CHAPTER 1

INTRODUCTION

1.1 GENERAL

The structure and the operation of electricity industry have completely changed in the last two decades. This sector is moving from a monopoly structure to a more competitive one, similar to the transportation and telecommunications sectors. Chile in Latin America was a pioneer in the early 1980s with the development of a competitive system for electricity generation based on marginal prices. In 1992, Argentina privatized an inefficient government owned electricity sector, splitting it into generation, transmission and distribution companies. It introduced a competitive generation market. These experiences were repeated in other countries such as Bolivia, Peru, Colombia, Guatemala, El Salvador, Panama, Brazil and Mexico. Scotland and Northern Ireland in Europe followed the experience of England and Wales (Littlechild and Beesley 1989). The Scandinavian countries, followed by Norway, have gradually created a Nordic wholesale electricity market.

The state of Tamil Nadu in India has restructured the Tamil Nadu Electricity Board (TNEB) into (i) Tamil Nadu Generation and Distribution Corporation (TANGEDCO) Ltd and (ii) Tamil Nadu Transmission Corporation (TANTRANSCO) Ltd, since 2010.
1.2 UNREGULATED POWER SYSTEM

Traditionally, a vertically integrated single utility has been the only electricity provider in its service territory in every country. It was obligated to supply electricity to all customers in its territory. The monopoly (single seller) status of the provider, the regulator periodically sets the tariff to earn a fair rate of return on investments and to recover operational expenses. Under this regulated framework, firms maximize the profit subjected to many regulatory constraints.

In Unregulated organizational structure, all the control functions, like Automatic Generation Control (AGC), state estimation, generation dispatch, unit commitment, etc., are carried out by an energy management system. Generation is dispatched in a manner that realizes the most economic overall solution. In such an environment, an optimal power flow can perform the dual function of minimizing production costs and of avoiding congestion in a least-cost manner. Congestion management thus involves determining a generation pattern that does not violate the line flow limits. Line flow capacity constraints, when incorporated in the scheduling program, lead to increased marginal costs. This may then be used as an economic signal for rescheduling generation or, in the case of recurring congestion, for installation of new generation/transmission facilities.

1.3 DEREGULATION AND RESTRUCTURING

Deregulation and restructuring processes are carried out by governments through the introduction of electricity markets to increase efficiency and to reduce prices. This unbundling of the electric power market has led to the evolution of new organizational structures. The goal of deregulation is to enable competition and to disable the monopoly control and market imperfections in vertically integrated utility structure. The economic
decision-making mechanism also responds to a decentralized process whereby each participant maximizes profit equal to the difference between total revenue and total cost.

Three major models are being discussed as alternatives to the traditional vertically integrated monopoly. The three models are:

- **The PoolCo model** is comprised of competitive power providers as obligatory members of an independently owned regional power pool, vertically integrated distribution companies, vertically integrated transmission companies and a single and separate entity. This separate single entity is responsible for: establishing bidding procedures, scheduling and dispatching generation resources, acquiring necessary ancillary services to assure system reliability. They also administer the settlements process and ensure non-discriminatory access to the transmission grid. PoolCo does not own any generation or transmission components and centrally dispatches all generating units within the service jurisdiction of the pool. PoolCo controls the maintenance of transmission grid and encourages an efficient operation by assessing non-discriminatory fees to generators and distributors to cover its operating expenses.

- **The Bilateral Contracts (Direct Access) model** has two main characteristics that would distinguish it from the PoolCo model. These two characteristics are: the ISO’s role is more limited; and buyers and sellers could negotiate it directly in the marketplace. In this model, small customers’ aggregation is essential to ensure that they would benefit from
competition. This model permits direct contracts between customers and generators without entering into pooling arrangements. By establishing non-discriminatory access and pricing rules for transmission and distribution systems, direct sales of power over a utility’s transmission and distribution systems are guaranteed. Wholesale suppliers would pay transmission charges to a transmission company to acquire access to the transmission grid and pays similar charges to a distribution company to acquire access to the local distribution grid.

- **The hybrid model** combines various features of the previous two models. The hybrid model differs from the PoolCo model as utilizing the Power Exchange (PX) is not obligatory and customers are allowed to sign bilateral contracts and choose suppliers from the pool. The pool would serve all participants (buyers and sellers) who choose not to sign bilateral contracts. The California model is an example of the hybrid model. This structure has advantages over a mandatory pool as it provides end-users with the maximum flexibility to purchase from either the pool or directly from supplier.

1.4 UNBUNDLING GENERATION, TRANSMISSION AND DISTRIBUTION

The restructuring of the electricity sector transforms radically the monopolistic electric power industry to a new model industry which is characterized by competition in generation and distribution with guaranteed accessibility of transmission. The unbundled and restructured electric utilities are Generation Companies (GENCOS), Transmission Company (TRANSCO)
and Distribution Companies (DISCOS). The above three companies are separate entities to look after Generation, Transmission and Distribution subsystems respectively.

The open access transmission plays a vital role in competitive electricity markets. It is desirable to be able to transmit power to all parts of network without violating system security constraints. The electrical power that can be transmitted between two locations in a network is limited by several security criteria such as voltage limits, lines thermal limits and stability limits. When power cannot be transmitted to a part of network due to one or more transmission limits, the system is said to be congested. Consequently, it is likely to encounter market power problem. Electricity markets will not be able to operate at its competitive equilibrium with congestion in the system.

1.5 REVIEW OF THE LITERATURE

Transmission congestion in a competitive electricity market refers to the overloading of lines or transformers due to market settlement. In the deregulated environment, the customers would like to purchase electricity from the low cost sources available in the market. As the deregulated market is a monopolistic market, the chances of congestion are high. The congestion is undesirable and it should be alleviated to maintain the system security.

A survey of literature on congestion management problem reveals that many mathematical programming methods and optimization techniques have been applied to solve this problem. Recently, with the emergence of artificial and computational intelligence techniques, attention has been given to solve congestion management problem using Artificial Intelligence (AI) techniques. Soft computing techniques like Tabu Search (TS), Artificial Neural Networks (ANN), Genetic Algorithm (GA), Ant colony Algorithm
Artificial Bee Colony optimization (ABC), Evolutionary Programming (EP) and Particle Swarm Optimization (PSO) have been used to solve congestion management problem.

Based on the review of literature, the congestion management methods can be categorized as:

- Sensitivity factors based methods
- Auction based congestion management
- Congestion cost or price based congestion management
- Re-dispatch and willingness to pay methods
- Available Transfer Capability (ATC) based congestion management
- Optimal Power Flow (OPF) based congestion management.
- Generation Rescheduling / Load Curtailment based congestion management
- FACTS devices based congestion management

1.5.1 Sensitivity Factors Based Methods

Alvarado (1999) proposed power system application data dictionary to implement codes in MATLAB used for congestion management. Bialek et al. (2000) proposed improvements in National Electricity Regulatory Commission’s (NERC) transmission loading relief (TLR) procedures based on Power Transfer Distribution Factors (PTDFs) and congestion management process by allowing multilateral trades. Chung et al. (2004) proposed a new strategy to improve the power transfer capability constrained using small-
signal stability. Two sensitivity-based dispatch methods are proposed to reschedule the generation in order to maximize power transfer subject to the small-signal stability constraint under a set of selected contingencies.

Deladrue et al. (2003) proposed a statistical method to predict line congestion, which can help ISO to alleviate congestion. Kumar et al. (2003) proposed congestion clusters based on AC load flow approach to manage congestion. They also proposed an efficient zonal congestion management approach using real and reactive power rescheduling based on AC transmission congestion distribution factors considering optimal allocation of reactive power resources. Lee et al. (2001) proposed Network congestion assessment methodology by introducing congestion cost index. Liu et al. (2002) provided the effectiveness of distribution factors approximations used in congestion modeling.

Liu et al. (2004a) provided systematic study on the role of distribution factors in Congestion Revenue Right (CRR) application for congestion management. Goncalves et al. (2003) proposed a method of detecting possible critical coalitions in open energy market. Nimura et al. (2002) proposed simple and transparent set of indices to represent the level of agreeable load curtailment in congestion conditions.

Overbye et al. (2001) discussed assessment of impact of PTDFs in TLR procedures in NERC’s congestion management. Shirmohammadi et al. (1998) proposed a system of advanced analytical methods and tools for secure and efficient operation of the power system in the emerging energy markets. Shubhanga et al. (2004) proposed, a structure preserving Energy Margin (EM) sensitivity-based analysis to determine the amount of preventive generation rescheduling to stabilize a transiently unstable power system. Stoft (1997) proposed linear sensitivity factors based approaches for congestion management. Vlachogiannis (2000) proposed formulae to express the
contribution of each generator to the power flows, loads, and losses in power systems and these formulae are tested to relieve transmission congestion.

1.5.2 Auction Based Congestion Management

Hogan (1992) proposed a concept of contract network and introduced FTR to hedge the financial risks of congestion induced price variations. Chao et al. (1996) proposed market mechanism for electric power transmission. Chao et al. (2000) proposed Flow Gate Right (FGR) to price each congested line explicitly. Seeley et al. (1999) examined integrated auction mechanism to prevent congestion. Harvey et al. (1996) proposed a combined zonal and FTR scheme has been presented to manage congestion. Bushnell (1999) discussed the issue of Transmission Congestion Contract (TCC) to manage congestion.


Lyons et al. (2000) discussed the issues of financial transmission rights to manage congestion. Richter et al. (2001) proposed FTR options as a new product to manage congestion. Yoon et al. (2001 a) examined secondary markets for transmission rights and compared to its performance with TCC and FTR. Yoon et al. (2001) proposed market mechanism for inter-regional transmission management. Raikar et al. (2001) introduced interruptible
physical transmission contracts mechanism to ensure optimal curtailment policy for congestion management. Pope (2001) proposed congestion management options in three southeastern states based on LMP, FTR, and rescheduling of generation resources.


1.5.3 Congestion Cost or Price Based Congestion Management

Singh et al. (1998) proposed DC-OPF based approach to compute congestion cost. Wu (1996) proposed that the surplus collected by the ISO from congestion charge in Hogan’s method can be shared by generators and
consumers as the profit that lead to economic operating point. Baran et al. (2000) proposed bid based congestion management scheme and new method of allocating congestion cost to the bilateral contracts. Rau (2000) proposed AC-OPF based re-dispatch problem to alleviate congestion along with congestion cost allocation. Yu et al. (2001) proposed a new method to calculate and settle zonal congestion cost for a pool and bilateral model. Lo et al. (2001) proposed a new congestion management model for inter-scheduling coordinator (SC) trade and introduced a concept of congestion charge compensation between SCs.


Karaki et al. (2002) proposed the pool based model for the problem of congestion management in a restructured Electricité du Liban (EDL). Yamin et al. (2003 a) proposed a coordination process between GENCOs and the ISO for congestion management to reduce the risk of failure to supply loads. Nimura et al. (2002) proposed transparent indices approach to transmission congestion management in a deregulated power system. Hussin et al. (2006) proposed an assessment of transmission congestion management in the deregulated electricity market. Selvi et al. (2007) proposed a modified OPF to minimize the rescheduling of generation for alleviating transmission
system overloads has been. Inwai et al. (2007) proposed the TCM scheme that would be possible to be implemented in Thailand during its transformation to the deregulated environment.


1.5.4 Re-Dispatch and Willingness-to-pay Methods

David et al. (1997) proposed Pool and bilateral contract dispatches and the priority arrangements for line congestion and curtailment strategies. Srivastava et al. (2000) proposed an OPF based model for reducing the congestion with minimum curtailment of contracted power. David (1998) proposed mathematical model for pool, bilateral and multilateral dispatch coordination including congestion and transmission charges. Fosso et al. (1999) proposed an overview of short, medium, and long-term scheduling of generators along with congestion management for Norway electricity market. Fang et al. (1999 b) proposed optimal transmission dispatch methodology considering willingness to pay premium for minimum curtailment strategy. Fang et al. (1999) proposed an integrated strategy to manage congestion in a
real time operational environment. Niioka et al. (2000) proposed Reliability management considering optimal dispatch under transmission congestion.


congestion management through contract curtailment strategy. Yamin et al. (2002) proposed a coordination process between Gencos and ISO for congestion management reducing the risk of failure to supply loads.


curtailment relying on “online” evaluation of transmission congestion constraints.

1.5.5 Available Transfer Capability Based Congestion Management

In power market environment, Available Transfer Capability is an important index which is defined as the maximum additional power that can be transmitted in an interchange schedule between the specified buses. Liu et al. (2007) proposed a decentralized model for dc load flow based congestion management for the forward markets via Optimal Resource Allocation (ORA). Shayesteh et al. (2009) has proposed Emergency Demand Response Program, which is one of the incentive-based demand response programs for Available Transfer Capability enhancement. Tuglie et al. (2001) proposed a probabilistic approach for assessing the congestion risk associated with the transfers exceeding Available Transfer Capability. Farahmand et al. (2007) proposed a novel technique to identify the optimal location for UPFC. Santiago et al. (2005) proposed fast, accurate algorithms to compute network capabilities are indispensable for transfer-based electricity markets.

1.5.6 OPF based Congestion Management

Wang et al. (2000 a) proposed a methodology to develop a competitive market structure in transmission service to help facilitating the dispatch management and solving transmission congestion problem. Venkatesh et al. (2003) proposed Evolutionary Computation (EC) methods such as Genetic Algorithm (GA), Micro- GA (MGA), and Evolutionary Programming (EP) to obtain ELD solutions. Yu et al. (2003) proposed interchange capability evaluation problem in a competitive system with individual and group electricity transactions. Rosehart et al. (2006) proposed, a detailed analysis of the use of optimization techniques in the study of voltage stability problems, leading to the incorporation of voltage stability
criteria in traditional OPF formulations. Sood (2007) proposed an efficient evolutionary programming based optimal power flow and compares its results with well known classical methods, in order to prove its validity for present deregulated power system analysis. Capitanescu et al. (2007) proposed three Interior-Point (IP) based algorithms, namely the pure Primal-Dual (PD), the Predictor–Corrector (PC) and the Multiple Centrality Corrections (MCC), to solve various classical OPF problems: minimization of overall generation cost, minimization of active power losses, maximization of power system loadability and minimization of the amount of load curtailment. Saini et al. (2010) proposed a concept of transmission congestion penalty factors and implemented it to control power overflows in transmission lines for congestion management.

1.5.7 Generation Rescheduling / Load Curtailment based Congestion Management

based congestion management technique based on generation rescheduling and/or load shedding.


Chanana et al. (2007) proposed an active and reactive power flow tracing based approach for selecting the most appropriate generators to reschedule their active and reactive power output based on their power flow contribution on the congested line. Chakrabarti et al. (2008) proposed a sensitivity based methodology for voltage stability enhancement of a power system by rescheduling real power outputs of the participating generators. Dutta et al. (2008) proposed a technique for optimum selection of participating generators on congested lines. Fang et al. (2010) proposed a new generation rescheduling model for transient stability enhancement of power systems. Muneender et al. (2009) proposed the reactive support of generators, in addition to the rescheduling of real power generation.

Muneender et al. (2009 a) proposed the method of selection of generators from the most sensitive cluster/zone to re-dispatch the real and
reactive powers simultaneously using two distribution factors. Yesuratnam et al. (2010) proposed a simplified approach for security oriented power system operation. Boonyaritdachochai et al. (2010) proposed an optimal congestion management approach in a deregulated electricity market. Fang et al. (1999 a) proposed an open transmission dispatch environment in which pool and bilateral/multilateral dispatches coexist and proceed to develop a congestion management strategy. Padhy (2004) proposed an efficient and practical hybrid model has been proposed for congestion management analysis for both real and reactive power transaction under deregulated fuzzy environment of power system. Ford et al. (2009) proposed a new adaptive load shedding scheme that provides emergency protection against excess frequency decline, whilst minimizing the risk of line overloading.

1.5.8 FACTS Devices Based Congestion Management

Farahani et al. (2006) proposed that Congestion management can be solved by curtailment loads or using FACTS devices. Yao et al. (2005) proposed the application of Static Series Synchronous Compensator (SSSC) for the purpose of congestion management and transfer capability of power systems with high penetration of wind power. Reddy et al. (2006) proposed that by using FACTS devices, congestion can be reduced without disturbing the economic matters. Zhang (2006) proposed an OPF control in electric power systems incorporating IPFC. Saravanan et al. (2007) proposed particle swarm optimization (PSO) technique to find the optimal location of FACTS devices with minimum cost of installation of FACTS devices and to improve system loadability (SL). Chong et al. (2007) proposed Unified Power Flow Controller as a viable solution to the problem of congestion management. Gitizadeh (2010) proposed a novel optimization-based methodology for placement of FACTS devices in order to relieve congestion in the
transmission lines. Nabavi et al. (2010) proposed a corrective solution for congestion management by using TCSC.

1.6 CONTRIBUTION IN THIS THESIS

Based on the above literatures, there are certain issues still to be investigated on congestion management in deregulated power systems. The motivation and objective of the thesis are as follows.

Conventional optimization methods works satisfactorily if the function to be optimized has good characteristics such as continuity, differentiability etc. It may leads to local optimal solution if the initial guess or solution is not proper. This restricts the use of these methods to real world problems. So in this thesis, stochastic optimization techniques such as EP & PSO have been used for relieving congestion in deregulated power systems.

Solving a congestion management with more than one objective is a very challenging task. Usually multi objective optimization problem is converted into single objective optimization with suitable weights or penalty factors. Tuning the weighting factor is a difficult task. The solution of such multi objective problem depends on the weights, so the conventional methods may not be suitable for multi objective optimization problem. So overcome these difficulties, in this thesis Evolutionary Programming and Particle Swarm Optimization methods are used. In this thesis the various objectives considered are the minimization of generation cost, power loss and transmission line overload.
1.7 OBJECTIVES OF THE THESIS

In this research work, the primary aim is to reduce the congestion in the deregulated and restructured power systems. It is a multi-objective optimization problem. The three objective functions are:

1. The minimization of transmission congestion,
2. The minimization of transmission loss and
3. The minimization of the cost of generation.

These three objectives are combined to a single objective function by choosing proper weighted function. The minimization of this augmented objective function with constraints shall provide a solution which relieves the congestion.

The objectives of this research work are, therefore

1. To model the utility for the congestion as a multi-objective problems with constraints
2. To apply soft computing based algorithms to solve this problem in the following sequences, considering:
   - Generation rescheduling only
   - Generation rescheduling with load shedding
   - Generation rescheduling with FACTS devises and
   - Generation rescheduling and FACTS devices with load shedding.

In order to verify the effectiveness of the proposed techniques, four standard test power systems were considered.
1.8 CHAPTERWISE ORGANIZATION OF THE THESIS

The congestion management problem statement, review of the related literature and the objective of this research work were presented in Chapter 1.

The congestion management in deregulated power system was dealt in Chapter 2. This chapter described the various approaches of congestion management in different countries. To relieve congestion in this research work, it is proposed to consider (i) generation rescheduling; (ii) load shedding and (iii) optimal sizing and locating FACTS controller. The general solution procedure for the soft computing techniques is described. The soft computing techniques considered were Evolutionary Programming (EP) and Particle Swarm Optimization (PSO). The results of the sample systems by soft computing techniques are compared with the results due to Interior Point Method (IPM).

Congestion management using generation rescheduling was considered in Chapter 3. The three objectives, namely transmission congestion, transmission loss and cost of generation are combined to form a single objective function by properly choosing the weighted function. After generation rescheduling for congestion management, the load shedding is also considered. The load shedding was adapted only as the worst case scenario. The multi-objective optimization problem was solved using EP and PSO. The effectiveness of the algorithms was tested on IEEE 30, IEEE 118, IEEE 300 and Indian Utility 66 bus system. The results obtained from EP and PSO were compared with the conventional IP method. It was observed that the PSO gives better results compared to other methods.

Chapter 4 dealt with the congestion management using generation rescheduling, and optimal location of FACTS devices. The congestion
management in a deregulated and restructured power systems were carried out by considering the multi-objectives transmission congestion, transmission loss and fuel cost. This multi objective optimization problem was resolved into single objective optimization problem and solved by EP and PSO algorithms. This was tested on IEEE 30, IEEE 118, IEEE 300 and Indian Utility 66 bus system. The results obtained by EP and PSO methods were compared with the conventional method. It was found PSO gives better results compared to other methods.

The results obtained for the different proposed techniques have been reviewed and the conclusions are summarized in Chapter 5. The scope for further work was also indicated.

1.9 CONCLUSION

In this Chapter, problem of congestion management was presented. The literature relating to different methods of alleviating congestion were reviewed. The soft computing techniques such as EP and PSO have been proposed to relieve the congestion by considering Generation Rescheduling, Generation Rescheduling with Load shedding (adopted only at the worst case scenario), Generation Rescheduling with FACTS devices, Generation Rescheduling and FACTS devices with Load shedding.