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Congestion management of deregulated power systems by optimal setting of Interline Power Flow Controller using Gravitational Search algorithm

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Abstract

In a deregulated electricity market it may at times become difficult to dispatch all the required power that is scheduled to flow due to congestion in transmission lines. An Interline Power Flow Controller (IPFC) can be used to reduce the system loss and power flow in the heavily loaded line, improve stability and loadability of the system. This paper proposes a Disparity Line Utilization Factor for the optimal placement and Gravitational Search algorithm based optimal tuning of IPFC to control the congestion in transmission lines. DLUF ranks the transmission lines in terms of relative line congestion. The IPFC is accordingly placed in the most congested and the least congested line connected to the same bus. Optimal sizing of IPFC is carried using Gravitational Search algorithm. A multi-objective function has been chosen for tuning the parameters of the IPFC. The proposed method is implemented on an IEEE-30 bus test system. Graphical representations have been included in the paper showing reduction in LUF of the transmission lines after the placement of an IPFC. A reduction in active power and reactive power loss of the system by about 6% is observed after an optimally tuned IPFC has been included in the power system. The effectiveness of the proposed tuning method has also been shown in the paper through the reduction in the values of the objective functions.

Keywords: Congestion; Interline Power Flow Controller; Line Utilization Factor; IPFC placement; IPFC tuning; Gravitational Search algorithm

Abbreviations: IPFC, Interline Power Flow Controller; SSSC, Static Synchronous Series Compensator; TCSC, thyristor controlled series compensator; LUF, Line Utilization Factor; PSO, particle swarm optimization; GSA, Gravitational Search algorithm; VSC, voltage source converter; VD, voltage deviation; SM, security margin.

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Nomenclature

n	Bus j, k
V_n	Complex voltage at bus (j, k)
V_n, θ_n	Magnitude and angle of V_n respectively
Vse_{in}	Complex controllable series injected voltage source
Vse_{in},θse_{in}	Magnitude and angle of Vse_{in} respectively
V_i	Complex voltage at bus i
V_i, θ_i	Magnitude and angle of V_i respectively
P_i,Q_i	Sum of active and reactive power leaving bus I
Zse_{in}	Series transformer impedance of line i-n
G_{in}	Series transformer conductance of line i-n
B_{in}	Series transformer susceptance of line i-n
P_{gi}, Q_{gi}	Generated active and reactive power at bus i
P_{di}, Q_{di}	Load active and reactive power at bus i
Lk	Number of transmission lines
S	MVA flow in the transmission line

1. Introduction

Deregulated electric power industries have changed the way of operation, structure, ownership and management of the utilities. The issue of transmission congestion is more prominent in deregulated and competitive markets, and it needs an appropriate management strategy. In the new competitive electric market, it is now mandatory for the electric utilities to operate such that it makes better utilization of the existing transmission facilities in conjunction with maintaining the security, stability and reliability of the supplied power (Abdel-Moamen and Padhy, 2003). In the process of better utilization of the existing transmission facilities, the transmission lines tend to get overloaded or congested. Increased congestion in the transmission lines may lead to contingency in the network (Kumara et al., 2005). A series of uncontrolled contingencies have been cited as the major reason for blackouts (Mishra and Nagesh Kumar, 2015). Thus, to properly utilize the transmission lines and at the same time maintain the security, stability and reliability of the transmission system, the use of FACTS devices has become inevitable. Economic constraints put a limitation on the number of FACTS devices that can be used. Hence, optimal placement and tuning of the FACTS devices in power system is mandatory.

Several authors (Singh and David, 2001; Besharat and Taher, 2008; Mandala and Gupta, 2010) have suggested the use of sensitivity index based on real power performance index for the optimal placement of FACTS devices. The method consists of determining the optimal location of thyristor controlled series compensators (TCSCs) for congestion management. The optimal location is determined based on real power performance index and based on reduction in total system active power and reactive power losses. Minguez et al. (2007) proposed a method of optimal placement of IPFC such that the load margin is maximized. Reddy et al. (2010) have presented optimal location of FACTS controllers considering branch loading (BL), voltage stability (VS) and loss minimization (LM) as objectives at once using genetic algorithm for management of congestion. Acharya and Mithulananthan (2007) propose two new methodologies for the placement of series FACTS devices for congestion management. The overall objective of FACTS device placement can be either to minimize the total congestion rent or to maximize the social welfare. Out of all FACTS devices IPFC is considered to be most flexible, powerful and versatile as it employs at least two VSC's with a common DC link. Hence IPFC has the capability of compensating multi transmission line (Hingorani and Gyugyi, 2000). IPFC has been used successfully for many transmission system applications. Several authors (Zhang, 2006; Teerthana and Yokoyama, 2004) presented an optimal power flow (OPF) control in electric power systems incorporating IPFC for the minimum total capacity of the converters of IPFC. Kargarian and Falahati (2012) proposed a multi-objective function for performing optimal power flow in the presence of IPFC for microgrids. Mohamed et al. (2010) have compared three variants of PSO namely basic PSO, inertia weight approach PSO and constriction factor approach PSO considering a single objective i.e. to minimize the transmission line loss. It has also been used for improvement of voltage stability (Sai

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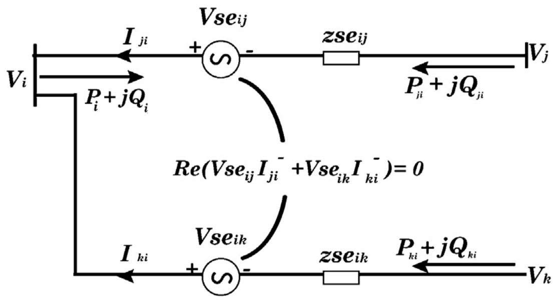

Fig. 1. Equivalent circuit of IPFC.

Ram and Amarnath, 2013) and for controlling g multi transmission lines (Karthik et al., 2012). MATLAB software has been used very successfully for various applications (Valipur and Montazar, 2012a,b,c). Nature inspired algorithms are among the most powerful algorithms for optimization (Yang, 2008). GSA is a heuristic optimization algorithm which has been gaining interest among the scientific community recently. GSA is a nature inspired algorithm which is based on the Newton's law of gravity and the law of motion. GSA is grouped under the population based approach and is reported to be very intuitive. The algorithm is intended to improve the performance in the exploration and exploitation capabilities of a population based algorithm, based on gravity rules (Rashedi et al., 2009a,b).

FACTS devices are preferred in modern power systems based on the requirement and are found to deliver good solution. Index based method of placement of FACTS devices has been found to be the most efficient of all methods e.g. computational intelligence method and LMP method. Line Utilization Factor (LUF) is one of the most effective indexes for measurement of overloading in terms of percentage of MVA flowing with respect to the rated capacity. Usually, FACTS devices like TCSC and SSSC are also placed on the most congested line determined on the basis of the index. However, IPFC being a multi-converter device is placed on multiple transmission lines. Proper placement of IPFC is therefore a subject to be analyzed. Optimal tuning of the FACTS devices is very important for proper utilization of the devices' properties. Metaheuristic methods are the most recent advancement in the field of optimization. Performance of GSA, which is one of the recent metaheuristic methods, in tuning IPFC should therefore be analyzed in detail.

In this paper, the difference of Line Utilization Factors between two lines has been used for determination of the optimal location of IPFC. It gives an estimate of the difference of the percentage of line being used for the power flow. Thus all the line pairs with a common bus are ranked in terms of line congestion. The IPFC is placed in the lines with maximum value of DLUF to reduce congestion and power loss in the system. A multi objective optimization has been formulated for optimal tuning of IPFC using Gravitational Search algorithm. The multi objective function comprises of reduction of active power loss, minimization of total voltage deviations and maximization of security margin with the usage of minimum size of installed IPFC. Tuning of IPFC for reduction of loss further reduces line congestion. Reduction of voltage deviation and increase in security margin ensures power quality and system security. The proposed method is implemented and tested on an IEEE 30 bus system with different loading conditions.

2. Implemented mathematical model of IPFC

IPFC consists of at least two back to back DC–AC converters connected by a common DC link (Acha et al., 2004). The equivalent circuit of the IPFC with two converters is represented in Fig. 1. P_i and Q_i as given in Eqs. (1) and (2) are the sum of the active and reactive power flows leaving the bus i. The expressions for IPFC branch active and reactive power flows leaving bus n and further details are given in Zhang (2003).

$$\begin{aligned} P_i = {} & V_i^2 g_{ii} - \sum_n V_i V_n \left[g_{in} \cos(\theta_i - \theta_n) + b_{in} \sin(\theta_i - \theta_n) \right] \\ & - \sum_n V_i Vse_{in} \left[g_{in} \cos(\theta_i - \theta se_{in}) - b_{in} \sin(\theta_i - \theta se_{in}) \right] \end{aligned} \quad (1)$$

$$Q_i = -V_i^2 b_{ii} - \sum_{n=j,k} V_i V_n \left[g_{in} \sin(\theta_i - \theta_n) - b_{in} \cos(\theta_i - \theta_{n)})\right] - \sum_{n=j,k} V_i Vse_{in} \left[g_{in} \sin(\theta_i - \theta se_{in}) - b_{in} \cos(\theta_i - \theta se_{in})\right] \quad (2)$$

where

$$g_{in} + jb_{in} = 1/zse_{in} = yse_{in}, g_{nn} + jb_{nn} = 1/zse_{in} = yse_{in}, g_{ii} = \sum_{n=j,k} g_{in}, b_{ii} = \sum_{n=j,k} b_{in} \quad (3)$$

3. Disparity Line Utilization Factor

LUF is an index used for the measurement of the degree of loading of a transmission line in terms of MVA. The expression for LUF of line connected to bus i and j is mentioned in Eq. (7).

$$LUF_{ij} = \frac{\text{MVA power flow in line ij}}{Max \text{ MVA power flow in line ij}} \quad (4)$$

LUF gives an estimate of the percentage of line being utilized. It is an efficient method to estimate the congestion in a line. But an IPFC has at least two converters placed on transmission lines connected through a common bus. Since, IPFC can directly transfer real power via the common DC link, it has the capability to transfer power demand from overloaded to under loaded lines. Hence a new index Disparity Line Utilization Factor is hereby proposed for the optimal placement of an IPFC. DLUF indicates the difference between the utilization of the lines. It gives an estimate of the difference of the percentage of line being used for the power flow. Assuming both lines of same rating

$$DLUF_{(ij)-(ik)} = |LUF_{(ij)} - LUF_{ik}| \quad (5)$$

where

$DLUF_{(ij)-(ik)}$ is the Disparity Line Utilization Factor (DLUF) of the line set ij and ik connected to bus-i and bus-j.

The procedure for the implementation of DLUF is mentioned below.

Step by step procedure:

1. Read the bus data and line data and perform load flow analysis.
2. Calculate the LUF values of all lines.
3. Calculate the DLUF for lines connected to the line ranking highest in congestion.
4. Place the IPFC on lines with highest value of DLUF.
5. Perform load flow analysis with IPFC and calculate the LUF of the transmission lines.

4. Optimal tuning of IPFC

An objective function is formulated to find the optimal size of IPFC which minimizes the active power loss, total voltage deviations, and maximizes the security margin with the usage of minimum value of installed IPFC.

4.1. Objective function

The objective of the study is minimization of a multi objective function formulated as given in Eq. (6)

$$F = w_1 \times Active\ power\ loss + w_2 \times Voltage\ \ deviation\ + w_3\,\text{Securitymargin} + w_4\, IPFC\ Size \quad (6)$$

where

w_1, w_2, w_3, w_4 are the weighting factors.

$$w_1 + w_2 + w_3 + w_4 = 1 \quad (7)$$

$w_1 = w_2 = w_3 = w_4 = 0.25$

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The expression for reduction of active power loss is given in Eq. (8).

$$P_{loss} = \left(|V_i|^2 G_{in} - |V_i||V_n| \left[G_{in}\cos\theta_{in} + B_{in}\sin\ \theta_{in}\right] - |V_i||V_{sein}| \left[G_{in}\cos\theta_{sein} + B_{in}\sin\ \theta_{sein}\right]\right) + \left(|V_n|^2 G_{in} - |V_i||V_n| \left[G_{in}\cos\theta_{in} + B_{in}\sin\ \theta_{in}\right] - |V_n||V_{sein}| \left[G_{in}\cos\theta_{sein} + B_{in}\sin\ \theta_{sein}\right]\right) \tag{8}$$

The voltage deviation can be expressed by Eq. (9):

$$VD = \left(\sum_{k=1}^{Nbus} |V_k - V_k^{ref}|^2\right) \tag{9}$$

V_k is the voltage magnitude at bus k.

The security rate of a system according to the critical state can be expressed as follows in Eq. (10).

$$SM = \frac{\sum_{j\in J_L} S_j \lim - \sum_{j\in J_L} S_j initial}{\sum_{j\in J_L} S_j \lim} \tag{10}$$

where J_L = A set contains all load buses.

SM takes a value between zero and one for a system with normal operating condition. Since it is intended to minimize the function, the objective function in Eq. (10) is rewritten in Eq. (11).

$$1 - SM = \frac{\sum_{j\in J_L} S_j initial}{\sum_{j\in J_L} S_j \lim} \tag{11}$$

The size of the installed IPFC is required for solving the overload on the transmission lines formulated as in Eq. (12).

$$PQ_1^2 + PQ_2^2 = \left(Vse_{ij}\left(\frac{\overline{V_i - Vse_{ij} - V_j}}{Z_{ij}}\right)\right)^2 + \left(Vse_{ik}\left(\frac{\overline{V_i - Vse_{ik} - V_k}}{Z_{ik}}\right)\right)^2 \tag{12}$$

where PQ: size of each VSCs of IPFC.

4.2. Equality constraints

$$P_{gi} + P_i - P_{Di} = \sum_{n=j,k} V_i V_n Y_{in}\ \cos(\theta_{in} + \theta_n - \theta_i) \quad \forall i \tag{13}$$

$$Q_{gi} + Q_i - Q_{Di} = \sum_{n=j,k} V_i V_n Y_{in}\ \sin(\theta_{in} + \theta_n - \theta_i) \quad \forall i \tag{14}$$

4.3. Inequality constraints

$$V_i^{\min} \le V_i \le V_i^{\max} \forall \mathrm{i} \in \text{ loadbus} \tag{15}$$

$$Sij(V,\delta)| \le Sij\max \quad \forall ij \tag{16}$$

4.4. IPFC constraints

$$V_{se}^{\min} \le V_{se} \le V_{se}^{\max} \tag{17}$$

$$\theta_{se}^{\min} \le \theta_{se} \le \theta_{se}^{\max} \tag{18}$$

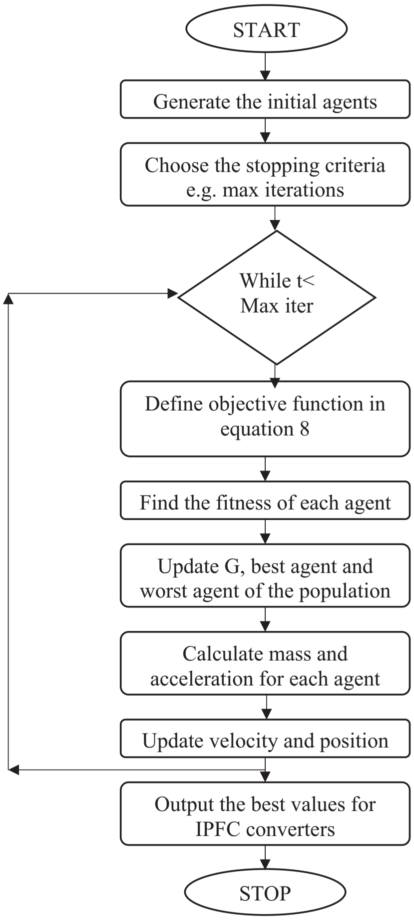

Fig. 2. Application of GSA to IPFC tuning.

5. Gravitational Search algorithm

Gravitational Search algorithm is a new optimization method based on the Newton's gravitational law. Gravitation is the inclination of the masses to accelerate towards each other. In GSA, agents are considered as objects and their performance is measured by their masses. All objects attract each other by the force of gravity, and this force causes a global movement of all objects towards the objects with heavier masses. Hence, masses have a direct form of communication, via gravitational force. Heavier the masses, better is the solution and slower is the movement in comparison to the lighter ones. Each mass (agent) has four specifications: position, inertial mass, active gravitational mass, and passive gravitational mass. The position of the mass corresponds to a solution of the problem, and its gravitational and inertial masses are determined using a fitness function. The position of each mass is considered as a solution, and the algorithm adjusts the gravitational and inertia masses to get better solution. By lapse of time, we expect that masses be attracted by the heaviest mass, which represents an optimum solution in the search space. The GSA can be considered as a small artificial world of masses obeying the Newtonian laws of gravitation and motion. For detailed mathematical equations refer to Valipur and Montazar (2012a). GSA Application to optimal tuning of IPFC is mentioned in Fig. 2.

6. Results and discussion

The proposed methodology has been tested on an IEEE 30 bus system shown in Fig. 3. The IEEE 30 bus test system load flow is obtained using MATLAB software and the results have been presented. Only load buses are considered

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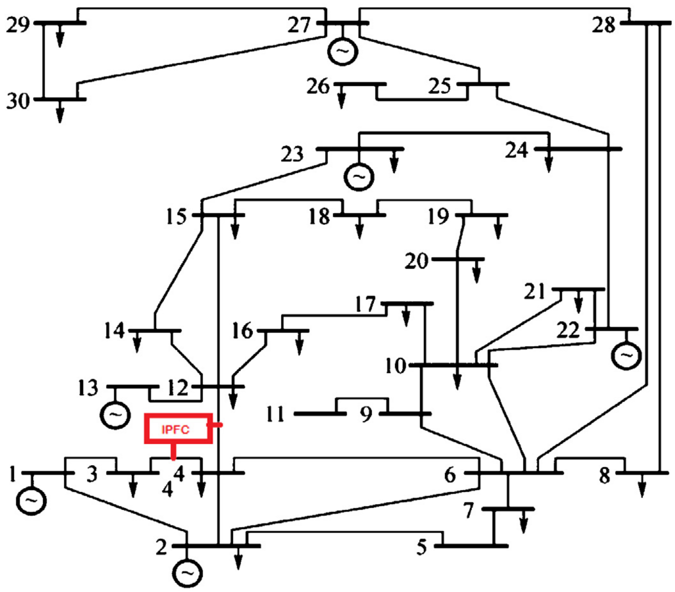

Fig. 3. IEEE 30 bus test system with IPFC installed at line connected between buses 3-4 and 4-12.

for IPFC placement. Equal weights of 0.25 have been considered for all objectives. The results have been analyzed for normal loading, 110% loading and 125% loading condition.

LUF values of all the lines without and with optimal placement of IPFC have been presented in Table 1. It is observed that without IPFC, the line connected between buses 3 and 4 is the most congested line. It is observed that two lines, namely, lines 4-12 and 4-6, are connected to bus 4. The DLUF index for both the lines with respect to line 3-4 is calculated and presented in Table 2. It is observed that the line connected between buses 4 and 12 has the minimum DLUF value with respect to the line 3-4. Hence, lines 3-4 and 4-12 is the proposed location for the placement of IPFC. After the placement of IPFC at the proposed location the LUF of line 3-4 reduces from 0.8415 p.u. to 0.8338 p.u.

In order to set the number of agents of the Gravitational Search algorithm, the value of each objective function is studied for varying values of the parameters and the results have been presented in Fig. 4. It is observed that with an increase in the number of agents greater reduction in the values of the objective function is achieved. However, with the rise in the number of agents, the computation time of the algorithm also increases as seen in Fig. 5. Fig. 6 shows that the algorithm has a very fast convergence rate in general; it takes greater time to converge as the number of agents increases. Hence, in order to achieve a balance, the number of agents for the algorithm is chosen to be 50.

The LUF values before and after placement of tuned IPFC have been compared in Fig. 7. It is observed that the congestion in the lines reduces to a great extent after placement and tuning of the IPFC by the proposed method. The LUF value of the overburdened lines reduces, while the LUF values in the underutilized lines increases. Thus, there is a redistribution of power flow in the system after the placement of IPFC. The proposed methodology has been tested for normal load, 110% load and 125% loading condition. The parameters of the IPFC used for the various loads have been mentioned in Table 3. The real and reactive power loss of the system without IPFC, with untuned IPFC and with GSA tuned IPFC for all the three loads are compared in Table 4. It is observed that the real and reactive power losses of the system increase with increase in loading. Also, the placement and tuning of IPFC by the proposed method reduces the losses in the system for normal as well as severe load conditions.

Further, the multi objective function, namely, real power loss, voltage deviation, 1-SM and size of the installed IPFC have been observed for unturned and optimally tuned IPFC using GSA in Fig. 8. The values of the multiple functions reduce effectively as a result of tuning of the device. Similar observations have been made for increased load conditions also. However, the values of all the chosen objectives increase with the increase in loading. In Fig. 9 the reactive power loss of the system has been compared without IPFC, with optimal placement of IPFC and with optimally tuned IPFC for various loads. Reduction of real and reactive power loss improves the power transfer capability of the system. Reduction in voltage deviation reduces the chances of voltage instability. Reduction in 1-SM increases the security

Table 1
LUF values of all lines in 30 bus system.

Line no.	From bus (SB no.)	To nus (RB no.)	LUF without IPFC (p.u.)	LUF with optimal setting of IPFC using GSA (p.u.)
1.	2	4	0.4939	0.4751
2.	3	4	0.8415	0.8338
3.	2	5	0.8532	0.8449
4.	2	6	0.6473	0.6274
5.	4	6	0.7173	0.7407
6.	5	7	0.2539	0.2348
7.	6	7	0.3866	0.3834
8.	6	8	0.397	0.4838
9.	6	9	0.3273	0.3045
10.	6	10	0.2479	0.2331
11.	9	11	0.4704	0.5137
12.	9	10	0.6789	0.6802
13.	4	12	0.5284	0.5034
14.	12	13	0.6929	0.7502
15.	12	14	0.1645	0.1642
16.	12	15	0.3858	0.3862
17.	12	16	0.2122	0.2134
18.	14	15	0.0317	0.0324
19.	16	17	0.0868	0.0889
20.	15	18	0.1481	0.1485
21.	18	19	0.037	0.0378
22.	19	20	0.0651	0.0644
23.	10	20	0.1622	0.1599
24.	10	17	0.1002	0.0977
25.	10	21	0.2525	0.2509
26.	10	22	0.1296	0.1308
27.	21	23	0.0571	0.0563
28.	15	23	0.0924	0.0954
29.	22	24	0.0545	0.0555
30.	23	24	0.0305	0.0328
31.	24	25	0.0356	0.0318
32.	25	26	0.0434	0.0433
33.	25	27	0.078	0.0740
34.	28	27	0.3122	0.3013
35.	27	29	0.1158	0.1147
36.	27	30	0.089	0.0882
37.	29	30	0.0426	0.0427
38.	8	28	0.0799	0.0956
39.	6	28	0.2166	0.2025

Table 2
IPFC placement on the basis of DLUF.

Sl. no.	Line 1 SB No- RB no.	Line 2 SB No- RB no.	LUF line 1 (p.u.)	LUF line 2 (p.u.)	DLUF (p.u.)
CASE-1	3-4	4-6	0.8415	0.7173	0.1242
CASE-2	3-4	4-12	0.8415	0.5284	0.3131

margin of the system. With the increase in security margin the system becomes more stable. Reduction in size of the IPFC reduces the budget required for installation of the device.

The voltage profiles before and after the tuning of the IPFC for all the loadings have been compared in Fig. 10. A marked improvement in voltage profile of the buses with optimal placement of tuned IPFC is observed in comparison to voltage profile of the system without IPFC. Thus, the voltage deviation of the overall system is reduced. The convergence characteristics of GSA have been shown in Fig. 11. The GSA shows a fast convergence for all the loadings.

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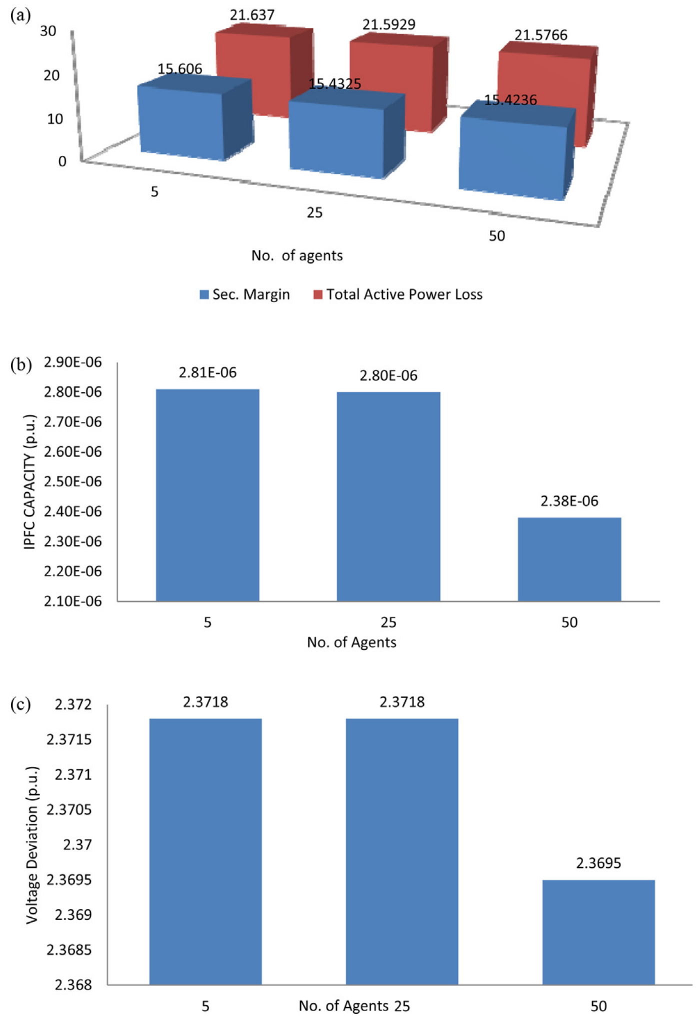

Fig. 4. Objective functions vs. number of agents (a) active power loss and security margin (b) installed IPFC size (c) voltage deviation.

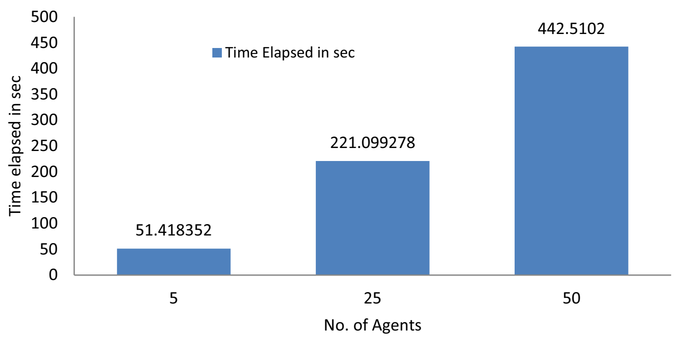

Fig. 5. Computation time required for different values of the number of agents.

Thus, it is established that by optimal tuning of IPFC using Gravitational Search algorithm the system loss, voltage deviation is reduced, while the security margin is maximized with the usage of minimum size of the IPFC. Reduction in loss relieves the system from congestion. Maximization in security margin protects the system against collapse.

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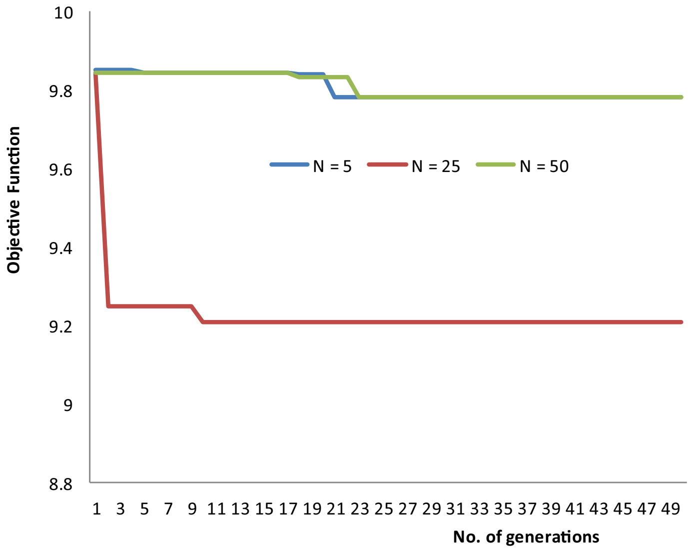

Fig. 6. Objective function value for different parameter settings of the Gravitational Search algorithm.

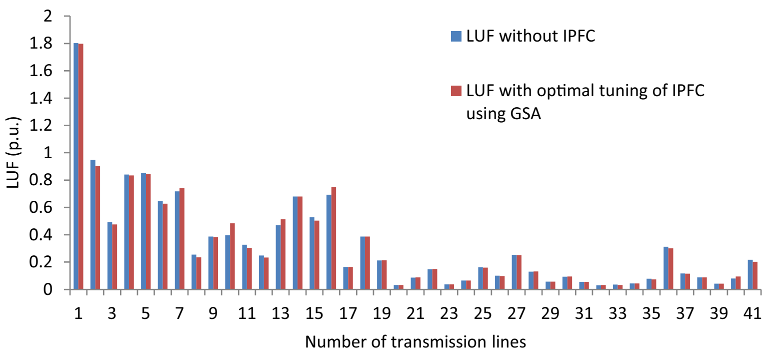

Fig. 7. LUF of lines of 30 bus test system without IPFC and with optimally tuned IPFC.

Table 3
IPFC parameters before and after tuning of IPFC.

IPFC parameters	Normal load		110% load		125% load	
	Untuned IPFC	Tuning of IPFC using GSA	Untuned IPFC	Tuning of IPFC using GSA	Untuned IPFC	Tuning of IPFC using GSA
VSe1 (p.u.)	0.0050	0.0012	0.0050	0.0011	0.0050	0.0010
VSe2 (p.u.)	0.0100	0.0084	0.0100	0.0081	0.0100	0.0079
Θse1 (radian)	−140.1182	180	−159.8295	180	−167.9689	180
Θse2 (radian)	180	−174.0203	180	−174.1855	180	−175.0070

Decrease in size of the IPFC reduces the cost of the device. Hence the overall system performance has been improved at a minimum cost.

7. Future scope

- This paper deals with fixed load on power system with increased loading as test cases. Further detailed study should be performed on real time loading.

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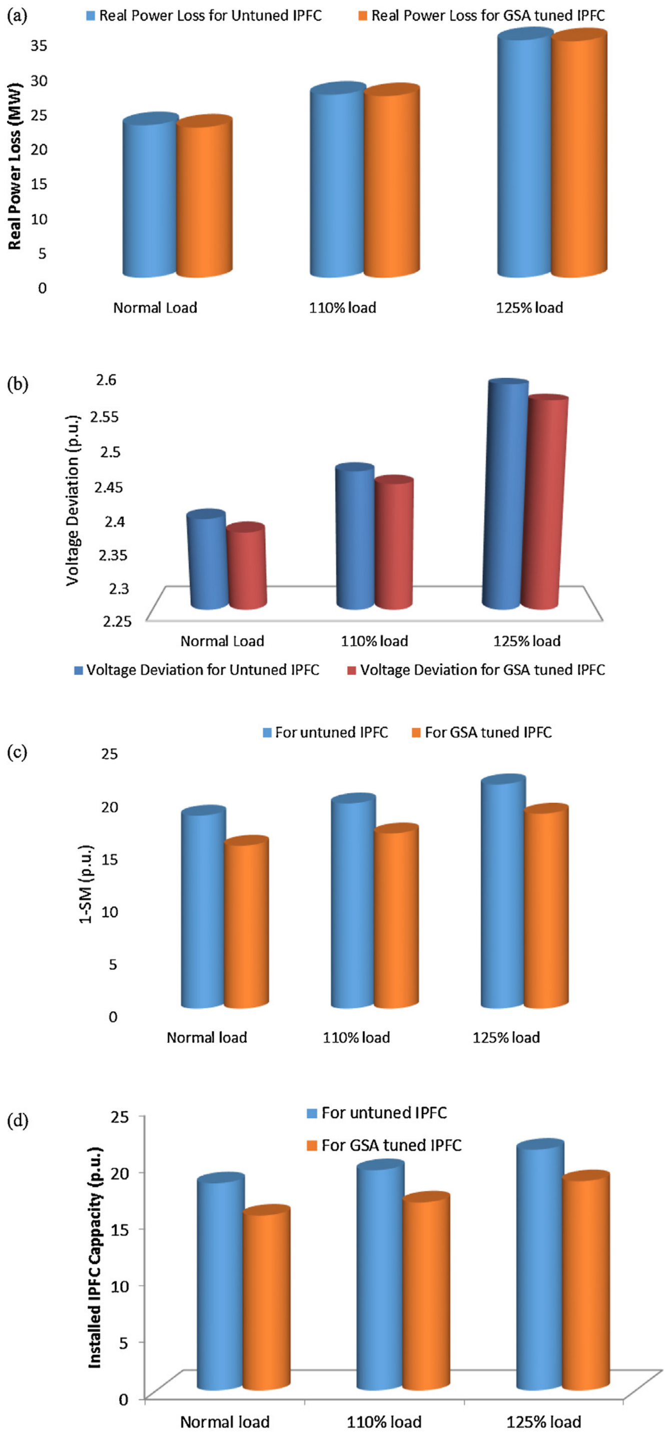

Fig. 8. Comparison of the objective functions for unturned IPFC and GSA tuned IPFC for normal load, 110% load and 125% load (a) real power loss (b) voltage deviation (c) security margin (d) installed IPFC.

- Contingency study can be performed on the system to further test the effectiveness of IPFC in adverse condition.
- More complicated models of IPFC can be used for the study.

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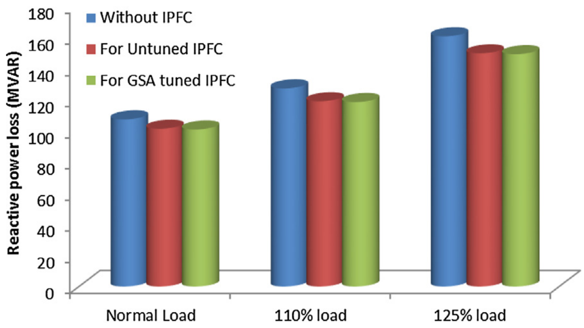

Fig. 9. Comparison of reactive power loss without IPFC, with unturned IPFC and GSA tuned IPFC for all loadings.

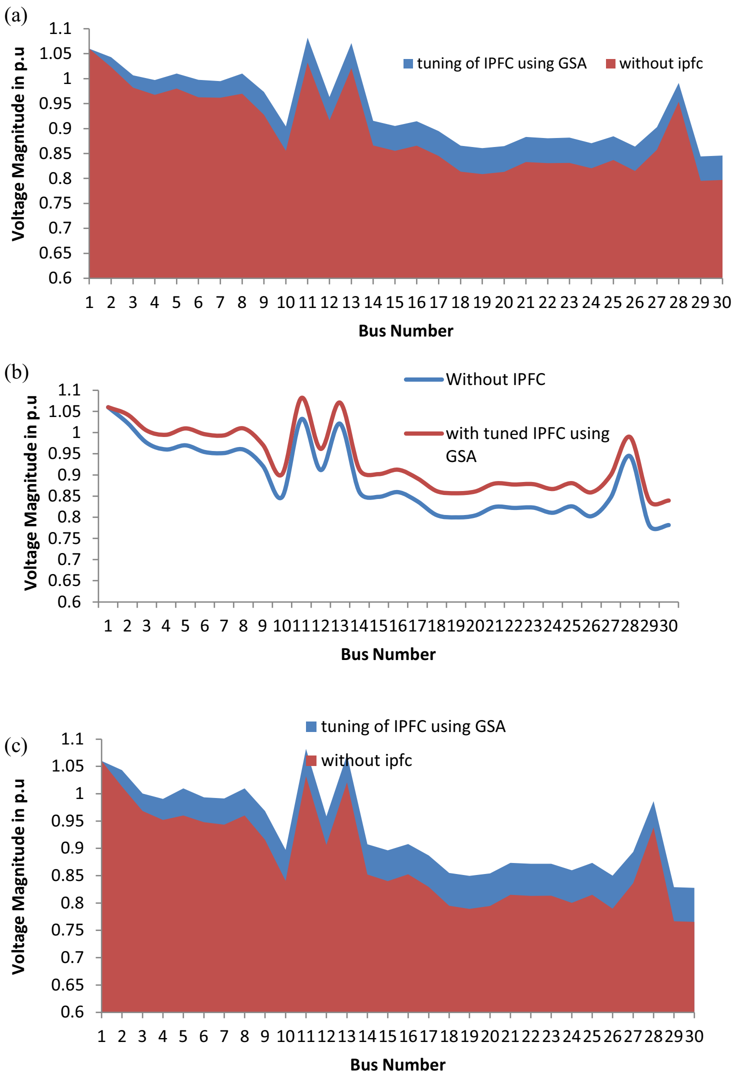

Fig. 10. Comparison of voltage profile without and with GSA tuned IPFC (a) normal loading (b) 110% loading (c) 125% loading.

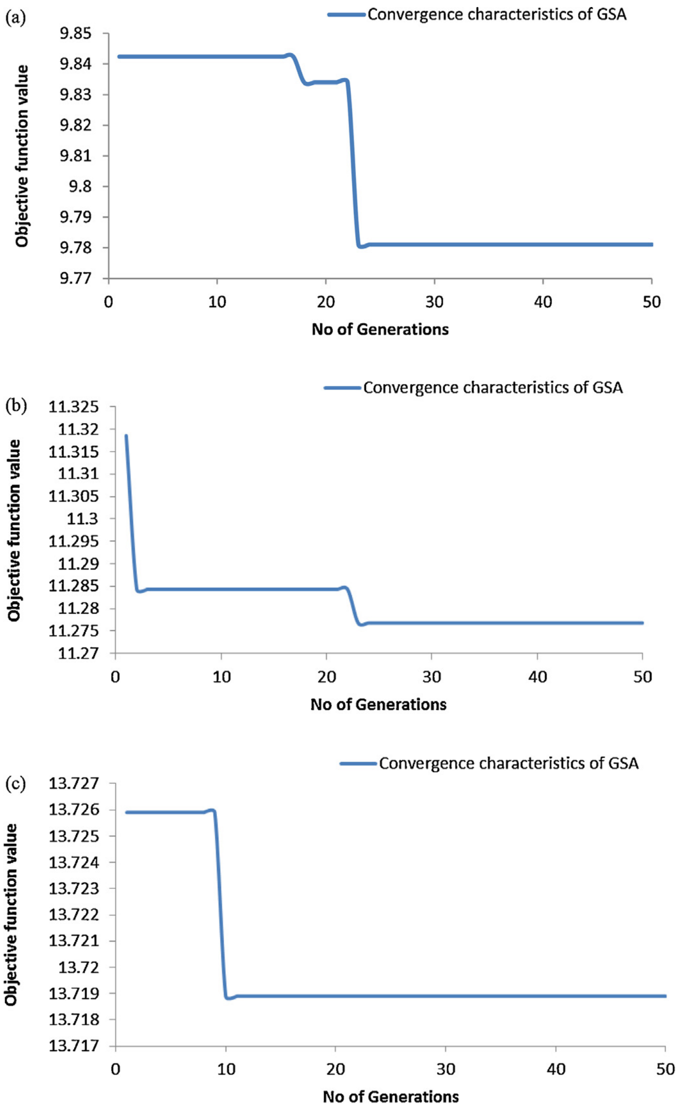

Fig. 11. Convergence characteristics of Gravitational Search algorithm (a) with normal loading (b) 110% loading (c) 125% loading.

Table 4
Comparison of real and reactive power loss for various system settings for all loads.

Loading condition	Loading condition	Without IPFC	Untuned IPFC	GSA tuned IPFC
Real power loss	Normal load	22.941	21.909	21.5766
	110% load	27.806	26.294	26.0795
	125% load	36.074	34.115	33.975
Reactive power loss	Normal load	107.37	101.334	100.853
	110% load	127.295	118.994	118.507
	125% load	160.733	149.791	149.263

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8. Conclusion

Congestion can prove to be very fatal to the transmission systems. Hence, reduction of congestion in the transmission lines is an issue of primary importance. In this paper,

- A Disparity Line Utilization Factor for the optimal placement of IPFC for congestion management has been implemented. It has been established that placement of IPFC using DLUF effectively reduces line congestion and power loss.
- A multi objective function comprising of reduction of active power loss, minimization of total voltage deviations, and maximization of security margin with the usage of minimum value of installed IPFC is considered for the optimal tuning of IPFC using Gravitational Search algorithm.
- Effect and importance of the GSA parameter for IPFC tuning have been supported. The proposed method is implemented in MATLAB software for IEEE-30 bus test system.
- The results have been presented and analyzed under normal loading, 110% loading and 125% loading condition to establish the effectiveness of the proposed method on the power system performance.
- Simulation results have demonstrated the effectiveness and accuracy of the Gravitational Search algorithm technique to achieve the multiple objectives and to determine the optimal parameters of the IPFC under different loading conditions.
- A reduction in real power loss, voltage deviation, size of the installed IPFC has been achieved with an improvement in the security margin of the system. The reduction of active and reactive power loss of the system is about 6% after the tuning of the IPFC device has been performed. The reduction in loss helps in congestion management of the system. Improvement in security margin protects the system against collapse. Decrease in size of the IPFC reduces the installation cost of the device. Hence the overall system performance has been improved at a minimum cost.

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