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Solving unit commitment and economic load dispatch problems using modern optimization algorithms

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Abstract

Economic Load Dispatch (ELD) and Unit Commitment (UC) are very important applications to predict the optimized cost of load in a power system. UC determines working states for existing generating units under some operational constraints and then optimizing the operation cost for all running units w.r.t. load demand using economic dispatch. This paper introduces Genetic Algorithm (GA) or Dynamic Programming (DP) to solve UC and then Shuffled BAT (BAT) technique as an evolutionary based approach is presented to solve the constrained ELD problem of thermal plants depending on the results obtained from UC solution. The IEEE 30 bus system is used to test the demonstration of the solution quality, computation efficiency and the feasibility of the application of BAT algorithm for ELD problem.

Keywords: Unit Commitment, Economic load dispatch, Dynamic Programming, Genetic Algorithm, Shuffled BAT, IEEE 30 bus system.

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1. Introduction

Thermal plants are main sources to supply electricity to loads in a power system and their primary fuels used to generate electricity have high cost and become intermittent in the next years (Nguyen and Ho, 2016). The target of the economic operation of generators is to ensure the ideal blend of generators associated with the power system to give the load demand. This operation includes two separate stages to be specific Unit Commitment (UC) and on-line Economic Load Dispatch (ELD). The unit responsibility includes the choice of units over a required time frame at minimum cost is the UC responsibility and determining a working units supply the load to less the aggregate cost using the on-line Economic Dispatch (Surekha, 2012). UC and ELD (Pang, 1981) are notable issues in the power business and can possibly spare large money every year in expenses. The problem is an intricate basic leadership process and it is hard to build up any thorough numerical advancement strategies fit for tackling the UC-ELD issue for any real system. Additionally, different limitations ought to be forced that should not be abused when the optimal arrangement is found (Surekha, 2012).

The nonlinear programming techniques are applied to solve the UC and ELD problem (conventional method). A convex objective function over a convex set is minimized using these techniques thus insuring a single minimum. Newton or gradient based search algorithms can be used to minimize these problems. These techniques may be trapped at local minima in solving nonconvex problems that have multiple minima. Dynamic programming has limitations due to the “curse of dimensionality” but it may be used to solve this problem (Li, 2013). Other method for taking care of nonconvex streamlining issues is metaheuristic advancement (Fletcher, 2013). Metaheuristic methods are perfect for nonconvex issue as they do not experience the ill effects of confinement of continuity, convexity and differentiability. Actually numerous metaheuristic methods are used to solve ELD problem such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Simulated Annealing (SA), Tabu search (TS) and Bat algorithm (BA) (Frank, 2012; Steponavice, 2012). However these methods give a reasonable and fast solution, they do not insure the global optimal solution in finite time (Dao, 2015).

Numerous variations of GA have already been utilized with great outcomes to take care of ELD issues (Abido, 2003; Subbaraj, 2011; Amjady, 2010). GA has an advantage of using a chromosome coding technique concerned to the defined problem and the two basic disadvantages are very long execution time and the global optimum solution has no guarantee of convergence. Nonconvex problems are solved also using PSO and many of its variants (Selvakumar, 2007; Thanushkodi, 2008; Gaing, 2003;Cai, 2007) There are many advantages of PSO such as easy performance and minimum adjustable parameters. It is also very efficient in global search (exploration). The main disadvantages of PSO are its weak local search ability and it is slow convergence at refined search stage (exploitation). A new population based metaheuristic algorithm is BA and it is the same as PSO and GA (Yang, 2010; Yang, 2013) This calculation mirrors the echolocation capacity of smaller scale bat that they utilize it for exploring and chasing. The bat position gives a conceivable arrangement for this issue. Wellness of arrangement is indicated by bat's best position to its prey. A major preferred standpoint BA different calculation is having various tunable parameters giving a greater control along advancement procedure. BA and its variations have additionally been utilized to take care of the ELD issue (Sidi-Bel-Abbes, 2014; Niknam, 2012; Ramesh, 2013). It has demonstrated productive in for lower dimensional advancement issue (Fister, 2013; Latif and Palensky, 2014). BAT algorithm may be used for solving a combined economic and emission dispatch problem as in (Nguyen and Ho, 2016; Gonidakis and Vlachos, 2015). A modified version of BAT algorithm as an evolutionary meta-heuristic algorithm is employed to solve non-smooth ELD as in Namdari and Sedaghati (2014); it is also used in solving nonconvex dynamic economic dispatch problem and give good results. This algorithm can easily be coded in any programming language due to less number of operators. The performance of the algorithm compared with other algorithms to prove its strength (Arsyad et al., 2017) and used in solving thermal unit commitment problem (Anand.and Rahman, 2014).

In this paper DP and GA is applied to select and choose the combination of generating units that commit and de-commit during each hour. These pre-committed schedules are optimized by BAT algorithm thus producing a global optimum solution with feasible and effective solution quality, and minimum cost. The effectiveness of the proposed technique is investigated on IEEE 30 bus system. The significance of this approach is to obtain a least cost solution for the UC-ELD problem.

2. Problem Formulation

The scheduling problem of generators solved ideally by acquiring exhaustive trial of all solutions and best solution is chosen amongst them. All possible units supplying a load and reserve requirements would be tested and choose the optimal solution that have the minimum operating cost (Aruldoss, 2005). The generating units' output power with system constraints over a time period T and startup/shut down times at each step required to scheduling problem of generator. The running cost significant term of a thermal units is the output power of the committed units (Surekha, 2012). The fuel cost, $\mathrm{FC_i}$ is represented in a quadratic form of output power in a time interval given in Equation (1).

$$\mathrm{F_T} = \sum_{i=1}^{n} \mathrm{F_i}\,(\mathrm{P_i}) = \sum_{i=1}^{n} \mathrm{a_i} + \mathrm{b_i p_i} + \mathrm{c_i p_i^2}\ \$/\mathrm{Hr} \tag{1}$$

where$\mathrm{a_i}$,$\mathrm{b_i}$, $\mathrm{c_i}$are cost coefficients of unit and $\mathrm{p_i}$ is the unit generating power. The start-up cost (SC) calculation depends on the treatment strategy for a thermal unit during down time periods and an exponential cost curve shown in Equation (2) is its representation. where σ_i , δ_i , $\tau_i$is the hot startup cost, the cold startup cost and the cooling time unit constant and $\mathrm{T_{off}}$, is the time at which the unit has been turned off so The total production cost, $\mathrm{F_T}$is the sum of the operating, startup and shut down costs for all the units illustrated in Equation (3).

$$\mathrm{SC_i} = \sigma_i + \delta_i * \left\{1 - \exp\left(-\frac{\mathrm{T_{off}}}{\tau_i}\right)\right\} \tag{2}$$

$$\mathrm{F_T} = \sum_{i=1}^{T} \sum_{i=1}^{N} \mathrm{FC_{i,t}} + \mathrm{SC_{i,t}} + \mathrm{SD_{i,t}} \tag{3}$$

where N is the number of generators and different load demands number is T at estimated commitment, SD is the shutdown cost. Some constraints should be taken into consideration to minimize $\mathrm{F_T}$ as:

(i) power balance equation is given by Equation (4):

$$\sum_{i=1}^{N} \mathrm{P_i U_i} - (\mathrm{P_D} + \mathrm{P_L}) = 0 \tag{4}$$

where $\mathrm{P_D}$is the load demand and $\mathrm{P_L}$ is the power loss of the system.

(ii) The hourly spinning reserve (R) is given by Equation (5):

$$\sum_{i=1}^{N} \mathrm{P_i^{max}}\,\mathrm{U_i} - (\mathrm{P_D} + \mathrm{P_L}) = \mathrm{R} \tag{5}$$

(iii) Unit rated minimum and maximum capacities as in Equation (6):

$$P_i^{min} \leq P_i \leq P_i^{max} \tag{6}$$

The initial conditions of each unit and Minimum up/down (MUT/MDT) time limits of units are given by Equations (7) and (8) respectively.

$$\left(T_{t-1,i}^{on} - MUT_i\right) * (U_{t-1,i} - U_{t,i}) \geq 0 \tag{7}$$

$$\left(T_{t-1,i}^{off} - MDT_i\right) * (U_{t,i} - U_{t-1,i}) \geq 0 \tag{8}$$

where the unit off / on time is Toff / Ton the and the unit off / on [0,1] status is $U_{t,i}$.The enhancement of ELD problem is represented by Equation (9):

$$F_T = \sum_{i=1}^{n} F_i\,(P_i) \sum_{i=1}^{n} a_i + b_i p_i + c_i p_i^2 \ \$/Hr \tag{9}$$

Subject to the equality and inequality constraints are given by Equations (10) and (11) respectively.

$$\sum_{i=1}^{N} P_i = (P_D + P_L) \tag{10}$$

$$P_i^{min} \leq P_i \leq P_i^{max} \tag{11}$$

3. Modern Optimization Algorithms

The viability of the applied optimization techniques is made on an IEEE 30 bus system. For UC the control parameters for Genetic Algorithm are total number of generations, population size, selection type, mutation and crossover rate. The chromosomes number in a single generation is decided by the population size. A sensible number between [20,100] is chosen for population size, 24 is the population size with 0.6 crossover probability and 0.001 mutation rate of flip bit are chosen values for this system maintaining population diversity. The DP steps are given in (Gaurav, 2015) to maintain the UC solution.

3.1 BAT Algorithm: Bats are some animals with entrancing creatures. One of its characteristics it has wings have propelled ability of echolocation (Gherbi, 2011; Gherbi et al., 2014).

The vast majority of bats use echolocation to a defined degree; among every one of the animal types, microbats are renowned such as microbats use echolocation widely, while megabats do not (Steponavice, 2012). Echolocation is a type of sonar used to recognize prey by Microbats and find their perching hole oblivious. In order to portion qualities of microbats of the echolocation, different bat-propelled calculations or bat calculations can be produced. For straightforwardness, in our approach, the accompanying rough or romanticized guidelines were utilized:

Bats utilize echolocation for detecting separation, and they know a difference between foundation hindrances and food/prey. Arbitrarily Bats fly by velocity v_i , position x_i , a settled frequency f_{min} (or wavelength λ), look for a prey varying frequency f (or wavelength λ) and loudness A_0. Depending on the proximity targets; the rate of pulse emission r ⊂ [0, 1] may be conformed and thewavelength (or frequency) of their radiated beats can be modified.

There are some simplifications as changing the loudness from A_0 , a large (positive), to A_{min} , a minimum value, and no ray tracing is used in approximating the time delay and three dimensional topographies. Also there are some approximations for simplicity as the frequency f in a range [f_{min}, f_{max}] related to a wavelength range [λ_{min}, λ_{max}]. For example, a frequency range of [20 kHz, 500 kHz] correlated to a wavelengths range from 0.7 mm to 17 mm. In simulations, normally we use virtual bats. The positions xi and velocities vi in a d-dimensional search space and its new updates x_i^0 and v_i^0 at time t is given by:

$$f_i = f_{min} + (f_{max} - f_{min})\beta \tag{12}$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_0) f_i \tag{13}$$

where β ⊂ [0, 1] is an arbitrary vector and the current best location (solution) is x_0 which is situated in the wake of looking at arrangements between n bats. A product $\lambda_i f_i$ is the increment velocity, either f_i (or λ_i) is used to adjust the velocity change while fixing the other factor λ_i (or f_i), depending on the type of the problem of interest. For each bat, a new solution is generated locally using:

$$X_{new} = X_{old} + E.\,A^t \tag{14}$$

where an arbitrary number E⊂ [0, 1], while $= A^t = < A_j^t >$ is the loudness average of all the bats. In view of above approximations and idealization, the BAT algorithm flow chart is summarized in Figure 1. Experimentally, once a solution is improved the pulse emission rate and loudness are varied. The bat movement to optimal solution is given by:

$$A^{t+1} = \alpha A^{t}, r^{t+1} = r^{0}[1 - e^{\gamma t}] \qquad (15)$$

where α and γ are constants (Gherbi, 2011).

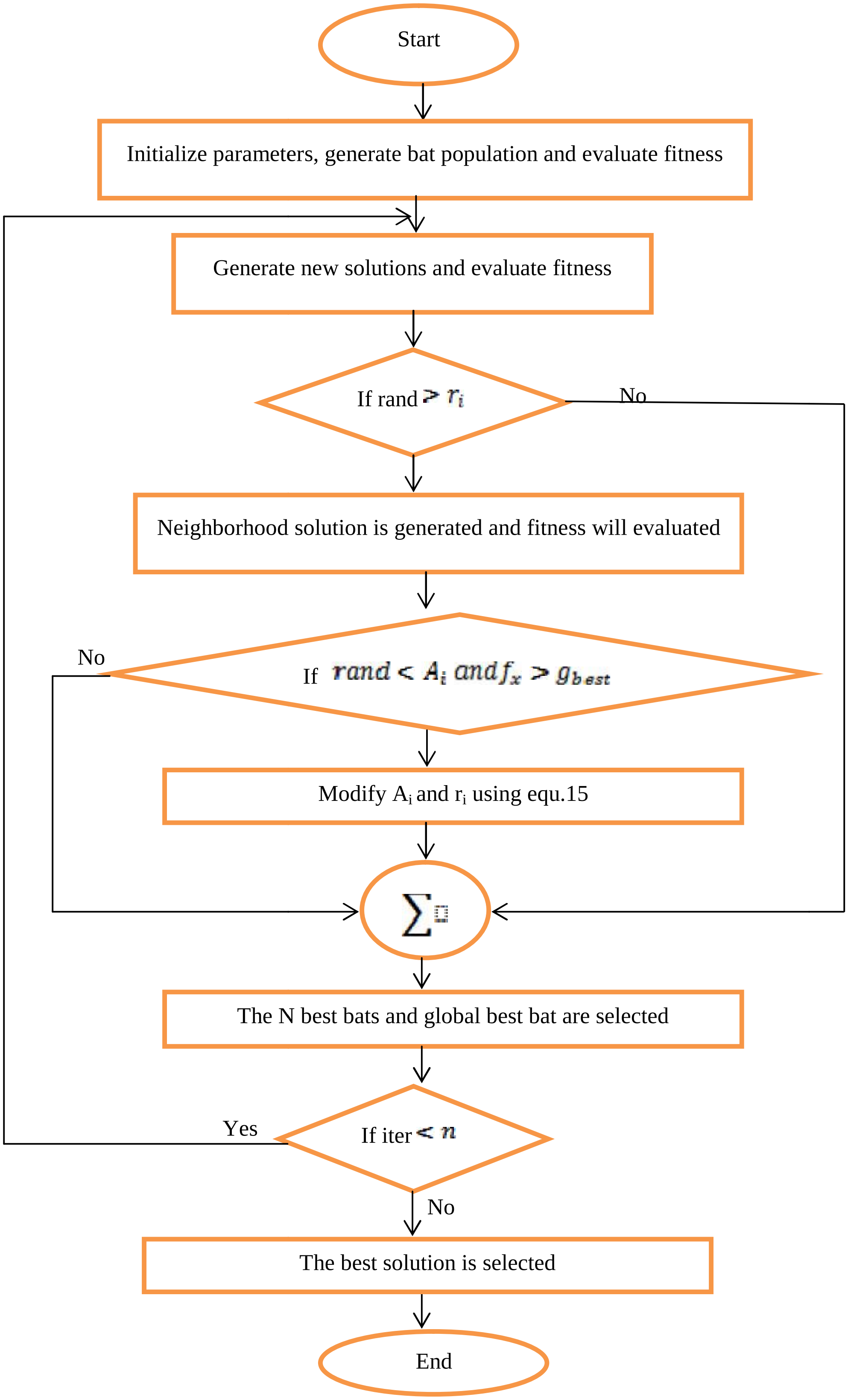

Figure 1. Bat Algorithm Flowchart

4. Simulation Model

The IEEE 30 bus system is used in this paper consists of 41 transmission lines, 6 generators and 30 buses. It has 117 MW minimum capacity and 435 MW maximum capacity (Thenmozhi and Mary, 2004). The load demand for 24 hour time interval is given in Table 1and the characteristics of the system (generating units cost coefficients and capacity of each one) is given in Table 2.

Table 1. Load Demand of IEEE 30 bus system

Hour	Load(MW)	Hour	Load(MW)
1	166	13	170
2	196	14	185
3	229	15	208
4	267	16	232
5	283.4	17	246
6	272	18	241
7	246	19	236
8	213	20	225
9	192	21	204
10	161	22	182
11	147	23	161
12	160	24	131

Table 2. IEEE 30 bus Generator Characteristics

Parameters					
Units	A ($/W-h^2)	B ($/W-h)	C ($)	Min Power (MW)	Max Power (MW)
1	0.00375	2	0	50	200
2	0.01750	1.75	0	20	80
3	0.06250	1	0	15	50
4	0.00834	3.25	0	10	35
5	0.02500	3	0	10	30
6	0.02500	3	0	12	40

The test system transmission loss coefficients are given in Equation (16):

$$B_m = \begin{bmatrix} 0.000218 & 0.000103 & 0.000009 & -.000010 & 0.000002 & 0.000027 \\ 0.000103 & 0.000181 & 0.000004 & -0.000015 & 0.000002 & 0.000030 \\ 0.000009 & 0.000004 & 0.000417 & -.000131 & -.000153 & -.000107 \\ -.000140 & -.000015 & -.000131 & 0.000221 & 0.000094 & 0.000050 \\ 0.000002 & 0.000002 & -.000153 & 0.000094 & 0.000243 & 0.000000 \\ 0.000027 & 0.000030 & -.000107 & 0.000050 & 0.000000 & 0.000358 \end{bmatrix} \tag{16}$$

5. Simulation Results

Control parameters of DP or GA are applied to solve UC problem. Table 3 gives the results for UC solution as (1/0) status of the test system for 24 hour time interval. The commitment of the units varies according to varying the load demand hourly(a load of 1 means the unit is on and 0 refers to the unit is off). From the data tabulated, unit P1 is ON all the day due to its minimum value of 'A'and units P5 , P6 is OFF for most of the day hours because the value of 'A' maximum for these two units. As the value ofcoefficient 'A' is minimum, the unit is ON mostly because it gives minimum fuel cost and vice versa. For the forecasted power demand, GA or DP provides a cost effective solution by using the appropriate units. After solving UC, BAT is used to solve ELD problem. The power to be shared by units P1 to P6 for each power demand is given in Table 4. The contribution of power generated by each unit per day is graphically represented in Figure 2. The total fuel cost in each hour is shown in Table 5 and represented graphically using Figure 3. It can be observed that the load demand of 131 MW gives a minimum fuel cost and 283.4 MW gives a maximum fuel cost and so the operating cost is directly proportional to the power demand through the day.

Table 3. Commitment of IEEE 30 bus system by GA or DP

Hr	P_D(MW)	Combination of Units					
		P_1	P_2	P_3	P_4	P_5	P_6
1	166	1	0	1	1	0	1
2	196	1	0	1	1	1	1
3	229	1	1	1	1	1	0
4	267	1	1	1	1	1	0
5	283.4	1	1	1	1	1	0
6	272	1	1	1	1	1	0
7	246	1	1	1	1	1	0
8	213	1	1	1	1	1	0
9	192	1	1	1	1	0	0
10	161	1	1	1	0	0	0
11	147	1	1	0	0	0	0
12	160	1	1	0	0	0	0
13	170	1	1	0	0	0	0
14	185	1	1	0	0	0	0
15	208	1	1	0	0	0	0
16	232	1	1	1	0	0	0
17	246	1	1	1	0	0	1
18	241	1	1	1	0	0	1
19	236	1	1	1	0	0	1
20	225	1	1	1	0	0	1
21	204	1	1	1	0	0	1
22	182	1	1	1	0	0	1
23	161	1	1	1	0	0	1
24	131	1	1	1	0	0	0

Table 4. BAT results for ELD problem

Hr	P_D(MW)	Power Generated/Unit (MW)					
		P_1	P_2	P_3	P_4	P_5	P_6
1	166	130.1031	0	22.06295	15.0176	0	12.0187
2	196	155.4972	0	23.1801	15.0221	10.009	12.0386
3	229	159.9655	0	50	15.0242	14.0503	12.0282
4	267	159.0321	66.1885	24.8229	15.0219	10.0328	0
5	283.4	161.9093	80	24.9679	15.0406	10.0172	0
6	272	163.2663	67.1902	24.9386	15.0446	10.0107	0
7	246	153.5876	57.6183	22.3557	10.0433	10.0163	0
8	213	127.2086	50.922	20.4353	10.0246	10.0070	0
9	192	50	80	50	12.4885	0	0
10	161	115.3728	33.7081	15.9716	0	0	0
11	147	116.9810	34.0319	0	0	0	0
12	160	84.0855	80	0	0	0	0
13	170	136.6549	38.7800	0	0	0	0
14	185	123.7691	67.0960	0	0	0	0
15	208	135.3853	80	0	0	0	0
16	232	172.9976	47.5824	20.2924	0	0	0
17	246	177.3546	55.3996	22.8679	0	0	12.0254
18	241	173.1598	54.1568	22.5796	0	0	12.0050
19	236	168.8771	53.1387	22.1627	0	0	12.0113
20	225	88.8233	80	50	0	0	24.6147
21	204	68.8696	80	50	0	0	16.4022
22	182	123.5043	41.2668	18.3858	0	0	12.0623
23	161	50	80	50	0	0	21.4925
24	131	90.5023	27.9899	15.0798	0	0	0

Table 5. Operating Cost for IEEE 30 bus System

Hour	Demand (MW)	Operating cost using BAT	Operating cost using PSO (Surekha P, October 2012).
1	166	546.8259	754
2	196	674.8398	877.1272
3	229	855.7722	1003.6
4	267	847.4716	1088.6
5	283.4	918.5618	1169
6	272	868.2019	1109
7	246	735.6475	999.7102
8	213	612.9562	873.7686
9	192	535.0097	801.6312
10	161	391.4492	694.9884
11	147	365.1030	670.7778
12	160	405.4985	718
13	170	437.5226	758.2500
14	185	487.1330	737.6875
15	208	566.9452	792.9700
16	232	627.1455	852.2500
17	246	718.4746	1028.6
18	241	698.9065	1005.2
19	236	679.5739	982.4672
20	225	637.8642	934.1477
21	204	561.3279	847.8409
22	182	485.4036	765.8500
23	161	416.8895	693.6478
24	131	303.695	594.2260

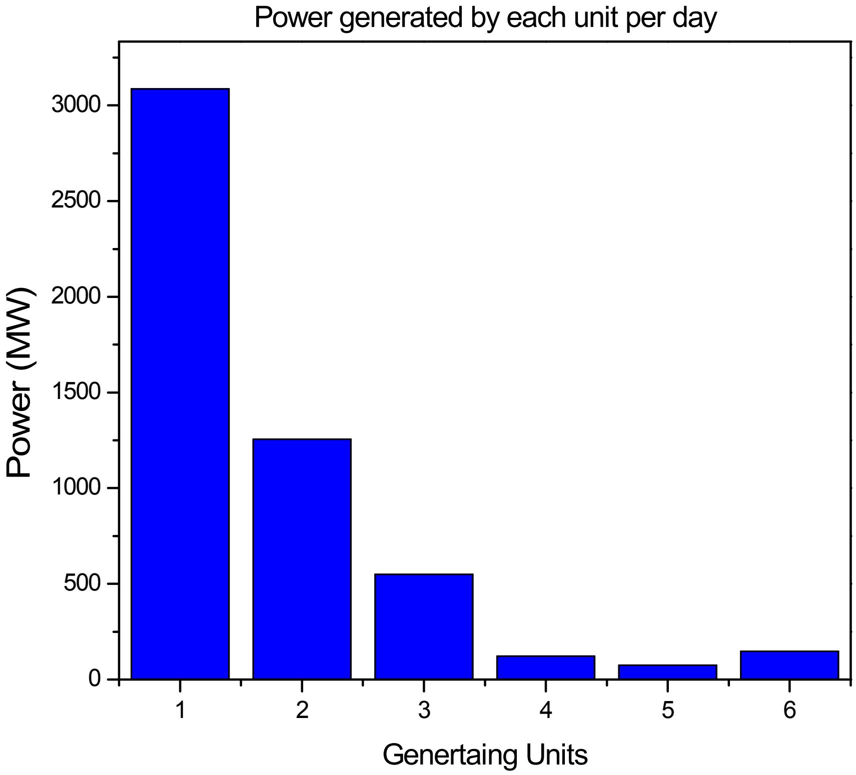

Figure 2. Power generated by each unit using BAT for Six- unit System

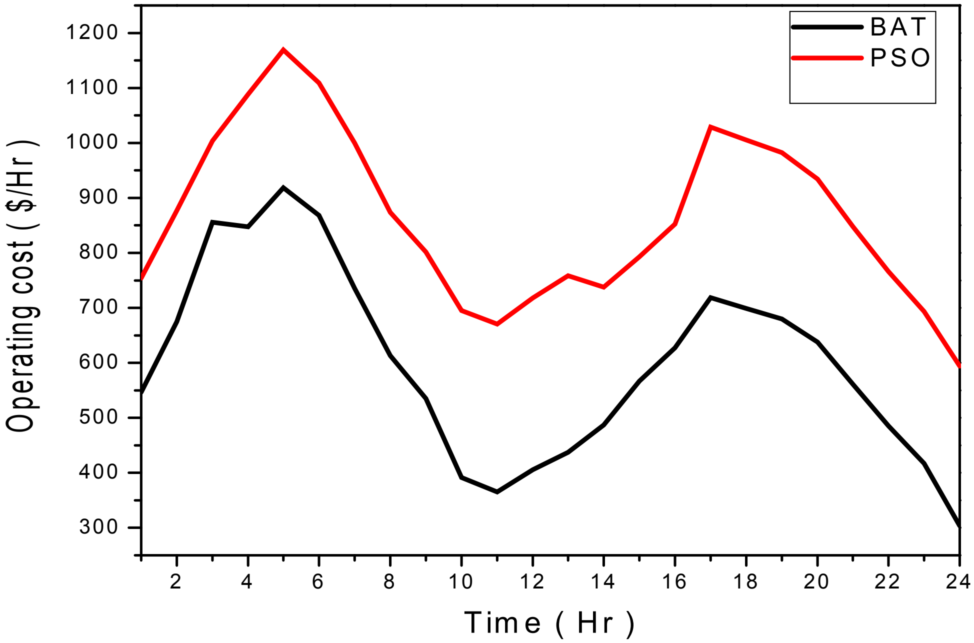

Figure 3. Operational cost for Six- unit System

6. Conclusions

Economic Load Dispatch (ELD) and Unit Commitment (UC) are very important study as a large amount of money is optimized and saved in electric utilities which improve system reliability. This paper introduces GA or DP to solve UC and then BAT algorithm is applied to solve the ELD problem at 24 hours with different load demands. The optimal solution in terms of total fuel cost and algorithmic efficiency is proved by comparing the cost with PSO results. Results obtained for different daily hour's to the test system show the robustness, consistency, quality and efficiency of the algorithm as it generates optimal solution through repetitive runs. In future, modern optimization algorithms as Population-based incremental learning, Stud Genetic Algorithm, Bio-Geography based algorithm ,Intelligent water drop algorithm, and hybrid combination of these paradigms may solve the UC-ELD problem taking into consideration real time constraints which contain network security, spinning reserves and emission constraint to new enhancement systems.

Nomenclature

UC	Unit Commitment.
ELD	Economic load dispatch.
DP	Dynamic Programming.
GA	Genetic Algorithm.
TS	Tabu search
PSO	Particle Swarm Optimization
BA	Bat algorithm

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