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DISPARITY LINE UTILIZATION FACTOR AND GALAXY-BASED SEARCH ALGORITHM FOR ADVANCED CONGESTION MANAGEMENT IN POWER SYSTEMS

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ABSTRACT

In this paper a new approach has been used for finding the optimal location for placing the Interline Power Flow Controller (IPFC). The IPFC is used to reduce the system loss and power flow in the heavily loaded lines and improve stability of the system. Here a new method, the Disparity Line Utilization Factor (DLUF) is used for determining the optimal placement of the (IPFC) to control the congestion in transmission lines. The DLUF ranks the transmission lines in terms of line congestion. The IPFC is accordingly placed in between the most congested and the least congested line connected to the same bus. The Galaxy-Based Search Algorithm (GBSA) is used for the optimal sizing of the IPFC. The results obtained by the proposed algorithm have been compared with that of the Genetic Algorithm (GA) to ascertain the effectiveness of the proposed method on the power system performance. The proposed method is tested on an IEEE 30 bus test system. It has been shown that by using the GBSA, the tuning of the IPFC further reduces congestion in the system by about 15%.

Keywords: Congestion; Galaxy-based search algorithm; Interline power flow controller; Line utilization factor; Optimal placement; Optimal tuning

1. INTRODUCTION

The task of maintaining power system security is one of the major concerns in competitive electricity markets driven by trade demands and regulations. Congestion mainly occurs when the power flow in the lines increases beyond the power transfer limits of the lines. It is therefore necessary to improve power delivery of the system by reducing power loss in the interconnected electric power system. One of the best methods for reducing this problem is using Flexible Alternating Current Transmission System (FACTS) devices. Hence, optimal placement and tuning of FACTS devices in a power system is mandatory. Singh et al., (2001); Kumar, et al., (2005); and Besharat and Taher, (2008) have suggested different methods for congestion management. Minguez et al., (2007) have proposed a method of optimal placement of the IPFC such that the load margin is maximized. Mandala and Gupta (2010) proposed a method to determine the optimal location of Thyristor Controlled Series Compensators (TCSC) for congestion management. Metaheuristic Algorithms have been employed for the optimal placement and tuning of FACTS devices to reduce congestion in transmission lines as noted by Reddy et al. (2010) and Acharya et al., (2007). Zhang (2006) presented an Optimal Power Flow (OPF) control in electric power systems incorporating IPFC with the minimum

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total capacity of the converters of IPFC and minimizing the total active power loss of the system for reducing congestion in the lines. Mohamed et al., (2010) have compared three variants of Particle Swarm Optimization (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.

FACTS devices are preferred in modern power systems based on the requirement and are found to deliver good solution, (Abdel-Moamen & Padhy, 2003). Out of all FACTS devices the IPFC is considered to be most flexible, powerful and versatile, (Hingorani & Gyugyi, 2000). FACTS devices like TCSC and Static Synchronous Series Compensator (SSSC) are also placed on the most congested line. However, the IPFC is a device connected to multiple transmission lines. In its simplest form it has at least two converters placed on two transmission lines connected to a common bus. Hence optimal placement and tuning of IPFC has been proposed based on a previous study (Teerthana & Yokoyama, 2004) and Kargarian and Falahati (2012). Nature inspired algorithms are among the most powerful algorithms for optimization (Yang, 2008). Galaxy-Based Search Algorithm is one of the most recent metaheuristic algorithms developed by H.S. Hosseini in 2011. GBSA is a heuristic optimization algorithm which has been gaining interest among the scientific community recently. GBSA is a nature inspired algorithm which imitates the action of spiral galaxy to search in its surroundings (Hosseini, 2011).

This paper proposes a Disparity Line Utilization Factor (DLUF) which is the difference of the Line Utilization Factors (LUF) between two lines for determination of the optimal location of the IPFC. It gives an estimate of the difference of the percentage of the number of lines 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 a maximum value of DLUF to reduce congestion and power loss in the system. The Galaxy-based Search algorithm has been used to optimize a multi-objective function comprising the reduction of active power loss, the minimization of total voltage deviations and the minimization of the security margin, using a minimum capacity value of an installed IPFC. Simulations on the proposed method are implemented and tested on an IEEE 30 bus system with different loading conditions.

2. DISPARITY LINE UTILIZATION FACTOR

Line Utilization Factor (LUF) is an index used for determining the congestion of the transmission lines. It is given by Equation 1,

$$LUF_{ij} = \frac{MVA_{ij}}{MVA_{ij\max}} \tag{1}$$

where LUF_{ij} is Line utilization factor (LUF) of the line connected to bus i and bus j, $MVA_{ij(max)}$ is the Maximum Mega-Volt Amphere (MVA) rating of the line between bus i and bus j and MVA_{ij} is the Actual MVA rating of the line between bus i and bus j.

The LUF gives an estimate of the percentage of lines being utilized and is an efficient method to estimate congestion in a line. For placement of the IPFC, there should be at least two lines connected to a common bus. Since, the 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 proposed for the optimal placement of an IPFC. The DLUF indicates the difference between the utilization values of the lines. It gives an estimate of the differences in the percentage of line being used for the power flow. All the lines are first ranked in descending order according to their line utilization factors. The line which has the first rank is considered to be the most congested line. The DLUF is calculated for all the lines connected to the line with the highest congestion. All the line pairs connected to the same bus are ranked on the basis of the DLUF. The line set that has highest value of DLUF is considered to be the optimal location of the IPFC for Congestion Management. Assuming both lines of same rating as shown in Equation 2.

$$DLUF_{(ij)-(ik)} = \left| LUF_{(ij)} - LUF_{ik} \right| \tag{2}$$

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

3. OPTIMAL TUNING OF THE IPFC

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

3.1. Objective Function

A multi-objective function is formulated and given in Equation 3.

$$MinF = Min \sum_{i=1 to 4} w_i \, f_i \tag{3}$$

$$w_1 + w_2 + w_3 + w_4 = 1 \tag{4}$$

where w_1, w_2, w_3, w_4 are the weighting factors:

3.2. Reduction of Loss

The expression for the reduction of active power loss is given in Equations 5 and 6,

$$\text{Minimize} \quad f_1(x) = \sum P_{loss} \tag{5}$$

$$P_{loss} = \left(|V_i|^2 G_{ik} - |V_i||V_k|[G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}] - |V_i||V_{sik}|[G_{ik}\cos\theta_{isik} + B_{ik}\sin\theta_{isik}] \right) + \left(|V_k|^2 G_{ik} - |V_i||V_k|[G_{ik}\cos\theta_{ki} + B_{ik}\sin\theta_{ki}] - |V_k||V_{sik}|[G_{ik}\cos\theta_{ksik} + B_{ik}\sin\theta_{ksik}] \right) \tag{6}$$

where, lk is the number of transmission lines, $V_L = V_L\angle\theta_l$ and $V_k = V_k\angle\theta_k$ are the voltages at the end buses l and k (k = m,n). $V_{slk} = V_{slk}\angle\theta_{slk}$ (k = m,n) is the series injected voltage source of k^{th} line, s stands for series, G_{lk} and B_{lk} are the transfer conductance and susceptance (B) is the imaginary part of admittance between bus l and k (k = m, n) respectively. The magnitude and phase angle of the series injected voltage of VSC1 and VSC2 are determined optimally.

3.3. Minimization of Voltage Deviation

To have a good voltage performance, the voltage deviation at each bus must be made as small as possible. The Voltage Deviation (VD) can be expressed by Equation 7:

$$f_2(x) = \min(VD) = \min\left(\sum_{k=1}^{Nbus} |V_k - V_k^{ref}|^2\right) \tag{7}$$

where $V_k$is the voltage magnitude at bus k.

3.4. Minimization of Security Margin

The security margin is given in Equation 8.

$$f_3(x,u,z) = 1 - SM = \frac{\sum_{j \in J_L} S_j initial}{\sum_{j \in J_L} S_j \lim} \tag{8}$$

3.5. Minimization of Total Capacity of the Installed IPFC

The total capacity of the installed IPFC is required for solving the overload on the transmission lines formulated as shown in Equation 9, where PQ is the capacity of each one of the Voltage-Source Converters (VSCs) of the IPFC.

$$PQ_1^2 + PQ_2^2 = \left(Vse_{ij} \left(\frac{\overline{V_i - Vse_{ij} - V_j}}{Z_{ij}} \right) \right)^2 + \left(Vse_{ik} \left(\frac{\overline{V_i - Vse_{ik} - V_k}}{Z_{ik}} \right) \right)^2 \tag{9}$$

The generalized procedure for placement and tuning of the IPFC for congestion management has been mentioned in Figure 1.

4. GALAXY-BASED SEARCH ALGORITHM

The Galaxy-Based Search Algorithm (GBSA) is a nature-inspired, meta-heuristic algorithm proposed by Hamed Shah-Hosseini in 2011. The GBSA imitates the spiral arm of the spiral galaxies to search within its surroundings. The GBSA, which is based on the variable neighborhood search algorithm, has two main components.

4.1. Spiral Chaotic Move

It actually mimics the spiral arm nature of galaxies. It searches around the current solution (SG) by spiral movement. This movement uses some chaotic variables around the current best solution. If it obtains a better solution than the current solution, it immediately updates and goes for the local search to obtain a more suitable solution around the newly updated solution.

4.2. Minimization of Voltage Deviation

This component is activated to search locally around the newly updated solution. The local search ensures the exploitation of search space and the spiral chaotic move provides exploration of the search space ensuring results towards the global optimum solution. Parameters of the GBSA are shown in Figure 1.

4.3. Algorithm

STEP1 : Generate the initial Solution F given in Equation 8.

STEP2 : Local search (SG) searches the space around the given Solution S with small step sizes. Then it gradually increases the step sizes to explore the search spaces faster. At the end, it returns the locally best solution found around the given Solution S.

STEP3 : While the condition is not satisfied, then the flag is set to false.

STEP4 : Spiral chaotic move is the first component in the loop, which globally searches around the solution SG. It stops searching whenever it reaches a solution better than SG (or) it exceeds Max Rep.

STEP5 : If flag is set to true, then the local search is called to search locally around the newly updated solution SG.

STEP6 : The above process is repeated until a stopping condition is satisfied.

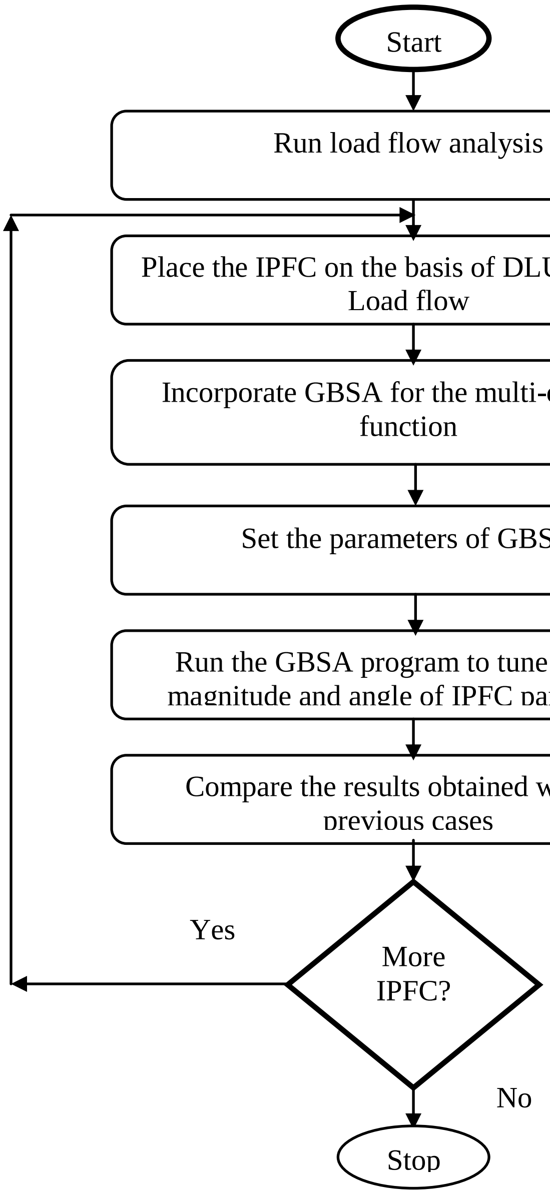

Figure 1 Flow chart for generalized procedure for incorporation of IPFC in a power system

5. RESULTS AND DISCUSSION

5.1. Placement of the IPFC

An IEEE 30 bus test system is considered as shown in Figure 2. In the IEEE 30 bus system bus no. 1 is considered as a slack bus and bus nos. 2, 5, 8, 11, 13 are considered as PV buses while all other buses are load buses. This system has 41 interconnected lines. The IEEE 30 bus test system load flow is obtained using MATLAB Software. Only load buses are considered for the IPFC placement. Equal weights of 0.25 have been considered for all objectives. The results have been analyzed for normal loading. LUF values of all the lines without IPFC have been presented in Table A1. It is established that line 3-4 is the most congested line connected with LUF 0.8415 p.u between the load buses. All possible DLUF index calculations for line 3-4 have been shown in Table 1 as test cases.

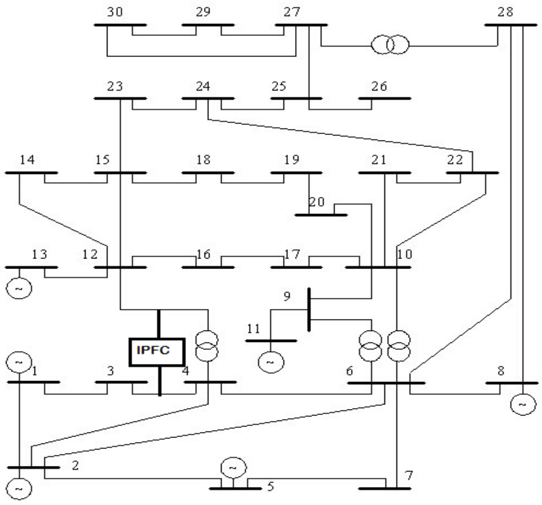

Figure 2 IEEE 30 Bus Test System with IPFC installed at line connected between buses 3-4 and 4-12

Table 1 IPFC Placement on the basis of DLUF

S. No.	Line 1 From Bus-To Bus	Line 2 From Bus-To Bus	LUF Line1 (p.u)	LUF Line 2 (p.u)	DLUF (p.u)	LUF of Line1 after placement of IPFC (p.u)
Case-1	3-4	4-6	0.8415	0.7173	0.1242	0.8365
Case-2	3-4	4-12	0.8415	0.5284	0.3131	0.8341

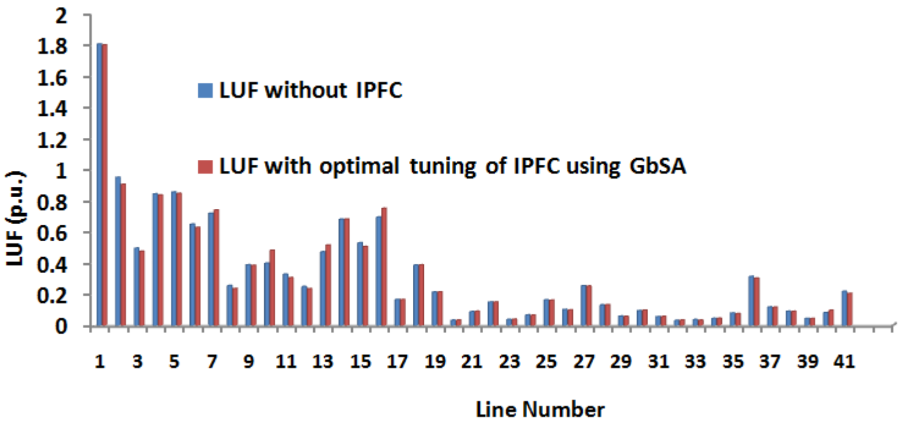

Figure 3 Comparison of LUF of lines of 30 bus test system without the IPFC and with the optimally tuned IPFC

As observed in Table A1, the line connected between buses 3-4 was the most congested line connected to the loaded bus. In the 30 bus system, two lines were connected to line 3-4. So, two test cases for the IPFC placement have been considered. The DLUF has been calculated for each test case, as shown in Table 1. It was observed that the DLUF was maximum between lines connected to buses 3-4 and 4-12. The IPFC was placed in each of the test locations and the LUF value of the line 3-4 is as presented in Table 1. It was observed that LUF for line 3-4 was found to be lower, when the IPFC was placed in locations 3-4 and 4-12, which is the proposed location for the IPFC placement on the basis of the DLUF. Hence, lines connected between buses 3-4 and buses 4-12 have been selected for the optimal placement of the IPFC. It is observed from Table 1 that the placement of the IPFC at the proposed location reduces the LUF of line 3-4 from 0.8415 to 0.8341.

5.2. Tuning of the IPFC

After the IPFC has been optimally placed, the Galaxy-Based Search Algorithm is used to properly tune the IPFC at the specified location. The values of the GBSA parameters used for tuning the IPFC have been mentioned in Tables 2A and 2B. The LUF values of all lines after the tuning of IPFC have been mentioned in Table A1. It is observed that the optimal tuning of the IPFC at the proposed location further reduces the congestion in line 3-4 to 0.8338 p.u. The LUF values before and after placement of the tuned IPFC have been compared in Figure 3. The results obtained by the GBSA have been compared with GA in this study. The parameters ofthe Genetic Algorithm (GA) used for tuning the IPFC have been mentioned in Table 3.

Table 2 Galaxy-based search parameters for IPFC tuning

A. Spiral Chaotic Move:

Parameters	Value
Max Rep	150
Δr	0.001
$\Delta\theta$	0.01
a	4

B. Local Search:

Parameters	Value
Kmax	100
ΔS	10
S step size	0.0001
I step size	0.05

Table 3 Parameters of the genetic Algorithm for tuning IPFC

Sl. No.	Parameter	Value
1.	Population Size	20
2.	Maximum generations	50
3.	Stall gen. limit	100
4.	Time limit	300

Voltage deviation, security margin, capacity of installed IPFC, and the real and reactive power loss of the system under different system conditions have been compared in Figures. 4, 5, 6, 7 and 8, respectively. All the objective function values have been minimized after tuning the IPFC with the GBSA. In comparison to the GA, the objective of minimization of the multi-objective function is better obtained through the GBSA. It was observed that the active and reactive power loss of the 30 bus system has been reduced from 22.941MW, 107.370MVAR to 21.909MW, 101.334MVAR after the optimal tuning of the IPFC with GBSA. Table 4 provides the value of IPFC parameters after tuning, using GBSA for normal load.

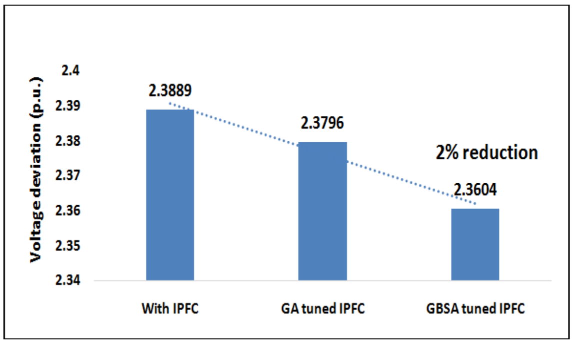

Figure 4 Comparison of voltage deviation for various system conditions

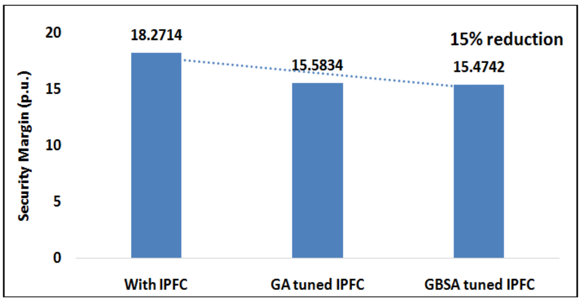

Figure 5 Comparison of security margin for various system conditions

The voltage profile of the IEEE 30 bus system with and without the optimally tuned IPFC for normal load has been compared in Figure 9. It is observed that the voltage at the buses was improved by a good extent with the optimal tuning of IPFC using GBSA.

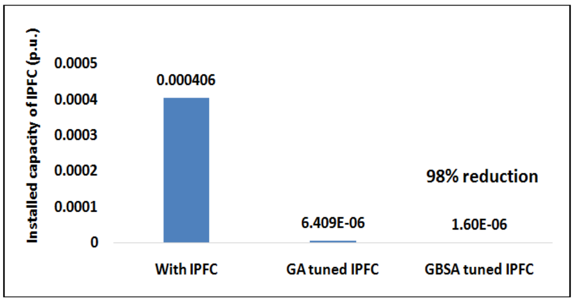

Figure 6 Comparison of installed IPFC capacity for various system conditions

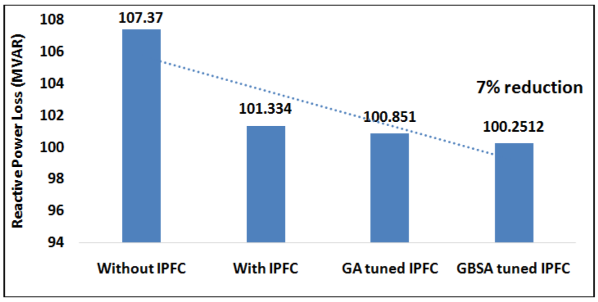

Figure 8 Comparison of reactive power loss for various system conditions

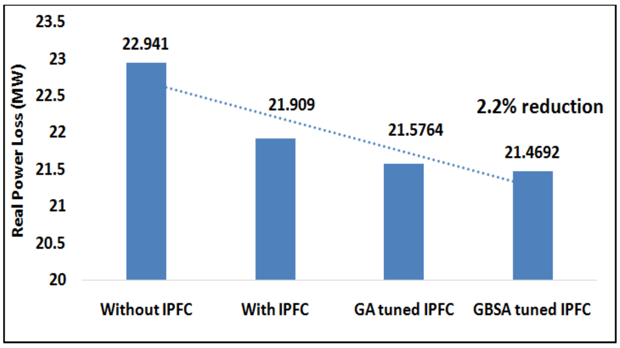

Figure 7 Comparison of real power loss for various system conditions

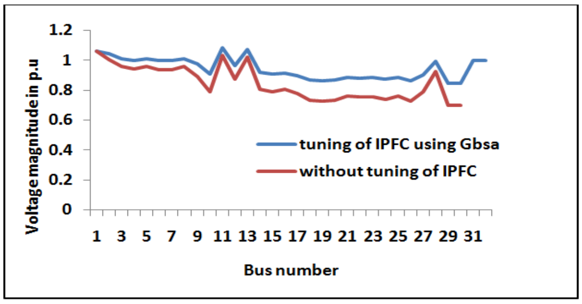

Figure 9 Comparison of Voltage Profile without and with GBSA tuned IPFC

Table 4 IPFC parameters before and after tuning for IEEE 30 bus test system

IPFC parameters	Untuned IPFC	Tuning of IPFC using GBSA
VSe1	0.0050	0.00128
VSe2	0.0100	0.0083
Θse1	-159.8295	-88.38
Θse2	180	-102.8745

6. CONCLUSION

In this paper congestion management has been implemented using a Disparity Line Utilization Factor for the optimal placement of the IPFC. It can be observed that placement of the IPFC using the DLUF effectively reduces line congestion and power loss. A multi- objective function comprising reduction of active power loss, minimization of total voltage deviations, and minimization of a security margin with the usage of the minimum value of installed IPFC is considered for the optimal tuning of IPFC using the Galaxy-Based Search Algorithm. The effect and importance of the GBSA parameters for IPFC tuning has been supported. The results have been presented and analyzed under normal loading to verify the effectiveness of the proposed method on the power system performance. It was observed that placement of IPFC by the proposed methodology caused an effective reduction in congestion in the lines. Tuning of the IPFC using the GBSA further reduces the congestion in the system by 15%. The results of the simulation show the effectiveness and accuracy of the proposed 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, and a security margin has been achieved with a much smaller capacity of installed IPFC. Hence, the overall system performance has been improved at a minimum cost.

7. REFERENCES

Abdel-Moamen, M.A., Padhy, N.P., 2003. Optimal Power Flow Incorporating FACTS Devices-bibliography and Survey. *IEEE PES Transmission and Distribution Conference and Exposition*, pp. 669–676

Acharya, N., Mithulananthan, N., 2007. Locating Series FACTS Devices for Congestion Management in Deregulated Electricity Markets. *Electric Power Systems Research*, Volume 77, pp. 352–360

Besharat, H., Taher, S.A., 2008. Congestion Management by Determining Optimal Location of TCSC in Deregulated Power Systems. *Electrical Power and Energy Systems*, Volume 30, pp.563–568

Hingorani, N.G., Gyugyi, L., 2000. Understanding FACTS: Concepts and Technology of Flexible AC Transmission System. *IEEE Press*

Hosseini, H.S., 2011. Principal Components Analysis by the Galaxy-based Search Algorithm: A Novel Metaheuristic for Continuous Optimization. *Int. J. of Computational Science and Engineering*, Volume 6, pp.132–140

Kargarian, B., Falahati, 2012. Multiobjective Optimal Power Flow Algorithm to Enhance Multi-microgrids Performance Incorporating IPFC. *2012 IEEE Power and Energy Society General Meeting*, San Diego, CA, 22-26 July 2012, pp.1–6

Kumar, A., Srivastava, S.C., Singh, S.N., 2005. Congestion Management in Competitive Powermarket: A Bibliographical Survey. *Electric Power Systems Research*, Volume 76, pp.153–164

Mandala, M., Gupta, C.P., 2010. Congestion Management by Optimal Placement of FACTS Device. *2010 Joint International Conference on Power Electronics, Drives and Energy Systems (PEDES) & 2010 Power India*, 20-23 December, pp.1–7, New Delhi, India

Minguez, R., Milano, F., Zarate-Minano, R., Conejo, A.J., 2007. Optimal Network Placement of SVC Devices. *IEEE Trans. on Power Systems*, Volume 22, pp. 1851–1860

Mohamed, K.H., Rama Rao, K.S., Hasan, K.N.Md., 2010. Application of Particle Swarm Optimization and Its Variants to Interline Power Flow Controllers and Optimal power Flow. *International Conference on Intelligent and Advanced Systems* (ICIAS), 15th-17th June, pp.1–6

Reddy, S.S., Kumari, M.S., Sydulu, M., 2010. Congestion Management in Deregulated Power System by Optimal Choice and Allocation of FACTS Controllers using Multi-objective Genetic Algorithm. *IEEE PES Transmission and Distribution Conference and Exposition*, Latin America

Singh, S.N., David, A.K., 2001. Optimal Location of FACTS Devices for Congestion Management. *Electric Power System Research*, Volume 58, pp.71–79.

Teerthana, S., Yokoyama, A., 2004. An Optimal Power Flow Control Method of Power System using Interline Power Flow Controller (IPFC), TENCON 2004. *IEEE Region 10 Conference 3*, pp. 343–346

Yang X.S., 2008. *Nature-inspired Metaheuristic Algorithms*, Luniver Press

Zhang, J., 2006. Optimal Power Flow Control for Congestion Management by Interline Power Flow Controller (IPFC). *International Conference on Power System Technology, PowerCon 2006*, 22-26 October, pp.1–6