Generation Scheduling Problem Using Particle Swarm Optimization Algorithm and GAMS

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Abstract

Generation scheduling problem commonly known as Economic load dispatch (ELD) has the objective of generation allocation to the power generators such that the total fuel cost is minimized and all operating constraints are satisfied. Traditional optimization methods assume the generator cost function to be monotonically increasing quadratic functions. In this paper presents a comparative analysis of efficient and reliable modern programming approach using particle swarm optimization algorithm (PSO) and general algebraic modeling system (GAMS) to solve economic load dispatch (ELD) problem. The proposed methodology easily takes care of different equality and inequality constraints of the power dispatch problem to find optimal solution. The paper reviews and compares the performance of the proposed PSO variants with traditional solver GAMS for economic load dispatch (ELD) on two test cases having 15 and 20-units. Experimental results support the claim of proficiency of the method over other existing techniques in terms of robustness and most importantly its optimal search behaviour.

I. Introduction

One of the objectives in the operation of today's complex electric power systems is to meet the demand for power at the lowest possible cost, while provides consumers with adequate and secure electricity .
So there should be a proper scheduling of generation for the minimization of cost of operation [1]. Thus the economic dispatch problem is one of the most important operational functions in modern power system. The basic objective of economic dispatch (ED) of electric power generation is to schedule the committed generating unit outputs so as to meet the load demand at minimum operating cost while satisfying all unit and system equality and inequality constraints [2].
Generation allocation problem which is commonly called Economic Load Dispatch (ELD) is the problem to meet the continuous variation of power demand economically. The power demand is dispatched among the generating units and economic of operation is the main consideration in assigning the power to be generated by each generating units. Therefore, ELD is implemented in order to ensure for economic operation of a power system. ELD is an optimization problem that determines the optimal output of online generating units so as to meet the load demand with an objective to minimize the total generation cost [3].
Over the years, many efforts have been made to solve the ELD problem, incorporating different kinds of constraints or multiple objectives through various mathematical programming and optimization techniques. The conventional methods include Newton-Raphson method, lambda Iteration method, base point and participation factor method, gradient method, etc. However, these classical dispatch algorithms require the incremental cost curves to be monotonically increasing or piece-wise linear [4].
Recently, the advances in computation and the search for better solution of complex problems have lead to using stochastic optimization techniques, such as ant colony optimization, evolutionary

algorithm, particle swarm optimization, differential evolution, and etc., for solving economic dispatch problems [5].
PSO, first introduced by Kennedy and Eberhart in reference [3], is one of the modern heuristic algorithms. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous non-linear optimization problems [6].
General Algebraic Modelling System (GAMS) [7] is a high-level model development environment that supports the analysis and solution of linear, non linear and mixed integer optimization problems. GAMS is especially useful for handling large dimension and complex problem easily and accurately.
In this paper we compares the performance of proposed PSO based techniques with traditional solver GAMS for Economic Load Dispatch (ELD) on a large power system. Performance comparison is carried out for two standard test systems having different sizes and complexity levels.

II. ELD Problem Formulation

Consider an ELD problem with N generators. The problem is to find the optimal combination of power generation that minimizes the total cost while satisfying the total demand. The cost function of ELD problem is defined as follows [8], [9]:

$$\min F_T(P_G) = \sum_{i=1}^{N} F_i(P_{Gi}) \tag{1}$$

In (1), the generation cost function F_i (P_{Gi}) in \$/h is usually expressed as a quadratic polynomial [10].

$$F_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \tag{2}$$

where FT (PG) is the total production cost (\$/h); Fi (PGi) is the cost of the ith generator in \$/h; PGi is the power output of generator i in MW and ai, bi, ci are the cost coefficients of the i th generator.
When minimizing the total production cost, the equality constraint (power balance) and inequality constraint (power limits) should be satisfied.

A. *Equality constraint*

$$\sum_{i=1}^{N} P_{Gi} - P_D - P_L = 0 \tag{3}$$

where PD is the power demand and PL is the active power losses.
The transmission loss can be represented by the B-coefficient method [11], [12] as:

$$P_L = \sum_i \sum_j P_{Gi} B_{ij} P_{Gj} \tag{4}$$

where Bij are the transmission loss coefficients; Pi, Pj are the power generation of ith and jth units. The B-coefficients are found uzing the Z-bus calculation technique.

B. *Inequality constraint*

The generation capacity of each generator has some limits and it can be expressed as:

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \tag{5}$$

III. Particle Swarm Optimization method

PSO works by adjusting trajectories through manipulation of each coordinate of a particle. Let x_i and v_i denote the positions and the corresponding flight speed (velocity) of the particle i in a continuous search space, respectively [13]. The particles are manipulated according to the following equations.

$$v_i^{(t+1)} = Iv_i^{(t)} + c_1 r_1 (x_{gbest}^{(t)} - x_i^{(t)}) + c_2 r_2 (x_{ipbest}^{(t)} - x_i^{(t)}) \quad (6)$$

$$x_i^{(t+1)} = x_i^{(t)} + v_i^{(t+1)} \quad (7)$$

where t is iterations pointer (generations); I is the inertia weight factor; c_1, c_2 are acceleration constants; r_1, r_2 are uniform random values in the range (0,1); $v_i^{(t)}$ is the velocity of particle i at iteration t; $x_i^{(t)}$ is the current position of particle i at iteration t, $x_{ipbest}^{(t)}$ is the previous best position of particle i at iteration t; $x_{gbest}^{(t)}$ is the best position among all individuals in the population at iteration t; $v_i^{(t+1)}$ is the new velocity of particle i and $x_i^{(t+1)}$ is new position of particle i.

Factors affecting the flying experience of each particle in its search for optimal solution are shown in Fig. 1.

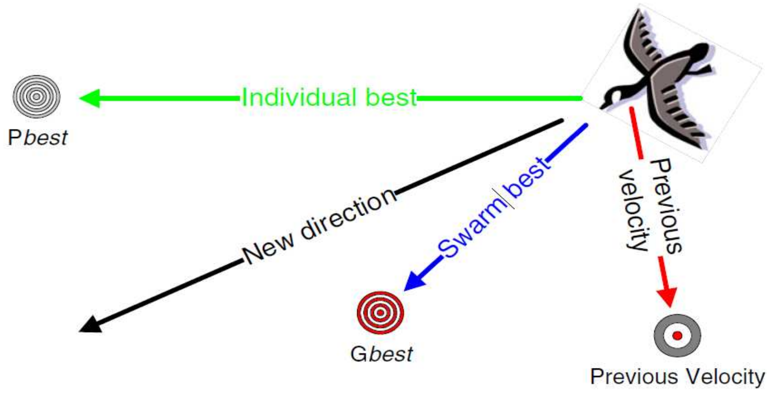

Fig. 1: Influential elements on the particle's movement during its search for an optimum.

The acceleration constants c1 and c2 serve to attract each particle to pbest and gbest positions, respectively. According to past experiences [14], c1 and c2 are often set to be 2.0.
The inertia constant controls the exploration of the search space. To balance between local and global explorations, we must select a suitable value of inertia weight I. The inertia weight factor I is set as follow:

$$I = I_{max} - t \times (I_{max} - I_{min}) / t_{max} \quad (8)$$

where *Imax* and *Imin* are the maximum and minimum value of inertia weight factor, respectively and *tmax* is the maximum iteration number.

IV. Application Of PSO Method To Economic Scheduling

To map the PSO for solving ELD, we have to follow the following steps:

- Using (1) for fitness function initialization. Calculate the total cost function including generation cost of the conventional unit.
- Initialize the PSO parameters like population size, acceleration constants, maximum and minimum value of inertia weight factor, etc.
- Read the input data concerning the fuel cost functions, MW limits the B-coefficient and the total demand for conventional unit.
- At the first iteration, allocate a random population of individuals of active power satisfying the MW limits.
- At iteration *t*, for each individual, calculate the fitness function using (7) and obtain *pbest* by comparison which is itself compared to obtain the *gbest*.
- At each step the value of *gbest* is compared to a pre-specified ε.
- gbest final value represent the minimum generation cost and the corresponding individual vector represent the ELD solution.

The PSO algorithm solution to the ELD problem can be easily modified to account for transmission losses. The only modification required is in the computation of the power output of the reference generator P_{Gk} from (3):

$$P_{Gk} = P_D + P_L - \sum_{i \neq k}^{N} P_{Gi} \qquad (9)$$

where the losses P_L is computed using the B-coefficients.
The loss formula (4), separating the terms containing the power output of the reference generator k, P_{Gk}, gives:

$$P_L = B_{kk} P_{Gk}^2 + 2\sum_{i \neq k}^{N} P_{Gi} B_{ik} P_{Gk} + \sum_{i \neq k}^{N} \sum_{j \neq k}^{N} P_{Gi} B_{ij} P_{Gj} \qquad (10)$$

For a particular individual, the power output vector ($P_{G1,,...,} P_{GN}$) contains only one unknown $P_{Gk.}$ Then transmission losses can be expressed as a function of the output of the reference generator P_{Gk} only:

$$P_L = C_{kk} P_{Gk}{}^2 + C_{0k} P_{Gk} + C_{00} \qquad (11)$$

where C_{00} , C_{0k} and C_{kk} are evaluated by direct comparison of (9) and (10).
From (10) and (11) it is evident that for the computation of the reference generation the solution of a quadratic equation in P_{Gk} is required. :

$$\begin{aligned} & B_{kk} p_k^2 + (-1 + 2\sum_{i \neq k}^{N} p_i B_{ik}) p_k + \\ & P_D + \sum_{i \neq k}^{N} \sum_{j \neq k}^{N} p_i B_{ij} p_j - \sum_{i \neq k}^{N} p_i = 0 \end{aligned} \qquad (12)$$

V. General Algebraic Modeling System (GAMS)

GAMS is a high-level model specially designed for modeling linear, nonlinear and mixed integer optimization problems. GAMS can easily handle large and complex problems. It is especially useful for handling large complex problems, which may require much revision to establish an accurate model. Models can be developed, solved and documented simultaneously, maintaining the same GAMS model file. The basic structure of a mathematical model coded in GAMS has the components: sets, data, variable, equation, model and output [15] and the solution procedures are shown below.

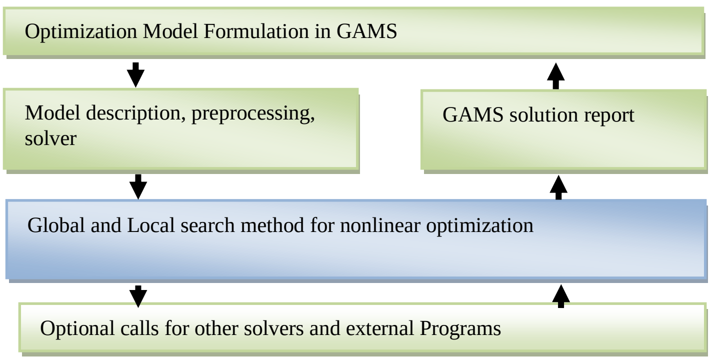

Fig. 2: GAMS modeling and solution procedure.

GAMS formulation follows the basic format as given below:

- **Sets**: Declaration, Assignment of members;
- **Data** (parameters, tables, scalars), Declaration, Assignment of values;

- **Variables**: Declaration, Assignment of type, Assignment of bounds and/or initial values (optional);
- **Equations**: Declaration, Definition;
- **Model and solve statements**;
- **Display statements** (optional).

VI. Simulation and Results

The performance of particle swarm optimization (PSO) has been compared with traditional optimization approach using the NLP minimization module of GAMS and its variants for two test cases having different sizes and complexity levels as described below. Simulations were carried out using MATLAB 7.4 on a Pentium IV processor, 2.8 GHz with 1 GB RAM.
The PSO algorithm parameters are as follow: the population size is 100; the maximum N° of iteration is 2000; the inertia weight factor (W) are W_{max} = 0.9 and W_{min} = 0.4; the acceleration constant are c_1=2 and c_2=2 and the maximum number of iterations is chosen as the stopping criterion.

A. 15-Unit test system

The ELD problem, defined by the conventional unit parameters presented in Table I and loss parameters taken from [16]. The power demand to meet is 2630MW. The summarized and comparative results of the 15 unit test case obtained by the PSO and GAMS algorithm are listed in Table II. The results are compared Genetic Algorithm (GA) [17] for this system.

TABLE I: GENERATOR PARAMETERS FOR A 15-UNIT ELD PROBLEM

Unit	Gen.limits (MW)		Generation cost parameters		
	Min	Max	*c* ($/hr)	*b* ($/hr-MW)	*a*($/hr-MW^2)
1	150	455	671.03	10.07	0.000299
2	150	455	574.54	10.22	0.000183
3	20	130	374.59	8.8	0.001126
4	20	130	374.59	8.8	0.001126
5	150	470	461.37	10.4	0.000205
6	135	460	630.14	10.1	0.000301
7	135	465	548.2	9.87	0.000364
8	60	300	227.09	11.5	0.000338
9	25	162	173.72	11.21	0.000607
10	20	160	175.95	10.72	0.001203
11	20	80	186.86	11.21	0.003586
12	20	80	230.27	9.9	0.005513
13	25	85	225.28	13.12	0.000371
14	15	55	309.03	12.12	0.001929
15	15	55	323.79	12.41	0.004447

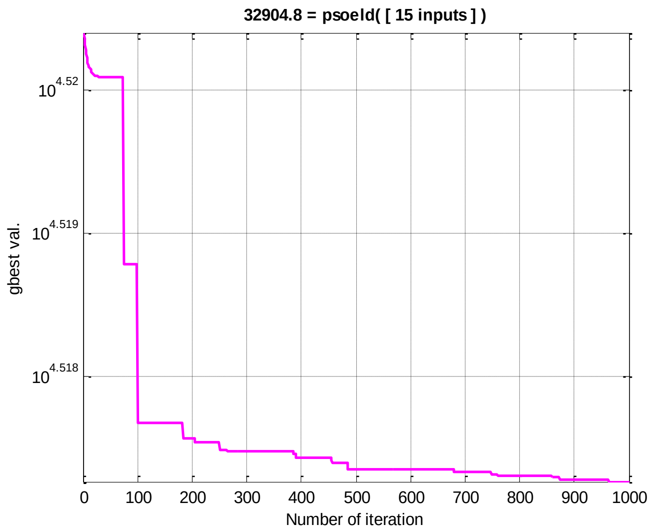

Fig. 3: Convergence characteristic of 15-generator system.

The convergence of fitness of 15 unit test system for load demand 2630 MW was converged in 6 second to the optimal solution in 900 iterations for the entire run algorithm as shown in Fig. 3.

TABLE II: RESULT OF 15 UNIT (PD=2630 MW)

Unit	GA [17]	PSO	GAMS
1	450	455	455
2	440	379.98	455
3	119.57	107.77	130
4	117.98	126.50	130
5	270	351.96	236.36
6	324.89	403.46	460
7	314.15	372.45	465
8	140.38	112.80	60
9	113.27	74.31	25
10	128.62	58.68	30.450
11	63.23	31.127	75.241
12	44.15	78.96	80
13	77.28	41.76	25
14	25.71	44.37	15
15	34.02	23.94	15
Demand PD (MW)	2630	2630	2630
Total cost FT ($/h)	33149	32904.77	32549.700
Total losses (MW)	38.249	33.139	27.051
execution time (s)		6.1	5.9

It can be seen from results that the result obtained from the proposed PSO algorithm is better in terms of total cost and total losses compared with the result calculated by Genetic Algorithm (GA) method.

B. 20-Unit test system

The system consists of 20-unit having quadratic cost function taking into account transmission losses. Power demand is set at 2500 MW. The parameters of all thermal units presented in Table III and loss coefficient are taken from [18]. The results are compared with Biogeography Based Optimization (BBO) [19] methods for this system. The results obtained by PSO and GAMS are listed in Table IV. It can be clearly seen from Table IV the proposed GAMS and PSO provides better results as compared to other reported evolutionary algorithm techniques like BBO.

Table II: generator parameters for a 20-unit eld problem

Unit	Gen. limits (MW)		Generation cost parameters		
	Max	Min	*c*($/hr)	*b*($/hr-MW)	*a*($/hr-MW^2)
1	600	150	1000	18.19	0.00068
2	200	50	970	19.26	0.00071
3	200	50	600	19.80	0.00650
4	200	50	700	19.10	0.00500
5	200	50	420	18.10	0.00738
6	100	20	360	19.26	0.00612
7	125	25	490	17.14	0.00790
8	150	50	660	18.92	0.00813
9	200	50	765	18.27	0.00522
10	150	30	770	18.92	0.00573
11	300	100	800	16.69	0.00480
12	500	150	970	16.76	0.00310
13	160	40	900	17.36	0.00850
14	130	20	700	18.70	0.00511
15	185	25	450	18.70	0.00398
16	80	20	370	14.26	0.07120
17	85	30	480	19.14	0.00890
18	120	30	680	18.92	0.00713
19	120	40	700	18.47	0.00622
20	100	30	850	19.79	0.00773

It can be seen from results that the result obtained from the proposed PSO reach the optimum results verified by many method listed in table VII. The convergence of fitness of 20 unit test system for load demand 2500 MW was converged in 8 second to the optimal solution in only 110 iterations for the entire run algorithm as shown in Fig. 4

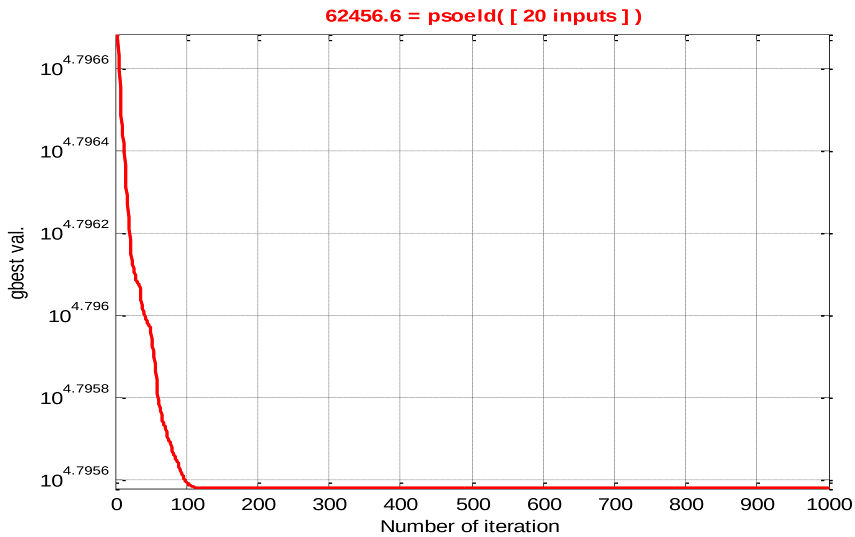

Fig. 3: Convergence characteristic of 20-generator system

Table II: result of 20 unit (pd=2500 mw)

Unit	BBO [19]	PSO	GAMS
1	513.089	512.781	512.782
2	173.353	169.101	169.102
3	126.923	126.890	126.891
4	103.329	102.867	102.867
5	113.774	113.682	113.683
6	73.066	73.571	73.572
7	114.984	115.289	115.290
8	116.423	116.399	116.400
9	100.694	100.404	100.405
10	99.999	106.027	106.027
11	148.977	150.238	150.239
12	294.020	292.766	292.766
13	119.575	119.114	119.114
14	30.547	30.831	30.832
15	116.454	115.805	115.806
16	36.227	36.254	36.254
17	66.859	66.859	66.859
18	88.547	87.971	87.971
19	100.980	100.802	100.803
20	54.272	54.304	54.305
Demand PD (MW)	2500	2500	2500
Total cost FT ($/h)	62456.79	62456.62	62456.633
Total losses (MW)	92.101	91.965	91.967
execution time(s)		8	7.8

VII. Conclusion

An enhanced PSO method was successfully employed to solve the ELD problem with all significant constraints. The proposed PSO has been demonstrated to have superior features including high quality solution and stable convergence characteristics

The performance of PSO variants was compared with traditional solver general algebraic modelling system (GAMS) for resolution the Economic Load Dispatch (ELD) on a large power system problem for two test system (15 and 20 units). The following conclusions were drawn.

- Both GAMS and PSO variants are able to handle complex constraints like generation limits, area-wise power balance ramp rate limits. The power balance constraints are satisfied satisfactorily and there is no violation.
- The PSO methods converge to different solutions near the global best solution. The traditional GAMS use mathematical operations to achieve the best solution so they are always consistent and converge to the unique global minimum solution.

The PSO and GAMS algorithm has superior features, including quality of solution and good computational efficiency, but GAMS provides much better result than PSO. The results show that GAMS is a promising technique for solving complicated problems in power system.

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