CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents the review of various concepts and techniques that were used for analysis of voltage stability, maximum loadability and transmission loss minimization. It also reviews the various types of FACTS devices, which are used in the power system network to improve the voltage stability.

2.2 VOLTAGE STABILITY

Flatabo et al (1990) have presented a method for determining the voltage stability condition in the power system. It is based on sensitivity techniques and considered the limits on reactive power generation capacities. Semlyen et al (1991) have proposed the method to calculate the extreme loading condition of a power system for the assessment of voltage stability. Its calculation is based on increasing the load admittances, while first keeping the generator voltage phasors constant and then adjusting these phasors for satisfying operational requirements with respect to the generation power. The secant method is used for the efficient and reliable determination of the maximal value of the loading parameter.

Gao et al (1992) have discussed the voltage stability analysis of large power systems by using a modal analysis technique. They computed a steady-state system model, a specified number of the smallest eigen values
and the associated eigenvectors of a reduced Jacobian matrix. The eigenvalues, each of which is associated with a mode of voltage or reactive power variation, provide a relative measure of proximity to voltage instability. The eigenvectors are used to describe the mode shape and to provide information about the network elements and generators which participate in each mode. Bridenbaugh et al (1992) have studied the existing and planned voltage control devices on the Ohio-Edison transmission and sub-transmission system. They determined the transformer tap settings and reactive allocation to provide the best possible voltage profile for all expected system conditions while minimizing losses and reactive imports. The estimation of the voltage stability region of power systems was presented by Hong & Wang (1995). The power flow solutions were utilized to estimate the voltage stability region of the taps of On-Load Tap Changers (OLTC), voltage magnitudes, and phase angles. The coupling relation between the real and reactive powers was taken into account.

Greene et al (1997) have presented a sensitivity of the loading margin to voltage collapse with respect to arbitrary parameters. Linear and quadratic estimates to the variation of the loading margin with respect to any power system parameter or control were derived. This estimate can predict the quantitative effect on the loading margin of altering the system loading, reactive power support, wheeling, load model parameters, line susceptance and generator dispatch.

Wan et al (2000) have presented the risk based voltage security assessment for a voltage stability constrained power system. The risk calculation accounts both the future uncertainties on the system and the consequences associated with voltage collapse and violation of limits. They also give an introduction to show how this reliability “leading indicator” penetrates the traditional rigid reliability boundary and how it may be used to
price reliability in order to make a trade off between reliability and economics. Wang & Lasseter (2000) have proposed a method to increase a power systems security margin and or support its low voltage bus by re-dispatching generator outputs, using a normal vector found at a voltage collapse boundary or a Low Voltage Boundary (LVB). This method uses the normal vector as an indicator to change the generation direction so that more power can be transferred before reaching a boundary of a critical limit such as the voltage collapse boundary or LVB, etc. Yoshida et al (2000) have presented PSO for voltage Var Control (VVC) considering voltage security assessment (VSA). They formulated the VVC as a Mixed-Integer Non-Linear Programming (MINLP) problem. This method expands the original PSO to handle a MINLP and determines an online VVC strategy with continuous and discrete control variables such as AVR's operating values of generators, tap positions of OLTC's of transformers, and the number of reactive power compensation equipment.

Sinha & Hazarikab (2000) have compared the effectiveness of voltage stability indices in providing information about the proximity of voltage instability of a power system. They proposed the three simple voltage stability indices, and their effectiveness was compared with some of the recently proposed indices. The comparison was carried out over a wide range of system operating conditions by changing the load power factor and feeder x/r ratios. Mohn & Souza (2002) have discussed the important aspects related to voltage collapse point identification and developed a fast decoupled continuation method is proposed, with some special features. Prada et al (2002) presented a voltage stability assessment for real-time operation. Network voltage stability is represented by nodal conditions associated with the maximum active and reactive power flow that can be transmitted from generators to loads. An analytical assessment tool is derived, based on a simple but sound mathematical background, modeling a straightforward physical characterization of the phenomena. They indicate the MVA margin
to the maximum, the region of operation, the relative importance among buses, the loading ranking of the buses, the sensitivity to control actions, and a measure of difficulty for power transmission. The correlative relationship between a generator var reserves and system voltage stability margins, a practical and systematic method for online voltage stability monitoring was proposed by Bao et al (2003). Amjady & Esmaili (2003) have proposed the method to evaluate voltage stability status efficiently in both pre-contingency and post-contingency states considering the effect of active and reactive power limits. They employed the adaptive continuation technique and local analysis of the contingency effect. They determine the vulnerable buses of the power system with respect to voltage security.

Kataoka (2003) has proposed a nodal loading model for use in voltage stability assessment of electric power systems. The formulation of worst cases based on this model, as well as related numerical methods, are described. In this nodal loading model, called the "hyper-cone" model, a set of future operating points in a load parameter space is modelled. That is, the "vertex" of the hyper-cone is taken to be the current operating point, and the "thickness" of the hyper-cone represents the uncertainty of future loading. The worst loading case is the point, among the set of transfer limit points on or within the hyper-cone, at which the total load is smallest. In other words, in terms of the uncertainty of future loading, the worst case corresponds to the most conservative transfer limit.

Luis et al (2004) have proposed a critical evaluation of a maximum loading point estimation method. The critical point was estimated from a set of operating points corresponding to different loading levels. Different factors that affect the efficiency and precision of the method are analyzed. Visakha et al (2004) have proposed the network sensitivity between load voltages and source voltages to compute voltage stability index, and it was used as the
basis to evaluate desirable load sharing for improving stability margins. Satpathy et al (2004) have proposed the critical switching of capacitors for preventing voltage instability in transmission networks. Through static analysis, the steady-state power flow solutions were obtained for the three distinct scenarios, namely, pre-disturbance steady-state, post-disturbance steady-state without any var support and post-disturbance steady-state with var support. Line outage contingencies supporting the disturbance were simulated and the effect was observed at the most critical bus bars for the analysis of voltage instability. A dynamic analysis was conducted involving the post-disturbance dynamic recovery of the aggregated load.

Esaka et al (2004) have presented the voltage stability preventive control using Voltage Stability Index (VSI). Here, Pre-contingency analysis was simulated and ranked by VSI. The VSI was based on the conventional index, and it was used for assessing the effect on voltage stability in different generators. Sauza et al (2004) have studied the problem of increasing the loadability of power systems linked to voltage collapse occurrences. They addressed the impacts of local control actions on the system loadability. The study was carried out in two steps. First, by using the tangent vector technique, two important areas of the power system are identified: the critical area under the point of view of voltage collapse, and the area most sensitive to active power losses reduction. Second, once these two areas are identified, an optimization technique takes place to optimize the amount of shunt reactive power compensation that should be available in each bus. Affonso et al (2004) have presented a methodology to improve the power system economic dispatch from a Voltage Stability Margin (VSM) perspective. It was based on active/reactive power re-dispatch for normal operation, and also minimum load shedding strategies in case of critical contingencies. The actions were taken in the direction provided by modal participation factors computed for generator and load buses. Arya et al (2005) have described a technique for
improving static voltage stability by rescheduling reactive power control variables. The algorithm was based on sensitivities of minimum eigen value with respect to reactive power control variables. Objective function was selected for minimization of deviation of squares of reactive power control variables subject to desired increase in minimum eigen value of the load flow Jacobian. They used the lagrangian optimization technique closed form relations for corrections in reactive power control variables.

Milano et al (2005) have proposed two novel techniques for including contingencies in Optimal Power Flow (OPF) based electricity market computations and for the estimation of a System-wide Available Transfer Capability (SATC). The OPF problem formulation includes voltage stability constraints and a loading parameter in order to ensure a proper stability margin for the market solution. The first technique was an iterative approach and computes an SATC value based on an (n-1) contingency criterion for an initial optimal operating condition. Then solve an OPF problem for the worst contingency case, this process was repeated until the changes in the SATC values are below a minimum threshold. The second approach solves a reduced number of OPF problems associated with contingency cases according to a ranking, based on a power transfer sensitivity analysis of the transmission lines.

Hongjie et al (2005) have focused on the aspect of improved VSI. They considered the influence of the load model for accurate indication to power system voltage instability. Dong at al (2005) have proposed an optimized reactive reserve management scheme based on the optimal power flow. They consider the generator limits in order to utilize the maximum reactive power capability of generators, so as to meet reactive power demands during voltage emergencies. Participation factors for each generator in the management scheme were predetermined based on the voltage-var curve
methodology. The bender's decomposition methodology was applied to the reactive reserve management problem. Kataoka & Shinoda (2005) have investigated the smoothness of the transfer limit surface or the loadability surface of power systems. They considered the reactive power output constraints of generators, and the investigation was based on characterizing each maximum loading point by the state of the generators. Then the transfer limit surface was investigated through careful observation of nose curves. Shao & Vittal (2005) have developed a algorithm to find corrective switching algorithm for relieving overloads and voltage. The algorithm is developed to find the best line and bus-bar switching action for relieving overloads and voltage violations caused by system contingencies based on a sparse inverse technique and fast decoupled power flow with limited iteration count. A general model of bus-bar switching action is also presented such that the algorithm can simulate any kind of complicated bus-bar switching action. Based on proposed voltage distribution factor by multiple iterations in power flow calculation, a novel algorithm for corrective voltage control by shunt switching is developed. These two algorithms are then integrated into a corrective switching algorithm.

Prada et al (2005) have proposed sequential iterative method for weakest bus, most loaded transmission path and critical branch identification for voltage security reinforcement. Esmin et al (2005) have studied a Particle Swarm Optimization (PSO) as a tool for loss reduction. The study was carried out in two steps. First, by using the tangent vector technique, the critical area of the power system was identified under the point of view of voltage instability. Second, once this area was identified, the PSO technique calculates the amount of shunt reactive power compensation that takes place in each bus.
Shao & Vittal (2006) have proposed the Linear Programming (LP)-based OPF algorithm for corrective FACTS control to relieve overloads and voltage violations caused by system contingencies. The optimization objective is chosen to minimize the average loadability on highly loaded transmission lines. A new set of parameter sensitivities of FACTS devices are derived to include the operational constraints of FACTS devices during optimization. In order to reduce the effect of errors due to linearization, all sensitivities can be updated during the OPF iterations.

Amgad et al (2006) have proposed the newly developed evolutionary PSO in solving this optimization problem. They formulate the maximum loading point estimation problem as an optimization problem and find the margin from the current operating point to the maximum loading point of the system. Pablo et al (2007) have presented the estimation of post-contingency voltages and reactive power generation and flow using sensitivities. Shin et al (2007) have presented an Optimal Routing Algorithm (ORA) for minimizing power loss and at the same time maximizing the voltage stability in radial power systems. VSI for real-time assessment was introduced based on the conventional critical transmission path framework. In addition, the algorithm can automatically detect the critical transmission paths that will result in a voltage collapse when additional real or reactive loads were added.

Amraee et al (2007) have proposed an optimal load-shedding algorithm to provide voltage stability. They modelled the voltage stability criterion directly into the load-shedding scheme. This approach was based on the concept of the static voltage stability margin and its sensitivity at the maximum loading point or the collapse point. Tripathy & Mishra (2007) have presented the bacteria foraging-based solution to optimize both real power loss and voltage stability limit. Optimal location and control of UPFC along
with transformer taps are tuned with a view to simultaneously optimize the real power losses and Voltage Stability Limit (VSL) of a mesh power network. Amgad et al (2007) have proposed a solution technique for finding the optimum location and sizing of the shunt compensation devices in transmission systems. They formulate the problem as an integer non-linear optimization problem and solved by using PSO method. Hu & Wang (2008) have introduced a method for obtaining the MLP of electric power systems based on the load flow method with optimal multiplier in rectangular coordinates. This method starts from an infeasible point beyond power system maximum loadability and approaches the MLP iteratively.

Kamarposhti & Soltani (2009) have proposed the effects of shunt capacitor, SVC and STATCOM in static VSM enhancement. Perninge et al (2010) have presented a novel method for estimation of the probability distribution of the time to voltage instability for a power system with uncertain future loading scenarios. The method uses a distance from the predicted load-path to the set of voltage unstable operating points when finding an estimate of the time to voltage instability.

Murali & Rajaram (2010) have described the real and reactive power flow control through a transmission line by placing the UPFC at the sending end of an electrical power transmission system. The power flow control performance of the UPFC was compared with other FACTS device. Zhang et al (2007) have proposed normal forms of diffeomorphism allocation method for power system voltage stability enhancement. This method makes use of the nonlinear participation factors, in which the nonlinearity of power systems can be taken into consideration. The suitable location where the SVC should be used in power system is determined even for the cases in which the system is characterized with strong nonlinearity.
Leonardi & Ajjarapu (2011) have investigated the use of Reactive Power Reserves (RPR) as an indicator to estimate VSM in an online environment. The methodology relies upon the relationship between system-wide RPRs and VSM. Statistical Multi-Linear Regression Models (MLRM) is utilized in order to express how variations in RPRs can be transformed into direct information about VSM. Data regarding RPRs and system VSM are obtained through an offline voltage stability assessment and stored in a database for further MLRM development. Different load increase directions and a comprehensive list of contingencies are considered to account for uncertainty present in real-time operations. Perninge & Soder (2011) presented a novel method for estimation of the probability distribution of the load-space distance to the point where voltage instability induced by saddle-node bifurcation occurs. This method is also estimate of the probability distribution of the time to voltage instability for a power system with uncertain future loading scenarios. The method uses a second order approximation of the saddle-node bifurcation surface.

Rambabu et al (2011) have proposed a systematic method for optimal location of multi-type FACTS devices. FACTS devices model was incorporated into a Newton Raphson (NR) algorithm to perform load flow analysis. Nagalakshmi & Kamaraj (2011) have proposed an algorithm for the optimal location and control of FACTS devices for enhancing the loadability in transmission system using PSO and Differential Evolution (DE) for pool and hybrid model in a deregulated electricity market.

Mansour et al (2013) have presented a method for selection of the most effective controls to prevent voltage instability in electrical power systems. It is based on a sensitivity analysis of both a maximum loadability estimate (which is obtained via Look-Ahead method) and the load flow solution with respect to the selected controls. These sensitivities are
calculated without computing the maximum loadability points, which significantly speeds-up the analysis.

2.3 CONTINUATION POWER FLOW

Ajjarapu & Christy (1992) have presented a method of finding a variety of power flow solutions starting at some base load and leading to the steady-state voltage stability limit (critical point) of the system. A salient feature of the CPF method is that it remains well-conditioned at and around the critical point. As a consequence, divergence due to ill-conditioning is not encountered at the critical point, even when single-precision computation is used. Musirin & Rahman (2002) have presented the use of line stability index termed as Fast Voltage Stability Index (FVSI) in order to determine the maximum loadability in a power system. The bus that is ranked highest is identified as the weakest bus since it can withstand a small amount of load before causing the voltage collapse.

deSouza et al (2003) have presented a contingency analysis approach for voltage collapse assessment. Here, tangent vector was employed for contingency analysis. The idea consists of monitoring tangent vector norm associated with each contingency, identifying the most critical ones. Dilson et al (2003) have presented the alternative parameters for the CPF method. They uses the new parameterization schemes, namely the total power losses (real and reactive), the power at the slack bus (real or reactive), the reactive power at generation buses, the reactive power at shunts (capacitor or reactor), the transmission lines power losses (real and reactive), and transmission lines power (real and reactive). Mori & Kojima (2004) have proposed the hybrid CPF method of linear and nonlinear predictors to speed up computational time in drawing the PV curve.
Mohn & deSouza (2006) have investigated the use of the Constraint Reactive Implicit Coupling (CRIC) method for the engine of a continuation power flow program. Full Newton continuation power flow methods are robust and accurate but are computationally expensive. Fast decoupled methods provide accurate results and require less computational time, but their performance worsens at heavy loading conditions, where the system active/reactive power decoupling characteristics are lost. The CRIC method preserves the decoupled power flow solution structure but, better models the active/reactive coupling. Garbelini et al (2007) have presented a geometric parameterization scheme that allows the complete tracing of the PV curves without ill conditioning problems. This technique associates robustness to simplicity and, it is of easy understanding. The Jacobian matrix singularity avoided by the addition of a line equation, which passes through a point in the plane determined by the total real power losses and loading factor. Xu et al (2007) have proposed the valuation of reactive power support services based on sensitivity and risk analysis. They proposed the evaluation methodology based on voltage sensitivity and risk analysis from the perspective of voltage regulation.

Li & Chiang (2008) have presented a continuation power flow method with multiple nonlinear power injection variations. To model the nature of nonlinear power injection variations, a piecewise-linear model is proposed to approximate the nonlinear model of power injections. The piecewise-linear model is studied and incorporated into continuation power flow, making it capable of handling nonlinear power injection variations.

2.4 CONTINGENCY ANALYSIS

Berizzi et al (2000) have presented a second order method for contingency severity assessment with respect to voltage collapse. Second order information derived from the singular value analysis of the Jacobian of
load flow equations is used to obtain an effective ranking of contingencies with respect to the voltage collapse. Besides, a quantification of the risk associated to a contingency is provided by a procedure that calculates quasi-linear indices useful both in planning and in operation. Jia & Jeyasurya (2000) have presented a contingency ranking for on-line voltage stability assessment. This method calculates the voltage stability margin considering branch outages.

Flueck et al (2002) have presented a procedure for identifying severe single branch outage contingencies with respect to saddle-mode bifurcation induced voltage collapse, given a power system operating point, a load demand forecast, and a generation dispatch. The power sensitivity ranking algorithm for voltage collapse provides "distance to collapse" estimates than linear admittance sensitivity. Ozdemir et al (2003) have presented a line outage simulation method for reactive power flows that minimizes the errors resulting from the use of linear system models. This method formulates a line outage as a local nonlinear constrained optimization problem. Optimization is used as a feedback to correct the errors resulting from linearized equations. Hwachang et al (2003) have presented a concept of Reactive reserve-based Contingency Constrained Optimal Power Flow (RCCOPF) for voltage stability enhancement. This concept was based on the fact that increase in reactive reserves was effective for enhancement of VSM of post-contingent states.

Bijwe et al (2004) have presented an efficient approach for line outage contingency ranking based on voltage stability concerns. They achieved the contingency ranking through non-iterative fast calculation of reactive support and voltage security indices using Norton’s equivalent. Chen & McCalley (2005) have presented a method for identifying high risk N-k contingencies for online security assessment. They formed a contingency list, based on substation configuration obtained from topology processing
data and probability analysis of protection system failures. This method is particularly suited for online security assessment.

Amjadi & Esmaili (2005) have presented a sensitivity analysis framework for voltage contingency ranking. The sensitivity analysis is a combination of linear sensitivities and eigen value analysis. The sensitivity analysis framework can determine the voltage stability status of the power system due to the occurrence of each contingency. Moreover, stability margin or instability depth of the post-contingency state is determined in the framework. In other words, a severity index is obtained for each voltage contingency and so the contingencies can be ranked. This rank shows bottlenecks of the power system in the priority order, a property that is a key issue for both planners and operators of the power system. This method can also evaluate islanding contingencies as well as the non-islanding ones.

Hazarika et al (2006) have described an algorithm for determining the line outage contingency of a line taking into account of line over load effect in remaining lines and subsequent tripping of over loaded lines leading to possible system split or islanding of a power system. Chen et al (2006) have discussed a number of probability models for multiple transmission line outages in power systems, including generalized Poisson model, negative binomial model, and exponentially accelerated model. These models are applied to the multiple transmission outage data for a 20-year period for North America. The probabilities of the propagation of transmission cascading outage are calculated. These probability magnitudes can serve as indexes for long-term planning and can also be used in short-term operational defence to such events.
Ruiz & Sauer (2007) have discussed the estimation of post-contingency voltage and reactive power generation and flow using sensitivities. Employing piecewise linear estimates, the effect of equipment limits on the estimates is effectively captured. Jafari & Afsharnia (2007) have investigated the application of FACTS devices to extend voltage stability margin in electric power systems. Using modal analysis, a probabilistic index is defined and it can be used to rank of system buses based on their effect on system voltage stability enhancement under all possible contingencies. Singh et al (2007) have presented a reactive power spot price index to determine the optimal location of SVC in the power system. This index has been computed at each bus based on the reactive power spot price under different loading conditions for the system intact and critical line outage contingency cases.

Li & Chiang (2008) have presented the method to improve the CPF method, mainly their speed and to a less extent, their reliability. Nonlinear predictors are developed based on the polynomial interpolations. In addition, a hybrid corrector was developed and incorporated into continuation power flow. Rios et al (2009) have proposed the voltage stability assessment with ranking of contingencies using voltage-var sensibility. They compares some approaches concerning to contingencies ranking using modal analysis of the Jacobian matrix, which include participation factors analysis, aggregated participation factors and nodal sensibility analysis.

Shankar & Ananthapadmanabha (2011) have proposed the method to Identification of critical or weak buses for a given operating condition. They used the fuzzy approach for ranking critical buses in a power system under normal and network contingencies based on line flow index and voltage profiles at load buses. The line flow index determines the maximum load that was possible to be connected to a bus in order to maintain stability before the system reaches its bifurcation point.
2.5 THE FLEXIBLE AC TRANSMISSION SYSTEM

Irisarri et al (1997) has proposed a non-linear optimization Interior Point (IP) method for the determination of maximum loadability in a power system. They presented the implementation of pure primal-dual and predictor-corrector primal-dual IP algorithms for the determination of the maximum loadability in a power system. Chang & Huang (1997) have presented a scheme of hybrid optimization using the Simulated Annealing (SA) and Lagrange multiplier techniques for optimal SVC planning and voltage stability enhancement. They also proposed 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 problem into two sub-problems, an optimal placement SVC and maximization of reactive margin is obtained. Tan & Wang (1997) have proposed the nonlinear coordinated generator excitation, Static Phase Shifter (SPS) and SVC controller to enhance the transient stability of a power system. They control the three main parameters affecting AC power transmission-voltage, phase angle and reactance-in a coordinated manner.

El-sadek et al (1999) have proposed the influence of tap-changing transformer on maximum transmitted power and nodes critical voltages, from the point of view of voltage stability. Canizares & Faur (1999) have presented the detailed steady-state models of SVC and TCSC, to study their effects on voltage collapse phenomena in power systems. Based on results at the point of collapse, design strategies are proposed for these two controllers. So, that their location, dimensions and controls are done optimally to increase system loadability.

Thukaram & Lomi (2000) have presented a methodology for selection of SVC location based on static voltage stability analysis of power
systems. Venkatesh et al (2000) have proposed a Multi-objective Fuzzy Linear Programming (MFLP) method of solution in the Successive Linear Programming (SLP) framework to solve the problem. A set of the least singular values of the load flow Jacobian was used as a VSM indicator. This set was expressed in terms of the control vector and was maximized in the proposed formulation to maximize VSM. Gerbex et al (2001) have presented a genetic algorithm to seek the optimal location of multi-type FACTS devices in a power system. The optimizations are performed on three parameters: the location of the devices, their types and their values. The system loadability is applied as a measure of power system performance. Shubhanga & Kulkarni (2002) have presented a structure preserving energy margin sensitivity based analysis to determine the effectiveness of FACTS devices to improve transient stability of a power system. A structure preserving energy model, which retains the topology of the network was used to derive simple analytical expressions for improvement in energy margin due to series or shunt compensation. The expressions were in terms of current magnitude through a line for series compensation and voltage magnitude at a bus for shunt compensation.

Yorino et al (2003) have proposed a formulation for reactive power planning problem, including the allocation of FACTS devices. A feature of the formulation lies in the treatment of security issues. They directly take into account the expected cost for voltage collapse and corrective controls, where the control effects by the devices to be installed were evaluated together with the other controls such as load shedding in contingencies to compute an optimal var planning. Orfanogianni & Bacher (2003) have presented an optimization-based methodology to identify key locations of a series-connected FACTS device in the network to increases the maximum megawatt power transfer. Canizares et al (2003) have proposed and validated the models to accurately represent static synchronous shunt compensators in voltage and
angle stability studies of power systems. Sharma et al (2003) have proposed the extended voltage phasors approach for placement of FACTS controllers in power systems. The voltage phasors approach identifies only the critical paths from the voltage stability viewpoint; the extended voltage phasors approach additionally locates the critical buses or line segments.

Kundur et al (2004) have addressed the issue of stability definition and classification in power systems from a fundamental viewpoint and closely examines the practical consequence. They define power system stability more precisely and provide a systematic basis for its classification, and discuss linkages to related issues such as power system reliability and security. Natesan & Radman (2004) have studied the effects of three FACTS controllers: STATCOM, SSSC and UPFC on voltage stability in power systems. Hao et al (2004) have presented a mathematical model about optimal location and parameters of UPFC to maximize the system loadability subject to the transmission line capacity limits and specified voltage level. An improved computational intelligence approach: Self-Adaptive Evolutionary Programming (SAEP) is used to solve the nonlinear optimization problem.

Kazemi & Badrzadeh (2004) have presented the steady-state modeling of SVC and TCSC with their control and limits. Bifurcation analysis is applied in order to find the optimal location and rating of these devices and a CPF is used to evaluate the effects of these devices on system loadability. Eigenvector analysis applied at the maximum loading point is used to rank the most critical voltage buses. Boonpirom & Pairoonwattanakij (2005) have investigated the enhancement of voltage stability using FACTS devices. The CPF method was proposed in case of the increasing loading of contingency. They studied the comparison of TCSC with STATCOM compensation to increase the steady-state voltage stability margin of power capability.
Yome et al (2006) have approached the Maximum Loading Margin (MLM) in finding generation directions to maximize the static VSM, where the MLM was evaluated at various possible generation directions in the generation direction space. An approximate and simple model representing the relationship between the generation direction and the loading margin was used to obtain the MLM point. Venkataramu & Ananthapadmanabha (2006) have proposed a novel placement strategy for UPFC, which enhances the voltage stability margin of the system. The location for the installation of UPFC was identified using VSI and the Voltage Change Index (VCI). Kazemi et al (2006) have studied the effects of STATCOM and UPFC, on voltage stability. CPF method with accurate model of these controllers is used for this study. The saddle node bifurcation theory is applied to determine the optimal location of these controllers.

Minguez et al (2007) have addressed the optimal placement of SVC in a transmission network for maximizing loading margin. They considered the multi-scenario framework that includes contingencies and problem was formulated as a non-linear programming problem that includes binary decisions. Yang et al (2007) have developed the planning method based on recently reported line flow equations and basic linearization of binary-continuous products. They considered the planning strategy to improve system loadability, voltage profile in the network, as well as to minimize the investment cost by choosing proper locations and settings of devices.

Yome et al (2007) have presented a comparison of FACTS devices for static voltage stability. They studied the various performance measures, including PV curves, voltage profiles, and power losses are compared under normal and contingency conditions. Sharma et al (2007) have investigated the optimal location of a shunt FACTS device for an actual line model of a transmission line having series compensation at the centre. They studied the
effect of change in degree of series compensation on the optimal location of the shunt FACTS device to get the highest possible benefit. Vijaykumar & Kumudinidevi (2007) have presented a method for optimal location of FACTS controllers in a multi machine power system using Genetic Algorithm (GA). Using this method, they simultaneously optimize the location of FACTS controller, their type and rated values. Saravanan et al (2007) have presented the application of PSO technique to find the optimal location of FACTS devices with minimum cost of installation and to improve System Loadability (SL). Phadke et al (2008) have presented a comparison of several voltage stability indices in an electric power system to identify the weakest bus/ area of the system. They compared the various line stability indices without and with shunt FACTS controller.

Bansal et al (2010) have presented a method for optimal location FACTS devices to control reactive power in multi-machine power system using genetic algorithm. They have chosen the TCSC is the FACTS device for the proposed algorithm and optimize the location of FACTS devices and their rated values simultaneously. Singh et al (2010) have presented review of various concepts of voltage instability, main causes of voltage instability, classification of voltage stability, dynamic and static voltage stability analysis techniques, modeling, shortcomings, in power systems environments. Zhu et al (2010) have presented an application of a coordinated SVC device as additional control for the reactive power optimization problem and analyze the impact on system loss and voltage profile. The coordinated SVC model controls internal, local, and remote devices simultaneously. They analyze the functions of the coordinated SVC and implement them in the practical power systems.

Gupta et al (2010) have proposed a review of the research and developments in the voltage stability improvement by using FACTS
controllers. Several technical issues related to FACTS installations have been highlighted and performance comparisons of different FACTS controllers have been discussed. In addition, real-world installations and semiconductor technology development have been reviewed and summarized. They also include the main causes of voltage instability and power scenario in India. Murali et al (2010) have investigated the improvement of transient stability of a two-area power system. UPFC is an effective FACTS device capable of controlling the active and reactive power flows in a transmission line by controlling appropriately its series and shunt parameters. The performance of UPFC is compared with other FACTS devices.

2.6 SUMMARY

In the above literature, it is found that the normal state of the system for placement of FACTS device is only considered. But, voltage instability problem usually occurs in stressed conditions. Hence, the analysis of FACTS devices under heavily stressed condition is very important.

In this work, FACTS devices are installed at the different locations of the power system network and system performance is analyzed without and with FACTS devices under maximum loadability condition. The locations of FACTS devices are determined based on the weak bus in the system and loadability of the transmission line. The main objective of this work is to reduce the real power loss under maximum loadability conditions and to maintain the bus voltage within the security level by suitable location of FACTS devices.