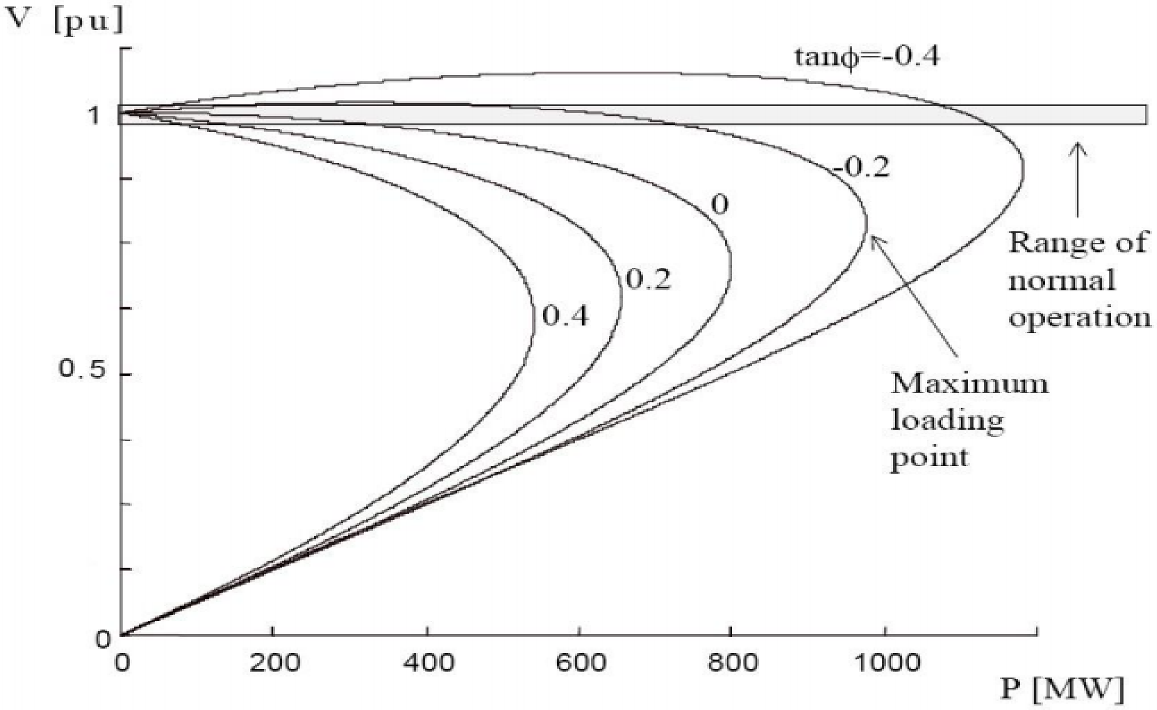

Fig.2.2 Load Voltage P-V Curve

Fig. 2.3 illustrates PV- curves for different load power factors. For each curve, it presents both solutions of power system. The higher voltage solution, which is corresponding to “+” sign in equation 2.2 is stable, while the lower voltage, corresponding to “ -” sign, is unstable. In normal operation, power systems are operated in the upper part of the PV-curve. The head of the curve is called the maximum power point where solutions unite [3]. The maximum power and the voltage of the point are obtained when impedance of the load is equal with impedance of the transmission line. They are calculated as follows:

$$P_{\max} = \frac{\cos\phi}{1+\sin\phi}\frac{E^2}{2X} \qquad \text{........................ 2.3}$$

$$V_{\max} = \frac{E}{\sqrt{2}\sqrt{1+\sin\phi}} \qquad \text{........................ 2.4}$$

$$\cos\phi = \frac{P}{\sqrt{P^2+Q^2}} \qquad \text{........................ 2.5}$$

PV-curves play a major role in understanding and explaining voltage stability. From a PV curve, the variation of bus voltages with load, distance to instability (VS margin) and critical voltage at which instability occurs may be determined.

2.4.2 Voltage Stability of a Simple 2-bus System

The basic concept of voltage stability can be explained with a simple 2-bus system shown in Figure 2.3.The load is of constant power type. Real power transfer from bus 1 to 2 is given by [16].

$$P = \frac{EV}{X}\sin\delta \qquad \text{.........................2.6}$$

Reactive power transfer from bus 1 to bus 2

$$Q = -\frac{V^2}{X} + \frac{EV}{X}\cos\delta \qquad \text{.........................2.7}$$

Where

$E = E\angle\delta$ is the voltage at bus 1.

$V = V\angle 0$ is the voltage at bus 2.

X = impedance of the line.

δ = power angle

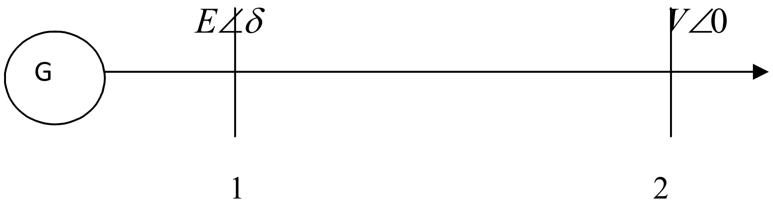

Fig.2.3 Two Machine System

Normalizing the term in (2.6) and (2.7) $v = \frac{V}{E}, p = \frac{P.X}{E^2}$ we obtain $q = \frac{Q.X}{E^2}$, one obtains

$p = v\sin\delta$ 2.8

$q = -v^2 + \cos\delta$ 2.9

$$v^2(\sin^2\delta + \cos^2\delta) = p^2 + (q + v^2)$$

or

$v^4 + v^2(2q+1) + (p^2 + q^2) = 0$ 2.10

Positive real solution of v from (2.10) are given by

$v = \sqrt{\frac{1}{2} - q \pm \sqrt{\frac{1}{4} - p^2 - q^2}}$ 2.11

2.5 Voltage Stability Analysis in Nonlinear Power Systems

Voltage instability is a dynamic phenomenon which may involve the interaction of many devices. It may occur in different time frames and involve different parts of the system with nonlinear behaviour due to interaction of different elements in power systems. Analysis of voltage stability must provide information on system state, proximity to, and mechanism of instability [1]. There are two main methods of voltage stability analysis in nonlinear power systems: dynamic analysis and static analysis.

2.5.1 Dynamic Analysis

In dynamic analysis, all elements in a power system are modelled by algebraic and differential equations. The behaviour of the system under different changes of the system is studied through time domain simulations. The whole power system can be expressed under set of algebraic and differential equations in general form as follows:

$$\frac{dx}{dt} = f(x, y, p) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.12$$

$$0 = g(x, y, p) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.13$$

with a set of known initial condition($x_0\ y_0\ p_0$).

- Where x is the state vector of the system (e.g. generator phase angle and angular velocities, tap ratio of on load tap changer transformers).
- y is the vector of algebraic variables (e.g. the direct and quadrature axis component of the stator currents).
- p is the vector of parameter variables (e.g. load factor).

For a fix parameter p, equations (2.12), (2.13) are solved directly in time domain by using numerical integration methods such as Euler, Range-Kutta methods [1]. Dynamic analysis can accurately replicate the actual dynamic of voltage stability, and show performance of system and individual elements. It can also capture the event and chronology leading to voltage instability. However, this method requires huge data information for modelling and expensive calculation efforts, while the degree of instability is not provided [3]. In practice, dynamic simulation is applied in essential studies relating to coordination of protections and controls and short-term voltage stability analysis.

2.5.2 Static Analysis

2.5.2.1. Steady-State Stability

Steady-state stability approach investigates the power system around each operating point, which is approximated by setting the time derivatives of state variables to zero, and the state variables take on values appropriate to the operating point. Consequently, the overall system equations reduce to purely algebraic equations:

$$0 = f(x, y, p) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.14$$

$$0 = g(x, y, p) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.15$$

The nonlinear algebraic equations (2.14), (2.15) are linearized around the operating point. It is presented in general form as follows:

$$\begin{bmatrix} \Delta \frac{dx}{dt} \\ 0 \end{bmatrix} = J \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.16$$

$$J = \begin{bmatrix} f_x f_y \\ g_x g_y \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.17$$

where f_x f_y are partial derivatives of $f(x, y, p)$ to x y respectively

g_x g_y are partial derivatives of $g(x, y, p)$ to x, y respectively.

Assuming that g_y is non singular Δy can be eliminated from 2.16.

$$\Delta \frac{dx}{dt} = F_x \Delta x \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.18$$

Where F_x is the reduced jacobian matrix of the system

$$F_x = [f_x - f_y g_y^{-1} g_x] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.19$$

The stability of an equilibrium point of the system depends on the eigen values of the reduced Jacobian matrix. If all the eigen value of this matrix have negative real parts, the operating point is asymptotically stable. If at least one eigen value has a positive real part, the operating point is unstable [3].

2.6 Tools for Voltage Stability Analysis

Study of voltage stability needs some parameters which can be known using voltage stability indices. These analyses based on static analysis or dynamics model of power system. The conventional methods can be broadly classified into the following types.

- P-V curve method.
- V-Q curve method and reactive power reserve.
- Continuation power flow method.

2.6.1 P-V Curve Method

This is one of the widely used methods of voltage stability analysis. This gives the available amount of active power margin before the point of voltage instability. For radial systems, the voltage of the critical bus is monitored against the changes in real power consumption. For large meshed networks, P can be the total active load in the load area and V can be the voltage of the critical or representative bus. Real power transfer through a transmission interface or interconnection also can be studied by this method.

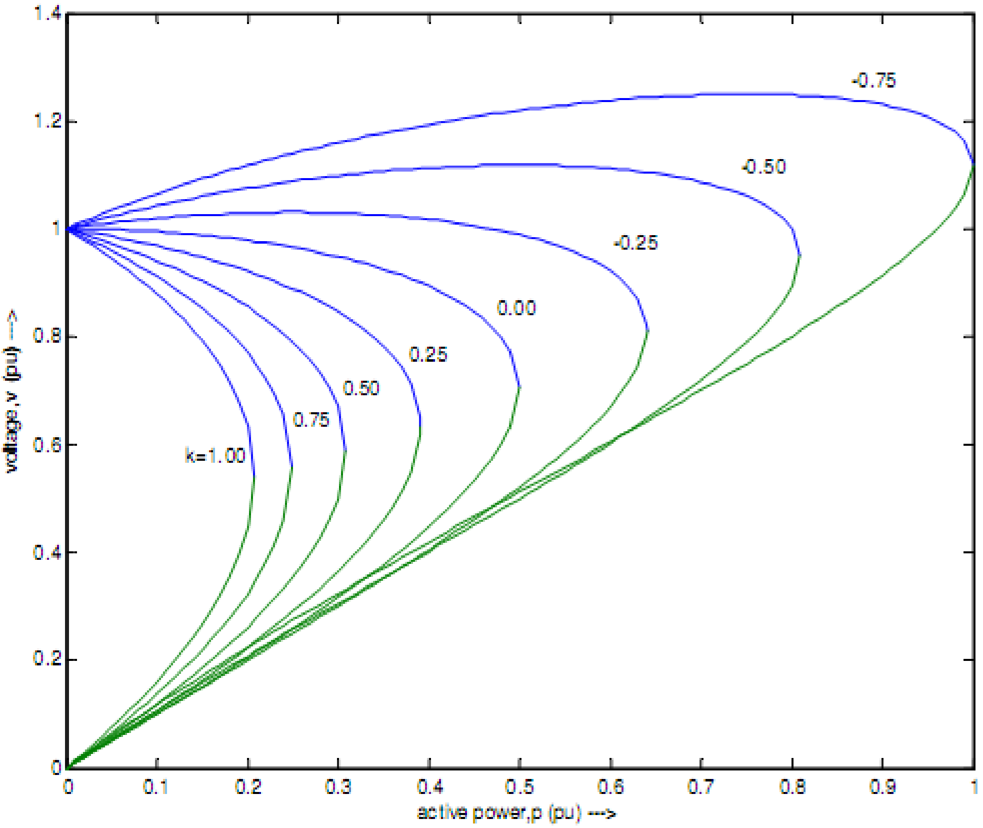

Fig. 2.4 Plot of P.V Curve

2.6.2 V-Q Curve Method And Reactive Power Reserve

The V-Q curve method is one of the most popular ways to investigate voltage instability problems in power systems during the post transient period. Unlike the P-V curve method, it doesn’t require the system to be represented as two-bus equivalent. Voltage at a test bus or critical bus is plotted against reactive power at that bus. A fictitious synchronous generator with zero active power and no reactive power limit is connected to the test bus. The power-flow program is run for a range of specified voltages with the test bus treated as the generator bus. Reactive power at the bus is noted from the power flow solutions and plotted against the specified voltage. The operating point corresponding to zero reactive power represents the condition when the fictitious reactive power source is removed from the test bus.

For the simple two-bus system shown in Figure 2.3, equations of V-Q curves for constant power loads can be derived as follows. From (2.8) the power angle d is computed for specified active power and used in (2.9). For a range of values of voltage and different active power levels, normalized V-Q curves are shown in Figure 2.5. The critical point or nose point of the characteristics corresponds to the voltage where dQ/dV becomes zero. If the minimum point of the V-Q curve is above the horizontal axis, then the system is reactive power deficient. Additional reactive power sources are needed to prevent a voltage collapse. In Figure 2.5, curves for p=1.00 and p=0.75 signify reactive power deficient busses. Busses having V-Q curves below the horizontal axis have a positive reactive power margin. The system may still be called reactive power deficient, depending on the desired margin.

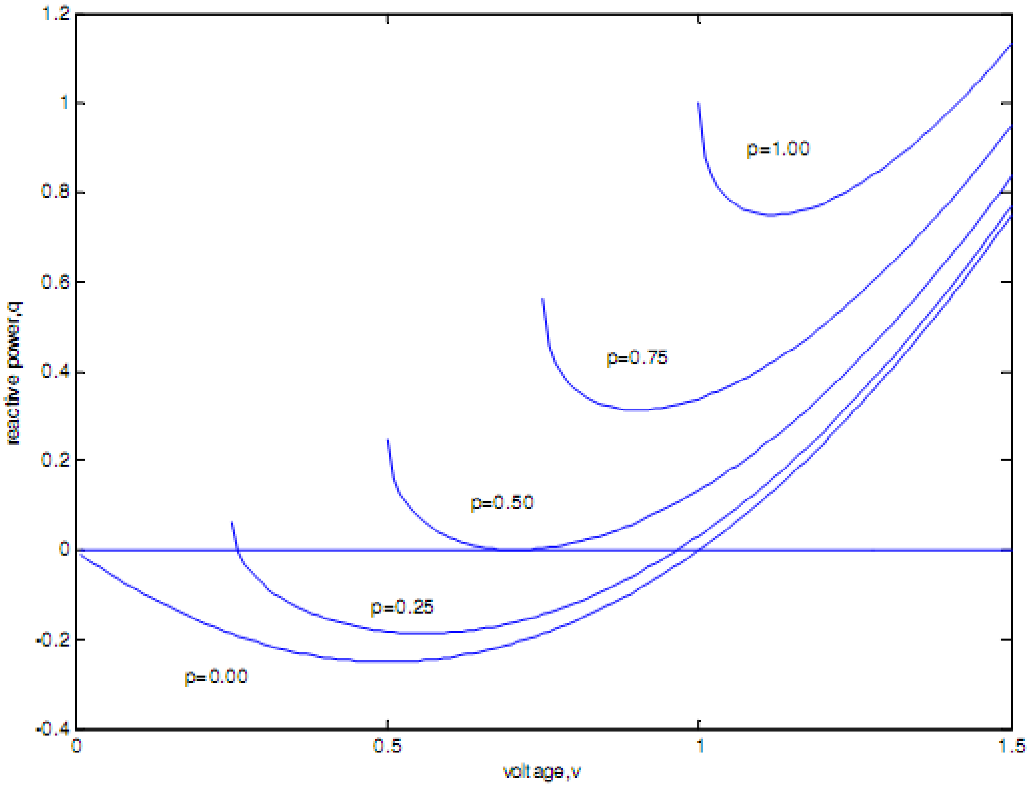

Fig 2.5 V-Q Curve

2.6.3 Continuation Power flow

It is numerically difficult to obtain a power flow solution near the voltage collapse point, since the Jacobian matrix becomes singular. Continuation power flow is a technique by which the power flow solutions can be obtained near or at the voltage collapse point.

Power flow equations can be represented as,

$$P_s = P(\delta, V) \qquad \text{. . . . . 2.20}$$

$$Q_s = Q(\delta, V) \qquad \text{. . . . . 2.21}$$

2.7 Prevention of Voltage Instability

Some of the prevention of voltage instability by following:

- Placement of Series and Shunt Capacitors.
- Generation Rescheduling.
- Placement of FACTS Controllers.
- Under-Voltage Load Shedding.
- Blocking of Tap-Changer under Reverse Operation.
- Coordination of Multiple FACTS Controllers.
- Installation of Synchronous Condensers.

2.8 Basic Types of Facts Controllers

In general, FACTS Controllers can be divided into four categories:

- Series Controllers.
- Shunt Controllers.
- Combined series-series Controllers.
- Combined series-shunt Controllers.

Fig. 2.6 Shows the general symbol for a FACTS Controller, a thyristor arrow inside a box.

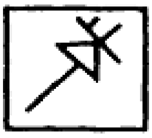

Fig. 2.6 General Symbol of Facts Controller

2.8.1 Series Controller

The series Controller could be a variable impedance, such as capacitor, reactor, etc., or a power electronics based variable source of main frequency, subsynchronous and harmonic frequencies (or a combination) to serve the desired need. In principle, all series Controllers inject voltage in series with the line. Even a variable impedance multiplied by the current flow through it, represents an injected series voltage in the line. As long as the voltage is in phase quadrature with the line current, the series Controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well.

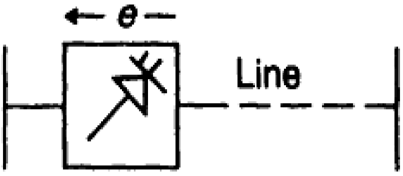

Fig.2.7 Series Controller

2.8.2 Shunt Controller

As in the case of series Controllers, the shunt Controllers may be variable impedance, variable source, or a combination of these. In principle, all shunt Controllers inject current into the system at the point of connection. Even variable shunt impedance connected to the line voltage causes a variable current flow and hence represents injection of current into the line. As long as the injected current is in phase quadrature with the line voltage, the shunt Controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well.

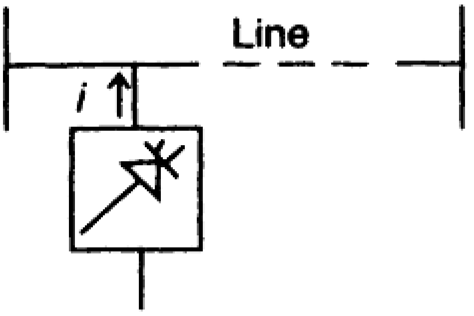

Fig.2.8 Shunt Controller

2.8.3 Combined Series-Series Controllers

This could be a combination of separate series controllers, which are controlled in a coordinated manner, in a multiline transmission system. Or it could be a unified Controller, Fig. 2.10, in which series Controllers provide independent series reactive compensation for each line but also transfer real power among the lines via the power link. The real power transfer capability of the unified series-series Controller, referred to as Interline Power Flow Controller, makes it possible to balance both the real and reactive power flow in the lines and thereby maximize the utilization of the transmission system. Note that the term "unified" here means that the de terminals of all Controller converters are all connected together for real power transfer.

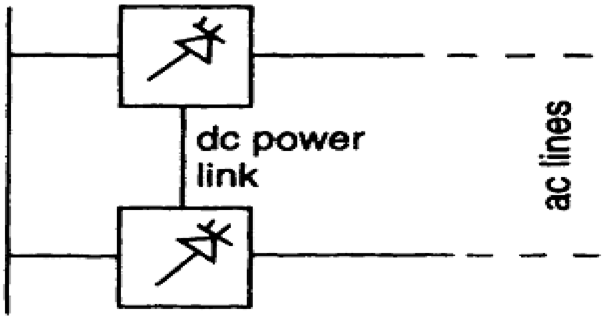

Fig.2.9 Unified Series Controller

2.8.4 Combined Series-Shunt Controllers

This could be a combination of separate shunt and series Controllers, which are controlled in a coordinated manner Fig.2.10, or a Unified Power Flow Controller with series and shunt elements Fig.2.11. In principle, combined shunt and series Controllers inject current into the system with the shunt part of the Controller and voltage in series in the line with the series part of the Controller. However, when the shunt and series in the line with the series part of the Controller. However, when the shunt and series Controllers are unified, there can be a real power exchange between the series and shunt Controllers via the power link.

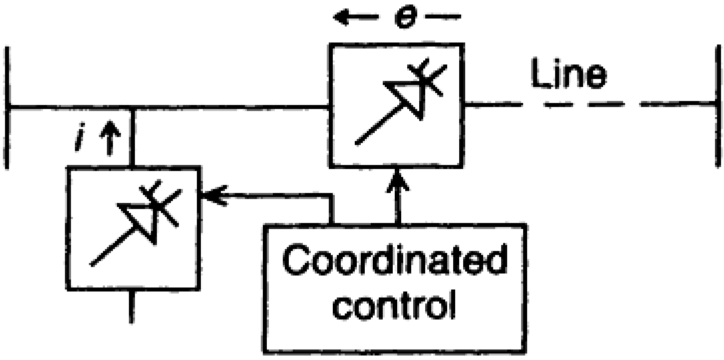

Fig.2.10.Cordinated Series Shunt Controller

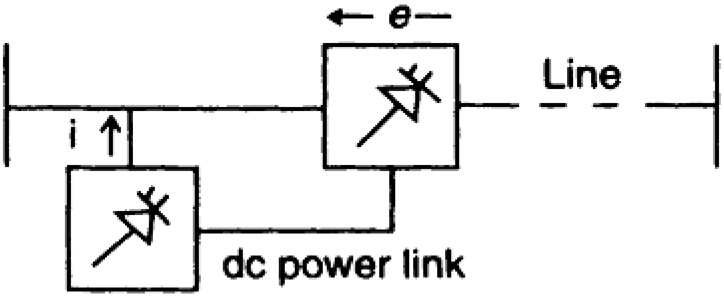

Fig.2.11 Unified Series Shunt Controller

2.9 Relative Importance of Different Types of Controllers

It is important to appreciate that the series-connected Controller impacts the driving voltage and hence the current and power flow directly. Therefore, if the purpose of the application is to control the current/power flow and damp oscillations, the series Controller for a given MVA size is several times more powerful than the shunt Controller. As mentioned, the shunt Controller, on the other hand, is like a current source, which draws from or injects current into the line. The shunt Controller is therefore a good way to control voltage at and around the point of connection through injection of reactive current (leading or lagging), alone or a combination of active and reactive current for a more effective voltage control and damping of voltage oscillations. This is not to say that the series Controller cannot be used to keep the line voltage within the specified range. After all, the voltage fluctuations are largely a consequence of the voltage drop in series impedances of lines, transformers, and generators. Therefore, adding or subtracting the FACTS Controller voltage in series (main frequency, subsynchronous or harmonic voltage and combination thereof) can be the most cost-effective way of improving the voltage profile. Nevertheless, a shunt controller is much more effective in maintaining a required voltage profile at a substation bus. One important advantage of the shunt Controller is that it serves the bus node independently of the individual lines connected to the bus. Series Controller solution may require, but not necessarily, a separate series Controller for several lines connected to the substation, particularly if the application calls for contingency outage of anyone line. However, this should not be a decisive reason for choosing a shunt-connected Controller, because the required MVA size of the series Controller is small compared to the shunt Controller, and, in any case, the shunt Controller does not provide control over the power flow in the lines.

On the other hand, series-connected Controllers have to be designed to ride through contingency and dynamic overloads, and ride through or bypass short circuit currents. They can be protected by metal-oxide arresters or temporarily bypassed by solid-state devices when the fault current is too high, but they have to be rated to handle dynamic and contingency overload. The above arguments suggest that a combination of the series and shunt Controllers Fig. 2.10 and2.11.can provide the best of both, i.e., an effective power/ current flow and line voltage control.

For the combination of series and shunt Controllers, the shunt Controller can be a single unit serving in coordination with individual line Controllers Fig 2.13. This arrangement can provide additional benefits (reactive power flow control) with unified Controllers.

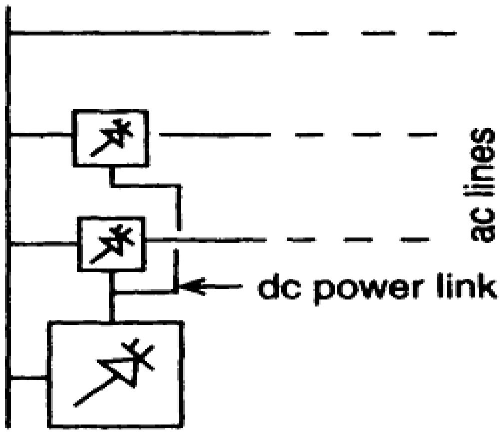

Fig.2.12 Unified Controller for Multiple Lines.

FACTS Controllers may be based on thyristor devices with no gate turn-off (only with gate turn-on), or with power devices with gate turn-off capability. Also, in general, as will be discussed in other chapters, the principal Controllers with gate turn-off devices are based on the de to ac converters, which can exchange active and/ or reactive power with the ac system. When the exchange involves reactive power only, they are provided with a minimal storage on the de side. However, if the generated ac voltage or current is required to deviate from 90 degrees with respect to the line current or voltage, respectively, the converter de storage can be augmented beyond the minimum required for the converter operation as a source of reactive power only. This can be done at the converter level to cater to short-term storage needs. In addition, another storage source such as a battery, superconducting magnet, or any other source of energy can be added in parallel through an electronic interface to replenish the converter's de storage. Any of the converter-based, series, shunt, or combined shunt-series Controllers can generally accommodate storage, such as capacitors, batteries, and superconducting magnets, which bring an added dimension to FACTS technology as shown in Fig. 2.13, 2.14and 2.15.

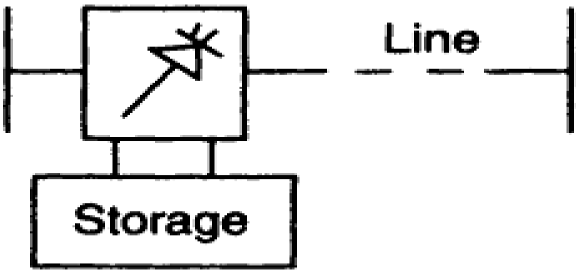

Fig.2.13 Series Controller with Storage

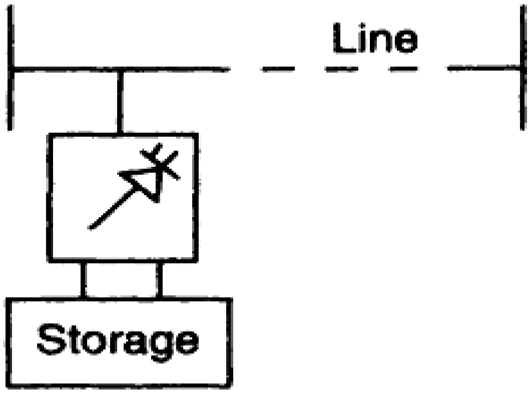

Fig.2.14 Shunt Controller with Storage

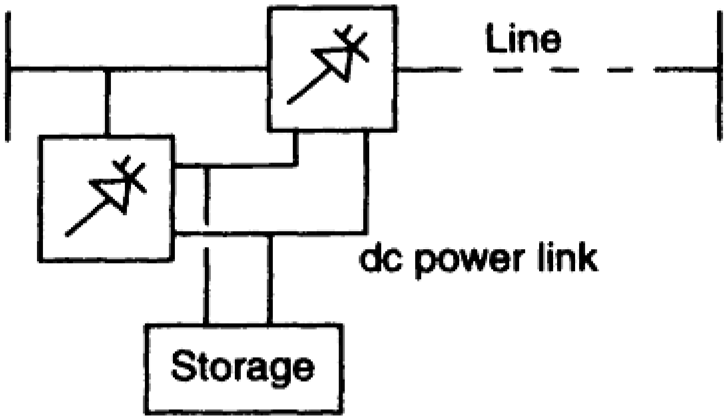

Fig.2.15. Unified Series-Shunt Controller with Storage.

2.10 Benefits From Facts Technology

Details of various FACTS Controllers will be discussed throughout the book. It is appropriate to state here the basic system security guidelines these Controllers enable the transmission owners to obtain, on a case-by-case basis, one or more of the following benefits:

- Control of power flow as ordered. The use of control of the power flow may be to follow a contract, meet the utilities' own needs, ensure optimum power flow, ride through emergency conditions, or a combination thereof.
- Increase the loading capability of lines to their thermal capabilities, including short term and seasonal. This can be accomplished by overcoming other limitations, and sharing of power among lines according to their capability. It is also important to note that thermal capability of a line varies by a very large margin based on the environmental conditions and loading history.
- Increase the system security through raising the transient stability limit, limiting short-circuit currents and overloads, managing cascading blackouts and damping electromechanical oscillations of power systems and machines.
- Provide secure tie line connections to neighbouring utilities and regions thereby decreasing overall generation reserve requirements on both sides.
- Provide greater flexibility in siting new generation.
- Upgrade of lines.
- Reduce reactive power flows, thus allowing the lines to carry more active power. • Reduce loop flows.

- Increase utilization of lowest cost generation. One of the principal reasons for transmission interconnections is to utilize lowest cost generation. When this cannot be done, it follows that there is not enough cost-effective transmission capacity. Cost-effective enhancement of capacity will therefore allow increased use of lowest cost generation.

2.11 SVC

Qsvc=Qmin≈Qmax

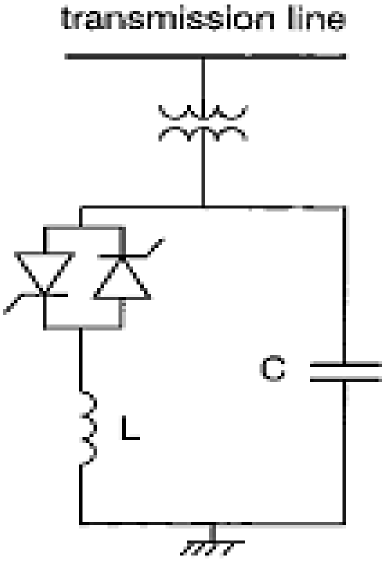

Fig.2.16 SVC Connected in Long Transmission Line.

power system is expected to operate under widely varying condition from no load to overloading to short circuit and it is desired that the quality of supply be maintained under all conditions i.e. constancy of voltage magnitude and freq of system should be maintained . To achieve these objectives line compensation is a must, which is done by SVC.SVCs are applied on transmission systems to improve voltage control and system stability during both normal and contingency system conditions. The SVC can be operated as both inductive and capacitive compensation which can control bus voltage by absorbing injecting reactive power. The SVC is modelled as a shunt variable susceptance added at both ends of the line. Hence, is modelled as ideal reactive power injections to perform the steady-state condition at bus i, as shown in Fig. By providing dynamic reactive power , SVC can be used for the purpose of regulating the system voltage compensating the voltage at a reasonable level, improving the power flow capacity of transmission line , enhancing the damping of low frequency oscillation as well as inhibiting the variation of bus bar voltage caused by fluctuating load , which is favourable for the recovery of transient voltage and the improvement of stabilization of the system voltage. For industrial user , it can effectively control the reactive power ,improve the power factor reduce the voltage influence and harmonic interference caused by the nonlinear load, balance three phase load , improve the power factor quality , improve the productive efficiency, reduce the energy consumption.

2.11.1Function of SVC

- Stabilizing of voltage.
- Reduction of harmonics.
- Minimum flicker disturbance on own and neighbouring facilities.
- Minimum malfunction of protective devices.
- Balanced load.
- Reducing harmonics distortion.

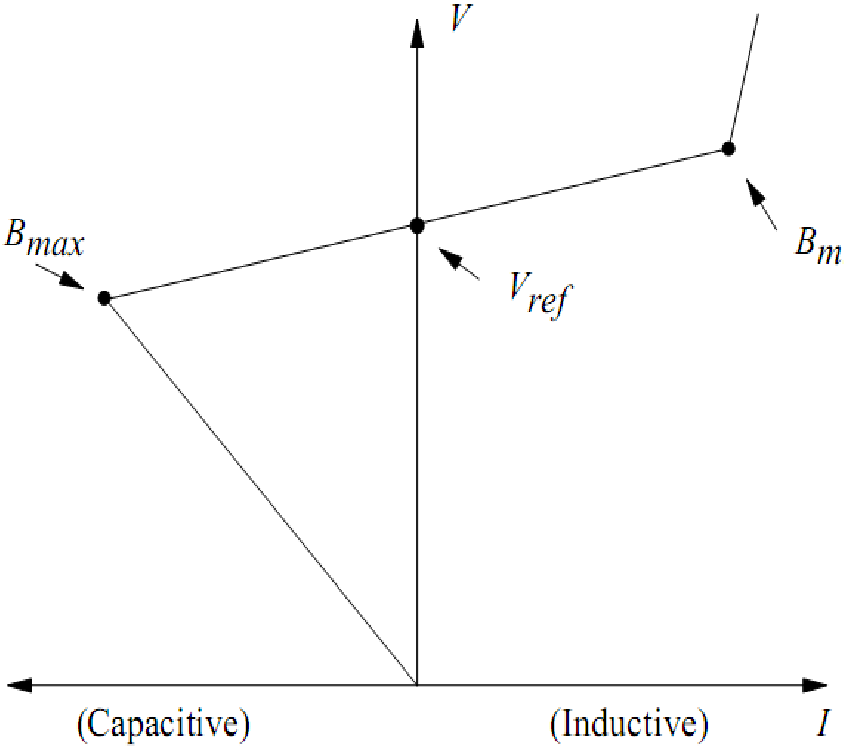

Fig.2.17 Typical Steady-State Voltage Control Characteristic of SVC.

CHAPTER 3

LITERATURE REVIEW

3.1 INTRODUCTION

Voltage stability is the major problem in the power system network. It any type of problem like harmonics voltage collapse distortion of voltage waveform. Static VAR compensator was developed in 1960 to provide fast reactive power (VAR) compensation for large, fluctuating loads. In 1970, SVCs were successfully used in dynamic compensation of power system to provide voltage support, increase the transient stability and to improve damping. It has been known that SVC can extend the stability limit and improve the system damping when connected at the midpoint of long transmission lines. While an SVC with pure voltage control may not adequately contribute to system damping, a significant enhancement can be achieved when the reactive power of the SVC is modulated in response to auxiliary control signals superimposed over its voltage control loop. Conventional linear methods were mainly used for the design of the supplementary damping controller in the previous research. Kundur.P described a design procedure with the classical pole-placement method [2]. Padiyar and Verma used the damping torque analysis technique to design the damping controller, but the method is limited to one-machine-infinite-bus system.

Battistelli.l et *al.* investigated that deregulated market requires great attention to be paid to analysis and control methodologies. This evolution has to satisfy reliability, security and optimisation objectives. In this context the importance of reactive control has to be highlighted. Power electronic devices can be efficiently employed to solve this crucial problem. A co-ordinated control strategy for the reactive power based upon a hierarchical structure is considered. An optimisation procedure is affected at a high level maximising the economic gain and avoiding the possibility of critical conditions deriving from voltage instabilities. The optimisation output data are used as reference signals for static VAr compensators. The rationale behind the SVC control design is the invariant manifold theory, allowing the reference signal to be tracked with accuracy and robustness. An application is presented with reference to the IEEE 118-bus system which outlines the flexibility and goodness of the proposed technique [4].

Wang.Y.et al. discussed voltage stability enhancement by a nonlinear SVC controller. The proposed controller is designed through direct feedback linearization (DFL) technique. The effect of the controller on voltage stability is studied through small signal stability analysis on both single-machine and multi-machine power systems. In both systems, voltage stability is lost when an unstable Hopfbifurcation is encountered. When the nonlinear SVC control is taken into account, the Hopfbihrcation can be eliminated. Voltage stability is therefore improved significantly [5].

Wang .Y.et al. Major objectives in power system control design are to prevent an electric power system losing synchronism after a large sudden fault and to achieve good postfault regulation of the generator terminal voltage. Important control ideas used to improve the transient stability of the power system are to rapidly increase excitation and to decrease the mechanical input power at the same time as a fault occurs. In this paper, we concentrate our attention on power systems after a symmetrical 3-phase short circuit fault. By using the direct feedback linearization (DFL) technique, a novel excitation controller and coordinated controller (excitation and fast valving controller) are given. The simulation results show that the power system can keep transiently stable and achieve good post fault voltage regulation with the nonlinear controllers [6].

Noroozian.M and Taylor C.W. Examined the behaviour of SVCs and STATCOMs in electric power systems is presented. The paper is based on analytical and simulation analysis, and conclusions can be used as power industry guidelines. Author explained the principle structure of SVCs and STATCOMs, the model for dynamic studies, and the impact of these devices on steady state voltage and transient voltage stability. Sensitivity analysis is provided which shows the impact of SVCs and STATCOMs with regard to network strength. Harmonic issues & space requirements, and price discussions are also briefly addressed [7].

Yome A. S compared the shunt capacitor, SVC in static voltage stability improvement. Various performance measures are compared under different operating system conditions for the IEEE 14 bus test system. Important issues related to shunt compensation, namely sizing and installation location, for exclusive load margin improvement are addressed. A methodology is also proposed to alleviate voltage control problems due to shunt capacitor compensation during lightly and heavily loaded conditions [8].

Masood. T, investigated the behaviour of statcom against SVC controller by setting up new control parameters. Essentially, statcom, SVC linear operating ranges of the V-I and V-Q as well as their functional compensation capabilities have been addressed to meet operational requirement with certain degree of sustainability and reliability. Hereby, the other operating parameters likewise transient stability, response time, capability to exchange real Power and Power Losses have also been addressed in statcom and SVC control models. [9].

Moghawemi M. and Faruque. M. has presented a study of FACTS devices mainly Static Var Compensator (SVC) . Their steady-state modelling and effects on power system performance have been studied. It also studies static stability improvement of power system and hence power flow improvement in the network. Standard stability evaluation technique has been used to identify the optimum place for the implementation of Flexible AC Transmission System (FACTS) devices and the effects of FACTS on system loadability has been studied and presented here. The technique to identify the optimum location for the placement of FACTS devices is based on the concept of maximum power transferring capability of the lines and buses. The study has been carried out on the IEEE 24 and 118 Bus Test Systems. Study reveals that incorporation of FACTS devices significantly enhanced system stability as well as power transfer capability of the system. [10]

Haque M.H. used a simple and direct method of determining the steady state voltage stability limit of a power system when equipped with a Static Var Compensator (SVC). The maximum permissible loading of a particular bus in a power system is determined through a simplified equivalent model of the original system. The method is very efficient and does not require repetitive load flow simulations to generate the system *P-V* or *Q-P* curve. The effectiveness of the proposed method is then tested on a simple 2-bus system and the IEEE 14-bus system. The effects of load power factor and SVC rating on voltage stability limit are also studied. The maximum permissible bus loading obtained by the proposed method in the IEEE system are also verified through repetitive load flow simulations and are found to be in excellent agreement[11].

Chang C.S. and Huang J.S described voltage collapse and other instability problems can be related to the systems inability to meet VAR demands. To maximise SVC's capability to enhance voltage stability, optimal SVC placement can be obtained by seeking a compensation scheme which maximises the system VAR margin. Several algorithms have been developed to evaluate the system VAR margin. Line transfer limits are other factors to be considered for voltage instability. These limits may he exceeded due to overloads or draining off of VAR reserves .Guarding against line overloads is therefore important in SVC planning, not only for economic benefits but also for security. Consequently, compensation schemes should be designed for minimum I^2R losses. Excessively low voltages can lead to an unacceptable eservice quality and bring about voltage instability problems, such as those caused by immense reactive power absorption of stalled induction motors. Thus, the system's capability in correcting severe voltage depressions should also be taken into account in SVC design [12].

Panda .S. and Patel R.N. explained Shunt Flexible AC Transmission System (FACTS) devices, when placed at the mid-point of a long transmission line, play an important role in controlling the reactive power flow to the power network and hence both the system voltage fluctuations and transient stability. This paper deals with the location of a shunt FACTS device to improve transient stability in a long transmission line with predefined direction of real power flow. The validity of the mid-point location of shunt FACTS devices is verified, with different shunt FACTS devices, namely static var compensator (SVC) and static synchronous compensator (STATCOM) in a long transmission line using the actual line model. It has been observed that the FACTS devices, when placed slightly off-centre towards sending-end, give better performance in improving transient stability and the location depends on the amount of local/through load [13].

Modi P.K. presented a fuzzy neural network for voltage stability in power system Now voltage stability has become of major concern for the power utilities. In this paper, multi input, single output fuzzy neural network is developed for voltage stability evaluation of the power systems with SVC by calculating the loadability margin. Uncertainties of real and reactive loads, real and reactive generations, bus voltages and SVC parameters are taken into account. All ac limits are considered. In the first stage, Kohonen self organizing map is developed to cluster the real and reactive loads at all the buses to reduce the input features, thus limiting the size of the network and reducing computational burden. In the second stage, combination of different non-linear membership functions is proposed to transform the input variables into fuzzy domains. Then a three-layered feed forward neural network with fuzzy input variables is developed to evaluate the loadability margin. The proposed methodology is applied to IEEE-30 bus and IEEE-118 bus systems [14].

Canizares ca and Faur Z.T. has presented a detailed steady state models with two flexible ac transmission system (facts) controllers, namely SVC and thyristor controlled series compensation (TCSCs), to study their effects on voltage collapse and instability phenomena in power systems. Based on results at the point of collapse, design strategies are proposed for these two controllers, so that their location, dimensions and controls can be optimally defined to increase system loadability [15].

Ping, H.S., et.al., presented a new solution method, the phasor simulation, a model of two-machine power system with Static Var Compensators (SVC) and power system stabilizers (PSS) is built. By this system model, the transient stability analysis of this two machine power system when single-phase fault and 3-phase fault is simulated. The result shows that the phasor solution method can reduce simulation time greatly of power grids ,and has good precision with the development of power grid and application of electronic converters, such as FACTS devices, the power systems are becoming more and more complicated.It also becomes more difficult to model and simulate power grid. Traditional quasi-stationary phase models can't be used for studying electromagnetic transient phenomena. On the other hand, the emtp models can be used to analyze the electromagnetic transient accurately. [16].

Gyugyi.L, used the method of dynamic var compensation of electric power systems, applying power electronics for reactive power generation and control. After an overview of the emergence and status of modern, solidstate var compensators in utility and industrial applications, the first part of the paper explains how dynamic var compensation increases transmittable power by providing voltage support, transient stability improvement, and power oscillation damping in electric power transmission systems. Subsequent sections describe the methods of reactive power generation and control using thyristor-controlled reactors, with fixed and thyristor- switched capacitors, or modern gate turn-off (GTO) power converters that can function without ac capacitors or reactors. The last part of the paper summarizes the control structure and operation to provide the desired characteristics and performance in power system applications [17].

Huang.M.G and Yan.P, investigated the effect of thyristor Controlled Series Capacitor (TCSC) and Static Var Compensator (SVC) on power system load curtailments. The research on TCSC and SVC is abundant, but most of them are on power system stability improvement. This paper proposes a new use of TCSC and SVC to reduce load curtailments. An algorithm of Optimal Power Flow (OPF) to reduce the load curtailment for installing TCSC/SVC in the system is proposed in this paper. Several examples are used to demonstrate the effect on load curtailment. The test results show that the effect of TCSC/SVC is significant. This paper also suggests some potential future research. Static Var Compensator (SVC) on power system load curtailments. The research on SVC is abundant, but most of them are on power system stability improvement. This paper proposes a new use of SVC to reduce load curtailments. An algorithm of Optimal Power Flow (OPF) to reduce the load curtailment for installing SVC in the system is proposed in this paper. Several examples are used to demonstrate the effect on load curtailment. The test results show that the effect of SVC is significant [18].

Haque, M.H., usually the transients energy function method is used to assess the stability of a power system without considering control devices but in modification of this method is discussed to determine the first-swing stability limit of a power system in the presence of a static VAR compensator (SVC). The effect of the SVC is carefully incorporated in determining the value of critical energy needed for system separation. The unstable equilibrium point at which the critical energy is to be evaluated is determined by considering that the SV C operates a t its full capacitive rating. A recent control strategy of SVC proposed to maximise the first-swing stability limit can justify the use of such an unstable e equilibrium point. The above technique of determining the first swing stability limit of a power system in the presence of a SVC is tested on both single and multi machine systems. The results obtained by the proposed technique are also compared with the corresponding actual values found through repetitive time-domain simulations of system dynamic equations [19].

CHAPTER 4

PROBLEM FORMULATION AND RESULTS

4.1 TWO MACHINE MODEL

A problem has been taken of two machine model consisting of two three bus model for analysis of transients stability using Matlab Simulation. To see effect the effect of the SVC in the system to stabilize the voltage wave form when the system subjected to three phase fault.

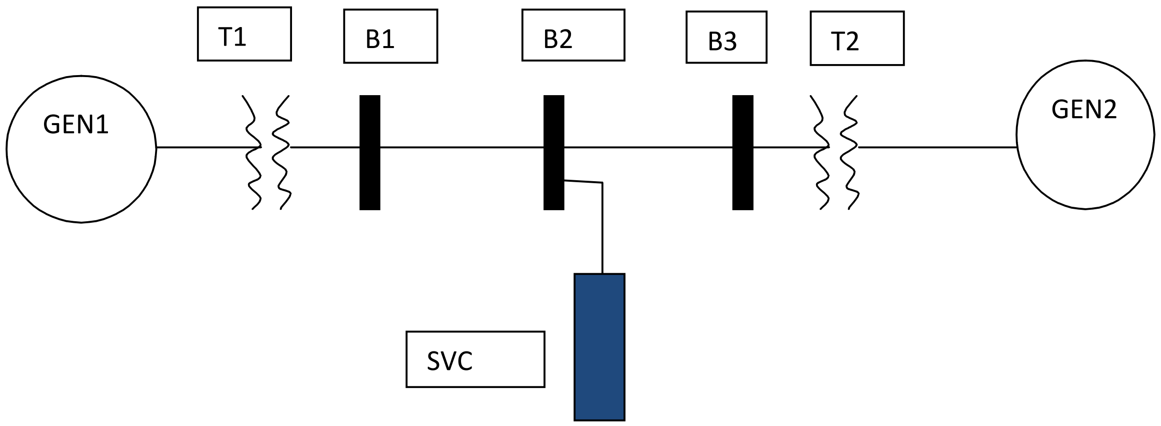

Fig 4.1 Single line diagram of Two Machine Model with SVC

The main parameter of the synchronous machine is reactance. The phasor solution method is mainly used to study electromechanical oscillations of power systems.

4.2 Rotor Angle Stability

Rotor angle stability is the stability of interconnected machines of a power system to remain in synchronism. The stability problem involves the study of electromechanical oscillations inherited in power systems. A fundamental factor in this problem is the manner in which the power outputs of synchronous machines vary as their rotors oscillate. When two or more synchronous machines are interconnected, the stator voltages and currents of all voltages of all machines must have the same frequency and the rotor mechanical speed of each is synchronized to this frequency. Therefore, the rotors of all synchronous interconnected machines must be in synchronism [1].

4.3 Power Versus Angle Relationship of Two Machine System

Power versus angle relationship is very important it is the relationship between interchange power and angular positions of rotor of synchronous machine. This relationship is highly non linear. The power transfer from generator to motor is a function of angular separation between rotors of two machines [1].

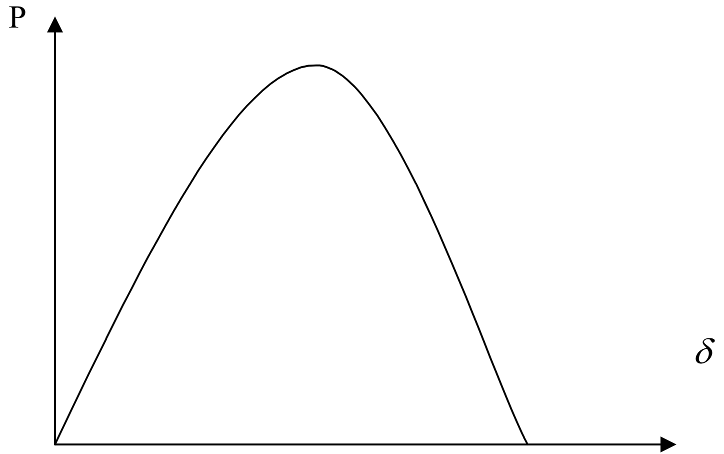

Fig 4.2 Power transfer characteristics of a two machine model

4.4 STATIC VAR SYSTEMS

A static var system is, as per CIGRE/IEEE definition, a combination of static compensators and mechanically-switched capacitors and reactors whose operation is coordinated. A static var system is thus not a well-defined compensating arrangement because it does not have a uniform *V-I* characteristic and its overall response time is greatly dependent on the mechanical switching devices used. The emphasis in a Static Var system is on coordination. The major objective is usually to ensure that the static compensator, having a well-defined *V-I* characteristic and fast speed of response, is available for dynamic compensation and other elements of the overall Var system handle the steady-state var demands. Another reason for coordination is to minimize the steady-state losses in the compensator and the overall power system. The var output coordination may follow different strategies With this arrangement, the availability of a specific amount of fast compensation capacity is enforced by an automatic control action, but the steady Var demand is left for unidentified "other means" in the power system (which may include generator voltage regulators, synchronous compensators (condensers), and mechanically switched capacitor and reactor banks activated by under- and over-voltage relays) to provide. An equally simple, but philosophically opposite, policy is to let the static compensator pick up the reactive compensation as required, but provide an alarm signal to the power system dispatcher if a specific Var output is exceeded. It is left to the dispatcher to determine whether the compensator should keep providing the compensation or other available means should be brought in operation. In a more rigorous coordination scheme, the compensator would control a number of dedicated capacitor and reactor banks within the overall Static Var system. That is, if the capacitive output of the compensator would exceed a preset level for specified time duration, then the compensator control would activate, in a predetermined sequence, the mechanically-switched capacitor banks until the output of the compensator is reduced below that level. Similarly, an excess in inductive var output would initiate the systematic disconnection of capacitor banks and, if required, actuate an appropriate number of mechanically-switched reactor banks. In providing automatic coordination, due attention must be paid to the capabilities of the mechanical switches with regard to the frequency of operation and, also, the limitation of possible surge currents. A microprocessor-based control is usually the most convenient for monitoring switch status, storing switching history, and effecting overall coordination according to established priorities and compensation policies.

SVC stabilizes voltage much faster than other devices as compared and its cost is also less as compared to the other equipment. Stabilize the system during the fault or during transients is very much important as the equipments are very much sensitive to voltage fluctuation, transients and faults. The synchronous generator forms principal source of energy. The generators are run by turbine and excited by the excitation system. As to meet the demand in today world reactive power compensation. The need of electricity is increasing which in turns into over loaded lines in the power system and results into instability. The main reason of the instability is the need of reactive power compensation.

4.5 Two machine Simulink Model

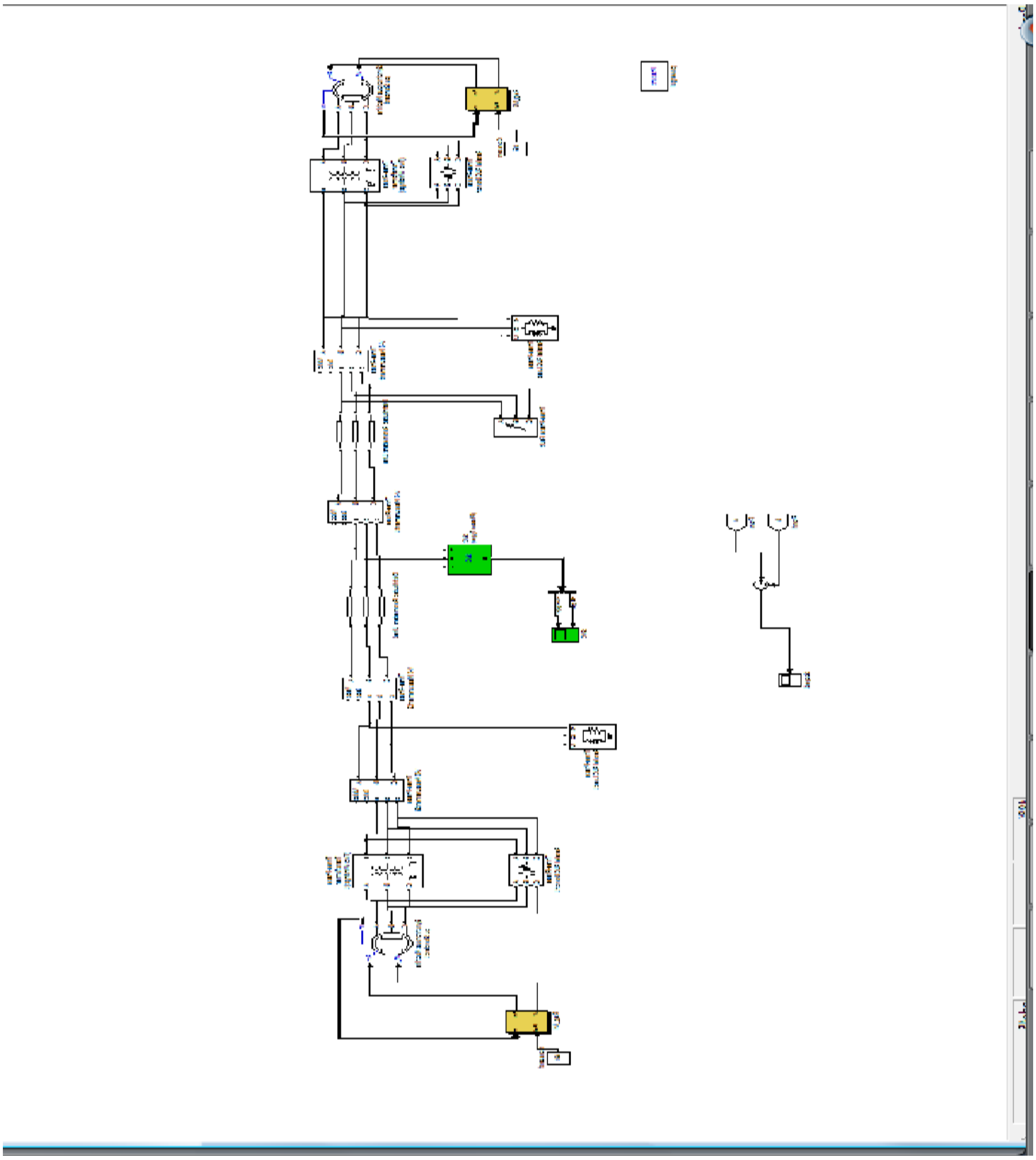

Fig. 4.3 Simulink Model of Two Machine model

Ratings of two machine model using synchronous machine and hydraulic turbine and excitation system. **Table 4.1 Generators Parameter**

Generators	Values
M_1	187MVA
M_2	500MVA
Xd	1.305pu
Xd'	0.296pu
Xd''	0.255pu
Xq	0.474pu
Xq''	0.243pu
$X1$	0.18pu

Table 4.2 Transmission Parameter

Trans mission line per km	Values
R_1	0.1755 ohm
R_0	0.2758 ohm
L_1	0.8737mH
L_0	3.22mH
C_1	13.33nF
C_0	8.297nF

Table 4.3 SVC parameter

SVC parameters	Values
V	500Kv
T_d	0.2758 ohm
V_{ref}	1.0
X_s	0.03
K_p	3
K_i	500

4.5 Results

Case1

When load 1 is 143MW and load 2 1485 MW Without svc

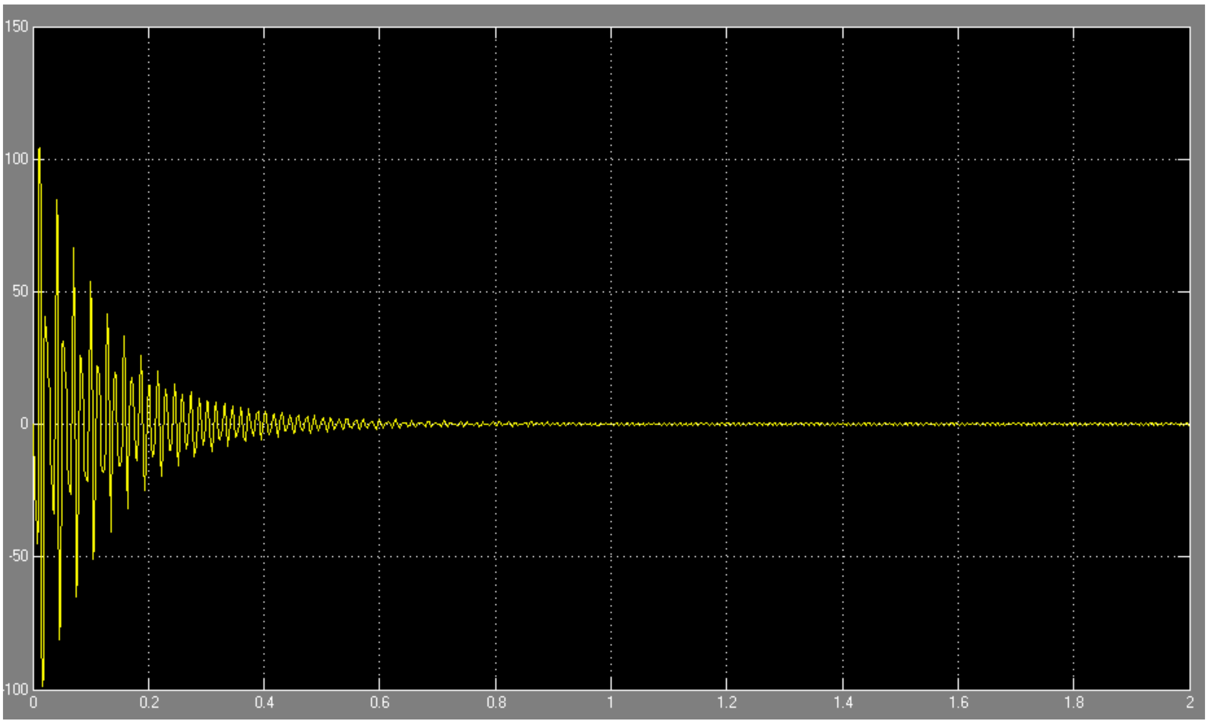

Fig 4.4 load angle differnce between generators during transients without SVC.

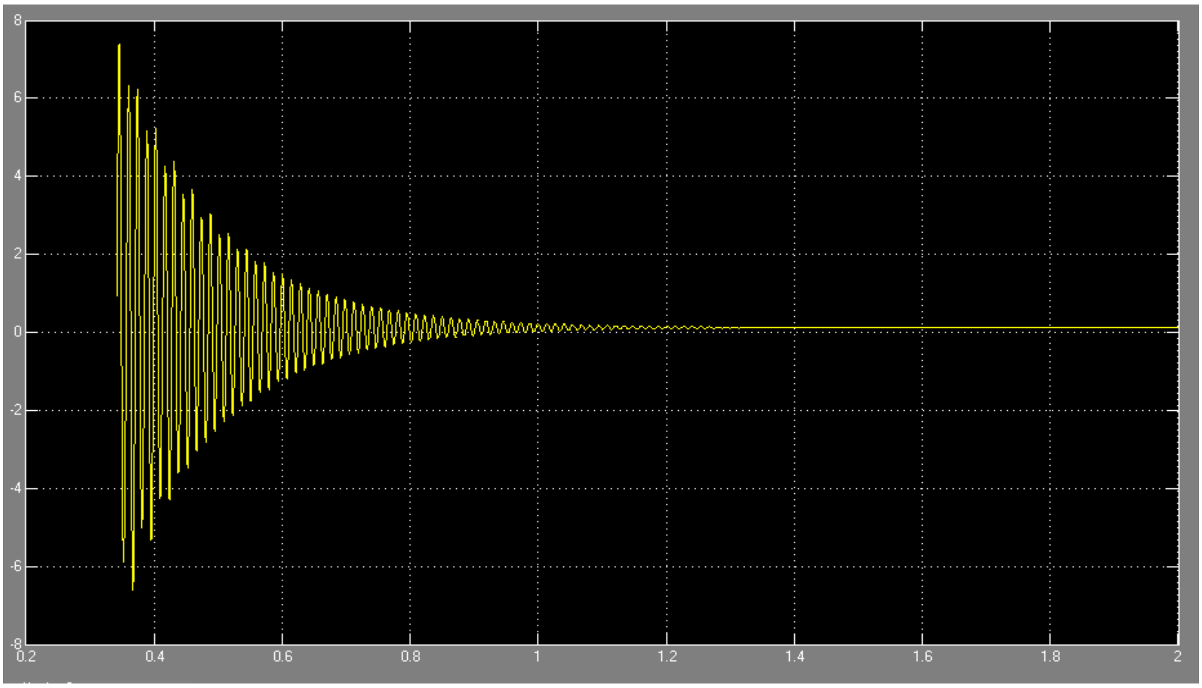

Fig 4.5 load angle differnce the between generators during transients with SVC.

Case 2

When load 1 is 200MW and Load 2 is 1485MW.

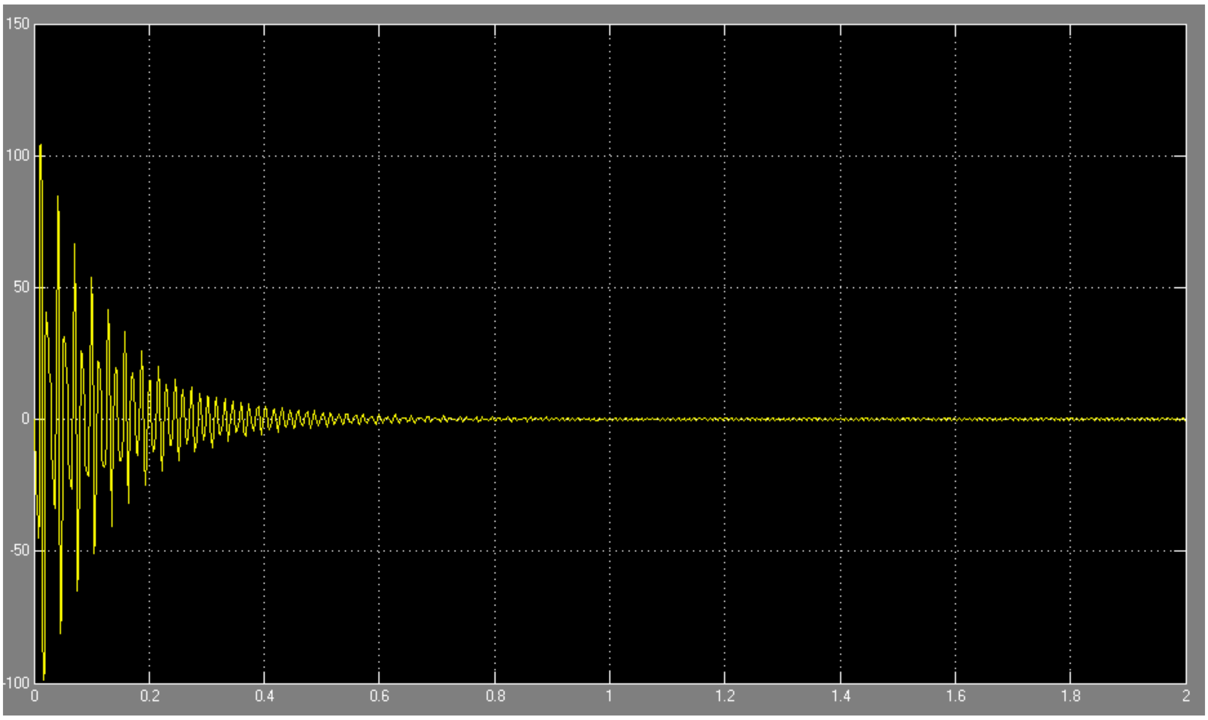

Fig 4.6 load angle differnce between generators during transients without SVC

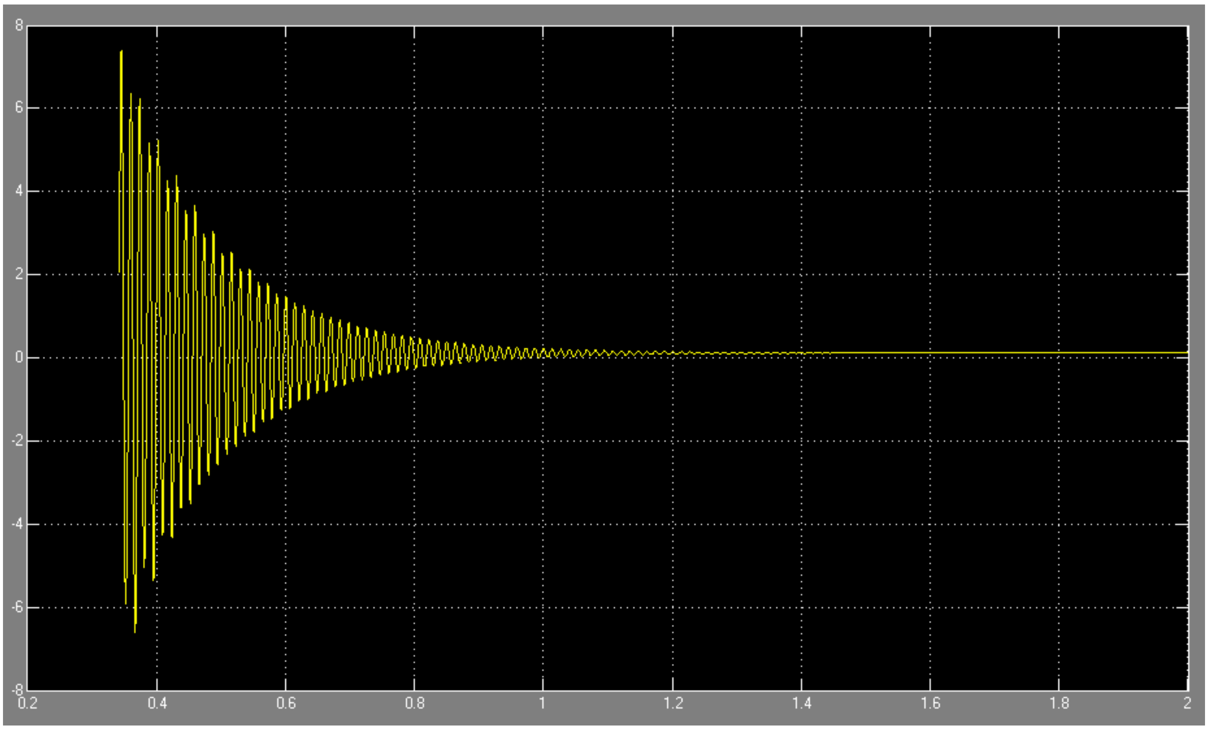

Fig.4.7 load angle differnce the between generators during transients with SVC

Case 3

When load 1 500MW and load 2 1485MW.

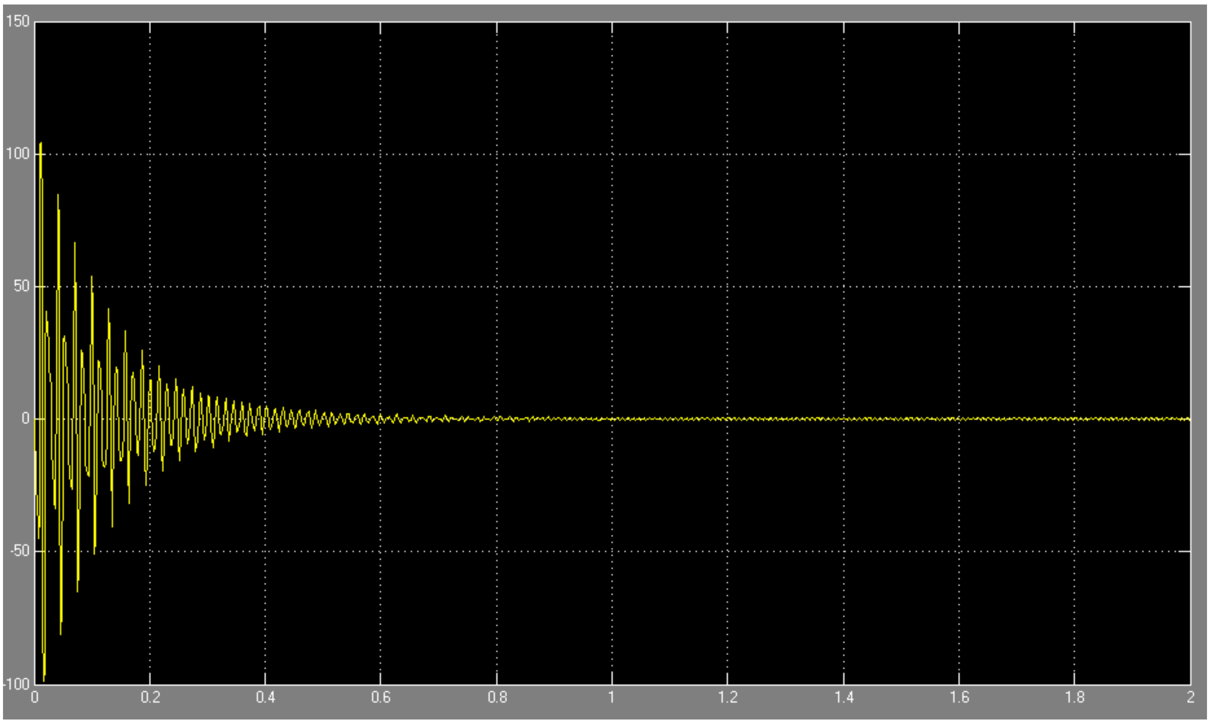

Fig 4.8 load angle differnce between generators during transients without SVC.

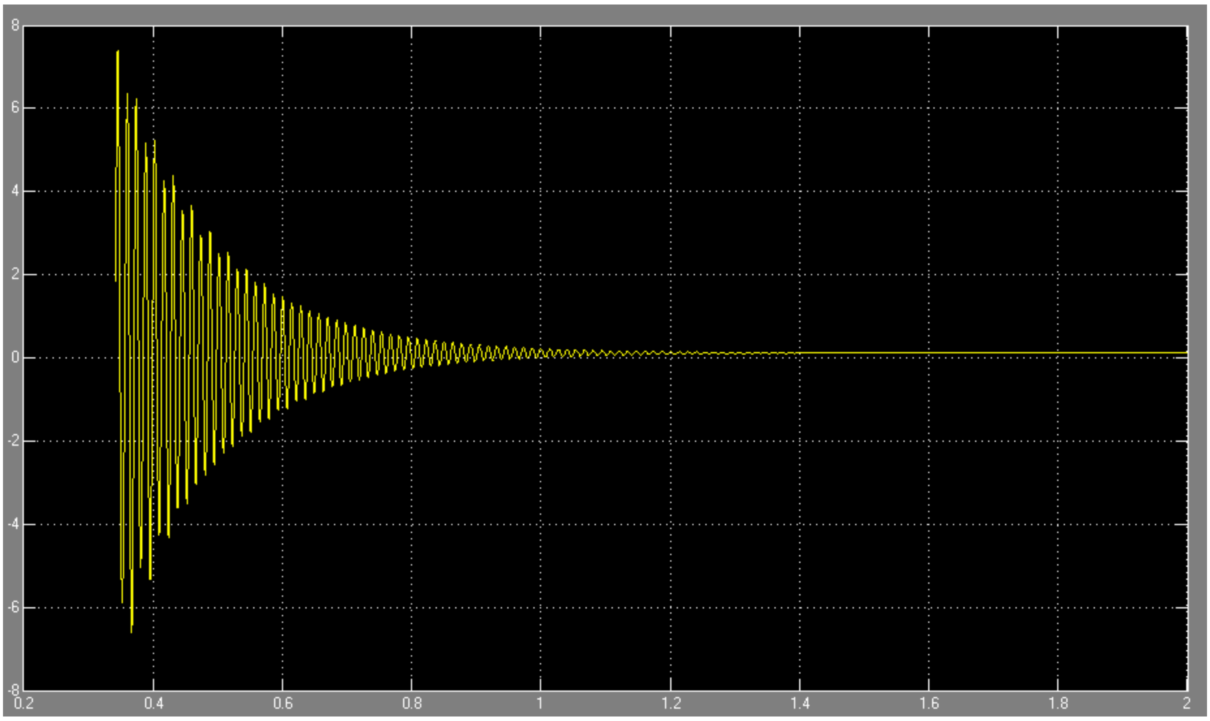

Fig 4.9 load angle differnce the between generators during transients with SVC.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

Power system is a network of electrical components which are used to generate , transmit and distribute electrical power with the expansion of power system network, complexity of the network is increasing rapidly. Due to restructuring in some countries competition among transmission among transmission and distribution companies is increased. The demand of good power quality along with additional load carrying capacity makes the use of compensating device necessary. In this thesis work a approach of FACTS devices is implemented for transients stability in power system and is better than other method and it is conclude that when the load increase suddenly on two machine system the transients appear. Fact devices are best way to improve the stability during the transients.

5.2 Future Scope

In this thesis work, FACTs device is used to improve transient's stability. Future of facts devices is brighter as its feature can be changed which makes it possible to use easily. Demand is keeping on increasing with time which makes the loaded heavily, results in deficiency of power, so only FACTS can improve these problem.

CHAPTER 6

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