A HYBRID APPROACH FOR IPFC LOCATION AND PARAMETERS OPTIMIZATION FOR CONGESTION RELIEF IN COMPETITIVE ELECTRICITY MARKET ENVIRONMENT

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***Abstract*— The deregulated power system operation with competitive electricity market environment has been created many challenging tasks to the system operator. The competition with strategic bidding has been resulted for randomness in generation schedule, load withdrawal and power flows across the network. The economic efficiency of electricity market is mainly dependent on network support. In the event of congestion, it is required to alter the base case market settlement and hence the economic inefficiency in terms of congestion cost can occur. In order to anticipate congestion and its consequences in operation, this paper has been considered Interline Power Flow Controller (IPFC). A strategic approach is proposed for optimal location and then its parameters in Decoupled Power Injection Modelling (DPIM) are optimized using a new heuristic algorithm Gravitational Search Algorithm (GSA). The case studies are performed on IEEE 30-bus test system and the results obtained are validating the proposed approach for practical implementations.**

Keywords*— *Deregulated power system, competitive electricity market, congestion management, IPFC, Gravitational Search Algorithm (GSA)

I. INTRODUCTION

The recent blackouts around the world have provided a movement for creating improvement in the operational security of interconnected power systems. Operational security management is highly challenging task and even more so in the presence of strategic market players, with both load fluctuations and abnormalities. Since network and market operations strongly coupled, any change in system operational security impacts the market economics and vice-versa. While the nature of the interactions between system security and market operations is well understood qualitatively, the quantification of operational security impacts on the overall market economics is, typically, not performed. In this paper, we proposed an approach to quantify the dependence of the performance of electricity market on the operational security taking into an account the interactions of the electricity markets and the presence of strategic bidding and load variations. We illustrate the application of strategic bidding to the IEEE-30 bus system for the study of its impacts of changing load periodically in a day-ahead energy market.

We also planned to mitigate congestion by the integration of Flexible AC Transmission Systems (FACTS) devices in the network. The approach to mitigating system congestion is technically through system reconfiguration and re-dispatch. This has not much before or after the deregulation and is proved a security constrained economic dispatch. The major difference between before and after deregulation lies in the financial settlement. Congestion is a major concern in the present competitive electricity market because it hinders free competition in electricity trade. The present trend in congestion management is to use pricing tools in the form of nodal and zonal pricing. Despite these tools, the congestion is still in the place and it is increasing alarmingly. Congestion management includes both the congestion relief actions and the associated pricing mechanisms [1]. Congestion relief by re-dispatch will causes to increase generation cost and hence by means of reconfiguration, erection of new transmission lines or integration of FACTS device can adopt. But due to Right of Way (RoW) and cost concerns, instead of erection of new transmission lines FACTS devices can be the better option. Since congestion is uneconomical and undesirable in market operation as well as system security, the validation of FACTS devices should address technical as well as economical benefits. Among all the FACTS devices Interline Power Flow Controller (IPFC) is a versatile device to control power flow in many transmission lines simultaneously. Several references in technical literature can be found on application of IPFC for congestion management. In [2], the IPFC is applied for congestion relief, power flow control and to minimize the transmission losses. In [3], the congestion relief has been achieved by the application of IPFC and GUPFC in strategic bidding environment. The impact of these FACTS devices as shown economically via reduction in transmission congestion cost.

This paper is organized as follows: After introduction, section II describes the market settlement mechanism in competitive electricity market. In section III, the power injection modeling (PIM) of IPFC, strategy for its location are explained. In section IV, the heuristic optimization technique GSA application for optimization of IPFC parameters is explained. In section V, the case studies and discussions are illustrated with IEEE-30 bus system network. After section V, the comprehensive conclusions are given.

II. COMPETITIVE ELECTRICITY MARKET

The strategic bidding is a process of change in bid functions to maximize GENCOs' profit. In a perfect competitive market, the supply curve created by aggregating generator offers should closely approximate the system marginal production cost of generation [4]. Hence the bidding cost function treated as a continuous function and is given by a power producer *i* (or supply curve) is:

$$C_{bi}\left(P_{gi}\right) = a_{bi}P_{gi}^{2} + b_{bi}P_{gi} + c_{bi} \tag{1}$$

where (a_{bi}, b_{bi} and c_{bi}) are the bid coefficients and related with the actual cost function coefficients (a_i, b_i and c_i) as follows:

$$\xi_i = \frac{a_{bi}}{a_i} = \frac{b_{bi}}{b_i} \text{ and } c_{bi} = c_i \tag{2}$$

where ξ_i is the bidding parameter and represents mark-up above or below the marginal cost that a generator *i* decide to set its marginal bid in competitive market. Now, the marginal cost function will become as:

$$C_{bi}\left(P_{gi}\right) = \xi_i a_i P_{gi}^{2} + \xi_i b_i P_{gi} + c_i \tag{3}$$

Then the equations for P_{gi} and λ_{MCP} will change as follows and the rest of procedure is as economic dispatch problem.

$$\lambda_{MCP} = \frac{P_D + \sum_{i \in NG} \frac{b_i}{2\xi_i a_i}}{\sum_{i \in NG} \frac{1}{2\xi_i a_i}} \tag{4}$$

$$P_{gi} = \frac{\lambda_{MCP} - \xi_i b_i}{2\xi_i a_i} \tag{5}$$

Now considered the effect of generator limits given by the inequality constraint:

$$0 \le P_{gi} \le P_{gi}^{\max} \qquad \forall i \in NG \tag{6}$$

If a particular generator loading P_{gi} reaches the maximum limit $P_{gi}^{\max}$, its loading is held fixed at this value and the balance load is shared between the remaining generators on an equal incremental cost basis.

III. INTERLINE POWER FLOW CONTROLLER

Objective of Interline Power Flow Controller (IPFC) is to provide a comprehensive power flow control scheme for a multi-line transmission system, in which two or more lines employ a Static Synchronous Series Compensator (SSSC) for series compensation as shown in Fig. 1. The IPFC scheme has the capability to transfer real power between the compensated lines in addition to executing the independent and controllable reactive power compensation of each line. The capability of IPFC makes it possible to equalize both real power and reactive power flow between the lines, to transfer demand from overloaded to under-loaded lines to compensate against resistive line voltage drops and the corresponding reactive line power and to increase the effectiveness of the compensating system for dynamic disturbance like transient stability and power oscillation [5].

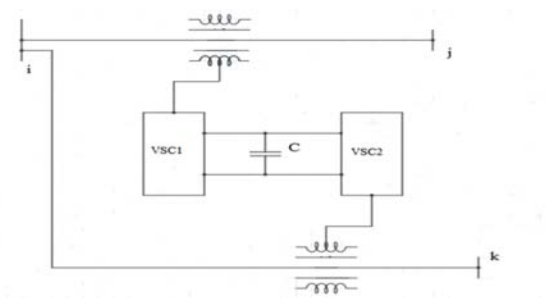


Fig.1 Schematic representation of IPFC

Fig.2 represents the equivalent circuit of the IPFC. This arrangement has two synchronous voltage sources with phasors V_{1pq} and V_{2pq} in series with transmission Lines 1 and 2, represent the two back to back dc to ac inverters. The common dc link is represented by a bidirectional link ($P_{12}=P_{1pq}=P_{2pq}$) for real power exchange between the two voltage sources. Transmission Line-1, represented by reactance X1, has a sending end bus with voltage phasor V_{1S} and a receiving end bus with voltage phasor V_{1R}. The sending end voltage phasor of Line- 2 represented by reactance X_2 is V_{2S} and the receiving end voltage phasor is V_{2R}.

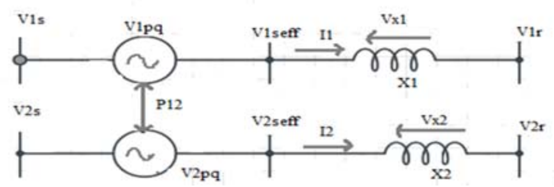


Fig.2 equivalent circuit of IPFC

A. Injection model of IPFC

Fig.3 shows the equivalent circuit of two converter IPFC. V_i , V_j and V_k are the complex bus voltages at the buses *i, j* and *k* respectively.

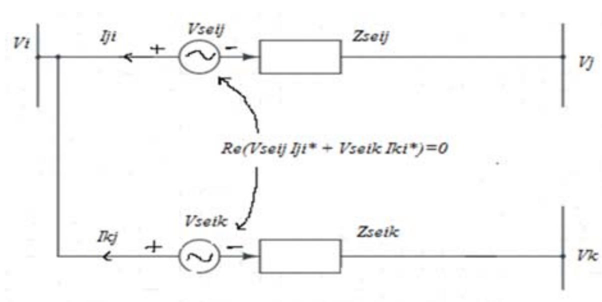


Fig.3 Equivalent circuit of two converter IPFC

The current source can be represented as follows

$$I_{se_{in}} = -jb_{se_{in}} V_{se_{in}} \tag{7}$$

Now, the current source can be modeled as injection powers at the buses *i, j* and *k*. the complex power injected at i[th] bus is

$$S_{inj,i} = \sum_{n=j,k} V_i (-I_{se_{in}})^* \tag{8}$$

$$S_{inj,i} = \sum_{n=j,k} V_i (jb_{se_{in}} V_{se_{in}})^* \tag{9}$$

After simplification, the active power and reactive power injections at i^{th} bus are

$$P_{inj,i} = \mathrm{Re}(S_{inj,i}) = \sum_{n=j,k} (V_i b_{se_{in}} V_{se_{in}} \sin(\theta_i - \theta_{se_{in}}))$$

(10)

$$Q_{inj,i} = \mathrm{Im}(S_{inj,i}) = \sum_{n=j,k} (V_i b_{se_{in}} V_{se_{in}} \cos(\theta_i - \theta_{se_{in}}))$$

(11)

The complex power injected at n^{th} bus (n=*j*,*k*) is

$$S_{inj,\mathrm{n}} = \sum_{n=j,k} V_n (-I_{se_{in}})^* \tag{12}$$

$$S_{inj,\mathrm{n}} = \sum_{n=j,k} V_n (jb_{se_{in}} V_{se_{in}})^* \tag{13}$$

After simplification, the active power and reactive power injections at n^{th} bus are

$$P_{inj,\mathrm{n}} = \mathrm{Re}(S_{inj,\mathrm{n}}) = \sum_{n=j,k} (V_n b_{se_{in}} V_{se_{in}} \sin(\theta_n - \theta_{se_{in}}))$$

(14)

$$Q_{inj,n} = \mathrm{Im}(S_{inj,n}) = \sum_{n=j,k} (V_n b_{se_{in}} V_{se_{in}} \cos(\theta_n - \theta_{se_{in}}))$$

(15)

The placement of IPFC plays a vital role for congestion management. Placement of IPFC can be done with different optimization techniques, among all optimization techniques Particle Swarm Optimization gives precise and quick results. So, in this paper optimal location of IPFC is done by using PSO. After placement, parameters of IPFC are very important, optimal parameters can be chosen based on the location. In this paper for optimal parameters are done by using GSA.

IV. PROPOSED HYBRID APPROACH

The placement of IPFC plays a vital role for congestion management. Placement of IPFC can be done with different optimization techniques, among all optimization techniques Particle Swarm Optimization (PSO) gives precise and quick results. So, in this paper optimal location of IPFC is done by using PSO with an objective of voltage profile improvement. After placement, the IPFC parameters are optimized by using GSA technique.

A. *PSO for voltage improvement*

The aim of optimization is to determine the best suited to a problem under a given set of constraints. In computer science, particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality [13]. PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search space according to simple mathematical formulae over the particle position and velocity.

Basic algorithm is proposed by Kennedy and Eberhart

x_i^k - Particle position

v_i^k - Particle velocity

p_i^k- Best remembered individual particle position

p_k^g- Best remembered swarm position

C_1, C_2 - cognitive and social parameters

r_1, r_2 - random numbers between 0 and 1

Position of individual particles updated as follows

$$x_i^{k+1} = x_i^k + v_i^{k+1} \qquad (16)$$

With the velocity calculated as follows

$$v_i^{k+1} = v_i^k + c_1 r_1 (p_i^k - x_i^k) + c_2 r_2 (p_k^g - x_i^k) \qquad (17)$$

Algorithm of particle swarm optimization

Step by step algorithms as follows:

1. Initialize
   a. a. Set constants $k_{\max}$, c_1 , c_2 .
   b. Randomly initialize particle positions x_0^i ϵ D in IR^n for *i =1,…..,p.*
   c. Randomly initialize particle velocities $0 \le v_0^i \le v_0^{max}$ ϵ D in IR^n for *i =1,…..,p.*
   d. Set *k* =1.

2. Optimize
   a. Evaluate function value f_k^i using design space coordinates x_k^i .
   b. If $f_k^i \le f_{best}^i$ then $f_{best}^i = f_k^i$, $p_k^i = x_k^i$
   c. If $f_k^i \le f_{best}^g$ then $f_{best}^g = f_k^i$, $p_k^g = x_k^i$
   d. If stopping condition is satisfied then go to 3.
   e. Update particle velocities v_k^i for *i =1,…..,p.*
   f. Update particle positions x_k^i for *i =1,…..,p.*
   g. Increment *k.*
   h. go to 2(a).

3. Terminate.

B. *GSA for optimizing parameters of IPFC*

In the proposed algorithm, agents are contemplated as objects and their performance is measured by their masses. All these agents attract each other by the gravity force, and this force occasions a global movement of all agents towards the agents with heavier masses. Hence, masses collaborate using a direct form of communication, through gravitational force. The ponderous masses, which correspond to best solutions, move more slowly than lighter ones, this assurance the exploitation step of the algorithm [11].

In GSA, each mass (agent) has four specifications: position, inertial mass, active gravitational mass, and passive gravitational mass. The position of the mass correlate with panacea of the problem, and its gravitational and inertial masses are determined using a fitness function.

The GSA could be treated as a separate system of masses. It is like a small synthetic world of masses obeying the Newton laws of gravitation and motion.

Algorithm of gravitational search algorithms as follows
Step1. Search space identification.
Step2. Generate initial population between minimum and
maximum values.
Step3. Fitness evaluation of agents.
Step4. Update G(t), best(t), worst(t) and Mi(t) for i = 1,2,. .,m.
Step5. Calculation of the total force in different directions.
Step6. Calculation of acceleration and velocity.
Step7. Updating agent's position.
Step8. Repeat step 3 to step 7 until the stop criteria is reached.
Step9. Stop.

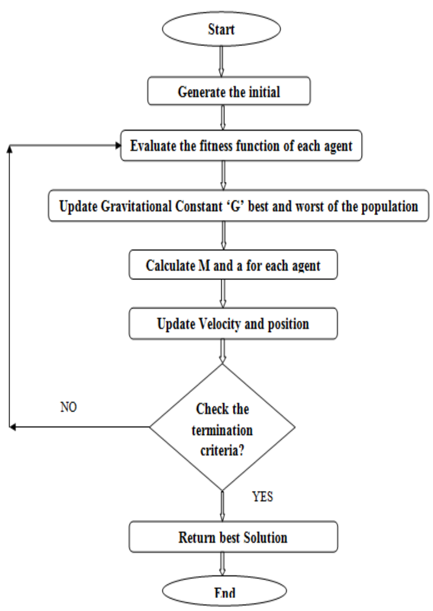


Fig.4 Gravitational search algorithm flow chart

V. CASE STUDIES

The proposed is approached is applied for IEEE-30 bus system. The cost coefficients are manipulated according to according to strategic bidding parameter. The total system has been divided into two areas in which area1 has generator buses 1 and 2, area2 has generator buses 13, 22, 23 and 27. With normal bidding parameter and for base case load, the generation schedule has been determined as explained in section II. In area 1, The market is cleared at 3.5233 $/MWh and the total cost is 243.2242 $. Similarly, in area 2 the market is cleared at 3.9605 $/MWh and the total cost is 396.4005 $. In order to optimize economics in both areas simultaneously, the system is considered as one grid consisting of two areas. Under this consideration, the total load is 193.451 MW. For this load the market schedule is cleared at 3.8155 $/MWh and total cost is 630.3476 $. The market schedules for area1 and area2 when they are not interconnected are given in Table I and Table II respectively. When they are interconnected, the schedule is given in Table III. By observing market schedules in both cases, there is a economic benefit with MW interchange between two areas. Since area1 has producing more generation than its own load of 88.751 MW, area 2 importing power from area 1 about 17.5935 MW. If the network supports for this economic interchange, system operator can reduce a total operating cost of 9.277 $. With this schedule the load flow is performed and we have observed the line 10 is overloaded. If a network subject to congestion, the IPFC has to control the power flow in such a way that all transmission lines are below their specified power ratings and so congestion impact on economic interchange can avoid. By placing IPFC in the lines connected between buses 10, 16 and 22. The congestion has been relieved and so market economic inefficiency situation is avoided. In addition to this the voltage profile has been improved and it can observe in Fig.5 and also the losses has been reduced from 9.7146 MW to 7.7402 MW.

TABLE I. AREA 1 GENERATION AND COST DETAILS

Load (MW)	PG1 (MW)	PG2 (MW)	MCP ($/MWh)	Total Cost ($)
88.751	33.3395	50.6672	3.5233	243.2242

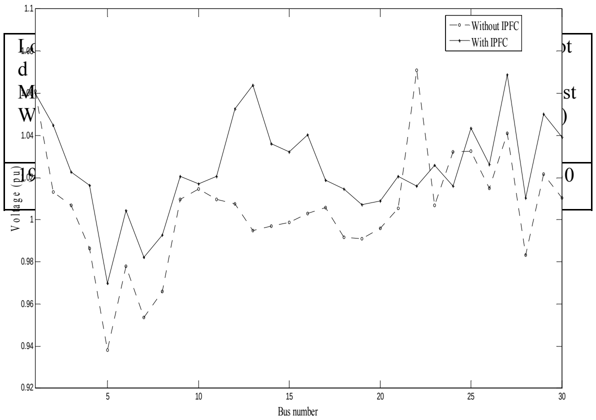
TABLE II. AREA 2 GENERATION AND COST DETAILS

Load (MW)	PG1 (MW)	PG2 (MW)	PG3 (MW)	PG4 (MW)	MCP ($/MWh)	Total Cost ($)

104.7	22.58	23.68	19.21	42.59	3.96	396.4

TABLE III. INTERCONNECTED SYSTEM DETAILS

Fig. 5 Changes in voltage profile at base case



The similar procedure is carried out for various loading level at various trading hours with different bidding parameters in different areas. The changes in load for 24 hours span in the form of a load curve are given in Fig.6.

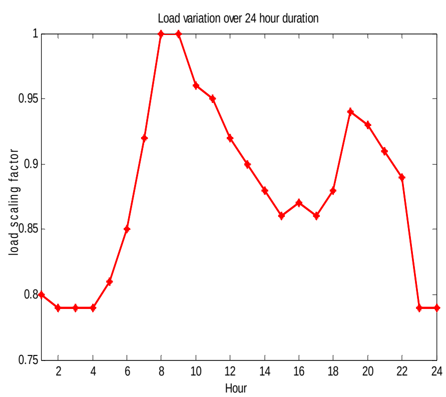


Fig.6 Load curve over 24 hours

The economic and power interchanges for different bidding parameters are shown in Fig.7 and Fig.8. Fig.7 shows when bidding parameters (Area1, Area2) = (0.5, 0.5) = (1, 1) = (2, 2). Fig.8 shows when bidding parameters (Area1, Area2) = (1, 0.5) = (2, 1).

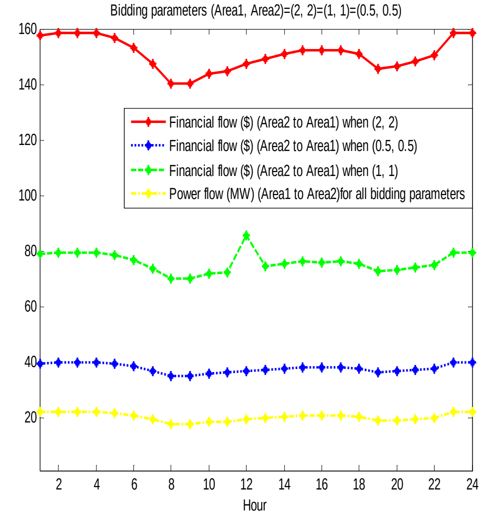


Fig.7 Financial and Power Interchanges

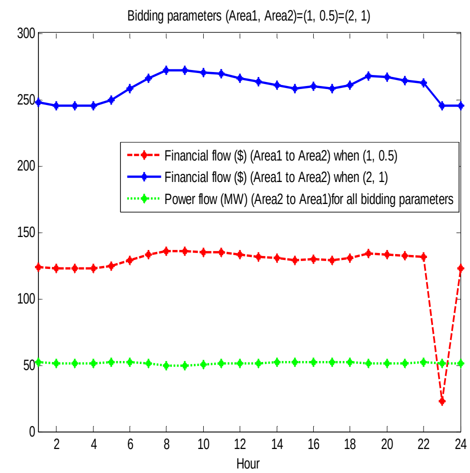


Fig.8 Financial and Power Interchanges

The congestion alleviation is occurred after connected the IPFC. These results are shown in Fig.9 and Fig.10

.Fig.9 shows the congestion alleviation when bidding parameters (Area1, Area2) = (0.5, 0.5) = (1, 1) = (2, 2). During this strategic bidding congestion is occurred in 10th line, when the load at 8, 9 and 10th hours. This congestion is mitigated by installing IPFC

Fig.10 shows the congestion alleviation when bidding parameters (Area1, Area2) = (1, 0.5) = (2, 1). During this strategic bidding congestion is occurred in 30th line, except the load at 5th hour. This congestion is mitigated by installing IPFC.

In both Fig.9 and Fig.10 the difference of loading on the lines without and with IPFC are shown.

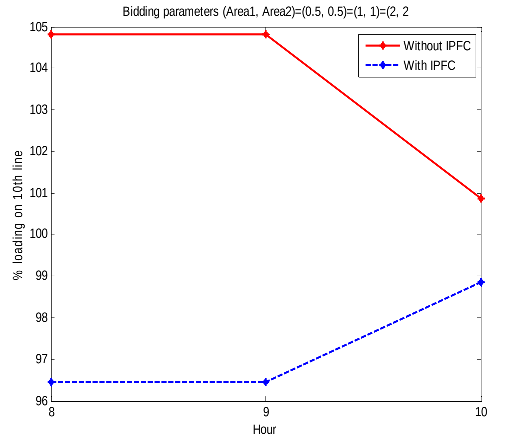


Fig.9 congestion relief in line 10 with IPFC

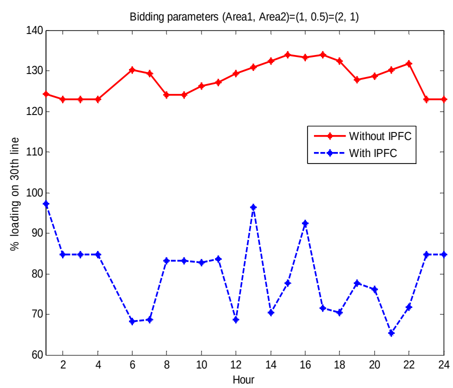


Fig.10 congestion relief in line 30 with IPFC

VI. CONCLUSIONS

This paper reviews the competition with strategic bidding in interconnected systems. In addition to this, the stress due to strategic bidding is increased; it leads to congestion in the system. This congestion is alleviated by installing IPFC in proposed IEEE 30-bus system. The case studies are performed on IEEE 30-bus test system and the results obtained are validated the proposed approach for practical implementation. This paper includes only generation side bidding, it will be useful for further study on both generation side and distribution side biddings.

REFERENCES

[1] Lommerdal, M. Soder, L., “simulation of congestion management Methods”, IEEE Power Tech, Bologna, Volume 2, 23-26 June 2003.

[2] Zhang, J., "Optimal Power Flow Control for Congestion Management by Interline Power Flow Controller (IPFC)," Power System Technology, 2006. PowerCon 2006. International Conference on , vol.,no., pp.1,6, 22-26 Oct. 2006.

[3] Kumar, Ashwani, "Comparison of IPFC and GUPFC for congestion management in deregulated electricity markets," Industrial and Information Systems (ICIIS), 2014 9th International Conference on , vol., no., pp.1,7, 15-17 Dec. 2014.

[4] J. Vara Prasad, K Chandra Sekhar, “ Evaluation of available transfer capability in a competitive energy market”, IEEE Transc.

[5] Narain G. Hingorani, Laszlo Gyugyi, “ Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems”, IEEE press, New-York, 2000.

[6] S.C.Srivastava, R.K.Verma, “Impact of FACTS devices on Transmission pricing in a de-regulated electricitymarket”, IEEE Trans. 2000,pp. 642-648.

[7] Gyugyi, L.Sen, K.K. and Schauder, C.D, “ The interline power flow controller concept a new approach to power flow management in transmission systems”, IEEE Trans. Power Del..14(3), pp. 1115-1123.

[8] A. Karami, M. Rashidinejad and A.A. Gharaveisi, “Voltage security enhancement and congestion management via STATCOM & IPFC using artificial intelligence”, Iranian Journal of Science & technology, Trans.B,Engineering, Vol.31, No.B3, PP 289-301.

[9] Kennedy Mwanza, You Shi, “Congestion Management: Re-dispatch And application of FACTS”, Chalimers university of technology, Goteborg, Sweden, 2006.

[10] Charles A. Gibson, Harold Zuniga, “ Interchange evaluation for electric power utilities”, IEEE Transc., session. 11D3, pp. 820-825. 1989.

[11] I.Sai ram, J. Amarnath, “Optimal setting of IPFC for voltage stability improvement using (GA-GSA) hybrid algorithm”, IEEE Conference,

2013.
[12] William W. Hogan, “Independent system operator (ISO) for a competitive electricity market”, Harvard University, June 1998.
[13] James Kennedy, Russell Eberhart, “ Particle Swarm Optimization”, IEEE Transc., pp. 1942-1948, 1995.
[14] A.R. Abhyankar, prof.S.A.Khaparde, “Introduction to deregulation in power industry”, IIT Bombay.