Congestion Management by Optimal Positioning of FACTS Devices

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ABSTRACT

The proposed work in this paper deals with the congestion problem in deregulated power system. Due to congestion in a deregulated power system, transmission system is unable to accommodate or transfer the desired power transaction. This problem can be overcome by the use of Flexible AC transmission systems (FACTSs) devices. FACTSs devices reduce the flows of power in heavily loaded lines as a result an increased in load ability of the system. Moreover, it will improve the stability of the system, lowering down the system loss and cost of production. The optimal location for installing thyristor controlled series compensators (TCSCs) based FACTS devices is carried out by using sensitivity based analysis method. In this paper TCSC optimal location is determined by using real power performance index, reduction of total system VAR power losses and based on reduction of total system Active power losses. MATLAB based programming platform is used for validation of proposed work.

Keywords—Congestion Management (CM), Flexible AC transmission systems (FACTSs), Thyristor Controlled Series Compensation (TCSC), sensitivity analysis.

I INTRODUCTION

All over the world, the electricity supplying industries are moving towards the competitive market for better and optimal electricity pricing and focusing on customer satisfaction. An independent system operator (ISO) ensures a healthy competitive environment. ISO sets the rules and protocols for open and non-discriminatory access of transmission services. Due to fair and open competitive market, maximum utilization of available transmission system by the consumers and producers of electricity may leads to violations of power system constraints limits such as power transaction limit on transmission line, power quality, power system security and stability at the minimum cost. A situation when the transmission system is unable to accommodate or transfer the desired power transaction because of power transfer limit of transmission line is called congestion [1]. Congestion occurs when all the transactions of power cannot be allowed due to overloading of line. When power flows through transmissions lines and transformers exceeds the power transfer capability of transmission lines, congestion takes place. Due to which, line outages and blackout takes place. It also weakens power system security as well as reliability. Consequently electricity prices increased in electricity markets [2].

The congestion management (CM) is handled by ISO. The market based approaches are used by ISO to alleviate the congestion. This approaches can be categorized on the basis of price area zones, generation rescheduling, financial transmission rights and locational marginal prices. Congestion does occur in both electrically bundled and unbundled systems but the management is simpler in bundled system. Hence, flexible AC transmission systems (FACTS) are used for in better utilization of available power system capacities. It is a cost free method for congestion management [3].

Reactive power is one of the key factor for controlling congestion in transmission lines. FACTS devices are 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 [4-6].

Reactive power and voltage control plays an important role in supporting the real power transfer across a large-scale transmission system [7]. In an open access system, the importance of this support is even greater as the power transfer is increased and the associated voltages then become a bottleneck in preventing additional power transfer. In simple terms, the most important aim of reactive power dispatch is to determine the sufficient amount and correct location of reactive support in order to maintain a secure voltage profile [8]. The local nature of the reactive power also implies that the generator may provide the reactive power support for a number of transactions even if that particular generator is not involved in the real power dispatch. The allocated contributions of the individual generator's reactive power output to a particular transaction can be negative or positive [9]. Reactive support is generally provided by the switching of shunt reactors, the positioning of transformer taps and the reactive power outputs of generators.

In recent years, a considerable amount of literatures have been published on congestion management issues in electricity market. An approach using the minimum total modification to the desired transactions for relieving congestion was presented in [10]. A variant of this least modifications approach [11] used a weighting scheme with the weights being the surcharges paid by the transactions for transmission usage in the congestion relieved network. Marginal cost signals were used in [12] for generators to manage congestion. In [13], transmission congestion distribution factors (TCDFs) based on AC power flow Jacobian sensitivity has been proposed. A willingness-to-pay premium [14] has been suggested to avoid curtailment of the transactions. Hogan proposed the contract path and nodal pricing approach [15] using spot pricing theory for the pool type market.

The optimal location of TCSC for congestion management by reduction of total system reactive power loss and real power performance index is proposed in [16]. In [17], cross border coordinated redispatching by regional transmission system operators is used for multi-area congestion management. An efficient and simple model in [18] is a used for congestion management by controlling their parameters optimally. Congestion management by reducing total transfer capability (TTC) and transaction curtailment is proposed by Huang and Yan [19]. In [20], A. Oudalove proposed the load shedding combined with multiple FACTS devices approach for the coordinated emergency control system for overload limitations in a transmission system. The optimal location of unified power flow controller (UPFC) based on sensitivity-based approach is proposed in [21] for congestion management.

In the past three decades various optimization techniques have been proposed to solve OPF problems. The gradient method [22], Newton method [23], successive sparse quadratic programming (QP) method [24] are few common methods for it. In 1984 [25], Karmarkar proposed interior point method for linear programming. An interior point method is used to solve power system optimization problems for both linear and convex quadratic programming in economic dispatch and reactive power planning [26].

This paper deals with the congestion management by using TCSC based FACTS devices and finding the optimal location for placing it. Reduction of total system real power loss approach is used an optimization method based on interior point method for minimizing the cost of TCSC based FACTS device and generation rescheduling. The proposed method has been demonstrated on IEEE 5 bus system and Modified IEEE-30 bus system using MATLAB based platform.

II CONGESTION MANAGEMENT

The formulation of congestion management (CM) problem is done by firstly finding the optimal location of TCSC based FACTs device for congestion alleviation process and then finding the minimum rescheduling cost to alleviate congestion using one of the available optimal power flow method. The CM problem formulation based on Sensitivity Analysis and Optimization Problem. Sensitivity Analysis is used for finding the optimal location for placement of TCSC. Interior Point Method is used for solving the optimization problem.

(a) Sensitivity Analysis - TCSC modelling is used for finding sensitivity coefficients in Sensitivity Analysis for optimal placement of TCSC.

(b) Modelling of TCSC - Fig. 1 shows a simple transmission line represented by its lumped π equivalent parameters connected between bus-i and bus-j. Let complex voltages at bus-i and bus-j are Vi(δi) and Vj(δj), respectively. The real and reactive power flow from bus-i to bus-j can be written as

$$P_{ij} = V_i^2 G_{ij} - V_i V_j [G_{ij} \cos \delta_{ij} + B_i \quad (1)$$

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

Where, .

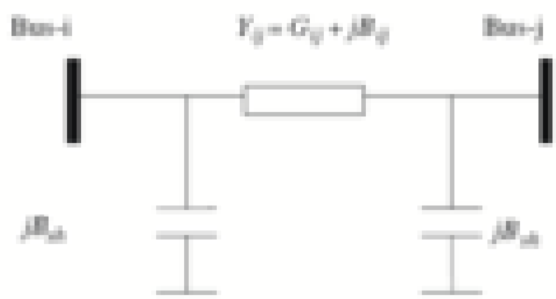

Fig. 1. Model of Transmission line

Similarly, the real and reactive power flow from bus-j to bus-i is

$$P_{ji} = V_j^2 G_{ij} - V_i V_j [G_{ij} \cos \delta_{ij} - B_{ij} \quad (3)$$

$$Q_{ji} = -V_j^2 (B_{ij} + B_{sh}) + V_i V_j [G_{ij} \sin \delta_{ij} + B_{ij} \cos \delta \quad (4)$$

Where,

$$G \quad (5)$$

$$B_{ij} = \quad (6)$$

The model of transmission line with a TCSC connected between bus-i and bus-j is shown in Fig. 2.During the steady state the TCSC can be considered as a static reactance –jxc. The real and reactive power flow from bus-i to bus-j and from bus-j to bus-i of a line having series impedance and a series reactance are

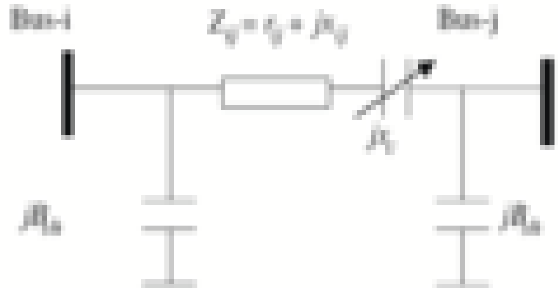

Fig. 2. Model of Transmission line with TCSC

$$P_{ij}^{c} = V_i^2 G_{ij}' - V_i V_j \left[G_{ij}' \cos \delta_{ij} + B_{i}' \right. \quad (7)$$

$$Q_{ij}^{c} = -V_i^2 (B_{ij}' + B_{sh}) - V_i V_j \left[G_{ij}' \sin \delta_{ij} - B_{ij}' \cos \delta \right. \quad (8)$$

$$P_{ji}^{c} = V_j^2 G_{ij}' - V_i V_j \left[G_{ij}' \cos \delta_{ij} - B_{ij}' \right. \quad (9)$$

$$Q_{ij}^{c} = -V_j^2 (B_{ij}' + B_{sh}) + V_i V_j \left[G_{ij}' \sin \delta_{ij} + B_{ij}' \cos \delta \right. \quad (10)$$

The active and reactive power loss in the line having TCSC can be written as

$$P_L = P_{ij} + P_{ji} = G_{ij}' (V_i^2 + V_j^2) - 2 V_i V_j G_{ij}' \, co \quad (11)$$

$$Q_L = Q_{ij} + Q_{ji} = -(V_i^2 + V_j^2)(B_{ij}' + B_{sh}) + 2 V_i V_j B_{ij}' \cos \delta_{ij} \quad (12)$$

Where,

$$G_{ij}' = r_{ij} / (r_{ij}^2 \quad (13)$$

$$B_{ij}' = -(x_{ij} - x_c)/(r_{ij}^2 + (x \quad (14)$$

(c) Optimal Location of TCSC - The optimal location of TCSC has been finding out by using the Sensitivity Analysis.

(i) Reduction of total system VAR power loss: Sensitivity factor aij is obtained by differentiating the reactive power loss (QL) with respect to net line series reactance between buses i and j as control parameter of TCSC. Hence, Loss sensitivity based on sensitivity of the total system reactive power loss is given as [16] :

$$a_{ij} = \frac{\partial Q_L}{\partial x_{ij}} = [V_i^2 + V_j^2 - 2 V_i V_j \cos \delta_{ij}] . \frac{r_i}{(r_{ij}^2} \quad (15)$$

(ii) Real power flow performance index sensitivity indices: The severity of the system loading under normal and contingency cases can be described by a real power line flow performance index[18], as given below

$$PI = \sum_i \quad (16)$$

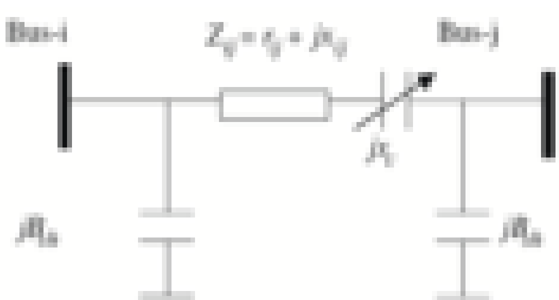

Fig. 3 Model of Transmission line with TCSC

Where,

is the real power is flow,

P is the rated capacity of the line-m,

N is the exponent and

w_m is a real non-negative weighting coefficient.

When the lines are overloaded the value of PI is high while the lines are within their limits then PI is small. The PI sensitivity factors for real power flow with respect to the TCSC parameters can be written as:

$$b_k \quad (17)$$

The sensitivity of PI with respect to TCSC parameter connected between bus-i and bus-j can be written as

$$\frac{\partial PI}{\partial X_k} = \sum_{m=1}^{N_L} Wm \, P_{Lm}^3 \Big(\quad (18)$$

Where,

$$\frac{\partial P_{Lm}}{\partial x_{ck}} = \begin{cases} S_{mi}\frac{\partial P_i}{\partial x_{ck}} + S_{mj}\frac{\partial P_j}{\partial x_{ck}}, \\ S_{mi}\frac{\partial P_i}{\partial x_{ck}} + S_{mj}\frac{\partial P_j}{\partial x_{ck}} + \frac{\partial P_j}{\partial x_{ck}}, \end{cases} \quad (19)$$

Where,

$$\frac{\partial P_i}{\partial x_{ck}} = -2(V_i^2 - V_iV_j\cos\delta_{ij})\frac{r_{ij}x_{ij}}{(r_{ij}^2+x_{ij}^2)^2} - V_iV_j\sin\delta_{ij}\frac{(x_{ij}^2-r_{ij}^2)}{(r_{ij}^2+x_{ij}^2)^2} \quad (20)$$

$$\frac{\partial P_j}{\partial x_{ck}} = -2(V_j^2 - V_iV_j\cos\delta_{ij})\frac{r_{ij}x_{ij}}{(r_{ij}^2+x_{ij}^2)^2} + V_iV_j\sin\delta_{ij}\frac{(x_{ij}^2-r_{ij}^2)}{(r_{ij}^2+x_{ij}^2)^2} \quad (21)$$

(iii) Reduction of total system Active power loss: The active power loss in the line can be written as:

$$P_L = P_{ij} + P_{ji} = G_{ij}'(V_i^2 + V_j^2) - 2V_iV_jG_{ij}'\cos\delta_{ij} \quad (22)$$

The sensitivity factor cij is calculated by differentiating the equation (11) with respect to control parameter of TCSC and can be written as:

$$c_{ij} = \frac{\partial P_L}{\partial x_{ij}} = [V_i^2 + V_j^2 - 2V_iV_j\cos\delta_{ij}].\frac{-2r_{ij}x_{ij}}{(r_{ij}^2+x_{ij}^2)^2} \quad (23)$$

(iv) Criteria for Optimal Location of TCSC

The static and dynamic performance of the system plays a vital role in placement of FACTS devices. The static performance of the system can be enhance by finding the optimal location for installing FACTS devices using sensitivity factor methods. The most sensitive line is choose for placing FACTS device.

The sensitivity indices can be calculated using three methods as bellows for TCSC placement:

- Reactive power loss reduction method – Line having most positive loss sensitivity index
- PI method - Line having most negative sensitivity index.
- Active power loss reduction method - Line having the most positive loss sensitivity index.

(v) Objective Function

FACTS devices cost are high, due to which it is necessary to use cost-benefit analysis. Weather the location of installing new FACTS device is cost effective among other locations or not.

The cost of installing TCSC in line-k is given bas:

$$C_{TCSC}(k) = c.x_c(k).P_L^2.Ba \quad (24)$$

Hence, the objective function for placement of TCSC will be

$$\min P_L \quad (25)$$

Where c is the unit investment cost of FACTS device x_c is the series capacitive reactance and PL is the power flow in line-k.

III CONGESTION MANAGEMENT PROBLEM FORMULATION

(a) Optimization Problem

Let the costs of rescheduled active powers and reactive powers are f_1 and f_2 .Hence, the objective function is :

Minimize $Z = f_1 + f_2$

$$Pg_i - Pd_i - P_i(V,\theta,T) = 0$$
$$Qg_i - Qd_i - Q_i(V,\theta,T) = 0$$

Mathematically, an OPF for minimization of the total operating cost can be written as follows:

Min $f(x) = \sum_i^{Ng}(\alpha_i * Pg_i^2 + \beta_i * Pg_i + \gamma_i) + C_{TCSC}$

Subject to the following constraints:

Non linear equality constraints (load flow equations)

g(x)=0 (26)

where g(x) represents equality constraints including bus power flow equations. i.e., i= 1,2,….N

Non-linear inequality constraints such as line flow constraints, interface flow constraints and simple inequality constraints of variables such as voltage magnitudes, generator active powers, generator reactive powers, transformer tap ratios

$$h_j^{min} \le h_j(P_g, Q_g, V, \theta, \quad (27)$$

j=1, 2,…,N_h

Where, $x =$,

$\alpha_i, \beta_i, \gamma_i$ are the coefficients of quadratic production cost functions at bus i,

Pg is the bus active generation,

Qg is the bus reactive generation,

Pd is the bus active load,

Q_d is bus reactive load,

V is the bus voltage magnitude,

θ is the bus angle vector,

T is the transformer Tap ratio vector,

h^{min} , h^{max} are lower bound and upper bound vectors, respectively, for inequality constraints,

Ng is the total number of generators,

N is total number of buses, and

Nh is the total number of double-side inequality constraints.

Transform the OPF problem into the following equivalent OPF problem by applying Fiacco and McCormick's barrier method as follows,

$$Min\{f(x) - \mu \sum_1^{Nh} \ln(s\,l_i) - \mu \sum_1^{Nh} \ln(su \quad (28)$$

Subjected to the following constraints

$$g(x)=0 \quad (29)$$

$$h(x)- sl- h^{min} =0 \quad (30)$$

$$h(x)+ su- h^{max} =0 \quad (31)$$

Where, μ>0.

The Lagrangian function for equalities optimization for problem (4) is

$$L = f(x) - \mu \sum \ln(sl) - \mu \sum \ln(su) - \lambda^T g(x)$$
$$-\pi l^T (h(x) - sl - h^{min}) - \pi u^T (h(x) + sl - h^{m} \quad (32)$$

Where λ, πl, πu are Lagrangian multiples for constraints (22),(23),(24),respectively.

The Karush-Kuhn-Tucker (KKT) first order conditions for the Lagrangian function of (3) are,

$$\nabla_x L_\mu = \nabla f(x) - \nabla g(x)^T \lambda - \nabla h(x)^T \pi l - \nabla h^T \pi u = 0 \quad (33)$$

$$\nabla_{\pi l} L_\mu = -(h(x) - sl - \quad (34)$$

$$\nabla_{\pi u} L_\mu = -(h(x) + su - \quad (35)$$

$$\nabla_{sl} L_\mu = l \quad (36)$$

$$\nabla_{su} L_\mu = \mu e \quad (37)$$

Where, Sl=diag(sl_j),

Su=diag(su_j),

Πl= diag(sl_j),

Πu= diag(su_j).

The Newton equation for the nonlinear interior point OPF algorithm derived above may be expressed as the following compact form,

$$\begin{bmatrix} -\pi l^{-1} Sl & 0 & - \\ 0 & -\pi l^{-1} Sl - & \\ -\nabla h^T & -\nabla h^T\, H & \\ 0 & 0 & -J \end{bmatrix} = \begin{bmatrix} - \\ -l \\ \\ \end{bmatrix} \quad (38)$$

$$\Delta sl = \pi l^{-1}(- \quad (39)$$

$$\Delta su = \pi u^{-1}(-\nabla_{su} \quad (40)$$

Where,

$$H(x, \lambda, \pi l, \pi u) = \nabla^2 f(x) - \lambda \nabla^2 g(x) - (\pi l + \pi u)\, \nabla^2 h(x),$$

.

By solving the Newton equation (7), , , , , , can be obtained. Then the Newton solution can be updated as follows,

(41)

(42)

x (43)

π (44)

πu (45)

(46)

Where σ =0.995~0.999 95. α_p, α_d are primal and dual step length respectively. They can be determined by

$$\alpha_p = min\left\{min\left(\frac{sl}{-\Delta sl}\right), min\left(\frac{s}{-\Delta}\right.\right. \quad (47)$$

$$\alpha_d = min\left\{min\left(\frac{-\pi l}{-\Delta\pi l}\right), min\left(\frac{\pi}{-\Delta}\right.\right. \quad (48)$$

The complementary gap of the nonlinear interior point OPF is,

$$C_{gap} \quad (49)$$

The barrier parameter can be determined by,

(50)

where β=0.01~0.2, m is the number of inequality constraints in (21)

(b) Algorithm:

The solution procedure for the nonlinear interior point OPF is summarized as the following:

(i) Set iteration count k=0, $\mu = \mu 0$, and initialize the OPF solution.

(ii) If KKT conditions are satisfied and complementary gap is less than a tolerance, output results. Otherwise go to step III.

(iii) Form and solve Newton equation in (25), then (26) and (27).

(iv) Update Newton solution by equation (26).

(v) Compute complementary gap by (28).

(vi) k=k+1 go to step II.

IV RESULTS AND DISCUSSIONS

Matlab is the software used for implementing the three sensitivity methods. Programming is written for all the three sensitivity methods in Matlab. Separate programming is written for the interior point method in Matlab. Method 1st is reactive power reduction method [16], method 2nd is the PI reduction method [18] and the active power loss reduction method is named 3rd method. It is the proposed method in the thesis work. All these three methods are discussed for the 5-bus and modified IEEE 30 bus system.

(a) IEEE 5- Bus System

The 5-bus system consists of 1 slack or reference bus, 3 generator buses and 2 load buses. The slack bus is numbered as 1 followed by the generating buses and load buses.

Table 1 gives the load flow analysis of IEEE 5-bus system. After load flow analysis, the real power flow in line 4rth between bus 2-5 is 1.034 p.u which is more than the line loading limit.

Table-2 gives the sensitivities index of reactive power loss reduction, real power flow performance index and active power loss reduction. Bold letter is used to show the sensitive line. From the column 3rd in Table 2, It is observed the line numbered 5 between buses 3-5 is suitable for placement of TCSC for reducing the total reactive power loss. Table 3 gives the value of power flow in the congested line 4th after placing TCSC is 0.99956 p.u. Hence, after placing the TCSC the congestion has been relieved in the system. The value of Control parameter of TCSC for computing power flow is taken as 0.2885p.u.

From the column 4th in Table 2, It is observed the line numbered 2nd between buses 1-4 is suitable for placement of TCSC for reducing the real power flow performance index (PI). Table 3 gives the value of power flow in the congested line 4th after placing TCSC is 0.99954 p.u. Hence, after placing the TCSC the congestion has been relieved in the system. The value of Control parameter of TCSC for computing power flow is taken as 0.0326p.u

From the column 5th in Table 2, It is observed the line numbered 1st between buses 1-2 is suitable for placement of TCSC for reducing the Active power loss. Table 3 gives the value of power flow in the congested line 4th after placing TCSC is 0.99936 p.u. Hence, after placing the TCSC the congestion has been relieved in the system. The value of Control parameter of TCSC for computing power flow is taken as as 0.3106p.u.

Table 1
Power Flow Result for 5- Bus System

		Method reported in [16]
Line	i-j	Power flow(pu)
1	1-2	0.07798
2	1-4	0.4145
3	2-3	0.51559
4	**2-5**	**1.034**
5	3-5	0.08441
6	4-5	0.40379

Table 2
Sensitivities for 5-Bus System

		Method reported in[16]	Method reported in[18]	PROPOSED METHOD
Line	i-j	aij	bij	cij
1	1-2	-0.008057	-0.0789	**-0.0004**
2	1-4	-0.967394	**-0.41433**	-0.0897
3	2-3	-0.240349	0.45582	-0.1235
4	2-5	-0.970852	1.95327	-0.5107
5	3-5	**-0.00784**	-0.10536	-0.0018
6	4-5	-0.261704	0.34953	-0.0837

Placement of TCSC in line 5th may reduce the reactive power loss and placement of TCSC in line 2nd will reduce the real power flow performance index value but it will be less effective than placing a TCSC in line 1st as can be seen from its sensitivity factors. Table 4 gives the total costs comparison of three methods. It can be observed that reduction of total system active power loss method is more economical than VAR power loss method and performance index method. The Voltage Profile of the IEEE 5-bus system obtained from the three-sensitivity analysis is given the Table 5.

Table 3
Power Flow Result for 5-Bus System after Placing TCSC Based on Sensitivity Methods

		Method reported in[16]	Method reported in[18]	PROPOSED METHOD
Line	i-j	Power flow(pu)	Power flow(pu)	Power flow(pu)
1	1-2	0.07614	0.10893	0.08791
2	1-4	0.41123	0.46051	0.42237
3	2-3	0.47879	0.51202	0.49789
4	2-5	0.99956	0.99954	0.99936
5	3-5	0.08441	0.08798	0.08798
6	4-5	0.40379	0.37453	0.40379

Table 4
Total Cost for Optimal Location of TCSC in 5-Bus System

METHOD	TOTAL COST($/DAY)
VAR reduction [16]	2126.30
PI [18]	2346.34
Active power reduction	2031.30

Table 5
Voltage Magnitude values obtained from various methods

BUS NO.	METHOD REPORTED IN[16]	METHOD REPORTED IN[18]	PROPOSED METHOD
1	1.020	1.020	1.020
2	1.040	1.040	1.040
3	1.050	1.050	1.050
4	1.090	1.120	1.060
5	1.019	1.102	1.017

(b) Modified IEEE- 30 bus system

The IEEE 30-bus system bid prices by generators for each buses are given in appendix. The 30-bus system consists of 6 generator buses and 24 load buses. The slack bus is numbered as 1 followed by the generating buses and load buses.

Table 6 gives the load flow of 30-bus system. There are two congested lines in case of 30-bus system. Those are line in between bus 1-2 numbered as line 1 and in between bus 2-9 numbered as line 5 as given in table 7. After performing load flow analysis, the real power flow at line 1 is 1.2748 p.u while at line 5 is 1.046 p.u. as shown in appendix VI. Which are more than the line loading limit.

Table-7gives the sensitivities index of reactive power loss reduction, real power flow performance index and active power loss reduction. Bold letter is used to show the sensitive line. From the column 3rd in Table 7, It is observed the line numbered 26 between buses 14-15 is suitable for placement of TCSC for reducing the total reactive power loss. Table 8 gives the value of power flow in the congested line 1 after placing TCSC is 0. 9987 p.u and in line-5 is 0. 9568p.u. Hence, after placing the TCSC the congestion has been relieved in the system.

The value of Control parameter of TCSC for computing power flow is taken as 0.17885p.u.

It can be observed from column 4th in table-7 that placing a TCSC in line-8 is optimal for reducing the real power flow performance index. After placing TCSC in line-8, the power flow Value of the congested line-1 is coming out to be 0.9984 p.u and in line-5 is 0.9476 p.u as given in Table 8. Hence, after placing the TCSC the congestion has been relieved in the system.

The value of Control parameter of TCSC for computing power flow is taken as 0.0326p.u.

From the column 5th in table-7, it is observed that placing a TCSC in line-40 is optimal for reducing the Active power loss. After placing TCSC in line-40, the power flow Value of the congested line-1 is coming out to be 0.9876 p.u and in line-5 is 0.9321 p.u as given in Table 8. Hence, after placing the TCSC the congestion has been relieved in the system

Placement of TCSC in line-26 may reduce the reactive power loss and placement of TCSC in line-8 will reduce the real power flow performance index value but it will be less effective than placing a TCSC in line-40 as can be seen from its sensitivity factors. Table 10 gives the total costs comparison of three methods. It can be observed that reduction of total system active power loss method is more economical than VAR power loss method and performance index method.

Table 6
Congested Line Details for 30-Bus System

CONGESTED LINE	POWER FLOW (PU)	LINE LIMIT (PU)
1-2	1.2748	1.00
2-9	1.046	1.00

Table 7
Sensitivity Indices for 30-Bus System

LINE	i-j	aij	bij	cij
1	1-2	-0.0012	1.1352	-0.0023
2	1-7	-0.5181	-0.6546	-0.3065
3	2-3	-0.3331	-0.0650	-0.1681
4	2-8	-0.1755	-0.8522	-0.1291
5	2-9	-0.3028	0.0099	-0.2239
6	3-10	-0.0151	-0.1674	-0.0142
7	4-28	-0.0051	-0.0003	-0.0036
8	7-8	-0.3965	**-0.8696**	-0.3143
9	8-9	-0.4864	0.0001	-0.3048
10	8-13	-0.1850	1.0923	-0.0012
11	9-4	-0.0924	-0.2237	-0.0575
12	9-10	-0.0282	-0.1678	-0.0205
13	9-11	-0.2399	0	-0.0026
14	9-12	-0.0423	-0.3252	-0.0037
15	9-28	-0.0184	0	-0.0113
16	11-5	-0.0468	0	-0.0043
17	11-12	-0.0341	-0.3270	-0.0024
18	12-17	-0.0013	-0.2618	-0.0012
19	12-20	-0.0030	-0.0654	-0.0033
20	12-21	-0.0200	-0.5054	-0.0237

21	12-22	-0.0042	0.6215	-0.0054
22	13-6	-0.1319	0.0169	-0.0032
23	13-14	-0.0052	-0.1687	-0.0065
24	13-15	-0.0319	-0.2155	-0.0437
25	13-16	-0.0112	-0.0872	-0.0138
26	14-15	**0.0001**	-0.2378	-0.0008
27	15-18	-0.0056	-0.0933	-0.0072
28	15-23	-0.0042	0.4660	-0.0056
29	16-17	-0.0064	-0.2607	-0.0066
30	18-19	-0.0024	-0.2607	-0.0031
31	19-20	-0.0011	-0.0636	-0.0015
32	21-22	-0.0010	0.6329	-0.0013
33	22-24	-0.0016	-0.2532	-0.0035
34	23-24	-0.0014	-0.2505	-0.0018
35	24-25	-0.0006	0.0004	-0.0010
36	25-26	-0.0007	-0.1014	-0.0018
37	25-27	-0.0026	0.7824	-0.0038
38	27-29	-0.0024	-0.0678	-0.0035
39	27-30	-0.0030	-0.3048	-0.0045
40	28-27	-0.0425	0.7821	**0.0015**
41	29-30	-0.0008	-0.3071	-0.0012

Table 8
Power Flow Result for 30-Bus System after Placement of TCSC Based on the Sensitivity Methods

		Method reported in[16]	Method reported in[18]	PROPOSED METHOD
LINE	i-j	Power Flow(pu)	Power Flow(pu)	Power Flow(pu)
1	1-2	0.9987	0.9984	0.9876
2	1-7	0.7670	0.7742	0.7637
3	2-3	0.5978	0.6023	0.5957
4	2-8	0.4590	0.4630	0.4571
5	2-9	0.9568	0.9476	0.9321
6	3-10	0.0741	0.0756	0.0735
7	4-28	0.0507	0.0513	0.0505
8	7-8	0.5851	0.6045	0.5763
9	8-9	0.5603	0.5764	0.5530
10	8-13	0.4073	0.4100	0.4061
11	9-4	-0.0166	-0.0194	-0.0154
12	9-10	0.1374	0.1393	0.1366
13	9-11	0.4752	0.4790	0.4735
14	9-12	0.2038	0.2044	0.2035
15	9-28	0.1296	0.1326	0.1282
16	11-5	0.0667	0.0672	0.0664
17	11-12	0.1159	0.1176	0.1151
18	12-17	-0.0060	-0.0059	-0.0061
19	12-20	0.0534	0.0539	0.0532
20	12-21	0.1167	0.1196	0.1154
21	12-22	0.0565	0.0572	0.0562
22	13-6	-0.2256	-0.2282	-0.2244
23	13-14	0.0881	0.0886	0.0878
24	13-15	0.2116	0.2141	0.2104
25	13-16	0.1270	0.1280	0.1265
26	14-15	0.0273	0.0274	0.0272

27	15-18	0.0919	0.0925	0.0916
28	15-23	0.0701	0.0707	0.0698
29	16-17	0.0919	0.0926	0.0915
30	18-19	0.0583	0.0589	0.0580
31	19-20	-0.0276	-0.0284	-0.0273
32	21-22	-0.0308	-0.0323	-0.0301
33	22-24	0.0153	0.0157	0.0152
34	23-24	0.0388	0.0391	0.0387
35	24-25	-0.0298	-0.0299	-0.0297
36	25-26	0.0348	0.0349	0.0347
37	25-27	-0.0635	-0.0639	-0.0633
38	27-29	0.0608	0.0611	0.0607
39	27-30	0.0701	0.0703	0.0700
40	28-27	0.1952	0.1960	0.1948
41	29-30	0.0364	0.0365	0.0364

Table 9
Voltage Magnitude (PU) values obtained from various methods

BUS	Method reported in[16]	Method reported in[18]	PROPOSED METHOD
1	1.000	1.000	1.000
2	1.000	1.000	1.000
3	0.983	0.981	0.900
4	0.980	0.984	0.900
5	0.982	0.985	0.920
6	0.973	0.978	0.980
7	0.967	0.961	0.970
8	0.961	0.958	0.965
9	0.981	0.984	0.979
10	0.984	0.984	0.985
11	0.981	0.987	0.983
12	0.985	0.986	0.987
13	1.000	1.000	1.000
14	0.977	0.982	0.984
15	0.980	0.981	0.986
16	0.977	0.98	0.974
17	0.977	0.977	0.977
18	0.968	0.965	0.974
19	0.965	0.962	0.978
20	0.969	0.978	0.987
21	0.993	1.000	1.020
22	1.000	1.000	1.000
23	1.000	1.000	1.000
24	0.989	0.900	0.920
25	0.990	0.990	1.040
26	0.972	0.976	0.980
27	1.000	1.000	1.000
28	0.975	0.979	0.980
29	0.98	0.984	0.987
30	0.968	0.968	0.971

Table 10
Total Cost for Optimal Location of TCSC

Method	**Total Cost**
VAR reduction	1186.5$/day
PI	1223$/day
Active power reduction	**1068**$/day

V CONCLUSION

In a deregulated power system, Congestion and its management is an important issue to deal with it. TCSC based FACTS device is one of the solution for congestion management. TCSC controls the power flows in the transmission line and reduces the power flow through over loaded lines. But due to high cost of FACTS devices, It is necessary to find the optimal location for installing It.

In the proposed work, Reduction of total system real power loss approach is used an optimization method based on interior point method for minimizing the cost of TCSC based FACTS device and generation rescheduling. The proposed method has been demonstrated on IEEE 5 bus system and Modified IEEE-30 bus system. The results obtained divulge that the proposed work is effective in managing congestion and finding the optimal location for placing TCSC based FACTS device.

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