The use of series capacitors in long distance Extra High Voltage (EHV) Transmission has become very common, since it offers an effective economical means of improving stability limits the transmission lines that are capable of carrying large blocks of power over long distances. They are also highly valuable in other respects such as voltage regulation, reactive power balance, load distribution etc. while the shunt reactors improve the voltage control facilitate line-energisation and reduce temporary transient over voltages.

Due to practical economical reasons, the compensating elements are located at few points along the line instead of being distributed over the entire length of the line location, circuit schematic of series capacitor shunt reactor stations are the deciding factors for maximum power transfer capability, voltage control conditions efficiency of power transmission of the compensated transmission system.

Due to above considerations, in the present work various schemes of series shunt compensation are considered for investigation. The analytical expressions for maximum load end power for various schemes are derived in terms of capacitive reactance used, sending end and load end voltages, and generalized line constants. The optimum value of compensation for each scheme has been determined.

In the present study, an analytical approach is presented for comparative study of series and shunt compensation schemes of long transmission lines connected to the large load area based on maximum power transfer capability for the voltage stability consideration. The following cases are considered for investigations.

1. Capacitor banks located at sending end of the transmission line without Static VAR System (SVS).
2. Capacitor banks located at midpoint of the transmission line without SVS.
3. Capacitor banks located at load end of the transmission line without SVS.
4. Capacitor banks located at sending end of the transmission line with SVS placed at the midpoint of the transmission line.
5. Capacitor banks along with SVS located at the midpoint of the transmission line.
6. Capacitor banks located at load end SVS located at the midpoint of the transmission line.
7. Capacitor banks and SVS located at load end of the transmission line.

For the 400 kV line under consideration the following simulation studies are performed in MATLAB for the various cases mentioned above:

1. Optimum value of degree of series compensation is determined.
2. With optimum value of degree of series and shunt compensation, the maximum $P_{R(max)}$ has been determined.
3. Based on results obtained in the above mentioned cases, a comparative study is made between the compensation schemes with or without shunt compensation.
4. Maximum power transfer capability within voltage stability limit is determined.

The variation of $P_{R(max)}$ and compensation efficiency ($\eta$) has been studied with degree of series compensation within voltage stability limit both tap changer transformers and static VAR compensator can contribute to power systems voltage stabilities. Combining these two methods will improve voltage stability. The effect of the presence of tap changing transformers on static VAR compensator controller parameters and ratings required to stabilize load voltages at certain values are highlighted. The inter relation between transformer off nominal tap ratios 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 v/s voltage nose curves are found their influences on the maximum power/critical voltage are studied. Several studies have shown that transformers with automatic tap changing can be used for improvement of voltage stabilities, for both steady state transient voltage stabilities. Some of these studies were interested in proposing new models for tap changing transformer.

On the other hand, static VAR compensator is used for improvement of voltage stabilities, due to lines opening in the presence of induction motors or due to recoveries of short circuit at induction motor terminals or due to heavy loadability or due to high impedance corridors due to switching off parallel circuits. Effects of the tap changing transformers static VAR compensator effects are studied. The influence of the tap changing transformers on compensator gains, reference voltage and values ratings are given in detail. The studied system represents any large system seen from the load node under consideration. Static VAR
compensator rating controller reference gains are found in order to stabilize load voltage at certain specified values.

The objective of the present research is enhancement of voltage stability in power systems using series and shunt compensation. For this in first phase work to determine the optimal amount and location of series compensation and SVS in long transmission line connected to the large load area is carried out. In second phase the research is carried out to improve voltage stability of the power system with the application of optimally located Static VAR compensator optimal series capacitor compensation of the long transmission line. The application of the tap changing transformer has also been explored for further improving the voltage stability.

The main contribution of the present thesis is to enhance the steady state voltage stability of power system using series capacitor compensation, shunt compensation by Static VAR System (SVS) and tap changing transformer. The optimal amount and location of series capacitor along the line feeding a large load area have been determined in order to enhance the voltage stability. During the literature survey it is observed that most of the work is based upon dynamic performance of the system. However the multi functional modeling represented in the literature do not reflect the accurate dynamics of the system and literature sufficiently lacks in the steady state performance of the system. In the literature it is observed that variable degree of series compensation has not been employed in the long transmission system and the system behavior under varying degrees of compensation requires further investigation. The shunt compensation FACTS devices have not been thoroughly explained with regards their application for voltage stability control. The characteristics of shunt and series FACTS devices is required to be investigated keeping in the view their steady state behavior.

The contribution of the current work are as follows:

- An analytical work has been carried out in order to locate the series and shunt compensation along the transmission line connected to the large load area. The comparison criterion have been developed in order to study the performance of the line. In the study the voltage stability of the power system, the location of series and shunt compensation are to play an important role. The compensation criterion include the
Maximum Load End Power \( (P_{R_{\text{max}}}) \), Optimum Value of Series Capacitive Reactance \( (X_{C_{\text{opt}}}) \) And Compensation Efficiency \( (\eta_{C}) \). The generalized expressions in terms of series capacitive reactance \( X_c \) have been derived.

- The compensation scheme where series capacitor and SVC both are located at the middle of the transmission line gives the best performance with regards to Maximum load power, \( P_{R_{\text{max}}}, \) Optimum series compensation \( X_{c_{\text{opt}}} \) and compensation efficiency \( \eta_{C} \) criterion developed.

- The series compensated large power system has been represented by its equivalent two nodes system. The effect of using SVC and tap changing transformer in enhancing the voltage stability of the series compensated power system has been observed. The detailed derivations for the terminal voltage \( V_{t1} \) and \( V_{t2} \) incorporating the series compensation have been derived.

- From the study of the P-V curves (nose-curves) without series compensation, it is seen that the knee – point voltage increase when the SVC gain is increased. Hence the voltage stability improves on increasing SVC gain.

- The effect transformer tap ratio \( (t) \) is negligible or almost zero at the knee point voltage. Although its effect is prominent at the lower values of load power.

- When series compensation is employed and varied from 10% to 90% the voltage of knee point improves and occurs at higher values of load power. For every 10% increase in degree of series compensation gives almost 7% increase in maximum load power corresponding to the knee point. The maximum load power corresponding to knee point varies linearly with the degree of series compensation.

- It is noticed that the off- nominal tap ratio variation does not affect the critical power values at various SVC gains i.e. its value remains constant at all off- nominal tap ratios. However the off-nominal tap ratio affects largely the voltage magnitude at no load or smaller load conditions.

- For a given load power below the maximum there are two solutions one with higher voltage and lower current and the other with lower voltage and higher current. The former gives the normal operating conditions with voltage closer to the generator voltage \( E \).

- As the load is highly compensated the maximum power increases, however the voltage at which this maximum occurs also increases. This situation is dangerous in the sense that
maximum transfer capacity may be reached at voltages closed to normal operating values. Also for a high degree of compensation and a load power close to the maximum, the two voltage solution are closed to the each other and without further analysis it may be difficult to decide if a given solution is the normal one.

- From the plots it is evident that terminal voltage is heavily dependent upon the reactive power. With increase in Q (Reactive power) the terminal voltage starts decreasing. It depicts need of capacitive reactance power compensation. But if there is increase in voltage with increase in Reactive power than inductive reactive power need to be injected. We can manage any kind of change in terminal voltage by using different tap setting of tap changing transformer but in actual practice the tap changing phenomenon is very cumbersome. In order to have minimum changes in tap setting we can control the terminal voltage by compensating the required reactive power with the help of fast switching(active) devices like “FACTS” devices.

- From the study of curves gain v/s active power and gain v/s reactive power it is seen that to obtain the same value of load power with different nominal tap ratios different SVC gains should be adjusted adaptively.

- From the study of the curves SVC gain v/s slop it is seen that different compensator power ratings are required at each compensator controller gain in order to keep load voltage constant in the presence of automatic tap changing transformer of different nominal tap ratios.

- In order to keep the load voltage constant at different values tap ratios, the gain v/s reactance relation is an inverse characteristics.

- The study of reference voltage v/s active power curves shows that increasing gain requires very close reference voltage at different off-nominal transformer tap ratios. A lower tap ratio requires lower reference voltages than those with high ratios in order to keep the terminal voltage constant.

- The use of series capacitor compensation and static var compensator for shunt compensation have been finally recommended for enhancing the voltage stability of power system feeding a large load area through a long transmission line.

This thesis is organized as under:
Chapter 1 presents the detailed introduction to the subject matter of the thesis and basic aspects of series and shunt compensation with a view to enhance voltage stability and power transfer capability of the power system.

Chapter 2 presents an exhaustive review starting from the first incidence of series compensation of a long transmission to VAR compensator, SVS Tap changing transformer for improving the voltage stability is carried out.

Chapter 3 is organized to analyze series compensation schemes considering all the six cases of compensation scheme. In each case, optimum value of series capacitive reactance, optimum value of degree of series compensation, maximum load end power, optimum value of compensation efficiency are calculated. Based on the results obtained in all the six cases, a comparative study is made between compensation schemes with and without shunt compensation.

Chapter 4 introduces a case study long transmission line connected to the large load area has been considered for analysis for different locations of series and shunt compensation. The analysis has been carried out and plots are drawn between $P_{R\text{max}}$ and degree of series compensation compensation efficiency ($\eta_c$) and degree of series compensation ($S\%$) for the six cases.

Chapter 5 discusses and analyze the work to improve voltage stability of the power system with the application of optimally located Static VAR compensator, optimal series capacitor compensation of the long transmission line. The application of the tap changing transformer has also been explored for further improving the voltage stability.

Chapter 6 simulates the suitable power systems for enhancement of steady state voltage stability using SVS, Tap changing transformer and series compensation. Following plots are rendered to study the effects:

- Power versus voltage curve with the presence static VAR compensator tap changing transformer.
- The plots between load power voltage responses with presence of series capacitor, tap changing transformer static VAR compensator are drawn.
- Static VAR compensator parameters in the presence of load tap changing transformer
• Influence of tap changing transformer on SVC controller gain versus slope relation
• Compensator controller reference in presence of tap changing transformer.
• (P,Q,V) Curve, voltage as function of load active and reactive powers.

Chapter 7 concludes the major outcomes of the thesis based upon case study and its simulation. The future directions of the current work are also projected. The thesis ends with a list of the references cited.