Chapter 1

Prologue

1.1 Motivation of the Work

The restructuring process in the electric power industry over the last decade has led to several structural and regulatory issues regarding transmission grid operation and planning, not fully anticipated at the design state of the grid. The transmission system has not evolved at the rate needed to sustain increasing demand matched with negligible generation addition evidenced in the deregulated environment. This has caused somewhat unexpected bottlenecks like voltage instability, low operating efficiency, poor loadability, price volatility, frequency droop and congestion in the system. Moreover, the functional unbundling of generation and transmission operations is aggravated due to the lack of coordination between generation resources and the transmission System Operator (SO). In this situation, the role of SO is not only to increase the profit margin of the market participants but also to improve the performance of the network for consumer welfare.

The inextricably complex and interconnected structure of the grid is the main hindrance of improving its performance. Unavoidable circumstances like voltage instability, frequency droop are quite evident in the dynamic response of the system. Their gruesome effect can cause the collapse or cascading failure of the system. In this respect, line congestion is not also lagging behind. A single line contingency can overburden the system to cause its failure even though all the generators are operational. Again, voltage instability according to the
research conducted in this field has an intimate relation with angle stability, which further attract frequency instability in the system. The loadability of a line is directly related with its voltage hence voltage instability determination and remedial action can shun severe effects of both frequency instability and poor loadability. Both in long and short run, poor efficiency can increase the marginal cost of the energy, which has dreadful effects on economical aspect of power generation. The ever-increasing numbers of constraints are also complicating the objective of optimal power system operation towards the most economical pattern of parameters. Hence, voltage instability, poor efficiency, sub-optimal operations and congestion are the four basic dimension of an ill-performing system.

In this context, it is increasingly important for the System Operator to project and assess the operating condition of the system in terms of the above constraints and to adopt corrective actions to minimize their deviations to maintain recommended and desired performance of the system. For this, SO would require the assistance of novel methodologies and algorithms to plan the most beneficial operating condition of the system, to model the network for optimizing the operating efficiency and for the maintenance of constraints with in safe operating limits.

These reasons have motivated power engineers of the last decade to develop modeling methods, optimization algorithms and constraint management techniques for upgrading the role of SO in the modern market in transition of getting deregulated. However, the efficiency of these works has been influenced by aggravated inaccuracy, one-dimensional objective, inefficient estimation capacity and time complexity. The search for more accurate, computationally simple, multi-objective fast response and robust algorithms still continues.

1.2 CONTRIBUTIONS OF THE THESIS

In pursuit of multi-dimensional flexible and efficient methodologies, the research works have focused on the steady state and dynamic behavior of modern power market in an endeavor of optimizing the system operating conditions. Main achievements of the work are as follows:

- The theoretical modifications of different voltage stability indices in practice have been adopted for implementation. For accurate and fast dynamic response, ANN based training methodologies have been developed. The conventional stability assessment technique has thus been modified for fast and accurate monitoring of the system and for the development of real time ancillary service for the generation of actuating signals to control the voltage stability of the system.

- Novel and effective modeling of compensation devices have been carried out in pursuit of maximizing the utilization of network capacity. ANN based FACTS models
have also been developed for faster prediction of the control parameter for effective redemption.

- A suitable contingency analysis technique has also been implemented to establish the effectiveness of the FACTS and HVDC links under regulated and deregulated environment for the restoration of the system operating point to a stable mode of operation. The techniques developed will assist the system operator to judge and place compensating devices in optimal locations to increase the reliability and efficiency of the system.

- To utilize the stability margin and optimum network capacity, the work has focused on novel methodologies to be undertaken by the System Operator to optimize consumer welfare. In this respect, the work has contributed in the field of cost optimization to minimize the price volatility of the power market. For the development of global search algorithm for optimal generation schedule, the work has deployed stochastic methods like GA, PSO and DE. Due to the uncontrollable rise of operating constraints, the objective function has become highly non linear and hence the amalgamation of these mathematical techniques can reduce the anomalies of market price in modern deregulated power market.

- The modern day power networks are out-stressed by the irrepresible rise of demand. Line congestion is an evident effect of out-stressing the network. The management method employed in this work has shown to be capable of sustaining the level of congestion. Non-derivative based optimization techniques have also been deployed in this respect.

- The development of optimization techniques went further to enable ISO to redistribute generation for effective up-gradation of transmission efficiency. In modern power markets, these algorithms can be effective for high profit margin with consumer relief.

- The modern day power markets can be equipped with efficient smart meters and work has employed these data collected by the meters to assess the present operating condition not only to reschedule generation but also to redistribute the demand for the over-all improvement of system performance. The System Operators of smart grid can be benefited to produce fast and accurate decisions for the maintenance of most suitable operational modes.

1.3 Organization of The Thesis

This thesis includes seven chapters, in addition to this prologue. Its organization is given below:
In Chapter 2, background and literature review are presented. This chapter starts with a general introduction to present power market scenario and the power network performance evaluation techniques. The importance of voltage stability on power networks and a thorough literature survey in this field has been depicted. To illuminate the developed methods for stability assessment so far, classical and neo-classical techniques have been discussed. All these methods pointed towards a common solution that is compensation; henceforth the recent developments of FACTS and HVDC technology have been depicted. To emphasize the improvement of system performance, different optimization methods have been studied, which includes cost optimization strategies, congestion management techniques and loss optimization methods. The deployment of Demand Response (DR) for effective enhancement of system performance has also been highlighted with a meticulous survey of the works in this field.

The work of Chapter 3 is based on the analysis of voltage stability of LPS using Artificial Neural Network. The introduction of this chapter covers the developments of voltage stability assessment techniques. The theoretical progress of voltage stability and collapse indicators in the power sector has been discussed for their comparison and for the development of efficient indicator for proper assessment of the voltage stability margin as applicable to practical system. This section of the thesis also deals with an elementary overview of ANN and the supervised training method adopted for the implementation of ANN based stability predictor. The results of this neo-classical technique have been compared with the classical technique for the assessment of accuracy and response.

In the quest of enriching system performance, Chapter 4 reinforces the utilization of FACTS devices and HVDC links. In introduction, it depicts the present scenario of FACTS and HVDC deployment in power sector. Elaborating the recent developments of the FACTS controllers like SVC, TCSC etc, the work concentrates on the modeling of these controllers for on-line prediction of control parameters to sustain the specified operating conditions. The HVDC system, being one of the modern invasions of power electronics into power systems incurs high installation cost but offers high reliability. Henceforth the work employed HVDC controllers to sustain the same operating conditions that can be done by FACTS controllers. These comparisons will enable the System Operator to choose proper aid for the network so far as compensation is concerned.

Chapter 5 deals with the multi-objective optimization algorithms to upgrade the performance of modern deregulated power markets. The transition from LPS to deregulation with an overview of deregulated market has primarily been introduced in the beginning of this chapter highlighting the operational constraints. In presence of these constraints, the objective function befalls to be highly non-linear and thus can only be solved with stochastic
methodologies like GA, PSO and DE, which have been illustrated and compared for implementation in the present day power market for maximization of utilities. For multi-objective solution, the work focuses on the development of the same in different optimization environments. Power loss, generation cost and load curtailment optimizations for congestion management have also been discussed. To sustain the reliability of power supply, without breaching the limits of operational constraints, an optimization model has also been developed to manage congestion without load curtailment. For contingency surveillance, some indices have also been formulated which can assist Independent System Operator (ISO) to control the limit violation incurring in the power system.

Apart from utility maximization, with the available smart metering system and SCADA, the system operator can schedule the loads of an interconnected network and some algorithms can be developed to improve the performance from demand side. This is the topic of discussion of Chapter 6. Elaborate depictions of innovative methodologies have been presented to utilize Demand Response (DR) for maximization of profit as well as consumer welfare in Smart Grid arena to be introduced shortly.

Finally, Chapter 7 contains the conclusion and future scope of this work.