A New Bat Optimization Algorithm to Solve EPD Problem Solving with Transmission Loss

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Abstract—**While, researchers work to make the systems operate economically and reduce operational cost, in this study, we work to reduce the fuel costs to make the power station running economically as much as possible by utilizing the Economic Power Dispatch (EPD) and the optimization algorithms. The economic power dispatch (EPD) is an integral part of the power system, The major roles and the purpose of its use are for achieving a reliable and efficient operation out of power system generation networks, and this operation should be obtained by minimizing the generator fuel cost. Getting optimal solutions to EPD problem requires efficient optimization algorithms. Novel Bat Algorithm (NBA) is one of the most recent methods and it has already proven its efficiency and reliability for solving the EPD problem. This paper proposes Novel Bat Algorithm (NBA) in order to solve the EPD problem based on the large scale power system. The NBA has proved its efficiency and it gave a perfect performance for small-scale systems compared with the original Bat algorithm (BA), because of considering the Doppler Effect and assumed that bat can move between various habitats. The study of the EPD for large-scale power systems is more important than study it for small ones, because all power systems in countries are considered large networks. This is why all modern studies focus on the study of EPD for large systems. To test the performance of NBA during small and large scale power system, we have applied it to many systems, including 3-thermal units, 6-thermal units, 31-Iraqi thermal units and IEEE 40-thermal units respectively, with transmission losses and generator limits, and we have made a comparison of the obtained results of NBA with other optimization methods. The Iraqi thermal units have been utilized as a new data.**

Index Terms— **Novel Bat Algorithm (NBA), Economic Power Dispatch (EPD).**

I. INTRODUCTION

THE EPD is a main and an integral portion of power system and it is embedded under the term of economic operations of the power system. The purpose of EPD is to determine optimal power outputs for the generating units in order to cover the load demand, according to the minimum fuel cost for each generating unit and satisfy different operational constraints over finite dispatch period [1]. That means, controlling the outputs for each generating unit is achieved by dealing with fuel cost equation for each thermal unit separately, and this status can be achieved by employing the optimization algorithms for the power system. As a result, the power system will start to operate economically and efficiently and the total fuel cost will be minimized and a lot of money can be saved. Because of that, we need to minimize the total fuel cost as much as possible, and it is required an efficient and reliable algorithm.

Many optimization methods were employed in order to solve the problem of EPD, and one of the most recent and efficient algorithms is the NBA. It was originally proposed in [2-4]. The proposed NBA has given a higher quality performance when it was applied for small scale power systems [3, 4] . The NBA performance can be achieved by making comparison with other well-known optimization methods that they proved their efficiency and reliability in solving the EPD problem, such as Genetic Algorithm (GA) [5-7], Particle Swarm Optimization (PSO) [8-11] and Quadratic Programing (QP) [12-14], and the performance of NBA will be studied by comparing the obtained simulation results of it with the other optimization algorithms which they mentioned above.

In this paper, two parts of dataset are used. The first part points to the small-scale power system and it consists of 3-thermal units and 6-thermal units. These networks have been taken from [3, 4]. The transmission loss is considered for these networks and it is calculated by the B-coefficient method. The second part of power network indicates to the large-scale power system and it also consists of 31-thermal units of Iraqi network and IEEE 40-unit system. Also the transmission loss is considered and it is calculated by the B - coefficient method. The study of the EPD for large-scale power systems is more important than the study of small-scale systems, because all power systems in countries are considered large networks. This is why all modern studies focus on the study the EPD for large systems [15-17].

Many of optimization algorithms have been used to solve the problem of EPD problem and almost most of them have proven a good and high performance in reducing the fuel costs for running the electrical stations (thermal units) as we have shown previously, but the important goal that researchers are working on is to find the best algorithm which it will reduce fuel costs as much as possible in order to get an ideal

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operation of generating units. In this study, we monitor the performance of NBA when it will apply to large scale systems, where the NBA has already proven that it is the best by applying it to small scale systems, and we also compare this performance with the other algorithms that we will show them later.

II. METHODOLOGY

A. *Economic Power Dispatch*

Economic Power Dispatch (EPD) shortly means the limitation of the values of the generators outputs for a specific power network, according to the lowest fuel cost for each unit, in order to cover the system load demand. EPD gives an efficient and economic operation of the power system by minimizing the fuel costs that are given by a specified combination of diverse generation units, while satisfying the units constraints, network equilibrium and load demand standard [18]. The EPD is a constrained and complicated optimization problem and it can be mathematically presented by minimizing the following equation:

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

Where:

F_T: Total fuel cost of generation units ($/HR), and F_i is the fuel cost function of the generator (i). The value (n) is the total generators number. (P_i) is the active power in (MW). The values of a_i, b_i and c_i are the fuel cost coefficients of generator (i).

The fuel cost in thermal units usually is taken as a function in quadratic form or other forms, and this function determines the total fuel cost for the unit according to the power output (Pi), and the total cost of fuel increases by increasing the power output of the generator as shown in Figure 1.

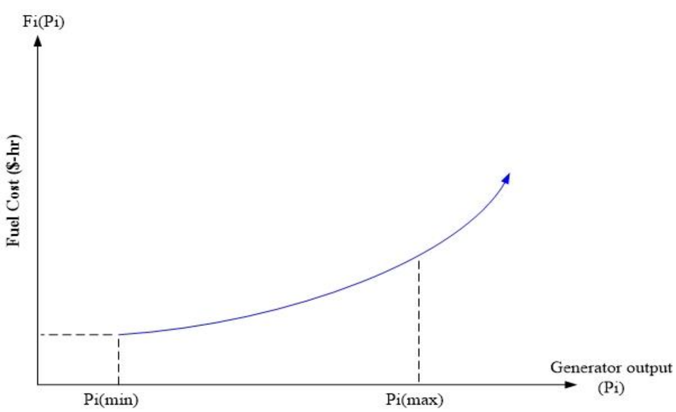

Fig. 1 Fuel cost characteristic of the thermal generating unit

The function of the fuel cost for a thermal generating unit can be expressed in quadratic form as follows:

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 \quad (2)$$

B. *Operational Constraints*

There are some operational factors in the power systems, and if we want to obtain optimal results in the study of EPD, these factors must be taken into consideration [19]. The operational constraints considered in our study can be presented as follows:

C. *Power Balance Constraint*

This constraint is classified as an equality constraint, and it can be achieved by equality the total power generation amount for all generating units in (MW) to the summation of total load demand of the system and transmission losses, and it can be expressed mathematically as follows:

$$P_D + P_L = \sum_{i=1}^{n} P_i \quad (3)$$

Where, P_D expresses the total load demand in (MW) and P_L expresses the transmission line losses in (MW) which they are calculated by using B-coefficients method and it can be presented mathematically as follows [20, 21]:

$$P_L = \sum_{j=1}^{n} \sum_{k=1}^{n} P_j B_{jk} P_k + \sum_{j=1}^{n} P_j B_{j0} + B_{00} \quad (4)$$

Where, 1< j, k ≤ n indicate to indexes of the generating thermal units, and B_{jk}, B_{j0} and B_{00} are known as the B-coefficients. This equality constraint is so important in the study of the EPD and it must be satisfied by the optimization algorithm.

D. *Generation Capacity Constraint*

The real power output for each generating unit must be specified within upper and lower limits and the obtained output of the generator must be during this limit, and it can be submitted as follows:

$$P_i^{min_i}{}_i^{max} \quad (5)$$

Where, P_i^{min} and Pi^{max} are the output powers of generators with maximum and minimum amount of generating unit (i).

E. *Spinning Reserve Constraint*

The aggregate of maximum power limits of whole generation units of a specified power system must be greater than the sum of total load demand and transmission losses. The mathematical equation of spinning reserve constraint generally can be expressed as follows:

$$\sum_{i=1}^{n\sum_L} PD_{imax} \quad (6)$$

III. NOVEL BAT ALGORITHM

In the original BA, the effects of Doppler and foraging idea of bat were not considered and each essential bat is expressed by position and velocity and it searches preys during dimensional spaces with achieved trajectory[22, 23]. Actually, this case does not exist only. For the NBA, the Doppler effect is included and the essential bat can recompense adaptively for Doppler effect in phenomenon of

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echoes [24].

The essential bat is viewed to possess foraging habitats diversely in the NBA. Bat searches for its food solely in one habitat in BA because of the mechanical conduct of virtual bat. In summary, the NBA is obligated for the following idealized basics:

1. The motion of bats can be around in various habitats.
2. Bats can recompense for the effect of Doppler in echo phenomenon.
3. Bats can acclimate and set their compensation averages and they depend on its target proximity.

A. Quantum Behavior

It is supposed that bats are going to conduct in such a behavior that while one of bats group found its prey in a specific habitat, immediately the rest bats would start to feed from the same prey. This supposition guides mathematically to the following formulation of the bat positions [24].

$$X_{i,j}^{t+1} = \begin{cases} g_j^t + \theta * \left|mean_j^t - x_{i,j}^t\right| * \ln\left(\frac{1}{u_{i,j}}\right), \text{if } rand_j(0,1) < 0.5 \\ g_j^t - \theta * \left|mean_j^t - x_{i,j}^t\right| * \ln\left(\frac{1}{u_{i,j}}\right), \text{otherwise} \end{cases} \quad (7)$$

B. Mechanical Behavior

It is supposed that the speed of the virtual bat will not overtake the sound speed which is estimated 340 m/s. The bat will compensate the Doppler Effect and this compensation will be expressed mathematically as CR that it varies among various bats. CR and the inertia weight (w) are in the range of 0 to 1. The value (ζ) represents the smallest constant to avoid the probability of division by 0. CR will be 0, if there is no compensation for the Doppler Effect by the bat, and it will be 1, if there is compensation. This description can be expressed mathematically as follows:

$$f_{i,j} = fminmax_{min} \quad (8)$$

$$f_{i,j} = \frac{c+v_{i,j}^t}{c+v_{g,j}^t} * f_{i,j} * \left(1 + CR_i * \frac{g_j^t - X_{i,j}^t}{\left|g_j^t - X_{i,j}^t\right| + \xi}\right) \quad (9)$$

$$V_{i,j}^{t+1} = w * V_{i,j}^t + (g_j^t - X_{i,j}^t) * f_{i,j} \quad (10)$$

$$X_{i,j}^{t+1} = X_{i,j}^t + V_{i,j}^t \quad (11)$$

C. Local Search

It is supposed logically that bats will raise the value of the pulse emission rate and reduce loudness when they approach prey. Whatever loudness value bats use, the loudness factor needs to be considered in the around environment. This description means the equations have been developed and expressed as follows:

If (rand (0, 1) > ri)

$$X_{i,j}^{t+1} = g_j^t * (1 + tandn(0, \sigma^2)) \quad (12)$$

$$\sigma^2 = |A_i^t - A_{mean}^t| + \xi \quad (13)$$

Where, rand n $(0,\sigma^2)$ is the Gaussian distribution with a mean value 0, (σ^2) is the standard perversion, and (A^t_{mean}) is the mean loudness.

In our study, we will use the NBA in [3] to check the performance of it based on large-large scale system. The parameters of the NBA are shown in Table 1, and the flowchart of it is shown in Figure 2.

Table I The parameters of NBA

Parameter	Value	Parameter	Value
Iterations (M)	1000	POP	30
r0Max, Min	0-1	A. MAX, MIN	1-2
f. D max, min	0-1.5	G	10
Prop.max, min	0.7-0.9	Theta max, min	0.5-1
C max, min	0.1-0.8	w. Max, min	0.5-.08

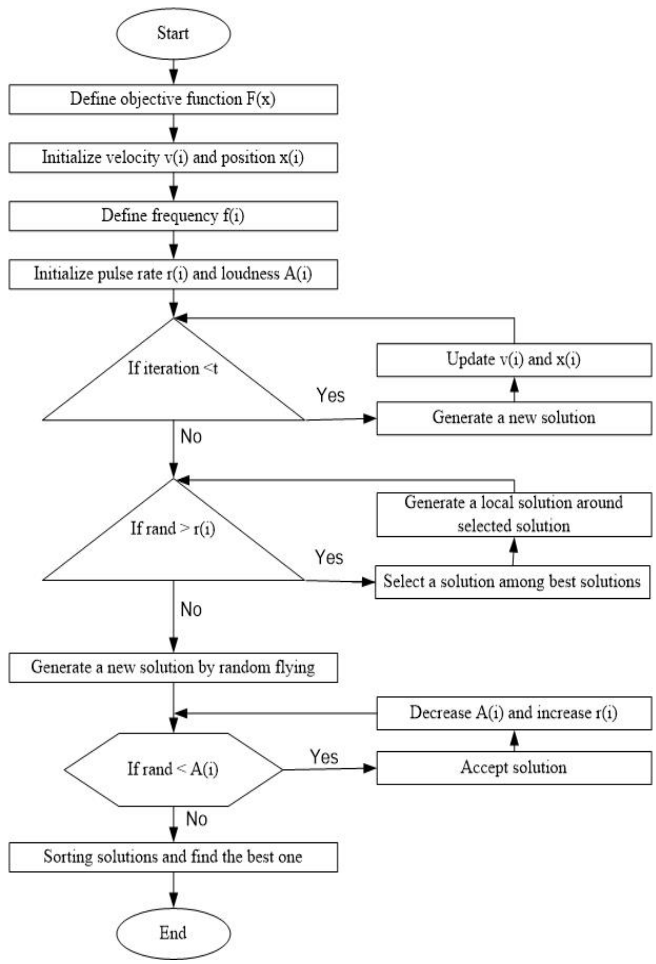

Fig. 2 Flowchart of NBA

IV. RESULTS AND DISCUSSION

The performance of the proposed NBA is tested with many power systems, including 3, 6, 31 and 40 generation units respectively. The intention of using several different networks is to monitor the performance of the algorithm during small and large scale system. The transmission line losses are done by the B-coefficient method. All the results are calculated by using MATLAB R2015a.

A. *Test of 3-unit system*

In this test, three thermal units are utilized, and their cost coefficient and generator power limits are shown in [4]. The virtual system has been solved by the NBA and the achieved results of the NBA were compared with other optimization methods which they are GA, PSO and QP. The obtained results are shown in Table 2.

Table II Test results for 3-unit system with load demand 500 MW

Algorithm	P1 (MW)	P2 (MW)	P3 (MW)	Ploss	Cost ($-hr)
NBA	107.3479	200.2140	219.5278	27.0897	26167.3565
GA	102.8798	189.7938	234.1524	26.8260	26177.6196
PSO	107.3453	200.2042	219.5406	27.0901	26167.3925
QP	107.4327	200.5192	219.1217	27.0736	28674.0000

From Table II, the assumed load demand was 500 MW and transmission losses were considered for this test and they have been calculated by the B - coefficient method. According the obtained results, the NBA is the best in solving the EPD problem and it gave a higher quality performance in minimizing the fuel cost compared with the other algorithms.

B. *Test of 6-unit system*

This test has been done for six thermal units, and the cost coefficient and power limits of units are expressed in [3]. The achieved results have been solved by the NBA, and then there was comparison with other optimization methods which they are GA, PSO and QP.

From Table III, the suggested load demand was 700 MW for this test and the performance of NBA was effective in getting optimal results for generators output.

Table III Test results for 6-unit system with load demand 700 MW

Pi (MW)	NBA	GA	PSO	QP
P1	312.7083	286.6210	312.7083	312.7083
P2	72.5257	58.5750	72.5256	72.5252
P3	159.8879	171.0042	159.8878	159.8879
P4	50.0000	67.1123	50.0000	50.0000
P5	54.8817	62.3938	54.8816	54.8817
P6	50.0000	54.2969	50.0000	50.0000
Ploss (MW)	0.0036	0.0032	0.0033	0.0036
Cost ($-hr.)	8299.4	8325.2	8299.418	8299.4

C. *Test of 31-Iraqi unit system*

The 31-unit system were utilized in this test as a large-scale power system and they are the Iraqi thermal unit. All details, including the cost coefficients and generator limits have been taken by the Iraqi ministry of electricity.

From Table 4 (A and B), the suggested load demand for this test was 4500 MW with considered transmission losses.

Table IV-A Test results for 31-unit system with load demand 4500 MW

Pi (MW)	NBA	GA	PSO	QP
P1	15	31.5749	15	15
P2	18.8356	55	15	15
P3	16.5991	55	15	15
P4	35.1213	160	35	35
P5	35.0037	160	35	35
P6	25.0161	138.0627	35	35
P7	35.0139	160	35	35
P8	300	165.1530	299.9999	300
P9	300	214.8092	299.9999	300
P10	300	300	299.9999	300
P11	300	300	299.9999	300
P12	220	34.0234	219.9999	220
P13	30.0288	220	219.9999	220
P14	220	220	219.9999	220
P15	220	220	219.9999	220
P16	220	220	219.9999	220

Table IV-B Test results for 31-unit system with load demand 4500 MW

Pi (MW)	NBA	GA	PSO	QP
P17	220	39.4235	219.9999	220
P18	20.5322	100	20	20
P19	100	100	20	20
P20	35.1448	48.7172	35	35
P21	35.0183	44.8555	35	35
P22	66.3707	94.2457	48.2087	48.2088
P23	76.2477	210	48.8043	48.8044
P24	72.9164	68.0822	48.0280	48.0281
P25	80.8614	46.2235	48.4702	48.4703
P26	610	311.2984	610	610
P27	610	122.2744	609.9999	610
P28	63.0292	171.2775	63	63
P29	63.1460	79.0213	63	63
P30	73.0908	218.7376	73	73
P31	73.0627	193.8328	73	73
Ploss	0.0389	1.6228	0.5115	0.5116
Cost$-HR	60860	70012	60119.6	60131

From the obtained results, we found the performance of NBA started to decrease compared with the other algorithms that are shown below. The PSO was the best in getting an optimal solution.

D. *Test of 40-unit system*

In this test, IEEE 40-unit system (IEEE 30 bus system) has been utilized as a large-scale power system. The details of this system - including the cost coefficient and the power limits of generators are shown as a file on Math-Work site.

From Table 5 (A, B and C), the assumed load demand for this test was 6500 MW with considered transmission losses.

Table V-A Test results for IEEE 40-unit system with load demand 6500 MW

Pi (MW)	NBA	GA	PSO	QP
1	40	47.7988	40	40
2	60.3730	120	61.8501	61.8501
3	80.1652	81.4008	80	80
4	24.0472	42	24	24
5	28.3045	42	26	26
6	73.3975	140	68	68
7	111.4304	300	217.1984	217.1984
8	300	146.4729	258.7956	258.7956
9	135.0618	146.4857	260.0330	260.0330
10	130.0025	131.4314	130	130
11	94.3453	137.8951	94	94
12	94.0382	106.6941	94	94
13	195.3256	239.5136	195	195
14	196.0112	213.5743	195	195
15	195.2119	275.6720	195	195
16	195.0475	197.9386	195	195

Table V-B Test results for IEEE 40-unit system with load demand 6500 MW

Pi (MW)	NBA	GA	PSO	QP
17	195.1048	213.9538	195	195
18	220.0003	229.1696	257.2110	257.2110
19	388.8812	242.5194	260.0793	260.0793
20	550	469.9283	251.8288	251.8288
21	243.2754	284.6752	257.6483	257.6483
22	550	292.3266	494.6209	494.6209
23	254.1536	394.0592	495.2679	495.2679
24	550	274.9325	507.8255	507.8255
25	550	294.7605	514.2391	514.2391
26	550	550	446.9388	446.9388
27	254.0040	335.6258	447.6347	447.6347
28	10.2862	150	10	10
29	11.4445	15.1741	10	10
30	10.1169	14.3578	10	10

Table V-C Test results for IEEE 40-unit system with load demand 6500 MW

Pi (MW)	NBA	GA	PSO	QP
31	20.7115	70	20	20
32	20.0393	70	20	20
33	20.0050	22.6434	20	20
34	20.3573	23.4375	20	20
35	18.2462	20.5085	18	18
36	18.0036	18.1234	18	18
37	20.0263	31.0269	20	20
38	25.0251	25.3631	25	25
39	25.2612	31.4245	25	25
40	25.7147	60	25	25
Ploss	3.4205	2.9108	3.1719	3.1719
Cost ($-HR.)	94865.73 6	110845.00 1	94020.383	94081.370

The achieved results showed that the NBA was not the best in getting an optimal solution. The PSO and QP were better than NBA at minimizing the fuel cost and getting optimal results.

Table 6 indicates to the summary of fuel costs obtained from the forth tests and these summarized results showed the performance of NBA compared with the obtained results of rest algorithms.

Table VI Summary of fuel cost

System	NBA	GA	PSO	QP
3-units	26167.3565	26177.6196	26167.3925	28674
6-units	8299.4	8325.2	8299.418	8299.4
31-units	60860	70012	60119.6	60131
40-units	94865.7363	110845.0015	94020.3830	94081.370

The NBA has given higher quality performance for test 1 and 2 (small-scale systems) and it recorded the best solution for EPD problem. But when NBA applied in test 3 and 4 (large-scale systems), it has recorded a low performance and accuracy compared with PSO, and the NBA will give a lower performance if the number of units increases. The PSO has given the best solution for EPD problem.

V. Conclusion

In this paper, we used the principle of Economic Power Dispatch (EPD) with optimization algorithms, which in turn, it reduces the operating costs of fuel that is used in thermal power plant, we proposed the NBA as an optimization method in order to solve the EPD problem. The aim of this study was to watch the performance of NBA with the large-scale power system. Four tests were used, including 3-units, 6-units, 31-units and IEEE 40-units respectively. The high quality performance of NBA has been already proved in small-scale power system such as 3 and 6 units. When NBA has been applied for large-scale power system, including 31 and 40 units, the performance of it started to decrease gradually in minimizing the fuel cost compared to other well-known optimization methods which they have been used and they were including Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Quadratic Programming (QP). According to the achieved results, we concluded that NBA performance with small-scale power systems is better than large ones. In addition, most tests proved that the GA algorithm was the best in minimizing the transmission line loss.

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