Middle-East Journal of Scientific Research 24 (S1): 177-183, 2016
ISSN 1990-9233
© IDOSI Publications, 2016
DOI: 10.5829/idosi.mejsr.2016.24.S1.36

Economic and Emission Thermal Power Dispatch with Practical Constraints Using Firefly Algorithm

[1]S. Anbudasan, [1]Mr. P. Sundara Mallayan and [2]S.S. Vignesh

[1]Department of EEE, J.J College of Engineering and Technology, Trichy, India
[2]Department of EEE, Valliammai College of Engineering, Chennai, India

Abstract: This Project proposes Firefly stochastic Algorithm (FFA) to deal with the Multi-objective Problem of fuel cost and emission minimization. Due to strict governmental regulations on environmental protection, the conventional thermal power operation at absolute minimum fuel cost cannot be only basis for dispatching electric power .It is necessary to include environmental problem in the economic load dispatch problem. The economic dispatch and emission dispatch are considerably different. The economic dispatch deals with only minimizing the total fuel cost (operating cost) of the system violating the emission constraint. On the other hand emission dispatch deals with only minimizing the total emission of NO_X from the system violating the economic constraints because it is a significant issue at the global level. Therefore it is necessary to find out an operating point, that strikes a balance between cost and emission. This is achieved by combined economic and emission dispatch (CEED). In this thesis, the Bi-objective problem is converted into single objective problem known as Combined Economic Emission Dispatch (CEED) by using Modified price penalty factor (PPF). Recently, Evolutionary optimization techniques are observed to be effective in solving CEED issues. FFA is an efficient optimization technique which shows good results. The proposed method also considers the nonlinear characteristics of a generator such as ramp rate limits and prohibited operating zone for actual power system operation. This is tested with IEEE 30 bus system by considering the non-linearity such as transmission losses, ramp rate limits, prohibited operating zone and valve point effect. The solutions going to be obtained are quite encouraging and useful in the practical economic emission environment.

Key words: Economic Dispatch · Emission Dispatch · Price Penalty Factor (PPF) · Firefly Algorithm (FA) · Ramp Rate Limit and Valve - point effects

INTRODUCTION

An efficient and optimum economic operation of electric power generation systems has always occupied an important position in the electric power industry. This involves allocation of the total load between the available generating units in such a way that the total cost of operation is kept at a minimum. In recent years, the rapid increase in world population and widespread economic activities result in a continuously increasing demand for energy services. Contrary to this increase in energy demand, the reduction of the energy sources requires the economic distribution of the produced energy. Despite the fact that economic dispatch can optimize the fuel cost of the generators, it still cannot produce a solution for the environmental pollution due to the excessive emission of fossil fuels. Now, most of the needed quantity of electrical energy is produced in thermal power plants. In these plants, the mechanical energy that will move the rotor shafts of the generators is produced by fossil fuels. This situation causes a large amount of sulfur dioxide (SO_2) and nitrogen oxide (NO_X) emissions to be mixed in the atmosphere, which then lead to environmental pollution. This may give rise to the problem of global warming. For this reason, in recent years, emission control is now important in power plants, in that it is produced by the use of fossil fuels. Due to increasing concern over the environmental consideration, energy demands requirements and secure electricity not only at the cheapest possible price, but also at minimum level of pollution. So the optimal scheduling of generation in a thermal power plant involves the allocation of

Corresponding Author: S. Anbudasan, Department of EEE, J.J College of Engineering and Technology, Trichy, India.

generation so as to optimize the fuel cost and emission level simultaneously. Hence the optimization problem becomes Combined Economic and Emission Dispatch problem (CEED).In addition, the increasing public awareness of the environmental protection and passage of clean Air Act Amendments of 1990 have forced the utilities to modify their design or operational strategies to reduce pollution and atmospheric emission of thermal plants such that the electricity using industry must decrease its SO_2 emission by 10 million ton/year and the NO_X by 2 million ton/year [1]. Apart from heat, power utilities using fossil fuel as primary energy source, produces harmful gasses such as CO_2, SO_2 and NO_X, which cause detrimental effect on human being. The solution of economic power dispatch or minimum emission problems, when attempted in isolation will be different and conflicting with each other.

Therefore in order to solve these two objectives (economic and emission) simultaneously, the problem is formulated into multi-objective problem that concurrently reduce both fuel cost and total emissions. While the emission is reduced the fuel cost may be inappropriately increased or while the fuel cost is reduced the emission may be increased. This difficulty of Multi-objective CEED problem is overcome by changing the multi-objective into a single objective function with the help of a price penalty factor and linear weighted sum method[2]. The Price penalty factor (PPF) blends the fuel cost and emission output.Recently price penalty approach is presented for solving emission, reserve and economic load dispatch (ERELD) problem with non-smooth and non-convex cost functions problem. For convenience in solving the ED problem, the unit generation output is usually assumed to be adjusted smoothly and instantaneously [3]. Practically, the operating range of all online units is restricted by their ramp rate limits for forcing the units operation continually between two adjacent specific operation periods. In addition, the prohibited operating zones in the input-output curve of generator are due to steam valve operation or vibration in the shaft bearing. Because it is difficult to determine the prohibited zone by actual performance testing or operating records. The best economy is achieved by avoiding operation in areas that are in actual operation. Hence, the nonlinear constraints (valve point loading and ramp rate limits and prohibited operating zones) of generator operation must be taken into account to achieve true economic operation [4]. The paper is organized as follows: Section 2 deals with the formulation of CEED problem. Section 3 describes detail of firefly algorithm. Section 4 describes the details of the proposed method apply for solving the economic dispatch problem and simulation results. Lastly, conclusion is given in Section 5.

Problem Formulation

Mathematical Model for Combined Economic Emission Dispatch: The Environmental/Economic Dispatch (EED) problem aims at finding the optimal combination of load dispatch of generating units and minimizes both fuel cost and emission while satisfying the total power demand[5]. The economic dispatch and emission dispatch are considerably different. Because of this conflicting nature of these two objectives it is necessary to find an operating point that makes a balance between fuel cost and emission which is possible by means of CEED problems. The Combined Economic Emission Dispatch problem is to minimize simultaneously the two competing objective functions fuel cost and emission while satisfying all equality, inequality and practical/non-linear constraints.

Since CEED problem deals with two single objectives, the mathematical model for the above problem is described as follows:

$$TC = Min\ (\sum_{i=1}^{Ng}[F_i\ (P_i),\ Ei\ (Pi)])Rs/hr.$$

where,

$F_i\,(P_i) = a_i * P_i^2 + b_i * P_i + c_i$[fuel objective]

$E_i\,(P_i) = d_i * P_i^2 + e_i * P_i + f_i$ [emission objective]

TC-the total operating cost objective function

Fi Pi - the fuel cost of ith generating unit in Rs/h

Ei Pi - the Emission output of ith generating unit in Kg/hr

ai, biand ci - fuel cost co-efficient of ithgenerating unit

d_i, ei and fi- Emission co-efficient of ithgenerating unit

Subject to

$$\sum_{i=1}^{Ng}(Pi) = P_D + P_{Loss}\ [equality\ constraint]$$

$Pi,\ min \le Pi \le Pi,\ max$ [inequality constraint]

where, PD -Power Demand in MW.

Pi, min -Minimum power generation limit of the ithunit in MW.

Pi, max -Maximum power generation limit of the ith unit in MW.

Transmission Loss Constraints: Since there is no electrical network without loss, the transmission losses between two generating units must be accounted in order to have an exact CEED problem. In this proposed method transmission loss is calculated using B-Coefficient's method which can be expressed as

$$P_{Loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_{Gi}B_{ij}P_{Gj} + \sum_{i=1}^{n} B_{0i}P_{Gi} + B_{00}$$

where,

Pi -power generation of the i^{th}unit in MW. Pj -power generation of the j^{th} unit in MW. Bij -the loss coefficientsbetweenith and jth generating unit in MW. PLoss -the power loss in MW.

CEED Problem Considering Practical Operation Constraints of Generator: As all the thermal generating units are having some non-linear characteristics in their operation, in order to make the solution to be practical those non-linearity's such as valve point effect, generator ramp-rate limits and prohibited operating zones must be considered while solving problem [6]. Here those nonlinearities are presented as follows.

Valve Point Loading: Real input – output curves of the generator units are non-convex due to the valve point effect.Typically, ripples are introduced in the fuel cost curve as each steam valve starts to operate. A cost function that includes the valve point effect can be expressed as follows:

$$F_i(P_i) = a_i * P_i^2 + b_i * P_i + c_i + |d_i * \sin(e_i \times (P_i^{min} - P_i))|$$

where, Fi (Pi) is total fuel cost of generation in (\$/hr) including valve point loading, d_i, e_i are fuel cost coefficients of the ith generating unit reflecting valve-point Effect.

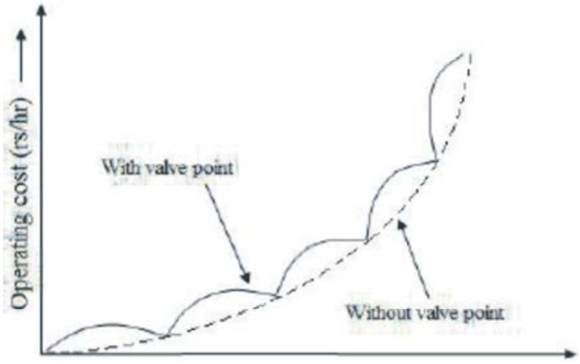

Fig. 1: Valve point loading curve

Ramp Rate Limit: The inequality constraints due to ramp rate limits for unit generation changes are given in terms of

1) As generation increases, $P_i - P_i^0 \leq UR_i$

2) As generation decreases, $P_i - P_i^0 \leq Dri$

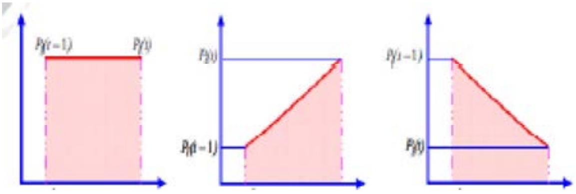

Fig. 2: Ramp Rate Limit

The inclusion of ramp rate limits modifies the generator operation constraints as follows,

$$Max\,(P_i^{min}, P_i - P_i^0) \leq P_i \leq Min\,(P_i^{max}, P_i - P_i^0)$$

Prohibited Operating Zone: Physical operating limitations may result in generation units with prohibited operating zones. To model these zones, the following constraints must be added to the problem formulation:

$$Pi^{min} \leq Pi \leq P^{l}_{i,1}$$
$$P^{u}_{i,j-1} \leq Pi \leq P^{l}_{i,j}\; j=1, 2, \ldots.n$$
$$P^{u}_{i,ni} \leq Pi \leq P_i^{max}$$

Modified Price Penalty Factor Algorithm: Since the CEED problem is of conflicting in nature (i.e. Minimization cost increases emission and vice versa), a price penalty factor (PPF) method has been chosen as a suitable method to convert a bi-objective problem into a single objective [7]. Since the above PPF algorithm provide an approximate value of PPF for the power demand, an accurate method of determining PPF called as Modified Price Penalty Factor (MOPPF) Algorithm is used in this work. Determination of MOPPF is gives as follows.

Step 1: Evaluate the Maximum cost of each generator at its Maximum output is

$$F_i\,(P_i) = a_i * P_i^2 + b_i * P_i + c_i \; Rs/hr.$$

Step 2: Evaluate the Maximum NO_X emission of each generator at its Maximum output is

$$E_i\,(P_i) = d_i * P_i^2 + e_i * P_i + f_i \; Kg/hr.$$

Step 3: Divide the Maximum cost of each generator by its average NO_X emission, i.e

☻ = ☻

Recalling that

☻ = h_i *Rs/Kg*

Step 4: Arrange h_i ($i=1,2,\ldots..N_G$) in ascending order

$h= [h_1, h_2, h_3\ldots.., h_n]$

Step 5: Let P_m be the vector having the maximum values of the respective h values

$P_m=[P_{m1,} P_{m2},\ldots\ldots, P_{mn}]$

Let m be the vector having $m= [m_1, m2_{,\ldots\ldots,} m_n]$

where, $m_{i+1} = m_i + P_{mi+1}$

Step 6: Add the maximum capacity of each unit P_{mi} one at a time Until
Case1: If the load demands $P_D = m_i$, then
$h_m= h_i$ is the modified price penalty factor Rs/Kg for thegiven load.
Case2: If the load demand P_D is between m_i and m_{i+1}then

$h_m= h_i +$ ☻ $* (P_D - m_i)$

where, h_m is the modified price penalty factor in Rs/Kg, which is fixed for a load demand.

Complete Optimization Problem: The complete CEED optimization problem using Modified Price Penalty Factor is determined by using the following equation.

$$MinimizeTC = Min\ (\sum_{i=1}^{Ng}[F_i(P_i) + h_m * E(P_i)])\ Rs/hr.$$

Firefly Algorithm

Introduction to Firefly Algorithm: The Firefly Algorithm (FA) developed by Dr. Xin-She Yang is a nature inspired algorithm which is based on the flashing behavior of fireflies. The firefly algorithm possess many similarities with other swarm intelligence algorithms such as particle swarm optimization (PSO), Bacterial Foraging (BFA) algorithm and Artificial Bee colony Algorithm (ABC), it is much simpler both in implementation and concept [8]. Its major advantage includes that it is based on the global communication among the fireflies and it uses mainly real random numbers and as a result, it seems more effective in optimal power flow problems.

According to flashing characteristics of real fireflies, the firefly algorithm has three idealized rules. They are:

- All fireflies are unisex in nature so that they will move towards more attractive and brighter fireflies regardless of their sex.
- Attractiveness is proportional to their brightness which decreases as the distance from the other firefly increases due to the fact that the air absorbs light. If there is not present a brighter or more attractive firefly than a particular one, it will select random movement.
- The value of the objective function of a given problem is used to determine the brightness or light intensity of a firefly. The light intensity is proportional to the value of the objective function, in case of maximization problems.

Attractive Function: Attractiveness function of a firefly is a monotonically decreasing function in the firefly algorithm. As a firefly's attractiveness is proportional to the light intensity seen by adjacent fireflies, we can now define the variation of attractiveness β with the distance r by

$$\beta(r) = \beta_0 * exp(-\gamma r^n), \text{ with } n \geq 1$$

where, β_0 is the initial attractiveness at r=0. r represents the distance between any two fireflies and γ is an light absorption coefficient.

Distance between Fireflies: Cartesian or Euclidean distance is defined as the distance between any two fireflies i and j, at positions x_i and x_j, respectively.

$$r_{ij} = \| X_i - X_j \| = [\sum_{k=1}^{d}(X_{i,k} - X_{j,k})^2]^{1/2}$$

where, $X_{i,k}$ gives the k^{th} component of the spatial coordinate X_i of the i^{th} firefly and d gives the number of dimensions.

Movement Function: The movement of a firefly i is attracted towards another more attractive (brighter) firefly j is given by:

$$X_i = X_i + \beta(r) * (X_j - X_i) + \alpha * [rand - (1/2)]$$

where the first element is the firefly's current position, the second term is used for considering a firefly's attractiveness to adjacent fireflies and the third element shows the random movement of a firefly if there is no any brighter ones[9]. The $\alpha$is a randomization parameter, while rand is a random number generator uniformly distributed in the space [0, 1]. In this implementation of the algorithm, choose of $\beta_0 = 1.0$, $\alpha=[0,1]$ and the absorption coefficient $\gamma = 1.0$ guarantees a quick convergence of the algorithm to the optimal solution.

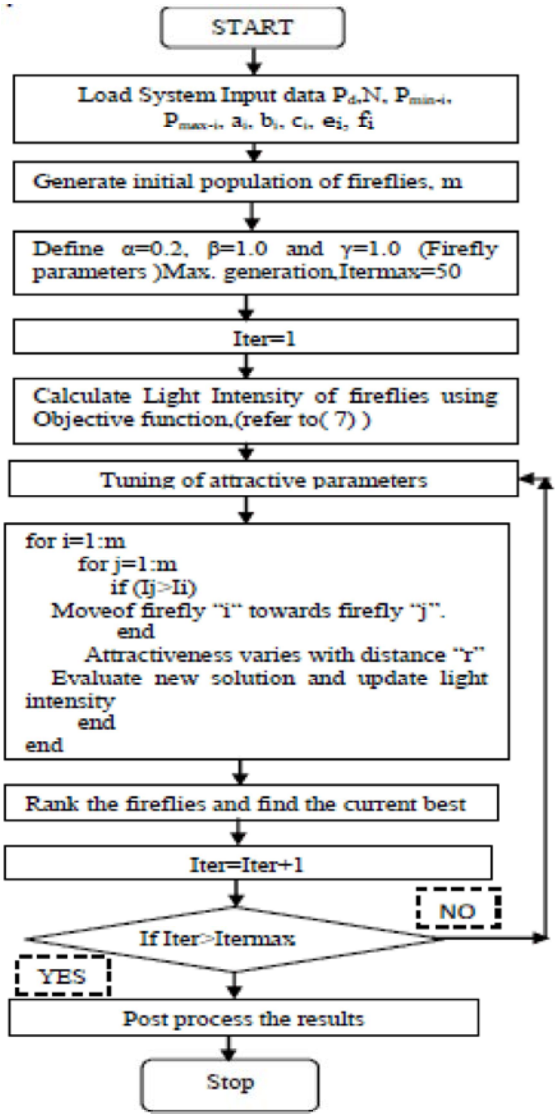

Fig. 4: Flowchart of Firefly Algorithm

The convergence of the algorithm is obtained when $m \geq n$ for any large number of fireflies (m), where n is the number of local optima of an optimization problem. However, it is under search a formal proof of the convergence of the algorithm that the algorithm will attain global optima when $m \rightarrow \infty$ and $t \geq 1$. The proper choice of the number of iterations together with the selection of parameters γ, β, α and m depends on the nature of the given optimization problem as this affects the convergence of the algorithm [10]. If population size increases the computational time also increases.

Based on the absorption coefficient γ, there are two special cases, one with $\gamma \rightarrow \infty$ and other with $\gamma \rightarrow 0$. In the case $\gamma \rightarrow 0$, the light intensity does not decrease with distance r between twofireflies increases and the attractiveness coefficient is constant $\beta = \beta_0$. So firefly can be seen anywhere, optimum can be easily reached. In case $\gamma \rightarrow \infty$, attractiveness coefficient is the Dirac delta function $\beta(r) > \delta(r)$. In this attractiveness is almost zero, fireflies cannot see each other and they move randomly.

RESULTS AND DISCUSSIONS

Description of the Test System: Here, the experimental study performed for the effectiveness of Firefly Algorithm (FA) over solving CEED problem is described. The results energy for the load demand have been examined in the experiment. The problem formulations and FA algorithm is implemented using M-file in Matlab 2010. In the experimental study, FA algorithm is tested over standard IEEE 30-bus power system with six generators. The algorithm is tested for 283.4 MW load demand. The coefficients of CEED problem and the transmission loss coefficients matrix are shown in table below. The coefficients of fuel cost, emission and the capacities of the generating units are shown in table below.

However, the transmission loss coefficient matrix is given below:

B=[0.000218 0.000102 0.000010 0.000010 0.000001 0.000027
0.000102 0.000187 0.000004 0.000015 0.000003 0.000031
0.000010 0.000004 0.000430 0.000134 0.000160 0.000108
0.000010 0.000015 0.000134 0.000097 0.000097 0.000051
0.000001 0.000003 0.000160 0.000256 0.000256 0.000000
0.000027 0.000031 0.000108 0.000000 0.000000 0.000359];

The generator unit operating ranges are given below:
$50 \text{ MW} \leq P_1 \leq 200 \text{ MW}$
$20 \text{ MW} \leq P_2 \leq 80 \text{ MW}$
$15 \text{ MW} \leq P_3 \leq 50 \text{ MW}$
$10 \text{ MW} \leq P_4 \leq 35 \text{ MW}$
$10 \text{ MW} \leq P_5 \leq 30 \text{ MW}$
$12 \text{ MW} \leq P_6 \leq 40 \text{ MW}$

Table 1: Fuel cost coefficients with valve point Data

a ($/MW^2-H)	b ($/MW-H)	c ($)	α ($)	β ($/MW_H)
0.00375	2	0	0	0
0.0175	1.75	0	0	0
0.0625	1	0	40	0.08
0.0834	3.25	0	50	0.09
0.025	3	0	0	0
0.025	3	0	0	0

Table 2: Emission cost coefficients

Unit	d ($/MW^2-H)	e ($/MW-H)	f ($)
1	0.0126	-1.1	22.983
2	0.02	-0.1	25.313
3	0.027	-0.01	25.505
4	0.0291	-0.005	24.9
5	0.029	-0.004	24.7
6	0.0271	0.0055	25.3

Table 3: Generating units previous hour generation, Ramp Rate Limit, Prohibited Zones

Unit	Pi^0 (MW)	DRi (MW)	Uri (MW)	Prohibited zone1 (MW)	Prohibited zone2 (MW)
1	150	60	80	[55 66]	[80 120]
2	35	28	10	[21 24]	[50 60]
3	39	10	20	[30 36]	-
4	20	10	05	[25 30]	-
5	18	10	05	[25 28]	-
6	20	15	06	[24 30]	-

Table 4: Effective Lower and Upper Generation Limit considering Ramp Rate Limit

Unit	Pmin (MW)	Pmax (MW)
1	70	200
2	25	63
3	19	49
4	15	30
5	13	28
6	14	35

Results for CEED Problem:

Table 5: CEED solution of IEEE 30 bus system

	Power Demand (MW)
	283.4
P1 (MW)	147.67
P2 (MW)	49.96
P3 (MW)	20.33
P4 (MW)	15.09
P5 (MW)	24.89
P6 (MW)	34.025
Fuel cost ($/hr)	831.24
Emission (Kg/hr)	372.52
Price Penalty Factor ($/Kg)	1.9862
Total System Loss (MW)	8.2444
Total Cost ($/hr)	1571.15

The multi-objective CEED problem is solved by the FA algorithm for the standard IEEE-30 bus system considering non linearity practical constraints such as transmission losses, ramp rate limit, prohibited operating zone and valve point effect.The proposed Firefly Algorithm has been implemented in MATLAB 2010 programming language and MS Windows 7 as an operating system. The performance of each system has been compared with other method like Real coded Genetic algorithm.Table 1 gives the minimum fuel cost solutions for CEED problem using FA with energy load demand of 283.4 MW. As seen in table 2, when the minimum fuel cost solutions fortest power system with load demand are considered, it is observed that the proposed FA algorithm can reduce the fuel cost as compared to the Real coded genetic algorithm.

Table 6: Operating Cost (Rs/h) for different optimization techniques

	Generators Real Power in MW							
Optimization techniques	G1	G2	G3	G4	G5	G6	Total loss (MW)	Total cost ($)
RGA (Real Coded Genetic Algorithm)	145.03	46.62	27.03	18.31	23.98	30.84	8.4224	1588.492
FFA	147.67	49.96	20.33	15.09	24.89	34.02	8.5791	1571.158

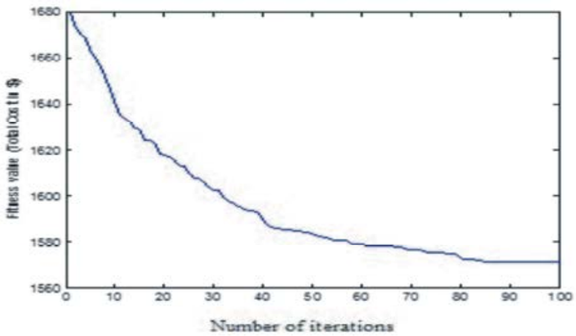

Fig. 2: Convergence characteristics of FFA for load demand of 283.4

CONCLUSIONS

Results showed that FFA method is well suited for obtaining the best solution for operating cost, fuel cost and Emission output.Savings of approximately 17 Rs/h and above were obtained by the RGA method for six generator test system.The Proposed FFA is also tested with IEEE 30 bus system by considering the non linearity practical constraints such as transmission losses, ramp rate limits, prohibited operating zone and valve point effect. The solutions obtained are quite encouraging and useful in the practical economic emission environment.

REFERENCES

1. Abido, M.A., 2006. Multiobjective Evolutionary Algorithms for Electric Power Dispatch Problem, IEEE Transactions on Evolutionary Computation, 10(3).
2. Whei-Min Lin, Fu-Sheng Cheng and Ming-Tong Tsay, 2002. An Improved Tabu Search for Economic Dispatch with Multiple Minima, IEEE transactions on power systems, 17(1).
3. Abido, M.A., 2009. Multiobjective particle swarm optimization for environmental/economic dispatch problem, Electric Power Systems Research 79: 1105-1113.
4. Deepan, B. and R. Janani, 2013. A Real Coded Algorithm for Solving CEED with practical constraints, International Journal of Engineering Research & Technology, 2(6).
5. Sonmez, Y., 2011. Multi-objective environmental/economic dispatch solution with penalty factor using artificial bee colony algorithm, Scientific Research and Essays, pp: 6.
6. Loia, V. and A. Vaccaro, 2014. Decentralized Economic Dispatch in Smart Gridsby Self-Organizing Dynamic Agents, IEEE transactions on systems, man and Cybernetics: Systems, 44(4).
7. Jun Sun, Vasile Palade, Xiao-Jun Wu, Wei Fang and Zhenyu Wang, 2014. Solving the Power Economic Dispatch Problem withGenerator Constraints by Random Drift ParticleSwarm Optimization, IEEE Transactions on Industrial Informatics, 10(1).
8. Shiping Yang, Sicong Tan and Jian-Xin Xu, 2013. Consensus Based Approach for Economic Dispatch Problem in a Smart Grid, IEEE Transactions on Power Systems, 28(4).
9. Ahsan Ashfaq and Akif Zia Khan, 2014. Optimization of Economic Load Dispatch Problem by Linear Programming Modified Methodology, International Conference on Emerging Trends in Engineering and Technology.
10. Devendra Bisen, Hari Mohan Dubey, Manjaree Pandit and B.K. Panigrahi, Madhav, 2011. Solution of Large Scale Economic Load Dispatch Problem Using Quadratic Programming and GAMS: A Comparative Analysis, Journal of Information and Computing Science, 7(3): 200-211.