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# Economic Operation of Power Wheeling under Deregulated Environment Using Soft Computing

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**Abstract:** The electric power industry is undergoing many fundamental changes due to implementation of deregulation policy. Traditionally, the electric power systems were structured vertically integrated, providing the three services generation, transmission and distribution by a single party. After deregulation the three service sectors may be operated (provided) by different company or party. As such the power can be generated by a company, it could be sold to any other company for distribution at load centers and it may be transmitted by a third party from the generation point of selling point (load center/buyer), i.e., power wheeling from the generation point to the distribution point (buyer). In this study, it is proposed to consider the economic power wheeling from the generation point to the distribution point through Gravitational Search Algorithm (GSA) on the basis of MW-Mile method under two operating conditions with and without transmission line power limit. The method is explained by an example of 4-grid power system. The result of GSA method is compared with the result obtained by Particle Swarm Optimization (PSO) method. It has been shown that the GSA method is more efficient than the PSO method as the computation time by GSA is less than computation time by PSO method.

**Key words:** Soft computing optimization, gravitational search algorithm, power system, particle swarm optimization, MW-mile method, power wheeling

## INTRODUCTION

Electrical energy is playing a fundamental role in our day to day life. It is used in household appliances such as light, air-conditioning, cooking, television sets, office equipments, industrial machines and furnace, etc. Probably the electrical power industry is the largest industry in the world. It is composed of mainly three component power generation, transmission of power to load centers and distribution of power at load centers to the consumers. Since, many years the power industry is operating in regulating manner or monopolistic way. Traditionally, this industry is run by a single company which is serving all the three activities generation, transmission and distribution. It is referred as vertically integrated utilities. These vertically integrated utilities are owned and run by the government in many parts of the world. This system of operation has some drawbacks such as low efficiency, less cost effective and limited financial support. Based on previous experience of deregulation in communication, natural gas and air-line industry, it is felt by the researchers the necessity to deregulate the electric power industry (Talati, 1998). It results with higher operational efficiency and lower energy cost to the consumers.

**Deregulation:** Deregulation in the power sector is a process by which government removes or reduces restrictions on power industry and invite private sector to invest in the power industry. Many reforms have been undertaken by introducing commercial investment by private sectors in generation, transmission and distribution of electricity. Some of the main advantages of deregulation are to provide consumers cheaper, reliable energy supply and generate financial supports in the operation of power industry (Sood *et al*., 2002). Deregulation of power industry offer consumers more choices in their energy purchase.

**Open access:** Generally, transmission open access refers to having a regulatory restructure which will address the obligations, rights, operating procedures and economic conditions which ultimately enable two or more parties to access the same transmission network (grid) which belongs to either party or fully to a third party or parties for transfer electric power (Pan *et al*., 2000).

**Wheeling:** There are several definitions for the term wheeling in the power industry. Basically wheeling means the operation of the transmission system and associated facilities of transmission utility are used by

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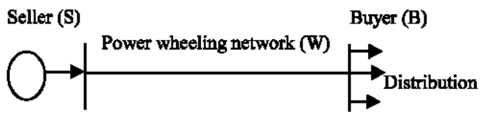

Fig. 1: Power wheeling system

other party/parties for power transfer. The other definition of power wheeling is "the transmission of electrical power takes place between a seller and a buyer using a transmission network that belongs to a third party (Murali *et al*., 2013). An example of power wheeling is presented in Fig. 1. In this example S represents power seller and B represents power buyer. They do not have the transmission link between them of their own. Therefore, they have to engage wheeling utility W to provide a transmission path between them for flow of electrical energy. There may be more than one wheeling transmission going on simultaneously. The interconnected transmission system provides multiple routes to deliver/wheeling power to the utilization point or load centers. Since, interconnecting transmission lines create large networks, they do more than transmit power from generating plant to load centers. They provide an alternative path for power flow serves as a source of reactive power flow (Vars) and provide stability and other ancillary supports.

## MATERIALS AND METHODS

**MW-Mile methodology (Murali *et al.*, 2013; Lee *et al.*, 2001):** The wheeling power cost is computed by a number of methods such as postage stamp method, contract path method, boundary flow method and MW-Mile method. In MW-Mile method the wheeling power cost is computed on the basis of wheeling transaction, i.e., wheeling power multiplied by the actual distance in miles of power flow. The MW-Mile method attempts to allocate the wheeling cost on the basis of actual system usage as close as possible (Shrmohammadi *et al*., 1996).

A number of population based Meta heuristic optimization methods are developed and implemented for solving power system problems (Behesti and Shamsuddin, 2013). Recently a new meta heuristic method is developed by Rashide *et al*. (2009) based on Newton's laws of motion and gravity known as Gravitational Search Algorithm (GSA). This method has been applied to optimum power flow problem of power system (Duman *et al*., 2012) and other fields of electrical engineering (Swain *et al*., 2012; Roy, 2013; Shaw *et al*., 2012; Duman *et al*., 2010; Rout *et al*., 2013). In this study, it is proposed to use MW-Mile method for solving the economic operation of power wheeling problem of power system through GSA. This problem is also solved by Particle Swarm Optimization (PSO) (Valle *et al*., 2008) and the results obtained by the two methods are compared. It has been shown that the GSA method is more efficient than PSO. In the next study, the optimization problem of power wheeling is formulated. Section three the solution procedure by GSA method of the problem is discussed. The solution method is explained by an example of 4-grid power system and the results by GSA are compared with the results obtained by PSO in section four. It has been shown that GSA method is more efficient than PSO method. Lastly, the conclusion and comment is presented.

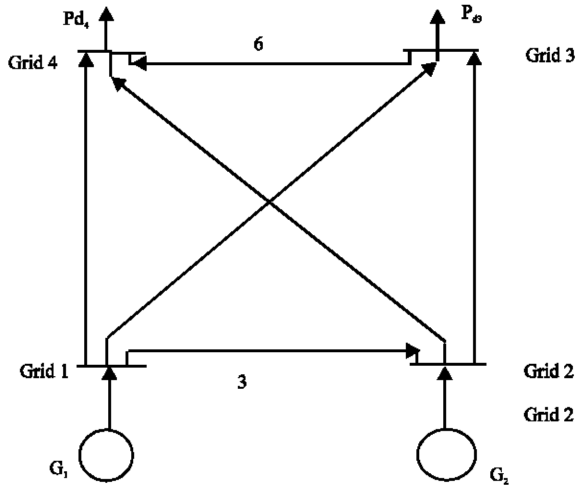

Fig. 2: The 4-grid interconnected power wheeling system

**Problem formulation:** An interconnected power system is shown in Fig. 2. It is assumed that there are areas/grids interconnected by transmission lines. It is further assumed that first r grids have additional power available then the base load requirement say which can be sold to a buyer and there is a buyer who purchases power which is to be transferred to $S_{g1}$, $S_{g2}$, ..., $S_{gr}$, grids say the total power available for selling (wheeling) at the seller level to the buyers at r grids is represented by Eq. 1:

$$S_G = S_{g1}+S_{g2}+,...,+S_{gr} \tag{1}$$

The total power purchased and distributed at r+1 to N grids is given by Eq. 2:

$$P_D = Pd_{r+1}+Pd_{r+2}+,...,+Pd_N \tag{2}$$

It is assumed that neither the buyer nor the seller has a network to transfer power from seller point to buyer point. It has to be transferred by a third party who owns the transmission network connecting seller point to buyer point. The party charges for the transmitted power on the basis of absolute value of MW-Mile of the power transferred (wheeling power) and it is assumed that it is constant per MW-Mile ($\lambda$) for each line. Let there are m numbers of transmission lines connecting N grids. The length of lines is $d_1$, $d_2$, ..., $d_m$ miles and the power transferred by lines is $P_1$, $P_2$, ..., $P_m$ in the direction of the arrow. If the power flow is in opposite direction then it should be considered as negative. Total cost (J) of power wheeled is computed as the product of $\lambda$ and total MW-Mile of all the lines represented by Eq. 3:

$$J=\lambda\sum_{i=1}^{m}abs\left(p_i d_i\right) \tag{3}$$

Since, $\lambda$ is constant, minimization of (Eq. 4) represents minimization of Eq. 4:

$$JJ=\sum_{i=1}^{m}abs\left(p_i d_i\right) \tag{4}$$

Now the problem can be stated as "find out the wheeling power $P_i$ in each line for a given total power demand $P_D$ (buyer) and available total power generation $S_G$ (seller) such that the total power wheeling cost involved represented by Eq. 3 is minimum subject to all the equality and inequality constraints".

**Solution procedure:** The economic operation of power system is stated in the previous section. The solution of the problem by GSA method is proposed. Before going to the solution a brief out-line of the GSA (a heuristic intelligence based optimization method) method is presented below.

**Gravitational search algorithm:** The GSA method of solution is based on Newton's laws of gravity and motion. The Newton's law of gravitation states that each particle attracts every other particle with a force known as gravitational force of attraction. This force is proportional to the product of the mass of the particles and inversely proportional to distance between them. Rashedi *et al.* developed a new meta heuristic optimization method in 2009 on the basis of this natural phenomenon, known as Gravitational Search Algorithm. The optimization method is presented in brief as follows.

A set of agents 'n' (as number. of particles in PSO) each having a mass mi is considered. The position of each mass mi is represented by:

$$X_i=\left(x_{i1}, x_{i2}, ..., x_{im}\right) \text{ for } i = 1, 2, ..., n \tag{5}$$

where, n is the number of agents and mm is the dimension (number of variables) of each agent or mass (search space). The mass of each agent at current ($K^{th}$ iteration is computed on the basis of fitness function (cost function in case of PSO) as follows:

$$Q_i^k=\frac{fit_i^k\text{-}worst_i^k}{best^k\text{-}worst^k} \tag{6}$$

$$M_i^k=\frac{Q_i^k}{\sum_{i=1}^{n}Q_i} \tag{7}$$

where, k is the iteration count $M_i^k$ and $fit_i^k$ represent the mass and fitness value of ith agent at kth iteration, respectively. For minimization problem $worst^k$ and $best^k$ are defined as:

$$best^k=\min_{i\in 1\,to\,n}\left\{fit_i^k\right\} \tag{8}$$

$$worst^k=\max_{i\in 1\,to\,n}\left\{fit_i^k\right\} \tag{9}$$

The acceleration of an agent is computed by considering total forces from a set of heavier masses that apply on it based on the Newton's law of gravity. The total forces can be computed by using Eq. 10:

$$F_{ij}^k=\sum_{l\in kbest,l\neq i}rand_i G^K\frac{M_l^k M_i^k}{(R_{il}+\delta)}\left(x_{lj}^k\text{-}x_{ij}^k\right) \tag{10}$$

where, rand is uniformly distributed random number in the interval (0 and 1). $\delta$ is a constant small value. $R_{il}$ is the Euclidean distance between two agents 'i' and 'l' represented in Eq. 11. The gravitational constant is represented by Eq. 12:

$$R_{il}^k=\left\|X_i^k, X_i^k\right\|_2 \tag{11}$$

$$G^k=G_0 e^{-\left(\beta\frac{k}{m}\right)} \tag{12}$$

Where:

$G_0$ = Initial value of gravitational constant

$k_m$ = The maximum number of iterations specified

$\beta$ = Constant

Here kbest is the set of first k agents with the best fitness value and biggest mass which is a function of iteration k (time) initialized to $k_0$ at the beginning and decreasing with iteration k (time). Here $k_0$ is set to n (total number of agents) and is decreasing linearly to 1. The acceleration of an agent i in jth dimension ($\alpha_{ij}$) can be computed using Eq. 10 presented in Eq. 13:

$$\alpha_{ij}^{k} = \frac{F_{ij}^{k}}{M_{i}^{k}} \tag{13}$$

$$\sum_{l\in kbest, l\neq i} rand_i G^k \frac{M_l^k}{R_{il}^k+\delta}\left(x_{lj}^k - x_{ij}^k\right) \tag{14}$$

Once the acceleration of an agent is computed, the velocity of the agent is updated by Eq. 15:

$$V_{ij}^{k+1} = rand.\, V_{ij}^{k} + \alpha_{ij}^{k} \tag{15}$$

Now the position of the agent can be updated by adding the velocity to the kth position Eq. 14:

$$X_{ij}^{k+1} = x_{ij}^{k} + V_{ij}^{k+1} \tag{16}$$

The complete solution step for the optimization problem by GSA method is presented in algorithm 1. The solution of the problem is considered under following simplifying assumptions:

**Algorithm 1; GSA and PSO algorithm:**

```
Step 1. Identify the number of variables (m)
Step 2. Select the number of agents (n)
Step 3. Select the initial position of each agent satisfying all constraints equality and inequality
Step 4. Select initial value of gravitational constant Go. Specify the other constants $\beta$ and $\delta$. Specify the velocity limit
Step 5. Assume initial value of velocity
Step 6. Specify the maximum number of iterations Km
Step 7. Compute the fitness function fitk at kth iteration. Compute best k and worst k by Eq. 3a, 7 and 8 respectively
Step 8. Compute the mass of each agent using Eq. 5
Step 9. Compute per unit mass of each agent using Eq. 6
Step 10. Compute the gravitational constant Gk at kth iteration by Eq. 11
Step 11. Compute Euclidean norm Rij k using Eq. 10
Step 12. Compute acceleration in each dimension by using Eq. 12
Step 13. Update the velocity by using Eq. 13
Step 14. Update the position by using Eq. 14
Step 15. Check if the position of each agent satisfies the equality and inequality constraint
Step 16. Test if the stopping criterion is reached if not then go to step 7
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The power wheeling company is not responsible for line loss incurred during power wheeling. It has to be taken care either by the seller or by the buyer of power, i.e., 1st party or 2nd party.

The total power demand $P_D$ (as per Eq. 2)) is less than the total power available for wheeling $S_G$ (as per Eq. 1). Under the above assumed operating conditions the total power demand $P_D$ is equal to total the total power supplied $S_S$ for wheeling for power wheeling company as the company is not responsible for loss during power wheeling:

$$P_D = S_s \tag{17}$$

The constraining equations are the sum of all the power input is equal to sum of all the power out at each grid (equality constraints). Mathematically, it can be represented as:

$$\sum \text{P into grid} = \sum \text{P out of grid (at each grid)} \tag{18}$$

Now the solution of the problem is discussed. The GSA method is a population based optimization method. Hence the size of population (the number of the objects/agents) is selected to be 'n'. The dimension of each agent is the number of variables of the problem. The variables are the power flow in each transmission line. In this case the dimension of each agent is m.

**Initialization of position and velocity:** The initial position of each agent is initialized keeping in view of per the equality and inequality constraints. The initial velocity is initialized in a random way in low velocity limit may be between 10 and -10.

The value of other constants $G_0$, $\delta$ and $\beta$ are selected. The maximum number of iterations km for the process is also selected. The stopping criterion of the iterative process is selected may be absolute value of (worst-best) less than tolerance band or maximum number of iterations. A program is developed using MATLAB 7 software following the steps presented in Alogrithm 1 for solution. The complete solution procedure is explained by an example of 4-grid interconnected power system in the next section.

## RESULTS AND DISCUSSION

A 4-grid interconnected power system example is considered in Fig. 2 to illustrate the optimal power wheeling problem as proposed above. The buyer 'B' buy power from seller 'A' at grid 1- 282 MW and at grid 2- 418 MW and ask the power wheeling company 'W' to transfer 400 MW to grid 3 (distribution load) and 300 MW (distribution load) to grid 4.

The distances of the transmission lines are indicated in Table 1. The equality constraining equations are presented below as per Eq. 16. At grid 1:

$$P_1+P_2+P_3 = 282 \tag{20}$$

Table 1: Distance of transmission lines and power flow in lines

| From grid | To grid | Nomenclature of distance | Distance in miles | Power flow |
|---|---|---|---|---|
| 1 | 4 | d1 | 200 | p1 |
| 1 | 3 | d2 | 300 | p2 |
| 1 | 2 | d3 | 150 | p3 |
| 2 | 3 | d4 | 220 | p4 |
| 2 | 4 | d5 | 250 | p5 |
| 3 | 4 | d6 | 100 | p6 |

At grid 2:

$$P_4+P_5-P_3 = 418 \tag{21}$$

At grid 3:

$$P_4+P_2-P_6 = 400 \tag{22}$$

At grid 4:

$$P_1+P_5+P_6 = 300 \tag{23}$$

For the solution of the problem by GSA method the initial value of gravitational constant $G_0$ assumed 10.0 and other constants assumed are $\beta = 10$ and $\varepsilon = 0.9$. In this case, the number of variables (m) is the power flow through transmission lines (wheeling power) are 6 as the number of transmission lines are 6. Since, the GSA is population based optimization method, the population (number of agents/objects = n) assumed is 7 a bit higher than the number of variables. The solution of this problem is computed under two conditions firstly without power limit of transmission lines and secondly with power limit of transmission lines.

**Solution without power limit of transmission lines:** The position of each agent is initialized as per Eq. 16-19 and (16d) and presented in Table 2. The velocity of each agent is initialized in random way between 10 and -10 and presented in Table 3. The values of other constants required for solution are assumed as follows:

- Initial value of gravitational constant $G_0 = 10$
- Maximum number of iterations $K_m = 1000$
- $\delta = 0.9$ and $\beta = 10$

The program is developed using the MATLAB 7 software following the steps of Algorithm 1. The stopping criterion for the iterative method is assumed as absolute value of (worst-best) is <1. The computed results are indicated below:

$$P_1 = 282, P_2 = 0, P_3 = 0, P_4 = 400, P_5 = 18 \text{and} P_6 = 0$$

- Number of iterations for convergence = 243
- Computation time taken = 0.181366 sec
- The minimum cost computed (JJ) = 148900 MW-Mile

Table 2: Initial position of agents

| Agents | p1 | p2 | p3 | p4 | p5 | p6 |
|---|---|---|---|---|---|---|
| 1 | 100 | 100 | 82 | 200 | 300 | -100 |
| 2 | 120 | 100 | 62 | 250 | 230 | -50 |
| 3 | 200 | 150 | -68 | 100 | 250 | -150 |
| 4 | 100 | 200 | -18 | 200 | 200 | 0.0 |
| 5 | 160 | 22 | 100 | 318 | 200 | -60 |
| 6 | 130 | 80 | 72 | 300 | 50 | 20 |
| 7 | 150 | 250 | -118 | 200 | 100 | 50 |

Table 3: Initial velocity of agents

| Agents | V1 | V2 | V3 | V4 | V5 | V6 |
|---|---|---|---|---|---|---|
| 1 | 8 | 7 | 6 | 5 | 4 | 2 |
| 2 | 1 | 2 | 3 | 4 | 5 | 6 |
| 3 | 7 | 8 | -2 | 2 | 6 | 2 |
| 4 | 3 | 1 | 4 | 7 | 8 | -5 |
| 5 | 3 | 4 | -4 | 3 | 2 | 1 |
| 6 | -4 | 3 | 2 | 8 | -7 | 0 |
| 7 | 1 | 4 | 6 | 5 | 3 | 1 |

This problem has also been solved by Particle Swarm Optimization (PSO) for comparison. The results are indicated below: The line flows and minimum cost are same as in GSA shown above:

- Number of iterations for convergence = 1330
- Computation time taken = 0.248479 sec

**Solution with power limit of transmission lines:** In addition to the problem considered in part (a) above it is considered here that the power limit of each transmission line is 350 MW and stopping criterion abs (worst-best) <0.1. The computed results by GSA method are as follows:

$$P_1 = 247.2,\ P_2 = 34.8,\ P_3 = 0,\ P_4 = 350,$$
$$P_5 = 68 \text{and} P_6 = -15.2$$

- Number of iterations for convergence = 295
- Computation time taken = 0.217166 sec
- The minimum cost computed (JJ) = 155400 MW-Mile

This problem has also been solved by Particle Swarm Optimization (PSO) for comparison. The results are indicated:

$$P_1 = 247.6, P_2 = 7.4, P_3 = 0,$$
$$P_4 = 350, P_5 = 68 \text{and} P_6 = -42.6$$

- Number of iterations for convergence = 6586
- Computation time taken = 1.156848 sec
- The minimum cost computed (JJ) = 155400 MW-Mile

A graph has been plotted between best value of cost and the iterations as shown in Fig. 3. The optimum value is achieved around 300 runs. At optimum all the agents have same value of the optimum cost. At optimum all the agent have the same value of wheeling power in each line.

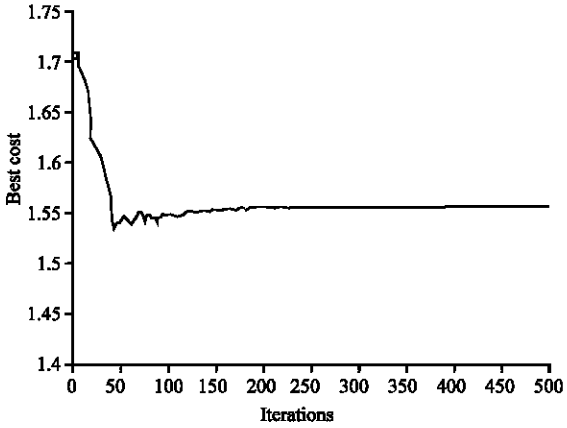

Fig. 3: Iteration vs. best cost plot

At optimum both the velocity and acceleration will be zero for GSA method. It has been observed that for different run the power flow in the linear are different but the cost is same when the power limit for different line is considered. It shows that in this condition the solution has multiple optima having same cost. But for unconstrained line flow only one value of the power flow is observed and the optimal cost is due for different runs.

The computation time and the number of iterations are more in case of PSO than GSA method in both the cases with and without limitation on transmission line. In case of without limiting transmission line power flow, the computed minimum cost and power flow in each line is same by both the methods of solution GSA and PSO.

In case of limiting power flow in transmission line the optimum power flow computed is different by the methods PSO and GSA. However, the optimum cost computed is same by both the methods. It indicates that the problem has multiple optima with same optimum value of cost. In case of transmission line limit the optimum cost computed is more than the optimum cost computed without limiting the transmission line.

## CONCLUSION

Under deregulated environment the economic operation and control power wheeling of interconnected power system by GSA method is presented. With an example of 4-grid interconnected power system the complete procedure is explained. The result computed by GSA is compared with the results of PSO. It has been shown that the GSA method is more efficient than PSO as the computation time by GSA is less than the computation time by PSO. The optimum power wheeling is considered in two operating conditions with and without power limit of transmission lines. Without power limit of transmission line the result (wheeling power in each transmission line and the total cost of transmission) is same in both the methods GSA and PSO. In case of power limit of transmission lines the wheeling power in transmission lines computed by GSA and PSO are different but the cost computed by both the methods is same. It indicates that the problem space has multiple optima having the same cost.

## REFERENCES

Beheshti, Z. and S.M.H. Shamsuddin, 2013. A review of population-based meta-heuristic algorithms. Intl. J. Adv. Soft Comput. Appl., 5: 1-35.

Duman, S., U. Guevence and N. Yoeruekeren, 2010. Gravitational search algorithm for economic dispatch with valve-point effects. Int. Rev. Electr. Eng., 5: 2890-2895.

Duman, S., U. Guvenc, Y. Sonmez and N. Yorukeren, 2012. Optimal power flow using gravitational search algorithm. Energy Conversion Manage., 59: 86-95.

Lee, W.J., C.H. Lin and K.D. Swift, 2001. Wheeling charge under a deregulated environment. IEEE. Trans. Ind. Appl., 37: 178-183.

Murali, M., M.S. Kumari and M. Sydulu, 2013. An overview of transmission pricing methods in a pool based power market. Intl. J. Adv. Sci. Eng. Technol., 1: 58-63.

Pan, J., Y. Teklu, S. Rahman and K. Jun, 2000. Review of usage-based transmission cost allocation methods under open access. IEEE. Trans. Power Syst., 15: 1218-1224.

Rashedi, E., H. Nezamabadi-Pour and S. Saryazdi, 2009. GSA: A gravitational search algorithm. Inform. Sci., 179: 2232-2248.

Rout, U.K., R.K. Sahu and S. Panda, 2013. Gravitational search algorithm based automatic generation control for interconnected power system. Proceedings of the International Conference on Circuits, Power and Computing Technologies (ICCPCT), March 20-21, 2013, IEEE, Nagercoil, India, ISBN: 978-1-4673-4921-5, pp: 558-563.

Roy, P.K., 2013. Solution of unit commitment problem using gravitational search algorithm. Intl. J. Electr. Power Energy Syst., 53: 85-94.

Shaw, B., V. Mukherjee and S.P. Ghoshal, 2012. A novel opposition-based gravitational search algorithm for combined economic and emission dispatch problems of power systems. Int. J. Electr. Power Energy Syst., 35: 21-33.

Shirmohammadi, D., B. Gorenstin and M.V. Pereira, 1996. Some fundamental, technical concepts about cost based transmission pricing. IEEE. Trans. Power Syst., 11: 1002-1008.

Sood, Y.R., N.P. Padhy and H.O. Gupta, 2002. Wheeling of power under deregulated environment of power system-a bibliographical survey. IEEE. Trans. Power Syst.,17: 870-878.

Swain, R.K., N.C. Sahu and P.K. Hota, 2012. Gravitational search algorithm for optimal economic dispatch. Procedia Technol., 6: 411-419.

Talati, P.S., 1998. Transmission system management and pricing. Parsons B rinckerhoff, New York, USA. http: //cdn.wspgroup.com/8kzmue/transmission-system-management-and-pricing.pdf.

Valle, Y.D., G.K. Venayagamoorthy, S. Mohagheghi, J.C. Hernandez and R.G. Harley, 2008. Particle swarm optimization: Basic concepts, variants and applications in power systems. IEEE. Trans. Evol. Comput., 12: 171-195.