Chapter 1

Introduction

1.1 General

With growing interconnections and loadings in the modern power system networks all over the world, power utilities are observing a major challenge in maintaining desired superiority and security of power supply. Power system security and analysis forms an essential part of modern energy management system. The economic downturn coupled with environmental and ecological pressures have obliged the electric utilities, all over the world, to serve the augment in load demand without corresponding increase in generation and transmission facilities. This has forced the utilities to operate their generators and transmission systems to their maximum capabilities. Hence, the re-regulation [26] of the power system has been derived for getting maximum economical benefits to the society.

The Available Transfer Capability (ATC) calculation is a prime important issue for the smooth running of the Restructured power market [1] [27]. Because of industrial revolutions, the power demand has been increased in the last few years. In the open access market power players are stack holders. The congestion occurs when a transmission line loaded with simultaneous transactions beyond its capability. To reduce congestion, the optimal real and reactive power management can be done with the help of Particle Swarm Optimization (PSO) [2] using real coded Genetic algorithm. In this method, one can find a more sensitive generator for rescheduling using Transmission Congestion Distribution Factor (TCDF).

In the deregulated environment, the control over the transaction has been considered as a key factor for secure and stable operation of the power system. The Independent System

Operator (ISO) [3] has been responsible for the congestion management of power system. Hence to manage system it has been important to reschedule their real and reactive power optimally. The Adaptive Fuzzy Particle Swarm Optimization based Optimal Power Flow (AFPSO-OPF) has been introduced to solve the Congestion Management problem or multi-congestion case using the Non Linear Programming techniques.

1.2 Available Transfer capability and Congestion Management

The Available Transfer Capability and congestion management both has been treated as two sides of the coin. Without one of them, the system cannot survive. For the secure and stable operation of the electrical power network, the congestion management has been considered as a lifeline of the power system. The fundamental and latest developments of Congestion management and ATC has been discussed in next subsections.

1.2.1 Available Transfer Capability (ATC)

The rising in worldwide progress of deregulation has been made power system unstable because of simultaneous power transactions. Interconnected power networks has been made open for open access market of electricity with the reliable, economic and stable operation of the power system. Due to such revolution, the accurate calculation of ATC plays an important role in restructured electrical power network [28]. The Available Transfer Capability (ATC) has been defined as the additional capability of transmission line including Capacity Benefit Margin (CBM) and Transmission Consistency Margin (TRM).

$$ATC = WTC - TCM - CBM - ATA \tag{1.1}$$

Where ATA= Active Transmission Assurance

The fundamental equation has been represented by Equation: 1.1. The maximum power that can be transferred from one control area to other areas with all transmission limits are under the safe value and system stay secured [29] has been defined as the Whole Transfer Capability (WTC). The various ambiguity related with these factors cause major problems when calculating ATC values. Transmission Consistency Margin

(TCM) and Capacity Benefit Margin (CBM) has been used for modeling ambiguity in the ATC calculation. These two indices has been well defined in [29]. The WTC is commonly used as the basis for the evaluation of available transfer capability. It is assumed that TCM and CBM are both equal to zero as no framework has been made to evaluate these components.

The ATC value can be determined by Real Power Transmission Distribution Factor (RPTDF) and Line Outage Factor (LODF) [30]. The actual line flows has been compared with the line limits and price for congestion can be determined. The price is inversely proportional to generation. The price has been received by generator entities for energy supplied and load entities has to pay for energy used. As reliability depends on steady state voltage stability and ATC computation [31], both the factors has equal importance in the power system. From these two factors, the instability limits of the power systems has been identified.

1.2.2 Congestion Management

In deregulated environment all simultaneous transactions will pull the power system in unstable state or it is in congestion. Any violation in physical or operational constraints will results congestion.The constraints has been listed as under:

- Voltage Limits
- Thermal Limits
- Stability Limits

The power system must remain within above mentioned constraints. The transmission line operates beyond it maximum capability with the simultaneous transactions, the congestion has been observed the transmission line. The other factors affecting the congestion will be the Line outage or higher load on the transmission line. Congestion management has been identified the prime important activity for stable and secure power system. The main objectives of congestion management has been listed as under:

- Minimized hindrance of the transmission network in the open access market for electric energy.

- Secure operation of the power system.
- Enhancement of market efficiency
- Additional Power flow with the same Transmission line.

There are many Different methods like Optimal power flow based congestion management [32], Price area based congestion management [32] and ATC based congestion management [30] has been utilized for congestion management. For the congestion management, Particle Swarm Optimization with Time-Varying Acceleration Coefficients[4] algorithm has been used for optimal re-scheduling of real power generation.

The congestion in the transmission line can manage with help of three different contribution [5] factors like Network contribution factor, Generator contribution factor and load contribution factor has been used for congestion management. The first priority has been given to Network, second to Transmission line and lastly to load.

With increasing in load demand the power flow in the transmission line also increases. The structure of the transmission line has been fixed by geographical limitations and the setting of the new transmission line become costly. Hence, system operator has to manage power flow with the same line. The transmission lines has been congested with all the traded transactions simultaneously. To cope-up with this situation the pre-calculation ATC [1] has key importance for safe and reliable power system. The Federal Electrical Regulatory Commission (FERC) has mandated that the transmission line must be open for all the customers. As per the guideline of North American Reliability Council (NERC) and FERC, the posting of ATC on website called Open Access Same Time Information System (OASIS) in advance has become mandatory. The validity of the transaction has been decided by ATC data posted on OASIS. Hence ATC become the bridge between Generation, Transmission and Distribution of the power system.

Congestion Management [22] has been identified as a critical problem in deregulated Electrical Power network. The computation of optimized ATC value plays an important role in relieving of congestion in the network. The ATC has been calculated from the Real Transmission Congestion Distribution Factor (RTCDF) [23]. The RTCDF has been defined as the change in the distribution of power flow in the transmission line with simultaneous traded transactions in the electrical market.

For secure and reliable system operation, different Congestion management methods[24] has been used to relieve congestion. The traders are ready to sell their power to the consumer at a competitive rate. The Independent system operator plays an important role to manage extra power with the existing transmission line.

1.3 State-of-the-Art

With upward interconnections and loadings in the modern power system networks all over the world, power utilities are monitoring a major confront in maintaining desired control and security of power supply. Power system security and analysis become an vital part of modern energy management system. The economic droop coupled with environmental and ecological pressures have obliged the electric utilities, all over the world, to serve the enhancement in load demand without corresponding increase in generation and transmission facilities. This has forced the utilities to run their generators and transmission systems to their utmost capabilities. Hence, the deregulation of the power system has been derived for getting maximum reasonable benefits to the society.

A new congestion management system has been proposed in [18] [33], applied under nodal and zonal dispatches with the implementation of fixed Transmission Rights (FTR) and Flow Gate Rights (FGR), respectively. The FTR model has been proved especially suitable for congestion management in deregulated centralized market structures with nodal dispatch, while the FGR has been used for decentralized markets.

Congestion management is becoming increasingly important in deregulated power markets. Two main approaches to congestion management systems (CMS) can be found in the literature [33], nodal and zonal pricing. Congestion [30] can be handle with ATC based congestion management (many parts of U.S.), Price area congestion management (Nordic pool) and OPF based congestion management (U.K. power system). The information regarding ATC has been provided by Open Access Same Time Information System (OASIS) [30] for the future use.

Available Transfer Capability can be calculated through optimal power flow [6] approach. The voltage stability criteria has been utilized for congestion management with the help of economical cost of generation [7]. The Voltage stability has been calculated by an interior point method. Generator economic margin based on load margin and ranking, the lowest margin value will be adjusted to increase load margin to manage congestion.

The different congestion rates has been used to reduce congestion by deciding its rates for normal operation and abnormal operation of power system with the help of nonlinear programing [8]. Normally, the congestion has been alleviated with the help of generator rescheduling. The congestion relief management (CRM) has been used as ancillary services [9] in the restructured electrical power network to improve system security and stability. The CRM maintains system security and define charges as per congestion relieved. A Growing Radial Basis Function (GRBF) [10] Neural Network based methodology for congestion management has been used for prediction of Nodal Congestion Price (NCP) in deregulated power environment.

The impact of generator or load on the system has key importance in deregulation electrical power network. A novel method of identify the flow of electricity [34] in meshed electrical networks has been applied to both real and reactive power flows. The method permits the computation the real and reactive power output from a specific source and destination pair. It also presents the contribution of individual generator individual load. A software tool [35] has been used for congestion management and prices determination for transmission in electrical power network based on OPF.

The selection of generators to reschedule their output for the effective management of congestion has been carried out by an active and reactive power flow tracing-based approach [11]. The reactive power rescheduling cost has been calculated with the consideration of generator reactive power capability curve and reactive power bidding. The effect of congestion cost in a pool and mix of the pool with bilateral and multilateral transactions has been carried out in this study. For such secure operation, the transaction schedule and re-dispatch cost should be kept as minimum as possible. The value of Transmission Distribution Factors has been used to select re-dispatch of generator schedule and the re-dispatch cost can be optimized with the help of PSO with Time-varying Accelerating Coefficients (PSOTV)

The congestion has been relieved with the help of rescheduling of the generator using Particle Swarm Optimization (PSO) [12]. In this method, two different parameters to be determined namely; the location of the generator which is to be rescheduled and power to be rescheduled.

In a restructured electrical network, the congestion has been managed by rescheduling cost and real power loss minimization. These two parameters are taken as combined as single objective function by the weighted sum method. The Cluster/Zone based method has been used to find a number of generators participating in congestion management with the utilizing Transmission Congestion Distribution Factors (TCDFs). An optimization problem and Generalized Algebraic Modeling System (GAMS) tool [13] is used for solving the above problems.

The congestion has been managed by locating Flexible AC Transmission system (FACTS) devices optimally by Multi-objective PSO. In this method [14] ranking the optimal location of FACTS devices for relieving the congestion in the transmission line.To cope-up with congestion, optimal location and size of Distributed Generation can be found for reliable system operation [15]

The new concept of Relative Electrical Distance (RED) [16] has been introduced between the load and the generator. With this concept System operator have to manage those generator rescheduling having less RED. The generator sensitivity has been used for optimizing the participation of generators.

Due to congestion management, the traders gets benefit during no congestion or less congestion. They can manage their demand during less congestion period. With the help of congestion management risk associated with the transaction will be reduced. There have been certain methods [17] to manage congestion like implicit and explicit auction or counter trade, re-dispatch etc.

The FACTS devices has been used for Effective Management [19] of electrical power with existing transmission line. The FACTS devices penetrate reactive power to improve the capability of the transmission line. The operation of Power system become worse due to price unpredictability and system stability in a congestion state. The congestion of transmission line depends upon the load demand. Hence, load elasticity plays an important role to manage congestion. Hence, a new concept of demand elasticity has been discussed in [20]. Higher the demand elasticity index lower the charge to electricity.

Due to multiple transactions and penetration of wind power, the reactive power management has been essential for Congestion management. Hence, the rating and location of FACT devices has been decided by the two step and three step optimization techniques [21].

The frequent congestion [36] in transmission line has been identify as main hinders for the open access in a competitive power environment. The congestion management has been discussed in [37][38][39][40]. However, many of them has been focus on the cost and responsibility allocation.

Generally, the uncertainties has been attributed to unexpected system topology change, generation unavailability, weather conditions, human behavior patterns and so on, which in practice cannot be precisely predicted. The circuit or generator outages has been resulted in a considerable decrease of transfer capability. The measure of power transfer capability remaining apart from already committed capacity has been recognized as ATC. Thus, load forecast inaccuracy should also have a significant impact on ATC value. Therefore, it has been essential to address the influence of the inherent major uncertainties on ATC evaluation. In this respect, various approaches have been proposed with consideration of key uncertain factors affecting the value in addition to conventional methodologies for ATC calculation, which include sensitivity analysis [41][26], continuation power flow (CPF) algorithms [42] and optimal power flow (OPF).

A large number of OPF problems has to be calculated under different postulated system conditions. Unarguably, it is too time and labour consuming to give prompt answers to transmission-user requests and fulfill OASIS posting requirements. In [43], first order sensitivity has been applied to quantify the effect of network uncertainties efficiently, such as load forecast error and simultaneous transfers. However, it can only deal with continuous uncertainties. Considering one uncertainty at a time, this analysis can only measure the impact in a limited way. Additionally, the probabilistic characteristics of uncertainties have been ignored, which obviously affect the accuracy of the calculated value. How to evaluate ATC more rationally and efficiently is still a big issue. From the point of view of operational planning, a novel methodology has been proposed to evaluate the ATC of interconnected power networks[43]. With respect to the major uncertainties of power systems associated with determining ATC value, a realistic stochastic model for ATC evaluation is formulated. In the model, availability of generators and circuits are considered as random variables following binomial distributions.

For real-time calculation of Available Transfer Capability (ATC) can be possible with this work [44]. In deregulated environment, the fast and accurate calculation are the leading factors to be considered. Hence, the proposed iterative method overcomes disadvantages of existing methods. This method does not require the repetitive solution of power flow.

For traded Power transaction, ATC has been a vital indicator for congestion management in restructuring environment. In paper [45] a narrative method has been planned to pick the uncertainty faults in power system which change the value of ATC. For calculating ATC, diverse generator output method is also considered.

In [46], the method based on transient thermal circuit equation and modified thermal limit which involved Optimal Power Flow (OPF) for calculation of ATC. A nonlinear primal-dual interior point method [46] is utilized for the solution of OPF. In literature [47], the calculation of ATC has been carried out using DC load flow approach for multiple transactions power transfer sensitivity and succeptance matrices. The Total Transmission Capability (TTC) has been key component for the calculation of ATC in deregulated electrical power system. The main purpose of literature [48] is to compute TTC in the interconnections and also to improve it using reactive optimization technique. In paper [48] repeated power flow method has been used to calculate TTC due to its ease of implementation.

This paper [49] describes a speedy computation method for the tie-line ATC (Available Transfer Capability) with transient stability limitations. The calculation time has been drastically reduced with this work. A new index for finding decisive problems quickly with the help of a transient energy function and a screening method for ranking unstable cases using the stepping-out times are proposed.

In [50] , MATLAB software has been used to decide the Total Transfer Capability (TTC) of power transfers between dissimilar control areas in deregulated power systems without violating system limits such as thermal, voltage and stability constraints.

The concepts and calculation of ATC methods has been explained in [51] with relative advantages and disadvantages. The reviewed methods are based on DC and AC Power Transfer Distribution Factors, Continuation Power Flow (CPF) and repeated AC power flow.

In this paper [52] congestion management has been carried out with the concept of line flow sensitivities for line reactances based on DC method. The congestion can be relieved by charging reactances with FACTS devices.

In [53] describes the primary differences between locational pricing and redispatch-based congestion management, followed by an evaluation of their effects on grid operation and market efficiency. This work presents a modeling framework to decouple and analyze the effect of the transmission system on energy market efficiency. The demand side management based congestion management has been reported in [54] for a mix of pool and bilateral electrical market. For the congestion management, Generalized Power Flow Controller (GUPFC) has been studied.

Inappropriate execution of congestion management will disrupt the security and reliability of the power system and the free trading in the markets. The paper [55] shows a new scaffold for dynamic congestion management at unexpected contingencies.

In [56] paper examines the cost control issue of congestion management model in the real-time power systems. The enhanced optimal congestion cost model has been prepared by introducing the congestion factor for the generator side and load side simultaneously. The immune genetic algorithm, simulated annealing algorithm and ant colony algorithm has been used for the global optimal solution of real-time congestion management.

This [57] paper depicts an effectual method for Congestion Management by deciding the optimal place of Thyristor controlled series capacitor (TCSC) in a restructured power system. TCSC provides a powerful tool in raising overall transmission capability of line, upgrading of voltage profile and cutback of active power loss of transmission line. In some literature [57], an algorithm has been proposed for optimal location of TCSC to solve the congestion problem. In some literature [58], the Optimal location of multiple TCSCs for congestion management has been proposed for better congestion management. The different optimization techniques has been discussed in literature [59].

1.4 Motivation

In accordance with the Federal Energy Regulatory Commission(FERC) Order 888 (Promoting Utility Competition Through Open Access, Non-discriminatory Transmission service by Public Utility) and 889 (Open Access Same-time Information system), ATC must be calculated for electric utility[60]. FERC rulings declare that power system transmission network should be operated in a state of non-discrimination. Hence, Open Access Same-time Information System (OASIS) assumes an infrastructure in a competitive electricity market to ensure a fair opportunity for all competitors. FERC requires that updated ATC information be made available through the OASIS system. Utility engineers must compute and update hourly and daily ATC values.

Because of industrial revolution, the electrical power requirement has been tremendously rise in the open access market environment. Hence multiple transactions has been most considerable to keep system stable and reliable. If any violation in transmission limits occurs, the system gets damage. Whenever the physical or operational limits in a power system become live , the system is said to be in a congestion state. The main significance of proposed work is to manage congestion of transmission line in restructured electrical power network. The congestion management is based on cost criteria or operational criteria. This work based on congestion management with operational criteria. The transmission line has its own capability to allow the power flow. Due to environmental and Geographical limitations, it has not been possible to erect new transmission line for access power. The operation based congestion has been eliminated by Calculating "Available Transmission Capability" (ATC) of the transmission line. ATC is the capability of line over and above committed power transactions.

It is stipulated that the ATC values of some specific interfaces must be accessed by electricity market participants and system operators hourly through an Open Access Same-time Information System (OASIS). Apparently, the overestimation of ATC value will result in system operation risk, especially in the deregulated industry structure where the ;system situation is getting less predictable. It is also more difficult to gain the immediate co-operation of all possible resources during an emergency [61]. On the other hand, underestimating the ATC value will lead to a waste of the existing power network resources and result in unnecessary capital costs incurred. In a word, in a competitive power market, making mistakes in either situation inevitably means incurring a great penalty. As far as short-term operational planning is concerned, it is highlighted that one of the most important principles for ATC determination is the consideration of the reasonable uncertainties in the systems. This will ensure the security and reliability of the interconnected network operation under a broad range of changing system conditions [28].

According to the No-Free Lunch Theorem [25], there is no single meta-heuristic method which is top most for resolving all optimization problems. It means that, if one particular meta-heuristic may present very accurate results on a specific set of problems, but the same algorithm may represent poor results on a diverse set of problems. Hence, in this work, the performance of different artificial intelligence techniques (i.e. Roulette Wheel Selection Genetic Algorithm (RWSGA), Tournament Selection Based Genetic Algorithm (TSBGA), Particle Swarm Optimization (PSO), and Teaching Learning Based Optimization (TLBO)) has been analyzed for solving optimization of ATC.

The ATC has been calculated by Congestion Transmission Distribution factors. The optimized value of Available Transmission Capability calculation has been found noisy (Imperfect) with the help of Roulette Wheel Selection based Genetic algorithm (RWSGA).

To overcome this noisy fitness problem, Tournament Selection Based Genetic algorithm (TSBGA) has been proposed in this work. In this proposed work, different algorithms has been used to compute optimized ATC for a specific loading condition at three different load bus. The load has been served by varying generation at generating bus to get optimized ATC.

The objective function taken here is to maximize the value of Available Transmission Capability of the power line with the secured transactions. The projected method has been applied to an IEEE 30 bus test system and UPSEB 75 bus system. A data set of the generation and corresponding value of ATC for a specific load for IEEE 30 bus system has been used to frame statistical model with regression analysis. The regression has been used to frame a mathematical model from the data collected with TSBGA for a specific loading condition. The validity of the algorithm has been verified by statistical analysis. The most sensitive generation for a specific load has been predicted by mathematical model framed by Regression analysis. A more reliable transmission system with utmost safety can be obtained with the help of calculating ATC more accurately.

The main motivation behind this work is to develop new optimization techniques for calculation of ATC as follows:

1. To calculate value of optimized ATC, Genetic Algorithm with Roulette wheel selection (RWSGA) should be used for multiple transactions open access electrical power network. It has been observed that the evaluation of objective function contains noise in its final output.

2. Genetic Algorithm with Tournament Selection (TSBGA) method has been used to reduce noise in output.

3. To improve ATC results, Particle Swarm optimization techniques has been used.

4. With the help of mathematical modeling framed by Statistical tool, the most sensitive generation for a specific load has been identified.

5. To evaluate the performance of ATC value, a novel approach of Teaching Learning based Optimization (TLBO) techniques has been used with multiple transactions.

6. With the help of mathematical modeling framed by Statistical tool, the most sensitive generation for a specific load has been identified.

7. Comparison between all algorithms has been carried out to identify the best method.

1.5 Thesis Organization

The present *chapter-1* introduces the article survey for current scenario for Available transfer capability and congestion management in restructured electrical power network. This chapter presents the significance and scope of work to be carried out in the thesis.

In *chapter-2*, basics of Restructuring of the electrical power network and the importance of Available Transfer capability (ATC) in congestion management has been discussed. The Mathematical modeling of ATC using Power Transmission Distribution factor (PTCDF) has been carried out for congestion management. The algorithm has been developed for calculation of ATC for multiple traded transactions.

Chapter-3 presents the development Artificial Neural Network based algorithm for the evaluation of ATC. The data collected after running TSBGA, an ANN should be trained to give ATC value for any transaction. With the help of an ANN, the optimized ATC has been predicted for a specific loading condition.

Chapter-4 reports an evaluation of optimized ATC value using Genetic Algorithm (GA) incorporating Roulette Wheel Selection Based GA (RWSGA) and Tournament selection based GA (TSBGA) method. It also includes simple approach to develop statistical Model and analysis using the statistical tool with the data collected by TSBGA. With the help of this statistical model, the most sensitive generation for a specific loading condition among all the transaction has been identified.

In *chapter-5*, the ATC computation has been carried out with Particle Swarm Optimization Technique for more accurate results.

Chapter-6 a novel approach for assessment of optimized ATC value using Teaching Learning based optimization Technique (TLBO) has been presented.

Chapter-7 recapitulates the result comparison between different algorithms.

Chapter-8 Summarizes all main findings and important contribution of the thesis and give few ideas for further reach of exploring in this region