Economic Load Dispatch of Power System Using Grey Wolf Optimization with Constriction Factor

Sudip Kumar Ghorui[1], Roshan Ghosh[2], Subhashis Maity[3],

[1]Assistant Professor, Department of Electrical Engineering
Budge Budge Institute of Technology
Kolkata
sudipkumarghorui@gmail.com

[2]Assistant Professor, Electrical engineering Department
Budge Budge Institute of Technology
Kolkata
ghosh.roshan@gmail.com

[3]Student, Department of Electrical Engineering
Budge Budge Institute of Technology
Kolkata
ashiscool7@gmail.com

Abstract: ***In this paper, we propose a new meta-heuristic, nature inspired technique known as Grey Wolf Optimization to solve Economic Load Dispatch (ELD) problems of thermal power units considering transmission losses, and constraints such as ramp rate limits and prohibited operating zones. Grey Wolf Optimization Algorithm (GWOA) is a relatively new optimization technique. Mathematical models of this algorithm demonstrate the efficiency, quality of solution and convergence speed of the method and successful application of the algorithm on economic load dispatch problems. Simulation results found that the proposed approach outperforms several other existing optimization techniques in terms quality of solution obtained and computational efficiency. Results also be confirmed the robustness of the proposed methodology.***

Keywords: Economic *load dispatch, Grey Wolf optimization technique, prohibited operating zone, quadratic cost function, ramp rate limits,*

1. Introduction

Economic load dispatch (ELD) is applied in electric power utilities is to provide high-quality, reliable power supply to the consumers at the lowest possible tariff. It can be defined in normal condition the operation of generation facilities is to produce electrical power at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities. It is an important role in electrical power system operation for allocating generation among the committed units such that the imposed constraints and the energy requirement are satisfied. The characteristics of fuel cost for modern generating units are highly nonlinear with demand for solution techniques having no restrictions on to the shape of the fuel cost curves. For science and engineering, many optimization techniques are developed for used in ELD problem to accomplish to the main goal. But the calculus-based methods [1] are not fulfillment to solving ELD problems, as these techniques are required smooth, differentiable objective function. Another method which is Linear programming method [2] is speedy and reliable but it has some drawback related with the piecewise linear cost approximation. In power system small improvements in the unit output scheduling can give significant cost savings. So the dynamic programming approach was proposed by Wood and Wollenberg [3] to solve ELD problems but this technique does not impose any restriction on the nature of the cost curves, but suffers from the “curse of dimensionality” or local optimality and larger simulation time. In order to overcome this problem in current years, several attempts have been made to solve ELD with intelligent and modern technique which is meta-heuristic algorithm is helpful for solution of complex ELD problems they are Genetic algorithm [4], particle swarm optimization [5], Simulated Annealing (SA)[6], Artificial Neural Networks [7] ,Differential evolution [8], Tabu search [9], Evolutionary Programming (EP) [10], Ant colony optimization [11] , Artificial immune system (AIS) [12], Bacterial Foraging Algorithm (BFA) [13], Biogeography-based Optimization (BBO) [14] etc. This mentioned method may confirm to be very effective for solving nonlinear ELD problems without any restriction on the shape of the cost curves. They often provide a fast, reasonable nearly global optimal solution but these methods do not always assurance global best solutions, they often achieve a fast and near global optimal solution. In recent years, different hybridization and modification of GA, EP, PSO, DE, BBO like improved GA with multiplier updating (IGA-MU) [15] directional search genetic algorithm (DSGA) [16], hybrid genetic algorithm (GA)-pattern search (PS)-sequential quadratic programming (SQP) (GA-PS-SQP) [17], improved fast evolutionary programming (IFEP) [18], new PSO with local random search (NPSO_LRS) [19], adaptive PSO (APSO) [20], self-organizing hierarchical PSO (SOH-PSO) [21], improved coordinated aggregation based PSO (ICA-PSO) [22], improved PSO [23], combined particle swarm optimization with real-valued mutation (CBPSO-RVM)[24], DE with generator of chaos sequences and sequential quadratic programming (DEC-SQP) [25], variable scaling hybrid differential evolution (VSHDE) [26], hybrid differential evolution (DE) [27], bacterial foraging with Nelder–Mead algorithm (BF-NM) [28], hybrid differential evolution with biogeography-based optimization (DE/BBO) [29] etc are being anticipated to solve ELD for search better excellence and fast solution. Population based bio-inspired algorithm are Evolutionary algorithms, swarm intelligence and bacterial foraging etc. But they have common disadvantages which is these algorithms are complicated computation for using many parameters. For that reason it is also difficult to understand these algorithms for beginners.

This paper presents, a new global optimization technique which is GWOA, influenced by grey wolves' leadership and hunting behaviors to solve Economic Load Dispatch (ELD) problem. For superior performance of GWOA, it is used to solve ELD problem. Section 2 discusses the mathematical problem formulation of ELD while brief description of GWOA technique is presented in Section 3.Simulation studies are presented and discussed in Section 4. The conclusion is drawn in Section 5.

2. MATHEMATICAL MODELING OF THE ELD PROBLEM

The traditional formulation of the ELD problem is to minimize the fuel cost of generations for both convex and non-convex nonlinear constrained optimization problem. In this section, ELD problems have been formulated and solved by GWOA approach. These are presented below:

2.1 ELD with quadratic cost function, ramp rate limit, prohibited operating zone and transmission loss

The overall objective function F_T of ELD problem may be written as

$$F_T = \min \sum_{i=1}^{N} F_i\left(P_i\right) = \min \sum_{i=1}^{N}\left(a_i + b_i P_i + c_i P_i^2\right) \qquad (1)$$

Where, $F_i(P_i)$, is fuel cost function of the i^{th} generator, and is usually expressed as a quadratic polynomial function; N is the total number of committed generators; a_i, b_i and c_i are the cost coefficients of the i^{th} generator; P_i is the generated power of the i^{th} generator. The ELD problem consists in minimizing F_T subject to following constraints:

2.1.1. Real Power balance constraint:

$$\sum_{i=1}^{N} P_i - (P_D + P_L) = 0 \qquad (2)$$

Where, P_D is the total load demand by consumer; P_L is the total transmission loss in power system; Calculation of P_L using the B- coefficients matrix is expressed as:

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{0i} P_i + B_{00}$$

(3)

2.1.2 Generation capacity constraint:

There is a limit on the amount of active power generation. For normal condition, real power output of each generator is restricted by lower and upper bounds as follows:

$$P_i^{\min} \le P_i \le P_i^{\max}$$

(4)

Where $P_i^{\min}$ and $P_i^{\max}$ are the minimum and maximum power generated by generator i^{th} unit, respectively.

2.1.3 Ramp Rate Limit Constraint:

The power P_i generated by the i^{th} generator in certain interval could not exceed that of previous interval P_{i0} by more than a certain amount U_{Ri} is the up-ramp rate limit and neither may it be less than that of the previous interval by more than some amount D_{Ri} the down-ramp rate limit of the generator. These give rise to the following constraints.

As generation increases,

$$P_i - P_{i0} \le U_{Ri}$$

(5)

As generation decreases,

$$P_{i0} - P_i \le D_{Ri}$$

(6)

Modified generation limits after considering ramp rate limits are given bellow

$$\max(P_i^{\min}, P_{i0} - D_{Ri}) \le P_i \le \min(P_i^{\max}, P_{i0} + U_{Ri}) \qquad (7)$$

2.1.4 Prohibited Operating Zone:

The prohibited operating zones are the range of output power of any generator where the operation causes undue vibration of the turbine shaft. Generally such vibration occurs at the point of opening or closing of the steam valve which might cause damage to the shaft and bearings. It is difficult to determine the exact prohibited zone by actual testing or from operating records. Normally operation is avoided in such regions.

Hence mathematically the feasible operating zones of unit can be described as follows:

$$P_i^{\min} \le P_i \le P_{i,1}^{l}$$

$$P_{i,j-1}^{u} \le P_i \le P_{i,j}^{l}; \quad j = 2,3,\ldots n_i$$

$$P_{i,n_i}^{u} \le P_i \le P_i^{\max}$$

(8)

Where j represents the number of prohibited operating zones of unit i. $P_{i,j-1}^{u}$ is the upper and $P_{i,j}^{l}$ is the lower limit of j^{th} prohibited operating zone of i^{th} unit. n_i is the total number of prohibited operating zone of the i^{th} unit.

2.2 Calculation for slack generator:

Let N committed generating units are delivering their power output maintaining the power balance constraint (2) and the respective capacity constraints of (4) and/or (7), (8).It is assumed that the power loadings of first (N-1) generators are known, the power level of N^{th} generator (called Slack Generator) is given by

$$P_N = P_D + P_L - \sum_{i=1}^{(N-1)} P_i \qquad (9)$$

The transmission loss P_L ,which is a function of all the generator outputs including the slack generator, is given by

$$P_L = \sum_{i=1}^{N-1}\sum_{i=1}^{N-1} P_i B_{ij} P_j + 2P_N\left(\sum_{i=1}^{N-1} B_{Ni} P_i\right) + B_{NN} P_N^2 + \sum_{i=1}^{N-1} B_{oi} P_i + B_{ON} P_N + B_{00}$$

(10)

By expanding and rearranging, (10) becomes

$$B_{NN}P_N^2+\left(2\sum_{i=1}^{N-1}B_{Ni}P_i+B_{ON}-1\right)P_N+\left(P_D+\sum_{i=1}^{N-1}\sum_{j=1}^{N-1}P_iB_{ij}P_j+\sum_{i=1}^{N-1}B_{Oi}P_i-\sum_{i=1}^{N-1}P_i+B_{OO}\right)=0 \quad (11)$$

Using standard algebraic method, loading of the dependent generator (i.e., N^{th}) can be found out by solving (11). The above equation can be simplified as

$$XP_N^2+YP_N+Z=0 \quad (12)$$

Where

$$X=B_{NN}$$

$$Y=\left(2\sum_{i=1}^{N-1}B_{Ni}P_i+B_{oN}-1\right)$$

$$z=\left(P_D+\sum_{i=1}^{N-1}\sum_{j=1}^{N-1}P_iB_{ij}P_j+\sum_{i=1}^{N-1}B_{oi}P_i-\sum_{i=1}^{N-1}P_i+B_{oo}\right)$$

The positive roots of the equation are obtained as

$$P_N=\frac{-Y\pm\sqrt{Y^2-4XZ}}{2X}, \text{Where } Y^2-4XZ\geq 0$$

(13)

In order to satisfy the equality constraint (9), the positive root of (13) is taken as output of the N^{th} generator. If the positive root of quadratic equation violates operation limit constraint of (4) at the initialization process of the algorithm, then Generation value of first *(N-1)* generators is reinitialized until the positive root satisfies the operation limit and other constraints (if any).

3. Grey Wolf Optimization Algorithm (GWOA)

This section presents an interesting new optimization algorithm called grey wolf optimization algorithm (GWOA) which was proposed by Mirjalili and Mirjalili [30]. This technique based on behaviour of grey wolf in searching and hunting of their quarry. The leaders of the group, a male and a female are called alpha (α). The next levels of grey wolves, which are subordinate wolves mainly provide help to the leaders for decision making or in other activities, are called beta (β). The third level of grey wolves dominate the omega which are known as delta (δ). The last rank of the grey wolves is called omega (ω), which surrenders to all the other governing wolves. The proposed technique (GWOA) is provided in the mathematical models as follows:

A. *Social hierarchy:* If we draw a mathematical model of this algorithm, we consider social hierarchy of the grey wolves; here alpha (α) has best fittest solution. The second best solution beta (β) and third best solution delta (δ) belong to the grey wolf family. The omega (ω) is the last candidate solution. Therefore alpha (α), beta (β) and delta (δ) helped in the GWO technique (hunting). The last member, of the wolves ω follows these three wolves.

Encircling Prey: The wolf during hunting period tends to encircle their prey. The following equations express the behavior [30]:

$$\vec{D}=\left[\vec{C}.\vec{X}_p(t)-\vec{X}(t)\right]$$

(14)

$$\vec{X}(t+1)=\vec{X}_p(t)-\vec{A}.\vec{D}$$

(15)

Where $\vec{A}$ and $\vec{C}$ are the coefficient vectors, $\vec{X}_P$ is the prey's position vector, $\vec{X}$ denotes the grey wolf's position vector and't' is the current iteration.

The mathematical calculation of vectors $\vec{A}$ and $\vec{C}$ is done as follows [30]:

$$\vec{A}=2.\vec{a}.\vec{r}_1.\vec{a}$$

(16)

$$\vec{C}=2.\vec{r}_2$$

(17)

Where values of '$\vec{a}$' are linearly reduced from 2 to 0 during the course of iterations and r_1, r_2 are arbitrary vectors in the gap [0, 1].

B. *Hunting:* Alpha, beta and delta guided the entire group with their better knowledge about the potential location of prey. The other agents update their positions according to the best search agent's position. The update of their agents can be expressed as follows [30]

$$\begin{Bmatrix}\vec{D}_\alpha=\left|\vec{C}_1.\vec{X}_\alpha-\vec{X}\right| \\ \vec{D}_\beta=\left|\vec{C}_2.\vec{X}_\beta-\vec{X}\right| \\ \vec{D}_\delta=\left|\vec{C}_{\delta}.\vec{X}_\delta-\vec{X}\right|\end{Bmatrix}$$

(18)

$$\begin{Bmatrix}\vec{X}_1=\vec{X}_\alpha-\vec{A}_1.\left(\vec{D}_\alpha\right) \\ \vec{X}_2=\vec{X}_\beta-\vec{A}_2.\left(\vec{D}_\beta\right) \\ \vec{X}_3=\vec{X}_\delta-\vec{A}_3\left(\vec{D}_\delta\right)\end{Bmatrix}$$

(19)

$$\vec{X}(t+1)=\frac{\vec{X}_1+\vec{X}_2+\vec{X}_3}{3}$$

(20)

C. *Search for prey and attacking prey* This is the final position of this algorithm. Under this circumstance they will be in a random position within a circle which is defined by the positions of the alpha, beta, and delta in the search space. In fact alpha, beta, and delta estimate the victim's position and other wolves update their positions randomly around the victim.

3.2. METHODOLOGY

Since the appraisal variables for ELD problem are real power output for each generator but here they are used to represent the wolf's population structure where *P* is total population for each group and *n* is number of groups. The whole population is *n*P*. Each individual population structure represents the real power output for each generator and also fulfillment (4). For initialization purpose we can choose the number of generating units *N* and total number of population structure *PopSize*.

By the following the complete population structure is represented as

$$P=P_i=\left[P_1,P_2,P_3,\ldots P_{popsize}\right] \quad \text{Where, i=1, 2,….PopSize.}$$

Here the population set is *P* which is each individual element of the population structure of matrix. This population set *P* is initialized randomly within the fulfillment real power balance constant and generator capacity constant. This initialization is based on (4), (7) and (8) when consider ramp rate limit, prohibited operating zone. For this initialization process, choose no. of generator units N and also Specify maximum and minimum capacity of each generator, power demand, B-coefficients matrix for calculation of transmission loss.

In ELD problem here fitness value is fuel cost of generation for all the generators which calculated using (1) for the system having quadratic fuel cost characteristic. This Eq. (1) applies to determine performance evolution of ELD problem until the optimum cost is achieved. The technique will continue until the maximum no. of iteration is met and the optimum result is obtained.

4. RESULTS AND DISCUSSIONS

Proposed GWOA has been applied for solving ELD problem in a test system and its performance has been compared to several other optimization technique like GA [5], CTPSO [23] and PSO [5, 23] for verifying its feasibility. The essential codes has been written in MATLAB-7 language and executed on a 2.0 GHz Intel Pentium (R) Dual Core personal computer with 1-GB RAM.

4.1. Description of the Test System

Test System 1: In this paper, 15 generating units with ramp rate limit and prohibited operating zones constraints has been considered and transmission loss has been also included in this problem. Consumer power demands are 2630 MW and the characteristics of the fifteen thermal units are given in Tables 1 and 2. The loss coefficients are given in [5]. This paper results obtained from proposed GWOA, PSO [5] and different versions of PSO [23] and other method are presented in this paper. Their best results are shown in Table 3. Minimum, average and maximum fuel costs obtained by GWOA and different versions of PSO [23], over 50 trials are presented in Table 4.

TABLE NO. 01
GENERATING UNIT DATA
CONSUMER POWER DEMANDS ARE 2630 MW

Unit	P_i^{min} (MW)	P_i^{max} (MW)	a_i ($)	β_i ($/MW)	γ_i ($/MW^2)	UR_i (MW/h)	DR_i (MW/h)	P_i^0 (MW)
1	150	455	671	10.1	0.000299	80	120	440
2	150	455	574	10.2	0.000183	80	120	300
3	20	130	374	8.8	0.001126	130	130	105
4	20	130	374	8.8	0.001126	130	130	100
5	150	470	461	10.4	0.000205	80	120	90
6	135	460	630	10.1	0.000301	80	120	400
7	135	465	548	9.8	0.000364	80	120	350
8	60	300	227	11.2	0.000338	65	100	95
9	25	162	173	11.2	0.000807	60	100	105
10	25	160	175	10.7	0.001203	60	100	110
11	20	80	186	10.2	0.003586	80	80	60
12	20	80	230	9.9	0.005513	80	80	40
13	25	85	225	13.1	0.000371	80	80	30
14	15	55	309	12.1	0.001929	55	55	20
15	15	55	323	12.4	0.004447	55	55	20

TABLE NO. 02
PROHIBITED ZONES OF GENERATING UNITS

Unit	Prohibited zones (MW)
2	[185 225] [305 335] [420 450]
5	[180 200] [305 335] [390 420]
6	[230 225] [365 395] [430 455]
12	[30 40] [55 65]

TABLE 3
BEST POWER OUTPUT FOR 15-GENERATORS SYSTEM
(P_D=2630MW)

Unit	Proposed GWOA	GA [5]	PSO [5]	CTPSO [23]	CSPSO [23]
P_1	454.000000	415.3108	439.1162	455.0000	455.0000
P_2	381.000000	359.7206	407.9727	380.0000	380.0000
P_3	130.000000	104.4250	119.6324	130.0000	130.0000
P_4	130.000000	74.9853	129.9925	130.0000	130.0000
P_5	170.000000	380.2844	151.0681	170.0000	170.0000
P_6	460.000000	426.7902	459.9978	460.0000	460.0000
P_7	430.000000	341.3164	425.5601	430.0000	430.0000
P_8	73.523145	124.7867	98.5699	71.7430	71.7408
P_9	51.852314	133.1445	113.4936	58.9186	58.9207
P_{10}	160.000000	89.2567	101.1142	160.0000	160.0000
P_{11}	80.000000	60.0572	33.9116	80.0000	80.0000
P_{12}	80.000000	49.9998	79.9583	80.0000	80.0000
P_{13}	26.523652	38.7713	25.0042	25.0000	25.0000
P_{14}	14.962321	41.9425	41.4140	15.0000	15.0000
P_{15}	18.002324	22.6445	35.6140	15.0000	15.0000
Fuel Cost ($/hr.)	**32701.870839**	33113	32858	32704	32704

TABLE 4
COMPARISON BETWEEN DIFFERENT METHODS TAKEN AFTER 50 TRIALS (15-GENERATORS SYSTEM)

Methods	Generation Cost ($/hr.)			Time/Iteration (Sec)	No. of hits to minimum solution
	Max.	Min.	Average		
GWOA	**32705.452356**	**32701.870839**	**32702.15735**	**14.25**	**46**
CTPSO[23]	32704.4514	32704.4514	32704.4514	22.5	NA*
CSPSO[23]	32704.4514	32704.4514	32704.4514	16.1	NA
COPSO[23]	32704.4514	32704.4514	32704.4514	85.1	NA
CCPSO[23]	32704.4514	32704.4514	32704.4514	16.2	NA

* NA:- Data

4.2. Comparative study:

1) Solution Quality: Table 3 represents comparable studies of GWOA algorithm with other optimization methods and it is found that GWOA algorithm reaches the best result of fuel costs in power system. Table 4 gives comparative

studies for minimum, maximum and average values for different technique with other method. From these results it is observed that the performance of GWOA is better, in terms of quality of solutions obtained.

2) Computational Efficiency: Table 3, shows 15 units while comparing it with other technique and the cost is found to be ***32701.870839*** $/hr., The cost is compared to the results obtained by many previously developed techniques and it is found to be lesser. The time taken by GWOA to achieve minimum fuel costs is quite less compared to that obtained by many other techniques. These are shown in Table 4. These outputs prove significantly better computational efficiency of GWOA.

3) Robustness: Performance of any heuristic algorithms cannot be judged by the results of a single run. Normally their performance is judged after running the programs of those algorithms for certain number of trials. A large numbers of trials with different initializations of population size should be made to obtain a useful conclusion about the performance of the technique. An algorithm is said to be robust, if it gives consistent result during all trials. This performance is much superior compared to many other algorithms, presented in the different literatures in table 4. Therefore, the above results establish the enhanced capability of GWOA to achieve superior quality solutions, in a computational efficient and robust way.

CONCLUSION

In this paper, we present a newly developed GWOA method, which is very flexible, quite efficient, rarely gets trapped in global minima. It does not require computationally expensive derivatives, and is quite easy. It has been successfully implemented to solve different constraints, ELD problems. This simulation results proved that the performance of GWOA is better as compared to that of several previously developed optimization techniques. Therefore GWOA process can be considered as one of the powerful tool to solve ELD problem. In future, GWOA can also be tried for solution of complex hydrothermal scheduling, optimal power flow problems and dynamic ELD, in the search for good characteristics results.

REFERENCES

[1] A. A. El-Keib, H. Ma, J. L. Hart, "Environmentally constrained economic dispatch using the Lagrangian relaxation method", IEEE Trans. Power Syst., Vol. 9, no.4, pp. 1723–1729, November 1994.
[2] S. Fanshel, E. S. Lynes, "Economic Power Generation Using Linear Programming", IEEE Trans. on Power Apparatus and Syst., vol. PAS-83, no. 4, pp. 347-356, 1964.
[3] J. Wood, B. F. Wollenberg, "Power Generation, Operation, and Control", John Wiley and Sons, 2nd Edition, 1984.
[4] D. C. Walters and G. B. Sheble, "Genetic algorithm solution of economic dispatch with valve point loadings", IEEE Trans. Power Syst., vol. 8, no.3, pp.1325-1331, August 1993.
[5] Z.-L. Gaing, "Particle swarm optimization to solving the economic dispatch considering the generator constraints," IEEE Trans. Power Syst., vol. 18, no.3, pp. 1187-1195, August 2003.
[6] C. K. Panigrahi, P. K. Chattopadhyay, R. N. Chakrabarti, and M. Basu, "Simulated annealing technique for dynamic economic dispatch", Elect. Power components and syst., vol. 34, no.5, pp.577-586, May 2006.
[7] C.-T. Su and C.-T. Lin, "New approach with a Hopfield modeling framework to economic dispatch", *IEEE Trans. Power Syst.*, vol. 15, no. 2, pp. 541, May 2000.
[8] N. Nomana and H. Iba, "Differential evolution for economic load dispatch problems", Elect. Power Syst. Res., Vol. 78, No. 3, pp. 1322–1331, 2008.
[9] S. Khamsawang, C. Boonseng and S. Pothiya, "Solving the economic dispatch problem with Tabu search algorithm". *IEEE Int. Conf. Ind. Technol*., vol. 1, pp. 274–278, 2002.
[10] T. Jayabharathi, K. Jayaprakash, N. Jeyakumar, and T. Raghunathan, "Evolutionary programming techniques for different kinds of economic dispatch problems," Elect. Power Syst. Res., vol. 73, no. 2, pp.169-176, February 2005.
[11] Y. H. Hou, Y. W. Wu, L. J. Lu, X. Y. Xiong, "Generalized Ant Colony Optimization for Economic Dispatch of power systems", Proceedings of International Conference on Power Syst. Technology, Power-Con 2002, Vol. 1, pp. 225-29, 13 – 17 October 2002.
[12] B. K. Panigrahi, S. R. Yadav, S. Agrawal, and M. K. Tiwari, "A clonal algorithm to solve economic load dispatch", Elect. Power Syst. Res., Vol. 77, No. 10, pp. 1381–1389, 2007.
[13] B. K. Panigrahi and V. R. Pandi, "Bacterial foraging optimization: Nelder-Mead hybrid algorithm for economic load dispatch," IET Gener., Transm., Distrib., Vol. 2, No. 4, pp. 556–565, 2008.
[14] A. Bhattacharya, P. K. Chattopadhyay, "Biogeography-Based Optimization for Different Economic Load Dispatch Problems", IEEE Trans. Power Syst., vol. 25, no. 2, pp. 1064-1077, May 2010.
[15] C.-L Chiang, "Improved genetic algorithm for power economic dispatch of units with valve-point effects and multiple fuels", IEEE Trans. Power Syst., vol. 20, no. 4, pp. 1690–1699, 2005.
[16] T. Adhinarayanan, and M. Sydulu, "A directional search genetic algorithm to the economic dispatch problem with prohibited operating zones", in Proc. IEEE/PES Transm. and Distrib. Conference Expo. 2008, vol. 1, pp. 1–5, Chicago, IL, 21–24 April 2008.
[17] J. S. Alsumait, J. K. Sykulski, A. K. Al-Othman, "A hybrid GA–PS–SQP method to solve power system valve-point economic dispatch problems", Appl. Energy, vol. 87, no.5, pp. 1773–1781. 2010.
[18] N. Sinha, R. Chakrabarti, P. K. Chattopadhyay, "Evolutionary programming techniques for economic load dispatch", IEEE Trans. Evol. Comput., vol. 7, no. 1, pp. 83–94. 2003.
[19] I. Selvakumar and K. Thanushkodi, "A New Particle Swarm Optimization Solution to Nonconvex Economic Dispatch Problems", IEEE Trans. Power Syst., vol. 22, no. 1, February 2007.
[20] B. K. Panigrahi, V. R. Pandi, S. Das, "Adaptive particle swarm optimization approach for static and dynamic economic load dispatch", Energy Conversion & Managt., vol.49, no.6, pp.1407–15, 2008.
[21] K. T. Chaturvedi, M. Pandit, L. Srivastava, "Self-Organizing Hierarchical Particle Swarm Optimization for Nonconvex Economic Dispatch", IEEE Trans. Power Syst, vol. 23, no. 3, pp. 1079, August 2008.
[22] J. K Vlachogiannis, and Y. Lee Kwang, "Economic Load Dispatch—A Comparative Study on Heuristic Optimization Techniques With an Improved Coordinated Aggregation-Based PSO", IEEE Trans. Power Syst., vol. 24, no. 2, pp. 991-1001, May 2009.
[23] J.-B. Park, Y.-W. Jeong, J.-R. Shin, Y. Lee Kwang, "An improved particle swarm optimization for nonconvex economic

dispatch problems", IEEE Trans. Power Syst., vol 25, no. 1, pp. 156–166. 2010.
[24] H. Lu, P. Sriyanyong, Y. H. Song, T. Dillon, "Experimental study of a new hybrid PSO with mutation for economic dispatch with non-smooth cost function", Int. J. Elect. Power Energy Syst., vol. 32, no. 9, pp. 921–935, 2010.
[25] Leandro dos Santos Coelho and V. C. Mariani, "Combining of Chaotic Differential Evolution and Quadratic Programming for Economic Dispatch Optimization With Valve-Point Effect", IEEE Trans. Power Syst., vol. 21, no. 2, pp. 989-996, May 2006.
[26] J.-P. Chiou, "Variable scaling hybrid differential evolution for large-scale economic dispatch problems", Elect. Power Syst. Res., vol. 77, no. 3-4, pp. 212–218, March 2007.
[27] N. Duvvuru, and K. S. Swarup, "A Hybrid Interior Point Assisted Differential Evolution Algorithm for Economic Dispatch", IEEE Trans. Power Syst., vol. 26, no. 2, pp. 541–549, 2011.
[28] B. K. Panigrahi, V. R. Pandi, "Bacterial foraging optimization: Nelder–Mead hybrid algorithm for economic load dispatch", Proc. Inst. Elect. Eng. Gener. Transm. Distrib., vol. 2, no. 4, pp. 556–565, 2008.
[29] A. Bhattacharya, P. K. Chattopadhyay, "Hybrid differential evolution with biogeography-based optimization for solution of economic load dispatch", IEEE Trans. Power Syst., vol. 25,no. 4, pp. 1955-1964, 2010.
[30] S. Mirjalili, S. M. Mirjalili, & A. Lewis "Grey Wolf Optimizer". *Advances in Engineering Software*, vol. 69, pp. 46-61, March 2014.

Author Profile:

Sudip Kumar Ghorui is Assistant professor, Department of Electrical Engineering, Budge Budge Institute of technology. He obtained B-Tech (Electrical Engineering) in 2011 and M-Tech (Power System) in 2013. He has 3 years teaching experience. His research interests include power system operation, optimization, neural networks and fuzzy logic.

Roshan Ghosh is Assistant professor, Department of Electrical Engineering, Budge Budge Institute of technology. He obtained B-Tech (Electrical Engineering) in 2008 and M-Tech (Electrical Engineering) in 2012. He has 3 years teaching experience. His research interests include power electronics and electric drives, Non-conventional energy sources.

Subhashis Maity is a student, Department of Electrical Engineering, Budge Budge Institute of technology. His research interests include Power System, Power system Operation.