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Solution of Economic Load Dispatch Problem using Gravitational Search Algorithm with Valve Point Loading

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***Abstract* : This paper describes gravitational search algorithm for solving the non convex Economic load Dispatch (ELD) problem with valve point effect. The main objective of economic load dispatch problem is to generate the required amount of power so that the total operating cost of system is minimized, while satisfying load demand and system equality and inequality Constraints. Different heuristic optimization methods have been proposed to solve this problem in previous study. So in this paper, gravitational search algorithm (GSA) based on law of gravity and mass interaction is proposed. This proposed approach has been tested on 3, 13, 40 unit systems. Simulation results of proposed approach are compared with some well-known heuristic search methods. The obtained results verify the efficiency of the proposed method with minimum computational time in solving various nonlinear functions.**

Keyword : economic load dispatch, gravitational search algorithm, valve point effect.

1. INTRODUCTION

The increasing energy demand and decreasing energy resources have necessitated the optimum use of available resources. Economic load dispatch is optimization scheme intends to find the generation outputs that minimize the total operating cost while satisfying several unit and system constraints. In main aim of economic load dispatch is to schedule the output of all generating units so as to meet total load demand at minimum fuel cost, also subject to equality and inequality constraints on power output. There are many methods developed for solving the economic load dispatch problems which are classified as classical and heuristic methods. In classical method, fuel cost curve is monotonically increasing one and it represented by quadratic function. Most of classical optimization techniques such as lambda iteration method, gradient method, Newton's method, linear programming, Interior point method and dynamic programming have been used to solve the basic economic dispatch problem. But due to non convex and nonlinear behavior of ED problem and large number constraints, classical method cannot be execute well in solving the ED problems. So in order to overcome these non linear dispatch problems heuristic technique are developed. Many heuristic techniques like Hardiansyah[2] introduced Solving economic load dispatch problem with valve point effect using modified ABC algorithm. K.Senthil, K.Manikandan [3] proposed Economic Thermal Power Dispatch With Emission Constraint and Valve Point Effect Loading Using Improved Tabu Search Algorithm.
J.Jain, R.Singh [4] introduced Biogeographic-Based Optimization Algorithm for Load Dispatch in Power System. K. Meng, H. G. Wang, Z.Y. Dong, and K. P. Wong [7] proposed Quantum-Inspired Particle Swarm Optimization for Valve-Point Economic Load Dispatch. Chao-Lung Chiang proposed Improved Genetic Algorithm for Power Economic Dispatch of Units With Valve-Point Effects and Multiple Fuels.
Recently, a heuristic technique called as gravitational search algorithm (GSA) is proposed. Gravitational search algorithm is inspired by law of gravitational and mass interaction. Gravitational search algorithm has been proposed by Rashedi et al. Gravitational search algorithm gives better performance than other optimization techniques. In this paper, Gravitational search algorithm is applied to non linear economic load dispatch problem with equality and inequality in power systems. The results obtained for proposed technique is compared with other optimized techniques

2. ECONOMIC LOAD DISPATCH PROBLEM FORMULATION

The main objective of economic load dispatch is to minimize operating cost of thermal power plant while satisfying the operating constraints and meeting the total demand of a power system. The ED problem is to minimize the total fuel cost which can be defined mathematically as the sum of the cost function of each generator. The ED problem mathematically formulated with constraints as following

$$\text{Min } F_T = \sum_{i=1}^{n} F_i(P_i) = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i$$

Where

F_T = total fuel cost of generation

F_i =cost function of ith generator ($/hr)

a_i , b_i , c_i = cost coefficients of ith generator

P_i = power output of ith generator

n = number of generator

Subjected to following equality and equality constraints

1. Power Balance Constraint

$$\sum_{i=1}^{n} P_i = P_d + P_l$$

P_d = total load demand

P_l = total transmission loss

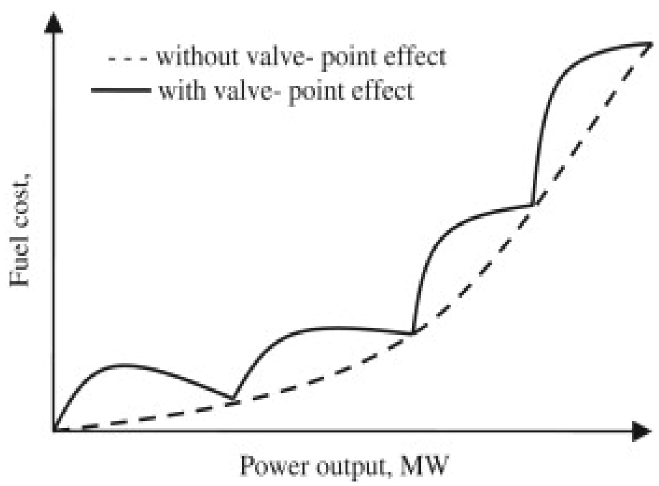
2. Generator Constraints

$$P_i^{MIN} \le P_i \le P_i^{MAX}$$

P_i^{MIN} And P_i^{MAX} is minimum and maximum value of ith Generators

ELD problem with valve point effect

For more accurate and precise modeling of incremental fuel cost function, the above expression of incremental cost function is to be modified suitably. When multivalve steam



turbines are used for generating unit then it exhibits large number variation in incremental fuel cost. The valve opening process produces large number of ripple like effect in heat curve and it looks like sine wave. These "valve-point effects" are illustrated in Fig. 1. Therefore cost function is modified as following

Min

$$F_T = \sum_{i=1}^{n} F(P_i) = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i + abs(e_i \times (\sin(f_i + (P_i^{min} - P_i))$$

Where

a_i , b_i , c_i = cost coefficients of ith generator

e_i , f_i , = fuel cost coefficients of the ith generating unit reflecting valve-point effects

3. GRAVITATIONAL SEARCH ALGORITHM

Gravitational search algorithm is first introduced by Rashedi et al. in 2009.[1] This optimization algorithm is based on the gravitational law of physics. In the proposed algorithm, agents are considered as objects and their performance is measured by their masses. All these objects attract each other by the gravity force, and this force causes a global movement of all objects towards the objects with heavier masses [1]. Hence, masses cooperate using a direct form of communication, through gravitational force. The heavy masses – which correspond to good solutions – move more slowly than lighter ones, this guarantees the exploitation step of the algorithm. In GSA, each mass (agent) has four specifications: position, inertial mass, active gravitational mass, and passive gravitational mass. The position of the mass corresponds to a solution of the problem, and its gravitational and inertial masses are determined using a fitness function. In other words, each mass presents a solution, and the algorithm is navigated by properly adjusting the gravitational and inertia masses. By lapse of time, we expect that masses be attracted by the heaviest mass. This mass will present an optimum solution in the search space. GSA algorithm can be summarized by following steps.

Step 1) Set up number of masses/agents, N to be processed in GSA and initialize gravitational constant Go.

Step 2) Initialization of the GSA: For each ith mass, the agents are randomly generated in the range (0-1) and located between the maximum and the minimum operating limits of the generators. If there are N generating units, the ith particle is represented as

$P_i = (P_i^1, P_i^2, \ldots\ldots.. P_i^d \ldots\ldots.. P_i^N)$ where i=1,2,3……….N

The d-dimension of the ith particle is allocated a value of P_i^d as given below to satisfy the constraints.

$P_i^d = P_{dmin}$ + rand (P_{dmax} -P_{dmin})

Step 3) Calculate the gravitational constant G(t) for iteration t

G(t)= G_0exp(-α$\frac{t}{T}$)

Where G_0 is initial value gravitational constant choose randomly, α is a user defined constant, t is current iteration and T is the total number of iteration.

Step 4) Evaluation of Fitness for All Agents in search space. Fit_i(t) shows the fitness value of the ith agent at time t, and worst(t) and best(t) are defined as follows:-

Best(t)=min(Fit_i(t))

Worst(t)=max(Fit_i(t))

Where best(t) and worst(t) is best and worst fitness value of all agents respectively and

Fit_i(t)= F_T +Λ $|(\sum_{i=1}^{n} P_i - P_d - P_l)|$

Where, Λ is penalty factor

Step 5) Evaluation of gravitational mass of each agent: In this step mass of each agent is updated. A heavier mass means more efficient agent. This means that better agents have higher attractions and walk more slowly. Therefore, gravitational mass is equal to

m_i(t) =$\frac{Fit_i(t) - Worst(t)}{Best(t) - Worst(t)}$

M_i(t)=$\frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)}$

Step5) Evaluation of force between agents: In this step we compute the force acting in d-dimension on ith mass due to mass j at specific time t.

$$F_{ij}^d(t) = G(t)\frac{M_{pi} \times M_{ai}}{R_{ij} \times}(x_j^d - x_i^d)$$

Where, M_{ai} is the active gravitational mass related to jth agents, M_{pi} is the passive gravitational mass of ith agent, R_{ij} is Euclidian distance between i and j agent

$R_{ij}(t) = ||X_i(t), X_j(t)||_2$

And

is a small constant

Step6) Determine the total force

In this step find out total force of agent i in dimension d

$F_i^d(t)$ =$\sum_{j \in Vbest}^{N} rand_j F_{ij}^d(t)$

Where rand is random number and its value lies between (0, 1) and Vbest is the set of first V agents with the best fitness value and biggest mass.

Step 7 Calculate Acceleration and Velocity

By applying law of motion of physics, Acceleration $a_i^d(t)$ of ith agent in d-dimension at iteration t is shown as following:

$$a_i^d(t) = \frac{F_i^d(t)}{M_i(t)}$$

Where $M_i(t)$ is inertial mass of ith agent.

And velocity of ith agent in dimension d is equal to

$V_i^d(t+1)$=$rand_i$×$V_i^d(t)$+$a_i^d(t)$

Where, $rand_i$ vary in interval (0, 1) and $V_i^d(t)$ is previous velocity of an agent.

Step 8) Update the position of agent: Position of ith agent in d-dimension at iteration t could be calculated as

$$X_i^d(t+1) = X_i^d(t) + V_i^d(t+1)$$

Step 9) In last step we repeat the 3 to 8 steps until the stop criteria reached.

4. SIMULATION RESULTS

In order to demonstrate the performance of the proposed method, it is tested with 3 system tests with 3,13and 40 unit system are used to test the proposed approach for solving the ELD problem.

Parameters for proposed approach are shown in table 1which contains number of iteration T, gravitational constantG_0, number of agents N, and user defined constant α.

Table 1: Parameters used in GSA for different unit system

Parameters	3 unit system	13unit system	40unit system
α	10	10	10
N	10	20	50
G_0	100	100	100
T	100	1000	2000

A. UNIT SYSTEMS DATA FOR 3 GENERATOR SYSTEMS [12]

The system consists of 3 thermal generating units. The total load demand on the system is 850 MW. The parameters of all thermal units are presented in Table 2.The obtained results for the 3-unit system using the GSA method are given in Table 3 and the results are compared with other methods reported in literature

TABLE 2: Cost coefficients and unit operating limits for 3 unit system

Units	Pmin	Pmax	a	b	c	e	f
1	100	600	0.001562	7.92	561	300	0.0315
2	50	200	0.004820	7.97	78	150	0.063
3	100	400	0.001940	7.85`	310	200	0.043

TABLE 3: Simulation Results and Its Comparison with GA

Generator	Generator output of GSA	Generator output of GA
1	414.7959	300.266900
2	133.1194	149.733100
3	302.0847	400.000000
Total demand	850 MW	850
Fuel Cost($/h)	8197.7	8 237.071729

B. UNIT SYSTEMS DATA FOR 13 GENERATOR SYSTEMS [13]

The system consists of 13 thermal generating units. The total load demand on the system is 2520 MW. The parameters of all thermal units are presented in Table 4

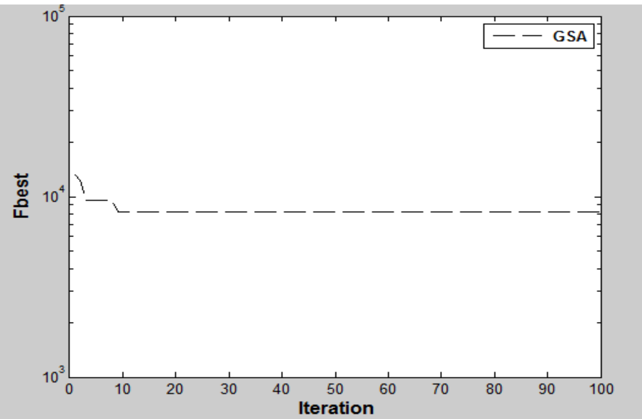


Figure 1. Convergence graph for 3-units with PD=850 MW

The obtained results for the 13-unit system using the GSA method are given in Table 5 and the results are compared with other methods reported in literature.

TABLE 4: Cost coefficients and unit operating limits for 13 unit system

units	Pmin	Pmax	a	b	c	d	e
1	0	680	550	8.1	0.00028	300	0.035
2	0	360	309	8.1	0.00056	200	0.042
3	0	360	360	8.1	0.00056	200	0.042
4	60	200	307	7.74	0.00324	150	0.063
5	60	200	240	7.74	0.00324	150	0.063
6	60	200	240	7.74	0.00324	150	0.063
7	60	200	240	7.74	0.00324	150	0.063
8	60	200	240	7.74	0.00324	150	0.063
9	60	200	240	7.74	0.00324	150	0.063
10	40	120	126	8.6	0.00284	100	0.084
11	40	120	126	8.6	0.00284	100	0.084
12	55	120	126	8.6	0.00284	100	0.084
13	55	120	126	8.6	0.00284	100	0.084

TABLE 5: Simulation Results and Its Comparison with GA and TSA

Generator	Generator output of GSA	Generator output of GA	Generator output of TSA
1	652.5274	628.32	628.317
2	305.8146	356.80	299.206
3	360.0000	359.45	331.991
4	139.0306	159.73	159.733
5	123.8629	109.86	159.711
6	146.9523	159.73	159.744
7	154.6544	159.73	159.739
8	103.6574	159.73	159.742
9	159.8448	159.73	159.700
10	106.6390	76.92	40.009
11	95.5759	75	77.720
12	83.8732	60	92.378
13	103.5621	55	92.335
TOTAL	2520MW	2520	2520
FUEL COST($/h)	24249	24400	24314.755

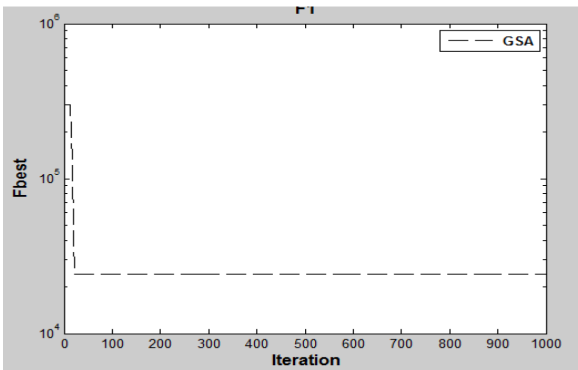


Figure2. Convergence graph for 13-units with PD=2520 MW

C. UNIT SYSTEMS DATA FOR 40 GENERATOR SYSTEMS [11]

The system consists of 40 thermal generating units. The total load demand on the system is 10500 MW. The parameters of all thermal units are presented in Table 6.The obtained results for the 40-unit system using the GSA method are given in Table 7 and the results are compared with other methods reported in literature

TABLE 6: Cost coefficients and unit operating limits for 40 unit system

Unit	Pmin	Pmax	a	b	c	d	e
1	36	114	94.705	6.73	0.00690	100	0.084
2	36	114	94.705	6.73	0.00690	100	0.084
3	60	120	309.540	7.07	0.02028	100	0.084
4	80	190	369.030	8.18	0.00942	150	0.063
5	47	97	148.890	5.35	0.01140	120	0.077
6	68	140	222.330	8.05	0.01142	100	0.084
7	110	300	278.710	8.03	0.00357	200	0.042
8	135	300	391.980	6.99	0.00492	200	0.042
9	135	300	255.760	6.60	0.00573	200	0.042
10	130	300	72.820	12.90	0.00605	200	0.042
11	94	375	635.200	12.90	0.00515	200	0.042
12	94	375	654.690	12.80	0.00569	200	0.042
13	125	500	913.400	12.50	0.00421	300	0.035
14	125	500	1760.4	8.84	0.00752	300	0.035
15	125	500	1728.3	9.15	0.00708	300	0.035
16	125	500	1728.3	9.15	0.00708	300	0.035
17	220	500	647.85	7.97	0.00313	300	0.035
18	220	500	649.690	7.95	0.00313	300	0.035
19	242	550	647.830	7.97	0.00313	300	0.035
20	242	550	647.810	7.97	0.0313	300	0.035
21	254	550	785.960	6.63	0.00298	300	0.035
22	254	550	785.960	6.63	0.00298	300	0.035
23	254	550	794.530	6.66	0.00284	300	0.035
24	254	550	794.530	6.66	0.00284	300	0.035
25	254	550	801.32	7.10	0.00277	300	0.035
26	254	550	801.32	7.10	0.00277	300	0.035
27	10	150	1055.1	3.33	0.52124	120	0.077
28	10	150	1055.1	3.33	0.52124	120	0.077
29	10	150	1055.1	3.33	0.52124	120	0.077
30	47	97	148.89	5.35	0.0114	120	0.077
31	60	190	222.92	6.43	0.00160	150	0.0063
32	60	190	222.92	6.43	0.0016	150	0.0063
33	60	190	222.92	6.43	0.0016	150	0.0063
34	90	200	107.87	8.95	0.0001	200	0.042
35	90	200	116.58	8.62	0.0001	200	0.042
36	90	200	116.58	8.62	0.0001	200	0.042
37	25	110	307.45	5.88	0.0161	80	0.098
38	25	110	307.45	5.88	0.0161	80	0.098
39	25	110	307.45	5.88	0.0161	80	0.098
40	242	550	647.830	7.97	0.0031	300	0.035

TABLE 7: Simulation Results and Its Comparison with PSO

Generator	Generator output of GSA	Generator output of PSO
1	110.2604	113.116
2	105.8822	113.010
3	96.5985	119.702
4	161.3755	81.647
5	76.0761	95.062
6	118.3619	139.209
7	277.7329	299.127
8	282.9290	287.491
9	255.8505	292.316
10	198.4792	279.273
11	194.7330	169.766
12	261.4072	94.344
13	302.8148	214.871
14	363.7843	304.790
15	325.7610	304.563
16	382.4561	304.302
17	470.1274	489.173
18	451.5342	491.336
19	478.0455	510.880
20	500.7619	511.474
21	529.9021	524.814
22	515.3287	524.775
23	529.2006	525.563
24	518.1049	522.712
25	489.4889	503.211
26	513.8339	524.199
27	10.6119	10.082
28	10.2303	10.663
29	12.8966	10.418
30	92.6348	94.244
31	187.9979	189.377
32	176.9925	189.796
33	184.4834	189.813
34	146.4241	199.797
35	172.6954	199.284
36	183.6914	198.165
37	101.0808	109.291
38	104.7847	109.087
39	90.2306	109.909
40	514.4148	512.348
Total demand	10500 MW	10500
Total cost	121940.0	122624.35

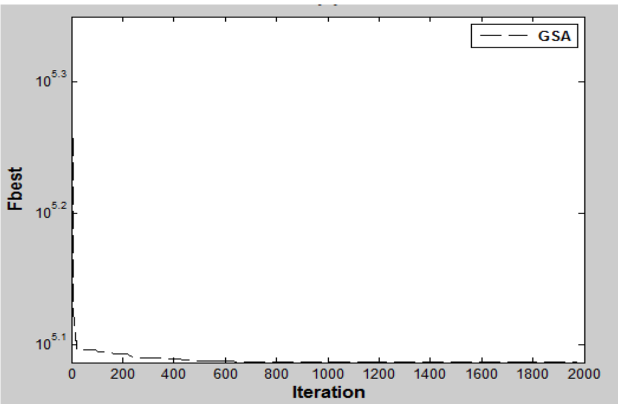


Figure 3. Convergence graph for 40-units with PD=10500MW

5. CONCLUSION

In this paper, a novel approach based on the Newton's laws of gravity and mass interaction GSA has been presented and applied to economic power dispatch optimization problem with valve point effect. Here this technique is applied to 3, 13, 40 unit system and effectiveness of GSA was tested. From the simulation results, it can be seen that GSA has better convergence rate and also less number of iteration when it is compared to other methods.

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