Research Article

Investigation of Equilibrium Optimizer to Solve Economic Dispatch with Practical Constraints

Y Venkata Krishna Reddy

***Abstract*— Presently power demand keep on increasing due to rapid changes occurs in power industry. For that purpose establishing new generating is costlier rather than effectively utilize the available generating stations. In order to properly planning of power system generation sharing Economic Dispatch (ED) plays vital role. In this paper, Equilibrium Optimizer (EO) is used to solve the ED problem with effect of valve-point, prohibited operating zones (POZs), ramp rate up/down limits and pollution like practical constraints. In order to analyze the capability of the EO algorithm, the algorithm is applied to four test systems with 6 unit systems and the results are compared with other optimization algorithms. The comparative results proven that EO is better optimization technique to solve ED problem with practical constraints.**

Index Terms— **Power Industry, Economic Dispatch, Equilibrium Optimizer, Valve-point, Prohibited operating zones, Ramp rate up/down limits.**

I. Introduction

THE SYSTEM which can deals with generation, transmission nd distribution to supply the energy to the consumers on economic basis is known as power systems. Electric power demand is increasing in the current context due to developments in both the industrial and public sectors. The main source of this electricity is primarily thermal plants are likely to meet load demand. In general, the cost of generating for any thermal plant will be proportional to the cost of fuel.

As a result, proper load sharing of generating units is essential to give lower generation costs. The Economic Dispatch (ED) problem is examined for this purpose in order to obtain optimal allocation of generation by all generating units while minimizing total fuel cost while meeting both the equality and inequality requirements. ED problems are typically complicated by practical limits of thermal units such as transmission network losses, valve-point loading, banned operating zones, and numerous fuels. The operational cost function is approximated by a single quadratic function in standard ED problems, and valve-point loading is neglected.

Y V KRISHNA REDDY, SV College of Engineering, Dept. of EEE, Tirupati, India. (e-mail: yvkrishnareddy36@gmail.com).

https://orcid.org/0000-0002-1832-2193

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Typically, the Lambda Iteration approach is employed to solve the ED problem for proper thermal unit allocation at the lowest possible fuel cost. Therefore, proper distribution of producing units for large systems is problematic. To address this issue, researchers are looking for new methods that are similar to Particle Swarm Optimization (PSO) [1], Firefly Algorithm (FFA) [2], Quick Group Search Optimizer (QGSO) [3], Cuckoo Search Algorithm (CSA) [4] and Genetic Algorithm (GA). Because an ED problem in a practical power system is non-convex due to valvepoint loading, the applicability of traditional approaches is limited. Improved Differential Evolution (IDE) [5, 6], Tournament-based Harmony Search (THS) [7], and Oppositional based Grey Wolf Optimization (OGWO) [8] methods are utilized to tackle the ED problem with valvepoint loading.

However, note the discontinuities in the turbine-generator set performance characteristics, which are caused by valve-point (non-convex) loading in plants [9]. For tackling the ED with valve point effect (EDVPE) problem, hybrid approaches such as modified Sub-Gradient (MSG) and Harmony Search Algorithms hybrid GA-NSO [10] and MSG-HS [11] and methods are utilized.

Furthermore, instability in generation at certain levels of unit loading may be induced by physical restrictions or flaws. This issue can be overcome by employing the prohibited operating zones (POZ) paradigm [9] and switching the unit's generating level between any two. Its ramp rate restrictions for concurrent periods must not be exceeded [9]. Backtracking search algorithm (BSA) [12], PSO [13], Enhanced Random Drift PSO (RDPSO) [14], Exchange Market Algorithm (EMA) [15], Modified CSA [16] techniques are utilized to solve ELD with ramp rate limitations and POZs.

Despite the fact that ED reduces operational costs greatly, the environmental impact is still not addressed. By incorporating emission constraints into the ED problem, the problem is renamed the Economic Emission Dispatch (EED) Problem. For the EED problem with/without transmission losses, differential evolution (DE) [17], Glowworm Swarm Optimization (GSO) [18], MOEA [19], and Summation based Multi Objective DE (SMODE) [20] approaches are utilized. Approaches such as Multi objective BSA [21], multiobjective EA [22], new global PSO (NGPSO) [23] are used to combine fuel cost with emission as a specific objective problem.

Non-convex loading, emission, ramp rate restrictions, and POZs should all be considered while solving a practical ED problem, as it is extremely difficult to find an ideal solution. The Equilibrium Optimizer (EO) [24] approach was utilized in this article to tackle ED issues with numerous practical operating restrictions such as valve-point effect, nonlinear emission, ramp-up/down, and POZs. The EO method quality is applied to four case studies for solving practical ED difficulties.

II. PROBLEM FORMULATION

A. *Classical ED*

The theoretical cost curve of classical ELD problem is as shown in the Figure 1.

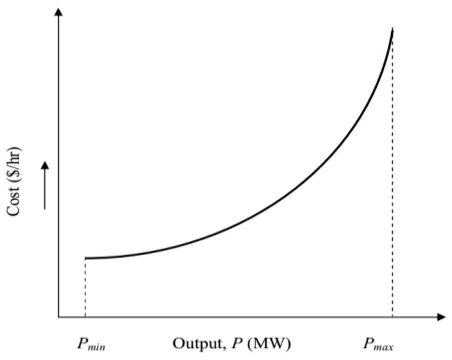

Fig.1 Convex Fuel cost function

The most simplified cost function of each generating unit i, can be represented as a quadratic function as: (
Minimize

$$F_T = \min f = \sum_{i=1}^{n} F_i(P_i) \qquad (\$/h) \tag{1}$$

$$F_i(P_i) = \sum_{i=1}^{N} (a_i P_i^2 + b_i P_i + c_i) \tag{2}$$

Equality Constraints:

$$\sum_{i=1}^{N} P_i = P_D + P_L \tag{3}$$

To calculate transmission losses the B-coefficient method used.

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{0i} P_i + B_{00} \tag{4}$$

Inequality Constraints

$$P_{i\,min} \le P_i \le P_{i\,max} \tag{5}$$

Where Pimin and Pimax are the minimum and maximum real power generation limits of the ith generating unit.

B. EDVPE

The ED problem cost objective function, considering the valve-point effects (EDVPE). Figure 2 shows the valve-point effect is incorporated in classic ED problem by superimposing the sine component model on the quadratic cost curve.

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + \left| e_i \sin(f_i (P_{min} - P_i)) \right| \tag{6}$$

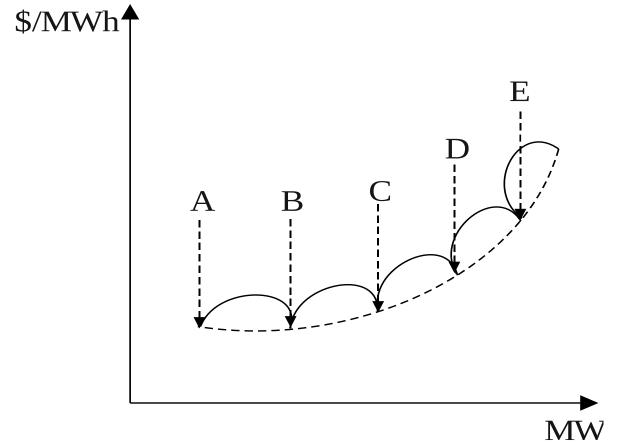

Fig. 2. Non-Convex Fuel cost function

C. EDRPOZ

ED problem with ramp rate Limits and prohibited operating zones (POZs) treated as EDRPOZ. Figure 3 shows the model of Ramp-rate limits.

$$\begin{cases} P_i - P_{0i} \le UR_i & \text{if generation increases} \\ P_{0i} - P_i \le DR_i & \text{if generation decreases} \end{cases} \tag{7}$$

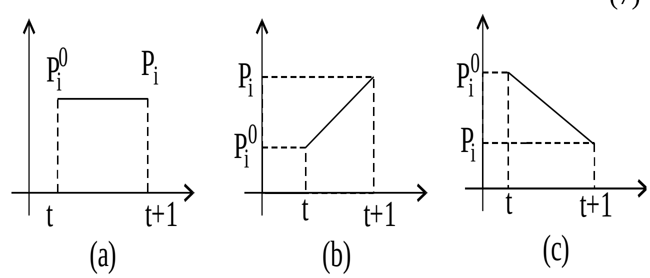

Fig. 3 Ramp rate limits of generating units

The new operation limits:

$$P_{i\,min,r} \le P_i \le P_{i\,max,r} \tag{8}$$

Where

$$\begin{aligned} P_{i\,min,r} &= \max(P_{i\,min}, P_{0i} - DR_i) \\ P_{i\,max,r} &= \min(P_{i\,max}, P_{0i} + UR_i) \end{aligned} \tag{9}$$

These POZs can be included in the ED formulation as follows:

$$P_i = \begin{cases} P_{i\,min} \le P_i \le P_{i,1}^{i} \\ P_{i,j-1}^{u} \le P_i \le P_{i,j}^{l} \quad j = 2,....n_i \\ P_{i,n_i}^{u} \le P_i \le P_{i\,max} \end{cases} \tag{10}$$

Figure 4 clearly shows the POZs modeled in the cost curve.

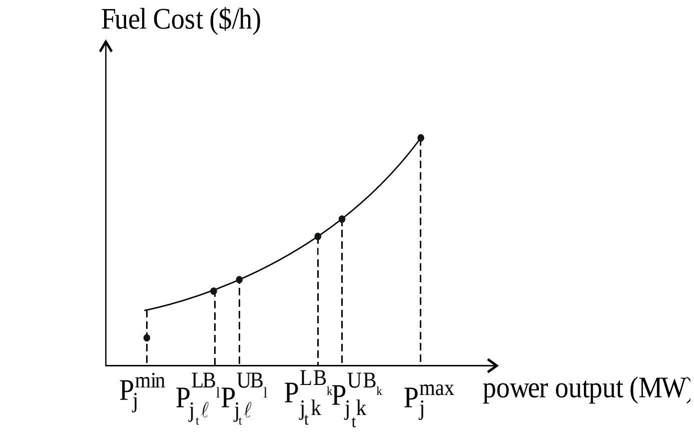

Fig. 4 Generator characteristics with POZs

D. EED

To reduce emissions along with the cost of generation considering the problem of environmental economic dispatch (EED). The fossil fuel power plants produce pollutants such as NO_X, CO_2 and SO_2 emissions which are usually represented by separate quadratic functions. Nevertheless, by combining all the pollutants as single emission introducing exponential function to the quadratic emission function as given in Equation (11) for overall emission level of the pollutants.

$$F = E(P_G) = \sum_{k=1}^{N_G} (\alpha_k P_{Gk}^2 + \beta_k P_{Gk} + \gamma_k) + \xi_{ck} \times \exp(P_{Gk}\lambda_k) \ (ton/h) \tag{11}$$

Weighted sum method: The fuel cost and emission objective problem is converted into single objective CEED problem given by Equation (12) by assuming weighting factor proportion to the importance of the objective.

$$\text{Minimize } F = W \times F_2 + (1-W) \times F_3 \tag{12}$$

III. Equilibrium Optimizer

A. Faramarzi proposes an Equilibrium Optimizer (EO). In EO, each solution with its position acts as a search agents.

A. Initialization and evaluation of the functions

The initial positions were randomly determined according to the number of particles in the search space

$$C_i^{initial} = C_{min} + rand_i (C_{max} - C_{min}) \quad i = 1, 2, 3, ...n \tag{13}$$

B. Equilibrium pool and candidates (Ceq)

The state of equilibrium is known as the final state of EO convergence. In EO these candidates are selected four best particles based on their fitness value during the entire optimization process with other particles whose positions are in the mean of the four best particles described above. Such five particles were called candidates for equilibrium and used to construct an equilibrium pool.

$$C_{eq,pool} = \{C_{eq(1)}, C_{eq(2)}, C_{eq(3)}, C_{eq(4)}, C_{eq(ave)}\} \tag{14}$$

C. Exponential term (F)

The key updating rule for concentration is controlled by the exponential term F

$$F = e^{-\lambda(t-t_0)} \tag{15}$$

$$t = \left(1 - \frac{iter}{max\,iter}\right)^{\left(a_2 \frac{iter}{max\,iter}\right)} \tag{16}$$

To achieve convergence by increasing the quest pace and improving discovery and exploitation capabilities, t_0 is modelled as

$$t_0 = \frac{1}{\lambda} \ln(-a_1 sign(r - 0.5)[1 - e^{-\lambda t}]) + t \tag{17}$$

Now equation (15) can be rewritten as

$$F = a_1 sign(r - 0.5)(e^{-\lambda t} - 1) \tag{18}$$

D. Generation rate (G)

Generation rate is the most significant parameter used in equilibrium algorithm to increase the process of exploitation.

$$G = G_0 e^{-k(t-t_0)} \tag{19}$$

Where

$$G_0 = GPC(C_{eq} - \lambda C) \tag{20}$$

$$GP = \begin{cases} 0.5r1 & r2 \geq GP \\ 0 & r2 \leq GP \end{cases} \tag{21}$$

Finally, EO's updating law shall be as follows:

$$C = C_{eq} + (C - C_{eq}) * F + \frac{G}{\lambda V}(1 - F) \tag{22}$$

IV. Results

A. Classical ED

In order to evaluate solution of classical ED problem generator practical constraints are not considered like valve-point effect, ramp limits and prohibited operating zones. But the transmission losses, equality and inequality constraints are considered for 6-unit test system [2] with power demand of 800 MW. The fuel cost function is convex function follows as Equation 1.

The simulation and comparison results for the given test system are presented in Table 1. Among all the methods, the proposed EO method is better interms of optimal cost and convergence characteristics shown in figure 5 for 25 trails.

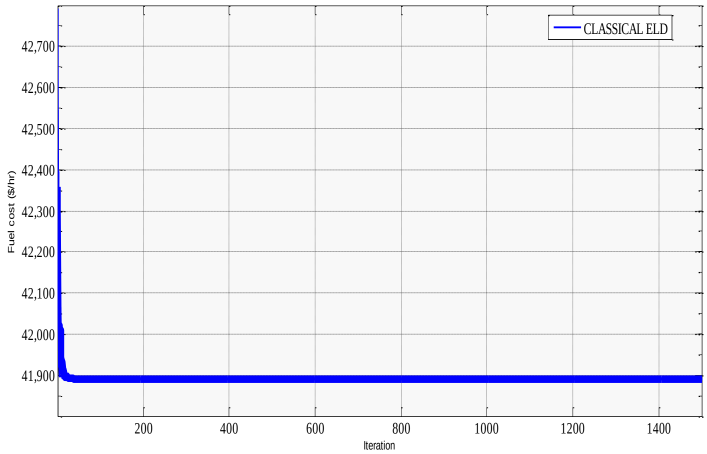

Fig. 5 Convergence characteristics of classical ED

Table 1: Comparison results for 6-unit to classical ED

	PSO [1]	FFA[2]	CSA[4]	EO
P_1 (MW)	32.67	32.5861	32.5863	33.9199
P_2 (MW)	14.45	14.4843	14.4843	14.4029
P_3 (MW)	141.73	141.548	141.548	141.2473
P_4 (MW)	136.56	136.045	136.045	135.6431
P_5 (MW)	257.37	257.664	257.664	257.3198
P_6 (MW)	242.54	243.009	243.009	242.6420
P_L (MW)	25.32	25.3309	25.3312	25.1749
P_T (MW)	825.32	825.3309	825.3312	825.1749
FC($/hr)	41896.66	41896.7	41896.9	41890.507
SD	--	--	--	0.44e-12

B. EDVPE

The cost function of the generation is represented by the Equation 6. The sinusoidal term added to convex cost function and resulting becomes non-convex cost function. The test system comprising six generating units [5] meets a power demand of 283.4 MW and includes valve-point effect and transmission loss.

The best and comparison results for test system are presented in table 2. Among all the methods the proposed EO method is better in terms of optimal cost and convergence characteristics shown in figure 6 for 25 trails.

Table 2: Comparison results for 6-unit to EDVPE

	GA-NSO[10]	MSG-HS[11]	PSO [11]	EO
P1(MW)	182.4784	199.6331	197.8648	199.5997
P2(MW)	48.3525	20.0000	50.3374	20.0000
P3(MW)	19.8553	23.7624	15.0000	23.8221
P4(MW)	17.1370	18.3934	10.0000	19.0903
P5(MW)	13.6677	17.1018	10.0000	18.1304
P6(MW)	12.3487	15.6922	12.0000	13.7463
PL(MW)	10.4395	11.1830	11.8022	11.0135
PT(MW)	293.839	294.5829	295.2022	294.0135
FC($/hr)	984.936	925.6406	925.7581	924.8883
SD	--	--	--	0.45e-12

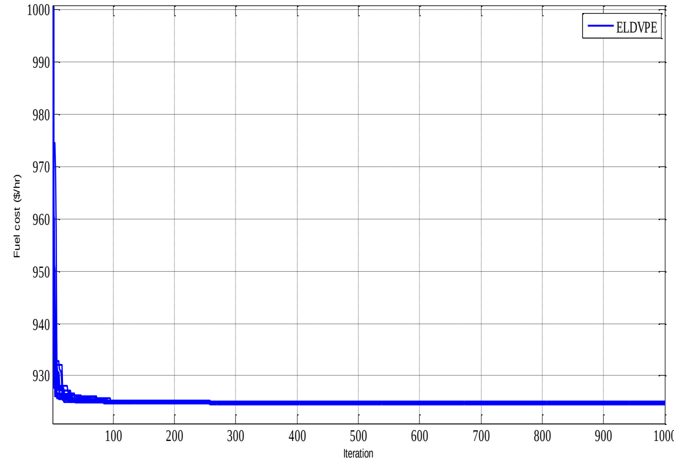

Fig. 6 Convergence characteristics of EDVPE

C. EDRPOZ

EDRPOZ comprising six generators meets [11] a load demand of 1263 MW and includes loss, POZs and ramp up/down limits. The optimal and comparison results for EDRPOZ problem are presented in Table 3. The total operating cost during practical constraints is 15442.6753 ($/hr) and it is found to be lesser than the other methods reported in the literature. The convergence characteristics of 6 unit system with proposed method for EDRPOZ are shown in Figure 7 for 25 trails.

Table 3: Comparison results for 6-unit to EDRPOZ

	BSA [12]	EMA [15]	MCS[16]	EO
P1(MW)	447.4902	443.3872	447.5038	447.0649
P2(MW)	173.3308	173.2524	173.3182	173.1643
P3(MW)	263.4559	263.3721	263.4628	263.9481
P4(MW)	139.0602	138.9894	139.0653	139.0668
P5(MW)	165.4804	165.3650	165.4764	165.5847
P6(MW)	87.1409	87.0781	87.1347	86.5868
PL(MW)	12.9583	12.4430	12.9582	12.4154
PT(MW)	1275.95	1275.443	1276.958	1275.4164
FC($/hr)	15449.89	15443.07	15449.89	15442.675
SD	--	--	--	0.52e-12

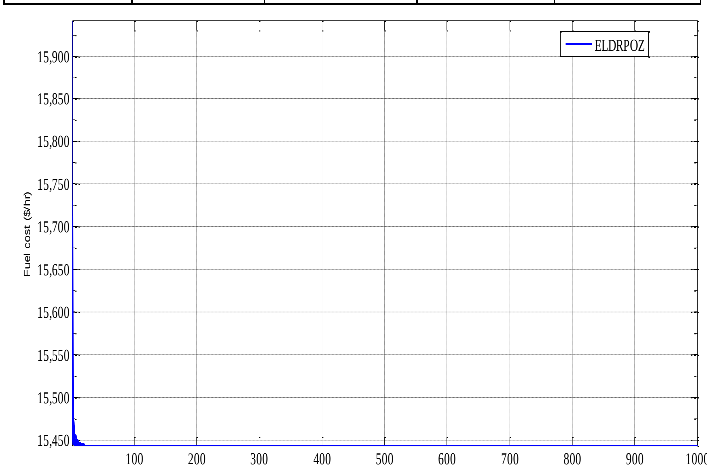

Fig. 7 Convergence characteristics of EDRPOZ

D. EED

The fossil fuel power plants produce pollutants such as NO_X, CO_2 and SO_2 emissions which are usually represented by separate quadratic functions. Nevertheless, by combining all the pollutants as single emission introducing exponential function to the quadratic emission function is given in Equation (11) for overall emission level of the pollutants. The fuel cost and emission objective problem is converted into single objective Economic Emission Dispatch (EED) problem by using the equation (12), assuming weighting factor proportion to importance of the objective.

Table 4: Optimal results for to EED by EO

Unit	Cost minimization	Emission minimization	EED
P1 (MW)	5.0000	40.9793	50.0000
P2 (MW)	30.3402	46.2677	17.9027
P3 (MW)	64.1857	54.2949	15.0798
P4 (MW)	102.4765	38.8797	12.2136
P5 (MW)	48.0259	54.3078	15.0798
P6 (MW)	35.1204	51.4338	18.6104
PTotal (MW)	285.1486	286.6741	284.6620
P loss (MW)	1.7486	3.2741	1.2620
Gcost ($/h)	604.9688	649.5788	598.9677
E (ton/h)	0.226023	0.1942	0.2242
SD	0.51e-12	0.49e-12	0.48e-12

The IEEE 30-bus 6-Unit system is considered as test system. Data is taken [16] with power demand of 283.4 MW. Table 4 represents the optimal results for test system for minimizing the cost, emission and combined economic emission with the help of EO. Table 5 provides comparison results for EED problem and figure 8, 9 and 10 represents convergence characteristics of test system.

Table 5: Comparison results for 6-unit system to EED

Methods	Fuel Cost Min. ($/Hr)	Emission Min. (ton/Hr)	CEED Min.($/Hr)
BSA [19]	605.9984	0.194203	608.9169
MOEA [21]	607.78	0.1942	NA
NGPSO [22]	605.9983	0.194178	623.8705
SMODE [23]	619.07	0.1942	NA
EO	604.9688	0.1942	598.9677

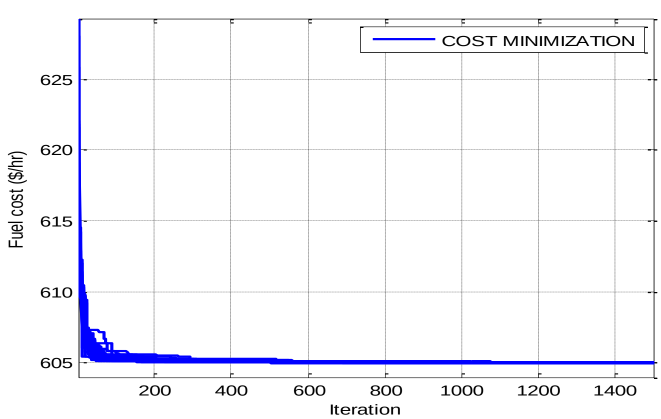

Fig. 8 Convergence characteristics of EED to cost minimization

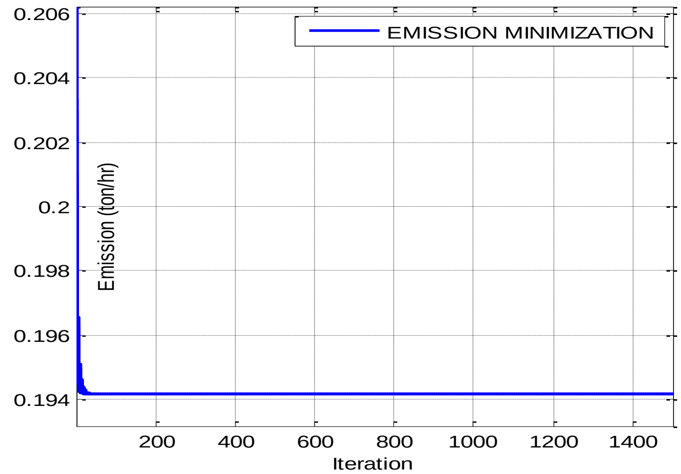

Fig. 9 Convergence characteristics of EED to emission minimization

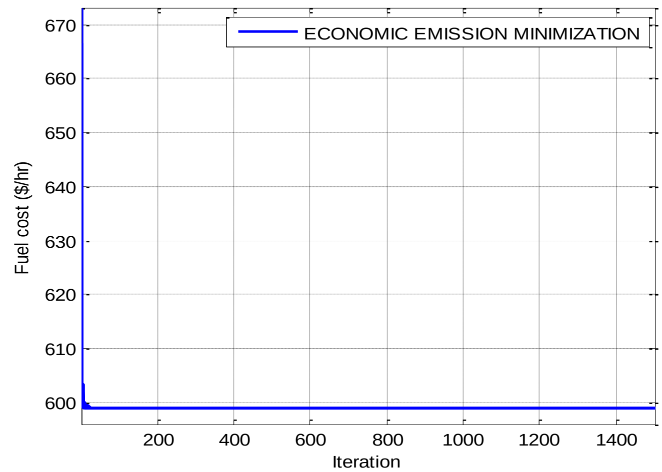

Fig. 10 Convergence characteristics of EED

V. CONCLUSION

A new optimization algorithm called Equilibrium Optimizer (EO) is used in this paper to solve the economic dispatch problem with realistic restrictions such as valve point effect, ramp rate up/down limits, prohibited operating zones and pollution. The EO has been used to evaluate four separate 6-unit test systems. The findings were consistent with other methods listed in the literature and showed that EO had quick convergence speed, better fuel cost outcomes, prevailing computational performance and more cognizant achievement. The suggested algorithm would be a viable solution to solve ED problem practical constraints. The proposed methodology is a potential approach in large-scale framework to solve complex non-smooth optimization problems.

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BIOGRAPHIES

Y. Venkata Krishna Reddy has four years' experience in teaching and 4 years of experience in research. Received M.tech in the specialization of Power Systems from JNTUACE, Anantapur in the year 2014. Awarded PhD degree in the year of 2019 at Sri Venkateswara University. Five times qualified in all India GATE entrance exam from 2012-2016. Presently he works as associate professor in SV College of engineering, tirupati. His research area is Power System Optimization and reactive power compensation.