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A solution procedure to the economic load dispatch problem through the gravitational search technique

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Abstract

The central goal of the Economic Load Dispatch (ELD) is to establish the power by all committed generating units so that generating cost is minimized as the load demand and inequality constraints are satisfied. This paper presents a new stochastic optimization algorithm inspired by the law of gravity and interaction between masses to solve ELD problems, called Gravitational Search Algorithm (GSA). This proposed algorithm has been tested on some standard power systems including IEEE 6-bus 3 generator, IEEE 14-bus 5 generator, IEEE 30-bus 6 generator systems using different non-linear effect like valve point loading, ramp rate limits, prohibited zones etc. This result has been compared by many well-known heuristic search methods. This result provides the efficiency, robustness, fast convergence and proficiency of the proposed algorithm with less computational time over other existing algorithm.

Keywords: Economic Load Dispatch, Gravitational Search Algorithm, Prohibited operating zone, Ramp rate limit, Valve point loading effect

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1. Introduction

Economic load dispatch is an important and one of the fundamental optimization techniques in power system operation(Wood and Wollenberg, 1996). The main objective of ELD problem is to minimize the generating cost of thermal units and to improve overall system efficiency satisfying the load demand and equality and inequality constraints (Gaing *et al*, 2003 & Bhattacharya *et al*, 2010). Many investigations on ELD problems have been undertaken until date (Sinha *et al*,2003). In the past decade, the cost function of ELD problem is represented by a single quadratic function and the problem is solved by a number of derivative based approaches like Lagrangian multiplier method and many mathematical based optimization techniques such as lambda iteration method, gradient method, Newton's method, linear programming, interior point method and dynamic programming (Wood *et al*, 1996) . In this numerical method for solution of ELD problem, an important assumption is that, the incremental cost curve of the generating unit is piecewise-linear monotonically increasing function (Wood and Wollenberg, 1996). But all these methods become feasible because of non-linear characteristics in practical system. Practically the input-output characteristics are inherently complex and non-linear because of valve point loading effect (Duman *et al*, 2015& Ghasemi *et al*, 2013), ramp rate limit (Agrawal *et al*,2012), prohibited operating zones (Jain *et al*,2012& Hota *et al*, 2015) etc.

Due to the limitation of the traditional optimization techniques for non-convex input-output characteristics in solving ELD problems, many optimization algorithms have been successfully applies in solving high dimensional optimization problems. These algorithms can be listed as hybrid Differential Evolution (HDE)(Wang *et al*, 2007), Artificial Bee Colony (ABC) (Karaboga *et al*,2007), Biogeography Based Optimization (BBO) (Bhattacharya *et al*, 2010), Charged System Search (CSS) (Kaveh *et al*,2010), Harmonic Search Algorithm (HSA) (Jeddi *et al*,2014), Gravitational Search Algorithm (GSA)(Hota *et al*,2015),Oppositional Invasive Weed Optimization (OIWO) (Barisal *et al*,2015), Oppositional Chemical Reaction Optimization (OCRO) (Hazra *et* *al*,2015), Hybrid PSO-GSA (Duman *et al*,2015), Exchange Market Algorithm (Ghorbani *et al*,2016), Lambda Iteration and Back Propagation Neural Network(Suman *et al*,2016), Differential Evolution Algorithm (DEA) (Jebaraj *et al*, 2018),Hybrid MILP and IPM(Pan *et al*, 2018) These algorithms are widely used to solve ELD problems considering the non-linear behavior of input-output characteristics. The main objective of all algorithms is to determine optimum solution of all optimization problems.

In the past decades, a global optimization technique GA is extensively used in optimization problems. But it suffers from some disadvantages like using of complex operator for selection, taking long computational time etc. Glover and Mc Millan introduces TS algorithm which is a meta-heuristic local search algorithm and it is used to find improved solution from current solution. Due to the local and random interaction between particles in swarm-based algorithm, PSO is widely used in ELD problem. But it suffers from slow convergence and it gets trapped while solving complex optimization problems.

Thus over the years many algorithms/methods have been used to solve the ELD problem though each method has its own limitations and solution inaccuracies. However, GSA being quite effective (with certain limitation) for ELD, till date limited experimentation has been done with GSA for the small scale as well as large scale power system optimization problems. The potential of the pure GSA is not sufficiently explored. In GSA, the fitness of the new population is evaluated by using the laws of gravity and motion of GSA, thereby accommodating maximum logical features in the new population. GSA is good in local search and one advantage of employing GSA in ELD problem over the other algorithms or methods is to achieve fast convergence with near optimal result. However one of its strong limitations is localized trapping and premature convergence. It is to be seen how far this limitation can be mitigated by to improve the overall output quality.

The aim of this work is to apply the improved GSA to the small scale ELD problem by varying the program parameters and experimenting with different combinations of constraints and compare its effectiveness and feasibility with other strong heuristic methods like the PSO-GSA, PSO, IGA etc.

This paper presents a heuristic approach based on GSA for the solution of economic power dispatch with non-linear constraints. GSA is applied to standard test system of 3-unit, 5-unit, 6-unit. For more realistic solution, loss co-efficient and different non-linear factors like valve point, ramp rate limit, prohibited zone and emissions are considered. This MATLAB simulation result has been compared by many well-known heuristic search algorithms, among which the result of our proposed technique is better. GSA (Duman *et al*.2015) is a meta-heuristic algorithm based on Newton's law related to gravity and motion. According to Newton, every object in the universe attracts each other by the gravitational force. The magnitude of the force is directly proportional to the product of masses and inversely proportional to the square of the distance between them. The direction of movement of the particle occurs towards the particle of higher masses. In GSA every object in the universe is treated as an agent. The heavier masses move more slowly than the lighter one. This ensures the exploitation steps of this algorithm.

The objective of this paper is to obtain solution of the ELD problem by GSA. Section 1 contains the introduction part with the related work. Section 2 describes the ELD Problem. Section 3 discusses gravitational search algorithm. Section 4 describes Simulation Result and Analysis. Section 5 concludes the paper with indication on future scope of work.

2. Economic load dispatch problem

The ELD problem is a nonlinear programming optimization technique (Sinha *et al.*. 2003). The main objective of ELD is to minimize the fuel cost by generating real power output for a specific period of operation while satisfying several equality and inequality constraints. Two models of ELD are considered, convex ELD problem which assumes the quadratic cost function along with the system load demand and non-convex ELD (NCELD) problem which contains generator nonlinearities such as valve point loading effects, ramp rate limits, prohibited zones. Both convex and non-convex ELD problems are discussed in this paper. Generally, ELD mathematical model can be mathematically described as follows.

2.1 Economic Load Dispatch with Quadratic Cost Function and Transmission Loss

The total cost of ELD problem may be written as:

$$F_{Total} = \min\left(\sum_{i=1}^{n} F_i\left(P_{Gi}\right)\right)$$

$$F_i\left(P_{Gi}\right) = \min\left(\sum_{i=1}^{n} a_i + b_i P_{Gi} + c_i P_{Gi}^2\right) \tag{1}$$

Where $F_i(P_{Gi})$ is the i^{th} generator cost function and generally expressed as quadratic equation, a_i, b_i and c_i are the cost coefficient of i^{th} generator, n is the generator connected to the system, P_{Gi} is the power output of the i^{th} generator.

2.2 Real Power Balance Constraint

In this world, power generated P_{Gi} by the generators must be equal to the sum of power demand P_D by the consumers and total power loss P_L in the transmission line. That is expressed by the following equation:

$$\sum_{i=1}^{n} P_{Gi} - P_D - P_L = 0 \tag{2}$$

As the total power loss is a function of power generation, so it can be calculated by solving the power equation as follows:

$$P_L = \sum_{i=1}^{m}\sum_{j=1}^{m} P_{Gi} B_{ij} P_{Gj} + \sum_{i=1}^{m} B_{0i} P_{Gi} + B_{00} \tag{3}$$

Where, B_{ij} is the ij^{th} element of loss co-efficient square matrix, B_{0i} is the i^{th} element of loss co-efficient vector; B_{00} is the loss co-efficient constant, P_{Gi} is the power generated by i^{th} generator, P_D is total demand, P_L is power loss in line.

2.3 Generator Capacity Constraints

The power generated by each generator must be in between the maximum and minimum value as follows:

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}, Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max}, V_{Gi}^{\min} \le V_{Gi} \le V_{Gi}^{\max},\ i \in \{1,2,3,....,n\} \tag{4}$$

$P_{Gi}^{\min}$ is the minimum value below which it becomes uneconomical and $P_{Gi}^{\max}$ is the maximum value. Equation (4) also shows the maximum and minimum values of reactive power and voltage of the i^{th} transmission line.

2.4 Economic Load Dispatch with Valve Point Loadings

The total cost F_{Total} of power generation in any thermal unit is expressed by equation (1). As ELD problem with valve point loading introduces ripple in the heat-rate curve, so it becomes complex. The model of valve point loading has been discussed by introducing a sinusoidal function with the quadratic equation (Walter *et al.*.1993, Deslshad *et al.*.2016). The variation of fuel cost "F_i (P_{Gi})" due to effect of valve point loading with the change of generated output power P_{Gi} is shown in Fig.2.The actual cost function with valve point is given by equation (6).

$$F_{Total} = \min\left(\sum_{i=1}^{n} F_i\left(P_{Gi}\right)\right)$$

$$= \min\left(\sum_{i=1}^{n} a_i + b_i P_{Gi} + c_i P_{Gi}^2 + \left|e_i \times \sin\left\{f_i \times \left(P_{Gi}^{\min} - P_{Gi}\right)\right\}\right|\right) \tag{5}$$

2.5 Economic Load Dispatch with Ramp Rate Limit Constraints

Under practical circumstances ramp rate limit restricts the operating range of the i^{th} generator by adjusting generation between two limits. The power generated, P_{Gi} , by i^{th} generator in a certain interval may not exceed that of previous interval P_{i0} by more than the certain amount UR_i ,the upper rate limit and neither less than that of the previous interval by more than some amount DR_i, the down-ramp limit of the generator. The inequality constraint due to the ramp rate limit (Agrawal *et al*.2012) and due to the change in generation in any thermal unit is given by the following:

$$P_{Gi} - P_{i0} \le UR_i \quad \text{, as the generation increases} \tag{6}$$

$$P_{i0} - P_{Gi} \le DR_i \quad \text{, as the generation decreases} \tag{7}$$

and

$$\max\left(P_{Gi}^{\min}, P_{i0} - DR_i\right) \le P_{Gi} \le \min\left(P_{Gi}^{\max}, P_{i0} + UR_i\right) \tag{8}$$

2.6 Economic Load Dispatch with Prohibited Operating Zones

The variation of fuel cost "F_i (P_{Gi})" due to effect of prohibited zone with the change of generated output power P_{Gi} is shown in Fig.3.The prohibited zones are the range of the output of the generator where operation is generally avoided due to valve point loading and vibration due to shaft bearing. The vibration might cause damage of shaft and bearings.It is difficult to determine exact prohibited zone.So,normaly operation is phohibited in this region.The operating zone is described as follows:

$$P_{Gi} \in \begin{cases} P_{Gi}^{\min} \le P_{Gi} \le P_{Gi1}^{L} \\ P_{Gik-1}^{U} \le P_{Gi} \le P_{Gik}^{L},\ i = 1,2,...N \\ P_{Gik}^{U} \le P_{Gi} \le P_{Gi}^{\max} \end{cases} \tag{9}$$

Where k represents the number of prohibited zones of i^{th} unit, P_u is the upper limit of (k-1)th prohibited zone of i^{th} unit, P_L is the lower limit of k^{th} prohibited zone of i^{th} unit.

3. Gravitational Search Algorithm

Till now a number of evolutionary algorithms have been studied in power system to obtain the optimal solution. Among them GSA is a newer technique, having capability to handle the multi-dimensional problem. GSA has been implemented hitherto on limited number of power system problems, such as for Post-Outage Bus Voltage Magnitude Calculations , combined economic and emission dispatch problems of power systems, Optimal power flow, Parameters identification of hydraulic turbine governing system, multi-objective economic emission load dispatch, solution of unit commitment problem.

GSA is based on Newton's law of Gravity. In this algorithm, the solutions are analyzed in terms of masses of respective agents. Each mass has their own position, inertial mass, active gravitational mass and passive gravitational mass. The solution of the problem is represented by the position of the respective mass. Good solution and worst solution are represented by heavier and lighter mass respectively.

Sum of all forces acting on an object is depicted in Fig. 1.

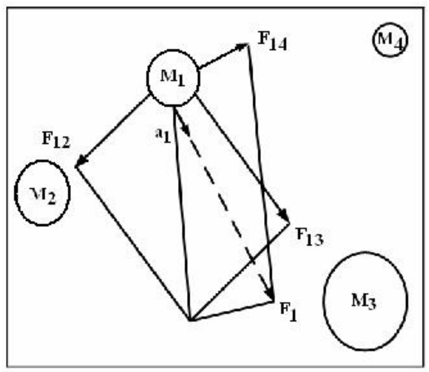

Fig.1. Sum of all the forces acting on an object.

Two well-known equations used in GSA are:
Gravitational force equation represented as

$$F=G\,\frac{M_1M_2}{R^2} \tag{10}$$

and equation of acceleration of a particle when a force applied to it, written as

$$a=\frac{F}{M} \tag{11}$$

Gravitational constant value $G(t)$ is represented as

$$G(t)=G(t_0)\times\left(\frac{t_0}{t}\right) \tag{12}$$

In the above equations, M_1 and $M_2$are two different masses, F represents force, a is acceleration, R represents the distance between two masses, t is the actual time and $G(t_0)$ is the value of the gravitational constant at the initial time,t_0 respectively. β<0.
Active gravitational mass (M_a), passive gravitational mass ($M_{p)}$. and inertial mass (M_i) are defined in physics.
The equation representing the decrease in gravitational constant can be represented as

$$G(t)=G_0e^{-\frac{\sim t}{T}} \tag{13}$$

Where, α is a user specified constant, T is the total number of iteration, and t is the current iteration. If i^{th} active and passive gravitational masses are equal, then $M_{a_i}=M_{p_i}=M_{i_i}=M_i$ and for $i=1,2,\cdots,N$ number of masses, these gravitational masses can be represented in terms of their respective fitness values and the equations can be represented as,

$$m_i(t)=\frac{fitness_i(t)-worst(t)}{best(t)-worst(t)},$$
$$M_i(t)=\frac{m_i(t)}{\Sigma_{j=1}^{k}m_j(t)} \tag{14}$$

The total force acting on mass i in d dimensions may be represented as,

$$F_i^d(t) = \sum_{j \in Kbest, j \neq 1}^{K} rand_j F_{ij}^d(t) \qquad (15)$$

Where, $rand_j$ is the random number between 0 and 1, *Kbest* is the set of first K objects with the best fitness value and biggest mass, F_{ij}^d is the force on mass i from mass j in d dimensions.

The acceleration in d^{th} dimension, velocity (v) and position(x) at time ($t+1$) of object i may be expressed as

$$v_i^d(t+1) = rand_i \times v_i^d(t) + a_i^d$$
$$x_i^d(t+1) = x_i^d + v_i^d(t+1) \qquad (16)$$

$rand_i$ is the random number between 0 and 1. The procedural steps of ELD problem solution with GSA is shown in Fig. **2.**

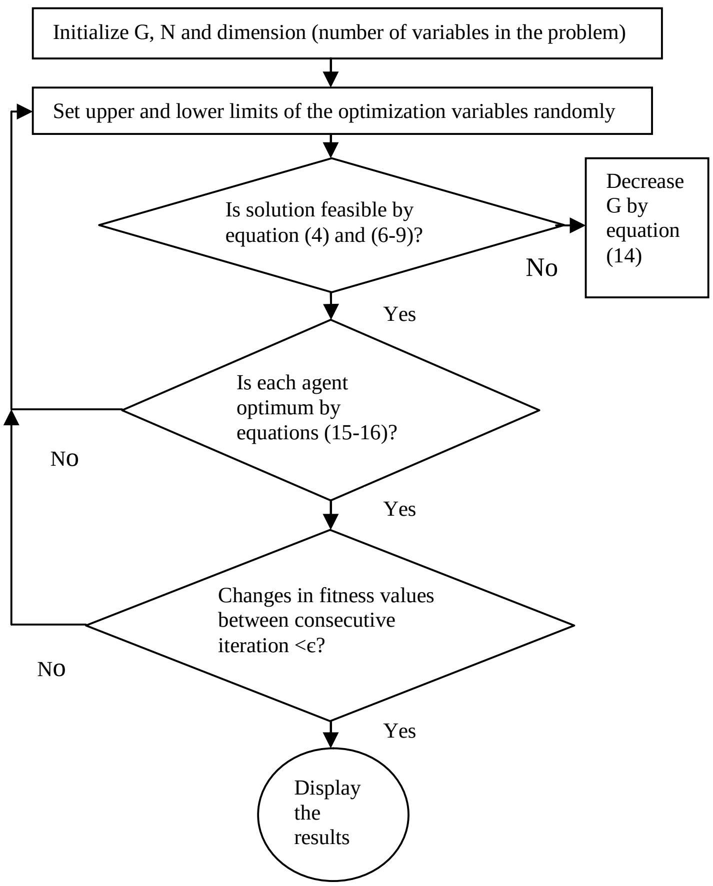

Fig. 2. Flow chart of GSA algorithm

4. Matlab simulation result and analysis

The proposed GSA has been applied to solve ELD problems of different test systems to demonstrate its performance in comparison to several established optimization techniques reported in literature. The GSA has been implemented using Matlab-8.1 environment on a core i5/4GB/500 GB/Win 8.1 personal computers.

4.1. Description of test systems

4.1.1 Case Study 1: IEEE 6-Bus 3-generator test system

In this case study, IEEE 6-Bus 3-generator is considered. The input data (Wood and Wollenberg, 1996 & Chiang *et al.*2005) and B-coefficient matrix or loss co-efficient matrix are given in Table 1.

Table 1. Generating unit coefficient, capacity, valve point, ramp rate limit and prohibited zones data.

a_i (\$/h)	b_i (\$/MW)	c_i (\$/MW^2)	$P_{i\,min}$ (MW)	$P_{i\,max}$ (MW)	e_i (\$/h)	f_i	P_i^0	UR_i (MW/h)	DR_i (MW/h)	*Prohibited zones* (MW)
328.13	8.663	0.00525	50	250	130	0.064	215	55	95	[105,117][165,177]
136.91	10.04	0.00609	5	150	90	0.06	72	55	78	[50, 60] [92,102]
59.16	9.76	0.00592	15	100	100	0.069	98	45	64	[25,32] [60,67]

B-Loss Coefficients

$$B = \begin{bmatrix} 0.000136 & 0.0000175 & 0.000184 \\ 0.0000175 & 0.000154 & 0.000283 \\ 0.000184 & 0.000283 & 0.00116 \end{bmatrix}$$

$$B_0 = \begin{bmatrix} 0.0046 & 0.0035 & 0.0019 \end{bmatrix}$$

and B_{00}=0.00055711;

This test has been made for with and without VPL with transmission loss Eq.1 to 4 and Eq. 6 to 9. The experimentations are accomplished on a system possessing on three units, in Table 2, total cost and generating power by each generator are calculated for IEEE-3 generators 6-bus test system for different conditions. The load demand is 300 MW. As it is obvious, the minimum system losses is 1.3215 MW and the minimum fuel cost are achieved better as compare to literature (Wood et al,1996 & Chiang *et al.*,2005) DE/BBO (Bhattacharya and Chattopadhyay, 2010), EHSA (Vanitha and Thanushkodi,2012), HPSO (Vanitha and Thanushkodi,2012) by applying proposed GSA optimization technique. Also the result, we have obtained from Table 2 is satisfied the prohibited zone and ramp rate limit conditions. Fig.3 and Fig.4 represent the generator output power Vs power loss and generator output power Vs total generation cost respectively for IEEE 6-bus 3-generator system with and without valve point loadings. Fig 5 represents the convergence characteristics of 6-bus 3 generator system when we consider loss, valve point effect, ramp rate & prohibited zone.

Table 2. Results for IEEE-3 generators 6-bus test system for different condition with P_D = 300 MW.

(MW)	With loss	With Loss, RRL & POZ	With loss, VPL	With loss, VPL, RRL & POZ
P1	183.9549	184.0264	198.26160	197.939000
P2	45.1053	46.3688	5.12490	5.282500
P3	72.0994	70.9263	97.75360	97.918000
P_{total}	301.1596	301.3215	301.14010	301.139500
P_{loss}	1.1596	1.3215	1.14010	1.139500
Total cost \$/h)	3495.169	3496.8737	3570.0190	3572.52730
CPU time (s)	3.18954	3.214350	3.199380	3.219410

Table 3. Comparison of Proposed GSA with other different methods of 3-generators system) with loss, RRL & POZ at P_D=300 MW.

Output (MW)	**Proposed GSA**	DE/BBO (Bhattacharya and Chattopadhyay, 2010)	EHSA (Vanitha and Thanushkodi,2012)	HPSO (Prabakaran *et al*,2015)
P_1	**184.0264**	207.637	207.6422	200.18
P_2	**46.3688**	87.2833	87.2783	76.26
P_3	**70.9263**	15.0000	15.0000	34.40
Total Power(MW)	**301.3215**	309.9204	309.9205	310.84
Ploss(MW)	**1.3215**	9.9204	9.9204	10.84
Total Cost (\$/hr)	**3496.8737**	3619.7568	3619.7289	3623.11

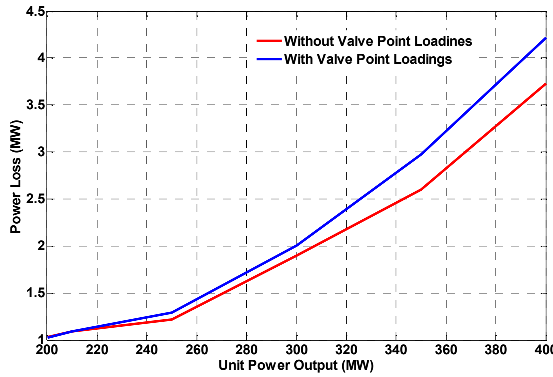

Fig. 3. Generator output power Vs Power loss for 6-bus 3-generator system with and without valve point loadings.

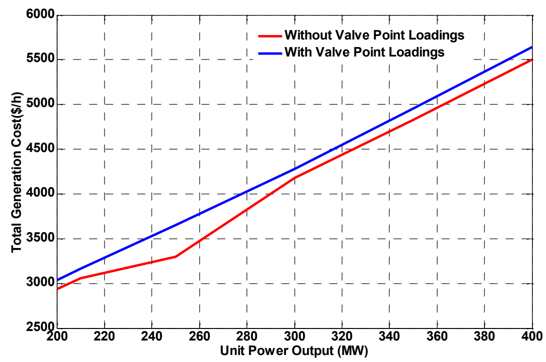

Fig. 4. Generator output power Vs total generation cost for 6-bus 3-generator system with and without valve point loadings.

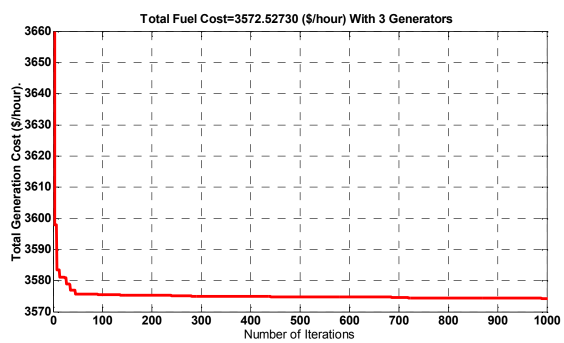

Fig.5. Convergence characteristics of 6-bus 3 generator system considering loss, valve point effect, ramp rate & prohibited zone.

4.1.2. Case Study 2: IEEE 14-Bus 5-generator test system

In Case 2, IEEE 14-bus 5-generator system is considered also for with VPL using Eq.1 to 9 and without VPL effect using Eq.1 to 4 and Eq. 6 to 9. The input data and B –coefficients are taken from (Duman *et al.*,2015). Total cost is determined for different load demand and for each load demand without valve point loading the distribution of power among each generator is also shown in Table 4. Total cost is calculated for different load demand using valve point loading effect and shown in Table 5. The optimal solution for this system is reported in (Duman *et al.*,2015) for the load demand of 259 MW. In the literature, no other heuristic method is found that is applied in this identical ELD test case.

Table 4. Results for IEEE-5 generators 14-bus test system **without valve point effects** for different demands

P_D (MW)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P_{loss} (MW)	Cost ($/hr)
150	92.89	20.85	16.01	10.13	10.20	0.08	530.06
200	142.78	20.25	15.92	10.62	10.49	0.07	649.38
259	**199.92**	**20.23**	**17.35**	**10.04**	**11.50**	**0.05**	**800.93**
300	199.94	55.38	17.61	10.76	16.45	0.14	937.02
340	99.94	71.19	24.42	32.56	12.30	0.42	1084.56
350	99.87	67.66	21.27	32.94	28.60	0.35	1125.52

Table 5. Results for IEEE-5 generators 14-bus test system **with valve point loading effects** for different demands.

Load Demand P_D (MW)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P_{loss} (MW)	Total Cost ($/hr)
150	92.45	20.01	15.71	10.16	11.75	0.07	553.82
200	142.03	20.53	15.08	11.67	10.77	0.08	675.85
259	**199.69**	**20.04**	**18.58**	**10.09**	**10.64**	**0.05**	**801.32**
300	199.98	53.96	21.71	10.02	14.45	0.13	944.79
340	199.95	51.45	24.85	35	29.06	0.32	1093.18
350	199.83	80	22.68	35	12.95	0.46	1140.83

Table 6. Comparison between Proposed GSA with other methods taken after 50 trials (5-generators system) at P_D =259 MW.

Unit power Output (MW)	**Proposed GSA**	FPSOGSA (Duman *et al*, 2015)	PSO (Yasar *et al*, 2011)	GA (Malik *et al*,2010)
P1	**199.69**	199.5997	197.4696	172.765
P2	**20.04**	20.0000	20.0000	26.6212
P3	**18.58**	20.9133	21.3421	24.8322
P4	**10.09**	15.4893	11.6762	23.4152
P5	**10.64**	12.5527	17.7744	19.1885
Total Power output(MW)	**259.05**	268.555	268.2623	266.8217
Power Loss(MW)	**0.05**	9.555	9.26230	7.8250
Total cost ($/h)	**801.32**	834.1308	836.456	926.5530

Total cost is also determined for different load demand considering valve point loading effect shown in Table 5. For the load demand 259 MW the cost becomes **801.32**$/h which is better than that of 834.1308 ($/h), 836.456($/h), 926.5530 ($/h) corresponding the other methods like FPSOGSA (Duman *et al*,2015), PSO (Yasar *et al*, 2011) and (Malik *et al*,2010). At the same time it is seen that Transmission loss 0.05MW obtained by proposed method is lower than other methods which shown in Table 6. Fig.6 and Fig.7 represent generator output power vs total generation cost and generator output power vs Power loss for IEEE 14-bus 5-generator test system with and without valve point loadings respectively. Fig.8 shows the convergence characteristics of IEEE 14-bus 5 generator test system with valve point loading effect for the load demand 259 MW.

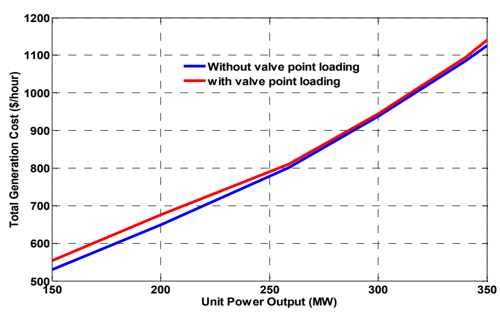

Fig. 6. Generator output power Vs total generation cost for 14-bus 5-generator system with and without valve point loadings.

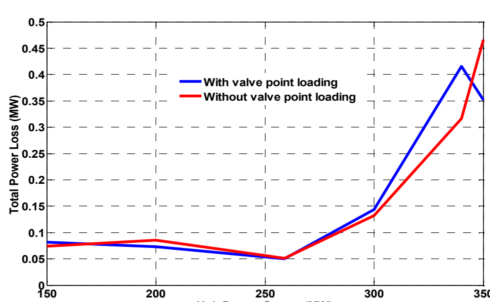

Fig. 7. Generator output power Vs Power loss for 14-bus 5-generator test system with and without valve point loadings.

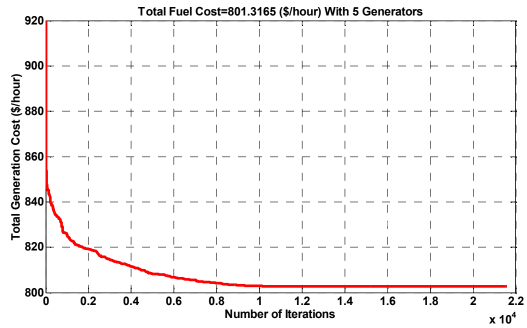

Fig.8. Convergence characteristics of IEEE 14-bus 5 generator test system with valve point loading effect for the load demand 259 MW.

4.1.3 Case Study 3: IEEE 30 bus 6 generator test system

In this case study, IEEE 30 bus 6 generator system is considered. The B-coefficient matrix or loss coefficient matrix and input data are taken from (Gaing *et al.*.2003 , Wood and Wollenberg, 1996). Our proposed GSA optimization technique is applied for load demand of 1263 MW. In Table 7, total generation cost is determined for IEEE 30-bus six-generator system for different condition using our proposed GSA technique. In Table 7, transmission loss is not considered, using Eq.1 to 9. The generating cost obtained from the Table 5 is better than the reported (Gaing *et al.*.2003 , Wood and Wollenberg, 1996) generating cost. Fig.9 and Fig.10 show power output vs total generation cost and power output vs total Power Loss respectively for different demands and for different conditions .After considering transmission loss in Table 8, the generating cost of proposed GSA method which is**15301.837**($/h) , better than that of 15444.1564 ($/h), 15443.1($/h), 15442.3931 ($/h), 15,443.075($/h), 15442.6219($/h) and 15449.1672($/h) corresponding the other methods like BF-DE (Biswas *et al*,2009), HIGA (Hosseini *et al*,2012), PSO-GSA (Dubey *et al*,2013), OKHA(Bulbul *et al.*2018), FSS-PSO (Amiri *et al.*2018) and MCSA (Mohammadi *et al.*2018) respectively. The transmission loss 1.9031MW also lower compare to other recent published paper as shown in Table 9.

Table 7. Best Power output for IEEE 30-bus Six-Generator test System for different conditions but **without loss** using GSA optimization technique Eq.1 to 2 and Eq. 4 to 9.

Unit power Output (MW)	Without loss, VPL, RRL & POZ	With VPL	With VPL & POZ	With VPL, RRL & POZ
P1	446.7072716	459.2255	459.0831	459.6617
P2	171.2579896	200	200	200
P3	264.1056557	300	300	300
P4	125.2167668	99.8112	150	52.6206
P5	172.1188627	151.2393	101.774	200
P6	83.59345352	52.724	52.1429	50.7177
Total Power output	1263	1263	1263	1263
Total cost ($/h)	15275.93	15395.33	15430.243	15440.165

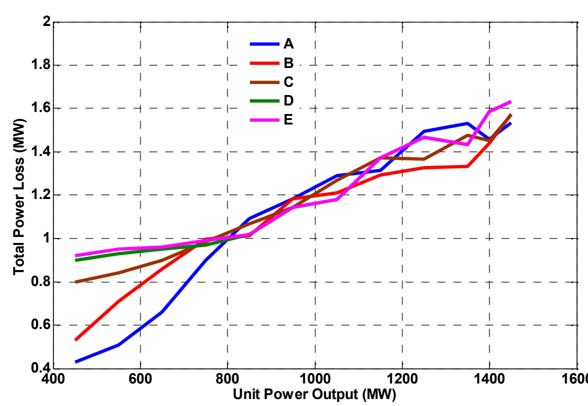

Fig.9. Comparative study for IEEE 30-bus 6 generator test system unit power output vs total Power Loss for different load demands (A) With Ramp rate limit, valve point loading & Prohibited operating Zone ,(B) With loss, (C) With loss & VPL, (D) With loss, VPL & RRL, (E) With loss, VPL ,RRL & POZ.

Table 8. Best Power output for IEEE 30-bus Six-Generator test System for different conditions but **with loss** using GSA optimization technique by Eq.1 to 9.

Unit power Output (MW)	With loss	With loss, RRL & POZ	With loss , VPL	With loss , VPL & RRL	With loss , VPL, RRL & POZ
P1	450.4442	**445.4502**	446.0334	436.8838	436.6456
P2	166.3067	**168.9623**	160.8813	177.404	167.7324
P3	263.1081	**259.3941**	254.5906	252.1655	251.3041
P4	126.435	**130.4466**	123.1433	121.7136	136.6571
P5	173.1791	**174.9173**	200	200	200
P6	84.9879	**85.7325**	82.6344	79.0818	74.7372
Total Power output	1264.4609	**1264.9031**	1267.2829	1267.2487	1267.0765
Ploss	1.4609	**1.9031**	4.2829	4.2487	4.0765
Total generation cost ($/h)	15295.67	**15301.837**	15340.80	15341.041	15345.379

Table 9. Comparison of result of GSA for 6-generator system for Ramp Rate Limits , Prohibited Zones and Transmission Loss with other methods at P_D = 1263 MW.

Output (MW)	**Proposed GSA**	BF-DE (Biswas *et al*,2009)	HIGA (Hosseini *et al*,2012)	PSO-GSA (Dubey *et al*,2013)	OKHA (Bulbul *et al*.2018)	FSS-PSO (Amiri *et al*.2018)	MCSA (Mohammadi *et al*.2018)
P_1	**445.4502**	446.7146	447.399	447.5144	447.3988	446.2766	444.6373
P_2	**168.9623**	173.1485	173.241	173.1461	173.2409	172.3898	174.6410
P_3	**259.3941**	262.7945	263.382	263.3337	263.3815	265	265.0000
P_4	**130.4466**	143.4884	138.98	138.9189	138.9802	142.5145	139.2251
P_5	**174.9173**	163.9163	165.392	165.3541	165.3914	162.9183	165.7121
P_6	**85.7325**	85.3553	87.052	87.1269	87.0520	86.2179	86.6807
Total Power(MW)	**1264.9031**	1275.4	1275.446	1275.3941	1275.448	1275.3171	1275.9576
Power Loss(MW)	**1.9031**	12.4220	12.446	12.39404	12.4448	12.3171	12.9576
Total Cost ($/hr)	**15301.837**	15444.1564	15443.1	15442.3931	15,443.075	15442.6219	15449.1672

5. Conclusion

This paper demonstrated a novel stochastic optimization approach named GSA to solve the convex and non-convex economic load dispatch (ELD) problems that is with and without valve point loading effects and transmission loss. GSA optimization technique is applied to solve ELD problems for test systems having 3, 5 and 6-units. The obtained results of the proposed GSA method have been compared and found better result in comparison with conventional optimization technique as well as recently published papers. This comparison results reveal the effectiveness, robustness, high quality solution, feasibility, stable convergence characteristics and good computation efficiency of the proposed GSA technique. In future the scope of fine tune is needed for less convergence time. The improved GSA used in this study can be combined with other heuristic methods like GA, PSO, ACO, BBO etc. to see if the exploitation and exploration feature of GSA can be further improved to get better ELD result. Also hybrid GSA techniques can be applied to CEED, DED or economic load dispatch of renewable energy.

References

Agrawal N., Agrawal S., warnkar K.K.S, Wadhwani S. and Wadhwani A.K., 2012. Economic load dispatch problem with ramp rate limit using BBO. *International Journal of Information and Education Technology*, Vol.2,No. 5, pp. 419-424.

Amiri M., Khanmohammadi S., Badamchizadeh M.A., 2018. Floating search space: A New Idea for Efficient Solving the Economic and Emission Dispatch Problem, *Energy*, (in press), doi: 10.1016/j.energy.2018.05.062

Barisal A.K.and Prusty R.C., 2015. Large scale economic dispatch of power systems using oppositional invasive weed optimization. *Applied Soft Computing*, Vol.29, pp. 122–137.

Bhattacharya A.. and Chattopadhyay P. K., 2010.Biogeography-Based Optimization for different economic load dispatch problems. *IEEE transactions on power systems*, Vol. 25 , No. 2, pp.1064–1077.

Bhattacharya A and Chattopadhyay P K, 2010, Hybrid differential evolution with biogeography-based optimization for solution of economic load dispatch, *IEEE Transactions on Power Systems*, Vol. 25, No. 4, pp. 1955–1964.

Biswas A., Dasgupta S. , Panigrahi B. K. , Pandi V. R. , Das S. , Abraham A. , Badr Y., 2009.Economic load dispatch using a chemotactic differential evolution algorithm, *In the Proceedings of International Conference on Hybrid Artificial Intelligence Systems* (*HAIS*) , pp 252-260.

Bulbul M. A., Pradhan M., Roy P. K., Pal T., 2018.Opposition-based krill herd algorithm applied to economic load dispatch problem, *Ain Shams Engineering Journal*, Vol. 9,pp. 423–440.

Deslshad M. M. and Rahim N. A., 2016. Multi-objective backtracking search algorithm for economic emission dispatch problem. *Applied Soft Computing*, Vol.40, pp.479-494.

Dubey H M, Pandit M, Panigrahi B K, Udgir M ,2013. Economic load dispatch by hybrid swarm intelligence based gravitational search algorithm. *International Journal of Intelligent Systems And Applications*,Vol.5,No.8,pp.21–32

Duman S., Yorukeren N., Atlas I. H., 2015. A novel modified hybrid PSO-GSA based on fuzzy logic for non-convex economic dispatch problem with valve-point effect. *Electrical Power and Energy System*, Vol.64, pp.121-135.

Gaing Z. L., 2003**.** Particle swarm optimization to solve the economic dispatch considering the generator constraints. *IEEE transactions on power system*, Vol. 18, No.3, pp. 1187–1195.

Ghasemi A., 2013. A fuzzified multi objective interactive honey bee mating optimization for environment/economic power dispatch with valve point effect. *Electrical Power and Energy System*, Vol.49, pp.308-321.

Ghorbani N. and Babaei E.,2016, Exchange market algorithm for economic load dispatch, *International Journal of Electrical Power & Energy Systems*, Vol.75,pp.19-27.

Hazra S., Roy P. K. and Sinha A, 2015. An efficient evolutionary algorithm applied to economic load dispatch problem. *In the Proceedings of the CCC and IT , Hooghly, India*, pp.1-6.

Hosseini MM, Ghorbani H, Rabii A, Anvari Sh, (2012). A novel heuristic algorithm for solving non-convex economic load dispatch problem with non-smooth cost function. *Journal of Basic and Applied Scientific Research*,Vol. 2,No.2,pp.1130–1135.

Hota P.K. and Sahu N.C., 2015. Non-convex economic dispatch with prohibited operating zones through Gravitational Search Algorithm. *International Journal of Electrical and Computer Engineering*, Vol.5, No.6, pp. 1234 -1244.

Jain P., Swarnker K.K., Wadhwani S. and Wadhwani A. K., 2012. Prohibited operating zones constraints with economic load dispatch using Genetic Algorithm . *International Journal of Engineering and Innovative Technology*, Vol.1, No. 3, pp. 419-424.

Jebaraj L., Venkatesan C., Soubache I., 2017. Application of differential evolution algorithm in static and dynamic economic or emission dispatch problem: A review, *Renewable and Sustainable Energy Reviews*, Vol. 77, pp.1206-1220.

Jeddi B. and Vahidinasab V., 2014. A modified harmony search method for Environmental/Economic load dispatch for real-world power systems. *Energy Conversion And Management*, Vol. 78, pp. 661-675.

Karaboga D. and Busturk B., 2007. A powerful and efficient algorithm for numerical function optimization: Artificial Bee Colony (ABC) algorithm, *Journal of Global Optimization*, Vol. 39, No. 3, pp.459-471.

Kaveh A. and Talatahari S., 2010. A novel heuristic optimization method: Charged System search. *International journal Acta Mechanica*, Vol.213, pp.267-289.

Mohammadi F., Abdi H., 2018. A modified crow search algorithm (MCSA) for solving economic load dispatch problem, *Applied Soft Computing Journal*, https://doi.org/10.1016/j.asoc.2018.06.040

Nadeem Malik T, ul Asar A, Wyne M F,and Akhtar S ,2010. A new hybrid approach for the solution of non-convex economic dispatch problem with valve-point effects. *Electric Power Systems Research*, Vol.80,No.9,pp.1128–1136.

Pan S, Jian J., Yang L., 2018.A hybrid MILP and IPM approach for dynamic economic dispatch with valve-point effects, *Electrical Power and Energy Systems*, Vol.97.pp. 290–298.

Prabakaran S., Senthilkumar V. and Baskar G., 2015. Economic dispatch using hybrid particle swarm optimization with prohibited operating zones and ramp rate limit constraints, *Journal of Electrical Engineering and Technology*, Vol. 10,No. 4, pp. 1441-1452.

Sinha N., Chakrabarti R.. and Chattopadhyay P.K., 2003. Evolutionary programming techniques for economic load dispatch. *IEEE Transactions on Evolutionary Computation*, Vol.7, No.1, pp. 83-94.

Suman M., Rao M. Venu G., Hanumaiah A., Rajesh K. 2016 Solution of economic load dispatch problem in power system using lambda iteration and back propagation neural network methods, *International Journal on Electrical Engineering and Informatics Bandung*, Vol.8,No.2, pp. 347-355.

Vanitha M and Thanushkodi K., 2012 . Solving non-convex economic load dispatch problem by efficient hybrid simulated annealing algorithm, *In the Proceedings IEEE International Conference on Advanced Communication Control and Computing Technologies* (ICACCCT), pp. 362-365.

Walter D.C. and Shebla G.B., 1993. Genetic Algorithm solution of economic load dispatch with valve point loading. *IEEE transactions on power systems*, Vol.8, No.3, pp. 1325-1332.

Wang S. K., Chiou J. P., Liu C. W., 2007. Non-Smooth/Non-Convex economic dispatch by a novel hybrid Differential Evolution algorithm, *IET Generation, Transmission and Distribution*, Vol.1, No. 5, pp. 793–803**.**

Wood A. J. and Wollenberg B.F., 1996. *Power Generation, Operation and Control*, John Wiley & Sons.

Yasar C and Özyön S., 2011. A new hybrid approach for non-convex economic dispatch problem with valve-point effect. *Energy*, Vol.35, pp.5838–5845

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