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Congestion Cost Calculation in Restructured Power System: An Overview

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ABSTRACT: Under the competitive power market environment, number of market participants has increased and all market participants try to get benefits of cheaper sources. The tendency of getting more profit margins may cause overloading and congestion in certain transmission corridors. Thus congestion may lead to violation of voltage or transmission capacity limits and threatens the power system security and reliability. Moreover, open access in transmission system and competition in generation and distribution, has introduced a more intensified and frequently occurring problem of congestion. Also the growing congestion may lead to unanticipated divergent electricity pricing. Owing to these facts congestion management has become a crucial issue in the deregulated power system scenario. The review work to unite various publications on Congestion Management in past few decades and to present a systematic overview for providing solution methods for the same has been discussed in this paper. The cases for Congestion Management in various countries like California, Switzerland (Etrans), Japan, Australia, Thailand, UK, and Nordic Countries are studied and reviewed in this paper.

KEYWORDS: Congestion Management, Transmission System Operator, Deregulation, Power market, Available Transfer Capacity (ATC), Optimal Power Flow (OPF), Generation Companies (Gencos).

I.INTRODUCTION

To deal with congestion in the competitive environment, several methods are experimented all over the world e.g. auctioning (Explicit auctioning and Implicit auctioning) methods [1], nodal or zonal pricing approach, counter trading and re- dispatching. To have a preventive Congestion Management a proper coordination must be there between ISO and Gencos [2,3]Restructuring means transforming a vertically integrated system into an unbundled system. The unbundling of the electric power supply system has evolved a new organizational structure. Restructuring itself means liberalization, deregulation and privatization [4].

The Traditional Regulated Power System has now become a competitive Power Market. In this changed scenario of Electric Power Supply System, the real time transmission congestion is the operating condition in which there is not enough transfer capability to implement all the traded transactions simultaneously due to either some unexpected contingencies or market settlement [5]. Congestion is associated with one or more violations of the physical, operational and policy constraints under which the grid operates. As compared to the conventional monopolistic power market, the chances of congestion are more in open competition power market because every transaction needs maximum benefits. Unlike traditional utility environment, Congestion Management has to include both, technical as well as financial tools that mean the congestion relief actions (i.e. overloading alleviation) and price allocation mechanisms [6].

An appropriate classification strategy for Congestion Management methods and their solution techniques are presented in [7], while [8] presents a bibliographical survey including web sites dealing various issues in Congestion Management. A comparative analysis of various Congestion Management schemes and the associated pricing mechanisms are briefly reviewed in [9]. In the Restructured Power environment the TSO, responsible for secured and reliable operation of his transmission network, plays a very important role in Congestion Management [9]. Apart from all other functions a TSO has to identify the users of individual transmission lines [10] so that in case of congestion it can charge proper transmission congestion fee to those users.

`The objective [11] of Congestion Management in the shifted power system scenario would now be: to provide MW schedules prepared by ISO on the basis of load forecasting with appropriate system security and reliability margins, to maximize the overall degree of satisfaction for all the market participants and to settle the power market at such an economic state which is consistent with the MW schedules. Appropriate invocation of interruptible loads by ISO as an aid to relieve congestion has been suggested in [12]. A heavily congested condition can be released by curtailing non-firm transactions [13].

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II.BRIEF DISCUSSION IN CONGESTION MANAGEMENT METHODOLOGIES

There are two broad paradigms that can be employed in Congestion Management. These are *cost-free* measures and *not-cost-free* measures. The nearly cost-free measures which the TSO has at disposal, are changing of the topology of the network, new setting for transformer taps, activation of conventional compensation devices e.g. phase-shifters and use of Flexible AC Transmission System (FACTS) devices. These are *cost-free* in sense that marginal costs (not capital investment) involve in their uses are nominal. The not-cost-free measures include generation re- scheduling and prioritization/ curtailment of loads/ transactions. A Security constrained generation rescheduling and load-shedding algorithm involving screening/ranking of contingencies is proposed in [14]. Different kinds of systems tackle the transmission congestion in different ways.

III.FACTS DEVICES ANALOGY IN CONGESTION MANAGEMENT

The major hurdle, which the congestion causes, is to obviate the main objective of Deregulation i.e. to supply most economical power to the consumer. Congestion raises the cost of supply due to addition of surplus congestion charges. FACTS devices not only increase the transfer capacity of existing transmission line but also reduce the congestion cost by performing voltage control, reactive power control and stability limit control for the power system. Some FACTS models like, Unified Power Flow Controller (UPFC) and Static Series Synchronous Compensator (SSSC) are suggested in [15,16]. An appropriate Loop Flow Controller by using DC-link and UPFC is implemented in [7]. The adequate pricing for these devices along with penalty on users to operate at their limits is still a challenging task [17].

IV.CONGESTION MANAGEMENT PRICE CONTROL THEME

In this method, the system is split into different price areas. Spot market bidders must have to submit separate bids for each price area. Area with excess generation will have lower price and those with excess demand will have higher price. Reference [18] Suggests a model for area price determination and handling joint market Congestion Management.

Congestion Management on ATC: In this method the day-ahead or hour-ahead ATC information is uploaded on a web site known as Open Access Same time Information System (OASIS) by ISO/ TSO. Anyone wishing to do transaction, can access OASIS web page and can have the information whether his transaction would be accommodated or not. OASIS implements the Electronic Scheduling [19], which is having very bright future to facilitate data sharing in the new electricity market in North America towards managing congestion.

Congestion Management on OPF: The objective of this method is, to minimize generators cost [8] and maximize consumers benefit subject to a set of constraints. OPF framework is the obvious choice for Congestion Management for most of the researchers. An optimization method can be an effective tool for analyzing and solving overloading problems. A complete mathematical formulation [20] for congestion management comprises, formulation for pool and bilateral/ multilateral dispatches, formulation for power balance constraints and transaction curtailment strategies. In congested scenario some transaction curtailment policies [21] have to be implemented by ISO in collaboration with market participants. The basic objective of these policies is to minimize any deviation from scheduled transaction. The impact of multilateral congestion management on the reliability of power transactions is assessed in [22]. This assessment is based on reliability indices and indicates that the multilateral management results in smaller curtailments and congestion costs than traditional bilateral management. An optimization problem solution called as Decentralized Risk based Congestion Management [23] is useful for predicting risk of thermal overloads.

Soft Computing techniques for Congestion Management: Highly optimized numerical algorithms have been developed using soft computing techniques to provide solution to the Congestion Management problems.

Genetic Algorithm based congestion management: Congestion Management is in fact a non-linear optimization problem, having an additional dimension of social welfare. A Genetic Algorithm approach proved to be a powerful tool for achieving global optimum specifically i counter trading [24]. The operating conditions that allow alleviating overloads are the conditions with optimum system parameters hence apart from many other Evolutionary computation techniques, Genetic Algorithms [25] are proved to be successful with smart definition of chromosomes in alleviating congestion. A Differential Evolution technique is presented [20] to tackle congestion problem. A large-scale mixed-integer programming problem for finding optimal topological configuration of power network using a deterministic and Genetic-Algorithm has been presented in [26].

Fuzzy logic connection approach: The present deregulated fuzzy environment of power system provokes the use of an optimization technique in coordination with a fuzzy logic implementation. A fuzzy decision opinion matrix approach is used in [27] to select optimal transaction strategy. In a similar manner, a symbolic simulation based approach with black- box optimization library function is used in [28] to solve congestion.

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Congestion Management methods on market analogy: Because of rapid growth of inter-regional trading, the development of new market-based methods is gaining popularity in Congestion Management. Many of the references in literature are having such methods like inter-regional electricity market [29], market integration and cross-border congestion management [30,31], market splitting, market coupling, inter-market congestion management etc. These are truly competitive and efficient in the new power market context and have been suggested in the Spanish electricity market and Spanish-French interconnected market [32,33]. These market-based approaches allow optimum use of available transfer capacity without any risk of system security.

The decentralized approach to inter market Congestion Management is proposed in [34]. A market splitting mechanism along with cross border coordinated re-dispatching is proposed in context of Iberian Electricity Transmission grid [35]. The combination of market splitting and counter trading has been analyzed in [36]. Inevitably some congestion may still arise and must be corrected in real time by centralized control [37]. Applying new concepts in unit commitment and economic dispatch now revolutionizes the traditional philosophy of power system planning and operation. [38], has proposed a binary linear programming tool for unit commitment and economic dispatch, taking nodal constraints into account. The annual report on market issues for PJM and California is presented in [39,40].

Congestion Management depend on Voltage Stability: A recent development [41] shows that inclusion of voltage stability constraints in a congestion- relieving algorithm results in a better economic outcomes (for consumers and producers) than using offline non-thermal line capacity limits. The real time congestion problem can take place due to voltage security requirements. [42] indicates that this kind of congestion affects the system operation, reliability, security, nodal prices, loss and generating costs and above all power quality and stability. So it should be dealt with proper attention. Extensive voltage stability margin assessment, for a test system [43] shows that in identification of congested area, modal analysis techniques can be proved to be powerful.

V. CONGESTION MANAGEMENT ON NODAL AND ZONAL BASED

In the initial stage of restructuring, zonal approach for congestion management is the best option, while nodal approach with even more accuracy, is not preferred in the transiting stage of restructured scenario due to its complexity. In zonal approach the whole system is divided into various zones based on either their sensitivity indices [44,45] or various contribution factors like network contribution factor, generator contribution factor and load contribution factor [46]. The generators in the most sensitive zones, with strongest and non- uniform distribution of sensitivity indices, are identified for rescheduling their outputs as an essential means of Congestion Management.

Lines having more severe and frequent congestion separate these zones. It can be carried out on Inter- zonal and Intra-zonal theme of Congestion Management in which phase-shifters and transformer taps play an important role without any generation re-scheduling [47,48]. Intra-zonal congestion refers to overloading of line(s) or part of transmission network within an area or a zone, whereas overloading of line(s) or transmission system between different areas/ zones is referred to inter-zonal congestion management. An efficient method for transmission network cost allocation using nodal pricing is proposed in [49]. A cluster based approach for Congestion Management is suggested in [50]. A zonal Congestion Management scheme with coordinated control of phase shifter is proposed in [51]. This method is looking attractive, as there is an extra remuneration announced for each phase shifter in proportion to their contribution to the increase of overall benefit due exclusively to the optimal phase shifting.

One essential function of Congestion Management is framing and allocating congestion charges. Two methods of evaluating congestion charges are nodal pricing and zonal pricing that are complemented by their respective Transmission Rights [52] and Congestion Revenue Rights [53]. A comparative analysis of various pricing schemes in Deregulated Electricity Market is presented [54]. The distribution factors have a great influence on the congestion revenue rights [55]. The nodal pricing method calculates locational marginal price at each node. The zonal pricing method consists of two steps: aggregation of individual nodes into zones on the basis of some criterion and computation of zonal prices. A new approach to allocate the cost of congestion and losses to the nodes of the transmission network based on nodal responsibility is proposed in [56].

VI.PROBLEMS GENERATED IN CONGESTION MANAGEMENT

Restructuring of the electricity supply industry is a very complex exercise. This is due to the fact that numerous factors such as national energy strategies and policies, macroeconomic developments and national geographical conditions, affect Congestion Management in various proportions. In the conventional monopolistic power system the problem of congestion (overloading) could easily be solved by re-dispatching the outputs of generator units by either corrective or preventive measures, while in the present scenario of deregulation any change in output of generation unit will lead to reallocation of economic benefits of various generation participating

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companies.

A direct consequence of transmission congestion is that position of Gencos in competitive environment along with their optimal bidding strategies are severely affected. A systematic approach is needed [57] for developing optimal bidding strategies saving their position in the competition. Because of their individual marketing strategies, during Congestion Management there is conflict with the objectives of various Gencos. The condition of congestion highly affects the bidding strategies [58]. LMP reveals important information for market participants to develop their bidding strategies. An efficient tool like neuro-fuzzy price forecasting approach [59] is required to forecast LMP values at a node or in an area. As each company wants to maximize its own benefits, generation re-dispatching can influence the benefits of others. Apart from it, curtailment of a bilateral transaction requires simultaneous and equal reduction at both the ends. All this makes Congestion Management a challenging task. Moreover Congestion Management becomes costly when congestion is severe.

The regulating bids for supplying and consuming electricity are increased due to congestion alleviation charges. The major problem identified in Congestion Management is the lack of alignment between regulatory body and market participants. With the deregulation, electricity market has become more flexible as compared to regulated monopolistic system. Hence it becomes increasingly difficult to perform preventive Congestion Management measures. The only option left is generation rescheduling using corrective Congestion Management measures, which is quite a costly affair. In this way congestion puts a constraint on energy market and in many instances makes them non-competitive, thus disregards the theme of deregulation.

VII. CASES IN CONGESTION MANAGEMENT

The cases for Congestion Management in countries like Japan, Switzerland (Etrans), Thailand, Australia and Nordic Countries are studied and reviewed in this paper.

Congestion Management at Switzerland

Due to recent increase in congestion, the Swiss TSOs have devised a refreshingly new day-ahead congestion management concept [60]. This novel concept incorporates three automatic processes namely, congestion forecast, determination of congestion elimination, system methodology and implementation. The day-ahead Congestion Forecast (DACF) comprises three parts namely preparation of Swiss DACF dataset, collection, check, scaling and merging of all DACF datasets and load flow calculation.

Congestion elimination determining process is performed with an OPF software package, which optimally combines two measures: topological measures and re-dispatch. Topological measures comprise the change of operational status of a network element, transformer tap adjustments and substation reconfiguration, while re-dispatch alleviates congestion by using globally optimal solutions.

Congestion Management in Japan

Japan has stepped into deep phase of liberalization, which has two noteworthy elements: a neutral organization and a wholesale power exchange [61]. The first one is unique, neither a regulator nor a system operator. In Japan the power transmission network is different from any other country. There is no loop flow problem with tie lines, as one interconnection route typically consists of two transmission lines. Each utility is obliged to supply electricity to all the consumers in its service area. The Congestion Management in Japan is governed by two schemes. The first scheme is based on ATC calculation, which is obtained by reducing total transmission capacity by the necessary margin to be reserved and scheduled flow. Second one includes the prevention of intentional overestimates i.e. a charge is imposed on scheduled changes, based on use-it or lose-it principle.

Transmission Congestion Management in Thailand

Thailand is in its infant state of adopting deregulated environment [62]. Being a developing country many socio-techno-economical issues, like advancement in information technology, energy security, social equity, price volatility and the need to subsidize poor consumers are necessary to be addressed before establishing Transmission Congestion Management process and its settlement. During the transition period to deregulated environment, Zonal Congestion Management is implemented first because of its simplicity. Then in the well-established competitive market, Nodal Congestion Management would be employed.

Congestion Management in Nordic Countries

In Nordic countries the whole task of Congestion Management is carried out in a Nordal Project: “Rules for Congestion Management, evaluation of capacity and possibility for counter trade”. Two broad paradigms of

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congestion management are to be adopted here [63]. These are capacity allocation and capacity alleviation. At present, market splitting and counter trading mainly manage congestion. A simulation of counter trading is developed, which is more effective in congestion management. A scheme of area price hedging with a new concept of „contracts for differences" was imposed by Nordic power Exchange in November 2000 [64].

Congestion Management in Australian National Electricity Market

As the name shows this is market-oriented approach, controlling energy transactions and managing transmission network congestion [65]. For limited level of congestion, the physical management is the common approach, while financial management is the choice when congestion becomes material. The Ministerial Council of Energy announced a revised policy in December 2003, which ensures provision of transportation service from generation source to load center, competition among market participants and provision of secured/ reliable electricity supply.

Congestion Management in California

California Power system has adopted Deregulation in 1998. However the improper implementation of Deregulation caused havoc in power market in the year 2000. Since then California ISO has been working on its market redesign. In California, congestion has recently been quantified through the use of LMP (locational marginal price) markets organized by non-for-profit Regional Transmission Organizers (RTOs) [66], adopting Zonal Portfolio Energy Schedules and Zonal Congestion Management.

The Scheduling Coordinators (SCs) [67,69] can participate in the process of Congestion Management through submission of "Adjustment Bids", which are incremental and decremental bids. The ISO can use those "Adjustment Bids" for both Inter-zonal as well as Intra- zonal Congestion Management. Some special features of CAISO (California ISO) for facilitating Congestion Management [68,70] are; minimum role in forward energy market, voluntary participation of SCs in Congestion Management, minimum rescheduling of generation to alleviate congestion, allocation of transmission to most cost effective users and no forced trade.

Congestion Management in UK

In UK, the process of Deregulation commenced in 1990. Since then, the power market in UK has evolved into a fully liberalized competitive market in generation and supply of electricity (distribution). At the same time, the national high voltage (400 kV and 275 kV) transmission system is still successfully managed and operated by a single integrated for-profit organization called as TSO, having monopoly in wire business.

The Congestion Management [66] is carried out by this integrated TSO through a combination of various methods. These methods provide efficient investment in infrastructure, effective planning and co-ordination of transmission system outages, development of innovative tools and techniques to increase network availability and optimization of generation and load through the use of balancing services. The significant techniques, which are the core of congestion management theme in UK, are critical circuit thermal rating enhancement by having HV cable thermal monitoring, accelerated maintenance to minimize outage duration, live line working for maintenance activities, procurement of balancing services.

VIII. CONCLUSION

In the fast emerging Deregulated Power System scenario, Congestion Management has become crucial task. Ever developing challenges and factors are forcing evolution of newer techniques. A review on the Congestion Management techniques available in the literature for last four years is presented in this paper. The problems encountered in Congestion Management are also discussed. A critical survey for existing Congestion Management methods in countries like Japan, Switzerland, Thailand, Australia, Nordic Countries, California and UK has been carried out in this paper. An attempt has been made to encompass all the emerging trends in Congestion Management however the list is not exhaustive.

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