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A Comparative Analysis of Different Congestion Management Techniques

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Abstract

Managing congestion is an important issue in deregulated power system. Due to congestion in transmission line, the electricity prices increases which makes the market inefficient and thus, results in market power. Because of this, managing congestion in the transmission line has become a very challenging task for the system operators so as to maintain the power system reliability which results in an efficient, secured and economical power markets. In this paper, focus has been given on different aspects and methodologies of managing congestion based on the survey of bibliographical literature which is available on congestion management. This paper gives the general concepts on congestion management, briefing of research and future aspects which is related to managing congestion andthe methodologies used in electricity markets for congestion management.

Keywords- Congestion, LMP (locational marginal price), market power,re- dispatch, zonal price, reactive power, FACTS.

I. INTRODUCTION

Problem of congestion in transmission line is studied from different transactions available in deregulated power system [1]. The open access of transmission line affect the reliable operation of transmission line which becomes the most crucial issue in restructured power system these days [2], [3] [4], [5], [6]. Because of this, the dispatching of generated power through transmission line to meet the demand required by the consumers has become a very challenging and complex issue [7]. The congestion which is there in a transmission line is not tolerated either in vertically organized or in unbundled power system as it can cause the cascade outages, also increase losses, it act as a barrier in energy transaction and also it can make the system unsecured and unreliable [8]. Therefore, the system for managing congestion is very important for the secured and reliable operation of power system. The Independent System Operator (ISO) is there in the deregulated power system which serves the multiple tasks in the market models. The ISO defines different rules so as to get control on the producers and consumers so that secured and reliable power market can be ensured and thus, increasing the market efficiency [9]. Leeprechanon et al. gives the idea of the development in the transmission network in deregulated power markets [10]. The congestion management is the very challenging area for the researchers worldwide from last two decades. Number of literatures on managing congestion is available. A. Kumar et al. had given the brief survey of congestion management [11]. But, the power market has seen many changes after that. Various techniques and algorithms are developed so as to minimize the congestion and establish the secured and reliable power market.

II. GENERAL BACKGROUND AND CONCEPTS

The power industry is converting rapidly from vertically regulated to unbundled deregulated power system. The power system get deregulated in many countries like UK, U.S., Australia, Chile, Peru, Columbia, and many other European countries. The power market differ from other markets in many aspects such that unlike any other commodity, the electricity cannot be stored easily in bulk, many physical laws, which act as a constraint, should be satisfied for the secured and reliable operation of power market [12], [13]. Because of an open access of transmission network, every consumer wants to purchase the power from the cheapest producer which is available in the power market without considering its geographical locations. Because the transmission line has the limited capacity to transmit power, this makes the transmission line overloaded [14]. Loop flows or parallel flows enhances the problem of transmission network congestion [15]. The general agreement on parallel paths (GAPP) is formed by the Interregional Transmission Coordination Forum to deal with the issues linked with the loop flows of the interconnected transmission network [2]. Managing congestion and electricity pricing are the debatable issues in the deregulated power market [16], [17]. The concepts and assessments related to congestion management are detailed in [18], [19], [20]. Bompard et al. has developed a framework for the mathematical model of the methodologies used for managing congestion [64]. A review of congestion management techniques and the mechanism for pricing adopted by deregulated power markets i.e. the old UK Pool, Nordic Pool is given in [170], Northeast American markets (PJM, ISO-NE, ISO-NY), and the UK NETA system, Thailand are given in [21], [22], [23], [24].

III. METHODOLOGIES FOR MANAGING CONGESTION

Various methods are adopted for managing congestion in the power markets worldwide. Literature reveals that congestion can be minimized using the cost free techniques [8] like rerouting of lines, (ii) operation of transformer taps, phase shifting transformers [25], and flexible AC transmission system (FACTS) devices [26]. Kaymazetaf.gives the idea that what are the effects of congestion in transmission network on the expansion of power generation [27]. The devices which control the reactive power and the techniques for managing load which includes the bidding interruptible load as a result of various market prices also helps in managing the congestion. In the paper [28] and [29], various techniques such as enhancement of critical thermal rating of circuits, improved maintenance, ancillary services and contingency planning to work on live line along with the investment in the software used as a tools for decision and staff training also helps in minimizing congestion.Broadly, Christie et al. has categorized the methods for managing congestion as the method based on price area, method based on optimal power flow (OPF) and the method based on available transfer capability (ATC) [5]. The literature survey shows that the congestion management techniques can be broadly classified as market based techniques and non-market based techniques.In nonmarket based techniques, the market strategy is not used to deal with the scarcity in the transmission capacity.Many non market techniques are there like contract type, on the basis of first come first serve, pro - rata methods, load curtailment, use it or lose it technique and, reserve pricing [30]. Such methods don’t need any investment for minimizing congestion in the transmission system. In market based methods, the techniques based on market approaches are used such as the bids submitted by the participants who are participating in the market (producers and consumers). Paper [30] and [31] shows that the market based techniques can be classified as Alleviation methods and Allocation methods. In the Allocation methods, usually transmission capacity is allocated in ex-ante manner [26] before physical transfer of power takes place. These methods are the method based on Network sensitivity factors, method based on explicit auctioning of network capacity and, method based on pricing (nodal pricing and locational marginal pricing (LMP) method [32]and zonal pricing [26]. The methods based on Price responsive demand methods and support through reactive power are also comes under the category of market based methods. To release the congestion in real time, Alleviation methods are used. These methods are re-dispatching of power, counter trading and, methods based on transmission loading relief (TLR) [31]. The various aspects of market based methods such as costs, advantages and limitations of various market based methods for minimizing congestion is detailed in [33]. Tao and Gross [34], [35] and [36] gives a flow-based congestion management allocation technique for multiple transfer networks. In paper [37], a sequential bidding model is proposed for executing the bilateral service contracts keeping all the security factors in view. In paper [38], the bilateral contract model is given using transaction matrix. Gedra has given a review that how optimal bus pricing and congestion cost can be calculated through DC load flow approximation technique [39]. GuIer et al. in paper [40] has analyzed the link between the real time security and the day ahead markets and also analyses the importance of the financial entities in the multi-settlement system. In paper [41], investigation has been done related to the exchange of information between the market participants according to the protocol for minimizing congestion. The market based methods are more transparent and is very supportive in the power supply industry [26].

IV. MARKET BASED METHODS

Bibliographical survey of the literature related to market based congestion management techniques and market power is discussed in this section. This method is categorized under 3 sections:

A. Network Sensitivity BasedMethods: Fradi et al. gives a technique to find out the factors based on network sensitivity factors for energy transaction allocation including ancillary service allocations [42].The iterative calculation of ATC and re-dispatching of load and generated power with the help of sensitivity analysis is given in [43]. Fernandes and Almeida [44] proposed a model for optimal active and reactive power dispatch based on current injections. Kumar et al. [45] proposed zonal/cluster based transmission CM method utilizing sensitivity indices- real and reactive power transmission congestion distribution factors (PTCDFs & QTCDFs respectively). Dutta and Singh [46] and authors of [47], [48] have provided a technique for optimum selection of generators for CM and made use of particle swarm optimization (PSO) in the solution of the CM problem. The generators contribution to reactive power flows as well as loads contributions to real and reactive line flows formed the basis for determining the most appropriate generators as well as loads for CM in [49]. Reference [50] presented the use of bus impedance matrix to determine the sensitivities of line flows in congested transmission lines as a function of bus injections.

B. Explicit Auctioning Methods: The principle of explicit auctioning is based on selling the available capacity of the tie line to the highest bidder through auction. This approach is commonly used in Europe for capacity allocation at several borders e.g. tie lines between Germany & the Netherlands, Germany & Denmark, France & the U.K. and the U.K. & Ireland [19]. Reference [51] considered both demand-side bidding and inelastic demand to price transmission congestion. Reference [52] has proposed use of energy balance service market for transmission congestion relief.

C. Pricing Based Methods: Congestion pricing is the primary means for CM [8], [53]. The spot pricing which is basis of the LMP was proposed by Schweppe et al. in [54]. Harvey and Hogan [55] analysed the nodal pricing and zonal pricing in context to locational market power. References [56] & [57] proposed the systematic procedures for implementing cluster-based CM systems. References [58], [28], [59] provided the description of components of nodal prices. LMPs are time variant and increases with loading levels and transmission congestion [16]. Reference [40] presented the wide acceptance of LMP in several electricity markets of the world like Argentina, Chile, Ireland, New Zealand, Russia, Singapore and, several US states. Zonal pricing is adopted by Australia, Scandinavian countries (Nord pool) and by most European countries. Zonal pricing method and congestion cluster pricing method are explained and compared in [56], [60], [61]. Ex ante transmission congestion prices are computed in [62], [63], and [64]. Reference [16] presented quantitative indices for locational market power screening. In comparison to uniform marginal pricing and zonal marginal pricing, LMP-based approach is effective in providing transparent economic signals [65]. Hao [66] presented a framework for decentralized intermarket CM of day-ahead markets in an interconnection. Cheng and Overbye [67] presented an algorithm in which both the marginal loss prices and the differences in the marginal congestion prices were independent of the reference bus. Reference [68] proposed a methodology to eliminate the reliance of loss component of LMP on presetting the loss related factors. Loss hedging rights hedge the price risks caused by marginal loss component of the LMPs [67]. The transmission rights are defined in four possible ways [69], [5], [70], [68]: (i) point-to-point financial rights, (ii) flow-based financial rights, (iii) point-to-point capacity reservations [69], and (iv) flowbased capacity reservations and an estimated congestion rent collected by the ISOs of these market is presented in [71]. Flow-based transmission rights, or flowgate rights (FGR) are financial entitlements and are used for zonal pricing associated with decentralized markets [70], [21]. Reference [72] presented literature review based on publications on analysis and mitigation of market power in electricity supply. References [73] & [34] investigated market power problems and related solution techniques in electric power market. Peng and Tomsovic [74] & [75] proposed a probabilistic bidding methodology to reduce the influence of congestion on market clearing price. Reference [76] proposed technique relied on imposing OPFbased constraints targeting voltage instabilities. Reference [77] proposed a multiobjective PSO method for CM. CM method considering operating and voltage stability constraints under normal and multi contingency conditions for day-ahead markets is given in [78]. Reference [79] proposed an algorithm based on differential evolution while authors of [64] proposed real coded GA transmission line over load alleviation. J. Dijk and B. Willems [80] compared nodal pricing and counter trading mechanisms to manage congestion. Authors of [41] proposed multiobjective fuzzy evolutionary programming and nondominated sorting GA and [81] proposed artificial bee colony methods for congestion alleviation. The PSO algorithm to optimally reschedule the active power of the generators and power consumption of the load for relieving congestion is employed in [82]. A set of indices has been introduced to measure the sensitivity of a particular load to the congested power flow, congested prices and the acceptance level of the amount to be curtailed in [83]. Reactive Power Support The reactive power supply and transmission network voltage control classified as ancillary services are required in order to maintain the necessary system security levels. The reactive power support can increase the active power transfer limit of the line. A considerable amount of literature has been published on the reactive power management and pricing. In this section those publications which are related to reactive power support in context of CM are presented. In [84], [85] real-time pricing of reactive power is discussed. The two part spot-pricing of reactive power is presented in [69]. Local reactive power market concept and the cost allocation methods for valuing reactive power have been detailed in [89]. A. Yousefiet at. [87] developed mixed integer constrained optimization formulation for coordinating both FACTS controllers and DR to achieve CM at a minimum cost. [88] described the dynamics of the price-elasticity of consumers. Jain et at. Flexible AC Transmission System FACTS controllers play an important role in increasing power transfer capability of the existing transmission system and controlling the network congestion [89]. Xiao et at. [90] presented load flow solutions with embedded FACTS devices. Alomoush [91] has presented impacts of putting unified power flow controller (UPFC) in service on out-of-merit costs and LMPs. References [92] & [93] have proposed thyristor controlled series compensators in a bilateral dispatch framework to reduce congestion in line and maintain system security. Reference [94] proposed application of PSO, GA and SA for optimal power flow using Interline Power Flow Controller in multi-terminal transmission system. Optimal placement of FACTS devices i.e. thyristor controlled phase-shifter transformer and their setting in real-time balancing market and its impact on generation re-dispatch costs is discussed in [95].

V.CONCLUSION

In this paper, an overview related to the concept of congestion management and different methodologies which can be used for minimizing congestion in restructured power system is given based on the bibliographical survey of literature.Various forms are there of congestion management in various countries worldwide. These forms vary on the type of restructured model adopted in the power market. Many methods based on pricing, re-dispatching of power and load curtailment are used worldwide for minimizing congestion in the transmission network. Every method has its own advantages and limitations.Various smart techniques hadbeen developed for getting the fast and better response.Use of FACTS devices in the transmission network is increasing for minimizing the congestion in the network.The literature shows that the ancillary services also play an important role in minimizing congestion. The reactive power insertion in the transmission line increases the transmission capacity along with decreasing the losses which further gives the voltage stability to the system. For further development to deal with the problem of congestion, the researchers and academicians should keep themselves bibliographically update time to time because the policies and regulation of power markets are changing continuously for further improvement.

VI. FUTURE ASPECTS

The use of distributed energy resources in congested areas have been envisaged as promising options for CM. Demand side response programs have potential to not only reduce congestion but also reduce the peak loads to give flatten smooth load curves. A careful planning of transmission expansion and optimal usage of FACTS devices on networks has bright prospects to mitigate congestion. The development of energy storage devices and integration of distributed generation, renewable energy sources & load side management are some areas which can be further explored for the efficient network management.

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