Multi-objective optimal power flow using NSGSA with IPFC

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Abstract: *Power demand increasing rapidly after 19th century. To meet this demand power generation must increase or existing transmission lines performance must improve. Installation of power plant costly manner hence in this paper performance of the transmission lines must improve using IPFC device. One of the important and latest FACTS device is Interline power flow controller (IPFC) is used to improve performance of the transmission line in terms of stated objective functions such as cost, emission and loss minimization. In this proposed Non dominated Sorting Gravitational Search Algorithm is used to solve multi objective optimization problem. The proposed stated objective functions are optimized for IEEE 14 bus system in the presence of IPFC. The results are compared with existing literature and shows proposed algorithm gives better result when compare to existing algorithms.*

Keywords: **Optimal power flow, Multi-object, Non-dominate sorting, Pareto front, Gravitational search algorithm**

1. INTRODUCTION

Latest development in Semiconductor devices and its advantages in transmission systems necessitates new generation of FACTS devices like SSSC, IPFC and other devices. In [1] described different modes of operation of SSSC. With the practical applications of converter-based FACTS controller synchronous series compensator is great impact in power system operation [2]. In [3] presented a PIM of SSSC for load flow analysis. D.Menniti, et al. proposed a method for optimal location of SSSC [4]. Suman Bhowmick, et al. given an indirect modelling approach for SSSC is proposed for Newton power flow analysis [5]. In [6], incorporates the SSSC in OPF solutions to improve the operation of the systems. A recent development in power electronic technology with FACTS device is described in [7-9]. The modelling of UPFC is described in [10-13]. Power flow control in single transmission line UPFC is used and for multi-line power flow control IPFC is used. The voltage source converter is described in [14].

2. Objective functions

The OPF problem can be represented as follows:

$$\text{Min } \left[A_m(x,u)\right]; \qquad \forall\, m = 1,2,\ldots,J \tag{1}$$

Subjected to the constraint $g(x,u) = 0$ (2)

$$h_{\min} \le h(x,u) \le h_{\max} \tag{3}$$

Objective 1: Generation fuel cost minimization

$$A_1 = \min(F_T) = \sum_{i=1}^{NG} F_i(P_{Gi}) \quad \$/h \tag{4}$$

$$F_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \quad \$/h \tag{5}$$

Objective 2: Emission minimization

$$A_2 = \min\left[E\left(P_{G_i}\right)\right] = \sum_{i=1}^{NG} e_i \quad (ton/h) \tag{6}$$

Objective 3: Total Power Loss minimization

$$A_3 = \min(TPL) = \sum_{i=1}^{nl} P_{Loss_i} \tag{7}$$

3. Proposed Gravitational Search Algorithm (GSA)

The detail procedure to apply GSA algorithm for solving OPF problem is discussed as follows

Step-1: Initialize the constants

This step starts by initializing the constants.

Let $G_0 = 0.165$, $\alpha = 20$, $Iter_{Max} = 100$, $N = 50$, $\varepsilon = 2\times10^{-52}$

Step-2: Random initialization

$$X_i(t) = \left[x_i^1(t),\ x_i^2(t),\ x_i^3(t),\ \ldots\ldots\ldots.,\ x_i^d(t),\ \ldots\ldots,\ x_i^n(t),\right]; \qquad i = 1, 2, 3, \ldots\ldots., N$$

Where $x_i^n(t)$ is the n^{th} control variable for i^{th} agent set

Step-3: Fitness evaluation of agents

A heavier mass means a more efficient agent.

$$best(t) = \min_{i \in \{1,2,\ldots,N\}} (fit_i(t))$$

$$worst(t) = \max_{i \in \{1,2,\ldots,N\}} (fit_i(t))$$

Where $fit_i(t)$ represent the fitness value of the agent i at time t.

Step-4: Calculate the masses of the agents

$$M_{ai} = M_{pi} = M_{ii} = M_i; \qquad i = 1, 2, 3, \ldots\ldots., N$$

$$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)}$$

$$M_i(t) = \frac{m_i(t)}{\sum_{k=1}^{N} m_k(t)}$$

Step-5: Calculate the gravitational constant

The gravitational constant is updated using following equation

$$G(t) = G_0 . e^{-\frac{\alpha t}{Iter_{Max}}}$$

Step-6: Calculation of force acting on mass

$$F_{ij}^d(t) = G(t) \times \left(\frac{M_{aj}(t) \times M_{pi}(t)}{R_{ij}(t) + \varepsilon} \right) \times \left(x_j^d(t) - x_i^d(t) \right)$$

Step-7: Total force in different directions

$$F_i^d(t) = \sum_{j \in K_{best}, j \neq i}^{N} rand_j \times F_{ij}^d(t)$$

Step-8: Calculate the acceleration of each agent

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)};$$

Step-9: Calculate the updated velocity and position of each agent

$$v_i^d(t+1) = a_i^d(t) + rand_i \times v_i^d(t)$$
$$x_i^d(t+1) = a_i^d(t) + v_i^d(t+1)$$

Step-10: Selection Process

Based on the greedy selection best solution will carry for the further iteration

Step-11: Stopping criteria

If current iteration is greater than or equal to the maximum number of iterations, $Iter_{Max}$ then stop the process and print the results.

4. Fuzzy decision methodology

fuzzy decision methodology is presented to identify the best suitable solution from the obtained Pareto front as per the user requirement. For the objective function minimization case, the member ship function can be expressed as

$$\mu_m^n = \begin{cases} 1 & ; \quad F_m^n \leq \min(F_m) \\ \frac{\max(F_m) - F_m^n}{\max(F_m) - \min(F_m)} & ; \quad \min(F_m) \leq F_m^n \leq \max(F_m) \\ 0 & ; \quad F_m^n \geq \max(F_m) \end{cases} \tag{8}$$

Finally, the normalized membership function is

$$\mu_{norm}^{n} = \max\left\{ \frac{\sum_{i=1}^{J} W_i \mu_i^n}{\sum_{k=1}^{P}\sum_{i=1}^{J} W_i \mu_i^k} \right\} \quad (9)$$

5. Multi-Objective Non-Dominated Sorting Approach

The following steps describe the methodology of the proposed algorithm to solve multi-objective optimization problem:

Step.1: Initialize the iteration counter=0.

Step.2: apply NR load flow with IPFC device and calculate the value of the objective function using GSA algorithm.

Step.3: The obtained solutions are treated as the parent solutions.

Step.4: Now perform the non-dominated procedure At last, the Pareto front (Pf) solutions are identified.

Step.5: Start the iterative process. These new solutions are treated as off-spring population.

Step.6: Combine the previously obtained parent and newly obtained off-spring solutions. Now repeat step 4 for this new set of solutions and identify new Pareto front.

Step.7: Each of the solutions the crowding distance is the sum of the individual crowding distance values.

Step.9: This distance is calculated for the considered objectives.

Step.10: Finally, the solutions in the Pareto front are arranged as per their crowding distances.

Step.11: Increase the iteration count

Step.12: Fuzzy membership values for each of the solutions in the Pareto front are calculated.

6. Results and Analysis

In this case, combination of two and three objectives is considered at a time for analysis using proposed NSGSA method. The multi-objective results with proposed method for cost-emission combination, cost-loss combination and emission-loss combination with different weights are given in Tables 1-3 respectively. Respective two-dimensional scattered plots for cost-emission, cost-loss and emission-loss combinations are shown in Figs. 1-3 respectively.

Based on the weights assigned to the objective function, the best Pareto solution is obtained using fuzzy decision approach. Firstly from Table 1, combination of cost-emission is considered for which optimal value of generation fuel cost is 728.8956 \$/h and 728.0078 \$/h with SSSC and IPFC with respect to 0.9 weights. Emission is

0.1832 ton/h and 0.1776 ton/h with SSSC and IPFC with respect to 0.9 weights. Secondly from Table 2, combination of cost-loss is considered for which optimal value of generation fuel cost is 732.6389 $/h and 729.9258 $/h with SSSC and IPFC with respect to the 0.9 weights. Loss is 5.655 MW and 5.5732 MW with SSSC and IPFC with respect to 0.9 weights. Finally from Table 3, combination of emission-loss is considered for which optimal value of emission is 0.2707 ton/h and 0.2693 ton/h with SSSC and IPFC with respect to 0.9 weights. Loss is 5.3988 MW and 5.3766 MW with SSSC and IPFC with respect to 0.9 weights. The objective function values are improved with IPFC.

From Figs. 1-3, it is observed that the best Pareto front solutions of cost-emission, cost-loss and emission-loss combinations are well distributed along the entire trade of region. The generated two dimensional best Pareto front for the cost-emission, cost-loss and emission-loss combinations with SSSC and IPFC are shown in Fig. 4 respectively. From Fig. 4 it is observed that the best Pareto front is good for IPFC than with SSSC device.

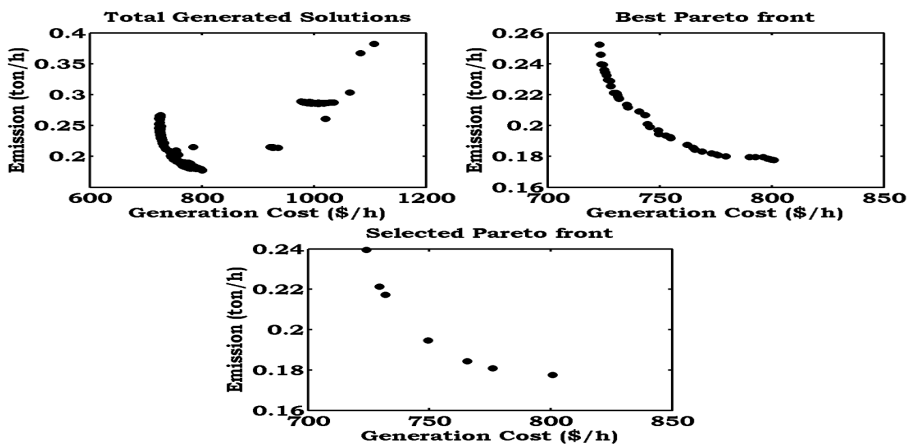

Figure 1. Two-dimensional Pareto front of cost-emission combination for IEEE 14 bus system with IPFC

Table 1. Summary of test results of cost-emission combination with SSCC and IPFC for IEEE 14 bus system

Set No	W1	W2	With SSSC		With IPFC	
			Fuel cost ($/h)	Emission (ton/h)	Fuel cost ($/h)	Emission (ton/h)
1	0.9	0.1	**728.8956**	0.2408	**728.0078**	0.2396
2	0.8	0.2	730.2657	0.2349	728.0078	0.2396
3	0.7	0.3	735.9097	0.2273	730.5049	0.2212
4	0.6	0.4	735.9097	0.2273	731.8192	0.2173
5	0.5	0.5	758.5981	0.1901	749.474	0.1946
6	0.4	0.6	758.5981	0.1901	749.474	0.1946
7	0.3	0.7	774.692	0.185	765.7143	0.1845

8	0.2	0.8	774.692	0.185	776.1116	0.1808
9	0.1	0.9	783.9985	**0.1832**	800.8043	**0.1776**

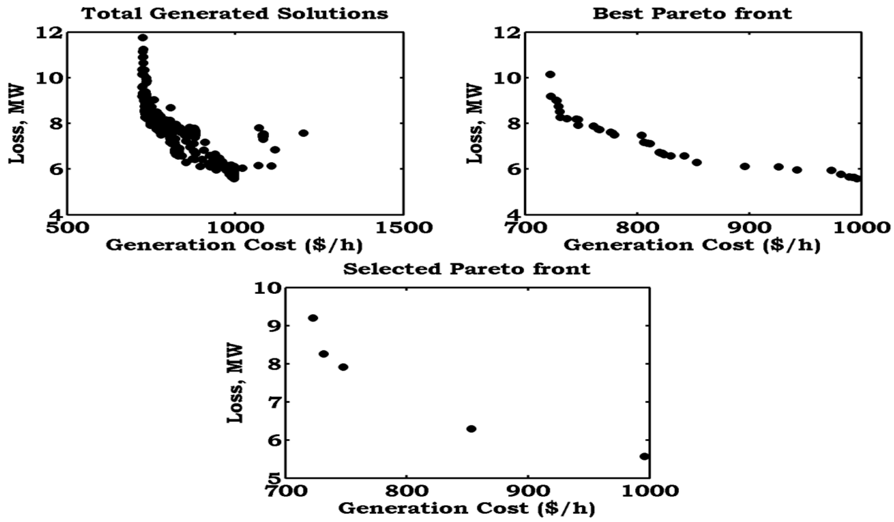

Figure 2. Two-dimensional Pareto front of cost-loss combination for IEEE 14 bus system with IPFC

Table 2. Summary of test results of cost-loss combination with SSCC and IPFC for IEEE 14 bus system

Set No	W1	W2	With SSSC		With IPFC	
			Fuel cost ($/h)	Loss (MW)	Fuel cost ($/h)	Loss (MW)
1	0.9	0.1	**732.6389**	9.4461	**729.9258**	9.1981
2	0.8	0.2	735.9681	8.3796	735.6712	8.2619
3	0.7	0.3	746.4344	7.908	735.6712	8.2619
4	0.6	0.4	746.4344	7.908	745.4026	7.9192
5	0.5	0.5	766.0441	7.1316	745.4026	7.9192
6	0.4	0.6	802.7291	6.3514	853.1352	6.292
7	0.3	0.7	802.7291	6.3514	853.1352	6.292
8	0.2	0.8	909.1919	5.655	995.891	5.5732
9	0.1	0.9	909.1919	**5.655**	995.891	**5.5732**

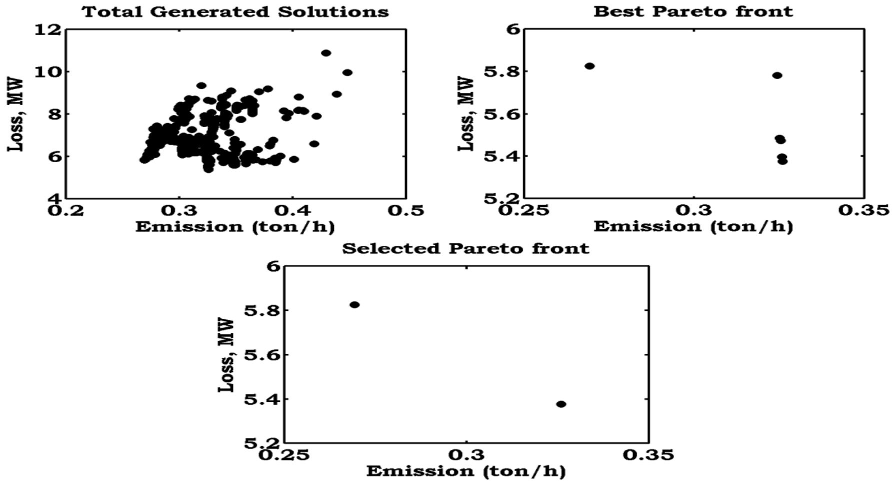

Figure 3. Two-dimensional Pareto front of emission-loss combination for IEEE 14 bus system with IPFC

Table 3. Summary of test results of emission-loss combination with SSCC and IPFC for IEEE 14 bus system

Set No	W1	W2	With SSSC		With IPFC	
			Emission (ton/h)	Loss (MW)	Emission (ton/h)	Loss (MW)
1	0.9	0.1	0.2707	5.8995	0.2693	5.8253
2	0.8	0.2	0.2707	5.8995	0.2693	5.8253
3	0.7	0.3	0.2707	5.8995	0.2693	5.8253
4	0.6	0.4	0.272	5.8667	0.2693	5.8253
5	0.5	0.5	0.2781	5.7717	0.2693	5.8253
6	0.4	0.6	0.2781	5.7717	0.326	5.3766
7	0.3	0.7	0.3321	5.3988	0.326	5.3766
8	0.2	0.8	0.3321	5.3988	0.326	5.3766
9	0.1	0.9	0.3321	5.3988	0.326	5.3766

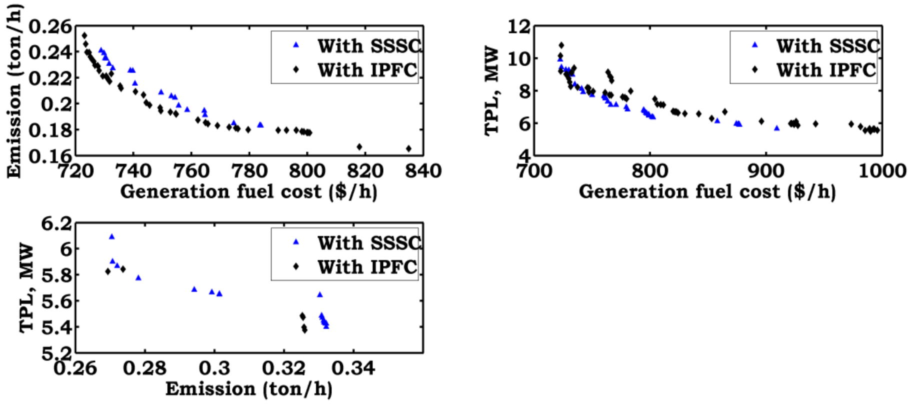

Figure 4. Two-dimensional Pareto front of all three combination for IEEE 14 bus system with IPFC

7. Conclusions

In this paper, a proposed non-dominated sorting gravitational search algorithm for multi objective optimal power flow problem with SSSC and IPFC has been presented. From the results, it can be observed that generation fuel cost, emission and total power losses are less due to the presence of the IPFC in the system than SSSC. The severity function value is less for IPFC than SSSC which indicates enhances the power system security more in IPFC. Further it was also observed that for multi objective function value has been depends upon the weights assigned to the respective objectives and these objective values are better with IPFC compared to SSSC. The Pareto solutions also confine the entire trade of region which indicates effectiveness of the method

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