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Application of Bat Evolutionary Algorithm in Optimization of Economic Dispatch for Unit-Commitment Problem with Large Uncertainties and High Efficiency

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Abstract In the recent years, unit commitment (UC) has been increasingly directed towards improving the quality of power to satisfy the customers' demand at a minimum cost. As a result, minimizing the cost function of the unit commitment problem has become a challenge for many research studies while assuring the power availability in distribution systems. In this paper, the new Bat Algorithm (BA) as an evolutionary algorithm is proposed to minimize the unit commitment cost function and to decrease the fluctuation of power in the distribution system. The cost function employs constraints including spinning reserve and generator ramp rate in addition to commonly used load balance, power limits, etc. Simulation studies on a 10-unit distribution system shows significant improvement in the convergence speed and minimum calculated cost when compared to the available methods.

Keywords Power System Operation, Unit Commitment, Optimization, Economic Dispatch, Smart Grids

NOMENCLATURE

N	Number of Units.
T	Scheduling horizon time
TC	Total Cost
FC	Fuel cost
SU_i	Start-up cost of the ith unit
D^t	Load demand at time t
SP^t	Spinning reserve at time t
U_i^t	Operation status of ith unit at time t. When the unit is off it is equal to 0 and when unit is on it is equal to 1.
RU_i	Ramp-Up rate for the ith unit
RD_i	Ramp-Down rate for the ith unit
T_i^{hot}	Hot start cost of unit i
T_i^{Cold}	Cold start cost of unit i
P_i^t	The output power of ith unit at time t
$P_{i\,max}$	The maximum output power of the ith unit
$P_{i\,min}$	The minimum output power of the ith unit
$P_{i\,max}^t$	The maximum output power of the ith unit at time t
$P_{i\,min}^t$	The minimum output power of the ith unit at time t

1. INTRODUCTION

Unit Commitment (UC) is an optimization problem which tries to determine which unit should be on or off during the schedule operation time. This problem divided into three areas based on demand and definition: 1) The Security Constrained Unit Commitment (SCUC) 2) The Profit Based Unit Commitment (PBUC) 3) The Cost Based Unit Commitment (CBUC). In this study, Bat algorithms as a new evolutionary algorithm is applied to optimize the cost function unit commitment problem based on some limitation and constraints. In fact, this method tries to minimize the cost of the power plant which is included the summation of the fuel and start-up cost. On the other hand, there are existing some constraints associated with unit commitment problems which is considered and satisfied in this paper such as ramp rates and spinning reserve. In many cases, usually, these two constraints are neglected to solve the problem easily. However, in this paper, these constraints are applied and the optimal cost function is calculated.

Solving unit commitment problems needed to solve two sub problems at the same time. First, take a decision to determine which units should be on or off during the schedule time according to the load demand. Second, the economic dispatch problem should be satisfied among the generation units with varying load demands which is quadratic programming problem.

In the recent years, many research papers with different methods tried to solve unit commitment problems such as dynamic programming (DP) [1], [2], genetic algorithm (GA) [3-8] and particle swarm optimization (PSO) [9-14]. However, these methods are associated with some problems. For instance, genetic algorithms needed a long time to solve unit commitment problems and there is no guarantee to find an optimal solution. Also, dynamic programming need more mathematical complexity and time. DP is a good method for less units while by increasing the number of units and taken more constraints system needed more time to solve the UC problems and in high level cases will goes to fault. Furthermore, particle swarm optimization needed more time to solve the unit commitment problems. In this paper, bat evolutionary algorithms which is proposed in [15-18] is applied to solve unit commitment problems with 10 units and one day scheduling time (24 hours). The results proved the high performance of the proposed method compared to other evolutionary algorithms.

Section two will explain about the mathematical model of the unit commitment. Constrain of the unit commitment has been reviewed in section three. Bat algorithm is explained in section four. Section five is about the case study and results of the paper. Finally section six is the conclusion.

2. Mathematical Model of Unit Commitmentj

The main goal and objective of this paper is try to minimize the cost function of the unit commitment. The cost function of the unit commitment is the combination of fuel and start-up/ shut down cost. As a result, the total cost of the unit commitment are:

$$TC(X) = \sum_{t=1}^{N} \sum_{i=1}^{j} FC_i^t + SU_i^t \tag{1}$$

Where N is the number of the units which is 10 in this paper, TC is the total cost, FC is the fuel cost and SU is the start-up cost of the ith unit at time t.
The fuel cost of is a quadratic function as below:

$$FC_i^t = U_i^t \left(a\, f_i + b\, f_i\, P_i^t + c\, f_i\, (P_i^t)^2\right) \tag{2}$$

Where a, b, c are the coefficients of the fuel cost. Table 1 shown the assumption of the unit of the UC. On the other hand, the start-up/ shut down cost is defined in equation (3):

$$St_i^t = \sum_{k=t-T_i^{OFF}-T_i^{Cold}}^{t-1} U_i^k \,.SU_i^t = f(x) = \begin{cases} SU_i^{hot} \,.\, U_i^t \,.(1 - U_i^{t-1}), & if\ St_i^t > 0 \\ SU_i^{hot} \,.\, U_i^t\,, & if\ St_i^t = 0 \end{cases} \tag{3}$$

It means that the start-up cost is depend on the status of the unit during the operation time. If unit is cold, more cost is needed to pay compare to when the unit is not completely cold.Table 1 shown the assumption of the UC problem.

Table 1: Assumption of the Unit Commitment problem

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
a_i	1000	970	700	680	450	370	480	660	665	670
b_i	19.16	17.26	16.6	16.5	19.7	22.26	27.4	25.92	27.27	27.79
C_i	0.00048	0.00031	0.002	0.00211	0.00398	0.00712	0.00079	0.00413	0.00222	0.00173
P_{max}	455	455	130	130	162	80	85	55	55	55
P_{min}	150	150	20	20	25	20	25	10	10	10
r	9.1	9.1	2.6	2.6	3.24	1.6	1.7	1.1	1.1	1.1
RU	227.5	227.5	65	65	81	40	42.5	27.5	27.5	27.5
RD	227.5	227.5	65	65	81	40	42.5	27.5	27.5	27.5
T_{ON}	8	8	5	5	6	3	3	1	1	1
T_{OFF}	8	8	5	5	6	3	3	1	1	1
T_{cold}	5	5	4	4	4	2	2	0	0	0
SU_{cold}	9000	1000	1100	1120	1800	340	520	60	60	60
SU_{hot}	4500	5000	550	560	900	170	260	30	30	30
In.State	8	8	-5	-5	-6	-3	-3	-1	-1	-1

Also, the horizon schedule time for this paper is a day scheduling time (24 hours). As a result, load demand for 24 hours has been shown in table 2 and figure 1.

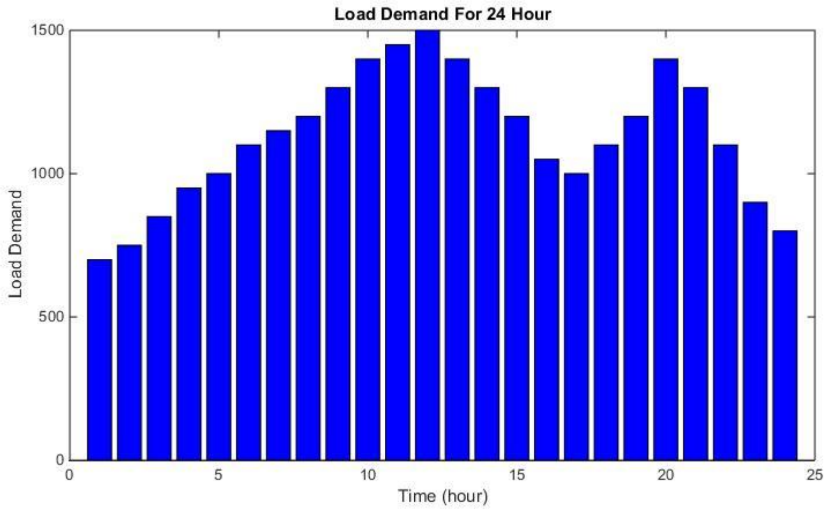

Figure 1: Load demand for one day scheduling time

Based on the table 2, the load demand is varying during the scheduling time. Therefore, considering a spinning reserve is not constant and it is based on demand. In this situation, considering a varying spinning reserve will make the unit commitment problem more complicate. However, in this paper spinning reserve is considered so that the optimal solution and minimum cost achieved.

Table 2: Load demmand for 24 hours

Hour [h]	1	2	3	4	5	6	7	8	9	10	11	12
Deman [MW]	700	750	850	950	1000	1100	1150	1200	1300	1400	1450	1500
Hour [h]	13	14	15	16	17	18	19	20	21	22	23	24
Deman [MW]	1400	1300	1200	1050	1000	1100	1200	1400	1300	1100	900	800

3. Constraints on Unit Commitment Problem

Solving the unit commitment problem needed to consider two different sub problems at the same time. First, take a decision to find out which units should be on or off during the operation time and second the economic dispatch between the units in order to satisfy the load demand. Based on these sub problems, some constrain will be risen as below [16-25]:

3.1 Constraint on load balancing

One of the most important constraint on unit commitment problems is loading balancing. Indeed, the generation power should be equal to the load demand because it is impossible to storage the power energy and electricity for the further uses. As a result, the generation power should at least equal to the load demand. The calculation on the load balancing for unit commitment problems has been defined by following. This limitation can be taken into account by the equation (4):

$$\sum_{i=1}^{n} P_i^t . \ U_i^t = D^t \tag{4}$$

Where P is the power of the ith unit at time t and U is the number which could be 0 (means the ith unit is turn off) or 1 (means the ith unit is turn on). As a result, the load demand at the time t should be equal to D which is determined by the load prediction (table 2). It means, the power generation in every interval hour should be at least equal to the energy demand at that time.

3.2. Constraints on power generations

In the unit commitment, every unit is designed based on a specific characteristic. As the result, every unit has some limitation in power generation. This limitation can be taken into account by the following equation:

$$P_{i,min} \leq P_i^t \leq P_{i,max} \tag{5}$$

Where P is the power of the ith unit, $P_{i,min}$ is the minimum power which is affordable to produce by ith unit and $P_{i,max}$ is the maximum power which can generate by ith unit based on its designed.

3.3. Constraints on power generations

Any changes in power generation of every unit have some constraint and limitations. In fact, every unit could not be able to increase or decrease its power generation rapidly. Changing the power needs time and in many cases it is not affordable and it's depended on the unit design. This limitation can be taken into account by the following equation:

$$(P_i^{t-1} - RD_i) \leq P_i^t \leq (P_i^{t-1} - RU_i) \tag{6}$$

Where RD_i and RU_i are hourly rate reduction and increase for ith unit respectively.

3.4. Constraints on Spinning Researve

Sometimes the prediction for load demand is not correct because of unknown condition and situation. As a result, the load demand will increase or decrease rapidly and satisfy the load demand is difficult without any reservation. Moreover, the storage of the electricity is impossible. As a result, a spinning reserve should be consider for the worse case situation. This limitation can be taken into account by the following equation:

$$SR_{UP}^{t} = \sum_{i=1}^{N} min\left(P_{i,max} - P_i^t, Mr_i\right).U_i^t \quad (6)$$

$$SR_{dn}^{t} = \sum_{i=1}^{N} min\left(P_i^t - P_{i,min} - , Mr_i\right).U_i^t \quad (7)$$

Where $\boldsymbol{SR_{UP}^t}$ represents the increase of the spinning reserve and SR_{dn}^t represent represents the decrease of the spinning reserve and Mr_i is the ramp rate coeeficient which is explained in the next section.

3.5. Ramp Rate

The ramping-up and -down limits of unit i while changing its power generation from time intervals $(t-1)$ to t need to be taken into account in the UC problem. This leads to the following constraint:

$$p_{it} - p_{i(t-1)} \le RU_i + M(2 - I_{i(t-1)} - I_{it}) \quad (8)$$

$$p_{i(t-1)} - p_{it} \le RD_i + M(2 - I_{i(t-1)} - I_{it}) \quad (9)$$

Where RU_i and RD_i are maximum ramp-up and -down rate of unit i in MW/hour, and M is a sufficiently large value.

3.6. Constraints on minimum and maximum ON or OFF time

Every unit has a limitation in the number of turn off and on in a day. For instance, consider a wind generation as a one unit. It is obviously clear that turn on the wind generation require some conditions such as weather in the system. As a result, it is impossible to turn off or on the wind generation every time a day. On the other hand, consider a fossil generation as a unit. It is not acceptable to turn on and off frequently a day because of the high cost. As a result, in this research paper, every unit can turn on or off just 5 times in a day.

4. Bat Algorithm

Bat algorithm is an evolutionary algorithm which has been developed in 2010 [23]. This algorithm is based on the following:

- All the bats use echolocation to find out their distance with foods and Obstacles
- Every bat uses a random position (x_i), with the velocity of V_i with a varying frequency of the f_i
- The frequency is same for all of the population [$f_{\min}$, f_{max}], which is related to the wavelength [$\lambda_{\min}$, λ_{max}].

The code of this algorithm is defined based on above assumptions. The process of the bat evolutionary algorithm is explained by following:

1: Generate the initial population
2: Evaluate the fitness function for each individual
3: while the termination criterion is not satisfied do
4: for i =1 to N_{bat} do
5: Update the velocity and the position of each bat

according to the following equations.
$\beta(r_{ij}) = \beta_{max} \exp\left(-\gamma r_{ij}^2\right)$
$X_i^k = X_i^{k-1} + V_i^k$
$f_i = f_i^{min} + rand(.)(f_i^{max} - f_i^{min})$
Generate a new solution for each bat locally using random walk:
if $rand(.) > r_i^k$ then
Generate a local solution around the $Pbest_i^k$ as follows
$f_i = f_i^{min} + rand(.)(f_i^{max} - f_i^{min})$
else
Generate a local solution around the randomly
selected solution m≠i as follows
$X_{i,new}^k = X_i^k + \varepsilon A_{mean}^k (X_m^k - X_i^k)$
end if
if $(rand(.) < A_i^k)$ and $f\left(X_{i,new}^k\right) < f\left(X_i^k\right)$ then
$X_i^k = X_{i,new}^k$
Increase r_i^k and decrease A_i^k as follows:
$X_{i,new}^k = X_i^k + \varepsilon A_{mean}^k (X_m^k - X_i^k)$
end if
end for
end while

It should be mention that $Pbest_i^k$ is the best position of the bat in the kth iteration, f_i^{max}, f_i^{min} are the maximum and minimum frequency which can be determine by th ith bat and ε is the random variable between -1 and 1. β and γ are constants which has been considered as 0.9.

5. Case Study and Results

In this paper, Bat evolutionary algorithm is applied for 10 unit-commitment problem with all of its constraints for 24 hours (a day) scheduling time. The main objective of this paper is minimize the cost function and find a global cost. Then, the result of the proposed method is compared with other evolutionary algorithm. Moreover, the speed performance of the proposed method is compared with other methods too. The result, will proved the high performance and best minimum cost of the proposed method which back to its less mathematical calculation and flexibility of the optimization methods.

The operation time for every unit is shown in table 3. It should be mention that the schedule time for load demand is defined for one day (24 hours). According to the table, the positive numbers shown the operation time of every unit and the negative numbers shown the time in which units should be off. For instance, unit 1 and 2 should be turn on for all interval horizon time (24 hours). Unit 3 is turn off for seven hours and then turn on for 14 hours. After that, it should be turn off for the rest of the day. The situation of the units are based on their design so that the total cost function minimize. Consequently, the units which are cheap should turn on for more interval hours compare to the expensive units. For instance, based on the assumption of the UC, units 1 and 2 are the cheapest and unit 11 is the highest. Indeed, unit 11, just turn on when the load demand is very high.

Table 3: Operation time for every unit

Cell	Cycle				
Unit	1	2	3	4	5
1	24	0	0	0	0
2	24	0	0	0	0
3	-7	14	-3	0	0
4	22	-2	0	0	0
5	-3	18	-3	0	0
6	-8	6	-5	4	-1
7	-9	5	-10	0	0
8	-9	4	-6	2	-3
9	-10	2	-7	1	-4
10	-11	1	-7	1	-4

Unit schedule for every hours

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
							■	■	■	■	■	■	■	■	■	■	■	■	■	■			
■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
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Figure 2 will show the decrease of the cost function when the Bat evolutionary algorithm is applied to the UC problem. According to the figure, in the first iteration, the total cost function is very high, but during the time and with more iteration, the cost is decreased. The final cost is the global and optimal cost by proposed method which is compared by other research studies in the same situation and environments.

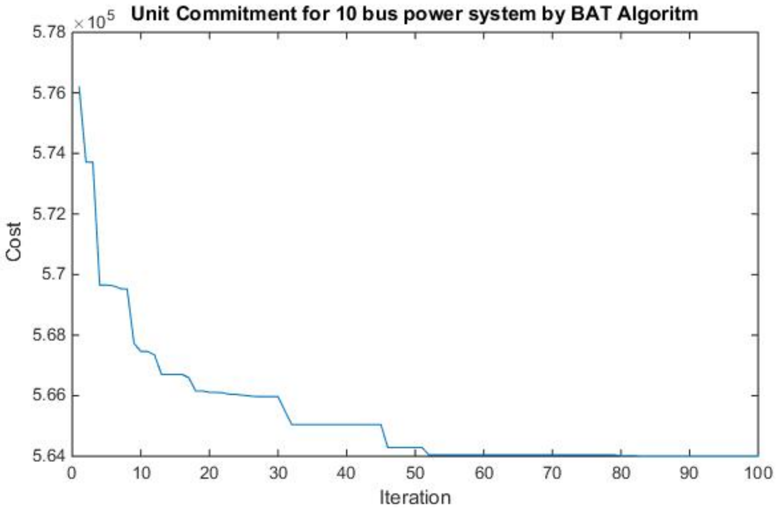

Figure 2: Decrease the cost by increase the iteration

Also, in this paper, Bat evolutionary algorithm is compared with other methods. Table 4 shows the comparison between the methods. The results proved that the cost of the proposed method is lower than other methods. It means that the optimization of the proposed method is better than other methods in the same situation and condition. Moreover, time play a very significant role in optimization problems and power system problems. As a result, a comparison between the proposed method and other methods is done by table 4. According to the result, in the same situation, the average speed of the proposed method is higher than other methods. However, when the number of unit is low, the speed of DP is higher than others and also the GA had good performance. On the other hand, by increasing the number of units, the performance of the proposed method is better than others.

Table 4: Comprasion between methods

Comparison between the different methods				
Methods	Start-Up Cost ($)	Fuel Cost ($)	Final Cost ($)	Time (s)
GA			565825	180
DP	2905	562899	565804	1200
PSO	4090	559852.3	563942.2	85
BA	4040	555997.7	560037.7	35

6. Conclusion

In this paper, Bat algorithm (BA) as a new method of optimization has been proposed for unit commitment problem. This method is compared with other optimizations methods such as GA, PSO and DP. In many cases, especially when the number of unit are two or three, the performance of DP and GA is better than BA. But in complicated cases, the performance of the BA is more acceptable than other methods because of less calculation and forward method. BA is a new algorithm with a reasonable computation effort and fluent concept. As the future work, the BA algorithm can also be employed to solve other complex linear and nonlinear optimization problems in the electric power systems.

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