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# Congestion Management in Deregulated Power System by Using FACTS Devices

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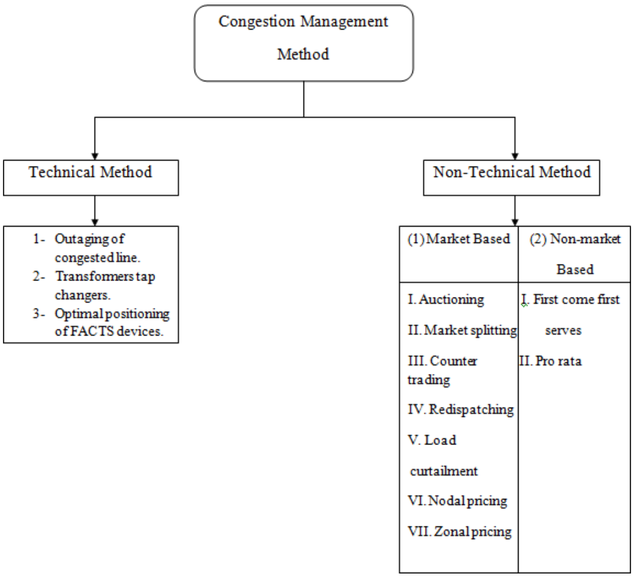
**Abstract -** *In today's scenario the most important problem stand in de-regulated power system is overloading of transmission lines. Overloading is also called transmission line congestion. In this case no more power can be injected in transmission line. It might be always not possible to dispatch all the contracted power transactions due to congestion of transmission line. Congestion can lead to market failure, violate transmission capability limits and high electricity prices and end up threatening the power system reliability and security. In this paper series Flexible Alternative Current Transmission System (FACTS) devices is used to reduce the flow in heavily loaded lines. By using FACTS devices cost of production is reduced, stability, loadability is improved and transmission losses are also reduced.*

*IEEE-14 bus test system is used for study about impact of FACTS devices on congested transmission lines. Power world simulator (Simulator 22 GSO) is used for visualizes the power flow in transmission lines.*

***Key Words*: Deregulation, Congestion management, Flexible alternative current transmission system (FACTS), Thyristor controlled series capacitor (TCSC), Power word simulator.**

## 1. INTRODUCTION

In modern world where people are aware with modern and physical facilities like air conditioners, refrigerators, heaters and many type of electrical appliances, then their demands and needs are increases. Due to this scenario load on the power system network also increases not only one reason is that to rapidly increase the load, the other aspects are now industries are grown up very fast, other companies are compete with each other in the market so for complete development of industries electricity is very necessary tool. Because of that needs of electricity sharply increases. With the rapid growth in industrialization, urbanization and enhancement of living behavior, dependency on the electrical energy has increased. This has caused the power sector to grown up very fast, resulting uncertainties [2]. With the increase in power demand, the transmission network must also meet the increased demand. When the power demand increases rapidly, some lines located on a specific line may become overloaded, and this phenomenon is called transmission line overload. When the current in a transmission line exceeds its thermal limit, that transmission path is overloaded. Therefore, the most challenging task is to ensure that transmission matches the conditions of new demand, uncertain power supply and demand from regulated power systems. In case of poor cooperation between the power generation company (Genco) and the transmission company (Transco) due to such a sudden situation occurring in the transmission line. Therefore, congestion management has become a topic of discussion to promote competition in the energy industry. Congestion control is an efficient mechanism that does not violate transport constraints. Power systems engineers implement a variety of methods to create systems that overcome or mitigate overloads and restore fast power transmission to consumers. In general, there are several methods of congestion management, non- technical and technical. On the transmission side, we can use technical methods like FACTS devices and phase shifters and the methods like zonal and nodal pricing, re-dispatching, market splitting, counter trading, load curtailment and auctioning are coming under non-technical categories [7].




For overcoming the congestion in transmission line we use technical method. In technical method we use FACTS devices to overcome the line congestion in this paper. FACTS devices can reduces the flow of power in heavily loaded lines, resulting increased load ability, low system losses, improved stability of network, reduced cost of production [10]. There is several numbers of FACSTS devices present but here TCSC is used in this paper. TCSC is a variable impedance type series compensator and it is connected in series with the transmission line to increase the power transfer capability, improve transient stability, reduces transmission losses and dampens power system oscillations.

In this paper optimal power flow (OPF) is applied by using power world simulator (Simulator 22 GSO) which provides visual understanding of power flow in a network.

## 2. FACTS DEVICES

Recently the fast growth in power semiconductor devices and control mechanism, that insure to supply fast voltage support by dynamic reactive power compensation of the transmission system and power flow control in transmission line [10]. Now a day's there are several difficulties facing by power system engineers that is how to improve the power transfer capabilities of existing transmission system? Dueto relatively low investment, compared to new transmission and generation facilities, the FACTS technologies permits the industries to better utilize the existing transmission and generation reserves, while enhancing the power system performance [4]. In the unregulated power market, FACTS devices will be used more efficiently while increasing various reliability limits. There are several typesof FACTS controllers on the market, all of which are products of FACTS devices. FACTS controllers improve power system reliability limits, supply quality and transmission line performance, and ensure optimal use of existing resources. In this article, we are using the TCSC controller.

TCSC faces a dynamical problem in transmission systems. TCSC increases the damping when large number of electrical systems is interconnected together and also it canovercome the problem of sub synchronous resonance. A phenomenon that involves an interaction between large thermal generating units and series compensated transmission system [9]. A TCSC has very fast switching capability which provides a tool for limiting the line powerflow, which allows enhanced loading of present transmission lines, and provide access for fast improvement of line power flow in response to various contingencies. The TCSC also canadjust steady state power flow within its rated limits. From a main technology point of view, the series capacitors are replaced by TCSC's. All the power equipment is located on an isolated steel platform, including the thyristor valve that is used to control the behavior of main capacitor bank [4].

## 3. DC OPTIMAL POWER FLOW

The values of DC optimal power flow are normally expressed in per unit, so the magnitudes of variable in this are nearly equal. So in DC optimal power flow some assumptions such as;

(i) Losses can be neglected.

(ii) Magnitudes of the voltage for various busses are considered as one per unit are considered.

(iii) Flows of reactive power in a transmission system are not considered.

(iv) Phase angle difference across line being generallysmall $\sin(\theta i - \theta j) \approx (\theta i - \theta j)$.

LMP is also known as shadow price, dual price or marginal cost which is measured in Rs/MWh. The price for a demandat a specific mode is governed by different shadow prices associated with one or more linear constraints. With LMP, energy retailers have the option to buy electricity at their bidding prices. This has significant influences on the required amount of generation for optimum dispatch because this determines new power flow pattern which reflects certain amount of loop flows in transmission lines. Insome cases, the increased flow exceeds the thermal capacity limit causing significant impact on LMP market [1]. To entitle specific charge to FTR holders, congestion charge iscomputed as in equation given below;

$$C = P \times ( \lambda_{sink} - \lambda_{source} ) \qquad (i)$$

Where,

C is the total congestion charge (Rs)

$\lambda_{source}$ = Nodal price for source node

$\lambda_{sink}$ = Nodal price for sink node

P = Amount of FTR in a specified path

Nodal price at bus j is driven by different shadow prices if any of constraints is binding as shown in equation below;

$$\lambda_j = \lambda_i + \phi_{ij} - \tau_{ij} \qquad (ii)$$

Where,

$\lambda_j$ = Nodal price at bus j$\lambda_i$ =

Nodal price at bus i

$\phi_{ij}$ = Shadow price due to line capacity constraints

$\tau_{ij}$ = Shadow price due to power flow using DC based model.

In above discussion shows that the impact of FACTS deviceson LMP and the cost of line congestion. In this article, we will use the Power world simulator to solve the DC optimization problem.

## 4. PROBLEM FORMULATION FOR DC OPTIMAL POWER FLOW

Mathematically, the OPF problem can be formulated as follows:-

The goal is to minimize the total cost of power generation i.e.

Minimize

$$F_T = \sum_{i=1}^{NG} Fi(PGi) \qquad (iii)$$

Where,

$F_T$ = Total cost of generation (Rs/hr)

$F_i(P_{Gi})$ = Total cost of $PG_i$ generation by $i^{th}$ generator (Rs/hr)NG =

Number of generators

$$F_i(P_{Gi}) = a_i (P_{Gi})^2 + b_i P_{Gi} + C_i \ (Rs/hr) \qquad (iv)$$

Where, $a_i$, $b_i$, $c_i$ are the cost coefficient for $i^{th}$ generator.

The above minimization problem is subjected to certain system constraints. The most common constraints are;

### 4.1 Active Power Balance Equation for the System

The total generation in the system must be equal to total load plus the total loss in the system i.e.

$$\sum_{i=1}^{NG} PGi = P_{load} + P_{loss} \qquad (v)$$

Where,

$P_{load}$ = Total active load in the system.

$P_{loss}$ = Total active power loss in the system.

### 4.2 Limits on the Outputs of the Generation Units

The output of each generating unit must be within some specified minimum and maximum limits, i.e.

$$(PG_i)_{min} \le PG_i \le (PG_i)_{max} \qquad (vi)$$

For, i = 1,2,………… ,NG

Where,

$PG_i$ = The unit MW generated by $i^{th}$ generator.

$(PG_i)_{min}$ = The specified minimum MW generation by $i^{th}$ generator.

$(PG_i)_{max}$ = The specified maximum MW generation by $i^{th}$ generator.

### 4.3 Operating line Constraints

The power flow over a transmission line should not exceed the specified maximum limit because of stability consideration, i.e.

$$P_{ij} \leq (P_{ij})_{max} \qquad (vii)$$

For, i = 1, 2,...................., n

j = 1, 2, ................... , n

Where,

$P_{ij}$ = Active power flowing in the line joining $i^{th}$ and $j^{th}$ bus.

$(P_{ij})_{max}$ = Maximum allowable active power flow in line joining $i^{th}$ and $j^{th}$ bus.

n = Number of busses in the system.

## 5. RESULT

### 5.1 Unconstraint System Dispatch

In unconstraint system when none of any transmission line are congested then the optimal power flow is same as economic load dispatch. So in this case all the locational marginal prices are same for every bus. In this project, to fulfill the total demand of 299 MW, the optimal solution is to have generator at bus 1, being the cheapest generator out of five generators and to supply all required power to the load. Based on this dispatch the system is subjected to operate under its thermal limit. So this type of dispatch which does not violet lines limits is called unconstraint system dispatch. In unconstraint system the LMP of each busses are same.

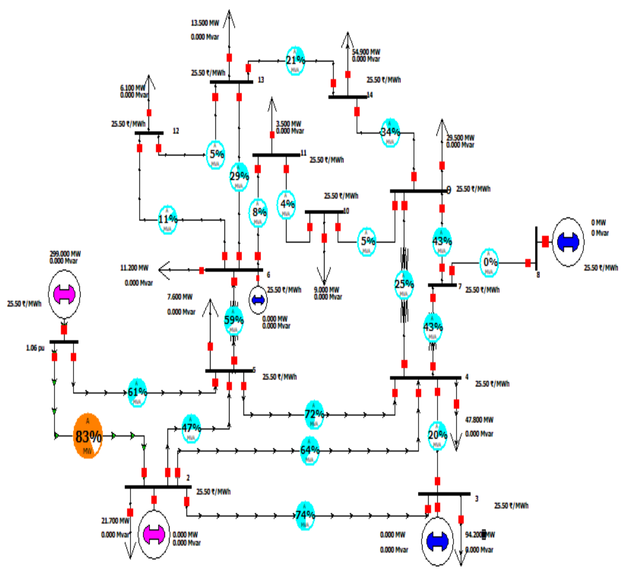



**Fig -1**: Unconstraint System

**Table -1:** Generation in Unconstraint

| | AGC | Fast Start | OPF Fast Start Status | OPF MW Control | Gen MW | Cost Shift ₹/MWh | Cost Multiplier | Cost ₹/Hr (generation only) | MW Marg. Cost of Bus | IC for OPF | Initial MW | Initial Cost | Delta MW | Delta Cost | Min MW | Max MW | Cost Model |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | YES | NO | | If Agcable | 299.0 | 0.000 | 1.000 | 6974.01 | 25.50 | 25.50 | 296.2 | 6902.41 | 2.8 | 71.60 | 100.0 | 350.0 | Cubic |
| 2 | YES | NO | | If Agcable | 0.0 | 0.000 | 1.000 | 100.00 | 25.50 | 100.20 | 0.0 | 100.00 | 0.0 | 0.00 | 0.0 | 100.0 | Cubic |
| 3 | YES | NO | | If Agcable | 0.0 | 0.000 | 1.000 | 100.00 | 25.50 | 50.20 | 2.8 | 238.01 | -2.8 | -138.01 | 0.0 | 100.0 | Cubic |
| 4 | YES | NO | | If Agcable | 0.0 | 0.000 | 1.000 | 100.00 | 25.50 | 100.20 | 0.0 | 100.00 | 0.0 | 0.00 | 0.0 | 100.0 | Cubic |
| 5 | YES | NO | | If Agcable | 0.0 | 0.000 | 1.000 | 100.00 | 25.50 | 100.20 | 0.0 | 100.00 | 0.0 | 0.00 | 0.0 | 100.0 | Cubic |

**Table -2:** Congestion Cost for Unconstraint

| | Number | Name | Area Name | MW Marg. Cost | Energy ₹/MWh | Congestion ₹/MWh |
|---|---|---|---|---|---|---|
| 1 | 1 | Bus1 | 1 | 25.50 | 25.50 | 0.00 |
| 2 | 2 | 2 | 1 | 25.50 | 25.50 | 0.00 |
| 3 | 3 | 3 | 1 | 25.50 | 25.50 | 0.00 |
| 4 | 4 | 4 | 1 | 25.50 | 25.50 | 0.00 |
| 5 | 5 | 5 | 1 | 25.50 | 25.50 | 0.00 |
| 6 | 6 | 6 | 1 | 25.50 | 25.50 | 0.00 |
| 7 | 7 | 7 | 1 | 25.50 | 25.50 | 0.00 |
| 8 | 8 | 8 | 1 | 25.50 | 25.50 | 0.00 |
| 9 | 9 | 9 | 1 | 25.50 | 25.50 | 0.00 |
| 10 | 10 | 10 | 1 | 25.50 | 25.50 | 0.00 |
| 11 | 11 | 11 | 1 | 25.50 | 25.50 | 0.00 |
| 12 | 12 | 12 | 1 | 25.50 | 25.50 | 0.00 |
| 13 | 13 | 13 | 1 | 25.50 | 25.50 | 0.00 |
| 14 | 14 | 14 | 1 | 25.50 | 25.50 | 0.00 |
| 15 | 15 | 15 | 1 | 25.50 | 25.50 | 0.00 |

### 5.2 Constraint System Dispatch

In constraint system optimal power flow is not same as economical load dispatch. There are the differences between these two dispatches. In constraint system when any transmission line is exceeds its thermal limit then that type of system is said to be constraint system. In this type of system the locational marginal prices of each bus is different. In this project, at bus 3 the demand is increased by the amount of 50 MW then the increased total demand of 349 MW. To fulfill the new demand, the system has new generation dispatch with actual flow pattern as shows in fig.2. As the line between bus 2-3 reaches its thermal limit of 100 MW it does not permit any more injection of power from generator at bus 1. Therefore generator at bus 3 is committed to supply additional amount of 1.512 MW to fulfill the new demand requirements.

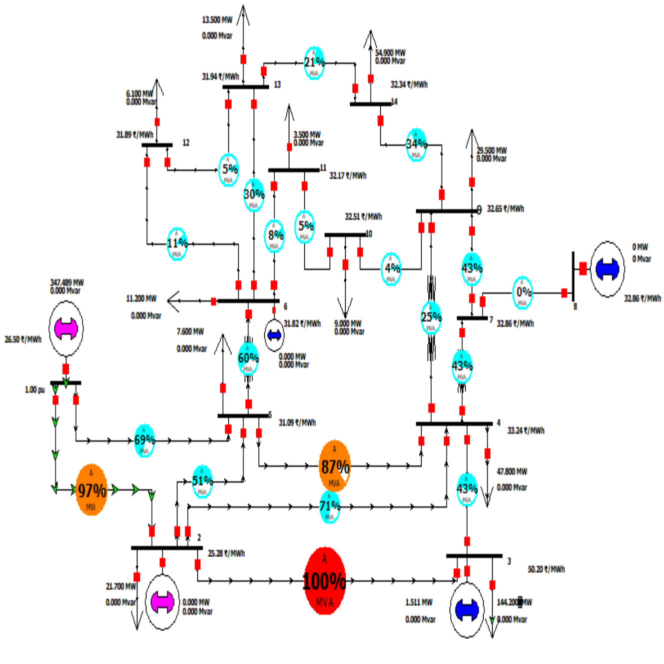


Fig -2: Constraint System

**Table -3:** Generation in Constraint System

| | AGC | Fast Start | OPF Fast Start Status | OPF MW Control | Gen MW | Cost Shift ₹/MWh | Cost Multiplier | Cost ₹/Hr (generation only) | MW Marg. Cost of Bus | IC for OPF | Initial MW | Initial Cost | Delta MW | Delta Cost | Min MW | Max MW | Cost Mode |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | YES | NO | | If Agable | 347.5 | 0.000 | 1.000 | 8257.27 | 26.50 | 26.50 | 347.5 | 8257.27 | 0.0 | -0.00 | 100.0 | 350.0 | Cubic |
| 2 | YES | NO | | If Agable | 0.0 | 0.000 | 1.000 | 100.00 | 25.28 | 100.20 | 0.0 | 100.00 | 0.0 | 0.00 | 0.0 | 100.0 | Cubic |
| 3 | YES | NO | | If Agable | 1.5 | 0.000 | 1.000 | 175.57 | 50.20 | 50.20 | 1.5 | 175.57 | 0.0 | -0.00 | 0.0 | 100.0 | Cubic |
| 4 | YES | NO | | If Agable | 0.0 | 0.000 | 1.000 | 100.00 | 31.82 | 100.20 | 0.0 | 100.00 | 0.0 | 0.00 | 0.0 | 100.0 | Cubic |
| 5 | YES | NO | | If Agable | 0.0 | 0.000 | 1.000 | 100.00 | 32.86 | 100.20 | 0.0 | 100.00 | 0.0 | 0.00 | 0.0 | 100.0 | Cubic |

**Table -4:** Congestion Cost for Constraint

| | Number | Name | Area Name | MW Marg. Cost | Energy ₹/MWh | Congestion ₹/MWh |
|---|---|---|---|---|---|---|
| 1 | 1 | Bus1 | 1 | 26.50 | 26.50 | 0.00 |
| 2 | 2 | 2 | 1 | 12.38 | 26.50 | -14.12 |
| 3 | 3 | 3 | 1 | 301.26 | 26.50 | 274.76 |
| 4 | 4 | 4 | 1 | 104.67 | 26.50 | 78.17 |
| 5 | 5 | 5 | 1 | 79.73 | 26.50 | 53.23 |
| 6 | 6 | 6 | 1 | 88.21 | 26.50 | 61.71 |
| 7 | 7 | 7 | 1 | 100.20 | 26.50 | 73.70 |
| 8 | 8 | 8 | 1 | 100.20 | 26.50 | 73.70 |
| 9 | 9 | 9 | 1 | 97.85 | 26.50 | 71.35 |
| 10 | 10 | 10 | 1 | 96.13 | 26.50 | 69.63 |
| 11 | 11 | 11 | 1 | 92.24 | 26.50 | 65.74 |
| 12 | 12 | 12 | 1 | 88.97 | 26.50 | 62.47 |
| 13 | 13 | 13 | 1 | 89.57 | 26.50 | 63.07 |
| 14 | 14 | 14 | 1 | 94.23 | 26.50 | 67.73 |
| 15 | 15 | 15 | 1 | 26.50 | 26.50 | 0.00 |

### 5.3 System Dispatch with TCSC

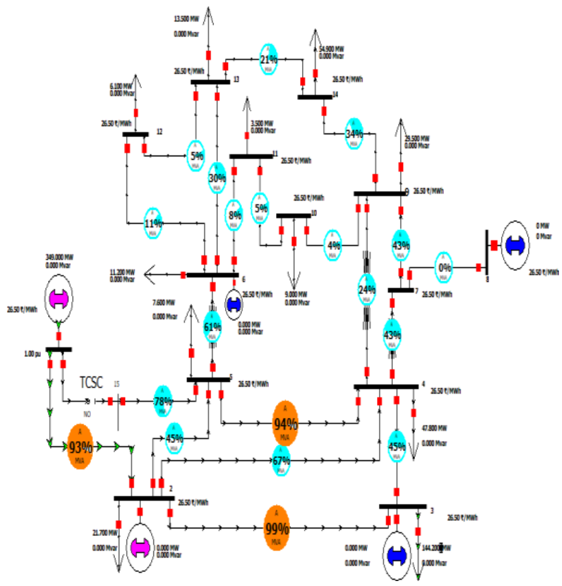


Fig -3: System with TCSC **Table -5:** Generation in Constraint System

In this dispatch TCSC is installed between buses 1-5 as shown in fig.3 to overcome the line reactance of this line. When TCSC is installed between bus 1-5 it changes the power flow pattern and by this the system is operates under its thermal limits. So by introducing TCSC congestion is overcomes. As result, LMP for all buses are same thus no congestion charge is imposed on any bus.

**Table -5:** Generation in Constraint System

| | Number | Name | Area Name | MW Marg. Cost | Energy ₹/MWh | Congestion ₹/MWh |
|---|---|---|---|---|---|---|
| 1 | 1 | Bus1 | 1 | 26.50 | 26.50 | 0.00 |
| 2 | 2 | 2 | 1 | 26.50 | 26.50 | 0.00 |
| 3 | 3 | 3 | 1 | 26.50 | 26.50 | 0.00 |
| 4 | 4 | 4 | 1 | 26.50 | 26.50 | 0.00 |
| 5 | 5 | 5 | 1 | 26.50 | 26.50 | 0.00 |
| 6 | 6 | 6 | 1 | 26.50 | 26.50 | 0.00 |
| 7 | 7 | 7 | 1 | 26.50 | 26.50 | 0.00 |
| 8 | 8 | 8 | 1 | 26.50 | 26.50 | 0.00 |
| 9 | 9 | 9 | 1 | 26.50 | 26.50 | 0.00 |
| 10 | 10 | 10 | 1 | 26.50 | 26.50 | 0.00 |
| 11 | 11 | 11 | 1 | 26.50 | 26.50 | 0.00 |
| 12 | 12 | 12 | 1 | 26.50 | 26.50 | 0.00 |
| 13 | 13 | 13 | 1 | 26.50 | 26.50 | 0.00 |
| 14 | 14 | 14 | 1 | 26.50 | 26.50 | 0.00 |
| 15 | 15 | 15 | 1 | 26.50 | 26.50 | 0.00 |

## 6. CONCLUSION

In this paper we analyze the performance of TCSC devise ontransmission line that how TCSC impact on congested transmission line and how it overcome the congestion charges of transmission line. For visualization of transmission line congestion, LMP and performing the optimal power flow, Power World Simulator software package (Simulator 22 GSO) is used.

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