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Review Article

Mitigating Congestion in a Power System and Role of FACTS Devices

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Congestion management refers to avoiding or relieving congestion. In transmission lines, congestion management is one of the most important issues for the reliable operation of power system in the deregulated environment. Restructuring has brought considerable changes in all possible domains including electric supply industry. By virtue of restructuring, electricity has now become a commodity and has converted into a deregulated one. The traditional regulated power system has now become a competitive power market. In the present scenario, the real time transmission congestion is the operating condition in which the transfer capability to implement all the traded transactions simultaneously is not enough due to either some expected contingencies or market settlement. Thus, congestion is associated with one or more violations of the physical, operational, and policy constraints under which grids operate. Thus, congestion management is about managing the power transmission and distribution among valuable consumers priority-wise. Placement of FACTS (Flexible Alternating Current Transmission System) devices for generation rescheduling and load-shedding play a crucial role in congestion management. FACTS devices are used to enhance the maximum load ability of the transmission system. FACTS increases the flexibility of power system, makes it more controllable, and allows utilization of existing network closer to its thermal loading capacity without jeopardizing the stability. FACTS technology can boost the transfer capability in stability limited systems by 20–30%. As a result, more power can reach consumers with a shorter project implementation time and a lower investment cost. This review work unites the various publications on congestion management in past few decades.

1. Introduction

Increasing demand of electricity made the congestion management a challenging task. Though generation has increased several times than ever before, even then the power companies like Transcos, Genecos, and Discos are not able to meet the reliability of power supply. With the advent of nonrenewable energy sources, distributed generation became a general practice nowadays, because of increase in congestion. Therefore, the electricity market is shifting from regulated market to a deregulated one.

Earlier in the electricity market, big giant companies enjoyed monopoly and were responsible for complete generation. Transmission and distribution were usually called Vertical Integrated Utilities (VIU). But nowadays, with the availability of nonrenewable resources and captive power plants, even a common person is able to generate the electricity and can utilize it for transferring it to a grid. This made restructuring of the system very essential. Restructuring means transposing Vertically Integrated System into a bundle system, that is, to give separate price for separate services. Restructuring itself means liberalization, deregulation, and privatization [1].

But there are many challenges in restructuring a system. It includes choosing an apt auction strategy for the electricity, relieving market hour of the participants, troubling transmission congestion, related locational price spikes, dependability of maintaining system, efficiency of market, and equilibrium in assessing market [2].

Because of the above challenges, congestion management has become one of the prime considerations in power industries. Power has to be carried from a generating station to a

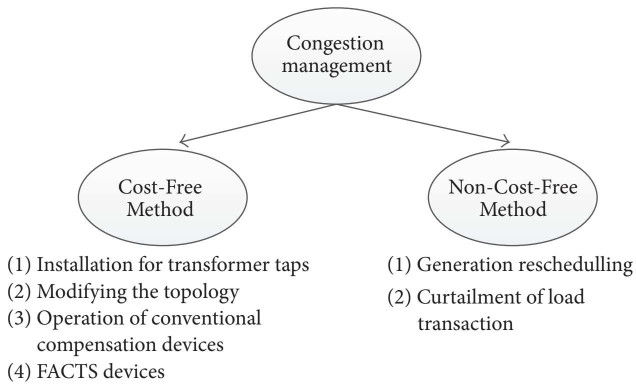

Figure 1: Flowchart showing the different methods of congestion management.

consumer via several substations through transmission and distribution lines. When demand is greater than the power transfer capacities of these lines, congestion takes place, and hence a management is required. Hence, congestion management is about managing the power transmission and distribution among the valuable customers priority-wise [3]. It also takes care of in-between technical concerns, for example, installation of transformer taps, modifying the topology, operation of conventional compensation devices, FACTS devices, generation rescheduling, and curtailment of load transactions. Technically, this management is offered in two ways. One is cost-free method and the other is non-cost-free method as shown in Figure 1.

Cost-free methods are all about the technical aspects for efficient power transfer from source to destination without taking the economy into consideration. On the other hand, in non-cost-free methods, everything is managed considering economy as one of the most important objective functions. Cost-free methods are generally studied at the disposal of Transmission System Operator (TSO), whereas non-cost-free methods are coined because of nominal economic basis but these methods are generally used by generation and distribution companies.

A comprehensive review on the various conventional methods has been presented for congestion management by Saxena et al. [4]. But the topics covered are confined on Available Transfer Capability (ATC) and on optimal power flow computing techniques. Congestion can also be managed through Genetic Algorithm, fuzzy logic, voltage stability, and Nodal and Zonal approach.

According to Vora Animesh [5], congestion is a phenomenon in which if the contracts are not controlled, some lines located on particular paths may become overloaded. In the existing power delivering systems because of various electrical utilities, generally physical limits get violated which leads to congestion.

Problems Occurring due to Congestion in Transmission Lines. Congestion in transmission lines occurs due to ever increasing power demand and different types of load may cause the following problems:

(i) The market efficiency is reduced.

(ii) The consumers are forced to reduce the consumption of power, as the electricity prices increases.

(iii) Security concern of the system may be affected.

(iv) The system is forced to operate at lower stability margins.

(v) The system may collapse due to initiation of cascade tripping.

(vi) Congestion holds the operator of the systems from transferring further power from a particular generator.

(vii) The surplus congestion charges are increased.

Congestion may occur due to the following reasons:

(i) Generator outages

(ii) Transmission line outages

(iii) Changes in energy demand

(iv) Uncoordinated transactions

(v) Infeasibility in existing and new contracts

(vi) Congestion that may damage the systems equipment.

Among the following two methods of reducing congestion, that is, cost-free method and non-cost-free method, the first one is more important because of security and several other technical concerns. It does not affect the economy of the system. In cost-free method, generation and distribution systems are not considered and it includes the installation of FACTS devices.

Classification of FACTS Device. Different types of FACTS device are [6] shown in Figure 2.

FACTS (Flexible Alternating Current Transmission System) devices are used to enhance the maximum load ability limit of the transmission system. These devices improve reactive power level. FACTS devices are used to improve Available Transfer Capability (ATC). ATC is a very essential term as far as deregulated market is concerned, as it helps in the planning and controlling of transmission infrastructure. Main constraints for ATC are voltage limits, steady state stability limits, and thermal limits.

2. Literature Review

The literature review for placement of FACTS devices for congestion management in various areas has been presented as follows.

In 2009, Reddy et al. [7] analyzed Genetic Algorithm for single-objective and multiobjective optimization techniques to improve congestion management in the deregulated system. TCSC (Thyristor-Controlled Series Capacitor) and SVC (Static Var Compensator) are the two FACTS devices, used for the analysis purpose, and are fully sufficient to match the essential requirements of the grid. Authors suggested the optimal placement and size of the FACTS device to improve

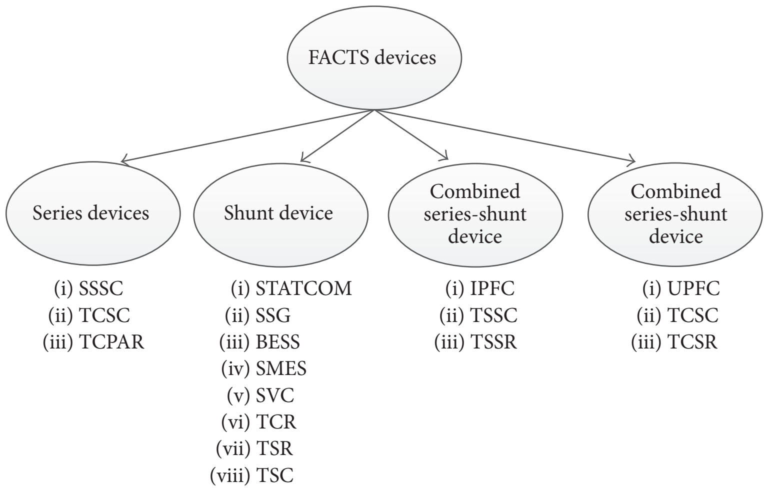

Figure 2: Flowchart showing the classification of FACTS device.

voltage stability and reduce the line losses to minimize the congestion. Further, the developed algorithm was tested on IEEE-30 bus transmission system. Many cases like line outage, uniform line loading, and bilateral and multilateral transactions were studied.

In 1988, Xing and Kusic [8] place TCPS (Thyristor-Controlled Phase Shifter) to minimize the active power loss and increase the stability of power system. The minimization of power losses is based on the phase shifter distribution factor.

In 2004, Song et al. [9] explained various FACTS devices and their placement by using various optimization techniques and considering security indices. The authors have applied these techniques on IEEE-57 bus system. FACTS devices were made to operate under two different conditions, one is normal condition and the other one is line contingency condition.

Rahimzadeh and Bina in 2011 [10] aimed at the optimal placement of shunt and series FACTS device. The author used STATCOM as a shunt device and SSSC as a series model by applying neural based technique. With this model, the authors took into account the power losses taking place in the converter and produced the required PQ-Phasor that is suitable for power system steady state analysis.

Thangalakshmi and Valsalal in 2013 [11] proposed Hybrid Fish Bee Swarm Optimization technique that was used to manage congestion. Hybrid Fish Bee Swarm Optimization technique is based on two techniques. One is Fish School Search (FSS) technique and the second is Artificial Bee Colony (ABC) technique. The authors have applied this technique on IEEE-30 bus transmission system. Results of the proposed technique show reduction in congestion.

Yu and Lusan in 2004 [12] proposed a multiple time period welfare maximization model for the placement of FACTS device in the deregulated market along with considering losses. The result shows that no FACTS device can be placed on one-hour basis discussion; it requires many hours for planning and managing the proper placement of these devices.

Srivastav and Kumar in 2000 [13] studied two market models, that is, bilateral and multilateral contracts. The authors used the combination of FACTS device with transmission rights for managing congestion. Two FACTS devices, TCSC and SVC, are modeled as variable reactance. Two cases were studied for TCSC. In the first case, TCSC was placed in inductive mode for congested lines, and in the second case, it was placed in capacitive mode for lightly loaded buses. The optimal placement of TCSC is decided by using trial and error method. SVC is placed at different buses. The placement of SVC is decided by observing the rate of improvement of minimization of deviations from transaction made by market participants.

Reddy et al. in 2006 [14] explained the uses and proper placement of FACTS device for reducing congestion on transmission lines with the help of Genetic Algorithm based technique.

Ushasurendra in 2012 [15] applied TCSC in series with transmission line to reduce congestion. Line Utilization Factor (LUF) is used to obtain the level of congestion in the transmission line. A fuzzy logic controller is used to control the active power flow for managing congestion. The proposed technique is applied on Modified IEEE-14 bus system. Then, the results based on fuzzy logic are compared with the results obtained by sensitivity method. Result shows that fuzzy logic based technique can also be used as an alternative technique for congestion management.

Dhansekar and Elango in 2013 [16] proposed Particle Swarm Optimization (PSO) based technique for reducing congestion in the transmission lines. UPFC (Unified Power Flow Controller) is optimally placed with appropriate sizing. UPFC is tailored solutions for special needs. The technique is applied on 5-bus test system. Results show reduction in congestion in transmission lines.

Rajderkar and Chandrakar in 2009 [17] studied the proper selection of FACTS device and their placement for congestion management, as FACTS device helps to reduce the congestion in the transmission lines. The authors uses Modified IEEE-14 bus test system and check the feasibility of TCSC (Thyristor-Controlled Series Capacitor) ans SSSC (Static Synchronous Series Compensator) FACTS device. In this paper, the comparative analysis has been done to solve the congestion problem.

Karami et al. [18] proposed an optimal solution for the placement of STATCOM. The author also calculates the capacity placed IPFC for congestion management. Artificial intelligence optimization technique was used to improve the voltage stability, security and reduce the congestion in the transmission lines.

Gitizadeh and Kalantar in 2008 [19] used Sequential Quadratic Programming (SQP) problem for judging static security margin to reduce congestion and, in a second step, the author simulated annealing method for optimizing the problem.

Rajalakshmi et al. in 2011 [20] explained that the proper placement of a FACTS device can increase the transmission capability of transmission lines. The authors have implemented a technique for proper location of FACTS device which is based on the performance index and reduction of total reactive power losses.

In 2012, Yousefi et al. [21] proposed an approach for transmission line congestion management by using combination of demand response FACTS device. In this paper, the work was carried out in two steps. In the first step, GENCOs bid the market for their maximum profit and clear ISO for the market based social welfare maximization. In the second step, network constraints, those related with congestion management, are included for market clearing procedure. A mixed integer optimization technique, a redespatch formulation is used in the second step. In this step, demand response and FACTS devices are optimally coordinated with conventional generator.

Esmaili et al. in 2014 [22] suggested a multiobjective congestion management technique. The author has optimized three objective functions (operating cost, voltage, and transient stability margin). The proposed technique efficiently placed and sized series FACTS devices on the congested transmission line by priority listing using LMP (Locational Marginal Prices).

Kulkarni and Ghawghawe [23] suggested that the proper placement of a series FACTS device like Thyristor-Controlled Series Compensator (TCSC) can be used to decrease the power flows in heavily loaded transmission lines can be enhanced, hence, enhancing the load-ability limit of transmission lines. This will result in decrease in power losses thereby managing congestion.

Hence, it can be said that proper placement to FACTS device can reduce the congestion and hence reduce surplus congestion cost. Many optimization techniques are proposed for proper placement of these devices on transmission line.

3. Study of Various Cases for Congestion Management in Different Countries

In this section, a brief discussion of the different cases for congestion management in different countries like Japan, Switzerland, Thailand, Australia, Nordic Countries, United States, and United Kingdom is presented.

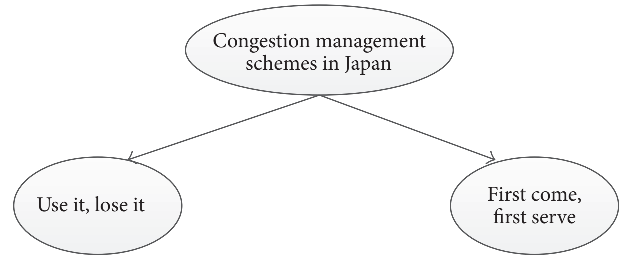

Figure 3: Flowchart showing various congestion management schemes in Japan.

3.1. Congestion Management at Japan. The transmission power system of Japan is different from other countries of the world. In Japan, two different transmission lines are rarely connected on one interconnection route. Hence, there is no problem of loop flow with tie lines. Each transmission is required to transmit electrical energy to all the consumers of its service area. There are two schemes, by which the congestion management is governed in Japan. These are (i) first come, first serve and (ii) use it or lose it scheme as shown in Figure 3. The first scheme is totally based on "Available Transfer Capability" and second scheme is based on " the prevention of intentional overestimates of capacity needs" [24].

3.2. Congestion Management at Switzerland. Due to increase in demand of electricity in Switzerland, congestion is also increasing day by day. Hence, the Swiss Transmission System Operator (TSOs) has invented a new congestion management concept [25]. These new inventions integrate on three automatic processes:

(i) *Day Ahead Congestion Forecast (DACF).* DACF consists of three parts suggested as (a) preparation of Swiss DACF dataset, (b) collection, checking, scaling, and merging of all DACF datasets, and (c) calculation of load flow.

(ii) *Determination of Congestion Elimination.* This process of elimination of congestion is based on optimal power flow (OPF) software package. This optimally consists of two measures: (a) topological measures which consist of the change in operational status of network, adjustment of transformer tap ratio, and reconfiguration of power substation and (b) redespatch measures congestion by utilizing in terminal optimal solutions.

(iii) *System Methodology and Implementation.* It can be seen from Figure 4.

3.3. Transmission Congestion Management (TCM) in Thailand. Thailand is one of the developing countries and is just adopting deregulated electricity environment. As it is developing country, it is facing lots of problems like energy security, advancement in information technology, social equity, price volatility, and the need to subsidize poor consumer [26]. These problems are essential to be focused

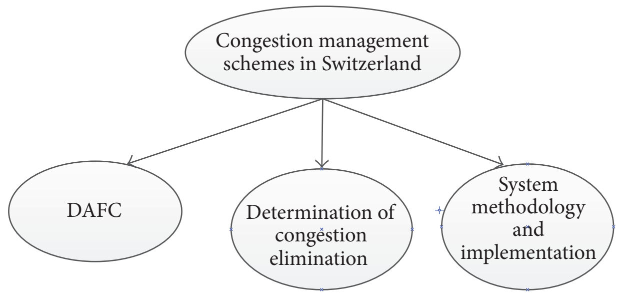

Figure 4: Flowchart showing various congestion management schemes in Switzerland.

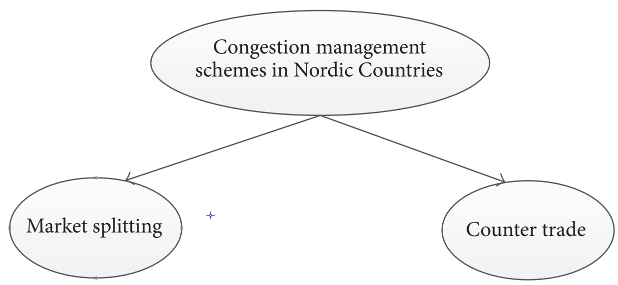

Figure 5: Flowchart showing various congestion management schemes in Nordic Countries.

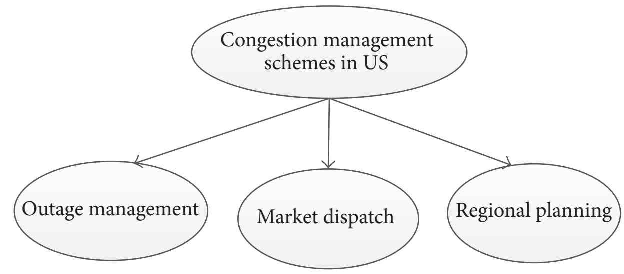

Figure 6: Flowchart showing various congestion management schemes in US.

Table 1: List of utility scale of various FACTS devices in various countries.

Capacity (MVAR)	Voltage level (KV)	FACTS devices	Countries
(i) 80	115	SVCs	Thailand
(ii) 190	500	SVCs	Thailand
(iii) −20 to +80	500	SVCs	Japan
(iv)	400	TCSC	Sweden
(v) +80 to −80	154	STATCOM	Japan
(vi) 50	500	STATCOM	Japan
(vii) 0 to +225	400	STATCOM	UK
(viii) −41 to +133	115	STATCOM	USA

before proceeding with Transmission Congestion Management (TCM) and settlement process. Zonal congestion management is first accomplishing because of its simplicity during transition period to deregulated environment. After zonal congestion management Nodal congestion management is to be employed, in well-settled competitive market.

3.4. Congestion Management in Australian National Electricity Market. Congestion management by Australian National Electricity (NEM) uses market oriented approach which controls transaction of energy and manage transmission congestion [27]. The combination of governance of Australia with market design works satisfactory for transmission congestion. In December 2003, the Ministerial Council of Energy launched a policy, which assured provision of transfer electricity from generating station to load centers and provision of secured/reliable electricity supply.

3.5. Congestion Management in Nordic Countries. The common Nordic Congestion Management scheme and the evaluations done in a Nordal project, that is, "rules for congestion management, evaluation of capacity, and possibilities for increase countertrade," are discussed by Gjerde et al. [28]. Recently, two methods are used by Nordic Countries for congestion management. These are market splitting and countertrade as it is shown in Figure 5.

According to Kristiansen [29], transmission congestion in the Nordic region is managed by using two schemes. These are (i) by using area price model and (ii) countertrade. Whenever there is congestion in Nordic region, two or more than two area prices come into a role within Norway, two in Denmark, and one each in Sweden and Finland. In November 17, 2000, Nordic Power Exchange imposed a new scheme of area price hedging with an idea of "contracts for differences."

3.6. Congestion Management in US and UK. In 1990, the process of deregulation of electricity comes into consideration in UK. England and Wales developed their power market into fully liberalized competitive market for all generation, distribution, and transmission market. The national transmission system for both the countries is owned and controlled by a "single integrated for profit organization based on profit" as shown in Figure 7. The whole system has a monopoly business and is controlled by regulatory price controls. The office of the Gas and Electricity Markets Authority (OFGEM) regulates the whole system of the country [30].

In the United States, congestion is calculated by the use of Locational Marginal Pricing (LMP) markets which are organized by nonprofit Regional Transmission Organization (RTOs) for power as shown in Figure 6. Approximately 2/3 of whole US electrical load resides in region with LMP markets in the Northeast, Midwest, and California.

Installation of various FACTS devices used to manage congestion for various countries is shown in Table 1 [31].

4. Conclusions

This paper presents a detailed review on congestion management. In the present scenario of fast emerging deregulated power system, congestion management plays a crucial role. The review initially focuses on the conventional methods of congestion management and then important discussions

Table 2: Applications of FACTS devices in power system operation for congestion management.

Operating problem	Corrective action	FACTS devices
(i) Voltage limit:		
(a) Low voltage at heavy load	Supply reactive power	STATCOM, SVC
(b) High voltage at low load	Absorb reactive power	STATCOM, SVC, TCR
(c) High voltage following an outage	Absorb reactive power; prevent overload	STATCOM, SVC, TCR
(d) Low voltage following an outage	Supply reactive power; prevent overload	STATCOM, SVC
(ii) Thermal limits:		
(a) Transmission circuit overload	Reduce overload	TCSC, SSSC, UPFC, IPC, PS
(b) Tripping of parallel circuits	Limit circuit loading	TCSC, SSSC, UPFC, IPC, PS
(iii) Loop flows:		
(a) Parallel line load sharing	Adjust series reactance	IPC, SSSC, UPFC, TCSC, PS
(b) Post-fault power flow sharing	Rearrange network or use thermal limit actions	IPC, TCSC, SSSC, UPFC, PS
(c) Power flow direction reversal	Adjust phase angle	IPC, SSSC, UPFC, PS

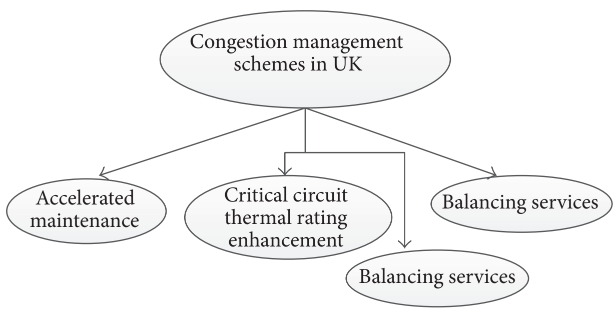

Figure 7: Flowchart showing various congestion management schemes in UK.

are made under each topic. For the satisfactory operation of electrical power system, it is essential that loading of transmission network is maintained without which cascade tripping is initiated, which ultimately forces the system to collapse. To alleviate congestion, FACTS devices are used. The reactive power rescheduling and application of FACTS device lower the cost of rescheduling and improve the voltage profile.

The problems encountered in congestion management have been thoroughly discussed and a critical survey for existing congestion management methods in countries like Japan, Switzerland, Thailand, Australia, US, UK, and Nordic Countries has been presented in this paper.

The application of various FACTS devices to the solution of steady state operating problems for congestion management is outlined in Table 2 [32].

Competing Interests

The authors declare that they have no competing interests.

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