

# CONGESTION MANAGEMENT USING FACTS DEVICES IN DEREGULATED POWER SYSTEM

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## Abstract

The deregulated power system offers more benefits to the customers so that it is quite popular in now days. The Increased power demand has forced the power system to operate very closer to its stability limits. This paper presents a new method to mitigate congestion in a deregulated Power system. The Increased power demand has forced the power system to operate very closer to its stability limits. So Transmission congestion, Voltage instability and power loss problems are arise in the power system. These are very serious problems which cause damage to the power system Congestion is a tough task in Deregulated power system. This paper deals with the best location for TCSC using priority list to have minimum total congestion rent and minimum total generation cost .The Simulation results were successfully tested on modified IEEE 9 bus system using Power world simulator 11.0.

**Keywords**— Deregulated power system, Congestion, Thyristor Controlled Series Capacitor (TCSC), Reactive power loss, Power Transfer capability,

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## 1. INTRODUCTION

The ongoing deregulation of the electric utility brings out opportunities and challenges. Conceptually, the power market introduced in deregulated power system is similar to a commodity market. This competitive electricity markets have resulted in growing prominence of transmission congestion.

Congestion occurs whenever the preferred generation/demand pattern of the various market players requires the provision of transmission services beyond the capability of the transmission system to provide. Under ideal conditions of the transmission unconstrained markets, the various buyers and sellers satisfy their required deals. But in practical applications, the constraints in the transmission network are considered such as physical, operational constraints. So the buyers and sellers are unable to meet the desired deals without violating one or more constraints. Therefore the congestion results from insufficient transfer capabilities between the various buyers and sellers.

One potential option to manage congestion is load curtailment. By reducing the demand from the customers, the power flow in the congested transmission line is reduced. As a result, the congestion of a transmission line is relieved. But, these methods aim at mitigating physical limit violations by using priority system to curtail transmission system. In such situations, a solution is needed to have successful transmission

congestion management considering both technical and economic considerations.

An independent entity is created to ensure that all suppliers and customers have open access to the transmission system while high system reliability is maintained. This entity is called independent system operator (ISO). On one hand, the ISO is independent from suppliers and customers in order to create a fair competitive environment. On the other hand, the ISO is responsible to coordinate the transmission system operation and to preserve system reliability in order to achieve maximum social welfare. The existence of ISO is very important and necessary especially for congestion management. Under normal conditions, all suppliers and customers can participate in the power market without any discrimination. The ISO manages different transactions subject to the power system constraints. When congestion happens, however, the ISO has to intervene in the market and manage the congestion.

Congestion can also potentially raise the price of power to levels much higher than normal because inexpensive power cannot be transferred to customers. A mechanism is used to control financial risks of congestion –induced price variation by setting up a system of contract network rights. These rights are called “Financial Transmission Rights” by the Federal Energy Regulatory Commission (FERC). A supplier or

customer can purchase transmission rights with the ISO in advance to protect itself against price variation due to congestion. This transaction is called a firm transaction. A transaction without a transmission right is called a non-firm transaction.

Congestion also allows market power to make a profit by sacrificing the total social welfare. A transmission system must be well organized to manage congestion if occurs. Congestion management is one of the important functions of an ISO. The ISO has other functions including the maintenance of reliability against contingencies by purchasing spinning reserves.

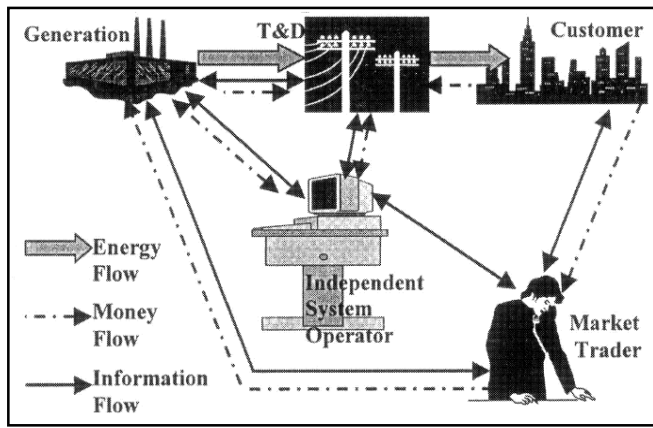


Fig.1. Typical structure of a deregulated electricity system

## 2. FACTS CONTROLLERS

### 2.1 Thyristor Controlled Series Compensator (TCSC):

Thyristor-controlled series capacitor (TCSC) is a capacitive reactance compensator, which consists of a series capacitor bank shunted by a thyristor controlled reactor in order to provide a smoothly variable series capacitive reactance.

Even though a TCSC in the normal operating range is mainly capacitive, but it can also be used in an inductive mode. The power flow over a transmission line can be increased by controlled series compensation with minimum risk of sub synchronous resonance (SSR).

CSC is a second generation FACTS controller, which controls the impedance of the line in which it is connected by varying the firing angle of the thyristors. A TCSC module comprises a series fixed capacitor that is connected in parallel to a thyristor controlled reactor (TCR) i. e. Shown in Fig.2.1.

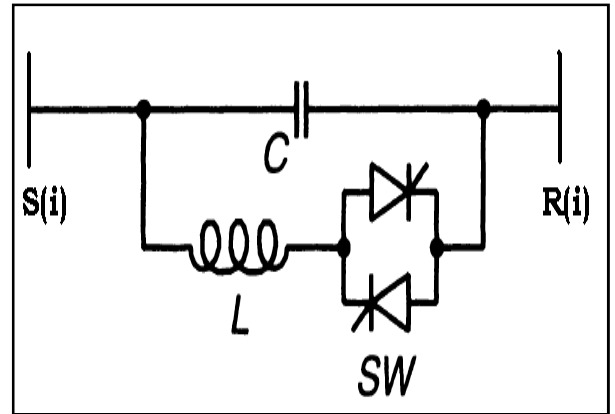


Fig.2 TCSC Module

A TCR includes a pair of anti-parallel thyristors that are connected in series with an inductor. In a TCSC, a metal oxide varistor (MOV) along with a bypass breaker is connected in parallel to the fixed capacitor for overvoltage protection. A complete compensation system may be made up of several of these modules.

## 3. MODELING OF FACTS DEVICES

For enhancing of transfer capability, the static models of these controllers are considered. It is assumed that the time constants in FACTS device is very small and hence this approximation is justified.

### 3.1 Analysis of Transmission Lines and its Power Flows and Loss

Let the complex voltages at bus  $i$  and bus  $j$  be denoted as  $V_i \angle \delta_i$  and  $V_j \angle \delta_j$  respectively as shown in figure 3.3.

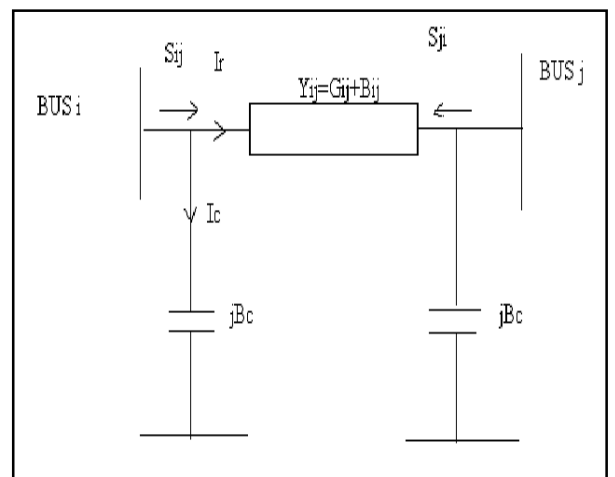


Fig. 3 Model of a Transmission line

The complex power flowing from bus i to bus j can be expressed as:

$$S_{ij}^* = P_{ij} - jQ_{ij} = V_i^* I_{ij} = V_i^* (I_R + I_C)$$

$$= [V_i^2 G_{ij} - V_i V_j G_{ij} \cos(\delta_j - \delta_i) + V_i V_j B_{ij} \sin(\delta_j - \delta_i)] + j[V_i^2 (B_{ij} + B_c) - V_i V_j B_{ij} \cos(\delta_j - \delta_i) - V_i V_j G_{ij} \sin(\delta_j - \delta_i)]$$

$$= V_i^* [(V_i - V_j)(G_{ij} + B_{ij}) + V_i (jB_c)]$$

The Active & Reactive power flow from bus i to bus j is

$$P_{ij} = V_i^2 G_{ij} - V_i V_j G_{ij} \cos(\delta_{ij}) - V_i V_j B_{ij} \sin(\delta_{ij})$$

$$Q_{ij} = -V_i^2 (B_{ij} + B_c) + V_i V_j B_{ij} \cos(\delta_{ij}) - V_i V_j G_{ij} \sin(\delta_{ij})$$

Where  $\delta_{ij} = \delta_i - \delta_j$

### 3.2 Power Injection Model of Thyristor Controlled Series Compensator (TCSC)

Thyristor controlled series compensators (TCSC) are connected in series with the lines. The effect of a TCSC on the network is as a controllable reactance in the related transmission line which compensates the inductive reactance of the line results in reducing the transfer reactance between the buses. This leads to an increase in the maximum power that can be transferred on that line in addition to a reduction in the effective reactive power losses. The series capacitors also contribute to an improvement in the voltage profiles.

Figure 3 shows a model of a transmission line with a TCSC connected between buses i and j. The transmission line is represented by its lumped  $\pi$ -equivalent parameters connected between the two buses. During the steady state, the TCSC can be considered as a static reactance  $-jX_C$ . This controllable reactance,  $X_C$  is directly used as the control variable to be implemented in the power flow equation.

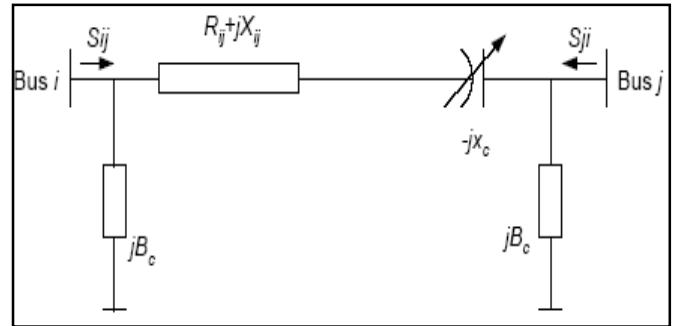


Fig. 4 Model of a TCSC

#### Line flows

$$G_{ij} + jB_{ij} = \frac{r_{ij}}{r_{ij}^2 + x_{ij}^2} + j \frac{-x_{ij}}{r_{ij}^2 + x_{ij}^2}$$

Without TCSC ( $-j X_c$ )

With TCSC ( $-j x_c$ )

$$G'_{ij} + jB'_{ij} = \frac{1}{r_{ij} + j(x_{ij} - x_c)} * \frac{r_{ij} - j(x_{ij} - x_c)}{r_{ij} - j(x_{ij} - x_c)}$$

### 3.3. OPTIMAL LOCATION BASED ON SENSITIVITY APPROACH FOR TCSC AND TCPAR DEVICES

The static conditions are considered here for the placement of FACTS devices in the power system. The objectives for device placement may be one of the following:

1. Reduction in the real power loss of a particular line
2. Reduction in the total system real power loss
3. Reduction in the total system reactive power loss
4. Maximum relief of congestion in the system

#### 3.3.1. Reduction of Total System VAR Power Loss

Here, a method based on the sensitivity of the total system reactive power loss ( $Q_L$ ) with respect to the control variables of the FACTS device for each of device considered, Net line series reactance ( $X_{ij}$ ) for a TCSC placed between buses i and j.

The reactive power loss sensitivity factors with respect to these control variables may be given as Loss sensitivity with respect to control parameter  $X_{ij}$  of TCSC placed between buses i and j,

These factors can be computed for a base case power flow solution. Consider a line connected between buses i and j and

having a net series impedance of  $X_{ij}$ , that includes the reactance of a TCSC, if present.

### 3.3.2. Selection of Optimal Placement of FACTS

#### Devices

Using the loss sensitivities as computed in the previous section, the criteria for deciding device location might be stated as TCSC must be placed in the line having the most positive loss sensitivity index  $a_{ij}$ .

$$a_{ij} = \frac{\partial Q_i}{\partial X_{ij}} = \left[ V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j) \right] \frac{X_{ij}^2 - X_{ij}^0}{(X_{ij}^0 + X_{ij}^2)^2}$$

### 4. LOCATIONAL MARGINAL PRICING (LMP)

When congestion occurs so that one or more transmission lines reach their thermal limit and are unable to carry additional power, a more expensive generation unit will be scheduled to serve the load since the cheaper generators could not reach the load location due to congestion which results in rise of electricity prices. In addition to transmission congestion, power transmission losses also contribute to the varying prices at the different locations. These characteristics lead to the concept of Locational Marginal Price (LMP).

The LMP can be decomposed into three parts: marginal energy price, marginal loss price, and marginal congestion price. These three parts represent the marginal cost associated with energy, loss, and congestion, respectively.

### 5. OPF FORMULATION

Mathematically, economic dispatch is a specific type of optimal power flow problem. Optimal power flow (OPF) normally refers to an optimization problem subject to the physical limitations of the power system.

The OPF model contains an objective function, equality constraints such as power balance equations, and inequality constraints such as the power flow thermal limit, generator ramp rate, and generator output limit.

Optimal Power flow (OPF) has been used in this work to calculate generation dispatch and load schedules to obtain LMPs and to manage congestion in the transmission systems. It is based on the bids submitted by the generators and loads and the network data. The overall objective function is to maximize the social welfare.

The problem is stated mathematically as

$$\text{Min}(\sum_{i=1}^{N_G} C_i P_{Gi})$$

Subject to

$$P_{Gi} - P_{Li} - P_i(V, \theta) = 0 (\text{Real power balance})$$

$$Q_{Gi} - Q_{Li} - Q_i(V, \theta) = 0 (\text{Reactive power balance})$$

If TCSC is located between buses  $i$  and  $j$ , the power balance equations in nodes  $i$  and  $j$  are given by

$$P_i(V, \theta) - P_{Gi} + P_{Li} + P'_i, \text{ for node } i$$

$$Q_i(V, \theta) - Q_{Gi} + Q_{Li} + Q'_i, \text{ for node } i$$

$$P_j(V, \theta) - P_{Gj} + P_{Lj} + P'_j, \text{ for node } j$$

$$Q_j(V, \theta) - Q_{Gj} + Q_{Lj} + Q'_j, \text{ for node } j$$

The OPF can be written as a problem of minimizing the total cost of generation subjected to the following constraints: Real and reactive power are balanced, real power generation is within the limits specified by the offer quantity, reactive power generation is within the limits, line flows are within the thermal limits, and voltages are within specified limits. Therefore, the Lagrangian function for linear optimized power flow (LOPF), augmenting all the constraints for TCSC becomes:

$$L = \left\{ \begin{aligned} & (\sum_{i=1}^{N_G} C_i(P_{Gi})) + \sum_{i=1}^N \lambda_{Pi}(P_i - P_{Gi} + P_{Di} + P'_i) + \\ & \sum_{i=1}^N \lambda_{Qi}(Q_i - Q_{Gi} + Q_{Di} + Q'_i) + \sum_{ij}^N \mu_{ij}(S_{ij} - S_{ij}^{max}) + \\ & \sum_{i=1}^{N_G} \mu_{P_{Gi}}^{min}(P_{Gi}^{min} - P_{Gi}) + \sum_{i=1}^{N_G} \mu_{P_{Gi}}^{max}(P_{Gi} - P_{Gi}^{max}) + \\ & \sum_{i=1}^{N_G} \mu_{Q_{Gi}}^{min}(Q_{Gi}^{min} - Q_{Gi}) + \sum_{i=1}^{N_G} \mu_{Q_{Gi}}^{max}(Q_{Gi} - Q_{Gi}^{max}) + \\ & \sum_{i=1}^{N_G} \mu_{V_i}^{min}(V_i^{min} - V_i) + \sum_{i=1}^{N_G} \mu_{V_i}^{max}(V_i - V_i^{max}) + \\ & \mu_{x_c}^{min}(x_c^{min} - x_c) + \mu_{x_c}^{max}(x_c - x_c^{max}) \end{aligned} \right.$$

Where  $\lambda_p$  and  $\lambda_q$  are the Lagrange Multipliers associated with the equality constraints and  $\mu_L, \mu_{P_G}^{min}, \mu_{P_G}^{max}, \mu_{Q_G}^{min}, \mu_{Q_G}^{max}, \mu_V^{min}, \mu_V^{max}, \mu_{x_c}^{min}, \mu_{x_c}^{max}, \mu_\alpha^{min}, \mu_\alpha^{max}$  are the Lagrange multipliers associated with the inequality constraints.

### 6. LMP DIFFERENCE METHOD

Algorithm of LMP difference method is summarized in the following steps:

- **Step 1:** Run the base case OPF to calculate the LMP at all buses and the power flow across all line sections.
- **Step 2:** Calculate the absolute value of the LMP difference and arrange in descending order of magnitude to form priority table (for LMP difference method).
- **Step 3:** For each line in the priority list, run OPF with FACTS device in that line and calculate the total congestion

rent and the value of the objective function (i.e. total generation cost or the total social welfare).

• **Step 4:** The best location of FACTS device is the one where by placing FACTS device gives the minimum congestion cost or minimum value of the objective function (i.e. minimum generation cost or maximum social welfare).

The advantage of the proposed method is that it helps to form the priority list for TCSC and TCPAR location directly from the OPF results and avoid excessive computation. Only, a few lines in the priority list need to be examined in detail to assess the best location. Since, these methods make use of economic signal given as LMP; it is easily applicable in the deregulated power systems.

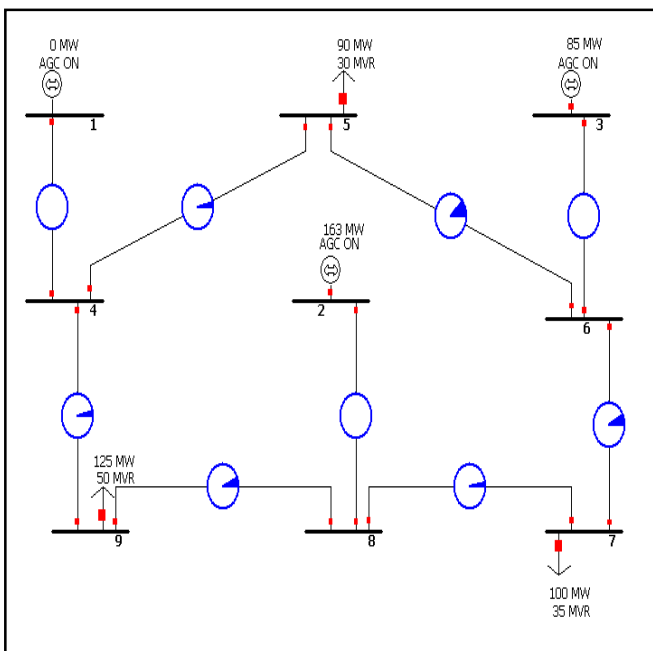
**5. CASE STUDIES:**

The Proposed method for optimal placement of TCSC for congestion management is tested on IEEE 9 bus system .The calculation of LMP is carried out using Power world Simulator8.0.

The priority location for the placement of TCSC and TCPAR based on the magnitude of LMP differences for each system is calculated. For each line in the priority table, TCSC is located in series with the line with 70% of the reactance of the line. OPF is carried out when TCSC is placed on each line one at a time and priority table is tabulated based on congestion rent and generation cost for each system.

**5.1. Case Study IEEE 9 Bus System**

This system consists of 9 buses, 9 line sections, 3 generator buses and 3 load buses



**Table.1:** Priority Table based on LMP difference for 9 Bus System

Priority	LMP Difference	Priority location
1	0.98	8-9
2	0.92	5-6
3	0.35	4-5
4	0.34	9-4
5	0.27	7-8

Table 1 shows the priority location for the placement of TCSC

**Table.2:** Priority Table based on Congestion rent with TCSC for 9 Bus System

Priority	Total Congestion Rent(\$/hr)	Priority location
1	182.109	9-4
2	182.316	7-8
3	183.315	4-5
4	184.769	8-9
5	187.168	5-6

Table 2 shows the total congestion rent when TCSC is placed on each line one at a time. Table 4.2 shows the first best location for placing TCSC to have minimum total congestion rent is the line from bus 9 to bus 4 ,with congestion rent of 182.109\$/hr.

**Table.3:** Priority Table based on Generation Cost with TCSC for 9 Bus System

Priority	Total Generation Cost(\$/hr)	Priority location
1	5386.09	4-5
2	5387.95	7-8
3	5390.28	9-4
4	5444.1	8-9
5	5453.18	5-6

Table 3 shows the total generation cost when TCSC is placed on each line one at a time.

Table 3 shows the first best location for placing TCSC to have minimum total generation cost is the line from bus 4 to bus 5 ,with generation cost of 5386.09\$/hr.

## 6. CONCLUSIONS IN SUMMARY

This competitive electricity markets have resulted in growing prominence of transmission congestion. In such situations, a solution is needed to have successful transmission congestion management considering both technical and economic considerations.

The static modeling of FACTS devices like Thyristor controlled Series Compensator (TCSC) is considered. Optimal Power flow is formulated considering all the constraints. The priority list of line sections are observed based on LMP differences between the buse for an IEEE-9 from the above table.

Based on priority table, OPF is carried out when TCSC is placed on each line one at a time and best locations for minimum congestion rent and minimum generation cost is observed from the above tables it is observed that by using priority table, depending on the criteria of requirement, we can capture the best location of TCSC.

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## BIOGRAPHIES



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