OPTIMAL ALLOCATION OF FACTS DEVICES WITH MULTIPLE OBJECTIVES USING SIMPLE GENETIC ALGORITHM AND PARTICLE SWARM OPTIMIZATION METHOD

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ABSTRACT
This Paper deals with optimal location of FACTS devices in a power system network to achieve Optimal Power Flow solution. The location of Facts devices and the setting of their control parameters are optimized by Particle swarm optimization and Simple Genetic algorithm to improve the performance of the power network. Facts devices are designed, modelled and incorporated in the Optimal Power Flow solution problem. The objective of the work is to seek the optimal location of TCSC device in a power system. The optimizations are performed on three parameters: the location of the devices, the type of the device used and their values. The system loadability and total generation fuel cost are applied as a measure of power system performance. Test cases are carried out on IEEE 30 bus power system. Results show that the proposed methods are capable of finding the suitable location for Facts controllers' installation, which suits the both objectives.

Keywords: *Optimal power flow (OPF), Newton Raphson Load Flow(NRLF), Particle swarm optimization(PSO) and Simple Genetic algorithm(SGA) ,Thyristor controlled series compensator (TCSC).*

I. INTRODUCTION

Modern power systems are facing new challenges due to deregulation and restructuring of electricity markets. The competition among utilities causes an increase of the unplanned power exchanges.

The basic idea about the FACTS devices have been well reported in Hingorani et.al [4].FACTS devices are expensive hence they need to be installed optimally. Many works related to this aspect have been presented in literature.Evolutionary Algorithms (EAs) mimic natural evolutionary principles to constitute search and optimization procedures. EAs are different from classical optimization algorithms in variety of ways.

Stephane Gerbex et al. presented Genetic Algorithm to seek the optimal location of multi-type FACTS devices in power systems. In this, location, type and rated values of FACTS devices are optimized simultaneously. Locations of FACTS devices in power system are obtained on the basis of static and dynamic performance. Seyed Abbas Taher et al. [5] presented a method to determine the optimal location of TCSC. The approach is based on the sensitivity of the reduction of total system reactive power loss and real power performance index.

A genetic algorithm based optimal power flow is proposed to determine the type of FACTS controllers, its optimal location and rating of the devices in power systems. The optimizations are performed on two parameters: the location of the devices and their values[12]. The value of TCSC and line losses is applied as measure of power system performance. Among the many types of FACTS controllers that are used and modelled for steady-state studies. TCSC, minimizes total generation fuel cost and maximize system loadability within systemsecurity margin. In order to test the effectiveness

of another evolutionary algorithm PSO is presented with detailed optimization process, algorithm. It is also found that optimal location and optimal value of TCSC.
In this paper, GA and PSO are applied to solve the optimization problem. It is found that the optimal location of FACTS devices and the setting of their control parameters .By applying GA and PSO to minimize total generation fuel cost and maximize system loadability within systemsecurity margin.
The rest of this paper is organized as follows: Section II describes the optimal power flow. Section III, introduces load flow models of facts controllers. Section IV and V Introduces the modern heuristic techniques used in this paper and explain how solution techniques have been applied in the proposed problem. As the the effectiveness of the proposed method, section VI is devoted to present the numerical study results

II. OPTIMAL POWER FLOW

Optimal Power Flow (OPF) refers to the generator dispatch and resulting in AC power flows at minimum and feasible cost with respect to thermal limits on the AC transmission lines. The OPF might include other constraints such as interface limits and other decisions such as the optimal flow on DC lines and phase shifter angles [11]. The OPF has been usually considered as the minimization of the objective function representing the generation cost and/or transmission loss.
Optimal Power Flow (OPF) has been widely used in power system operation and planning. Therefore, the objective of OPF is not only to minimize the total generation cost but also to enhance transmission security, to reduce transmission loss and to improve the bus voltage profile under normal & contingent states while satisfying a set of non-linear, equality, inequality & security constraints[6].
The primary goal of a generic OPF is to minimize the costs of meeting the load demand for a Power System while maintaining the security of the system[2]. It should be noted that the OPF only addresses steady-state operation of the power system.

2.1. Problem formulation

OPF problem is a static nonlinear constrained optimization problem, the solution of which determines the optimal setting for control variables in a power network.. The OPF problem can be formulated as a multi-objective optimization problem as follows:

$$F(x)= [f_1(x),\ldots\ldots, f_i(x),\ldots\ldots.. f_n(x)] \tag{1}$$

$$g_j(x)\leq 0 \qquad j=1,2,\ldots\ldots.M, \tag{2}$$

$$h_k(x)=0 \qquad k= 1,2,\ldots\ldots.K, \tag{3}$$

Where x is a decision vector that represents a solution and f_i is the, ith objective function. N, M and K denotes the number of objective functions, inequality constraints and equality Constrains, respectively.

2.2. Objective functions

Multi-objective optimization problem has two different objective functions to be optimized simultaneously, which can be denoted as:

$$F(x, u)= [f_1(x, u), f_2(x, u)] \tag{4}$$

The first objective is to minimize the total generation fuel cost ($ /h), which is represented as:

$$f_1(x,u) = \sum_{i=1}^{N_G} Fl_i = \sum_{i=1}^{N_G}\left(a_i + b_i P_{G_i} + c_i {P_{G_i}}^2\right) \tag{5}$$

Where a_i ,b_i and c_i are the fuel cost coefficients, P_{Gi} is the active power output generated by the ith generator, N_G is the total number of generators in the power network and Fl_i is the fuel cost for each generator.The second objective is to enhance the system loadability within security margin. which is expressed as:

$$f_2(x,u) = \lambda_1 \times \sum_{i=1}^{N_L} Vl_i + \sum_{j=1}^{N_E}\left(Bol_j + c\right) \tag{6}$$

Where Vl_i and Bol_j represent voltage levels and branch loading respectively, N_L and N_E are the total number of load buses and transmission lines respectively, c is a positive constant and $\lambda_1$is a load parameter of the system, which aims to find the maximum amount of power that the network is able to supply within system security margin. The load parameter $\lambda_1$in equation(6) is defined as a function of a load factor λ_f

$$\lambda_1= \exp[\gamma \left| \lambda_f - \lambda_f^{max} \right|] \qquad \lambda_f € [1, \lambda_f^{max}] \tag{7}$$

Where γ is the coefficient to adjust the slope of the function and λ_f^{max} is the maximal limit of λ_f. The maximal limit of the load factor λ_f^{max} is set at 1.5, which reflects a 50% increment of power demands The load factor λ_f effects the variation of power demands $P_{Di}$and Q_{Di} which is defined as:

$P_{Di}(\lambda_f) = \lambda_f P_{Di}$

$Q_{Di}(\lambda_f) = \lambda_f Q_{Di}$

Where i=1…….N_D and $N_D$is the total number of power demand buses.

λ_f =1 indicates the base load case. The index of system security state contains two parts. The first part Vl_i in (6) concerns the voltage levels for each bus of the power network. The value of Vl_i is defined as:

$$Vl_i = 0 \qquad V_L€[V^{min}_{Li}, V^{max}_{Li}] \tag{8}$$

$$Vl_i = \exp[\lambda_r \,|\, 1 - V_{Li} \,|\, -0.05] - 1 \qquad V_L€[V^{min}_{Li}, V^{max}_{Li}] \tag{9}$$

Where V_{Li} is the voltage magnitude at bus i and λ_r represents the coefficient used to adjust the slope of the exponential function in the above equation and the value is 0.5

$$Bol_j = 0 \qquad ;\text{for } S_j \leq S_j^{max} \tag{10}$$

$$Bol_j = \exp[(S_j^{max} - S_j/\lambda_q)] - 1 \quad ;\text{for } S_j > S_j^{max} \tag{11}$$

Where S_j and S_j^{max} are the apparent power in line j and the apparent power rating of line j respectively. λq is the coefficient which is used to adjust the slope of the exponential function and the value is 0.4 .

2.3.1.Equality Constraints

The equality constraints g(x,u) and the nonlinear power flow equations which are formulated as follows:

$$P_{Gi} = P_{Di} + V_i \sum_{j=1}^{Ni} V_j (G_{ij}\cos\partial_{ij} + B_{ij}\sin\partial_{ij}) \tag{12}$$

$$Q_{Gi} = Q_{Di} + V_i \sum_{j=1}^{Ni} V_j (G_{ij}\sin\partial_{ij} + B_{ij}\cos\partial_{ij}) \tag{13}$$

Where N_i is the number of buses adjacent to bus i including bus i.

2.3.2. Inequality Constraints

Generators have maximum and minimum output powers and reactive powers which add inequality constraints.

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max} \qquad ;i=1\ ,\ldots\ldots\ NG \tag{14}$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max} \qquad ;i=1\ ,\ldots\ldots\ NG \tag{15}$$

Both of these create inequality constraints.

$$T_i^{min} \leq T_i \leq T_i^{max} \qquad ;i=1,\ldots\ldots Ntap \tag{16}$$

$$Y_{shi}^{min} \leq Y_{shi} \leq Y_{shi}^{max} \quad ;i=1,\ldots\ldots Nsh \tag{17}$$

Regardless, these MVA ratings will result in another inequality constraint.

$$S_{Li} \leq S_{Li}^{max} \quad ;i=1,\ldots\ldots N_E \tag{18}$$

Where $N_E$is the total number of transmission lines.

$$V_i^{min} \leq V_i \leq V_i^{max} \quad ;\ i=1,\ldots\ldots N_L \tag{19}$$

Where $N_L$is the total number of load buses.

III. LOAD FLOW MODELS OF FACTS CONTROLLERS

3.1. Load Flow Model of Thyristor Controlled Series Compensator (TCSC)

Thyristor-controlled series compensator (TCSC) is defined as a capacitive reactance compensator, which consists of a series capacitor bank shunted by a Thyristor controlled reactor to provide a smoothly variable series capacitive reactance. In the steady state power flow study[3], the TCSC can be considered as a static capacitor or reactor offering a reactance with a series compensated transmission line represented by lumped π-equivalent parameters connected. In most cases, the shunt susceptances of a line usually are neglected therefore the TCSC's static capacitor will be directly in series with the line impedance.

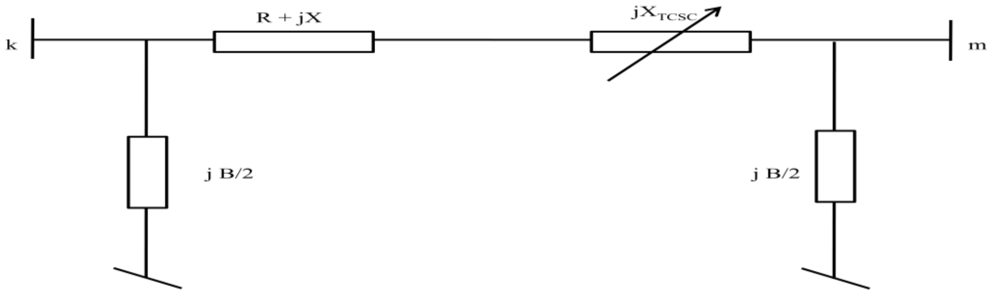

Figure1: TCSC modelled as series connected reactance

According to Figure.1 the TCSC is incorporated into the transmission line model by simply adding the variable reactance X_{TCSC} to the line reactance X.

$X_{Total} = X + X_{TCSC}$

Thyristor Controlled Series Capacitor (TCSC) is an important FACTS component which makes it possible to vary the apparent impedance of a specific transmission line [12].

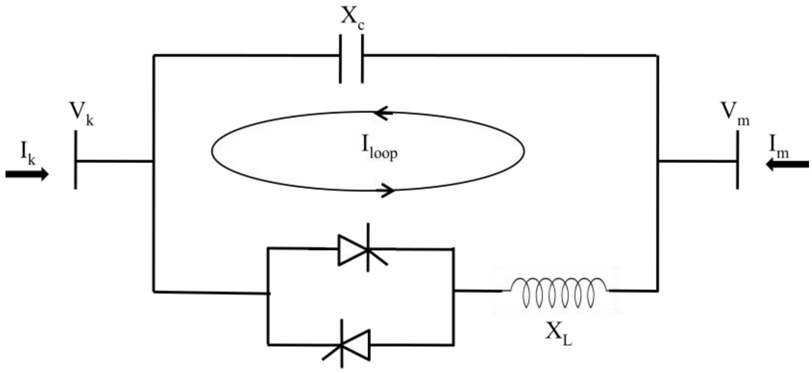

Figure2: TCSC module

The effect of TCSC on the network can be seen as a controllable reactance inserted in the related transmission line [13]. The model of the network with (TCSC) is shown in Figure.2. and the equivalent circuit of TCSC module is shown in Figure.3.

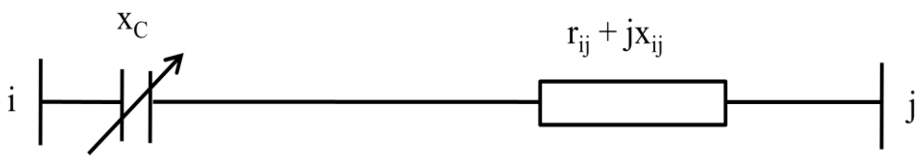

Figure3. Equivalent circuit of TCSC

The rating of TCSC is depending on the reactance of the transmission line where the TCSC is located, which is given by

$X_{ij} = X_{line} + X_{tcsc}$

$X_{tcsc} = r_{tcsc}\, x_{tcsc}$

Where x_{line} is the reactance of the transmission line.

r_{tcsc} is the coefficient which represents the degree of compensation by TCSC. To avoid over compensation, the working range of the TCSC is chosen between ($-0.5x_{line}$ and $0.5x_{line}$).

IV. OPTIMIZATION ALGORITHMS

4.1. Algorithm to Determine Optimal Location Of FACTS Controllers using Simple Genetic Algorithm Considering Objectives of Optimization Approach

1. Read input data

2. Form Y-Bus using sparsity technique
3. Initialize random population and set generation count gen=1
4. If gen>genmax go to step 14, else go to step 5
5. Initialize chromosome count ii=1.
6. If chromosome count ii<psize, go to step 7, else increment generation count (gen=gen+1) and go to step 4
7. Decode the chromosome and determine the actual control variables
8. Modify the Y-Bus depending on the control variables and run NR load flow
9. Compute the fuel cost and check all the constraints such as bus voltage limits, line power transfer limit, generator reactive power limit, slack generator active power limit. If the NR loadflow did not converge, assign a very high value as fuel cost
10. Determine the violated constraints and compute the associated penalty cost
11. Calculate the fitness of the chromosome
    Fit(ii) = K/(fuel cost+ penalty cost)
12. Arrange the chromosomes and their fitness values in descending order of fitness. Check for convergence. If converged goto step 14, else goto step 13
13. Apply GA operators and generate new population. Increment chromosome count (ii=ii+1), go to step 6
14. Maximum number of generations over. Print results.

V. PARTICLE SWARM OPTIMIZATION (PSO)

5.1. Position and Velocity Updation

$$V_i^{k+1}= V_i^k + C_1 \times rand1 \times (p_{besti} - S_i^k) + C_2 \times rand2 \times (g_{besti} - S_i^k) \quad (20)$$

$$S_i^{k+1}=S_i^k + V_i^{k+1} \quad (21)$$

Where

V_i^{k+1}=Velocity of particle i at iteration k+1

V_i^k = Velocity of particle i at iteration k

S_i^{k+1}=position of particle i at iteration k+1

S_i^k = position of particle i at iteration k

C_1=Constant weighing factor related to *pbest*

C_2= Constant weighing factor related to *gbest*

rand1, rand2 : Random numbers between 0 and 1

p_{besti} = *pbest* Position of particle i

g_{besti}: *gbest* Position of the swarm

Expressions (20) and (21) describe the velocity and position update, respectively. Expression (20) calculates a new velocity for each particle based on the particle's previous velocity, the particle's location at which the best fitness has been achieved so far, and the population global location at which the best fitness has been achieved so far.

5.2. Algorithm to Determine Optimal Location Of FACTS Controllers using Particle Swarm Optimization Considering Objectives of Optimization Approach

1. a) Read the data related to PSO (particle size, C1 & C2) .
   b) Number of generators, generator voltage magnitudes, cost coefficients, maximum and minimum power output of generators, Voltage limits of buses, line flow limit, and itermax.
   c) Data required for load flow solution. (n, Nl, nslack, max iterations, epsilon, line data, bus data, shunts)
2. Form Ybus using sparsity technique.
3. Randomly generate the current population members containing location and rated values of TCSC controllers
4. Modify the elements of Ybus depending on positions and rated values of TCSC.
5. Generate particles randomly within their variable bounds as explained in particle.
6. Run NR load flow.
7. From converged load flow solution compute slack bus power, line losses, bus voltage magnitudes,

phase angles.

8. Check for limits on load bus voltage magnitudes, generator reactive power limits, slack bus power limit, and line flow limit.

9. Determine the violated constraints and compute the associated penalty cost.

10. Compute the objective function of minimization of generation fuel cost and maximization of system loadability.

11. Compare each particles objective function value with its Pbest .The best evaluation value among the Pbest is denoted as gbest.

12. Modify the velocity of each particle according to equation (20).

If V > Vmax then V=Vmax

If V < (-Vmax) then V=-Vmax

13. Modify the position of each particle according to the equation (21). If a particle violates its position limits in any dimension, set its position to the proper limit

14. Each particle is evaluated according to its updated position .If the evaluation value of each particle is better than the previous pbest, the current value is set to be pbest. If the best pbest is better than gbest, the value is set to gbest.

15. If stopping criterion (maximum number of generations) is satisfied, then go to 17

16. Otherwise go to 10.

17. The particle that generates the largest gbest is the optimal value.

18. Calculate individual generation of generators & Corresponding fuel costs. Print the Total Fuel Cost, Voltage Profile. Then, STOP the procedure.

VI. RESULTS &DISCUSSION

These algorithms are implemented using MATLAB and are tested for their robustness on a standard IEEE 30 bus system. The IEEE 30 bus network consists of 6 Generator buses, 21 load buses & 41 lines, of which 4 lines are due to tap setting transformers. The total load on the network is 283.4 MW. The number of variables considered are 24.They are Five generator active power outputs, six generator-bus voltage magnitudes, four transformer tap-settings & nine shunt susceptances.

6.1. Minimization of Total Generation Fuel Cost

6.1.1. Comparison of Results

1. Simple Genetic Algorithm

Type of device: TCSC

Location of device: 16

Randomised value(RV) : -0.093750

Figure4shows convergence characteristics of fuel cost using simple genetic algorithm for opf with TCSC.It is observed from the waveforms that fuel cost obtained when TCSC is considered as decision variable is better than that obtained without TCSC . The total generation fuel cost obtained without TCSC is 802.862028 ($/hr) .The fuel cost obtained with TCSC placed at location 16th with its value as -0.093750 is 802.253820 ($/hr).

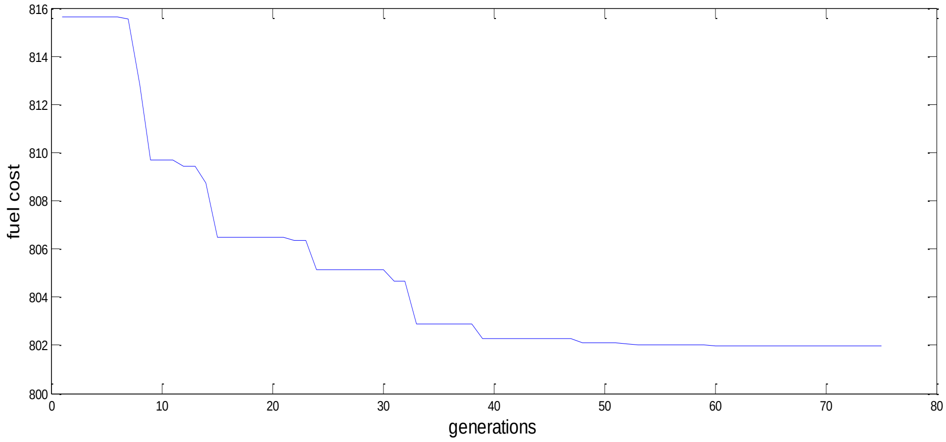

Figure 4 Convergence characteristics of fuel cost using simple GA for OPF with TCSC

2. Particle Swarm Optimization

Type of device :TCSC

Location of device :18Randomised value(RV) : 0.068750

Figure 5 shows convergence characteristics of fuel cost using particle swarm optimization for opf with TCSC. The fuel cost obtained without TCSC is 802.010 ($/hr) .The fuel cost obtained with TCSC placed at location 18th with its value 0.068750 as is 801.160 ($/hr).

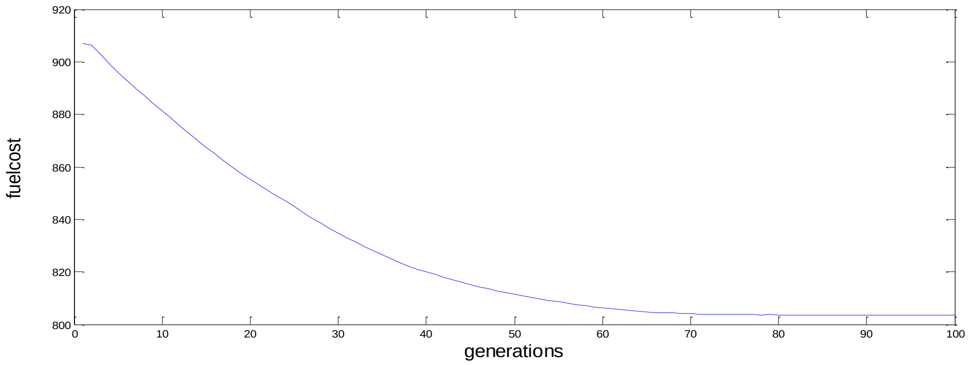

Figure 5 Convergence characteristics of fuel cost using PSO for OPF with TCSC

6.2. Maximization of System Loadability

6.2.1. Maximization of System Loadability in System Security Margin

1 .Simple Genetic Algorithm

Type of device :TCSC

Location of device :9

Randomised value(RV) :- 0.281250.Figure 6 shows convergence characteristics of fuel cost using SGA for opf with TCSC.The problem is handled as single objective optimization problem by considering fuel cost and system loadability are as different objectives and are optimized using GA with& without TCSC. The maximal limit of the load factor is set at 1.5, which reflects a 50% increment of power demands. The variation of the load factor is allowed in the bound of [1, 1.5].

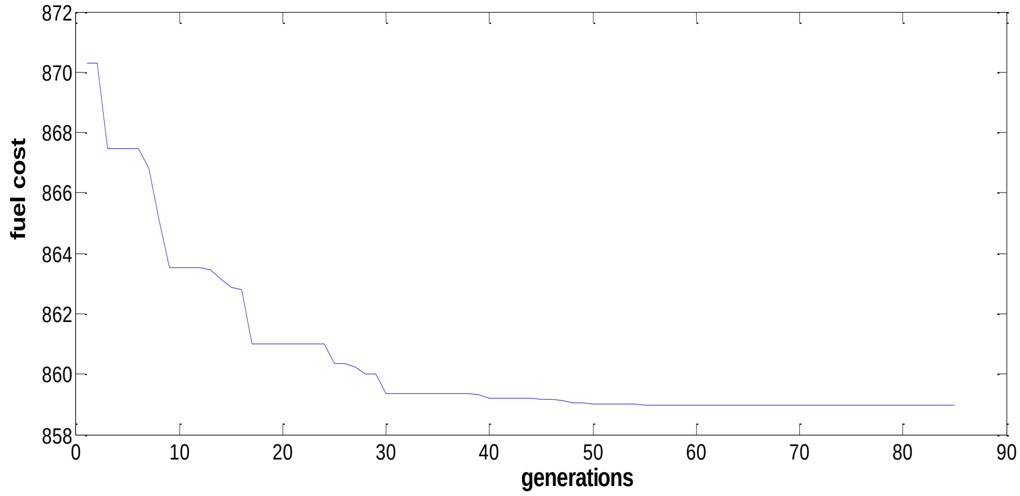

Fig 6 Convergence characteristic of fuel cost using simple GA for OPF with TCSC

2. Particle Swarm Optimization

Type of device :TCS
Location of device :14
Randomised value(RV) :-0.325000.Figure 7 shows convergence characteristics of fuel cost using particle swarm optimization for opf with TCSC.The problem is handled as single objective optimization problem by considering fuel cost and system loadability are as different objectives and are optimized using PSO with& without TCSC. The maximal limit of the load factor is set at 1.5, which reflects a 50% percent increment of power demands. The variation of the load factor is allowed in the bound of [1, 1.5].

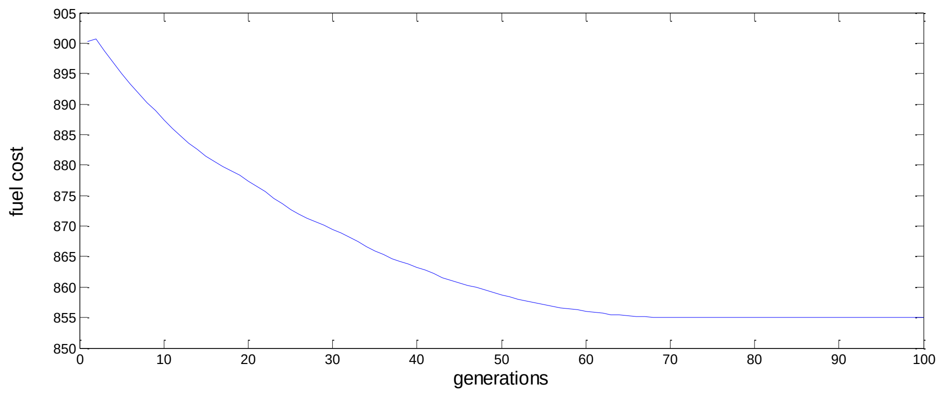

Fig 7 Convergence characteristic of fuel cost using PSO for OPF with TCSC

6.3. Comparison of Results

a).Comparison of Genetic Algorithm and Particle Swarm Optimization with minimization of total fuel cost.

Table 1. Minimization of total cost with optimal settings of control variables for OPF using GA and PSO with &without TCSC controller

	GA without TCSC	GA with TCSC	PSO without TCSC	PSO with TCSC
Total fuel cost **($/hr)**	802.862028	802.253820	802.010	801.160
Time	235.65 sec	238.66 sec	223.89sec	226.57sec

b).Comparison of Genetic Algorithm and particle Swarm Optimization with maximization of system loadabilty of total fuel cost.

Table 2. Maximization of system loadabilty with total fuel cost of optimal settings of control variables for OPF using GA and PSO with &without TCSC.

	GA without TCSC	GA with TCSC	PSO without TCSC	PSO with TCSC
Total fuel cost($/hr)	860.969002	859.362435	855.022443	854.062486
time	245.45 sec	247.78sec	235.86sec	238.26sec

Table 1 gives comparison of Minimization of total generation fuel cost with optimal settings of control variables for OPF using GA and PSO with &without TCSC controller. Table 2 gives comparison of Maximization of system loadability of total generation fuel cost with optimal settings of control variables for OPF using GA and PSO with &without TCSC controller. It is observed that total generation fuel cost with PSO applied to TCSC device is less as compared to GA and time taken is also less as compared to GA.

VII. CONCLUSIONS

In this paper, OPF problem is first attempted using simple Genetic Algorithm and Particle Swarm Optimization considering fuel cost as objective function. Next, Maximization of system loadability with security margin is considered along with fuel cost optimization. Case studies for the algorithms are made on the standard IEEE 30 bus test system. Based on the investigations carried out at various stages, the generator fuel cost with PSO is better compared to the value obtained using GA .when checked with the loadability margin of the system the load is increases by 50% taking all voltages and line flow violations as penalty OPF problem. Simulation results shows that PSO takes less time for convergence when compared with GA.TCSC controller has been used for fuel cost optimization it is observed that PSO works better than GA.

VIII. SCOPE FOR FUTURE WORK

Research and development is a continuous process. Each end of a research project opens many possibilities for future work. The objective functions considered to optimally locate the FACTS devices are branch loading, voltage stability and loss. It can be further extended by considering other criteria such as cost of installation of FACTS devices. Present study has considered the placement of FACTS devices from steady state point of view. Dynamic consideration of these devices can be explored

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