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Genetic Algorithm Technique for Social Welfare Improvement Using FACTS & Generation Rescheduling

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Abstract**—** This paper presents a framework to carry out an novel method based Optimal Power Flow (OPF) for transmission congestion management in deregulated power system using Thyristor Controlled Series Capacitor (TCSC) and Generation Rescheduling. In the deregulated environment, some generators may not be willing to participate in the congestion management process for their own economic interest or some other operational constraints. By using Generator Sensitivity (GS), we select generators actually participating in congestion alleviation. The research presented in this paper aims to maximize total system social welfare and alleviate congestion by best placement and sizing of TCSC device. The proposed approach makes use of the Genetic Algorithm (GA) to optimise the schedule of Generating Companies (GenCos), Distributing Companies (DisCos) and TCSC location and size based on severity power index, while the Newton–Raphson algorithm minimizes the mismatch of the power flow equations. Simulation results on the modified IEEE 30-bus test systems (with line flow constraints, before and after the compensation) are used to examine the impact of TCSC on the total system social welfare improvement. The results show clearly the effectiveness of suggested method.

Keywords—Congestion management, Generator Sensitivity, Severity power index, FACTS, TCSC, Genetic Algorithm.

I. INTRODUCTION

The restructuring in electric power industries from the last two decades was introduced with privatization in their sectors to improve their efficiency [1]. However, as the deregulation progresses among power utilities, the utility operators face new problems and challenges [2] as there is no single solution applicable to all entities which result in a broad range of diverse trends. Network stability and frequency regulation are the key factors to be considered for power system network. Since the generation investment decision currently is in the hand of private entity, obviously there is lack of coordination between the generation and transmission investments as well [3]. Moreover, the provision of bilateral transaction, that allows GENCO and DISCO pairs to negotiate power transactions, has lead to uncertainty in the amount and direction of power flows. In addition to deregulation challenges, electrical loads are rapidly growing and some transmission lines are reaching their thermal limits. Evidently, the overall consequence of this issue is the congestion in transmission network. Congestion can be relieved by building new transmission lines; however, this is an expensive solution that requires years for approval and construction. An accepted solution for the Independent System Operator (ISO) to perform congestion management (Process of ensuring transmission system does not violate its operating limits) includes two types of techniques which are as follows [4-5]:

A. Cost free means: This method includes out-ageing of congested lines, operation of transformer taps/phase shifters and operation of FACTS devices particularly series devices

B. Non-Cost free means: In this method, re-dispatching the generation amounts is performed. By using this method, some generators back down while others increase their output. The effect of re-dispatching is that generators no longer operate at equal incremental costs.

The congestion management results in maximization of social welfare of the electricity market entities Numerous methods have been reported for social welfare maximization and congestion management, which are based on market model [5], Particle Swarm Optimization (for generation rescheduling and/or load shedding) [6], Genetic Algorithms [7] and sensitivity analysis using transmission line susceptances [8].

The use of series FACTS device for congestion management in deregulated electricity markets is discussed in [9] [13].

This paper proposes a real code-based genetic algorithm for alleviating congestion (line overloads) and maximizing social benefit which is explained in section II by generation rescheduling alone [18], followed by optimal locating and sizing of one Thyristor-Controlled Series Capacitor (TCSC) unit to minimise the computational expenses [11] [12]. Simulations explained in section III are performed to investigate the impact of TCSC on congestion levels of the modified IEEE 30-bus system [21]. The proposed method shows the benefits of TCSC in a deregulated power market and demonstrates how they may be utilized by ISO to prevent congestion.

II. MATHEMATICAL PROBLEM FORMULATION

A. Social Welfare Function

A method which can guide the way of how to improve an existing network in an optimal way is to include the capacity limits of the transmission lines in the objective function of the optimization model. In that way the limits are not fixed anymore but are variable and subject to optimization. A term is introduced that is the social welfare function which is the sum of all transmission line capacities multiplied with the per unit cost factor for extension of the corresponding transmission line. Thus the electrical network becomes an integral part of the market [22].

The objective function for the optimization model is either the minimisation of total production cost of the generators for the produced power in case of congestion management or, if flexible loads are present in the network, maximisation of the social welfare.

The social welfare for flexible loads is defined as the sum of consumer's and producer's surplus (CS and PS). The consumer's surplus (CS) is calculated as the difference between the total price which the loads would be ready to pay for the amount of power consumed and the actual price they have to pay. The producer's surplus represents the difference between the amount of money the generators get for their power production and the amount of money which is at least required for that production. The addition of those two values is the social welfare (SW).

The social welfare means maximization of objective function but for all standard optimization algorithms, the algorithms are written by considering the minimisation of objective function. In general, maximizing a function is equivalent to minimizing the negative of this function. Thus the objective function, derived from the social welfare, for the considered optimization model in case of flexible loads is:

$$f(P_{gen}, P_{load}) = C_{gen}(P_{gen}) - C_{gen}(P_{load}) \quad (1)$$

$$SW = \max_{P_G} \left(\sum_{i=1}^{N_G} C_{Gi}(P_G) - \sum_{j=1}^{N_D} B_{Dj}(P_D) \right) \quad (2)$$

Where N_G and N_D are the number of generators and loads respectively, C_{Gi} (P_G) is the cost function of ith generator, and B_{Dj} (P_D) is the benefit function for the jth demand. Subjected to following equality and inequality constraints:

$$\begin{aligned} P_i(\delta, V) - P_{Gi} + P_{Di} &= 0 \quad for \;\; i = 1, \ldots\ldots N_G \\ Q_i(\delta, V) - Q_{Gi} + Q_{Di} &= 0 \quad for \;\; i = 1, \ldots\ldots N_G \end{aligned} \quad (3)$$

$$\begin{aligned} P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \qquad for\, i = 1, \ldots\ldots, N_G \\ Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \qquad for\, i = 1, \ldots\ldots, N_G \end{aligned} \quad (4)$$

Where P_{Gi}^{min} and $P_{Gi}^{\max}$ are the minimum and maximum real power generated at ith bus, Q_{Gi}^{min} and $Q_{Gi}^{\max}$ are minimum and maximum reactive power generated at the ith bus.

$$\left| S_{ij}(\delta, V) \right| \le S_{ij}^{max} \quad (5)$$

$$V_i^{\min} \le V_i \le V_i^{\max} \quad (6)$$

Where V_i^{min} is the minimum voltage level and V_i^{max} is the maximum voltage level of the transmission line.

B. Generator Sensitivity Distribution Factors

The line model of TCSC considered for the problem formulation is taken from [10]. A change in real power flow in a transmission line k connected between bus i and j due to change in power generation by generator g can be termed as generator sensitivity (GS) to congested line [14]. Mathematically, GS for line k can be written as

$$GS_g = \frac{\Delta P_{ij}}{\Delta P_{Gg}} \quad (7)$$

Where P_{ij} is the real power flow on congested line-k; P_{Gg} is the real power generated by the gth generator.

The basic power flow equation on congested line can be written as:

$$P_{ij} = -V_i^2 G_{ij} + V_i V_j G_{ij} \cos(\theta_i - \theta_j) + V_i V_j B_{ij} \sin(\theta_i - \theta_j) \quad (8)$$

Where V_i and θ_i are the voltage magnitude and phase angle respectively at the ith bus; G_{ij} and B_{ij} represent, respectively, the conductance and susceptance of the line connected between buses i and j; neglecting P-V coupling, (1) can be expressed as

$$GS_g = \frac{\partial P_{ij}}{\partial \theta_i} \frac{\partial \theta_i}{\partial P_{Gg}} + \frac{\partial P_{ij}}{\partial \theta_j} \frac{\partial \theta_j}{\partial P_{Gg}} \quad (9)$$

It is to be noted that the generator sensitivity values thus obtained are with respect to the slack bus as the reference. So the sensitivity of the slack bus generator to any congested line in the system is always zero.

GS_g denotes how much active power flow over a transmission line connecting bus-i and bus-j would change due to active power injection by generator g.

The system operator selects the generators having non uniform and large magnitudes of sensitivity values as the ones most sensitive to the power flow on the congested line and to participate in congestion management by rescheduling the power outputs.

C. **Optimal location of TCSC using Improved Performance**

The severity of system loading under contingency cases can be described by real power flow performance index (PI) as given below [15]

$$PI = \sum_{m=1}^{N_L} \frac{w_m}{2n} \left[\frac{P_{Lm}}{P_{Lm}^{\max}} \right]^{2n} \qquad (10)$$

Where P_{lm} is the real line flow and P_{lm}^{max} is the maximum capacity of line m, n is the exponent and w_m is the weighting coefficient to reflect the relative importance of lines. The modified performance index has been determined based on AC load flow equation including the slack bus contribution.

PI will be small when all line flows are within their limits and reach a high value when they are overloads [16]. The real power flow PI with (n=2) sensitivity factors with respect to parameter of TCSC, can be defined as

$$P_{Lm} = \begin{cases} \sum\limits_{\substack{n=1 \\ n\neq s}}^{N} S_{mn} P_n & for\ m\neq k \\ \sum\limits_{\substack{n=1 \\ n\neq s}}^{N} S_{mn} P_n + P_j & for\ m=k \end{cases} \qquad (11)$$

Using (11) following equation can be derived

$$\frac{\partial P_{Lm}}{\partial x_{ck}} = \begin{cases} \left(S_{mi} \dfrac{\partial P_i}{\partial x_{ck}} + S_{mj} \dfrac{\partial P_j}{\partial x_{ck}} \right) & for\, m \neq k \\ \left(S_{mi} \dfrac{\partial P_i}{\partial x_{ck}} + S_{mj} \dfrac{\partial P_j}{\partial x_{ck}} \right) + \dfrac{\partial P_j}{\partial x_{ck}} & for\, m = k \end{cases}$$

Where

$$\left.\frac{\partial P_i}{\partial x_{ck}}\right|_{x_{ck}=0} = (V_i^2 - V_i V_j \cos\delta_{ij}) \left.\frac{\partial \Delta G_{ij}}{\partial x_{ck}}\right|_{x_{ck}=0} - V_i V_j \sin\delta_{ij} \left.\frac{\partial \Delta B_{ij}}{\partial x_{ck}}\right|_{x_{ck}=0}$$

(12)

And

$$\left.\frac{\partial P_j}{\partial x_{ck}}\right|_{x_{ck}=0} = (V_j^2 - V_i V_j \cos\delta_{ij}) \left.\frac{\partial \Delta G_{ij}}{\partial x_{ck}}\right|_{x_{ck}=0} + V_i V_j \sin\delta_{ij} \left.\frac{\partial \Delta B_{ij}}{\partial x_{ck}}\right|_{x_{ck}=0}$$

(13)

According to PI method, TCSC should be placed in line most negative severity index.

D. **Generator Rescheduling for Congestion Management**

Based on the bids received from the participant generators, the amount of rescheduling is computed by solving the following optimization problem [19] [20]:

$$minimize \sum_{g}^{N_g} C_g \left(\Delta P_g \right) \Delta P_g \qquad (14)$$

Subject to

$$\sum_{g=1}^{N_g} \left(\left(GS_g \right) \Delta P_g \right) + F_K^0 \leq F_k^{max} \quad k=1,2\ldots..nl$$

$$P_g - P_g^{min} = \Delta P_g^{min} \leq \Delta P_g \leq \Delta P_g^{max} = P_g^{max} - P_g \quad g=1,2\ldots..N_g$$

$$\sum_{g=1}^{N_g} \Delta P_g = 0$$

Where ΔP_G is the real power adjustment at bus-g and C_G are the incremental and decremented price bids submitted by generators. These are the prices at which the generators are willing to adjust their real power outputs. $S_{ij}{}^0$ is the power flow caused by all contracts requesting the transmission service. $S_{ij}^{\max}$ is the line flow limit of the line connecting bus-i and bus-j. N_G is the number of participating generators, n_l is the number of transmission lines in the system, $P_g^{\min}$ and P_g^{max} denote respectively the minimum and maximum limits of generator outputs.

The rescheduling of generators for congestion management is formulated as a nonlinear programming problem and has been solved using the Genetic Algorithm [17].

E. **Proposed problem formulation**

OPF tool has been used normally in a deregulated power markets to calculate generation dispatch and load schedules, and to manage congestion in the system. The generally accepted objective function in this environment is the maximization of social welfare. In this paper, the cost of FACTS devices is included to the social welfare maximization problem of equation (2) which can be expressed as:

$$\max_{P_G} \left(\sum_{i=1}^{N_G} C_{Gi} \left(P_G \right) - \sum_{j=1}^{N_D} B_{Dj} \left(P_D \right) + Cost(FACTS) \right) \qquad (15)$$

Where N_G and N_D are the number of generators and loads respectively, C_{Gi} (P_G) is the cost function of ith generator, and B_{Dj} (P_D) is the benefit function for the jth demand.

subject to equation (4), (5), (6) and:

$$\begin{aligned} P_i \left(\delta, V \right) - P_{Gi} + P_{Di} &= 0 \quad for \;\; i = 1, \ldots\ldots N_G \\ Q_i \left(\delta, V \right) - Q_{Gi} + Q_{Di} &= 0 \quad for \;\; i = 1, \ldots\ldots N_G \end{aligned} \qquad (16)$$

Where P_{Gi} is the generated power and P_{Di} is the power demand at the i_{th} bus.

If TCSC is located in line between bus-i and bus-j, the power balance equations [18] in bus i and bus j are given by:

$$\begin{aligned} &P_i(\delta,V) - P_{Gi} + P_{Di} = 0 \quad for \;\; i = 1,\ldots\ldots N_G \\ &P_j(\delta,V) - P_{Gj} + P_{Dj} = 0 \quad for \;\; j = 1,\ldots\ldots N_G \\ &Q_i(\delta,V) - Q_{Gi} + Q_{Di} = 0 \quad for \;\; i = 1,\ldots\ldots N_G \\ &Q_j(\delta,V) - Q_{Gj} + Q_{Dj} = 0 \quad for \;\; j = 1,\ldots\ldots N_G \end{aligned} \tag{17}$$

Where P_{Gi} is the generated power and P_{Di} is the power demand at the i_{th} bus, P_{Gj} is the generated power and P_{Dj} is the power demand at the j_{th} bus.

TCSC reactance limit: After including TCSC, the inequality constraints will include the limits of this device, which means the maximum and minimum values of equivalent reactance (x_c).

$$x_c^{\min} \le x_c \le x_c^{\max} \tag{18}$$

The cost of TCSC is defined in the form of linear equation as

$$C_f = cx_c\left(\frac{S_{\max}^{\;2}}{S_B}\right) \tag{19}$$

Where C_f is cost of TCSC, C is the cost coefficient of TCSC (\$/MVA-year); S_{max} is the thermal limits of line where the FACTS device is placed (MVA); S_B is the base power (MVA); x_c is the series capacitive reactance (p.u.). In this study c=22,000 \$/MVA-year is adopted [9].

The formulation allows the capital cost of TCSC to vary with the TCSC capacity (MVA). Thermal limit inclusion in the problem formulation helps ISO to satisfy the thermal limit of the transmission line when a TCSC is added to that line.

F. Genetic Algorithm Technique

Evolutionary Algorithm (EA) is an adaptive technique, based on genetic processes and biological nature is able to provide solutions to real world power system problems and may provide solution to optimization problems.

GA process parameters with finite length. The problem is represented by parameters set. These parameters are represented by genes .Then these genes are linked together to construct a string called a chromosome. This makes the search to be unrestricted by continuous function with investigation or by the existence of a derivative function.

A gene explains specific option that is coded inside the chromosome. There is no unique solution for the problem. A solution through the encoding process is presents in the chromosome. A fitness function should be designed for the problem that required to be solved. This fitness function gives single numerical fitness for single chromosome. The chromosomes determine the capability of the individual it is representing in the optimization process. Second stage is the reproduction stage of GAs. In this two individuals are chosen from the population are permitted to mate to develop an offspring either through crossover or mutation, representing the next generation.

Selection is based on the **survival of the fittest**. It explains the individuals that survive in the next generation. The selection phase contains three sections. The first section determines the individual's fitness by the fitness function. A fitness function should be designed for the corresponding application; for a specific chromosome, the fitness function gives a single value, which is proportional to the capability, or utility, of the individual represented by that chromosome. The second stage transfers the fitness function into an expected value, and then is followed by the third and last stage where the expected value is then transferred to a discrete number of offspring. It has been illustrated in Figure 1.

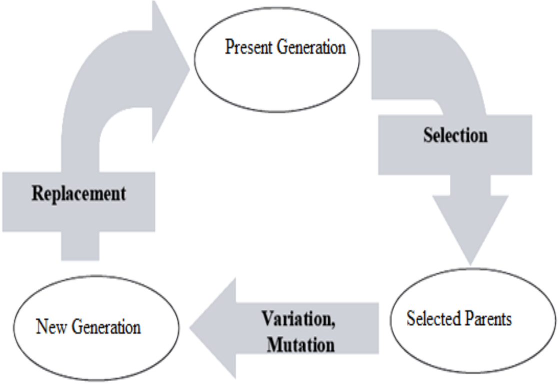

Figure 1: Illustrated Components of Genetic Algorithm

G. Application of Genetic Algorithm to proposed problem

The procedural steps involved in the proposed problem are given below.

Algorithm

Step 1 Initialize the parameters of GA and set generation *k*=1.

Step 2: Randomly generate the control variables X(k) (i.e. ΔP_G and ΔP_D) within the limit.

Step 3: Run power flow for the parent population generated in Step 2 and compute bus voltages and line flows. Evaluate the fitness values for the parent population using Equation (30).

Step 4: Select parents for recombination.

Step 5: Create new particles using crossover and polynomial mutation operation.

Step 6: Evaluate the fitness values for the new solution vectors using N-R power flow. Combine parent (Np) and child solutions (N_P). Among $2N_p$ individuals, best Np individuals are selected based on their fitness values.

Step 7: Check for stopping criteria. If maximum generation is reached then go the next step. Else go to step 4.

Step 8: Print the solution which yield minimum fitness value.

A MATLAB program is developed to implement GA in order to find optimum location of TCSC and maximise the social welfare benefits.

III. RESULTS AND DISCUSSIONS

The proposed approach is tested on IEEE 30 Bus System shown in Figure 2. It consists of 6 generators, 21 loads and 41 lines. The data for test system is taken from [21].The network parameters of the system are taken as the standard IEEE 30 bus system parameters.

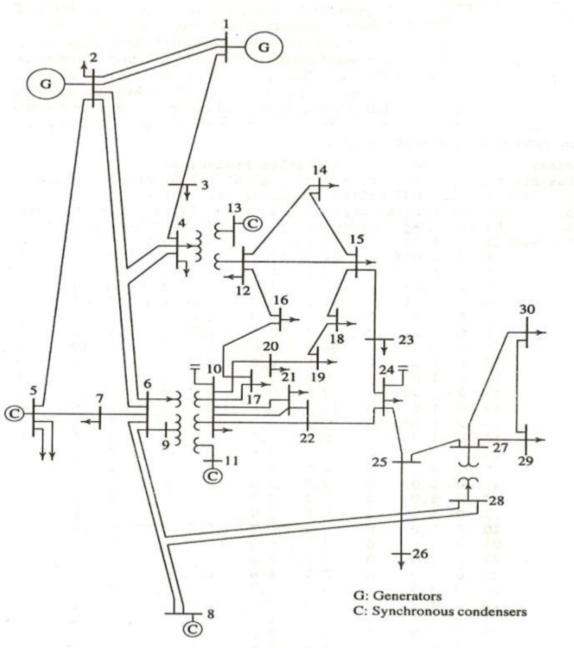

Figure 2: IEEE 30 Bus System

The optimal location and size of a TCSC unit is estimated by maximising the total social benefit function of equation (30). The minimum and maximum series capacitive compensation levels are limited to 10% to 70% of the compensated line reactance respectively. Selected parameters of GA are given in Table 1. It also shows the five cases for which the MATLAB program is run to find the optimal location of the TCSC on the transmission line in addition to maximise the social welfare. The case A is the reference or base case for the simulation and comparison analysis.

Table 1: Selected Parameters

Test System	**Simulated Cases**
IEEE 30-Bus	A- Base operation of the modified IEEE 30-Bus test system B- Line outage between buses 5 and 7 C- Increase of load by 250% at Bus 8 D- Increase of load by 250% at bus 10 and line outage between line 6 and 8 E- Increase of load by 200% at bus 3 and line outage between line 2 and 4
Selected GA Parameters	**Values**
Precision value	22
Population size	100
Cross over rate	0.85
Mutation Rate	0.05
Maximum Number of Generations	400

A. CONGESTION MANAGEMENT WITH GENERATOR RESCHEDULING

For each simulation cases N-R power flow has been run and the status of the overloaded lines are shown in Table 2. The power level is violated in case B, case C and case D by an amount of 1.459307MW, 190.6257MW and 26.35018MW respectively. Based on the generator sensitivities factors, generators G1, G2, G5, G8 and G11 for case B have been selected to reschedule their real powers. The generation for base case, change in the generation, new generation schedule has been shown in the Figure 3. It is observed that the generators reschedule their generation by increasing and decreasing their generation level within the specified limits.

Table 2: Power Flow Results for Test Cases

Case	**No. of lines conge-sted**	**Overloaded line**	**Line Limit MW**	**Amount of power violation (MW)**	**Total Power Violation (MW)**
A	0	-	-	-	-
B	1	1-2	180	1.459307	1.459307
C	5	1-2 2-4 2-6 4-6 6-8	180 65 65 90 32	58.81439 9.893181 13.26768 40.19798 68.45249	190.6257
D	2	1-2 6-28	180 32	8.323195 18.02699	26.35018

E	1	2-6	65	21.91121	21.91121

The generators 1, 2, 5, 8 and 11 are allowed to reschedule their generating real power for each case so that power limits are not violated.

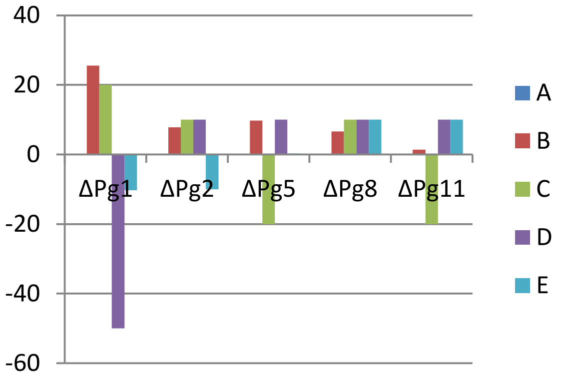

Figure 3: Change In Real Power For Tests With Generation Rescheduling.

The values of generator sensitivities computed for all cases are presented in Table 3. The generator with the most negative sensitive value is given the highest priority in the list. Consider the case A, the generator 2 is having the most negative sensitive value that is -0.187240. In case B, the generator 8 is having the highest negative value for generator sensitivity parameter. Hence, generator 2 and 8 will be given the highest priority for rescheduling their real power so that the power limits are constrained to the specified limits. In a similar way, for case C and case D, the generator 8 is having maximum negative generator sensitivity.

Table 3: Priority List of Generator Sensitivities (Cases in which power violation occurs)

S.No	Line	1	2	3	4	5	6
Gen. Bus No.		1	2	5	8	11	13
GS Case A	1-2	0	-0.18724	-0.156468	-0.026146	-0.002394	-0.00127
Case B	1-2	0	-1.087576	0.140086	-0.079648	0.000748	0.013076
	2-4	0	0.323543	-0.043736	-0.00203	-0.002679	-0.01748
	2-6	0	0.30055	-0.033539	0.141095	-0.008088	-0.06782
	4-6	0	-0.05804	0.041287	0.674894	-0.025935	-0.24021
	6-8	0	-0.113979	-0.934351	-1.173364	-0.788289	-0.53994
Case C	1-2	0	-0.186281	-0.099416	-0.051197	-0.004261	-0.00139
	6-28	0	0.005048	0.023546	-0.874921	0.003505	0.002795
Case D	2-6	0	0.058065	-0.018513	-0.091879	-0.009106	-0.00279

B. SOCIAL BENEFITS WITH TCSC PLACEMENT

The values of the sensitivity of performance index with respect to controllable parameter x of TCSC have been obtained for all cases. The values of the index for few most sensitive lines of each case are given in Table 4. Consider the case C in which the most sensitive line is 2-1 having the most negative performance index value of 185.0426. The other lines congested are having a lower value of performance index. So, the TCSC is placed on the line 2-1 to remove the congestion. For case D, the highest priority is given to line 5-7 having most negative performance index of 1.1423. The TCSC is placed on this line because of the highest performance index. It has been shown that line limits which has been violated because of congestion, has been removed after placement of TCSC in the lines preferred by sensitivity index shown by Figure 4 and Figure 5 for case C and case D respectively.

Table 4: Priority List For TCSC Placement

Case	**Line priority**	**$\delta P_i/\delta x_{ck}$**	**Case**	**Line priority**	**$\delta P_i/\delta x_{ck}$**

B	5-2 8-6 6-7 30-27	-3.7578 -0.3514 -0.1816 -0.0044	C	2-1 4-3 2-6 2-5	-185.0426 -12.8997 -6.0353 -4.9503
D	5-7 8-28 30-27 26-25	-1.1423 -0.0588 -0.0045 -0.0025	E	2-1 2-6 2-5 6-7	-60.9276 -5.4648 -4.5939 -0.7714

The line limit for line1-2 is 175MW. But due to occurrence of congestion, it violates the limits and enhances to 240MW. After the placement of TCSC on this line based on the performance index, the power limits again gets constrained to the specified level and reduces to 150MW. The congestion in other transmission lines 2-4, 2-6, 4-6 and 6-8 also gets removed due to the placement of TCSC.

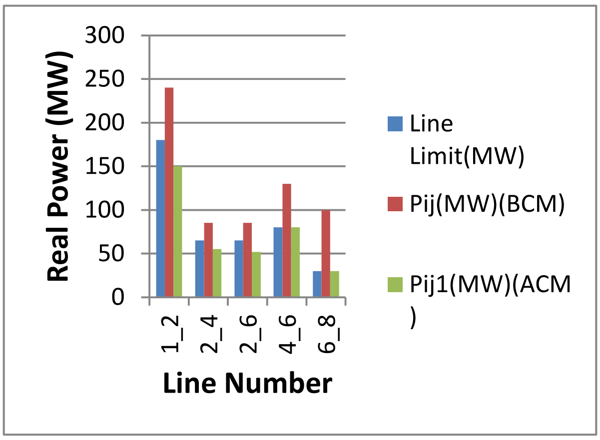

Figure 4: Power Flow For Case C With &Without Congestion

Consider case D in which the line 1-2 having the line limit 175MW gets congested as its power limit extends to 180MW. But after the congestion management due to placement of TCSC based on performance index the power level reduces to 155MW to remove the congestion in the line. The line limit of 6-28 is 40MW which increases to 50MW due to congestion in the line. After congestion management due to optimally placed TCSC, the congestion is removed and the power limits reduced to 40MW. Thus, by optimally placing the TCSC on the transmission line based on the performance index criterion the congestion is successfully removed and also the social welfare is calculated.

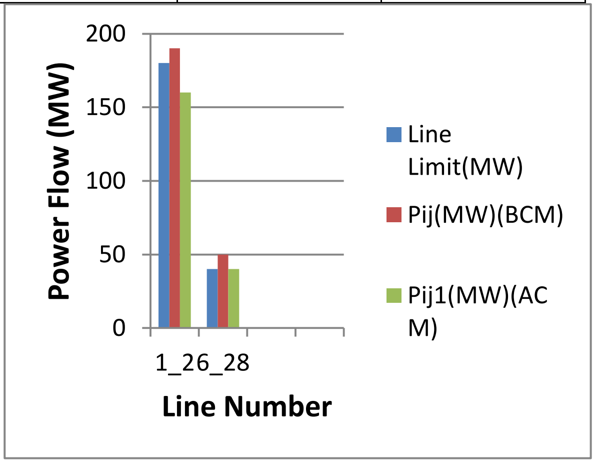

Figure 5: Power Flow for Case D With &Without Congestion

The social welfare is calculated using GA method Rescheduling and TCSC. The social benefits costs obtained for both the cases without (generation rescheduling) and with TCSC have been determined. Comparing the social benefits shown in the Figure 6, it is observed that the benefits for cases with TCSC has been found to be more as compared to the benefit costs obtained without the presence of TCSC and computed in Table 5. Consider the case B, the TCSC is placed on the line 5-2 to compensate the congestion with compensating value of 0.29971. The social welfare using TCSC optimally placed to remove the congestion on the line is calculated to be 1191.392$/hr which is 497.704$/hr more than social welfare of 693.688$/hr calculated with the rescheduling method of the generators to reschedule their real power to remove congestion from the lines. Similarly, for case C, the social welfare with optimally placed TCSC is 1176.678$/hr having the compensation value of 0.7872 is more than social welfare of 723.617$/hr with the rescheduling method to remove the congestion in the system.

Table 5: Comparison of Social Welfare

Case	TCSC Location	Compensation Value	Execution Time (s)	Social welfare	
				Using rescheduling	Using TCSC

				method (S/hr)	(S/hr)
A			12.94	693.715	779.12
B	5-2	0.0787	07.98	693.688	1191.3
C	2-1	0.0787	06.80	723.617	1176.6
D	5-7	0.0024	12.88	693.607	2891.9
E	2-1	0.0026	11.09	696.597	2478.4

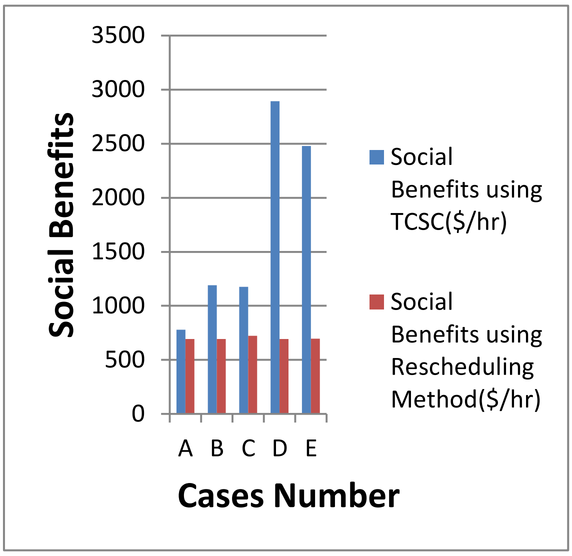

Figure 6: Comparison of Social Welfare

IV.CONCLUSIONS

An algorithm is developed for optimal choice and location of FACTS controllers for Congestion Management and Social welfare in deregulated power systems. It is presented that the system operator can identify most appropriate generators and the rescheduling is performed for congestion management based on the generator sensitivity factors. The social welfare is found to be less for generator rescheduling approach than FACTS (TCSC) method. TCSC has the ability to redistribute power flow, influence loads and generations levels at different buses, and significantly increase the social benefits. Installation of TCSC offers benefit that far exceeds its cost for the system conditions studied.

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