Swarm Intelligence based Security Constrained Congestion Management using SSSC

D M Vinod Kumar and Ch Venkaiah, Member IEEE

Department of Electrical Engineering
National Institute of Technology
Warangal – 506 004
Email: vinodkumar.dm@gmail.com

***Abstract*— The power system is said to be in a state of Congestion whenever the physical or operational constraints in a transmission network become active. In a deregulated environment, Congestion in the transmission lines can be relieved by one of the two congestion management methodologies viz. cost free and non-cost free methods. In this paper, Congestion is relieved by using Cost Free method and is reduced by employing Static Synchronous Series Compensator (SSSC). Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) techniques were used to obtain the global optimal solution as the objective function is nonlinear in Congestion Management and these techniques were tested on IEEE 30-bus system.**

Keywords- Congestion Management, Static Synchronous Series Compensator (SSSC), Optimal Power Flow, Genetic Algorithm, Particle Swarm Optimization

I. INTRODUCTION

The Independent System Operator (ISO) principal challenge in a deregulated environment is to maintain the power system security and reliability by maximizing market efficiency when the system is congested. The ISO has to create a set of transparent and robust rules that should not encourage aggressive entities to exploit congestion to create market power and maximize their profits at the cost of market.

Congestion in a transmission system can not be allowed beyond a short duration as there is an onset of cascading outages with uncontrolled loss of load. In order to relieve congestion, one can either use FACTS devices; operate taps of a transformer, re-dispatch of generation and curtailment of pool loads and/or bilateral contracts.

In a deregulated environment, all the GENCOs and DISCOs plan their transactions ahead of time. But by the time of implementation of transactions there may be congestion in some of the transmission lines. Hence, ISO has to relieve that congestion so that the system remains in secure state. To relieve the congestion, ISO can use mainly two types of techniques, which are as follows [2]-[4]:

Cost free means:

- (i) Out-aging of congested lines.
- (ii) Operation of transformer taps/phase shifters.
- (iii) Operation of FACTS devices particularly series devices.

Non-cost-free means:

- (i) Re-dispatch of generation in a manner different from the natural settling point of the market. Some generators back down while others increase their output. The effect of this is that generators no longer operate at equal incremental costs.
- (ii) Curtailment of loads and the exercise of (not-cost-free) load interruption options.

Flexible AC Transmission System (FACTS) devices are commonly used devices to relive congestion and maintain system security. They may be used to improve the transient responses of power system and also control the power flow (both active and reactive power). The main advantages of FACTS devices are enhancing system flexibility and increasing the load ability. Although FACTS devices have many advantages, they are handicapped due to the high cost of the components. Congestion Management based on DC OPF [5] and AC OPF [6] were discussed using conventional quadratic and interior point methods respectively. OPF programs based on above mathematical programming approaches are used daily to solve very large OPF problems. However, they are not guaranteed to converge to the global optimum of the general non-convex OPF problem, although some empirical evidence exists on the uniqueness of the OPF solution within the domain of interest. Congestion has been reduced in [7] using TCSC and it is observed that TCSC may cause sub-synchronous resonance.

In this paper Static Congestion Management using Conventional OPF, GA based OPF and PSO based OPF has been tested on IEEE 30-bus system and compared to find the global optimal solution. The Congestion is relieved by placing Static Synchronous Series Compensator (SSSC) in optimal location which has been arrived at by considering maximum line loading as an Objective Function.

II. PROBLEM FORMULATION

The OPF problem can be formulated as mathematical optimization problem with the objective to minimize the fuel

Authors are with the Department of Electrical Engineering, National Institute of Technology, Warangal 506 004 (A.P.) INDIA.
Email: vinodkumar.dm@gmail.com

cost of generation subject to several constraints. The Objective function of OPF [8] with equality and inequality constraints, which are self explanatory, is expressed as follows:

$$\min fp = \sum_{i \in N_g} \left(a_i + b_i P_{gi} + c_i P_{gi}^2 \right)$$

Subject to

$$0 = P_i - V_i \sum_{j \in N_i} V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right)$$

$$i \in N_B - 1$$

$$0 = Q_i - V_i \sum_{j \in N_i} V_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij} \right)$$

$$i \in N_{PQ}$$

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad i \in N_g$$

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \qquad i \in N_g$$

$$\left| S_k \right| \le S_k^{\max} \qquad k \in N_E$$

$$V_i^{\min} \le V_i \le V_i^{\max} \qquad i \in N_B$$

$P_{gs}^{\lim}$, $V_i^{\lim}$ & $Q_{gi}^{\lim}$ are defined as follows

$$P_{gs}^{\lim} = \begin{Bmatrix} P_{gs}^{\min} & if \;\; P_{gs} < P_{gs}^{\min} \\ P_{gs}^{\max} & if \;\; P_{gs} > P_{gs}^{\max} \end{Bmatrix}$$

$$V_i^{\lim} = \begin{Bmatrix} V_i^{\min} & if \;\; V_i < V_i^{\min} \\ V_i^{\max} & if \;\; V_i > V_i^{\max} \end{Bmatrix}$$

$$Q_{gi}^{\lim} = \begin{Bmatrix} Q_{gi}^{\min} & if \;\; Q_{gi} < Q_{gi}^{\min} \\ Q_{gi}^{\max} & if \;\; Q_{gi} > Q_{gi}^{\max} \end{Bmatrix}$$

The Active power generation at the slack bus P_{gs}, Load bus voltages V_L, Reactive power generation Q_g and Branch Apparent power flow S_k are taken as restricted state variables. The generalized objective function has been formed by adding the restricted state variables as quadratic penalty terms to the above objective function and is represented as follows:

$$\min f = \sum_{i \in N_g} \left(a_i + b_i P_{gi} + c_i P_{gi}^2 \right) + \lambda_{Pgs} \left(P_{gs} - P_{gs}^{\lim} \right)^2$$

$$+ \sum_{i \in N_{VPQLim}} \lambda_{vi} \left(V_i - V_i^{\lim} \right)^2 + \sum_{i \in N_{Qg\lim}} \lambda_{Qgi} \left(Q_{gi} - Q_{gi}^{\lim} \right)^2$$

$$+ \sum_{i \in N_{Sk\lim}} \lambda_{sk} \left(\left| S_k \right| - S_k^{\max} \right)^2$$

where λPgs, λ_{Vi}, λ_{Qgi}, λ_{Sk} are the penalty factors.

The above generalized objective function is a non-linear function and the gradient based conventional methods are not good enough to solve this problem. Hence, the Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) techniques have been used to solve this problem.

III. CONGESTION MANAGEMENT USING GA BASED OPF

The Genetic Algorithm is a population search method and is based on the mechanics of natural genetics and natural selection. The next generation is produced by the simulation of the natural processes of reproduction, gene crossover and mutation. The Genetic Algorithm uses the information of current population [8] to direct the next search.

In this paper the Active Power outputs of the generator (except slack bus) and voltage specified at each and every generator bus have been chosen as control variables. These Control variables are represented as series of binary bits which simulates a chromosome and random selection of chromosomes were done with in the limits of these control variables. The decoding of the variables is done using the following formula:

Continuous controls taking the values in the interval $\left[u_i^{\min}, u_i^{\max} \right]$ then

$$u_i = u_i^{\min} + \left(u_i^{\max} - u_i^{\min} \right) \cdot k / \left(2^{N_{ui}} - 1 \right)$$

Where k is the decimal number to which the binary number in a gene is decoded and N_{ui} is the gene length (number of bits) used for decoding the control variables u_i.

Fitness Function (FF) used here is

$$FF = \frac{A}{\sum_{i=1}^{N_G} F_i \left(P_{Gi} \right) + \sum_{i=1}^{N_C} w_j \cdot Pen_j}$$

FF=fitness function
A=constant
$F(P_{Gi})$=fuel cost function of unit
(in our case, a quadratic function)
w_j=weighting factor of functional operating constraint
Pen_j=penalty function for functional operating constraint

Roulette wheel technique is used for parent selection and uniform crossover is carried out for the formation of new children.

Algorithm for congestion management using GA based OPF

1) The whole system data along with data for genetic operator's like probability of elitism, cross-over, and mutation are read.
2) Population of chromosomes is initialized randomly within the control variables limits.
3) In the present population every chromosome is decoded and fitness using fitness function for the same is evaluated.
4) The chromosomes are sorted according to their fitness values in descending order and genetic operations are performed on the present set of chromosomes to get a new set of chromosomes.
5) Check for convergence. If convergence is not met go to step 3 and repeat the process. If the convergence is met display the results.

IV. CONGESTION MANAGEMENT USING PSO BASED OPF

PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. Compared to GA, the advantages of PSO are that PSO is easy to implement and there are few parameters to adjust.

Algorithm for congestion management using PSO based OPF

1) Generate the population of particles and velocities randomly.
2) For every particle compute the fitness using fitness function.
3) Find the P_{best} and G_{best} particles among the population.
4) Update the velocities and then the particles.
5) Check for convergence. If convergence is not met go to step 2 and repeat the process. If the convergence is met display the results.

V. CONGESTION MANAGEMENT USING SSSC

The voltage sourced converter based series compensation called static synchronous series compensator (SSSC) is used for shunt and series compensation as well as transmission angle control. The operating principle is based on the conventional series capacitive compensation and series capacitive compensation works by increasing the voltage across the impedance of a physical line which in turn increases the line current and transmission power. Series compensation is used as a means of reducing the line impedance which means increasing the voltage across the given physical line. In principle, the SSSC can generate and insert a series voltage, which can be regulated to change the impedance (more precisely reactance) of the transmission line. As such, the power flow of the transmission line or the voltage of the bus, when SSSC is connected in the line, can be controlled [11].

A. Equivalent circuit and power flow constraints of SSSC

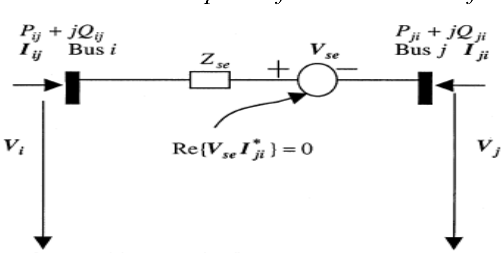

FIG 1 EQUIVALENT CIRCUIT OF SSSC

An equivalent circuit of the SSSC as shown in Fig.1 is based on the operating principle of the SSSC. In the equivalent circuit, the SSSC is represented by a voltage source V_{se} in series with a transformer's impedance. In the practical operation of the SSSC, V_{se} can be regulated to control the power flow of line i-j or voltage of bus i or j.

In the above equivalent circuit,

$$V_i = V_i\angle\theta_i ,\ V_j = V_j\angle\theta_j$$

The power flow constraints of SSSC in the equivalent circuit are as follows:

$$V_i\angle\theta_i = I_{ij}Z_{se} + V_{se}\angle\theta_{se} + V_j\angle\theta_j$$

$$\Rightarrow I_{ij} = \frac{V_i\angle\theta_i - \left(V_j\angle\theta_j + V_{se}\angle\theta_{se}\right)}{Z_{se}}$$

$$S_{ij} = V_i\angle\theta_i\left(I_{ij}^*\right)$$

$$S_{ij} = V_i\angle\theta_i\left(V_i\angle-\theta_i - \left(V_j\angle-\theta_j + V_{se}\angle-\theta_{se}\right)\right)\left(g_{ij} - jb_{ij}\right)$$

$$P_{ij} = V_i^2 g_{ii} - V_iV_j\left(g_{ij}\cos\left(\theta_i-\theta_j\right) + b_{ij}\sin\left(\theta_i-\theta_j\right)\right)$$
$$-V_iV_{se}\left(gij\cos\left(\theta_i-\theta_{se}\right) + b_{ij}\sin\left(\theta_i-\theta_{se}\right)\right)$$

$$Q_{ij} = -V_i^2 b_{ii} - V_iV_j\left(g_{ij}\sin\left(\theta_i-\theta_j\right) - b_{ij}\cos\left(\theta_i-\theta_j\right)\right)$$
$$-V_iV_{se}\left(g_{ij}\sin\left(\theta_i-\theta_{se}\right) - b_{ij}\cos\left(\theta_i-\theta_{se}\right)\right)$$

$$P_{ji} = V_j^2 g_{jj} - V_iV_j\left(g_{ij}\cos\left(\theta_j-\theta_i\right) + b_{ij}\sin\left(\theta_j-\theta_i\right)\right)$$
$$+V_jV_{se}\left(g_{ij}\cos\left(\theta_j-\theta_{se}\right) + b_{ij}\sin\left(\theta_j-\theta_{se}\right)\right)$$

$$Q_{ji} = -V_j^2 b_{jj} - V_iV_j\left(g_{ij}\sin\left(\theta_j-\theta_i\right) - b_{ij}\cos\left(\theta_j-\theta_i\right)\right)$$
$$+V_jV_{se}\left(g_{ij}\sin\left(\theta_j-\theta_{se}\right) - b_{ij}\cos\left(\theta_j-\theta_{se}\right)\right)$$

$$where \quad g_{ij} + b_{ij} = 1/Z_{se},\ g_{ii} = g_{ij},\ b_{ii} = b_{ij},\ g_{jj} = g_{ij},\ b_{jj} = b_{ij}$$

The operating constraint of SSSC (the active power exchange via the DC link) is

$$PE = \mathrm{Re}(V_{se}I_{ji}^*) = 0$$

$$\mathrm{Re}(V_{se}I_{ji}^*) = -V_iV_{se}\left(g_{ij}\cos\left(\theta_i-\theta_{se}\right) - b_{ij}\sin\left(\theta_i-\theta_{se}\right)\right)$$
$$+V_jV_{se}\left(g_{ij}\cos\left(\theta_j-\theta_{se}\right) - b_{ij}\sin\left(\theta_j-\theta_{se}\right)\right)$$

B. Voltage and Current Constraints of the SSSC

The equivalent voltage injection V_{se} bound constraints are as follows:

$$0 \le V_{se} \le V_{se}^{\max}$$
$$-\pi \le \theta_{se} \le \pi$$

where $V_{se}^{\max}$ is the voltage rating of V_{se}, which may be constant, or may change slightly with changes in the dc bus voltage, depending on the inverter design.

The current through the series converter of the SSSC should be within its current rating

$$I_{se} \le I_{se}^{\max}$$

where $I_{se}^{\max}$ is the current rating of the series converter of the SSSC while I_{se} is the practical current through the series converter. But, Here, active power flow control mode of SSSC is used in *Newton Raphson load flow Analysis*.

Initial voltage magnitude and phase angle parameters of SSSC for Newton-raphson power flow are as follows:

$$\theta_{se}^{0} = -\theta/2$$

$$V_{se}^{0} = 0.1$$

C. Implementation of active power flow model of SSSC using Newton power flow method

The Power mismatches at the respective buses after the inclusion of SSSC are as follows:

$$\Delta P_i = P_{gi} - P_{di} - P_i = 0$$
$$\Delta Q_i = Q_{gi} - Q_{di} - Q_i = 0$$
$$\Delta P_j = P_{gj} - P_{dj} - P_j = 0$$
$$\Delta Q_j = Q_{gj} - Q_{dj} - Q_j = 0$$

where P_k and Q_k are respectively, the real and reactive power bus injections at bus k (k=i,j,……….). While P_{gk} and Q_{gk} are respectively the real and reactive powers entering the bus k, and P_{dk} and Q_{dk} are respectively the real and reactive load leaving the bus k.

For the SSSC, it has only one control degree of freedom since the active power exchange with the DC link should be zero at any time. A Newton power flow [12] algorithm with simultaneous solution of power flow constraints and power flow control constraints of the SSSC is as represented below:

$$\begin{bmatrix} \frac{\partial F}{\partial \theta_{se}} & \frac{\partial F}{\partial V_{se}} & . & \frac{\partial F}{\partial \theta_i} & \frac{\partial F}{\partial V_i} & \frac{\partial F}{\partial \theta_j} & \frac{\partial F}{\partial V_j} \\ \frac{\partial PE}{\partial \theta_{se}} & \frac{\partial PE}{\partial V_{se}} & . & \frac{\partial PE}{\partial \theta_i} & \frac{\partial PE}{\partial V_i} & \frac{\partial PE}{\partial \theta_j} & \frac{\partial PE}{\partial V_j} \\ .... & .... & .... & .... & .... & .... & .... \\ \frac{\partial P_i}{\partial \theta_{se}} & \frac{\partial P_i}{\partial V_{se}} & . & \frac{\partial P_i}{\partial \theta_i} & \frac{\partial P_i}{\partial V_i} & \frac{\partial P_i}{\partial \theta_j} & \frac{\partial P_i}{\partial V_j} \\ \frac{\partial Q_i}{\partial \theta_{se}} & \frac{\partial Q_i}{\partial V_{se}} & . & \frac{\partial Q_i}{\partial \theta_i} & \frac{\partial Q_i}{\partial V_i} & \frac{\partial Q_i}{\partial \theta_j} & \frac{\partial Q_i}{\partial V_j} \\ \frac{\partial P_j}{\partial \theta_{se}} & \frac{\partial P_j}{\partial V_{se}} & . & \frac{\partial P_j}{\partial \theta_i} & \frac{\partial P_j}{\partial V_i} & \frac{\partial P_j}{\partial \theta_j} & \frac{\partial P_j}{\partial V_j} \\ \frac{\partial Q_j}{\partial \theta_{se}} & \frac{\partial Q_j}{\partial V_{se}} & . & \frac{\partial Q_j}{\partial \theta_i} & \frac{\partial Q_j}{\partial V_i} & \frac{\partial Q_j}{\partial \theta_j} & \frac{\partial Q_j}{\partial V_j} \end{bmatrix} \begin{bmatrix} \Delta\theta_{se} \\ \Delta V_{se} \\ .... \\ \Delta\theta_i \\ \Delta V_i \\ \Delta\theta_j \\ \Delta V_j \end{bmatrix} = \begin{bmatrix} \Delta F \\ \Delta PE \\ .... \\ \Delta P_i \\ \Delta Q_i \\ \Delta P_j \\ \Delta Q_j \end{bmatrix}$$

In the above matrix, the system Jacobian matrix is split into four blocks by the dotted line, the bottom diagonal block has the same structure as that of the system Jacobian matrix of conventional power flow though the terms of former should consider the contributions from the SSSC. The other three blocks of the system Jacobian matrix are SSSC related.

D. Optimal Placement of SSSC

The SSSC has to be placed in an optimal location by considering Line loads as its installation cost is high to relieve the congestion. The objective is to reduce the real power flow Performance Index (PI) as given below [14].

$$PI = \sum_{m=1}^{N_l} \frac{w_m}{2n}\left(\frac{P_{lm}}{P_{lm}^{\max}}\right)^{2n}$$

Where P_{lm} is the real power flow; $P_{lm}^{\max}$ is the rated capacity of the line-m; n is the exponent = 2; w_m is a real non negative weighing factor =1

PI will be small when all the lines are with-in their limits and reach a high value when there are overloads for a given state of the power system. In a congested system, the optimal location of SSSC can be effectively decided based on this reduction of real power flow PI.

The objective function in this case changes with the inclusion of performance index PI

$$\min f = \sum_{i\in N_g}\left(a_i + b_i P_{gi} + c_i P_{gi}^2\right) + \lambda_{Pgs}\left(P_{gs} - P_{gs}^{\lim}\right)^2$$
$$+ PI + \sum_{i\in N_{VPQLim}} \lambda_{vi}\left(V_i - V_i^{\lim}\right)^2$$
$$+ \sum_{i\in N_{Qg\lim}} \lambda_{Qgi}\left(Q_{gi} - Q_{gi}^{\lim}\right)^2 + \sum_{i\in N_{Sk\lim}} \lambda_{sk}\left(\left|S_k\right| - S_k^{\max}\right)^2$$

E. Algorithm for Congestion Management using SSSC with GA based OPF

1) The whole system data along with data for genetic operator's data like probability of elitism, cross-over, and mutation are read.
2) Population of chromosomes is initialized randomly within the control variables limits.
3) In the present population every chromosome is decoded, change occurred due to inclusion of SSSC are brought in and fitness using changed objective function for the same is evaluated.
4) The chromosomes are sorted according to their fitness values in descending order and genetic operations are done on the present set of chromosomes to get a new set of chromosomes.
5) Check for convergence. If convergence is not met go to step 3 and repeat the process. If convergence is met display the results

F. Algorithm for Congestion Management using SSSC with PSO based OPF

1) Generate the population of particles and velocities randomly.
2) For every particle count, include the changes occurred due to inclusion of SSSC and fitness using changed objective function for the same is evaluated.
3) Find the P_{best} and G_{best} particles among the population.
4) Update the velocities and then the particles
5) Check for convergence. If convergence is not met go to step 2 and repeat the process. If the convergence is met display the results.

VI. SIMULATION AND RESULTS

The study has been conducted on IEEE 30-bus system. The GA parameters are taken as P_e=0.15, P_c=0.95, P_m=0.001.The PSO parameters are taken as w=1.2, c1=2, c2=2. All the conventional OPF results are tested on MATPOWER software.

CASE 1: Here the base case OPF is run using GA and PSO for optimization of the fitness function. For GA the gene lengths are taken as 12 bits and 10 bits for active power outputs of generators and specified voltages respectively.

TABLE – I
ACTIVE POWER OUTPUTS AND FUEL COST UNDER BASE CASE (USING GA)

Generator bus number	active power outputs(MW)	Fuel cost ($/hr)
1	167.63	440.6343
2	41.055	101.3427
5	23.3675	57.49
8	24.8352	85.8544
11	11.4652	37.6819
13	19.3368	67.3582

TABLE – II
ACTIVE POWER OUTPUTS AND FUEL COST UNDER BASE CASE (USING PSO)

Generator bus number	active power outputs(MW)	Fuel cost ($/hr)
1	167.468	440.1067
2	47.5094	122.6415
5	22.2261	53.1011
8	22.8427	78.5905
11	15.076	50.9101
13	12.00	39.6

The Tables I & II gives the active power outputs of the generators and their respective fuel costs under base case using GA and PSO respectively. Table-III gives the comparison between Conventional OPF, GA based OPF and PSO based OPF. It can be inferred from Table-III that the PSO based OPF generation cost is reduced to the lowest cost of 784.949 $/hr compared to GA based OPF generation cost of 790.375 $/hr & conventional OPF cost of 801.49 $/hr.

TABLE – III
COMPARISON BETWEEN CONVENTIONAL OPF, GA OPF AND PSO OPF FOR BASE CASE

Active power output of Generators	Conventional OPF	GA OPF	PSO OPF
P1(MW)	161.33	167.63	167.468
P2(MW)	45.39	41.055	47.5094
P5(MW)	20.55	23.3675	22.2261
P8(MW)	35.00	24.8352	22.8427
P11(MW)	10.00	11.4652	15.076
P13(MW)	20.00	19.3368	12.00
Generation cost ($/hr)	801.49	790.375	784.949

CASE 2: The OPF was utilized by increasing the load by 15%. This was done intentionally to introduce congestion. It was found that line 1 got over loaded to 130.12 MW as against 130 MW. Table IV shows the comparison of Conventional OPF, GA OPF & PSO OPF for congested case.

TABLE – IV
COMPARISON BETWEEN CONVENTIONAL OPF, GA OPF AND PSO OPF FOR CONGESTED CASE

Active power output of Generators	Conventional OPF	GA OPF	PSO OPF
P1(MW)	191.54	194.482	190.274
P2(MW)	53.50	51.2234	52.5433
P5(MW)	23.32	22.4274	24.0779
P8(MW)	35.00	32.6252	31.3051
P11(MW)	15.85	15.2843	14.6912
P13(MW)	20.00	16.3897	18.5834
cost ($/hr)	961.78	942.713	940.66

CASE 3: The SSSC is included in the network and the above programs are re-run. It was found that SSSC not only reduced the total cost of generation but also relieved the congestion in the system.

TABLE – V
COMPARISON BETWEEN THE RESULTS OF OPF USING GA WITH AND WITHOUT SSSC

Active power output of Generators	GA OPF without SSSC	GA OPF with SSSC
P1(MW)	194.482	184.01
P2(MW)	51.2234	52.61
P5(MW)	22.4274	24.12
P8(MW)	32.6252	33.53
P11(MW)	15.2843	15.56
P13(MW)	16.3897	13.73
Generation cost ($/hr)	942.713	913.101

The Table-V results shows that the Optimal operating cost of generator employing GA OPF with SSSC (913.101 $/hr) is less than without SSSC (942.713 $/hr) in the transmission line.

TABLE – VI
COMPARISON BETWEEN THE RESULTS OF OPF USING PSO WITH AND WITHOUT SSSC

Active power output of Generators	PSO OPF with out SSSC	PSO OPF with SSSC
P1(MW)	190.274	191.01
P2(MW)	52.5433	57.21
P5(MW)	24.0779	19.17
P8(MW)	31.3051	25.67
P11(MW)	14.6912	17.9
P13(MW)	18.5834	13.08
cost ($/hr)	940.66	912.5

The Table-VI results shows that the optimal operating cost of generator employing PSO OPF with SSSC (912.5 $/hr) is less than without SSSC (940.66 $/hr) in the transmission line.

TABLE – VII
COMPARISON BETWEEN GA AND PSO BASED OPF WITH SSSC

Active power output of Generators	GA OPF	PSO OPF
P1(MW)	184.01	191.01
P2(MW)	52.61	57.21
P5(MW)	24.12	19.17
P8(MW)	33.53	25.67
P11(MW)	15.56	17.9
P13(MW)	13.73	13.08
cost ($/hr)	913.101	912.5

A comparison between PSO OPF and GA OPF with SSSC (Table-VII) revealed that PSO OPF gives a better operating point when compared to GA OPF.

TABLE-VIII
COMPARISON OF POWER FLOWS IN LINE 1-2 WITH & WITHOUT SSSC

TYPE OF OPF	FROM BUS – TO BUS	ACTIVE POWER FLOW WITHOUT SSSC (MW)	ACTIVE POWER FLOW WITH SSSC(MW)
GA	1 – 2	130.12	125.008
PSO	1 - 2	131.46	124.12

It is found (Table-VIII & Table-IX) that the power flow in the congested line (1-2) is reduced to 125.008 MW from 130.12 MW after placing SSSC in line-2 using GA OPF and is reduced to 124.12 MW from 131.46 MW after placing SSSC in line-5 using PSO OPF.

TABLE-IX
PARAMETERS OF SSSC

TYPE OF OPF	OPTIMAL LOCATION (From Bus -To Bus)	V_{se}	θ_{se}(degrees)	P_{line}(MW)
GA	2 (1-3)	0.0872	94.91	13.8
PSO	5 (2-5)	0.029	91.257	6.85

The optimal location of SSSC (Table-IX) was found to be in line-2 with a power flow of 13.8 MW through it using GA OPF and in line-5 with a power flow of 6.85 MW through it using PSO OPF.

VII. CONCLUSION

In this paper, Static Congestion Management using Conventional OPF, GA based OPF and PSO based OPF has been done to find the global optimal solution. The Congestion has been created in the lines by loading them and it is relieved by placing SSSC in an optimal location in IEEE 30-bus power system.

The optimal cost of generation obtained using GA OPF is less than the optimal cost of generation using Conventional OPF in both uncongested (790.375 $/hr with GA OPF V/s 801.49 $/hr with Conventional OPF) and congested cases (942.713 $/hr with GA OPF V/s 961.78 $/hr with Conventional OPF)

The optimal cost of generation obtained using PSO OPF is less than the optimal cost of generation using GA OPF in both uncongested (784.949 $/hr with PSO OPF V/s 790.375 $/hr with GA OPF) and congested cases (940.66 $/hr with PSO OPF V/s 942.713 $/hr with GA OPF).

The SSSC placed in an optimal location in the transmission line has relieved the congestion and the optimal operating cost for the congested case using SSSC is less than the operating cost with out SSSC for both GA OPF and PSO OPF techniques. The PSO OPF is giving better results than GA OPF when SSSC is included in the transmission line to relieve congestion. Hence, PSO OPF with SSSC can be used for real time applications.

VIII. REFERENCES

[1] R. S. Fang and A. K. David, "Optimal Dispatch under transmission contracts", IEEE Transactions on Power Systems, Vol. 14, No.2, pp.732-737, May 1999.

[2] A.K.David, "Dispatch methodologies for open access transmission systems," IEEE Transactions on Power Systems, Vol. 13, No. 1, pp 46-53, Feb. 1998.

[3] R. S. Fang and A. K. David, "Transmission congestion management in electricity market," IEEE Transactions on Power Systems, Vol. 14, No. 3, pp.877-883, August 1999.

[4] Harry Singh, Shan You, and Alex Papalexopalos, "Transmission congestion management in competitive electricity market," IEEE Transactions on Power Systems, Vol. 13, No. 2, pp.672-680, May 1998.

[5] P. W. Sauer, K. D. Demaree, and M. A. Pai, "Stability limited load supply and interchange capability," *IEEE Trans. Power Apparat. Syst.*, vol. PAS-102, pp. 3637–3643, Nov. 1983.

[6] V.Vittal, E. Z. Zhou, C.Hwang, and A. A. Fouad, "Derivation of stability limits using analytical sensitivity of the transient energy margin," *IEEE Trans. Power Syst.*, vol. 4, pp. 1363–1372, Nov. 1989.

[7] J. Sterling, M. A. Pai, and P.W. Sauer, "A method of secure and optimal operation of a power system for dynamic contingencies," *Electric Machine and Power Systems*, vol. 19, pp. 639–655, 1991.

[8] L. L. Lai, J. T. Ma, R. Yokoyama, and M. Zhao, "Improved genetic algorithms for optimal power flow under both normal and contingent operation states," *Elec. Power Energy Syst.*, Vol. 19, no. 5, pp. 287–292, 1997.

[9] Cui-Ru Wang, He-Jin Yuan, Zhi-Qiang Huang, Jiang-Wei Zhang, Chen-Jun Sun, "A Modified Particle Swarm Optimization Algorithm And Its Application In Optimal Power Flow Problem", Proceedings of the Fourth International Conference on Machine Learning and Cybernetics, Guangzhou, 18-21 August 2005

[10] E. Handschin and C. Lehmkoester, "Optimal power flow for deregulated systems with facts-devices," in *Proc. 13th Power Syst. Comput. Conf.*, Trondheim, Norway, pp. 1270–1276, June 28–July 2, 1999.

[11] Kalyan K. Sen, "SSSC - Static Synchronous Series Compensator: Theory, Modeling, and Applications", *IEEE Transactions on Power Delivery,* Vol. 13, No.1, pp 241-246, January 1998.

[12] Xing –Ping Zhang, "Advanced Modeling of the Multicontrol Functional Static Synchronous Series Compensator (SSSC) in Newton Power Flow", *IEEE Transactions on Power Systems*, Vol. 18, No. 4, Nov 2003.

[13] Muwaffaq I. Alomoush, "Static Synchronous Series Compensator to Help Energy Markets Resolve Congestion-Caused Problems", IEEE, pp 25-29, 2004.

[14] S.N. Singh and A.K. David, "Congestion Management by Optimizing FACTS Device Location" IEEE,pp-23-28, April, 2000.