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Congestion Management by Optimally Locating the Facts Devices: A Review

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Abstract – This paper presents the brief overview on congestion in power system, its causes, effects and remedies. It also deals with congestion management. Congestion management is a significant feature of power system. In power system, when power flows through transmission lines and transformers exceeds the power transfer capability of transmission lines, congestion takes place. Reactive power is one of the key factors for controlling congestion in transmission lines. It is mainly provided by regulating tap changing transformers shunt capacitors and generators excitation. Flexible AC transmission system (FACTS) devices are another effective means of controlling reactive power flow in transmission lines. They change the reactance across the transmission line by using fast acting power electronic switches along with inductors and capacitors. As a result, line loadability increases, system losses decline, power system's security enhances and overall cost reduces. This paper also gives a brief literature review on finding optimal location for placing FACTS devices.

Keywords— Congestion; Congestion Management; Reactive power; FACTS.

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I. INTRODUCTION

Congestion in power system is derived from the word conjunction in economics along with deregulation. The term congestion is used in power system much earlier than deregulation. Previously it was conferred on power system security and stability at the minimum cost (Singh, et. al., 1998) power flow through transmission lines and transformers exceeds the power transfer capability of transmission lines, congestion takes place that may lead to line outage and blackout. It also weakens power system's security as well as reliability. Consequently electricity prices increase in electricity markets (Papalexopoulos, 1997).

(a) Reasons for Congestion

Congestion in transmission lines occurs due to ever increasing power demand and different types of loads may be clubbed under the following reasons:

(i) Generator outages.

(ii) Transmission line outages.

(iii) Changes in energy demand above the specified limit.

(iv) Uncoordinated transactions

(v) Infeasibility in existing and new contracts

(b) The Congestion may lead to some of following problems:-

(i) The market efficiency is reduced.

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

(iii) Security concern of the system may get 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 transmitting further power from a particular generator.

(vii) The surplus power transmission charges increase.

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(c) Congestion Management

With proper congestion management techniques, the system can be made more efficient by reducing or completely eliminating the overloading of transmission line. Congestion management can be done by three approaches. The first approach is based on centralized optimization. In this type, system operators control the congestion either directly or indirectly by controlling the power flow in the system. The second way is based on price signals forecast for congestion by controlling the generator output prior to real time operation. In the third approach, congestion is controlled by permitting or prohibiting the bilateral power flow in transmission line. It basically depends upon the commitment between consumer and producer. Congestion is an unavoidable phenomenon and it must be corrected in real time by centralized control (Androcec, 2009). Congestion management can be classified as:-

(i) **Cost free method** - Cost free methods include tap changing in transformers and phase shifter operation, FACTs devices and modification in network topologies. They are called cost free because the cost involved is nominal.

(ii) **Non cost free method-** The non-cost free methods include load reduction and generation rescheduling. The conventional congestion management includes price control theme, fuzzy logic, genetic algorithm (GA), nodal pricing method, voltage stability, use of FACTS devices to reduce line loading and market-based analogy (Galiana and Ilic, 1998). Cost free methods have the merits over non cost free method because it does not affect the economy of the system as well as it concerns system security.

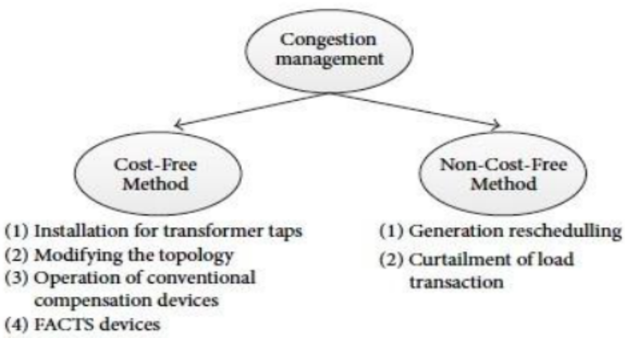

Fig. 1. Methods of congestion management (Gupta, et. al., 2017).

Reactive power is one of the key factors for managing congestion in transmission lines. It is mainly provided by regulating tap positions of transformers, shunt capacitors and generators excitation. Flexible AC transmission system (FACTS) devices are another effective means of controlling reactive power flow in transmission lines by changing the reactance across the transmission line by using fast acting power electronic switches along with inductors and capacitors. Congestion can also be managed in the existing system by Load Shedding (Singh, et. al., 1998) (NERC, 1996).

This paper presents the detailed overview on congestion and its management by optimal placement of FACTS devices by using optimization techniques. The paper is structured as follows: Section II - Literature review, Section III- Methods of congestion management and Section IV - Optimum placement of facts devices.

II. LITERATURE REVIEW

In 1980s, rapid changes have been undergoing in electric supply industry in which independent entrepreneurs are allowed for competition to supply power to the utility due to which efficiency of the electric supply industry increases. This competitive market makes the significant changes among electric supply industry for reducing the energy production and distribution cost such as manpower shedding, eliminates certain system inefficiencies and increase in customer preferences. Later in 1990's, worldwide, many electric sector, industries and companies were forced to deregulation because of various factors such as ever increasing power demand, high tariffs rate, political reforms, global economic crisis and managerial insufficiency. The only goal behind the deregulation is to enhance the completion among the electric supply industries. This will bring various choices and economical tariff rates or benefits to consumers.

Restructuring and deregulation of electric power industries promote open access. The open access means that the opportunity to use the transmission system must be equally available to all buyers and sellers. As a result, competitive environment for electric supply companies increases. But managing dispatch is a new challenge faced by transmission system operators.

The fair implementation of electricity restructuring is one of the major concerns for electric power companies. Transmission networks is one of the key factors affecting it because power transmission network has some limitations in terms of environment and economy. The other constraints that limit the power transfer between the two transmission networks are power system security and stability. The power flows through transmission line and transformers should be under the power transmission capability limit to avoids any network collapse due to voltage instability, angular instability or any line outages.

When the power flows through transmission lines and transformers above the physical limit of transmission lines, then transmission congestion occurs due to which existence of new contracts is restricted, line outages increase, system security and reliability degrade as well as the electricity prices increase (Papalexopoulos, 1997. Androcec, 2009. Gupta, et. al., 2017. Galiana and Ilic, 1998). Generally congestion occurs in both bundled and unbundled system but the congestion management is much simpler in case of bundled system. It is because a single utility manages generation, transmission as well as distribution system in some cases. In the competitive electricity markets, independent system operator (ISO) performs the important task of congestion management and pricing for its smooth functioning (NERC, 1996). ISO takes actions and remedial measures to manage congestion in transmission network.

In real time system, following measures are adopted for congestion management:

(a) Operation of FACTs devices for controlling power flow.

(b) Rescheduling of generation based on economical bidding.

(c) Timely collect the transmission line data and find out the probability of any line congestion. Consequently provide the incentives to the congested line so that system remains under constraints limit.

(d) Curtailment of loads.

Mostly System Operators (SO) uses the top two methods for congestion management. Load curtailment is always the last choice for it.

Real power transfer between transmission systems mainly depend upon the reactive power and voltages (Miller, 1982). For maintaining secure voltage profile, the sufficient amount of reactive power support is necessary at correct location. The importance of reactive power dispatch in an open access system is more important because the power transfer in an open access systems increases and the voltages associated with it prevents the system from further increase in power transfer (Mamadur & Chenoweth, 1981). The generators in the system provide the additional reactive power support whether they are involved in real power transfer or not (Dai and Ni, et. al., 2001). Mostly reactive power is provided by tap changing transformers, switching shunt reactors and capacitors, by controlling generators excitation.

England and Wales (E&W) market consists of only one zone, hence no constrained interfaces are considered for the market dispatch. The generator's offers decided the zonal pricing (Wolak and Patrick, 1997). In congestion management, ISO commanded the operation of generators and each bus is considered as a zone and all constraints are taken. The selection of generators for transmission congestion management is based on their bidding prices. Loads do not take part in congestion management. ISO incurred the additional charges on consumer as uplift. The uplift is a part of total price which is not directly related to energy production cost. It is the cost consisting of ancillary services and losses in the system.

In Pennsylvania–Jersey–Maryland (PJM), the ISO performs a centralized market dispatch for each time period in the scheduling horizon. State estimator data is used to compute the nodal price. Generally nodal prices can be determined as dual variables in an optimization framework corresponding to specific constraints (Interconnection, 1997). Each member is charged and paid according to its consumption and production based on its nodal price. Hence there may be a difference in nodal price between any bus pair. This difference in nodal price becomes the transmission usage charges for the power flow over the grid. Hence each node is considered as a zone with its own zonal price. Each line connected in a zone is an inter-zonal interface.

In California, ISO divided the grid into number of predefined zones (California ISO, 1998). In this market dispatch strategy, zonal prices are set up on hourly basis for the next day market. In bilateral markets, scheduling coordinators provide the dispatch schedules based on auction results. If any congestion takes place due to market dispatch solution then re-dispatch with zonal portioning is applied for its elimination. The transmission usage price and zonal prices are getting from this process and they are considered as dual variables. Hence, members are charged and paid according to zonal prices set up during the re-dispatch duration. One of the key features of this type of market is that ISO maintains the difference between different scheduling coordinators portfolios. Hence, ISO maintains a fair market for all and does not promote any implicit trade between them (Gribik, et. al., 1999).

In Nord Pool, two methods are used for congestion management. The first one is counter purchases for intra- zonal congestion and the second one is zonal pricing for inter-zonal. In counter purchasing method for congestion management, some generators are forced off at congestion location and forced on at better area. While in zonal pricing method, the system is divided into different price zones (Kumar, 2005).

In recent years, various articles are published on congestion management in electricity market (EM). In deregulated EM, three types of congestion

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management have been adopted. They are centralized optimization, price signaling and bilateral transmission. In the first method, SO executes the centralized optimization program for optimal power flow for congestion relief. Second method is based on price signals forecast for congestion by controlling the generator output prior to real time operation. In the third approach, congestion is controlled by permitting or prohibiting the bilateral power flow in transmission line between a producer and a consumer (Christie, et. al., 2000)

Madhvi Gupta et al. proposed an approach for mitigating congestion using the minimum total modification to the desired transactions (Gupta, et. al., 2017). A weighting scheme having least modifications approach is highlighted (Fang and David, 1999). In this approach, surcharges in the form of weights are being paid for the transmission usage under congestion relieved network. In (Glavisch and Alvarado, 1998), congestion management is done by using marginal cost signals of generators. Transmission congestion distribution factors (TCDFs) based on Jacobian sensitivity on AC power flow has been proposed in (Kumar, et. al., 2004) R. S. Fang et.al suggested a willingness to pay premium approach for avoiding curtailment of the transactions (Fang and David, 1999). In (Hogan, 1992), Hogan proposed nodal pricing and contract path approach using spot pricing theory for pool type market. (Sood, et. al., 2002) proposed the hybrid model for congestion management with real and reactive power transaction. Later in 2005, H. Iranmanesh et al. proposed an intelligent real genetic algorithm based technique for coordination between two different FACTS devices. In this approach, the power transfer capability of the system is increased (Iranmanesh, et. al., 2005). This approach is very effective for solving congestion in highly meshed transmission network. Alvarado used MATLAB based codes for congestion management (Alvarado, 1999). Congestion management in transmission system by determining the optical location for placing FACTS devices in deregulated power systems is proposed in (Taher and Besharat, 2008). TCSC based FACTS device is used for determining total reduction in reactive power loss and real power performance. P.N. Biskas et al. achieved decentralized or multi-area congestion management of interconnected power systems through cross border coordinated re-dispatching (Biskas and Bakirtzis, 2002). Lagrangian relaxation based pricing mechanism is used to performed coordination.

(Singh and David, 2000) proposed a simple and efficient method for finding out the optimal location for installing FACTS devices for congestion management by controlling their parameters. In this paper, congestion management by using TCSC and TCPAR devices is explained by two steps. In first step the optimal location of these devices in the network is obtained by one of the loss sensitivity indices from available three loss sensitivity indices which are known as total system loss sensitivity indices, line loss sensitivity indices and real power flow performance index sensitivity indices. In the second step, the optimal location for installing FACTS devices on the most sensitive line is carried out. After that, sensitive indices for both the devices are computed. The line having the largest absolute values of the sensitivity factor is placed by TCPAR and the line having the most negative sensitivity index is placed by TCSC. Huang and Yan in (Huang and Yan, 2002) examined the impact on congestion management by improving the total transfer capability (TTC) of the transmission lines and reducing transaction curtailment by the use of FACTS devices.

(Etingov, et. al., 2005) proposed Coordinated emergency control by using load shedding and multiple FACTS devices for overload limitations in a transmission system. The control technique is based on linear optimization technique and sensitivity analysis of the system. In this method TCSC and TCPST are used for coordination with load shedding. Later in 2007, D. Thukaram et al. proposed a new method for the alleviation of congestion management based on relative electrical distance (RED). The RED is the relative location of load buses with respect to generator buses (Yesuratnam and Thukaram, 2007) (Talukdar, et. al., 2005) used the heuristic method for load shedding and generation rescheduling for congestion management. In the proposed method, generators are selected based on the sensitivities of the generation buses to the overloaded lines and costs of generation at those buses.

(Verma, et. al., 2001) and (Liangzhong, et. al., 2005) published the work on the application of SSSC for improving the power transfer capability of transmission lines and congestion management with high penetration of wind power. This approach simultaneously considered voltage, thermal and voltage stability limits. The results obtained by using SSSC for congestion management and enhancing power transfer capability of the system are encouraging. In (Verma, et. al., 2001), published the work on the optimal location of UPFC explaining the static considerations for congestion management. The objectives achieved by using UPFC with controllable components are increase in stability margin, minimal losses, controlled thermal limits and fulfillment of contractual requirement without violating power dispatch limit. The suitable location for the placement of UPFC is found out by using sensitivity based approach.

III. METHODS OF CONGESTION MANAGEMENT

(a) **Congestion-** Transmission congestion is the phenomenon which occurs when the power flow through transmission lines and transformers are scheduled to flow above the physical limit of transmission lines. Electricity cannot be stored like other commodities. It has to be transferred over transmission lines in a secure manner and without violating power transfer limits. Deregulation of the electric power industry would be much simpler without transmission limits. Hence transmission congestion management is one of the major factors in any type of electricity market for any ISO (Miller, 1982) (Yong-Hua, 2008)

(b) **Congestion Management -** Open access to transmission network for any power industry restructuring is the first major step for proper working of competitive electricity market. Transmission SO faces a new challenge for managing dispatch in an open access environment. The issue of transmission congestion management is especially important. The fair implementation of electricity restructuring faces the difficulties due to transmission networks (Yong-Hua, 2008).

(c) **Causes for Congestion**

The causes for congestion are as follows (Yong-Hua, 2008):

(i) Due to deregulation of the electricity industry, the electricity prices drop down. As a result unexpected large scale transmission of electric power is trade off, which pushes transmission network to their physical limits.

(ii) In deregulated environments, there is a lack of transmission capacity because of lack of investment in electricity networks.

(iii) Due to large-scale integration of continuous and fast changing power flow with the existing grid such as wind and solar power integration, there are difficulties in managing congestion.

(iv) Increase in cross border electricity trade also makes congestion management a bigger challenge.

(d) **General Methodologies for Congestion Management-**There are various methods for congestion management depending upon market structures and market rules. Generally any approach for congestion management should have following features (Yong-Hua, 2008) (Wang, 2008):

(i) **Non - discriminatory**: For all the market members either consumer or producer, the price for any specific entity or place and time should be same. Everybody should be treated equally.

(ii) **Economically efficient**: The systems have to be economically efficient and beneficial for all the consumers, producers and network operators. Incentives have to be given among them for improving the system and reducing congestion scenario.

(iii) **Transparent**: The system should be transparent and well defined for all the members.

(iv) **Feasible**: The operating system should have all the resources i.e. information, computer system, etc. for the faster and efficient operation within the available time frame.

(v) **Compatibility**: The system should be compatible for any type of market such as short-term/long-term bilateral markets, spot market, ancillary services market and real-time balancing market.

The two main purposes for congestion management are as follows:

(vi) For safe and secure operation of power system by adjusting the power flow transactions to keep the system under security limits.

(vii) To compensate the investment on grid by collecting the congestion charges from all the market members and paying to the grid owners.

(e) **Overall Congestion Management Process**

The Figure 2 shows the basic overall transmission congestion management process. It consists of three major steps as shown in the following figure 2 (Wang, 2008):

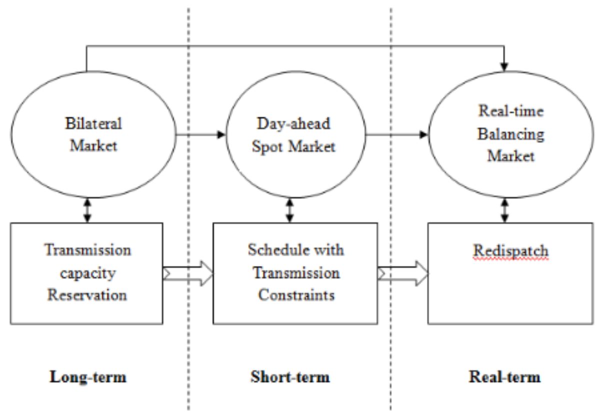

Fig. 2 Overall Congestion Management Process (Wang, 2008)

The first step is Long term transmission capacity reservation. The transmission capacity reservation

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can be made daily, weekly or annually. ISO provides the transmission rights to users through a centralized auction or exchange them through a secondary bilateral market. It can be either physical or financial. After getting transmission rights, users or market members create new or revise bilateral transactions.

The second step is short-term scheduling in the day ahead spot market. Transmissions constraints are considered in the day ahead schedules. The main objective of congestion management in short term scheduling is to maintain the physical and operational security and reliability of the system. It also promotes the competitive electricity market. In this step, congestion management has an important impact on the degree of competition, spot price and bidding incentives for energy market participants.

The third step is real-time re-dispatch in the real-time balancing market. In real time operation inspite of first two steps, transmission congestion may still occur because of fluctuating loads and unpredictable events. It is also a market based method. During any emergency, ISO can take any preventive measures to maintain system security.

(f) Congestion Management by using FACTS Devices

In the present deregulated electricity market, transmission congestion is one of the major hindrances for the free competition in electricity trade. Nodal and zonal pricing tools are used for congestion management. But inspite of these methods, congestion still persists in the system. Hence more technological advancement is needed to reduce this concern of transmission network. In this respect, the Flexible AC Transmission system (FACTS) devices can provide a very promising solution (Verma, et. al., 2001).

Deregulation of the electricity industry provides the electricity at competitive rates due to which unexpected large scale transmission of electric power is trade off that pushes transmission network to their physical limits. Moreover for keeping the system secure under such abnormal conditions, expansion of transmission network is needed for increasing the power transfer capability of the existing system. But many factors affect the power transmission network expansion such as environmental, economical, and so on. Hence, the unused potential of transmission system are opened. Flexible AC transmission systems (FACTS) devices offer a solution for better utilization of available power system capacities.

FACTS devices reduce the power flows in heavily loaded lines, as a result system network stability improves, line load ability increases, system losses reduces, Total Transfer Capability (TTC) of transmission line increases, production cost reduces and contractual power requirement fulfils by controlling the power flows in the transmission lines. Phase shifters, variable series capacitors and unified power flow controllers (UPFCs) are used for controlling the power flow through transmission line by changing their parameters [33]. FACTS devices maintain system stability during power flow under steady state as well as dynamic conditions.

The two main reasons for an increased emphasis on FACTS devices are as follows:

(i) Continuous advancement and development in high power electronics components make FACTS devices cost effective.

(ii) Deregulation of electrical power and frequent loading of power systems drive the use of power flow control techniques because these methods are cost effective for dispatching specified power flow.

The placement of these devices at a particular location is an important aspect because of their considerable costs. There are various methods for finding the optimal locations for installation of FACTS devices such TCPAR, TCSC, SVC and many more.

IV. OPTIMUM PLACEMENT OF FACTS DEVICES

Congestion management is a non-linear function. It involves a large no. of variables. It requires optimization algorithms for finding solution. Following are some of the most common optimization techniques for managing congestion in the transmission lines:

(a) Genetic Algorithm (GA):- Genetic Algorithm is a very attractive approach for solving a number of non-linear programming problems. In GA, the algorithm continuously iterates each individual solution. This algorithm stochastically picks individuals from the current population and is used to produce next generation. Granelli et al. aim to determine the optimal topological configuration of the transmission system. They use 33-bus CIGRE sample test system and 432-bus EHV Italian network to validate their work. For multi-objective optimization, SPEA inter-zone and for a multi-objective function, there exists no unique solution. So, the objective is determination of all the trade-off solutions (Pillay, et. al., 2015).

(b) Particle Swarm Optimization (PSO):- PSO is another effective algorithm for determining the optimal location of installing FACTS devices while minimizing the cost of installation and improving the loadability of the system. It is a computational method for optimization of a given problem by iteratively working to improve a candidate solution (Saravanan, et. al., 2005) has used PSO to determine the most suitable location of TCSC, SVC, and UPFC. The authors use IEEE 6, 30, 118 bus systems and a Tamil Nadu Electricity Board 69 bus system as a test. After simulation, it is found that the cost of installation of UPFC is much higher than TCSC. Also, it gives better load ability than UPFC. On systems with highest installation cost, UPFC gives maximum system load ability (Zhang and Handschin, 2001).

(c) **Interior point method:-** In the last few decades various optimization techniques have been used for solving optimal power flow (OPF) problems such as, Newton method, gradient method, successive sparse quadratic programming (QP) method, successive non sparse quadratic programming (QP) method and linear programming (LP) method. Each method has its own merits and limitations (Srivastava, 2006). Karmarkar in 1984 published work on interior point method for linear programming.

Optimization techniques are also referred as artificial intelligence approaches because in these techniques numerical algorithms are developed for congestion in power system networks and are solved with the use of computer. Some techniques are reviewed in this section, such as PSO, GA and Interior point method. Besides these methods, there are other methods such as Fuzzy-Logic systems, Simulated Annealing (SA) algorithm, General Algebraic Modelling Systems (GAMS) based optimization, Artificial Bee Colony (ABC) algorithm, Fish School Optimization (FSO) algorithm, Flower Pollination Algorithm (FLA), Strength Pareto Evolutionary Algorithm (SPEA), Multi-objective Evolutionary Algorithm (MOEA) and SFLA which can also be used for congestion management (Yusoff, et. al., 2017).

V. CONCLUSION

This paper presents a brief review on congestion management. With the rapid growth of deregulated power markets, congestion management has become significant for overcoming congestion issues. The loading on transmission network has to be maintained within the specified capacity so that system remains secure and reliable. Transmission line congestion may collapse the system. The application of FACTS device and reactive power rescheduling, lowers the cost of rescheduling and improves the voltage profile. To alleviate congestion, FACTS devices can be effectively used. It can be optimized by optimally selecting the location of installing FACTS devices. Various optimization techniques have been discussed in the paper for selecting the location.

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