Congestion Management in Deregulated Power Market – a Review

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ABSTRACT
In a deregulated power market, the optimum power flow (OPF) for an interconnected grid system is an important concern as related to transmission loss and operating constraints of power network. The increased power transaction as related to increased demand and satisfaction of those demand to the competition of generation companies (GENCOs) are resulting the stress on power network which further causes the danger to voltage security, violation of limits of line flow, increase in the line losses, large requirement of reactive power, danger to power system stability and over load of the lines i.e. congestion of power in system. It can be managed by rescheduling of generators or optimal location of distributed generation (DG) at minimum cost with minimum loss without disturbing the operating constraints. This paper reviews some of congestion management (CM) methods including the nodal pricing method, differential evolution (DE), addition of renewable energy sources, extended quadratic interior point (EQIP) based OPF, mixed integer nonlinear programming, particle swarm optimization (PSO), cost free methods and Genetic Algorithm (GA). Each technique has its own significance and potential for promotion of rescheduling of generators in a deregulated power system.

Keywords
EQIP, FACTS, OPF, MINLP

1. INTRODUCTION
The restructuring of power system contains the paradigm shift in power grids control activities. The deregulation of power network has caused a large usage of the transmission grids. Here mostly, power network operates at the rated capacity as market players maximize the profit by using as much as of existing transmission resources. The increased trend in the number of contracts signed for the electricity market trades and availability of less no. of transmission resources leads to power network congestion [36]. Real-time transmission congestion is considered as the operating condition for which there is not sufficient transmission capability to employ all traded transactions at same time due to few unexpected contingencies. The congestion problem is increasing day by day due to certain reasons:

- Unexpected power flows in the large-scale transmission due to reasons of higher service quality and lower electricity prices.
- Due to very small investment in the power networks to meet the demand in deregulated power market.
- Fast change in power flows of power networks due to integration of wind power into power transmission networks.

Efficient congestion management is necessary for effective operation of power market while congestion occurs. The objective of managing the congestion is to take control actions for relieving congestion of power transmission networks. As per principle, congestion management can be viewed at the different timescales, for example:

- Long-term transmission capacity planning that can be done yearly, monthly, weekly or daily;
- Short-term scheduling of the transmission constraints in day-ahead market; or
- Re-dispatching of the generation in real time balancing market.
- Various methods for congestion management may be broadly described under two domains [39]:
- Technical methods which take into consideration out-aging of the congested lines, operation of Flexible Alternating Current Transmission Systems (FACTS) devices and operation of the transformer taps or phase shifter.
- Non-Technical methods which take into consideration nodal and zonal pricing [18, 22], counter trading [21], re-dispatching [18], market splitting [21], auctioning and load curtailment [27].

This paper reviews some of important methods and techniques used for congestion management by optimal location of rescheduled generators and their sizing in power system networks.

2. CONGESTION MANAGEMENT METHODOLOGIES
There are two basic paradigms that can be applied for congestion management. These are cost-free means and not-cost-free means. The cost-free means take into consideration the actions like outages of the congested lines or operation of the transformer taps, phase shifters, or FACTS devices. These means are named as cost-free only due to reason that marginal costs taken in their usage are nominal. The not-cost-free means take into consideration the security-constrained generations re-dispatch, network sensitivity factors methods, congestion pricing and market-based methods, and application of the FACTS devices [35].

This paper reviews some of important methods and techniques used for congestion management by optimal location of rescheduled generators and their sizing in power system networks.

3. CONVENTIONAL OPTIMIZATION TECHNIQUES

This section reviews conventional methods for managing the congestion which include extended quadratic interior point (EQIP) based OPF [4], promotion of renewable energy sources [3], using Static Synchronous Compensator (STATCOM) [5,6], Unified Power Flow Controller (UPFC) [29] and mixed integer nonlinear programming (MINLP) [7].

Literature [4,17] has presented an improved method for transmission line over the load alleviation in deregulated power network using load shedding and FACTS devices. Load shedding and FACTS devices are employed for relieving the congestion by extended quadratic interior point based OPF. According to reference [5], FACTS devices may be an alternative to minimize the flows in the heavily loaded lines causing an improved power capability, low system loss, increased stability of network by controlling power flows in the network. Modelling, simulation and analysis of a 5-bus system using MATLAB is demonstrated in literature [5,6]. Simulation methods needed for both steady state and dynamic operation of systems with FACTS devices UPFC [14, 26, 29] and STATCOM [5, 6] are analyzed.

Another approach has proposed congestion management methodology in a deregulated environment by using optimal placement of thyristor controlled series compensators (TCSCs) in the transmission network [7, 23, 26]. The location of TCSCs in power network is decided by using the integer variables; therefore formulation of the proposed problem takes form of mixed integer nonlinear programming (MINLP) problem. The optimization problem also achieves the minimization of reactive power procurement cost paid to the GENCOs for reactive power supplied in deregulated power network. The comparison of proposed approach with existing approaches concludes that by placing TCSCs on locations as decided by proposed approach, congestion is managed efficiently [17, 20]. An optimal model for managing the congestion has been proposed with more concern to promotion of renewable energy sources (RES) in deregulated electricity market [3]. It developed an optimal model of congestion management for the deregulated power network that dispatches pool in combination with the privately negotiated bilateral and multilateral contracts while increasing social benefit. This model measures the locational marginal pricing (LMP) based on the marginal cost theory [24].

4. ARTIFICIAL INTELLIGENT TECHNIQUES

This section reviews artificial intelligent techniques for example differential evolution, firefly algorithm, particle swarm optimization, genetic algorithm, fuzzy system and hybrid approaches.

SujathaBalaraman [2] has presented an algorithm for managing the congestion in pool based power market with the use of differential evolution. The aim of proposed work is to avoid the deviations from transaction schedules resulting low cost of congestion. Numerical results on IEEE 30 bus test system are illustrated and compared with PSO for observing the solution quality [34]. Different case studies results have proved DE to be an efficient tool for managing the transmission congestion in deregulated power market. S.M.H Nabavi [1,26] has proposed genetic algorithm to obtain the optimal generation levels in the deregulated environment. The main concern is on congestion in the lines, which limits the transfer capability of network with the available generation capacity. Nodal pricing method is employed to calculate the locational marginal price of each generator at each bus. Simulation results on the basis of proposed GA and power world simulator software are demonstrated and compared for IEEE 30-bus system [29].

Literature [8, 13, 15, 34] has presented an algorithm for managing the congestion in pool based power market based on Particle Swarm Optimization. The proposed approach efficiently relieves the line overloads with lower deviations in generations from the initial market settlement. Security constraints for example load bus voltages and lines loading are efficiently handled in optimization problem [31]. Numerical results on two systems say modified IEEE 30 bus and IEEE 57 bus test systems are demonstrated and compared with random search method (RSM) and simulated annealing (SA) method in terms of solution quality. The experimental results show that PSO is one among challenging optimization methods, which is indeed capable of providing the higher quality solutions for proposed congestion management problem.

The deregulated power market suffers from the problems occurring in congestion management. FACTS devices may be used to minimize the flows in loaded lines, causing increased stability and low power loss in system [17]. Ushasurendra and S.S Parathasarthy [10] have presented a fuzzy technique to select optimal location of thyristor controlled series capacitor to control the active power flows and for the reduction of congestion in transmission line. Line utilization factors (LUF) and real power performance index (RPPI) factor are utilized to decide the level of congestion in transmission line [25]. Transmission congestion management is one of important and critical tasks of system operator. Literature [11, 15, 16] proposed a transmission congestion management algorithm by optimal rescheduling of active powers of generators using Firefly algorithm. The developed method has been tested on IEEE 30 bus test system and results of many case studies have been compared with that of SA and real coded genetic algorithm (RCGA) methods [19]. Results conclude that firefly algorithm is most capable of providing high quality solutions for CM problem. N. Chidambararaj and K. Chitra [12] have presented a combined technique to solve the problem of congestion in transmission lines. For improving CM of cuckoo search (CS) algorithm, artificial neural network (ANN) is combined with CS algorithm. CS optimizes active power changes of generator when transmission congestion exists. Then, ANN is employed to predict generator rescheduling according to transmission congestion [34]. Thus, performance of CS algorithm is improved.

S. Thangalakshmi and P. Valsalal [9] have developed a hybrid fish bee swarm optimization based algorithm to minimize the congestion. Fish bee swarm optimization is developed by two algorithms i.e. artificial bee colony (ABC) and fish school search (FSS) methods. The proposed algorithm is tested on IEEE 30 bus test system. Results show best performance of proposed optimization to decrease the congestion. Reference [33] solves CM model cost control problem in real-time power systems. Various technical areas in power system need simultaneous optimization of multiple and conflicting objectives with complex non-linear constraints. Recent research on multi-objective evolutionary methods has proved that population-based stochastic algorithms are most beneficial approaches for these types of problems [40]. Transmission congestion can largely limit less costly generation units from being dispatched in the power system operation. Optimal transmission switching acting as a

congestion management tool is employed to change the network topology which further would lead to more power system market efficiency. The transmission switching (TS) is formulated as an optimization problem to obtain most influential lines as the candidates for disconnection [37, 41]. Locational marginal prices are utilized in the transmission engineering mainly as near real-time pricing signals in deregulated power system. Literature extends this concept to the distribution engineering using formulation of distribution LMP signal on the basis of power flow sensitivities in distribution system. A Jacobean-based sensitivity analysis has been proposed to apply in distribution pricing method [42]. In a deregulated power market, when congestion exists in a transmission line, it violates the security and increase the cost of system. Generator rescheduling is one of ways adopted by ISO to minimize the transmission congestion in deregulated power market. Reference [43] developed an artificial bee colony (ABC) based generator rescheduling for managing the congestion. ABC algorithm is a new metaheuristic method inspired by the intelligent foraging behaviour of the honeybee swarm.

In literature [44], an evolutionary optimization technique based methodology has been presented to sustain total generation cost even in the contingent states of power network for the consumer welfare. Congestion management is one of technical challenges in the power system deregulation. Reference [45] proposes the single objective and multi-objective optimization approaches for the optimal choice, location and size of TCSC and Static Var Compensators (SVC) in deregulated power system to enhance the branch loading (minimize congestion), reduce the line losses and improve the voltage stability. Reference [46] presents an approach for selecting the optimal locations and capacities of multiple FACTS devices for relieving the congestion and considering the voltage stability in deregulated power market. Reference [47] develops the model of stochastic behaviour of nodal prices of electrical power in the deregulated power markets in USA. Congestion management is one of most important issues for reliable and secure system operations in a deregulated power market. Reference [48] proposes a cost/worth analysis approach for the optimal location and sizing of the distributed resources (DRs) to remove congestion and improve security of system. As one of large operating challenges in power market is to minimize the transmission system congestion for its secure operation. Reference [49] has addressed mainly the issue of congestion management employing TCSC.

In power system, transmission lines congestion and usage of FACTS devices are closely linked and it is significant due to their role in the power delivery system improvement. Reference [50] shows how GENCOS market power gets advancements due to FACTS devices. Reference [51] presents a Swarm intelligence based Optimization to minimize the congestion in power system with transmission line overload. The proposed algorithm utilizes a standard congestion sensitivity Index to choose the congested lines in a large power system network and optimizes congestion management charge without any installation of FACTS devices and the load curtailment.

5. CONCLUSION

In a fast changing deregulated power market, congestion management has become critical issue. New challenges and factors are focusing the evolution of newer methodologies. In this paper, a review on congestion management methods and techniques available in literature for recent years is presented. An attempt has been made to give importance to all emerging trends in Congestion Management. Table A1 (Appendix) compares the different algorithms for congestion management based on type of contingency using IEEE 30 bus test system. Table A2 (Appendix) compares conventional congestion management methods with different characteristics.

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7. APPENDIX

Table A1. Comparison of Different Algorithms used for Congestion Management Tested on IEEE 30-Bus System

S. No.	Congestion Management Methods	Type of Contingency	Net Power Violation	Real Power after CM (in MW)	CM Cost ($/MWH)	Change in Active Power (in MW)	References
1	Particle Swarm Optimization (PSO)	Outage of line 1 – 2	23.393	-	538.95	23.906	[8]
2	Random Search Method (RSM)			-	716.25	23.339	
3	Simulated Annealing (SA)			-	719.86	23.809	
4	Real Coded Genetic Algorithm (RCGA)		281.637	265.009	2737.2	110.957	[28]
5	Artificial Bee Colony Algorithm (ABC)			129.95	2867.3	107.711	
6	Simulated Annealing (SA)			264.214	3672.7	112.737	[11]
7	Firefly Algorithm (FFA)			-	2350.24	22.009	
8	Differential Evolution (DE)		23.393	252.83	457.694	23.014	[2]
9	Neural Network – Cuckoo Search (ANN – CS)	Outage of line 10 – 17	-	248.79	149.745	124.21	[12]
10	Cuckoo Search Algorithm (CS)		-	215.59	151.146	163.41	
11	Particle Swarm Optimization (PSO)		-	283.44	161.498	182.68	

TableA2. Comparison of Conventional Congestion Management Methods

S.No.	Method	Characteristics	Market Based	Generation Allocation	Alleviation	Example	References
1	Explicit Auctioning	Decentralized auctioning of transmission capacity	Yes	Yes	No	European interconnection	[21, 32, 40]
2	Nodal Pricing	Requires centralized dispatch implemented in pool based markets	Yes	Yes	No	New England, New York	[30, 38, 32, 40]
3	Zonal Pricing	Can be used with centralized dispatch or using market splitting	Yes	Yes	No	Australia and Nordic pool	
4	Counter Trade	Replacement of ill placed producer with better placed producer	Yes	No	Yes	Sweden	[21, 32, 40]
5	Pro-rata methods	Some norms of allocation, not necessarily economically	No	No	Yes	Most of the developing countries	