Solving Economic Load Dispatch Using A Novel Method Based On PSO Algorithm And GAMS Software

Soodabeh Soleymani, Mahdi Hayatdavudi

Abstract: Economic load dispatch (ELD) problem between power plant units is formulated as a nonlinear optimization with continuous variables. The main target in this problem is optimum planning in power plant units with minimum cost while equal and non-equal constraints consisting load request and unit production capacity are followed. In this paper an effective method based on particle swarm algorithm optimization for solving economic load dispatch optimization problem is presented which has a high ability to give optimum response in a proper time. GAMS software is used for this comparison.

Index Terms: economic dispatch, non-convex cost function, particle swarm optimization, GAMS software.

1 Introduction

ELD is a basic problem in applying power systems. The objective in ELD is minimizing power production cost regarding constraints on power plants and system. With respect to nonlinear objective function and complex constraints solving this problem is complicated [1]. Various methods are presented to obtain optimum solution in ELD. In [2], [3] linear and nonlinear programming is suggested. Linear programming is swift and accurate but this function estimates cost function partially therefore the result is not accurate. Nonlinear programming has complexity and convergence problem. Active programming is suggested for ELD [4]. This method cannot solve large scale problem nor needs a long time. Methods like Lagrange based on derivative are introduced [5]. These methods are not capable in considering practical constraints like valve point effect increase rate and prohibited zone because of their non-derivative nature. Mathematical analyzing methods cannot solve this problem regarding their mathematical nature. Therefore using complementary algorithm without nonlinearity and non-derivative of both objective function and constraints is suggested. A number of complementary algorithms are genetic algorithm [6-8], particle swarm algorithm [9-12], neural network [13], simulated annealing algorithm [14], bacterial foraging [15], particle swarm optimization [16], evolutionary programming [17], biography [18] and differential evolution [19]. Also a method based on combination of above algorithms is used for ELD problem and are different with each other in precision and speed [20].

- *Soodabeh Soleymani is with Technical Engineering Department, Science and Research Branch, Islamic Azad University-(IAU), Tehran, Iran.*
  E-mail: s.soleymani@srbiau.ac.ir
- *Mahdi Hayatdavudi is with Technical Engineering Department, Science and Research Branch, Islamic Azad University-(IAU), Tehran, Iran.*
  E-mail: mahdidavudi@yahoo.com

In this paper an idea based on particle swarm algorithm for solving ELD problem is used. To use a more real ELD cost functional power plant fuel are modelled non-convex. In this paper an innovative method for entering equal and non-equal constraints in producing primary population is presented which is very effective in obtaining optimum solution. Two system sample consisting of 13, 140 power plant units are used to show the effectiveness of this method and the obtained results are compared with some credible references. In the end the results of comparison between proposed algorithm and GAMS software are shown.

2 Formulating the Program

ELD is an optimizing problem for minimizing power plant cost regarding different constraints. In this section mathematical objective function and constraints are presented.

2.1 Objective Function

The total cost of power plant unit consists of fuel cost, personnel payment, maintenance cost and fuel cost is the main part of cost and has a direct relation with production. Cost function is based on fuel cost and other costs are constant values in this function. Power plant fuel cost function is usually a quadratic function based on active output power therefore ELD mathematical model is (1).

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

In equation (1), n is the number of generators, a_i, b_i, c_i are coefficient cost of i power plant and P_i is production capability of i power plant.

2.2 Considering Valve-Point Effects

Inspections show the figure of power plant cost function is not always convex and has non-differentiable points according to valve-point. Figure 1 shows a power plant cost function with 5 valve controllers. For modeling valve effect a sine part is added .therefore production cost of power plant is obtained using (2).

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

In equation (2) e_i, d_i objective function coefficient because of valve point effect and pi min show the minimum production capability.

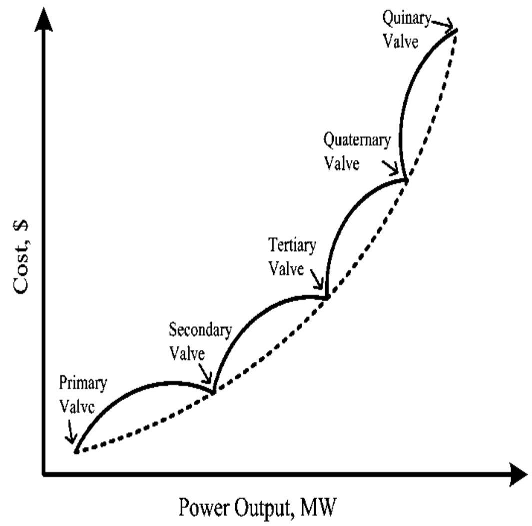

Fig. 1. Valve point effect on fuel cost curve

2.3 Considering Multiple Fuel Options

Different fuel types are usually used in power plants regarding their output power. Therefore for a more realistic ELD problem modelling multiple fuel effects must be considered in formulation. Cost function of *i* power plant with *k* fuel types is presented in equation (3).

$$F_i(P_i) = \begin{cases} a_{i1}P_i^2 + b_{i1} + c_{i1}, & \text{fuel } 1, \quad P_i^{\min} \le P_i \le P_{i1} \\ a_{i2}P_i^2 + b_{i2} + c_{i2}, & \text{fuel } 2, \quad P_{i1} \le P_i \le P_{i2} \\ \vdots & \vdots \\ a_{ik}P_i^2 + b_{ik} + c_{ik}, & \text{fuel } k, \quad P_{ik-1} \le P_i \le P_i^{\max} \end{cases} \tag{3}$$

In equation (3), $P_i^{\max}$ is maximum production of power plant. Multiple fuel effect on cost function is presented in figure 2. With considering valve effect sine effect is added to (3).

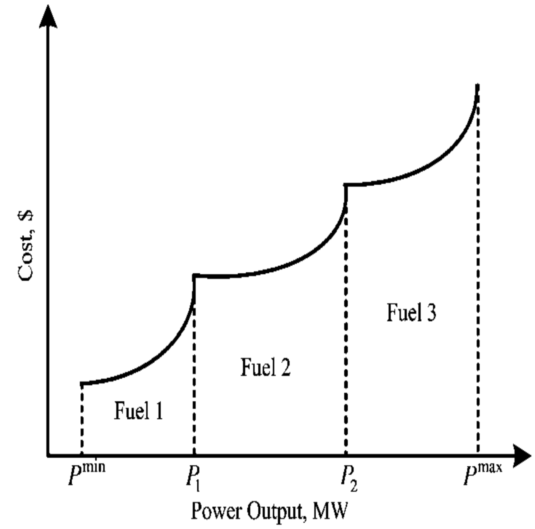

Fig 2. Multiple fuel effect on fuel cost curve

3 Problem Constraints

3.1 Generating Limit Constraint

Regarding electrical, mechanical and stability consideration, power plant production capability must be between minimum and maximum permissible range. This constraint is shown in (4) which $P_i^{\min}$ and $P_i^{\max}$ are minimum and maximum output power of i unit.

$$P_i^{\min} \le P_i \le P_i^{\max} \quad \text{for } i = 1, 2, \cdots, n \tag{4}$$

3.2 Power Balancing Constraint

For balancing capability in power systems, production of all power plant units must be equal to summation of load on system and network loss (equation(5)).

$$\sum_{i=1}^{n} P_i = P_D + P_L \tag{5}$$

In equation (5), P_D is load and P_L is network transition loss. The volume of loss depends on network physical structure and power plant output which is calculated by equation (6) [4].

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} + \sum_{i=1}^{n} B_{0i} P_i + B_{00} \tag{6}$$

Where B_{ij} , B_{0i} , B_{00} are B matrix coefficient which are directly derived from impedance matrix[4].

3.3 Slope Rate Constraint

In a real condition power plant production can be increased or decreased with slope rate therefore production capability has a minor difference in time intervals. This constraint is presented in equations (7), (8).

$$P_i - P_i^0 \le UR_i \quad \text{for} \quad i = 1, 2, \cdots, n \qquad (7)$$

$$P_i^0 - P_i \le DR_i \quad \text{for} \quad i = 1, 2, \cdots, n \qquad (8)$$

Where P_i^0 is primary production capability and UR_i, DR_i are maximum increasing and decreasing slope rate of *i* unit respectively. For considering slope rate constraint and *i* power plant capability simultaneously (4) and (8) are combined and considered as a non-equal constraint.

3.4 Prohibited Operating Zones

Prohibited production zone are in production intervals which vibration on turbines are above permitted limits therefore production is prohibited in these zones. Permitted intervals are shown in equation (9).

$$P_i \in \begin{cases} P_i^{min} \le P_i \le P_{i,1}^{l} \\ P_{i,k-1}^{u} \le P_i \le P_{i,k}^{l} \\ P_{i,z_i-1}^{u} \le P_i \le P_i^{max} \end{cases} , \quad k = 2, 3, \ldots, z_i \quad , \; i = 1, \ldots, nz \qquad (9)$$

Where $P_{i,k}^{u}$, $P_{i,k}^{u}$ are k low and high limits of prohibited zone I unit respectively. z_i is the number of *i* power plant prohibited zone and n_z is the number of power plants having prohibited zone[11]. The effect of prohibited zone on power plat cost function is shown in figure (3).

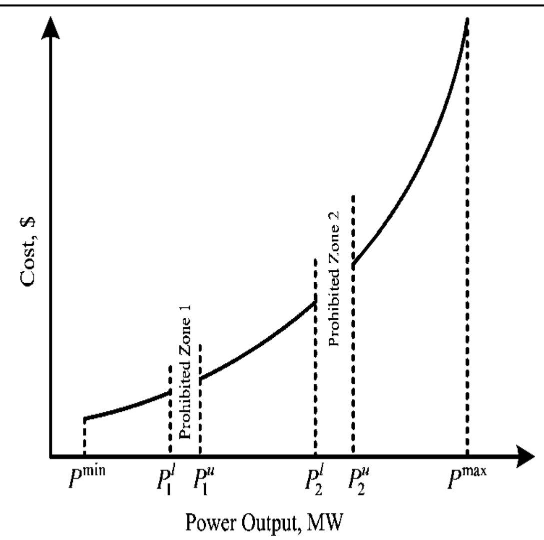

Fig 3. Prohibited zone effect on fuel cost curve

4 Optimizing Method Based On Particle Swarm Optimization Algorithm

Particle swarm optimization algorithm (PSO) is an optimization method based on population which was suggested first by Renndy and Eberhart [15]. The main idea in PSO algorithm is based on modeling and simulating particle swarm (like birds) behavior to find food. In this paper developed methods of this algorithm [16] which is highly capable in obtaining absolute optimized solution or a near solution is used for ELD problem among power plants. It needs to be mentioned that in this paper To increase the effectiveness of this algorithm operator crossover is added to this algorithm.

4.1 Classic Editing of PSO Algorithm

In PSO classic algorithm each *i* particle is consisted of two major parts current position of particle X_i and particle velocity V_i in each repetition the change of particle position is updated based on current position of particle and updated velocity. each Particle velocity is updated via equation (10) based on 3 major factors, current velocity, best experienced position (person) knowledge and the best position of particle among group particles (social knowledge).

$$V_{i+1} = K[wV_i + C_{1i}(Pbest_i - X_i) + C_{2i}(Gbest - X_i)] \qquad (10)$$

Where *w* is inertial coefficient of I particle for motion by previous velocity. C_{1i}, C_{2i} are personal and group learning of *i* particle which is randomly selected from [0-2] interval for preserving probability character algorithm. By determining next velocity of each *i* particle next position is achieved by equation (11). The process of updating particle in PSO algorithm is repeated until all particles are guided to a single point. And then use markup styles. Please keep the template at

$$X_{i+1} = X_i + V_{i+1} \qquad (11)$$

4.2 Following Problem Constraints Method

In ELD problem equality and non-equality constraint of production and consume and also generators production constraint must be followed [1]. In this paper for non-equal constraints which are related to high and low limits of generators power. During algorithm performance process variable is considered constant when violates from its limits or new value is replaced using (10) and (11). For equal constraint which is supplying load by generators a new method is used which variables change in a way that constraints conditions are followed. If equal constraint is not followed [3] first one of generators is selected as float variable and compensates extra or shortage of production. In this condition float variable may violates from its limits. If this occurs float variable is fixed in its limits and in the next step extra or shortage of production is divided among all units using (12). If deviation from limit occurs for each variable the process is repeated until all equal and non-equal constraints are followed.

$$[P]^{new} = [P]^{old} \cdot [\frac{P_D}{\sum_{j \in J} P_j}] \qquad (12)$$

4.3 Numerical Studies and Result Analysis

In this paper to evaluate the proposed method for ELD in power plant two sample system 13 and 140 units are used [17]. In order to compare the results of proposed method with results of other methods network loss are neglected.

A. 13 Unit System

This system has 13 production units and should supply 1800 megawatt demand. Table 1 shows the comparison between proposed methods with other methods for 13 unit system. Presented time in the last column is based on 100 times repetition of proposed algorithm in different populations. Presented results in table 2 show for all populations the best results are almost equal and the average of results for all populations are close to each other but their value decreases by increasing number of populations. It can be concluded from this table that the proposed algorithm in this paper has almost a proper result for different populations. For example the average of obtained results from proposed algorithm is even better than the best result from classic particle swarm algorithm. Figure 4 shows convergence best result by proposed algorithm. As it can be seen proposed algorithm is convergence after 100 epochs. This shows the capability of algorithm in obtaining optimized result in a short time. Table 3 shows the power production of units in optimized condition. In this severely nonlinear system simulations are done using GAMS software. Results are shown in table 3. It is clear that PSO algorithm presents better results.

TABLE 1. PROPOSED METHOD RESULTS AND OTHER METHODS IN 13 UNIT SYSTEM

running time(sec)	respond best($)	Method
--	17975.340	[7] GA
157.43	17994.070	[17] EP
121	17991.030	[21] EP-SQP
77	18030.720	[21] PSO
33.97	17969.930	[21] PSO-SQP
--	17963.950	[23] QPSO
12.6	17961.940	[22] CDEMD
--	17963.980	[7] IGA
2.22	17960.366	PSO

TABLE 2. PERFORMANCE RESULTS WITH DIFFERENT POPULATIONS IN 13 UNIT SYSTEM

time (s)	devia nce	Average Respond	worst Respon d	best Respon d	Primary populati on
0.78	51.09	18055.76	18209.7 1	17960.5 0	10
1.49	41.38	18032.75	18126.1 9	17960.6 6	20
2.22	37.62	18023.24	18110.7 5	17960.3 6	30
3.63	30.66	18004.99	18085.7 5	17960.3 6	50
7.52	27.28	17995.84	18088.6 4	17960.3 6	100

TABLE 3. PRODUCTION CAPABILITY 13 UNIT SYSTEM IN OPTIMIZED CONDITION

producing power(MW)		Unit
GAMS	PSO	
358.699	628.3185	1
70.746	149.5996	2
297.871	222.7491	3
161.587	109.8665	4
159.721	60	5
108.742	109.8666	6
109.595	109.8665	7
159.303	109.8665	8
109.583	109.8666	9
77.177	40	10
40.307	40	11
91.664	55	12
55	55	13
1800	1800	Total
18113	17961	Final cost

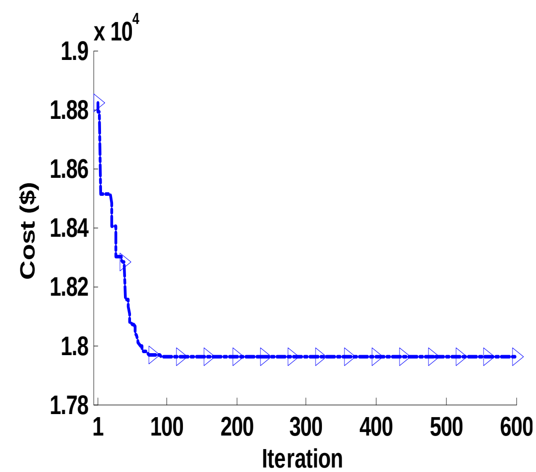

Fig 4: convergence process of best result algorithm in 13 unit system

B. 140 Generator System

This is a large scale system with 140 generators. The load of system is 49432megawatt. Systems have primary conditions and increasing and decreasing rate is considered. Experiments are done with PSO algorithm and GAMS software. Ultimate cost for PSO algorithm and GAMS software are 169600 and 1655680 respectively. Generators output is presented in table 4. It is obvious that GAMS software has obtained optimized solution. In fact by decreasing the complexity of cost function GAMS software has a good performance but in a small and complex problem PSO has a better performance. Convergence of best result by proposed algorithm is shown in figure 5.

5. CONCLUSIONS

In this paper ELD problem on two sample system using a novel method based on particle swarm algorithm is solved. In the proposed method for equal and non-equal constraints in producing primary population and performing algorithm process an idea is presented that is very effective for obtaining optimized solutions. Comparison of results between proposed algorithm and other references for ELD among power plants show high effectiveness of proposed algorithm. Also In this paper the comparison between results from proposed algorithm and GAMS software is presented and shows when the objective function is more nonlinear the proposed method is more proper to solve and if nonlinearity decreases GAMS software is a better option even if the scale of problem is large.

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TABLE 4. PRODUCTION CAPABILITY 140 UNIT SYSTEM IN OPTIMIZED CONDITION

unit	Output power		Unit	Output power		unit	Output power		unit	Output power		unit	Output power		unit	Output power		unit	Output power	
	GAMS	PSO		GAMS	PSO		GAMS	PSO		GAMS	PSO		GAMS	PSO		GAMS	PSO		GAMS	PSO
1	119	117.7	21	505	505	41	3	17.45	61	163	166.8	81	542	217.8	101	958	957.9	121	175	177.5
2	164	164	22	505	505	42	3	3.363	62	95	98.79	82	56	56.58	102	947.9	946.6	122	2	7.786
3	190	187.4	23	505	505	43	250	181.8	63	511	231.1	83	115	115.9	103	934	933.9	123	4	4.028
4	190	189.9	24	505	505	44	250	188.3	64	511	410	84	115	115.4	104	935	934.3	124	15	15.76
5	190	174.2	25	537	536	45	250	239.6	65	490	477.2	85	115	116	105	876.5	876.4	125	9	9.338
6	190	188.3	26	537	536	46	250	243.5	66	256.9	257.7	86	207	208	106	880.9	880.9	126	12	12.45
7	490	489.6	27	549	548	47	250	221.2	67	490	474.3	87	207	207.4	107	873.7	873.6	127	10	12.16
8	490	487.8	28	549	549	48	250	245.1	68	490	476.1	88	175	269	108	877.4	877.4	128	112	112.6
9	496	495.8	29	501	501	49	250	245.2	69	130	135.9	89	175	178.4	109	871.7	871.6	129	4	5.398
10	496	495.4	30	499	499	50	250	248.7	70	294.6	300.9	90	180.4	184.9	110	864.8	864.6	130	5	6.373
11	496	496	31	506	506	51	165	193.5	71	141.5	138.7	91	175	176.5	111	882	882	131	5	5.135
12	496	496	32	506	506	52	165	247	72	365.9	348	92	575.4	574.9	112	94	100.3	132	50	52.87
13	506	506	33	506	506	53	165	296.2	73	195	355.4	93	547.5	546	113	94	96.99	133	5	6.13
14	509	509	34	506	506	54	165	498.1	74	217.5	292	94	836.8	836.5	114	94	95.01	134	42	71.83
15	506	506	35	500	500	55	180	182	75	217.4	244.2	95	837.5	837.2	115	244	245.8	135	42	42.04
16	505	505	36	500	500	56	180	180.1	76	258.7	268	96	682	681.5	116	244	244	136	41	41.02
17	506	505.7	37	241	241	57	103	124.5	77	403.3	175	97	720	719.8	117	244	247.8	137	17	17.01
18	506	505.1	38	241	241	58	198	198.4	78	330	500.5	98	718	717.9	118	95	96.4	138	7	15.64
19	505	505	39	774	774	59	312	301.3	79	531	531	99	720	720	119	95	95.34	139	7	12.15
20	505	503.8	40	769	769	60	308.6	275.1	80	531	531	100	964	963.9	120	116	117.5	140	26	26.15

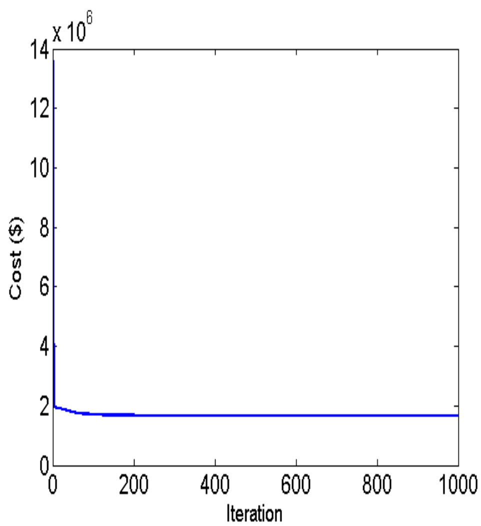

Fig5: convergence process in 140 unit system