CHAPTER 1

INTRODUCTION

1.1 GENERAL

Voltage stability is a major concern in power system planning and operation. In general terms, voltage stability is defined as the ability of a power system to maintain steady voltages at all the buses in the system after being subjected to a disturbance from a given initial operating condition. It depends on the ability to maintain/restore equilibrium between load demand and load supply from the power system. Instability that may result appears in the form of a progressive fall or rise of voltages of some buses. A possible outcome of voltage instability is loss of load in an area, or tripping of transmission lines and the other elements by their protection leading to cascading outages that in turn may lead to loss of synchronism of some generators.

The increase in the loading of the transmission lines sometimes can lead to voltage collapse due to the shortage of reactive power delivered at the load centres. This is due to the increased consumption of the reactive power in the transmission network and the characteristics of the load. Insertion of reactive power generation devices compensate the shortage of reactive power and minimize the possibility of voltage collapse and hence improve the voltage values in load buses.
The goal of an optimization problem can be stated to find the combination of parameters (independent variables) that optimize a given quantity, possibly subject to some restrictions on the allowed parameter ranges. The quantity to be optimized (maximized or minimized) is termed the objective function; the parameters that may be changed in the quest for the optimum are called control or decision variables; the restrictions on allowed parameter values are known as constraints. Optimization algorithms have constituted some of the most significant subjects in mathematics and industry. For all the traditional algorithms available to seek best solutions to a given function, however, optimization continues to pose a challenge in most real world cases because of the huge and complex solution space. Indeed, there are still large-scale optimization problems that necessitate speedy resolution in a time span between ten milliseconds and a few minutes, resulting in the exchange of optimality with speed gains.

The goal of the thesis is to optimize the voltage stability limit enhancement and real power loss minimization through two different evolutionary algorithms. Two different combinations of Flexible AC Transmission System (FACTS) controllers are inserted separately on each algorithm and compare the performance of each combination.

1.2 LITERATURE SURVEY

The recent day power systems are undergoing numerous changes and becoming more complex from operation, control and stability maintenance stand points when they meet ever-increasing load demand (Kundur 1994; Kundur et al 2004). Voltage stability is concerned with the ability of a power system to maintain acceptable voltage at all buses in the system under normal conditions and after being subjected to a disturbance (Cutsem and Vournas 1998). A system enters a state of voltage instability
when a disturbance, increase in load demand, or change in system condition causes a progressive and uncontrollable decline in voltage.

The authors (Kessel and Glavitsch 1986; Wan et al 2000) discuss methods to assess voltage stability of a power system to find the possible ways to improve the voltage stability. The main factor causing voltage instability is the inability of the power system to meet the demand for reactive power (Taylor 1994; Cutsem 2000). Voltage stability evaluation obtained by many conventional methods (Gao et al 1992; Ajjarapu and Christy 1992). Voltage stability control is also essential in a power transmission system. The authors make the Control of voltage stability through sensitive analysis (Flatabo et al 1990; Begovic and Phadke 1992). Excessive voltage decline can occur following some severe system contingencies and this situation could be aggravated, possibly leading to voltage collapse, by further tripping of more transmission facilities, var sources or generating units due to overloading. Many large interconnected power systems are increasingly experiencing abnormally high or low voltages or voltage collapse (CIGRE Task Force 1993).

Abnormal voltages and voltage collapse pose a primary threat to power system stability, security and reliability. Moreover, with the fast development of restructuring, the problem of voltage stability has become a major concern in deregulated power systems. To maintain security of such systems, it is desirable to plan suitable measures to improve power system security and increase voltage stability margins (Dobson and Chiang 1989; Fink 1994). In most of the previous works on voltage stability improvement, only normal operating condition is considered (Overbye and De marco 1999; El-Araby et al 2002).

Voltage instability is one of the phenomena which have resulted in major blackouts. Recently, several network blackouts have been related to
voltage collapse (Technical Analysis of the August 14, 2003, A Report). The modern power systems are facing increased power flow due to increasing demand and are difficult to control (Ge and Chung 1999).

The rapid development of fast acting and self commutated power electronics converters, well known as FACTS controllers, introduced in 1988 by Hingorani and Gyugyi (2000) are useful in taking fast control actions to ensure security of power systems (Matsuno et al 2002). Edris et al (1997) proposed terms and definitions for different FACTS controllers. The FACTS controllers are capable of supplying or absorption of reactive power at faster rates (Xu and Chen 2000; Mathur and Varma 2002; Padayar 2007). The introduction of FACTS controllers are increasingly used to provide voltage and power flow controls (Sen and Sen 2009; Zhang et al 2006).

Insertion of FACTS devices is found to be highly effective in preventing voltage instability and minimize the active or real power loss on transmission lines (Wu et al 1998; Xiao et al 2002; Yorino et al 2003;). Series and shunt compensating devices are used to enhance the Static voltage stability margin and reduce the real power loss appreciably (Binsongnern and Chusanapiputt 2006; Abido 2009; Bekri and Fellah 2010). The authors (Singh and David 2001; Verma and Srivastava 2005) implemented a sensitive based approach for optimal placement of FACTS controllers to enhance the voltage stability. Gerbex et al (2001) proposed multi type FACTS devices through genetic algorithm and the authors (Li et al 2000) proposed the design and application of coordinated multi type FACTS controllers.

Advances in power electronics technology together with sophisticated control methods made possible the development of fast Static Var Compensator (SVC) in the early 1970’s (CIGRE, Working group 38-01 1986). The SVC consists of a group of shunt-connected capacitors and reactors banks with fast control action by means of thyristor switching
(Hammad 1986; Al-Sadek et al 1997). From the operational point of view, the SVC can be seen as a variable shunt reactance that adjusts automatically in response to changing system operative conditions such as voltage instability problems (Mansour et al 1994; Chang and Huang 1997).

Depending on the nature of the equivalent SVC’s reactance, i.e., capacitive or inductive, the SVC draws either capacitive or inductive current from the network (IEEE Special Stability Controls Working Group 38-01 1995). Suitable control of this equivalent reactance allows voltage magnitude regulation at the SVC point of connection. Ambriz-Perez et al (2000) proposed both susceptance and firing angle models for optimal power flow studies. The SVC is modeled as a variable susceptance reactive power source/sink at the connected bus.

Thyristor Controlled Series Capacitor (TCSC) is a series connected FACTS device inserted in transmission lines to vary its reactance and thereby reduces the reactive power losses and increases the transmission capacity (Billinton et al 1999; Lu and Abur 2002; Ye and Kazerani 2006). But the conventional power flow methods are to be modified to take into account the effects of FACTS devices. The author (Kazemi and Badrzadeh 2004) discussed the limits of both SVC and TCSC on maximum loadability point.

Voltage stability assessment with appropriate representations of FACTS devices are investigated and compared under base case of study (Sode Yome and Mithulanganathan 2001; Musunuri and Dehnavi 2010; Canizares and Faur 1999). One of the shortcomings of those methods only considered the normal state of the system (Kundur et al 1993; IEEE/PES Special Publication 1999). The author (Ajjarapu 2006) presented the different computational techniques for voltage stability assessment and control. The Extended voltage phasors approach has been suggested for placement of FACTS controllers in power systems for identifying the most critical
segments/bus in power system from the voltage stability view point (Sharma et al 2003). However voltage collapses are mostly initiated by a disturbance like line outages. Voltage stability limit improvement needs to be addressed during network contingencies. So to locate FACTS devices, consideration of contingency conditions is more important than consideration of normal state of system and some approaches are proposed to locate of FACTS devices with considerations of contingencies too (Venkataramu and Ananthapadmanaba 2006; Jafari and Afsharnia 2007).

The Static Synchronous Series Compensator (SSSC) has been applied to different power system studies to improve the system performance (Gyugyi et al 1997; Mihalic and Papic 1998). There has been some work done to utilize the characteristics of the SSSC to enhance power system stability (Wang 2000; Akhilesh et al 2011). The linearized model of the SSSC integrated into power systems was established and methods to design the SSSC damping controller were proposed. Kumkratug and Haque (2003) demonstrated the capability of the SSSC to control the line flow and to improve the power system stability.

The generalized power injection model of SSSC needs modification of the jacobian matrix and makes quiet complex in coding. In the SSSC control parameters, voltage magnitude and angle of the series converters are presented as independent variables and their values are found through the traditional load flow iterative process (Zhang and Zhang 2006), In this case, the size of the Jacobian matrix increases to incorporate the additional independent variables. The new model of the SSSC changes only the bus admittance matrix and consequently reduces the coding of load flow problem incorporating SSSC simple. The SSSC control parameters, voltage magnitude and angle of the series converters, are presented as independent variables and their values are found through the traditional load flow iterative
process. In this case, the size of the jacobian matrix increases to incorporate the additional independent variables. Hence a simple and easy to implement SSSC model based on the circuit elements is used in this work (Motie birjandi and Sabzawari 2010).

Line stability indices provide important information about the proximity of the system to voltage instability and can be used to identify the weakest bus as well the critical line with respect to the bus of the system (Lof et al 1993). Different types of line stability indices are proposed to evaluate the proximity of the system to voltage instability (Moghavvemi and Omar 1998; Moghavvemi and Faruque 1998; Musirin et al 2002) The Line Quality Proximity index is used in this work for stability assessment (Mohmed et al 1989; Reis et al 2009).

Recently the advances in computer engineering and the increased complexity of the power system optimization problem have led to a greater need for and application of specialized programming techniques for large-scale problems including optimization of voltage stability, power flow, branch flow and real power loss minimization etc (Momoh 2001; Hady et al 2010). From the family of evolutionary computation, Shuffled Frog Leaping Algorithm (SFLA) and Differential Evolution (DE) Algorithm are used to solve a problem of real power loss minimization and Voltage stability maximization of the system.

The SFLA is a meta-heuristic optimization method which is based on observing, imitating, and modeling the behavior of a group of frogs when searching for the location that has the maximum amount of available food (Eusuff et al 2006). Shuffled Frog Leaping Algorithm (SFLA), originally developed by Eusuff and Lansey in 2003, can be used to solve many complex optimization problems. Earlier Duan et al (1993) proposed a shuffled complex evolution approach for global minimization. The author (Eusuff and
Lansey 2003) successfully implemented SFLA for optimization of water distribution network. Ebrahimi et al (2011) proposed the applications of SFLA in unit commitment problem solution. The DE algorithm is a population based algorithm like genetic algorithms using the similar operators of crossover, mutation and selection. Several transformer tap positions along with numbers of reactive power injections at some selected buses in a power system are simultaneously optimized as control variables, so that the multiple objectives are fulfilled, keeping an eye to all specified constraints (Price and Storn 1995; Storn and Price 1997; Storn 1999). The authors are (Chakraborty 2008; Qin et al 2009) make the advances of DE for global numerical optimization. Vasan et al (2010) successfully implemented Differential Evolution (DE) for optimization of water distribution network. Duvvuru et al (2011) proposed the applications of DE in economic load dispatch problem.

Because of higher cost of the FACTS devices, the installation is not recommended to all possible line outages. Hence line outage contingency screening and ranking carried out to identify the most critical line during whose outage FACTS controllers can be positioned and system can be operated under stable condition (Wood and Wollenberg 1996; Reppen et al 1993; Ejebe et al 1996; Vaahedi et al 1999; Jia and Jeyasurya 2000). Modi et al (2008) proposed the interior point method to assess the voltage stability during single line outage condition and Greene et al (1999) proposed the contingency ranking for voltage collapse from a single nose curve.

The prime objective of this work is to compare the voltage stability limit and real power loss optimization values during normal loading, critical loading and single line outage contingency conditions performed by combined series – shunt FACTS controllers insertion through SFLA and DE algorithms.
1.3 OBJECTIVE OF THE THESIS

The main objective of this thesis is to minimize the real power loss, voltage deviation and to maximize the voltage stability limit by optimizing the location and size of two different combinations of FACTS devices through two different evolutionary algorithms are summarized as follows

- Increase the voltage stability limit and minimize the active power loss incorporating TCSC and SVC devices through Differential Evolution Algorithm
- Increase the voltage stability limit and minimize the active power loss incorporating SSSC and SVC devices through Differential Evolution Algorithm
- Increase the voltage stability limit and minimize the active power loss incorporating TCSC and SVC devices through Shuffled Frog Leaping Algorithm
- Increase the voltage stability limit and minimize the active power loss incorporating SSSC and SVC devices through Shuffled Frog Leaping Algorithm
- Performance comparison obtained between the two different combinations of FACTS devices with two different optimization techniques under voltage stability limit improvement and active power loss minimization.

1.4 PROPOSED APPROACHES

Approach 1: Voltage stability assessment with appropriate representations of FACTS devices is investigated and compared under base case of study. One of the shortcomings of those methods only considered the normal state of the system. However
voltage collapses are mostly initiated by a disturbance like line outages. Voltage stability limit improvement needs to be addressed during network contingencies. So to locate facts devices consideration of contingency conditions is more important than consideration of normal state of system and some approaches are proposed to locate of FACTS devices with considerations of contingencies too.

Line stability indices provided important information about the proximity of the system to voltage instability and can be used to identify the weakest bus as well the critical line with respect to the bus of the system. The Line Stability Index (LQP) derived by Mohmed et al (1989) is used for stability assessment.

Due to the higher capital cost of the FACTS devices, the installation is not recommended to all possible line outages. Hence line outage contingency screening and ranking carried out to identify the most critical line during whose outage FACTS controllers can be positioned and system can be operated under stable condition.

**Approach 2**: In this thesis work, the FACTS devices are used in combined manner. The combination is based on two controllers having both series and shunt device. Two different combinations such as Variable susceptance model of SVC with Variable reactance model of TCSC and Variable susceptance model of SVC with Circuit element model of SSSC are used separately and compare the results behind the voltage stability limit improvement and active power loss minimization.
Approach 3: In this thesis work, two different optimization algorithms such as DE and SFLA are proposed to optimize the problem of real power loss minimization and Voltage stability maximization of the system. Results are obtained from these algorithms and compare them between the insertions of different combinations of FACTS devices in detail.

1.5 ORGANISATION OF THESIS

Chapter 1 Initiates with general introduction, literature survey, objective and proposed approach and organization of thesis chapters about this research work.

Chapter 2 Focuses an introduction about voltage stability and its importance related to transmission systems. It also discusses the voltage collapse, how to take prevention from voltage collapse, importance of voltage control and necessary of voltage stability improvement, real power loss minimization, voltage stability assessment and voltage stability indices.

Chapter 3 Gives with the introduction and importance of the FACTS devices with their classification. The power control concept, opportunities, possibilities of power flow control and benefits of FACTS devices are also discussed. The types of different FACTS devices are also included in this chapter. The configuration and model of SVC, TCSC and SSSC are discussed in detailed manner, which are only related to this research work.

Chapter 4 Exposes the basics and classification of optimization. The different conventional and evolutionary techniques are also discussed. Overview about the evolutionary optimization algorithms like Differential
Evolution and Shuffled Frog Leaping Algorithm are given in detailed manner, and their implementation to the applications regarding this research work.

Chapter 5 Highlights the detailed models of SVC, TCSC and SSSC to make the formulation of FACTS devices which are related to this research work. The formulation of LQP index is also presented. Implementation of DE and SFLA and their relevant optimal values of parameters are presented. The various objective functions and constraints regarding this research work were demonstrated. Finally the contingency ranking and its procedure is also discussed.

Chapter 6 Exposes with the proposed methodology and detailed results regarding the all objective functions. The results are discussed in detailed manner with the various operating cases related this work. The comparison and suitability of FACTS devices with their related optimization techniques are also discussed under voltage stability limit improvement and real power loss minimization.

Chapter 7 Focuses the conclusion in accordance with the FACTS devices insertion and the suitability of optimization techniques under all cases related to this research work.