ABSTRACT

The world has evolved very rapidly for the past few years. Huge developments have taken place in many countries. In order to support these progressive developments, a huge amount of energy is needed, in terms of electricity. Thus, the power system now-a-days, becomes more and more complicated and large, just to ensure enough energy for all activities. Due to this complexity, the power engineers would face problems like power system stability and power quality, among others. The demand of the electrical energy is ever increasing and it is desired to use the existing transmission network to its thermal stability limits. The transmission capacity can be increased by using certain compensation devices.

Both series capacitor and static VAR compensators can contribute to power systems voltage stabilities. Combining these two methods is the subject of this thesis. Effect of the presence of series capacitor on static VAR compensator controller parameters and ratings required to stabilize load voltages at certain values are highlighted. The interrelation between series compensation and the SVC controller gains and droop slopes and the SVC rating are found. For any large power system represented by its equivalent two nodes system, the power/voltage nose curves are found and their influences on the maximum power/critical voltage are studied.

This is the main aim of the thesis, effects of series capacitor alone forms the first part of this thesis, static VAR compensator (SVC) effects alone is given in another study. The influence of the series capacitor on compensator gains, reference voltage values and ratings are given in detail. The studied system represents any large system seen from the load node under consideration.

Static VAR compensator rating and controller references and gains are found in order to stabilize load voltage at certain specified values. Interrelation between these two means parameters are highlighted.

CHAPTER-1 INTRODUCTION

1.1 BACKGROUND

During the past two decades, the increase in electrical energy demand has presented higher requirements from the power industry. More power plants, substations, and transmission lines need to be constructed. The long switching periods and discrete operation of circuit breaker make it difficult to handle the frequently changed loads and the system from dynamic variation and recover from faults and damp out the transient oscillations quickly. In order to compensate this, large operational margins and redundancies are maintained. This not only increases the cost, but also increases the complexity of the system.

Therefore, it is necessary to study the security and stability of the power system. The reactive power compensation is used to increase the stability and the security of the power systems.

The Reactive power compensation plays an important role in the planning of a power system. This ensures a satisfactory voltage profile and a reduction in power and energy losses within the system. Reactive power also maximizes the real power transmission capability of transmission lines, while minimizing the cost of compensation.

The increase of real power transmission in a particular system is restricted by a certain critical voltage level. This critical voltage is dependent on the reactive power support available in the system. Use of series and shunt compensation is one of the corrective measures to produce an acceptable voltage profile, minimize the loss of the investments and enhance the power transmission capability.

The focus of this thesis and research is on the application of Static VAR Compensator with series capacitor to solve voltage regulation and power transfer capabilities. SVC is a mature thyristor based controller that provides rapid voltage control to support electric power transmission voltages during and immediately after major system disturbances. Since the advent of deregulation and the separation of generation and transmission systems in the electric power industry, voltage stability and reactive power-related system restrictions have become an increasingly growing concern for electric utilities. With deregulation came an "open access" rule to accommodate competition that requires utilities to accept generation and load sources at any location in the existing transmission system. This "open access" structure has challenged transmission owners to continually maintain system security, while at the same time trying to minimize costly power flow congestion in transmission corridors. When voltage security or congestion problems are observed during the planning study process, cost effective solutions must be considered for such problems. Traditional solutions to congestion and voltage security problems were to install new costly transmission lines that are often faced with public resistance, or mechanically-switched capacitor banks that have limited benefits for dynamic performance due to switching time and frequency. One approach to solving this problem is the application of "Flexible AC transmission System" (FACTS) technologies, such as the Static VAR Compensator (SVC). FACTS technologies are founded on the rapid control response of thyristor-based reactive power controls. Over the last several years, there were numerous installations of FACTS in the United States and around the world. FACTS have proven to be environmental friendly and cost effective solutions to a wide range of the power system needs. FACTS have given utilities the option to delay new transmission line construction by increasing capacity on existing lines and compensation of the system voltages.

1.2 LITERATURE REVIEW

Static VAR compensators, regarded as the first FACTS controllers, have been used in North American transmission systems since late 1977 in western Nebraska [1]. The aforementioned transmission SVC device was installed to provide "automatic, continuous voltage control". Since then, there have been about 300 transmission SVCs commissioned around the world, and about 90 transmission SVCs applied in North America [2]. The term "transmission system SVC" is used because SVCs are also applied at the distribution level to compensate for local voltage fluctuation problems due to industrial load operation [3]. The heart of the SVC is an a.c. power semi-conductor switch commonly known as the "thyristor valve" that is used in principle to replace mechanical switches to achieve rapid, repetitive, and in some cases continuous control of the effective shunt susceptance at a specific location in a transmission system by a set of inductors and capacitors [4]. For example, as shown in Figure 1-3, the fixed capacitor (FC) in parallel with a thyristor-controlled reactor (TCR), the valve continuously and "smoothly" controls the reactor to achieve a "net susceptance" that is varied to maintain the transmission system voltage to a desired value or range. The SVC configuration described in this example is known as FC/TCR. The overall steady-state characteristics of the SVC are described in the form of a volt current (VI) Curve, as illustrated in [5] [6] [7]. An automatic voltage regulator with a transfer function of [K * 1/ (1+sTp)] is often used.

Series capacitors (SC) are widely used in ultra-high voltage networks in order to compensate for the series reactance of the long lines [8-15]. Recently, they are being used in distribution networks in Japan. Moreover, they are proposed to be used in arc-furnaces feeding networks to increase production [12-14]. They are often the best and most economical solution to voltage fluctuations at welding machines terminals [8]. This arrangement enables the condenser to absorb a larger share of the reactive variations of the load powers. SC may allow low frequency harmonics to flow in the system following load changes. When an SC is used to partially cancel the inductive reactance of any circuit at system frequency, there will be an electrical natural frequency at something less than the system frequency, this is called subharmonic or subsynchronous frequency [11,16]. The SC is usually protected by shunt spark gaps. The rapid load changes can cause the subsynchronous (subharmonic) currents to build up until the protective gap across the series capacitor sparks over [11], taking the capacitor out of the circuit. If the capacitor is not automatically reinserted, the gap probably will spark over again during the period of rapid load changes, aggravating the flicker problem for the utility [16]. The currents can be neglected if the system has positive damping. If the system does not have sufficient loss to provide adequate positive damping of the subsynchronous transients, damping can be added by installing a resistor in parallel with the SC. However, resistor losses make the method uneconomical.

Shenghu Li, Ming Ding, Jingjing Wang, Wei Zhang, presented the work on Voltage control capability of SVC with var dispatch and slope setting [19]. In this paper, a sensitivity model for var dispatch is proposed to restore the var reserve of SVC while keeping desirable voltage profile, and the control capability of SVCs is defined by the available control margin, the slopes, the reference voltage, the static voltage characteristic of the system. The susceptance increment for expected compensation is found to define the critical SVC possibly violating the control limit, and coordinate outputs of SVCs at different locations.

Y. Wang, H. Chen, R. Zhou, presented the work on A nonlinear controller design for SVC to improve power system voltage stability [20]. This paper discusses a nonlinear controller design for Static Var Compensator (SVC) system. Direct feedback linearization (DFL) technique is employed to design a nonlinear controller. The effectiveness of the controller on voltage stability enhancement is studied on a three-bus power system through time simulation and bifurcation analysis. The results show that the collapse time is put off and the subcritical Hopf bifurcation is greatly affected by the controller. The performance of the controller is further compared with that of the conventional capacitor switching. It is found that in some cases the conventional control scheme cannot prevent voltage collapse while the nonlinear SVC control can stabilize the system. The results show that the proposed controller is effective in voltage stability enhancement.

C.S. Chang, J.S. Huang, presented the work on Optimal SVC placement for voltage stability reinforcement [21]. In this paper scheme of hybrid optimization using the simulated annealing and Lagrange multiplier techniques for optimal SVC planning and voltage stability enhancement is presented. It also proposes a 4-step procedure for synthesizing the optimal reactive reinforcement. The hybrid optimization is formulated into a constrained problem with non-differentiable objective function in both continuous and discrete variables. By decomposing the optimization into two sub problems, an optimal SVC placement is obtained and the reactive margin is maximized.

P.K. Modi, S.P. Singh, J.D. Sharma, presented the work on Fuzzy neural network based voltage stability evaluation of power systems with SVC[22]. 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.

M. Z. El-Sadek, G. A. Mahmoud, M. M. Dessouky, W. I. Rashed, presented the work on Effect of control systems on compensators rating needed for voltage stability enhancement[23]. In this paper effect of the presence of control systems in reducing the sizes of the ratings of such compensators is presented. The cost of the control systems of the controlled static VAR capacitive compensators, thyristor switched capacitor banks (TSC) can be balanced by the saving in their ratings, in large systems applications.

Perez, M.A. ; Messina, A.R. ; Fuerte-Esquivel, C.R, presented the work on Application of FACTS devices to improve steady state voltage stability[24]. In this paper the coordinated application of flexible AC transmission systems (FACTS) technology to extend steady-state voltage stability margins in electric power systems is discussed. A systematic analytical methodology based on the concept of modal analysis of the modified load flow equations and the study of controllability and observability characteristics of the equivalent state model is used to identify system areas prone to voltage instability, as well as to determine the most effective locations for placement of FACTS controllers. Results obtained using a practical system representative of the Central American interconnected network is presented illustrating the application of FACTS technology.

M.Z. El-Sadek, et al, discussed the Enhancement of steady-state voltage stability by using static VAR compensators [25]. Steady-state voltage instability can certainly be enhanced by static VAR compensators which can hold certain node voltages constant and create infinite buses within the system nodes. Static VAR compensator parameters needed for this purpose are found. Controller gains droop slopes, reference voltages and compensator ratings are determined for maintaining the load node voltages constant irrespective of system load abilities to values which lead to voltage instabilities. Influence of system equivalent impedances on these parameters is finally discussed.

Mark Ndubuka NWOHU, discussed the Voltage Stability Improvement using Static VAR Compensator in Power Systems [26]. They investigate the effects of Static VAR Compensator (SVC) on voltage stability of a power system. The functional structure for SVC built with a Thyristor Controlled Reactor (TCR) and its model are described. The model is based on representing the controller as variable impedance that changes with the firing angle of the TCR.

Dr. N Kumar, Dr. A Kumar, P.R. Sharma, discussed the Determination of optimal amount of location of series compensation and SVC for an AC Transmission System [27]. They have determined the optimal location of series compensation and SVC for a given transmission system, for this they have developed generalized expression for maximum receiving and power, compensation efficiency and optimal value of series compensation have been developed in terms of line constants and capacitive reactance used for different schemes of series compensation. On the basis of steady-state performance analysis, they have determined that in the compensation scheme the series compensation and SVC are located at the midpoint of the transmission line and yielded maximum receiving end power and maximum compensation efficiency.

M.Z. El-Sadek, et al, presented the work on Series capacitor combined with static VAR compensator for enhancement of steady-state voltage stability [28]. They discussed the nonlinear dynamic controller for a combination of static series capacitor compensation and power system stabilizer, for enhancement of both voltage and transient stability of power system. The proposed controller implements speed deviation signal and generator terminal current deviation signal. The proposed Scheme is validated using a sample single machine infinite bus power system loaded by a frequency dependent voltage dependent nonlinear dynamic load type.

1.3 OBJECTIVE OF WORK

This study is devoted to the application of these Series Capacitor (SC) for voltage stability enhancement. Combination of such devices with static VAR compensators (SVC) [12, 13, 17,18] is proposed. The influence of series compensation on compensator gains, reference voltage values and ratings are given in detail. The studied system represents any large system seen from the load node under consideration.

CHAPTER-2 VOLTAGE STABILITY IN POWER SYSTEM

2.1 INTRODUCTION

Voltage stability is a problem in power system which is lack of reactive power support when heavily loaded or the network transfer capability is reduced due to disturbances. The problem of voltage stability concerns the whole power system, although it usually has a large involvement in one critical area of the power system.

This chapter describes some basic concepts of voltage stability. First voltage stability, voltage instability and voltage collapse are defined. Infinite-bus system is introduced to present PV curve and maximum power transfer.

2.2 CONCEPT AND CLASSIFICATION OF VOLTAGE STABILITY

Beside rotor angle stability, or transient stability, power system stability also concerns to voltage stability. In [29], the voltage stability is defined as follows: "The **voltage stability** is the ability of a power system to maintain steady acceptable voltages at all buses in the system at normal operating conditions and after being subjected to a disturbance."

According to [30] the definition of **voltage instability** is "Voltage instability stems from the attempt of load dynamics to restore power consumption beyond the capability of the combined transmission and generation system."

Voltage instability may, or may not lead to **voltage collapse**, which is defined by [30] as the catastrophic result of a sequence of events leading to a low-voltage profile suddenly in a major part of the power system. 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 equipment's like tap changing transformers, generator current limiters. The study period of interest extends to several minutes [29].

2.3 CLASSIFICATION OF POWER SYSTEM STABILITY

For good understanding of the stability problem we have to classify the power system stability in more detailed way, not only by dividing it in to rotor angle stability and voltage stability. The subsequent classification is based on time scale and driving force criteria. Time scale is divided into short-term and long-term durations, and the driving forces for instability are generator-driven and load-driven.

TABLE 2.1 CLASSIFICATION OF POWER SYSTEM STABILIY

Time Scale	*Generator-driven*		*load-driven*	
Short-term	rotor angle stability		short-term voltage stability	
	small-signal	transient		
Long-term	frequency stability		long-term voltage stability	
			small disturbance	large disturbance

The rotor angle stability is divided into small signal and transient stability and is generator-driven. Small signal stability is the ability of power system to maintain the synchronism under small disturbances in the form of undamped eletromechanical oscillations [31]. Such disturbances occur continually on the power system because of small variation in load and generation. The transient stability is due to lack of synchronizing torque and is initiated by a large disturbance. The resulting system response involves large swings of generator rotor angles and is influenced by a non-linear power-angle relationship [32]. The time frame of rotor angle stability is called short- term time scale, because the dynamics typically last for a few seconds [31].

The voltage stability is divided into short-term and long-term voltage stability and it is load-driven. The distinction between long and short-term voltage stability is according to the time scale of load component dynamics. Short term voltage stability is characterized by components like induction motors, excitation of synchronous generators and devices like high voltage direct current (HVDC) or static var compensators. The time scale of short-term voltage stability is the same as rotor-angle stability. The distinction between these two phenomena is sometimes difficult, because voltage stability does not always occur in its pure form and it goes hand to hand with rotor-angle stability [31]. However, the distinction between these two stabilities is necessary for understanding of the underlying causes of the problem in order to develop appropriate designs and operating procedures [33].

The system enters the slower time frames after the short-terms dynamics has come to end. The duration of long-term dynamics is up to several minutes. In long-term consideration we have two types of stability problem as it is shown in table 2.1. First of it is frequency stability, this problem appears after a major disturbance resulting in power system islanding [32]. This form of instability is related to active power imbalance between generators and loads.

The long-term voltage stability is divided into small-disturbance and large disturbance. Large-disturbance voltage stability analyses the response of power system to a large disturbance, like for example faults, loss of load or loss of generation [32]. The ability to control voltages following large disturbance is determined by the system load characteristic and the interactions of both continuous and discrete controls and protections [32].

Small-disturbance voltage stability considers the power system's ability to control voltages after small disturbances like for instance changes in load [31]. It is determined by load characteristics, continuous and discrete controls at a given instant of time [32]. The analysis of small-disturbance voltage stability can be done in steady state by static methods like for examples load-flow programs. However, voltage stability is a single problem on which a combination of both linear and non-linear tools can be used [31].

2.4 ANALYSIS OF POWER SYSTEM VOLTAGE STABILITY

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 cosφ. The line impedance is Z=R+ j X.

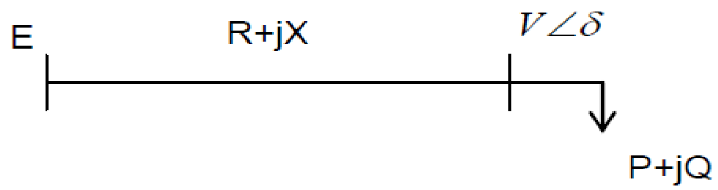

Fig 2.1 Single load, infinite-bus system

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

$$\frac{\underline{V}^*.(\underline{E}-\underline{V})}{\underline{Z}} = \underline{S}^* \tag{2.1}$$

Where, $\underline{E}$ is the voltage at the infinite bus, $\underline{E}$ = E

$\underline{V}$ is the voltage at the load, $\underline{V}$ = V∟ δ

$\underline{S}$ is the load power demand, $\underline{S}$ = P+ j Q

$\underline{Z}$ is the line impedance, $\underline{Z}$ = R+ j X

Solving equation 2.1 for the load voltage by eliminating the voltage angle, if assuming lossless line, or R=0 it is obtained as follows:

$$V = \sqrt{\frac{E^2}{2} - QX \pm \sqrt{\frac{E^2}{4} - X^2P^2 - XE^2Q}} \tag{2.2}$$

The solutions of load voltages are often presented as a PV-curve as show in figure 2.2.

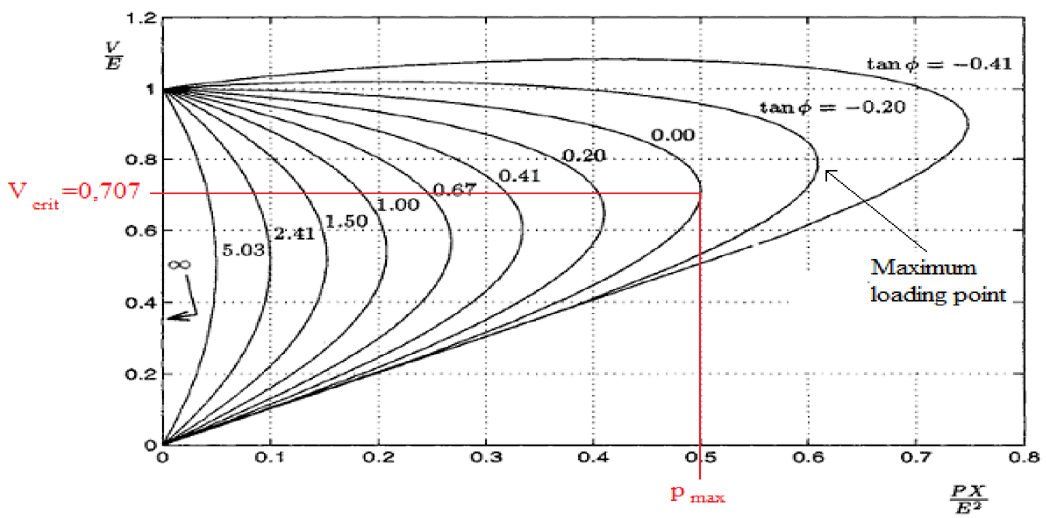

Figure 2.2 Normalized PV-curves for different power factor

The PV curve presents load voltage as a function of load or a sum of loads. Power systems are operated in the upper part of the PV curve. This part of the PV curve is statically and dynamically stable. The head of the curve is called maximum loading point. The critical point is called the voltage collapse point. The maximum loading point is more interesting from the practical point of view than the true voltage collapse point, because the maximum of power system loading is achieved at this point [31]. The maximum loading point is the voltage collapse when constant power loads are considered, but in general they are different. The voltage dependence of loads affects the voltage collapse point. Voltages decrease rapidly due to requirement for an infinite amount of reactive power [31]. The power system becomes unstable at the voltage collapse point. Power flow programs can only compute the upper part of the curve up to voltage collapse point, because at the lower part of the curve they cannot find a solution. The iteration process is divergent below the voltage collapse point. Thus the whole computation in this project will be finished at voltage collapse point.

As the load is more and more compensated, which corresponds to smaller $\tan\varphi$, maximum power increases and voltage increases as well. This situation is dangerous, because the maximum transfer capability may be reached at voltages close to normal operation values [34]. For overcompensated loads $\tan\varphi < 0$, there is a portion of the upper PV curve along which the voltage increases with the load power [34].

Figure 2.2 presents PV curves for the system. These curves represent different load compensation cases ($\tan\varphi = Q/P$). Since inductive line losses make it inefficient to supply a large amount of reactive power over long transmission lines, the reactive power loads must be supported locally [31]. According to Figure 2.2 addition of the load compensation (decrement of the value of $\tan\varphi$) is beneficial for the power system. The load compensation makes it possible to increase the loading of the power system according to voltage stability. Thus, the monitoring of power system security becomes more complicated because critical voltage might be close to voltages of normal operation range [31].

The opportunity to increase power system loading by load and line compensation is valuable nowadays. Compensation investments are usually less expensive and more environmental friendly than line investments. Furthermore, construction of new line has become time-consuming if not even impossible in some cases [31]. At the same time new generation plants are being constructed farther away from loads centers, fossil-fired power plants are being shut down in the cities and more electricity is being exported and imported. This trend inevitably requires addition of transmission capacity in the long run [31].

CHAPTER-3 FACTS CONTROLLERS FOR POWER SYSTEM

3.1 INTRODUCTION

The collective acronym FACTS has been adopted in recent years to describe a wide range of controllers, many of them incorporating large power electronic converters, which may, at present or in the future, used to increase the flexibility of power systems and thus make them more controllable [35].

Large interconnected systems develop too heavy loaded systems, especially if new lines cannot be built because of lack of right-of-ways. Further, the location for new generation is often far away from the load and the system takes over also the task of transmitting power over longer distances. Due to the deregulation in electric power industry the requirements arise to transmit the power through given corridors. In some countries with remote power sources main problems result from requirement to transmit power over long distances through weak system leading to insufficient power quality. Problems resulting from above mentioned development may be at least partly economically improved by the use of Flexible AC Transmission System FACTS controllers [35].

FACTS have been defined as "alternating current transmission systems incorporating electronic-based and other static controllers to enhance controllability and increase power transfer capability" [35].

The fast development of power electronic in last two decades made it possible to design power electronic equipment of high rating for high voltage systems. Due to the fast control abilities of this equipment the operating conditions can be controlled in the system. This equipment are known as FACTS-Controller. The development of turn off devices e.g. GTO, IGTB, MCT for larger ratings opens a new possibility to build new more improved and sophisticated FACTS controllers [35].

FACTS controllers generally fall into two families: one comprises mainly the conventional thyristor-controlled SVC, TCSC and phase shifter, the other the converter based STATCOM, static synchronous series compensator [SSSC], unified power flow controller [UPFC] and interline power flow controller [IPFC]. Although presently a large number of SVC installations exist, the converter based FACTS controllers like STATCOM clearly represent the future trend due to their superior performance and to their greater functional operating flexibility (which will be shown in following chapters) [36].

FACTS technology crates the following opportunities [35]:

- Control of power so that the desired amount of flows through the prescribed routes. This could be in the context of ownership, contract path, or to shift power away from overloaded lines.
- Secure loading of transmission lines near their steady state, short time and dynamic limits. Various contingency conditions can be accommodated to enhance the value off assets.
- Reduced generation and reserve margins through enhanced, secure transmission interconnections for emergency power with neighbouring utilities.
- Contain cascading outages by limiting the impact of multiple faults leading to major blackouts.
- Undertake and effectively utilize upgrading of transmission lines by increasing voltage and/or current ratings. In a gross sense, the concept of building a higher voltage grid for accommodating future load growth is now modified in that, current upgrading is also a valid alternative.

3.2 IMPACT OF CONTROLLER LOCATION

The shunt device operates by change of voltage and has its maximum impact on power flow if located at the point of the transmission line where voltage is weakest. The location of the equipment has a significant impact on power flow control performance. Therefore, the best place for compensation in radial lines is the end of the line, where is the biggest variation of load. If we consider line which connects two system buses, the best place for compensation is the middle of the line.

3.3 STATIC VAR COMPENSATOR (SVC)

Static var compensators are shunt-connected static generators or/and absorbers whose outputs are varied so as to control specific parameters of an electric power system. SVCs overcome the limitation of mechanically switched shunt capacitors or reactors. Advantages include fast, precise regulation of voltage and unrestricted, transient free capacitor switching. The basic elements of SVCs are capacitor banks or reactors in series with a bidirectional thyristors [32].

Basic types of SVCs:

- Saturated reactor (SR)
- Thyristor-controlled reactor (TCR)
- Thyristor-switched capacitor (TSC)
- Thyristor-switched reactor (TSR)
- Thyristor control transformer (TCT)
- Self- or line-commutated converter (SCC/LCC)

3.3.1 The Thyristor-Controlled reactor (TCR)

An elementary single-phase thyristor-controlled reactor TCR consists of fixed reactor of inductance L, and a bidirectional thyristor valve [36].

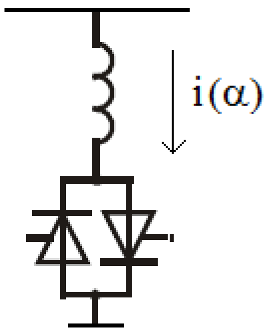

Figure 3.1 thyristor-controlled reactor

The thyristor conducts on alternate half cycles of the supply frequency depending on the firing angle α. The magnitude of the current in the reactor can be varied continuously by this method of delay angle control form maximum (α=0) to zero at (α=90), as illustrated in the Figure 3.2. The adjustment of current in the reactor can take place only once in each half cycle, in the zero to 90^0 interval. This restriction results in a delay of attainable current control. The worst case delay, when changing the current from maximum to zero, is a half cycle of the applied voltage [36].

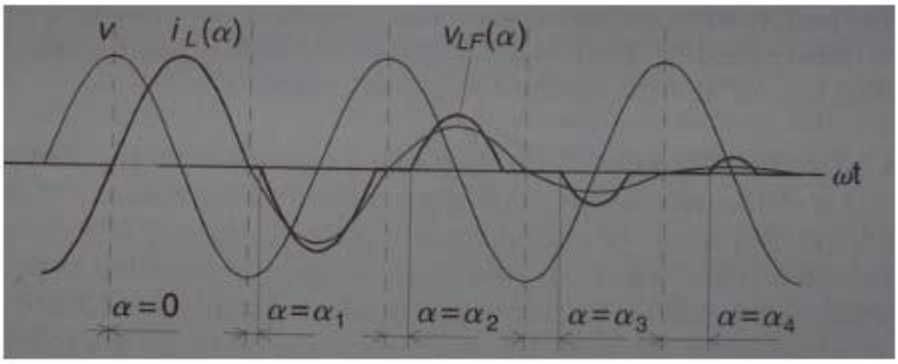

Fig 3.2 TCR operating waveforms

The amplitude $I_L(\alpha)$ of the fundamental reactor current $i_L(\alpha)$ can be expressed as a function of angle α [36]:

$$I_L(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2}{\Pi}\alpha - \frac{1}{\Pi}\sin 2\alpha\right)$$

Where V is the amplitude of the applied ac voltage, L is the inductance of the thyristor-controlled reactor, and ω is the angular frequency of the applied voltage. It is clear that the TCR can control the fundamental current continuously from zero (valve open) to a maximum (valve closed) as if it was a variable reactive admittance. Thus, an effective admittance, $B_L(\alpha)$, can be defined as [36]:

$$B_L(\alpha) = \frac{1}{\omega L}\left(1 - \frac{2}{\Pi}\alpha - \frac{1}{\Pi}\sin 2\alpha\right)$$

As we can see the admittance varies in the same manner as fundamental current. At each delay angle α an effective admittance can be defined which determines the magnitude of an effective current in the TCR at a given applied voltage. The magnitude of the applied voltage, thus the magnitude of corresponding current as well, will be limited by the ratings of the power components used. Therefore, a TCR can be operated anywhere in the defined V-I area, the boundaries of which are determined by its maximum attainable admittance, voltage and current ratings [36].

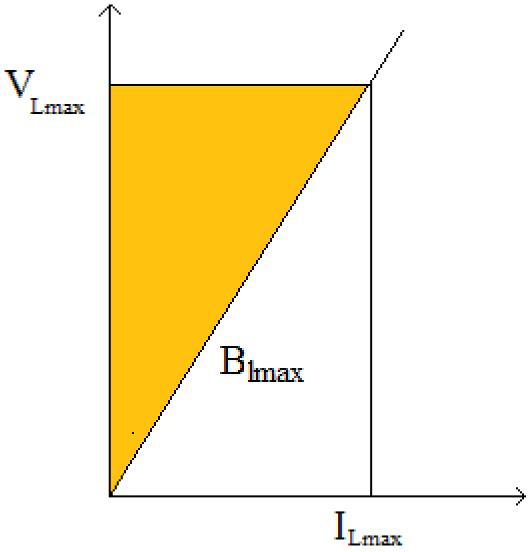

Figure 3.3 Operating V-I area of TCR

If the TCR switching is restricted just to a fixed delay angle α=0, then it becomes a thyristor-switched reactor TSR, which provides a fixed inductive admittance. Several TSRs can provide a reactive admittance controllable in a step-like manner.

The problem in using TCR is that as α is increased from 0^{0} to 90^{0}, the current waveform becomes less and less sinusoidal, thus the TCR generate harmonics. For identical positive and negative current half-cycles, only odd harmonics are generated [36]. For the three-phase system, the preferred arrangement is to have the three single phase TCR elements connected in delta (Fig.3.4). Thus for balanced conditions, all triple harmonics circulate within the closed delta and are therefore absent from the line currents. Elimination of 5th and 7th harmonics can be achieved by using two 6-pulse TCRs of equal ratings, fed from two secondary windings of step down transformer, one connected in Y and the other connected in delta as shown in Figure 3.5.Since the voltages applied to TCRs have phase difference of 30^{0}, 5th and 7th harmonics are eliminated from the primary-side current. With 12-pulse scheme, the lowest-order harmonics are 11th and 13th. These can be filtered with simple bank capacitor [32].

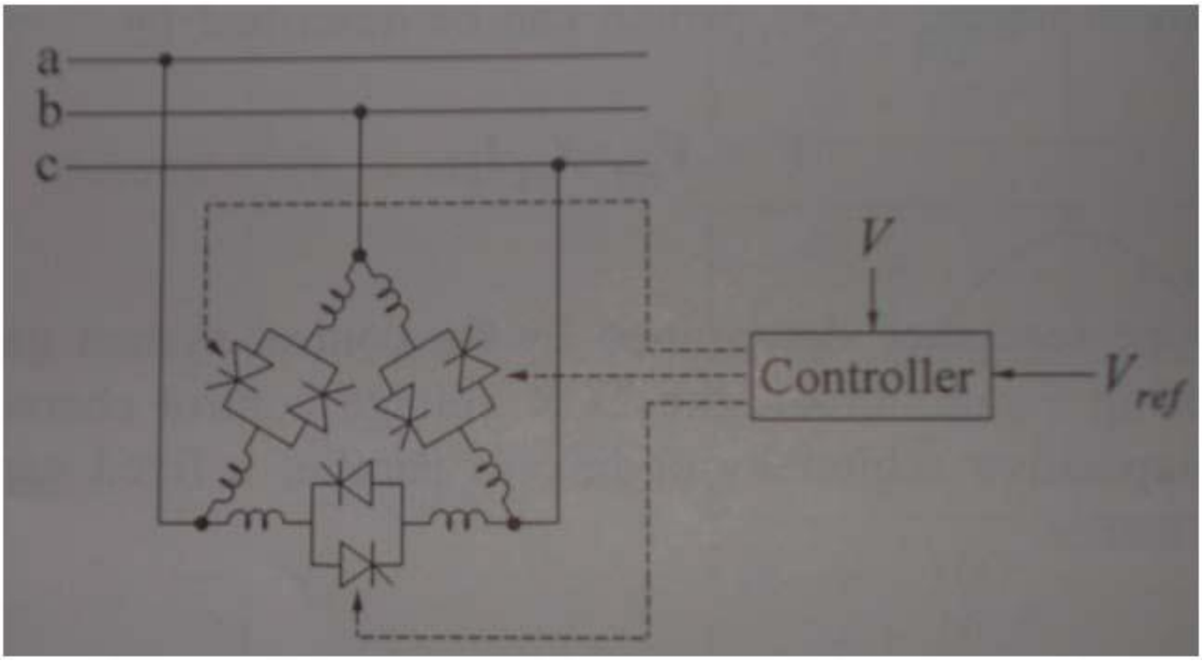

Figure 3.4 6-pulse TCR

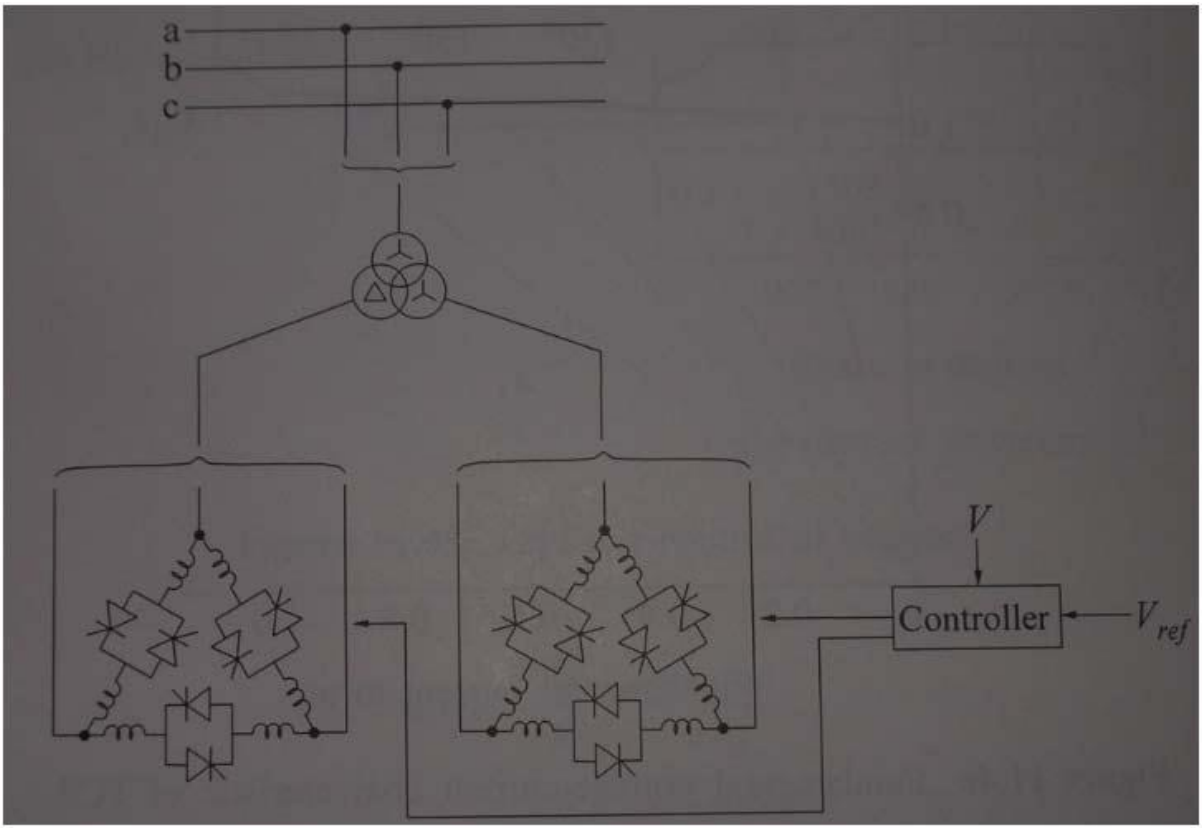

Figure 3.5 12-pulse TCR

3.3.2 Thyristor-switched capacitor (TSC)

A thyristor-switched capacitor scheme consists of a capacitor bank split up into appropriately sized units, each of which switched on or off by using thyristors switches [32]. Single phase consists of a capacitor, a bidirectional thyristor valve and a small inductor as shown in Figure 3.6. This reactor is needed to reduce switching transients, to dump inrush currents and it also is preventing from the resonance with network [36].

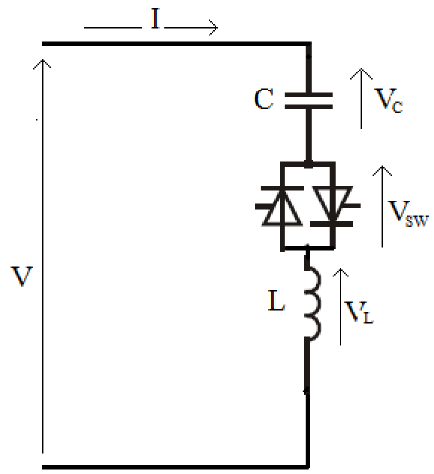

Figure 3.6 Single Phase TSC

When the thyristor valve is closed and the TSC is connected to a sinusoidal ac voltage source v=Vsinωt, the current in the brunch is given by [36]:

$$i(\omega t) = V \frac{n^2}{n^2 - 1} \omega C \cos \omega t$$

$$where$$

$$n = \frac{1}{\sqrt{\omega^2 LC}} = \sqrt{\frac{X_C}{X_L}}$$

The switching off capacitors excites transients which may be large or small depending on the resonant frequency of the capacitors with the external system. The disconnected capacitor stays charged, so the voltage across the non-conducting thyristor valve varies between zero and peak to peak value of the applied ac voltage. When the capacitors voltage remains unchanged, the TSC bank can be switched in again, without any transient, at the appropriate peak voltage of the applied voltage. For positively charged capacitor the switching in is at positive peak of applied voltage, for negatively charged capacitor switching in is at negative peak of applied voltage. Usually, the capacitor bank is discharged after disconnection, therefore the reconnection can be done at some residual capacitor voltage [36].

The transient free conditions can be summarized as two simple rules. One, if the residual capacitor voltage is lower than the peak ac voltage, then the correct instant of switching is when the instantaneous ac voltage becomes equal to the capacitor voltage. Two, if the residual voltage of the capacitor is higher or equal to the peak ac voltage, then the correct switching is at the peak of ac voltage at which the thyristor valve voltage is minimum[36].

Due to the fact that the capacitor switching must take place at the specific instant in each cycle, a TSC branch can provide only a step-like change in the reactive current. The current in the TSC brunch varies linearly with applied voltage according to the capacitors admittance as shown in Figure 3.7.

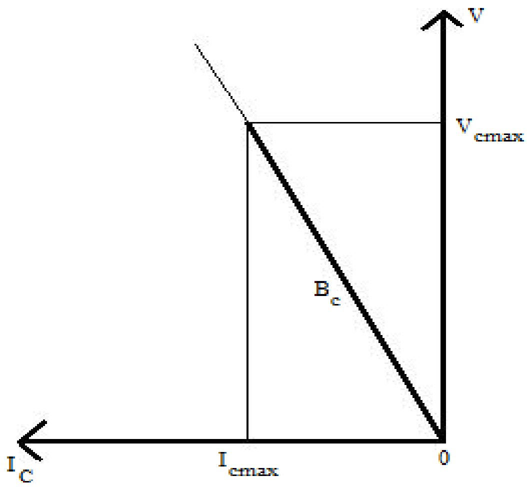

Figure 3.7 operating V-I area of a single TSC

If the TSC consists of couple parallel connected elements and controller (Figure 3.8), the operating area becomes more flexible, and it can regulate the bus voltage in a bigger range [32].

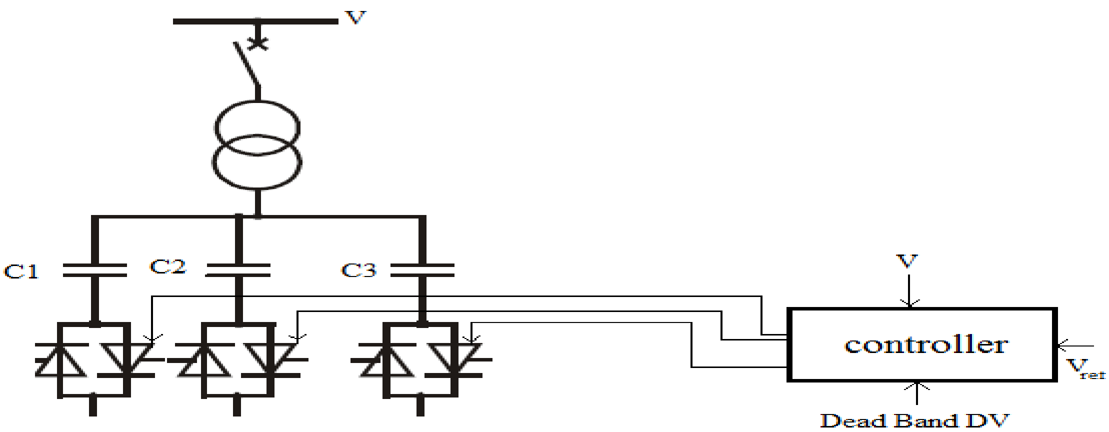

Figure 3.8 TSC scheme

When bus voltage deviates from the reference value V_{ref} beyond the dead band, the control switches in or out one or more capacitor banks until the voltage returns inside the dead band. The illustration of this kind of bus voltage regulation by TSC is shown in Figure 3.9 [32].

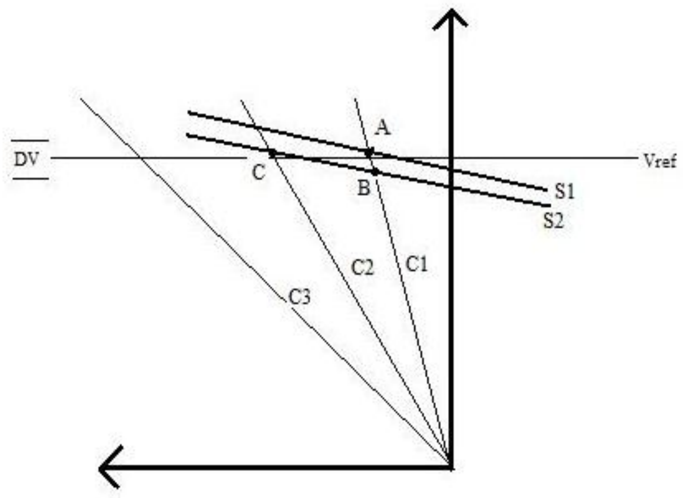

Figure 3.9 VI characteristics of a TSC and power system

We can see that the voltage control is stepwise. It is determined by the rating and number of parallel connected units. The bus voltage in this example is controlled within the range V_{ref} (+/-)DV/2, where DV is dead band. When the system is operating so that its characteristic is S1, then capacitor C1 will be switched in and the operating point of the system will be in A [32]. If some fault happens, and system characteristic will change to S2 there will be a sudden bus voltage drop to the value represented by operating point B. The TSC control switches in bank C2 to change the operating point to C, and thus bringing the voltage within desired range. The time taken for executing a command from the controller ranges from half cycle to one cycle [32].

CHAPTER-4 ANALYSIS OF SERIES CAPACITOR AND STATIC VAR COMPENSATOR

4.1 STUDIED SYSTEM:

A large Power System which feeds a certain load or power (P+ j Q) through a variable SC is used in this study as shown in Fig. 4.1. The system, at steady-state conditions can be represented by its Thevenin's equivalent seen from node 5 as shown in Fig. 4.2.

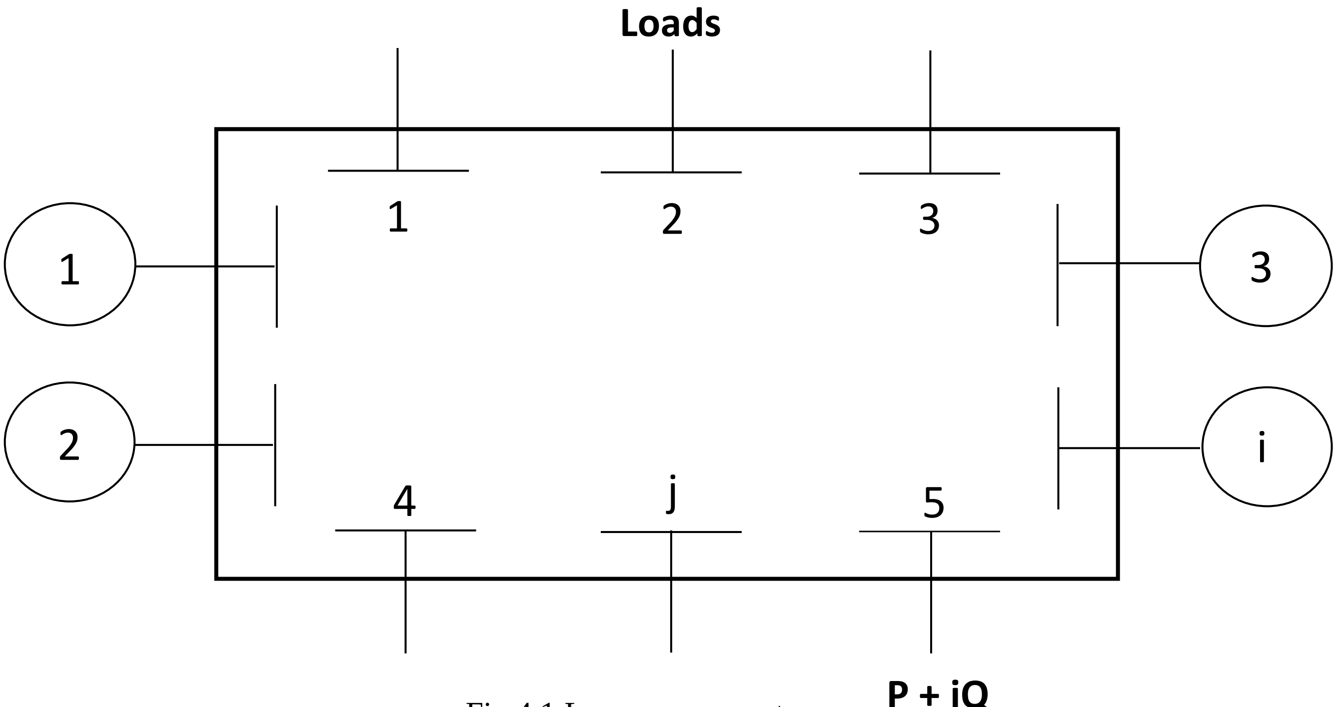

Fig.4.1 Large power system

.

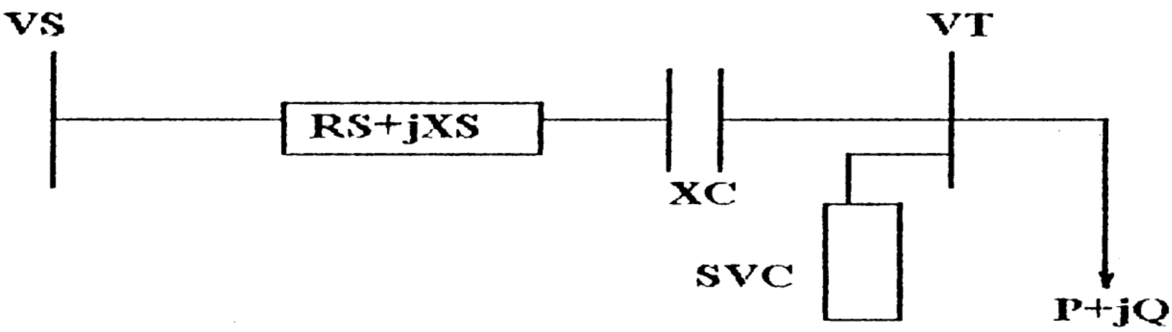

Fig.4.2 Thevenin's equivalent system shows the load node terminals.

The link voltage drop will therefore be.

$$\Delta V = |V_S| - |V_T| = \frac{((X_S - X_C)Q + R_S P)}{V_T} \qquad (1a)$$

Data used in this study: V_S= 1.004 p.u. , Z_S= 0.3228 p.u. , V_T = 0.99 p.u. , X_S=0.3p.u.

4.2 POWER SYSTEM MODEL WITH SERIES CAPACITOR AND STATIC VAR COMPENSATOR

A thyristor-control reactor /fixed capacitor (TCR/FC) type is used. Its control system consists of a measuring circuit for measuring its terminal voltage V_T, a regulator with reference voltage and a firing circuit which generates gating pulses in order to command variable thyristor current I_L, through the fixed reactor reactance X_L. This variable current draws variable reactive power $(I_L^2 X_L)$ which corresponds to variable virtual reactance of susceptance B_L given by: $V_t^2 B_C = I_L^2 X_L$, Together with the fixed capacitive reactive power , these from the hole variable inductive and capacitive reactive power of that static compensator. Fig. 4.3 shows a block diagram of that compensator when connected to a large power system.

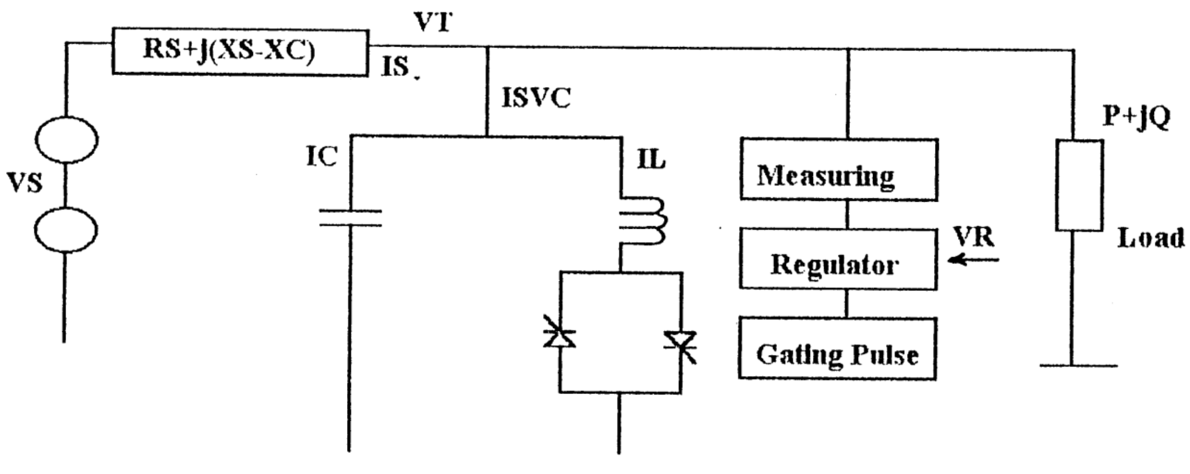

Fig. 4.3. Static VAR compensator and power system block diagram.

Fig. 4.4 shows the transfer function of the power system provided by the series capacitor and a static VAR compensator. Fig. 4.5 shows the simplified transfer function block diagram of that system with combined series capacitor and static VAR compensator.

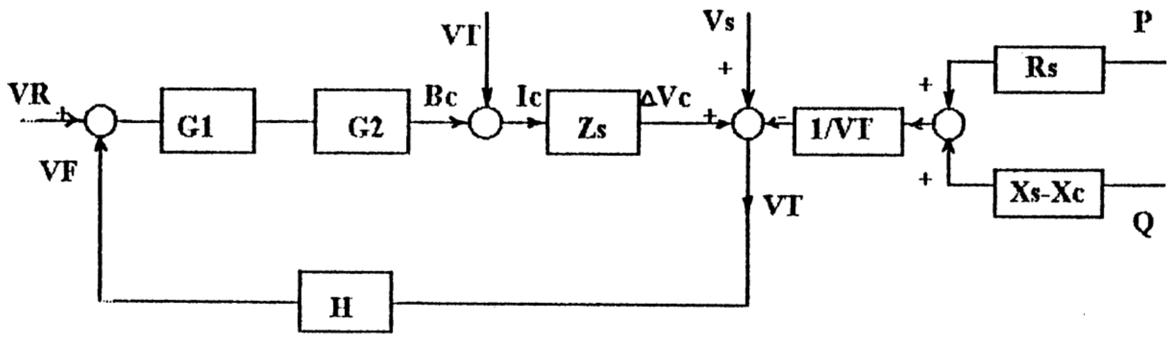

Fig.4.4. Block diagram of a loaded power system, series capacitor and SVC

4.3 SYTSTEM EQUATIONS:

The controller is usually of the proportional element (1/slop) with certain delay $T_{1,}$ followed by a controller compensator circuit of the form:

$$G_1 = \frac{\left(\frac{1}{slop}\right)(1+T_2 s)}{(1+T_1 s)(1+T_3 s)} \tag{1}$$

The slop is regulator droop slope equals to $\frac{\Delta V_C}{\Delta I_{max}}$ Volt/ampere. T_1 is a delay time. T_2 and T_3 are the time constants of regulator compensation circuits. The controller output is fed to the firing circuit which may be completely defined by a transfer function, consists of a gain K_d (nearly unity) and a time delay T_d as :

$$G_2 = K_d\, e^{-sT_d} \cong \frac{K_d}{(1+T_d s)} \tag{2}$$

which is equal to 2.77 x 10^{-3}s for TCR and equal to 5.55 x 10^{-3}s for TSC. The limiter refers to the limits of the virtual compensator variable susceptance 'B'.

The measuring circuit forms the feedback link and can be represented by a gain K_H equal nearly unity and a time delay T_H as:

$$H = K_H e^{-sT_H} \cong \frac{K_H}{(1+T_H s)} \qquad (3)$$

I_S of the order of 20-50 ms, While T_H is usually from 8 – 16 ms. K_H usually takes a value around 1.0 p.u,T_2 and T_3 are determined by the regulator designed for each studied system, as they are function in system parameter.

Solving block diagram of a loaded power system, series capacitor and SVC. Multiplication of B by V_T yields the SVC current following in the series link (I_S), which is given by:

$$I_S = BV_T \qquad (4)$$

The power system which is provided by a series capacitor at the load inlet can be represented by its Thevenin's voltage V_S, system and capacitor reactance R_S + j (X_S-X_C). The load voltage drop to system equivalent series impedance and through the series capacitance link is given by:

$$\Delta V = |V_S| - |V_T| = \frac{\left((X_S - X_C)Q + R_S P\right)}{V_T} \qquad (5)$$

Where V_T is the load node and SVC terminal voltage and '*S*' is the laplace operator, which vanishes in steady-state condition.

Defining

$$B_C = G_1 G_2 (V_R - V_T H)$$

And

$$G = G_1 G_2 V_T$$

The compensator current I_S is given by: $I_S = G(V_R - V_T H)$ (6)

And the SVC control system feedback voltage is given by:

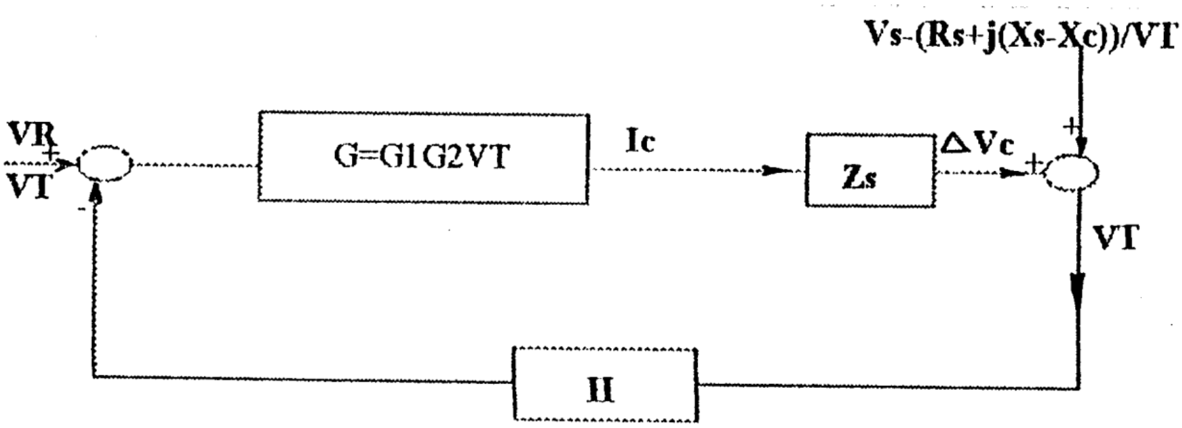

Fig. 4.5. Simplified transfer function block diagram of a loaded power system, series capacitor and SVC

$$\Delta V_C = I_S Z_S = G(V_R - V_T H) Z_S \quad (7)$$

Therefore, the load terminal voltage is given by:

$$V_T = \Delta V_C + \left(V_S - \frac{R_S P}{V_T} - \frac{(X_S - X_C)Q}{V_T} \right) \quad (8)$$

or:

$$V_T = G(V_R - V_T H) Z_S + \left(V_S - \frac{R_S P}{V_T} - \frac{(X_S - X_C)Q}{V_T} \right) \quad (9)$$

From which:

$$V_T^{\,2}(1+GHZ_S) - V_T(V_S+GZ_SV_R) + (R_SP+(X_S-X_C)Q) = 0 \quad (10)$$

Its solution is:

$$V_{T1} = \frac{(V_S+GZ_SV_R)+\sqrt{(V_S+GZ_SV_R)^2-4(1+GHZ_S)(R_SP+(X_S-X_C)Q)}}{2(1+GHZ_S)} \tag{11}$$

$$V_{T2} = \frac{(V_S+GZ_SV_R)-\sqrt{(V_S+GZ_SV_R)^2-4(1+GHZ_S)(R_SP+(X_S-X_C)Q)}}{2(1+GHZ_S)} \tag{12}$$

and the compensator controller gain is given from Eq. (10) by:

$$G = \frac{-V_T^2+V_TV_S-(R_SP+(X_S-X_C)Q)}{Z_SV_T(HV_T-V_R)} \tag{13}$$

While, the regulator reference voltage is given from Eq. (10) by:

$$V_R = \frac{V_T^2(1+GHZ_S)-V_TV_S+(R_SP+(X_S-X_C)Q)}{V_TGZ_S} \tag{14}$$

The regulator slope is obtained from the known *V/I* characteristics of SVC as:

$$slop = \frac{\Delta V_C}{I_{S(max)}} \tag{15}$$

After substituting of Eq. (7) and (4) in Eq. (15), we get:

$$slop = \frac{(V_R-V_TH)GZ_S}{B_CV_T} \tag{16}$$

Defining:

$$AK = \frac{(V_R - V_T H) Z_S}{V_T}$$

Eq. (16) becomes:

$$slop = \left(\frac{G}{B_C}\right) AK \tag{17}$$

With:

$$B_C = \frac{1}{X_C} \tag{18}$$

Where *Xc* is the compensator fixed reactance, *Bc* is its rating in p.u referred to its own rating (at 1.0 p.u terminal voltage basis).

4.4 COMPENSATOR RATING:

Compensator rating is given by $(B_C V_t^2)$ or simply by B_C at V_T= 1 p.u. It can therefore be calculated from Eq. (17) by:

$$B_C = \frac{G(AK)}{slop}$$

CHAPTER-5 RESULTS AND DISCUSSION USING MATLAB

5.1 SYSTEM DATA:

Having used the system under study with the mentioned data:

V_S = 1.004 p.u.

X_S = 0.3125 p.u.

V_r = 1 p.u.

H = 1 p.u.

R_S = 0.08126 p.u.

Z_S = 0.3228 p.u.

The load reactive power is assumed to be kept constant at Q = 0.18 p.u.

In order to kept the terminal voltage constant at V_T = 0.8 p.u up to 1.05 p.u for different system power P.

5.2 POWER VERSUS VOLTAGE (P-V) CURVE WITH THE PRESENCE OF SERIES CAPACITOR AND STATIC VAR COMPENSATOR

The famous nose curve of the Voltage/Power relation is plotted. Having a load of constant power factor, the voltage is plotted against the load VA power, in the presence of different SC compensation percentages (0 , 25 , 50 , 75 , 90%) in Fig. 5.1 .

5.2 (a) CASE 1: WHEN G= 0.0 (i.e. WITHOUT COMPENSATOR ACTION)

SCRIPT FILE:

```
G=0.0

Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.0
Vr=1
Zs=0.3228
Vs=1.004

for  P=0:.01:2.41

Vt=(((Vs)+(G*Zs*Vr))-((((Vs)+(G*Zs*Vr))^(2))-4*((1)+(G*Zs*H))*((Rs*P)+((Xs-
Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));


Vt1=(((Vs)+(G*Zs*Vr))+((((Vs)+(G*Zs*Vr))^(2))-
4*((1)+(G*Zs*H))*((Rs*P)+((Xs-Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));

plot(P,Vt,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','k',...
                 'MarkerFaceColor','K',...
                 'MarkerSize',1)

plot(P,Vt1,'--rs','LineWidth',2,...
                  'MarkerEdgeColor','k',...
                  'MarkerFaceColor','K',...
                  'MarkerSize',1)

            hold all

end
G=0.0
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.0781
Vr=1
Zs=0.3228
Vs=1.004

for  P=0:.01:2.58

Vt=(((Vs)+(G*Zs*Vr))-((((Vs)+(G*Zs*Vr))^(2))-4*((1)+(G*Zs*H))*((Rs*P)+((Xs-
Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));
```

```
Vt1=(((Vs)+(G*Zs*Vr))+((((Vs)+(G*Zs*Vr))^(2))-
4*((1)+(G*Zs*H))*((Rs*P)+((Xs-Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));

plot(P,Vt,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','b',...
                 'MarkerFaceColor','b',...
                 'MarkerSize',1)

plot(P,Vt1,'--rs','LineWidth',2,...
                  'MarkerEdgeColor','b',...
                  'MarkerFaceColor','b',...
                  'MarkerSize',1)

            hold all

end
G=0.0
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.1562
Vr=1
Zs=0.3228
Vs=1.004

for  P=0:.01:2.76

Vt=(((Vs)+(G*Zs*Vr))-((((Vs)+(G*Zs*Vr))^(2))-4*((1)+(G*Zs*H))*((Rs*P)+((Xs-
Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));


Vt1=(((Vs)+(G*Zs*Vr))+((((Vs)+(G*Zs*Vr))^(2))-
4*((1)+(G*Zs*H))*((Rs*P)+((Xs-Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));

plot(P,Vt,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','r',...
                 'MarkerFaceColor','r',...
                 'MarkerSize',1)

plot(P,Vt1,'--rs','LineWidth',2,...
                  'MarkerEdgeColor','r',...
                  'MarkerFaceColor','r',...
                  'MarkerSize',1)

            hold all

end
G=0.0
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
```

```
Xc=0.2343
Vr=1
Zs=0.3228
Vs=1.004

for  P=0:.01:2.93

Vt=(((Vs)+(G*Zs*Vr))-((((Vs)+(G*Zs*Vr))^(2))-4*((1)+(G*Zs*H))*((Rs*P)+((Xs-
Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));


Vt1=(((Vs)+(G*Zs*Vr))+((((Vs)+(G*Zs*Vr))^(2))-
4*((1)+(G*Zs*H))*((Rs*P)+((Xs-Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));

plot(P,Vt,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','g',...
                 'MarkerFaceColor','g',...
                 'MarkerSize',1)

plot(P,Vt1,'--rs','LineWidth',2,...
                  'MarkerEdgeColor','g',...
                  'MarkerFaceColor','g',...
                  'MarkerSize',1)

            hold all

end
G=0.0
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.28125
Vr=1
Zs=0.3228
Vs=1.004

for  P=0:.01:3.03

Vt=(((Vs)+(G*Zs*Vr))-((((Vs)+(G*Zs*Vr))^(2))-4*((1)+(G*Zs*H))*((Rs*P)+((Xs-
Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));

Vt1=(((Vs)+(G*Zs*Vr))+((((Vs)+(G*Zs*Vr))^(2))-
4*((1)+(G*Zs*H))*((Rs*P)+((Xs-Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));

plot(P,Vt,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','m',...
                 'MarkerFaceColor','m',...
                 'MarkerSize',1)

plot(P,Vt1,'--rs','LineWidth',2,...
                  'MarkerEdgeColor','m',...
                  'MarkerFaceColor','m',...
```

```
                    'MarkerSize',1)
              hold all
end
xlabel('Real Power  in  p.u ' , 'Fontsize',14)
ylabel('Voltage in  p.u','Fontsize',14)
```

5.2 (a) CASE 1 WHEN G = 0.0

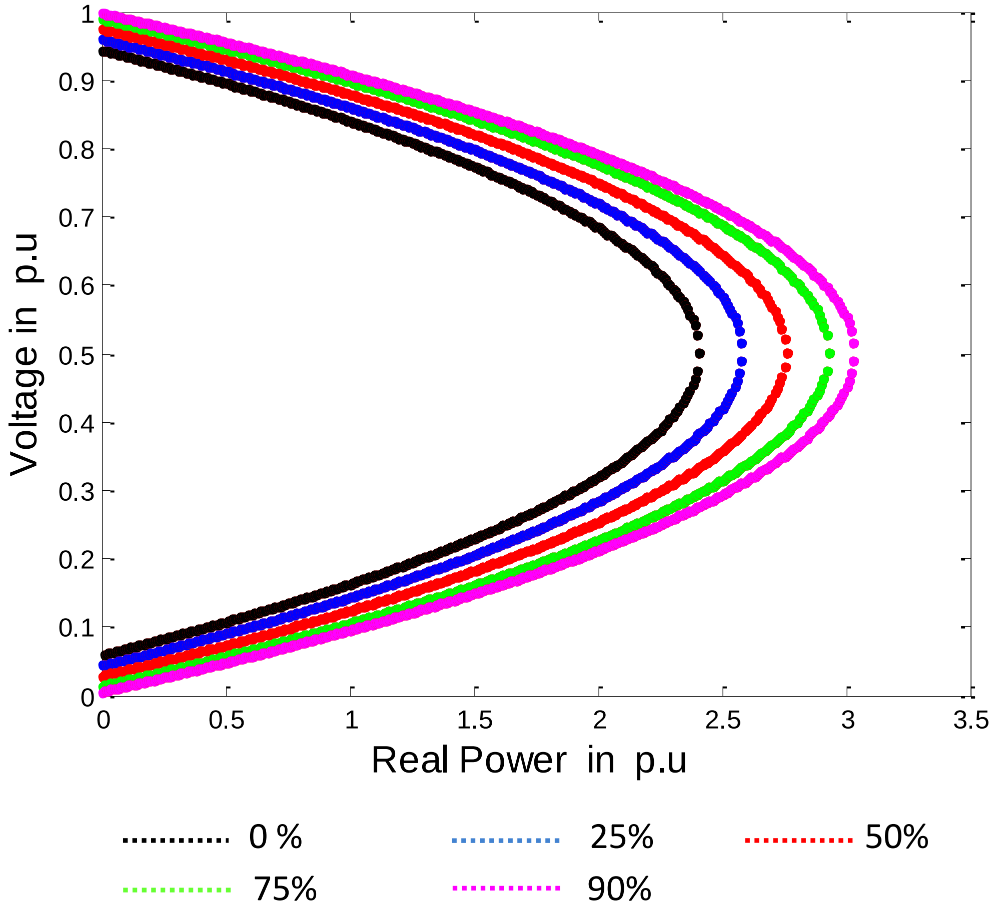

Fig. 5.1 Voltage/Power response with different series compensation(0-90%) , with constant Q and with G = 0.0

5.2 (b) CASE 2: WHEN VARYING G AND X_C=0.0781 (25% SERIES COMPENSATION)

SCRIPT FILE:

```
G=0.0
Q=0.18
Xs=0.3125
```

```
Rs=0.08126
H=1
Xc=0.0781
Vr=1
Zs=0.3228
Vs=1.004

for  P=0:.01:2.58

Vt=(((Vs)+(G*Zs*Vr))-((((Vs)+(G*Zs*Vr))^(2))-4*((1)+(G*Zs*H))*((Rs*P)+((Xs-
Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));
Vt1=(((Vs)+(G*Zs*Vr))+((((Vs)+(G*Zs*Vr))^(2))-
4*((1)+(G*Zs*H))*((Rs*P)+((Xs-Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));

plot(P,Vt,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','k',...
                 'MarkerFaceColor','K',...
                 'MarkerSize',1)

plot(P,Vt1,'--rs','LineWidth',2,...
                  'MarkerEdgeColor','k',...
                  'MarkerFaceColor','K',...
                  'MarkerSize',1)

            hold all

end
G=0.5
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.0781
Vr=1
Zs=0.3228
Vs=1.004

for  P=0:.01:3.08

Vt=(((Vs)+(G*Zs*Vr))-((((Vs)+(G*Zs*Vr))^(2))-4*((1)+(G*Zs*H))*((Rs*P)+((Xs-
Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));


Vt1=(((Vs)+(G*Zs*Vr))+((((Vs)+(G*Zs*Vr))^(2))-
4*((1)+(G*Zs*H))*((Rs*P)+((Xs-Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));

plot(P,Vt,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','b',...
                 'MarkerFaceColor','b',...
                 'MarkerSize',1)

plot(P,Vt1,'--rs','LineWidth',2,...
                  'MarkerEdgeColor','b',...
                  'MarkerFaceColor','b',...
                  'MarkerSize',1)

            hold all
```

```
end
G=1.0
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.0781
Vr=1
Zs=0.3228
Vs=1.004


for  P=0:.01:3.57


Vt=(((Vs)+(G*Zs*Vr))-((((Vs)+(G*Zs*Vr))^(2))-4*((1)+(G*Zs*H))*((Rs*P)+((Xs-Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));


Vt1=(((Vs)+(G*Zs*Vr))+((((Vs)+(G*Zs*Vr))^(2))-4*((1)+(G*Zs*H))*((Rs*P)+((Xs-Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));

plot(P,Vt,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','r',...
                 'MarkerFaceColor','r',...
                 'MarkerSize',1)


plot(P,Vt1,'--rs','LineWidth',2,...
                  'MarkerEdgeColor','r',...
                  'MarkerFaceColor','r',...
                  'MarkerSize',1)

            hold all

end
G=1.5
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.0781
Vr=1
Zs=0.3228
Vs=1.004

for  P=0:.01:4.08

Vt=(((Vs)+(G*Zs*Vr))-((((Vs)+(G*Zs*Vr))^(2))-4*((1)+(G*Zs*H))*((Rs*P)+((Xs-Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));


Vt1=(((Vs)+(G*Zs*Vr))+((((Vs)+(G*Zs*Vr))^(2))-4*((1)+(G*Zs*H))*((Rs*P)+((Xs-Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));
```

```
plot(P,Vt,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','g',...
                 'MarkerFaceColor','g',...
                 'MarkerSize',1)


plot(P,Vt1,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','g',...
                 'MarkerFaceColor','g',...
                 'MarkerSize',1)


            hold all

end
G=2.0
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.0781
Vr=1
Zs=0.3228
Vs=1.004

for  P=0:.01:4.58


Vt=(((Vs)+(G*Zs*Vr))-((((Vs)+(G*Zs*Vr))^(2))-4*((1)+(G*Zs*H))*((Rs*P)+((Xs-
Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));


Vt1=(((Vs)+(G*Zs*Vr))+((((Vs)+(G*Zs*Vr))^(2))-
4*((1)+(G*Zs*H))*((Rs*P)+((Xs-Xc))*Q))^(1/2))/((2)*((1)+(G*Zs*H)));


plot(P,Vt,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','m',...
                 'MarkerFaceColor','m',...
                 'MarkerSize',1)


plot(P,Vt1,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','m',...
                 'MarkerFaceColor','m',...
                 'MarkerSize',1)

            hold all

end
xlabel('Real Power  in  p.u ' , 'Fontsize',14)
ylabel('Voltage in  p.u','Fontsize',14)
```

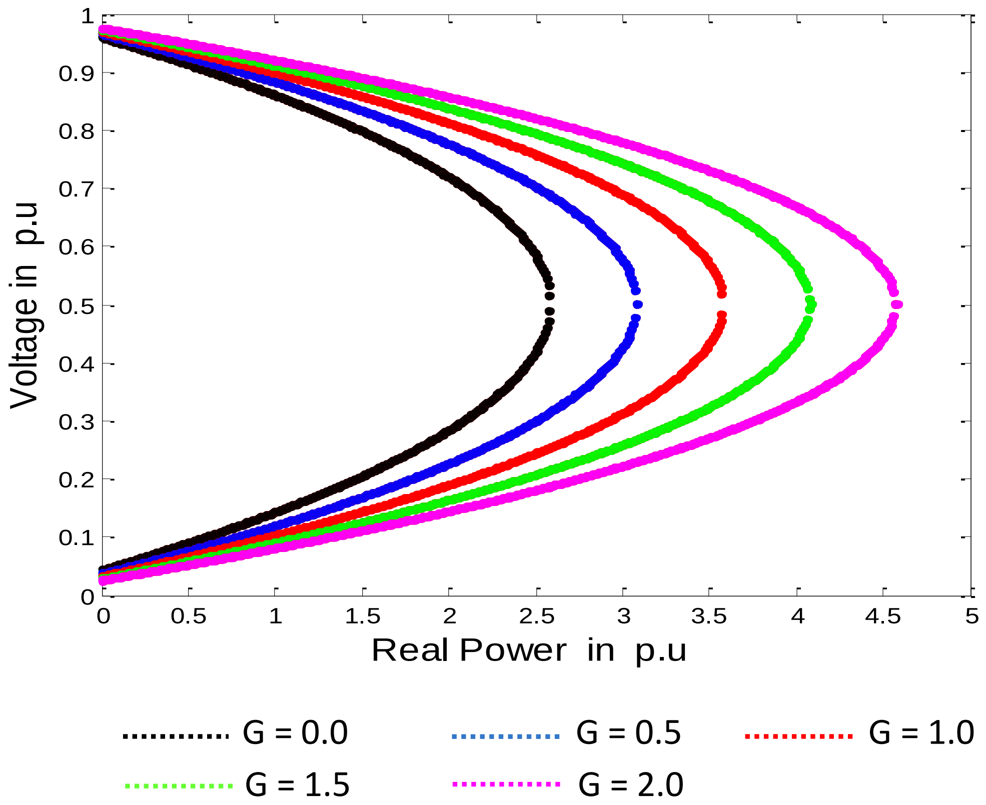

Fig. 5.2 Voltage/Power response with different SVC gains (0.0-2.5), with constant Q and with X_C = 0.0781

As we can see in these plots that by the use of Capacitor in the circuit, the peak-load voltage can be increased by increasing the series compensation. The figure 5.1 shows that maximum possible critical power increases with the increase of SC series compensation percentage. For example it becomes 125% at 90% compensation and 120% at 75% , 110% at 50% and 105% at 25% compensation .It is noticed that the critical voltage value is constant at 0.5 p.u. at all series compensation percentages . This is due to the fact that the critical voltage is independent of the value of system series reactance X_S.

Table -1, however shows the maximum load power corresponding to various values of SVC controller gains. Therefore, at a gain of 1.0 the maximum transmitted power can be increased to 140% and a gain of 2.0 can increase it by 180% of its value without static VAR compensator. This is important result illustrates the limited effects of the series capacitor compared to the static VAR compensator, significant effects, at different controller gains.

TABLE-1: MAXIMUM LOAD POWER AS AFFECTED BY COMPENSATOR CONTROLLER GAINS WITH 25% SERIES COMPENSATION.

Compensator Gain (G)	Approximate Maximum Power
0.0	2.58
0.5	3.08
1.0	3.57
2.0	4.58

5.3 STATIC VAR COMPENSATOR PARAMETERS IN THE PRESENCE OF SERIES CAPACITORS

5.3.1 COMPENSATOR CONTROLLER GAIN 'G':

5.3.1 (a) CASE 1: GAIN WITH ACTIVE POWER

For various load powers (at constant load power factor),the SVC gains required to keep the load voltage V_t constant at 0.99 p.u. , when the reference voltage V_r is adjusted to 1.0 p.u., is plotted in fig 5.3 with four compensation percentages (0, 25,50,75,90%).

SCRIPT FILE:

```
Q=0.18
Xs=0.3125
Rs=0.08126

H=1
Xc=0.0
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  P=0:.01:8
```

```
G =(-((Vt)^(2))+((Vt*Vs))-(((Rs))*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr))

plot(P,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','k',...
                 'MarkerFaceColor','K',...
                 'MarkerSize',1)



            hold all

end




Q=0.18
Xs=0.3125
Rs=0.08126

H=1
Xc=0.00781
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  P=0:.01:8


G =(-((Vt)^(2))+((Vt*Vs))-(((Rs))*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr))
plot(P,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','b',...
                 'MarkerFaceColor','b',...
                 'MarkerSize',1)



            hold all

end




Q=0.18
Xs=0.3125
Rs=0.08126

H=1
Xc=0.1562
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  P=0:.01:8
```

```
G =(-((Vt)^(2))+((Vt*Vs))-(((Rs))*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr))

plot(P,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','r',...
                 'MarkerFaceColor','r',...
                 'MarkerSize',1)



            hold all

end




Q=0.18
Xs=0.3125
Rs=0.08126

H=1
Xc=0.2343
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99



for  P=0:.01:8

G =(-((Vt)^(2))+((Vt*Vs))-(((Rs))*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr))





plot(P,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','g',...
                 'MarkerFaceColor','g',...
                 'MarkerSize',1)



            hold all

end


Q=0.18
Xs=0.3125
Rs=0.08126

H=1
Xc=0.2968
Vr=1
Zs=0.3228
Vs=1.004
```

```
Vt=.99

for  P=0:.01:8

G =(-((Vt)^(2))+((Vt*Vs))-(((Rs))*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr));

plot(P,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','m',...
                 'MarkerFaceColor','m',...
                 'MarkerSize',1)

            hold all

end

xlabel('Power in p.u ' , 'Fontsize',14)
ylabel('Gain','Fontsize',14)
```

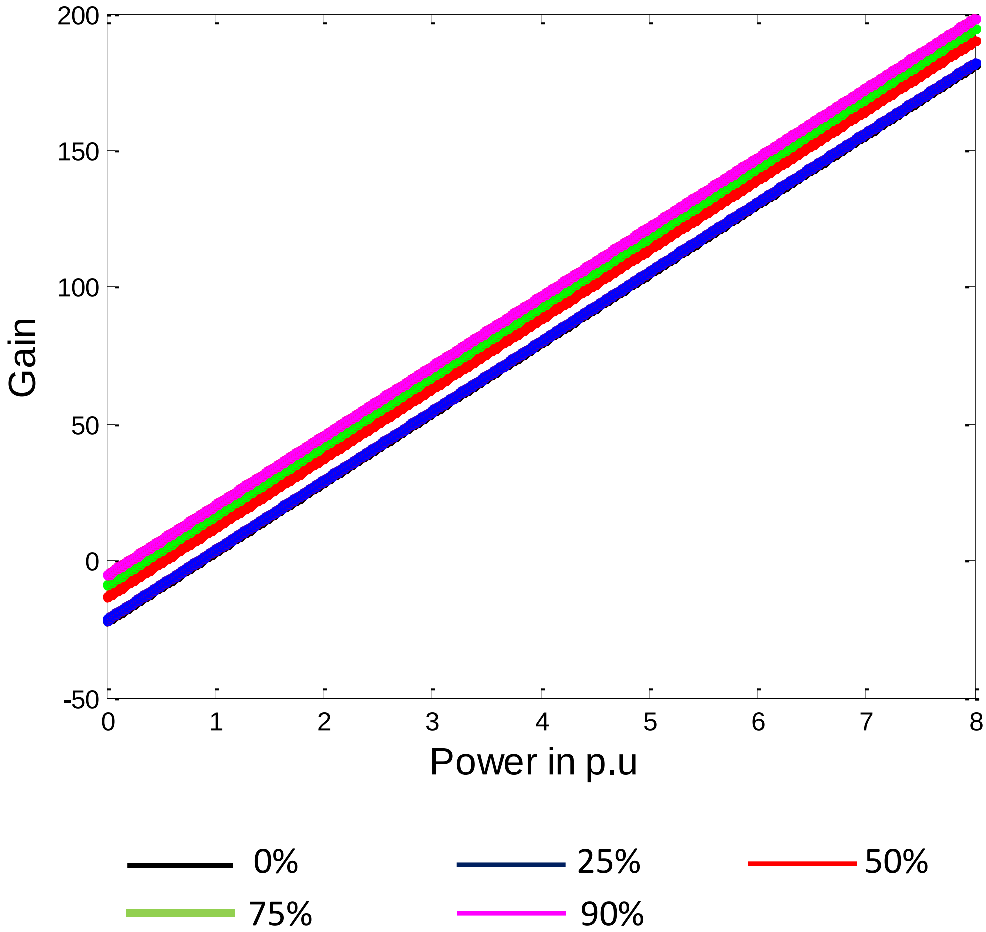

Fig. 5.3 Load power/SVC controller gain required to keep load constant in the presence of SC of different compensation percentages up to 100%

For the same load power, the SVC gain increases with increase of percentage series compensation .Or, in other words, for the same SVC gain, the load power decreases as the series condenser percentage increases.

5.3.1 (b) CASE 2 : GAIN WITH REACTIVE POWER.

SCRIPT FILE:

```
P=0.3
Xs=0.3125
Rs=0.08126

H=1
Xc=0.0
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  Q=0:.01:8

G=-((Vt)^(2))+((Vt*Vs))-(((Rs)*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr))

plot(Q,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','k',...
                 'MarkerFaceColor','K',...
                 'MarkerSize',1)



            hold all

end




P=0.3
Xs=0.3125
Rs=0.08126

H=1
Xc=0.0781
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  Q=0:.01:8

G=-((Vt)^(2))+((Vt*Vs))-(((Rs)*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr))
```

```
plot(Q,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','b',...
                 'MarkerFaceColor','b',...
                 'MarkerSize',1)



            hold all

end



P=0.3
Xs=0.3125
Rs=0.08126

H=1
Xc=0.1562
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  Q=0:.01:8

G=-((Vt)^(2))+((Vt*Vs))-(((Rs)*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr))

plot(Q,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','r',...
                 'MarkerFaceColor','r',...
                 'MarkerSize',1)



            hold all

end



P=0.3
Xs=0.3125
Rs=0.08126

H=1
Xc=0.2343
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  Q=0:.01:8
```

```
G=-((Vt)^(2))+((Vt*Vs))-(((Rs)*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr))


plot(Q,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','g',...
                 'MarkerFaceColor','g',...
                 'MarkerSize',1)


            hold all

end


P=0.3
Xs=0.3125
Rs=0.08126

H=1
Xs=0.2812
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99


for  Q=0:.01:8


G=-((Vt)^(2))+((Vt*Vs))-(((Rs)*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr))


plot(Q,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','m',...
                 'MarkerFaceColor','m',...
                 'MarkerSize',1)


            hold all

end


xlabel(' Reactive Power in p.u','FontSize',14)
ylabel('Gain','FontSize',14)
```

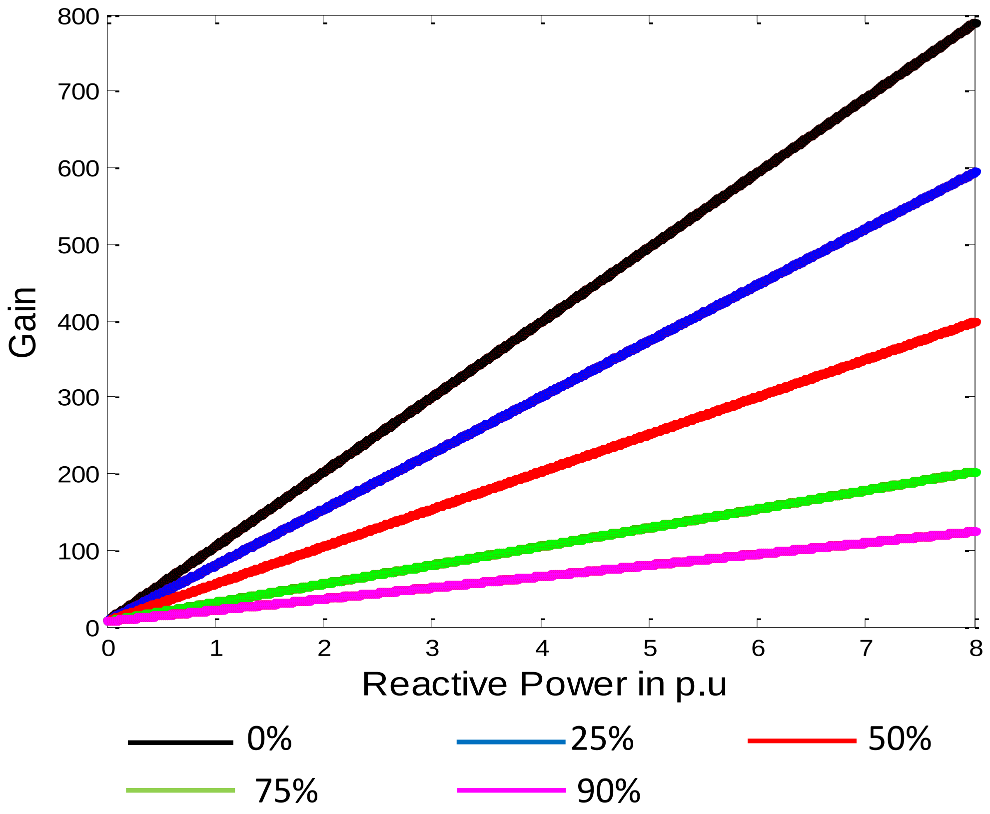

Fig. 5.4 Gain/Reactive Power response for constant load voltage (Vt = 0.99) and constant load active power (P = 0.3) in presence of different series compensation.

Similarly as the plot of Gain/Active power, the Gain/Reactive power plot is also showing that when the active power is kept constant at 0.3 p.u, it is clear that to obtain the same value of load power with different series compensation, different SVC controller gains should be adjusted adaptively. As shown in fig. 5.4.

5.3.2 EFFECT OF SERIES COMPENSATION PERCENTAGE ON THE SVC CONTROLLER REFERENCE VOLTAGE

Having selected a gain of three for the SVC controller and using the previously studied system, the load is changed upto the maximum value for the different percentage of series compensation. The SVC controller reference voltage required to keep the load voltage constant at 0.99 p.u. at all loading conditions is plotted in fig 5.5 for percentages (0-75%).

SCRIPT FILE:

```
G=3
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.0
Zs=0.3228
Vs=1.004
Vt=.9

for  P=0:.05:8

Vr=(((Vt)^(2))*(1+(G*H*Zs)))-((Vt*Vs))+(((Rs*P)))+(((Xs*Q)-
(Xc*Q)))/((Vt*G*Zs))

plot(P,Vr,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','k',...
                 'MarkerFaceColor','K',...
                 'MarkerSize',1)
     hold all


end

G=3
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.0781
Zs=0.3228
Vs=1.004
Vt=.9

for  P=0:.05:8

Vr=(((Vt)^(2))*(1+(G*H*Zs)))-((Vt*Vs))+(((Rs*P)))+(((Xs*Q)-
(Xc*Q)))/((Vt*G*Zs))

plot(P,Vr,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','b',...
                 'MarkerFaceColor','b',...
                 'MarkerSize',1)
     hold all


end
G=3
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.15625
Zs=0.3228
Vs=1.004
Vt=.9
```

```
for  P=0:.05:8

Vr=(((Vt)^(2))*(1+(G*H*Zs)))-((Vt*Vs))+(((Rs*P)))+(((Xs*Q)-
(Xc*Q)))/((Vt*G*Zs))

plot(P,Vr,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','r',...
                 'MarkerFaceColor','r',...
                 'MarkerSize',1)
     hold all
end

G=3
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.2343
Zs=0.3228
Vs=1.004
Vt=.9


for  P=0:.05:8


Vr=(((Vt)^(2))*(1+(G*H*Zs)))-((Vt*Vs))+(((Rs*P)))+(((Xs*Q)-
(Xc*Q)))/((Vt*G*Zs))


plot(P,Vr,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','g',...
                 'MarkerFaceColor','g',...
                 'MarkerSize',1)

     hold all


end
G=3
Q=0.18
Xs=0.3125
Rs=0.08126
H=1
Xc=0.2812
Zs=0.3228
Vs=1.004
Vt=.9

for  P=0:.05:8

Vr=(((Vt)^(2))*(1+(G*H*Zs)))-((Vt*Vs))+(((Rs*P)))+(((Xs*Q)-
(Xc*Q)))/((Vt*G*Zs))


plot(P,Vr,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','m',...
                 'MarkerFaceColor','m',...
```

```
                'MarkerSize',1)

    hold all


end

xlabel('Power in p.u ' , 'Fontsize',12)
ylabel('Reference voltage in p.u','Fontsize',12)
```

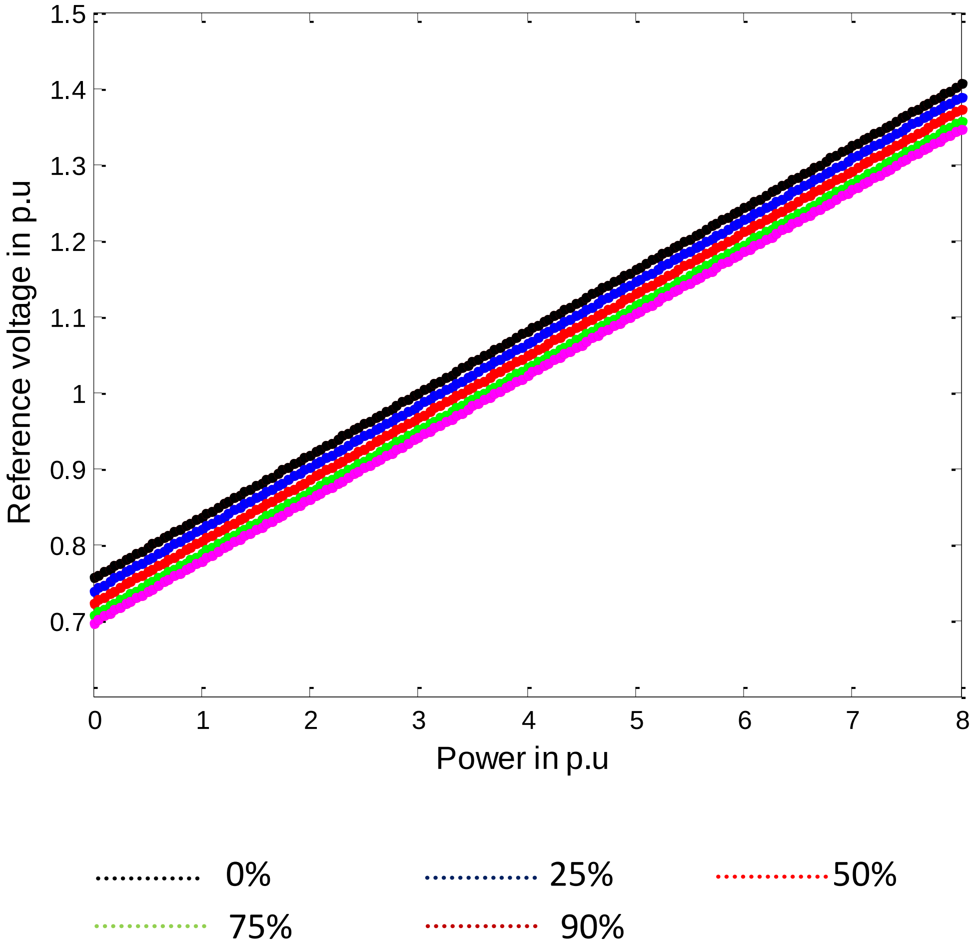

Fig. 5.5 SVC controller reference voltage required to keep voltage constant at variable load in the presence of several SC percentages

5.3.3 INFLUENCE OF THE SC PERCENTAGE ON THE SVC RATING

When combined SVC and SC, the SVC rating will clearly be changed. Fig 5.6 shows the new SVC rating in the presence of several series compensation percentages from 25-75%, the case without series compensation (0%) is also included for comparison purposes. First of all, the required SVC compensator rating to keep the load voltage constant at 0.99p.u. ranges from 0-0.5p.u. for loads from 0-3p.u.

5.3.3 (a) RATING OF SVC V/S LOAD POWER

SCRIPT FILE:

```
Q=0.18
Xs=0.3125
Rs=0.08126
slope = 0.2
H=1
Xc=0.0
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  P=0:.01:3

Bc =(((Vt)^(2))-((Vt*Vs))+(((Rs))*P)+((Xs*Q-Xc*Q)))/((Vt)^(2)*slope)

plot(P,Bc,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','k',...
                 'MarkerFaceColor','K',...
                 'MarkerSize',1)



            hold all

end
Q=0.18
Xs=0.3125
Rs=0.08126
slope = 0.2
H=1
Xc=0.0781
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99
for  P=0:.01:3
Bc =(((Vt)^(2))-((Vt*Vs))+(((Rs))*P)+((Xs*Q-Xc*Q)))/((Vt)^(2)*slope)

plot(P,Bc,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','b',...
                 'MarkerFaceColor','b',...
                 'MarkerSize',1)



            hold all
```

```
end
Q=0.18
Xs=0.3125
Rs=0.08126
slope = 0.2
H=1
Xc=0.15625
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  P=0:.01:3

Bc =(((Vt)^(2))-((Vt*Vs))+(((Rs))*P)+((Xs*Q-Xc*Q)))/((Vt)^(2)*slope)

plot(P,Bc,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','r',...
                 'MarkerFaceColor','r',...
                 'MarkerSize',1)



            hold all

end
Q=0.18
Xs=0.3125
Rs=0.08126
slope = 0.2
H=1
Xc=0.2343
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  P=0:.01:3

Bc =(((Vt)^(2))-((Vt*Vs))+(((Rs))*P)+((Xs*Q-Xc*Q)))/((Vt)^(2)*slope)

plot(P,Bc,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','g',...
                 'MarkerFaceColor','g',...
                 'MarkerSize',1)
            hold all

end
Q=0.18
Xs=0.3125
Rs=0.08126
slope = 0.2
H=1
Xc=0.28125
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99
```

```
for  P=0:.01:3


Bc =(((Vt)^(2))-((Vt*Vs))+(((Rs))*P)+((Xs*Q-Xc*Q)))/((Vt)^(2)*slope)


plot(P,Bc,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','m',...
                 'MarkerFaceColor','m',...
                 'MarkerSize',1)

            hold all

end
xlabel('Load Power  in  p.u ' , 'Fontsize',14)
ylabel('Rating of SVC ','Fontsize',14)
```

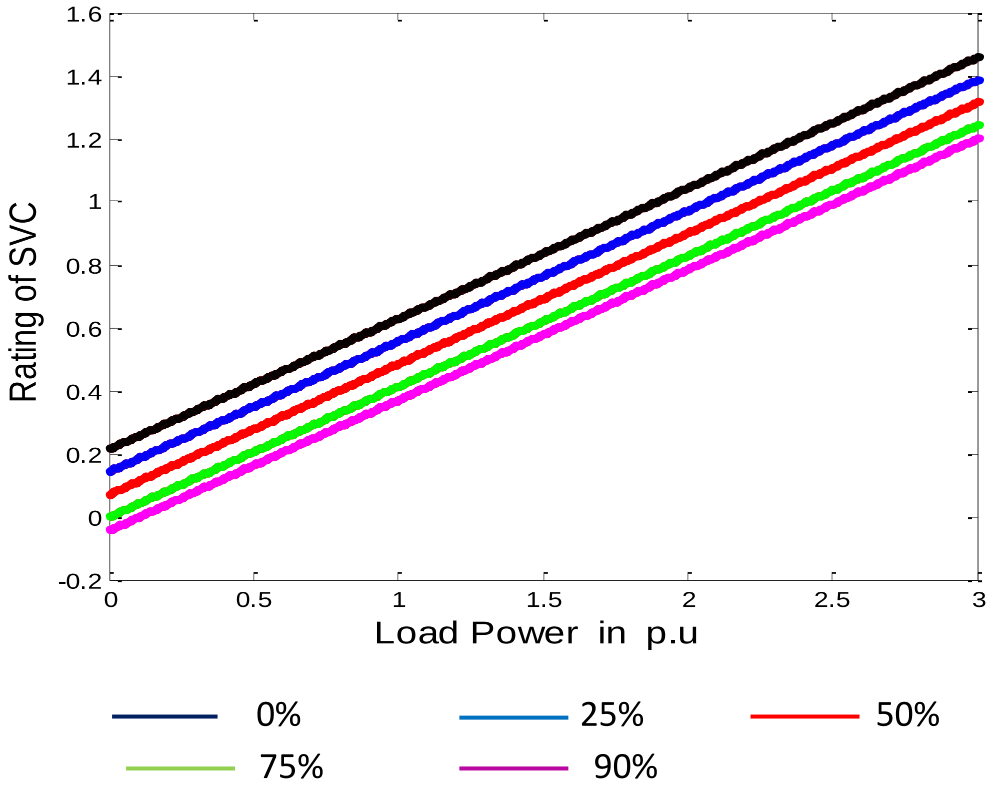

Fig. 5.6 SVC rating required to stabilize the load voltage at certain values in the presence of SC of different percentages

Fig 5.6 shows that the presence of SC leads to less SVC required rating for the same loading and voltage conditions .At the resonance condition (series compensation = 100%).Impracticable values are required for keeping the load voltage constant ,for a load of 3p.u. .An SVC rating of 80p.u. is required.

5.3.3 (b) RATING OF SVC(BC) V/S SERIES COMPENSATION

In order to study the influence of the series compensation on the SVC ratings with different SVC controller gains Fig 5.7 is plotted. The figure shows minimum ratings at higher series compensation percentages. Moreover, lower gains are accompanied by lower SVC rating and vice versa .Steep decrease with increasing the series compensation percentage is noticed.

SCRIPT FILE:

```
Q=0.18
Xs=0.3125
Rs=0.08126
slope = 0.2
H=1
P=0.3
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99
G=100

for  Xc=0:.001:0.3200

Bc =(((Vt)^(2))-((Vt*Vs))+(((Rs))*P)+((Xs*Q-Xc*Q)G))/((Vt)^(2)*slope)

plot(Xc,Bc,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','k',...
                 'MarkerFaceColor','K',...
                 'MarkerSize',1)



            hold all

end
Q=0.18
Xs=0.3125
Rs=0.08126
slope = 0.2
H=1
P=1.2
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99


G=150

for  Xc=0:.001:0.3200
```

```
Bc =(((Vt)^(2))-((Vt*Vs))+(((Rs))*P)+((Xs*Q-Xc*Q)G))/((Vt)^(2)*slope)


plot(Xc,Bc,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','b',...
                 'MarkerFaceColor','b',...
                 'MarkerSize',1)



            hold all

end
Q=0.18
Xs=0.3125
Rs=0.08126
slope = 0.2
H=1
P=2.4
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99
G=250


for  Xc=0:.001:0.3200


Bc =(((Vt)^(2))-((Vt*Vs))+(((Rs))*P)+((Xs*Q-Xc*Q)G))/((Vt)^(2)*slope)


plot(Xc,Bc,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','r',...
                 'MarkerFaceColor','r',...
                 'MarkerSize',1)



            hold all


end
xlabel('Series Compensation ' , 'Fontsize',14)
ylabel('Rating of SVC (Bc)','Fontsize',14)
```

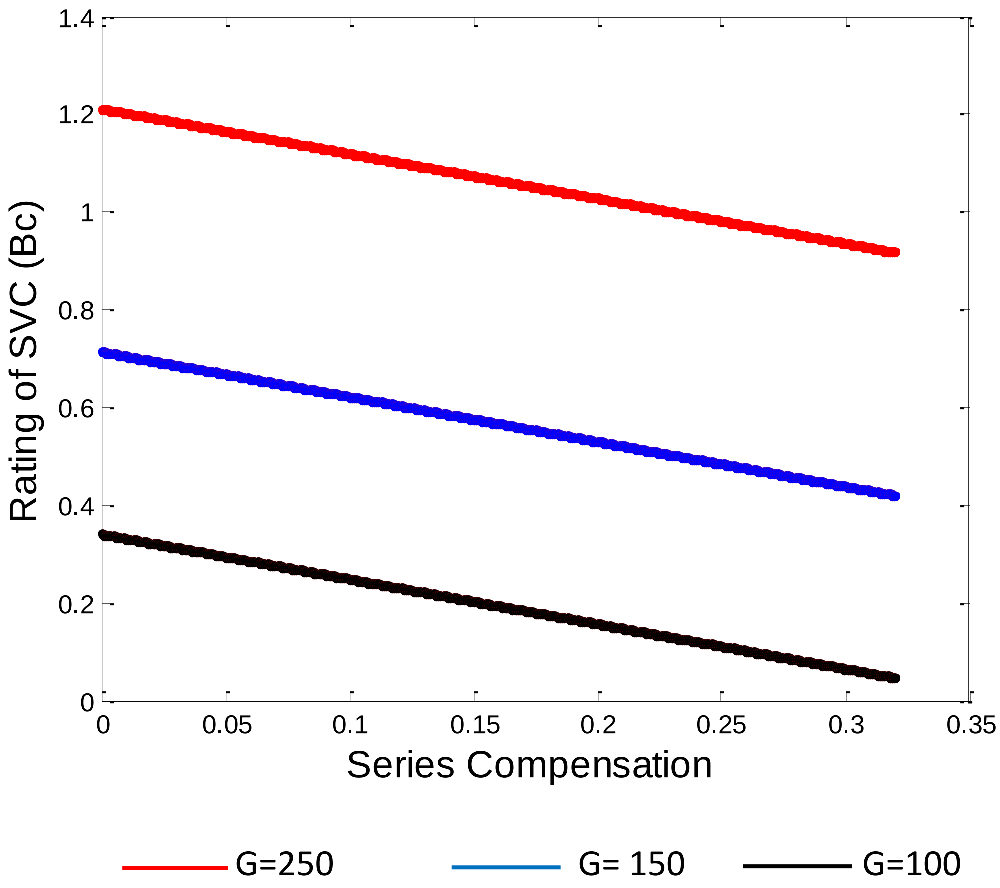

Fig. 5.7 SVC rating at different series copensation percentages and various SVC gains

5.3.4 SERIES COMPENSATION LIMIT FOR VOLTAGE STABILITY ENHANCEMENT

SVC controller gains with different series compensation ratios for certain loads are plotted in Fig 5.8. SVC ratings corresponding to these gains are given in Fig 5.10 .SVC controller reference voltage at three loads 0.3,1.2,2.4 p.u. are plotted in Fig 5.9 and constant reactive power Q=0.18 p.u. .Once more higher gains and higher impracticable reference voltages are required at 100% series compensation. Up to 75% series compensation these values are nearly adjacent. Above this percentage the values of gains and reference voltages are divergent for different series compensation percentages as well as at different load powers. For higher load power these gains or reference voltages become impracticable values. These results reveal clearly that series compensation should be lower than 75% from the voltage stability point of view.

5.3.4 (a) GAIN V/S SERIES COMPENSATION

SCRIPT FILE:

```
P=0.3
H=1
Q=0.18
Xs=0.3125
Rs=0.08126

Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  Xc=0:.001:0.3127

G=-((Vt)^(2))+((Vt*Vs))-(((Rs)*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr))

plot(Xc,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','k',...
                 'MarkerFaceColor','K',...
                 'MarkerSize',1)

            hold all
end
P=1.2
H=1
Q=0.18
Xs=0.3125
Rs=0.08126

Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  Xc=0:.001:0.3127

G=-((Vt)^(2))+((Vt*Vs))-(((Rs)*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr))

plot(Xc,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','b',...
                 'MarkerFaceColor','b',...
                 'MarkerSize',1)

            hold all
end
P=2.4
H=1
Q=0.18
Xs=0.3125
Rs=0.08126
```

```
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  Xc=0:.001:0.3127

G=-((Vt)^(2))+((Vt*Vs))-(((Rs)*P)+((Xs*Q-Xc*Q)))/(Zs*Vt*((H*Vt)-Vr))

plot(Xc,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','r',...
                 'MarkerFaceColor','r',...
                 'MarkerSize',1)

            hold all
end
xlabel('Series compensation ' , 'Fontsize',14)
ylabel('Gain','Fontsize',14)
```

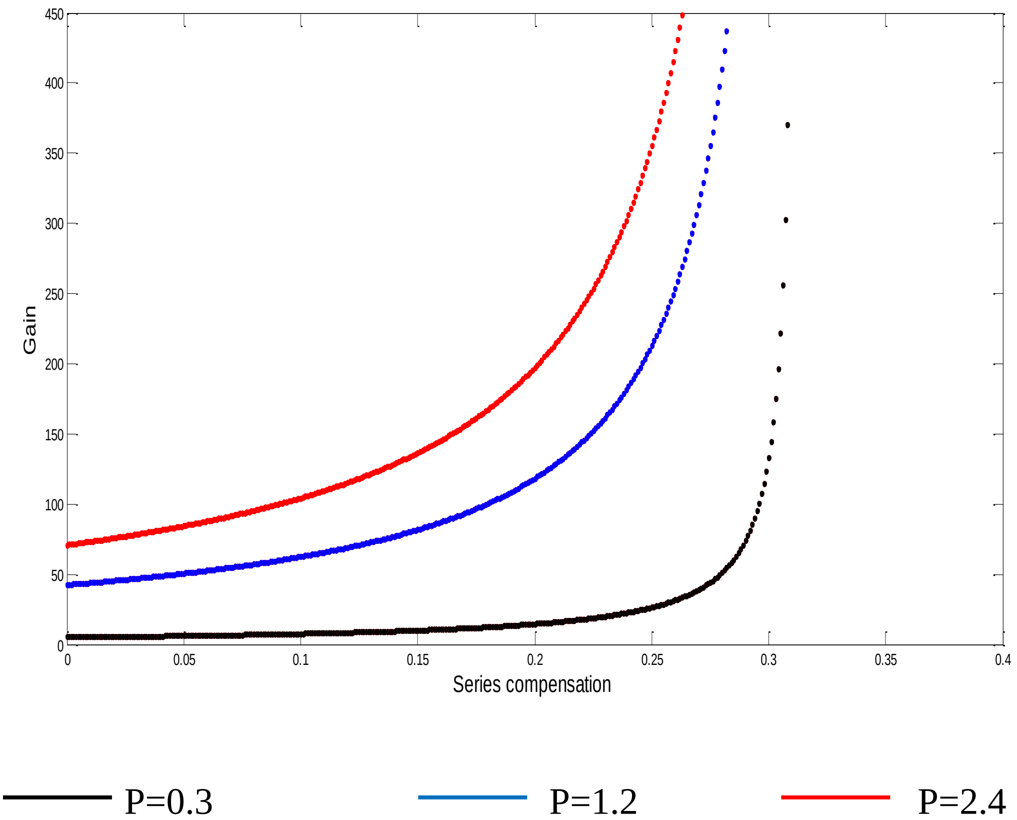

Fig. 5.8 SVC controller gains at different series compensation percentages at three load powers (Q is constant , V_R=1)

5.3.4 (b) REFERENCE VOLTAGE V/S SERIES COMPENSATION

SCRIPT FILE:

```
P=0.3
H=1
Q=0.18
Xs=0.3125
Rs=0.08126
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  Xc=0:.001:0.3127


Vr=(((Vt)^(2))*(1+(G*H*Zs)))-((Vt*Vs))+(((Rs*P)))+(((Xs*Q)-
(Xc*Q)))/((Vt*G*Zs))

plot(Xc,Vr,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','k',...
                 'MarkerFaceColor','K',...
                 'MarkerSize',1)



            hold all

end
P=2.4
H=1
Q=0.18
Xs=0.3125
Rs=0.08126
Vr=1
Zs=0.3228
Vs=1.004
Vt=.99

for  Xc=0:.001:0.3127


Vr=(((Vt)^(2))*(1+(G*H*Zs)))-((Vt*Vs))+(((Rs*P)))+(((Xs*Q)-
(Xc*Q)))/((Vt*G*Zs))


plot(Xc,Vr,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','b',...
                 'MarkerFaceColor','b',...
                 'MarkerSize',1)


            hold all
```

```
end
xlabel('Series Compensation ' , 'Fontsize',14)
ylabel('Reference Voltage in  p.u','Fontsize',14)
```

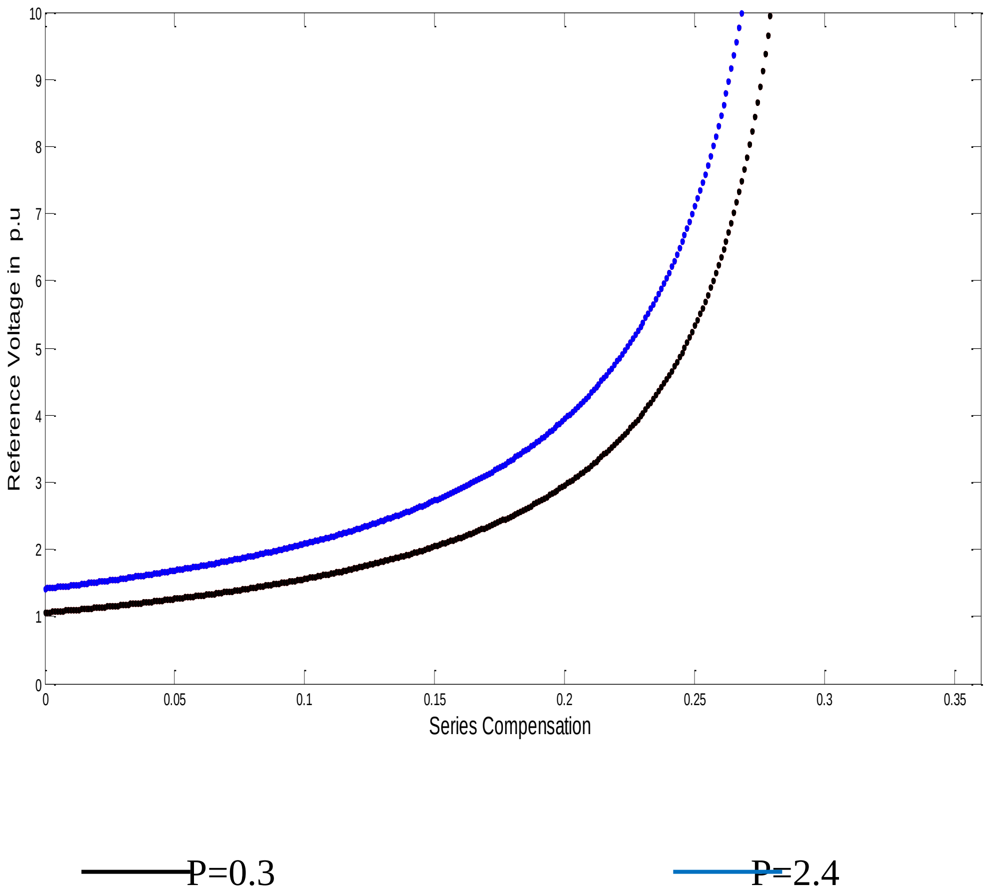

Fig. 5.9 SVC controller reference voltage against series compensation at two load powers (Q is consatant , G=5)

5.3.4 (c) GAIN V/S RATING OF SVC:

SCRIPT FILE:

```
slope=0.2
H=1
Zs=0.3110
Vt=0.99
Vr=1

 for G=0:2:200

rating=(G*(Vr-((Vt)*H))*(Zs))/((Vt)*(slope))

plot(rating,G,'--rs','LineWidth',2,...
                'MarkerEdgeColor','k',...
                'MarkerFaceColor','K',...
                'MarkerSize',1)
```

```
                hold all

 end
slope=0.3
H=1
Zs=0.3110
Vt=0.99
Vr=1

 for G=0:2:200

rating=(G*(Vr-((Vt)*H))*(Zs))/((Vt)*(slope))

plot(rating,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','b',...
                 'MarkerFaceColor','b',...
                 'MarkerSize',1)


                hold all

 end
slope=0.4
H=1
Zs=0.3110
Vt=0.99
Vr=1

 for G=0:2:200

rating=(G*(Vr-((Vt)*H))*(Zs))/((Vt)*(slope))

plot(rating,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','r',...
                 'MarkerFaceColor','r',...
                 'MarkerSize',1)


                hold all

 end
slope=0.5
H=1
Zs=0.3110
Vt=0.99
Vr=1


for G=0:2:200

rating=(G*(Vr-((Vt)*H))*(Zs))/((Vt)*(slope))

plot(rating,G,'--rs','LineWidth',2,...
                 'MarkerEdgeColor','g',...
                 'MarkerFaceColor','g',...
                 'MarkerSize',1)
```

```
                hold all

 end

xlabel('Rating of SVC ' , 'Fontsize',14)
ylabel('Gain','Fontsize',14)
```

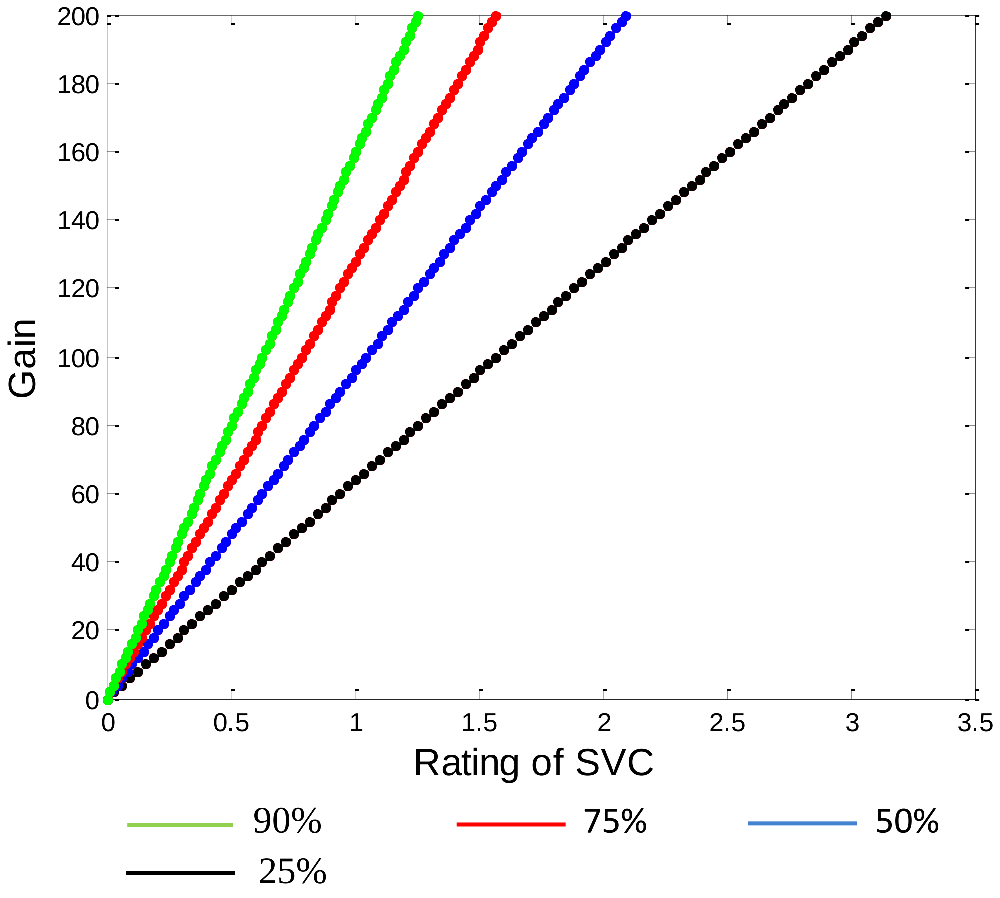

Fig. 5.10 SVC controller gains versus ratings at different series compensation percentage which are able to stabilize the load voltage at 0.99 p.u.(Q is constant)

CHAPTER-6 CONCLUSIONS

1. SC can enhance steady-state voltage stabilities by decreasing the effective series reactance of systems and increasing the load node short-circuit levels.

2. Certain compensation percentages should be avoided while other percentages are recommended.

3. The combination of SC with shunt SVC reduced the required ratings and expenses, with the probable risk of subsynchronous resonance. With network elements SVC ratings are obtained and savings are evaluated with and without SC.

4. The use of only SC has limited effects on voltage instability elimination. Its use with SVC is recommended in UHV networks. In low voltage networks SC effects are not remarkable.

REFERENCES

1. R.L. Hauth, T. Humann, R.J. Newell, “Application of a Static Var System to Regulate System Voltage in Western Nebraska,” IEEE Trans., Vol. PAS-97, No. 5, pp. 1955 1964, Sept/Oct 1978.

2. 2004 SVC User’s List, Report from IEEE Substation Committee, Working Group I4.

3. R.J. Koessler, “Dynamic Simulation of SVC in Distribution Systems,” IEEE Trans. on Power Systems, Vol. 7, No. 3, pp. 1285-1291, August, 1992.

4. P. Lips, Chairman, CIGRE Working Group 14.17, “Semiconductor Power Devices for Use in HVDC and FACTS Controllers,” CIGRE Technical Brochure 112, Paris, France, April 1997.

5. N. Hingorani, L. Gyugyi, “Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems,” New York: IEEE Press, 1999.

6. T. Petersson, Convener, CIGRE Working Group 38.05, “Analysis and Optimization of SVC Use in Transmission Systems,” CIGRE Technical Brochure 77, Paris, France, April 1993.

7. A.E. Hammad, “Comparing the Voltage Control Capabilities of Present and Future Var Compensating Techniques in Transmission Systems,” IEEE Trans. on Power Delivery, Vol. 11, No. 1, pp. 475-484, January 1996.

8. C.W. Brice III,Voltage drop calculations and power-flow studies for rural electric distribution lines,IEEE Trans. Ind. Appl. 28 (4) (1992).

9. I.B.Viswanathan, Effect of series compensation on the voltage instability of EHV long lines, Electr. Power Syst. Res. J. 6(1983) 185-191.

10. C.W. Taylor Power System Voltage Stability and Control, McGraw-Hill,New York,1993.

11. T.H.M.C,Series capacitors foil flickers,Electr. World(5) (1995) 84-85.

12. M.D. Cox, A. Mirbod, A new static VAR compensator for an arc furnace, IEEE Power Sys. PWRS-1 (3) (1986) 110-119.

13. E.R. Johnson, P.S. Hasler,R.J. Moran, C.H. Titus, Static high-speed VAR control for arc furnace flicker reduction , Proc. Am. Power Conf.(1972) 1097-1105.

14. G.D. Brener, H.M. Rustebakke, R.A. Gibley, H. Jirar,The use of series capacitor to obtain maximum EHV transbility, IEEE Trans. Power Appar. Syst. 11(1964) 1090-1101.

15. E.W Kimbark, Improvement of system stability by series capacitors,IEEE Trans. Power Appar. Syst. 2 (1966) 180-188.

16. J.M. Barcus, S.A. Miske Jr., A.P. Vitois,H.M. May,G. Peterson, The varistor protected series capacitor at substation, IEEE Trans. Power Deliery 3 (1988) 1980-1985.

17. A.E. Hammad, M.Z. El-Sadek, Prevention of transient voltage instability due to induction motor loads by static VAR compensators, IEEE Trans. Power Syst. 4 (3)(1989) 1182-1190.

18. D. Dickmander, B. Thorvaldsson, G.Stromberg, D. Osborn, A.Poitras, D. Fisher, Control system design and performance verification for the Chester, Maine static VAR compensator, IEEE Trans. Power Delivery 7 (3) (1992) 1492-1503[12].

19. Shenghu Li, Ming Ding, Jingjing Wang, Wei Zhang, "Voltage control capability of SVC with var dispatch and slope setting" , Electric Power Systems Research, Volume 79, Issue 5, May 2009, Pages 818-825.

20. Y. Wang, H. Chen, R. Zhou, "A non linear controller design for SVC to improve power system voltage stability", International Journal of Electrical Power & Energy Systems, Volume 22, Issue 7, 1 October 2000, Pages 463-470.

21. C.S. Chang, J.S. Huang, "Optimal SVC placement for voltage stability reinforcement", Electric Power Systems Research, Volume 42, Issue 3, September 1997, Pages 165-172.

22. P.K. Modi, S.P. Singh, J.D. Sharma," Fuzzy neural network based voltage stability evaluation of power systems with SVC", Applied Soft Computing, Volume 8, Issue 1, January 2008, Pages 657-665.

23. M. Z. El-Sadek, G. A. Mahmoud, M. M. Dessouky, W. I. Rashed," Effect of control systems on compensators rating needed for voltage stability enhancement*",* Electric Power Systems Research, Volume 50, Issue 2, 18 May 1999, Pages 139-145.

24. Perez, M.A.; Messina, A.R.; Fuerte-Esquivel, C.R," Application of FACTS devices to improve steady state voltage stability",Power Engineering Society Summer Meeting, 20 July 2000. IEEE, Volume: 2, Page(s): 1115 - 1120.

25. M.Z. El-Sadek,et al, "Enhancement of steady-state voltage stability by using static VAR compensators", Electric Power System Research, 43 (1997) 179-185.

26. Mark Ndubuka NWOHU, "Voltage Stability Improvement using Static VAR Compensator in Power Systems", Leonardo Journal of Sciences ISSN 1583-0233, P 167-172, issue 14 January-June 2009.

27. Dr. N Kumar, Dr. A Kumar, P.R. Sharma, “Determination of optimal amount of location of series compensation and SVC for an AC Transmission System”, IE (I) Journal-EL, Vol. 83, March 2003.

28. M.Z. El-Sadek,et al, “Series capacitor combined with static VAR compensator for enhancement of steady-state voltage stability”, Electric Power System Research, 44(1998) 137-143.

29. P. Kundur: “Definition and classification of power system stability”, in IEEE Transaction on Power Systems, Vol.19, No. 2, May 20004, p. 1387-1401.

30. T.V Cutsem: “Voltage stability of electric power system”, Springer, 1998 .

31. “On-line Voltage Stability Assessment of Power System -An Approach of Black-box Modelling” Sami Repo PhD Thesis.

32. “Power system stability and control” Prabha Kundur ISBN 0-07-035958-X.

33. “Power system voltage stability” Carson W. Taylor ISBN 10-0071137084.

34. “Voltage stability of electric power systems” Thierry Van Cutsen, Costas Vournas ISBN 0-7923-8139-4.

35. “Use of series FACTS devices in modern transmission system” Rafał Bukowski MSc. Thesis, Warsaw University of Technology, Poland 1999.

36. “Understanding FACTS” Narain G. Hingorani, Laszlo Gyugyi ISBN 0-7803-3455-8.

SCOPE FOR FUTURE WORK

1) Location of series capacitor can be determined for optimal performance along with tap-changing transformer and static VAR compensator for improving the voltage stability.

2) Future work related to study of voltage regulation and voltage stability should be focused in the area of load modeling. In particular, the static load characteristics and percentage of dynamic motor load needs to more accurately reflect, what is in the "real system" under study. The load model has significant influence on the system's response to disturbances, and therefore significantly influences the rating of any proposed solution.