Economic Dispatch Using Modified Hybrid BA/ATS

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ABSTRACT

In this paper, a new modified algorithm is proposed. This modified algorithm is BA/ATS. The main modifications are including negative value into the main equation of the bee algorithm (BA) and integrating adaptive tabu search (ATS) into BA. BA/ATS aims to improve the performance of hybrid BA/TS. The economic dispatch (ED) is set as the main problem to solve with the proposed algorithm. The operation of each generator is limit by constraints. All test results indicate that the overall costs of operation when using the proposed algorithm are better than test results from other compared algorithms. This means the modified hybrid BA/ATS is a good algorithm for the solving the ED problem.

Keywords: Hybrid Algorithm, Optimization, Bee Algorithm, Adaptive Tabu Search, Economic Dispatch

1. INTRODUCTION

Nowadays, electricity is indispensable for daily living. Industrial electricity demand is are the main factor that causes increased load demands. Many solutions are used to serve these demands such as building a new power plant and extending power network. These solutions will need a long time to complete. Another interesting solution is to increase the performance of the operation of the system by increasing total transfer capability (TTC) using the modern heuristics algorithm [1]. Algorithms can be used to optimize the performance of the power system. Also, an optional part of this solution is to install external devices such as Flexible Alternating Current Transmission System (FACTS) controller [2-4] or DG [5] with optimal allocation. The increased TTC can serve the minimum load demand.

The cost of operation must be determined. The engineer or operator must consider this cost and should optimize the TTC per ED to control the overall cost of operation. This challenge is well-known as an economic dispatch (ED) problem [6]. An interesting solution to optimize the ED is to use an optimization algorithm. In past, the classical optimization technique such as linear programming was used [7]. Currently, modern heuristics algorithms are used [8, 9].

However, these algorithms have disadvantages. For example, their convergence cannot evaluate the global answer. There are chances of sticking in local area of search space. The values from this local area will give the local answer. To deal with this issue, tabu search (TS) algorithm was developed [10, 11]. The main ability of TS is anti-back tracking of the trajectory of searching. Also, the TS is improved to be adaptive tabu search (ATS). The adaptive radius mechanism is integrated into TS to extend the performance of the original TS [12]. In addition, many concepts are used to improve the performance of these algorithms such as modifying the perturbation equation directly [13] or applying the hybrid concept.

In this paper, the modified hybrid algorithm of BA and the adaptive tabu search (ATS) are developed. The main modifications are applied negative value into the main equation of BA and the adaptive radius mechanism of ATS is integrated, respectively. The main objective of this development is to improve the performance of hybrid BA/ATS. Better ED results are expected from the proposed algorithm. The practical Taiwan power company (TPC) 15 unit system [14] and practical TPC 40 unit system [15] are used as test systems for ED. Test results of ED when using modified hybrid BA/ATS are compared with results from the GA, PSO, original BA and hybrid BA/TS [16].

2. PROBLEM FORMULATION

2.1 Objective function

Economic dispatch (ED) is defined as the intentional objective function of this paper. The general purpose of ED is to consider the optimal power of operation of generators to serve the system load demand. This operation should be done at the lowest possible lowest cost. The main important subject is the operation must be operated under the operational constraints [17]. Two types of constraints are used. The constraints are quality and inequality constraints, respectively. The value of each parameter is limited by these constraints. This limit control can ensure the safety of the operation.

The ED without loss is set as the first objective function. This objective function is expressed in (1) [18].

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$$\min F = \sum_{i=1}^{m} F_i(P_i) = \sum_{i=1}^{m}(a_i P_i^2 + b_i P_i + c_i) \qquad (1)$$

Where
F the total fuel cost of generator,
F_i the cost of the ith generator,
P_i the power output of the ith generator,
m the number of generators in the system, and

a_i, b_i, and c_i the cost coefficients of the ith generator. The ED objective function with losses from the valve point effect is set as the second objective function. This objective function is expressed in (2) [19].

$$\min \ F = \sum_{i=1}^{m} F_i(P_i) = \sum_{i=1}^{m}(a_i P_i^2 + b_i P_i + c_i) + |d_i \times \sin(e_i \times (P_{i,\min} - P_i))| \qquad (2)$$

Where d_i, and e_i the co-efficients of fuel cost.

2.2 Constraints

Equation 3 is the power balance constraint.

$$\sum_{i=1}^{m} P_i = P_D + P_{Losses}, \quad i = 1, \ldots, m \qquad (3)$$

$$P_{losses} = \sum_{i=1}^{m}\sum_{j=1}^{m} P_i B_{ij} P_j + \sum_{i=1}^{m} B_{0i} P_i + B_{00} \qquad (4)$$

Equation 5 is the generator constraint.

$$P_i^{\min} \le P_i \le P_i^{\max} \qquad (5)$$

Where
P_D, P_{losses} power demand and system losses of the system

B_{ij}, B_{0i}, B_{00} co-efficiency of system losses, and

$P_i^{\min}, P_i^{\max}$ the minimum and maximum generation limit of unit i.

3. PROPOSED ALGORITHM

3.1 Bee algorithm

The bee algorithm (BA) proposed by Karaboga in 2005 [20] which is one of the well-known bio-inspired algorithms. There are many different names of BA such as artificial bee colony (ABC), bee colony optimization (BCO).

3.2 Tabu search

In 1986, F. Glover published the tabu search (TS) and algorithm [21]. The special feature of TS is to increase the efficiency of searching according to the trajectory by using the list. This list is named the tabu list. Tabu list is used to remember the solutions that have been solved and accepted these answers.

3.3 Hybrid bee algorithm and tabu search

The hybrid BA/TS was developed by S. Chansareewittaya. This algorithm is used to solve the ED problem in [16]. The initialize of this algorithm is evaluated by using (6).

$$x_{ij} = x^{\min} + random(0,1) \times (x^{\max} - x^{\min}) \qquad (6)$$

Where
x_{ij} ith parameter of jth bee, and

$x^{\min}, x^{\max}$ minimum and maximum value of x.

These parameters are used to evaluate objective function values. After that, the tabu list is created. The parameters are put into the tabu list for use by of the anti-back tracking mechanism.

3.4 Adaptive tabu search

The adaptive tabu search (ATS) is an improved enhanced derivative of TS [12]. This enhanced ability is the result of adding an adaptive radius mechanism [22-24]. The radius means the range of feasible search area. The range will be decreased when the current solutions are found in the tabu list. The aim of this reducing process is to limit the search space area. Equations 7 and 8 present the equations of the adaptive radius mechanism.

$$radius_{new} = \frac{radius_{old}}{DF} \qquad (7)$$

$$radius_{new}^{\min} \le radius_{new} \le radius_{new}^{\max} \qquad (8)$$

Where
$radius_{new}$ new range of search space,
$radius_{old}$ previous range of search space,
DF decreasing factor equals 2,
$radius_{new}^{\min}$ new minimum value of search space, and

$radius_{new}^{\max}$ new maximum value of search space.

3.5 Modified hybrid bee algorithm and adaptive tabu search

The modified hybrid BA/ATS was developed from hybrid BA/TS [16]. The main equation of the BA is modified. According to equation 6, the value of each parameter is only increased. If the value reaches the maximum value, the new value is generated by randomizing. The improvement proposed in this paper is to modification is include a minus sign in the range of random numbers. The range of random numbers is between minus one to one instead of zero to one. This changed the various values of parameters of each bee. Equation (9), (10), and (11) are used as the evaluation equation for modified hybrid BA/ATS.

$$x_{new}^{\min} = radius_{new}^{\min} \quad (9)$$

$$x_{new}^{\max} = radius_{new}^{\max} \quad (10)$$

$$x_{i,j} = x^{\min} + random(-1,1) \times (x_{new}^{\max} - x_{new}^{\min}) \quad (11)$$

Where

$x_{new}^{\min}$ new lowest value of x, and

$x_{new}^{\max}$ new highest value of x.

The flowchart of the proposed method to evaluate the ED problem is shown as Fig. 1.

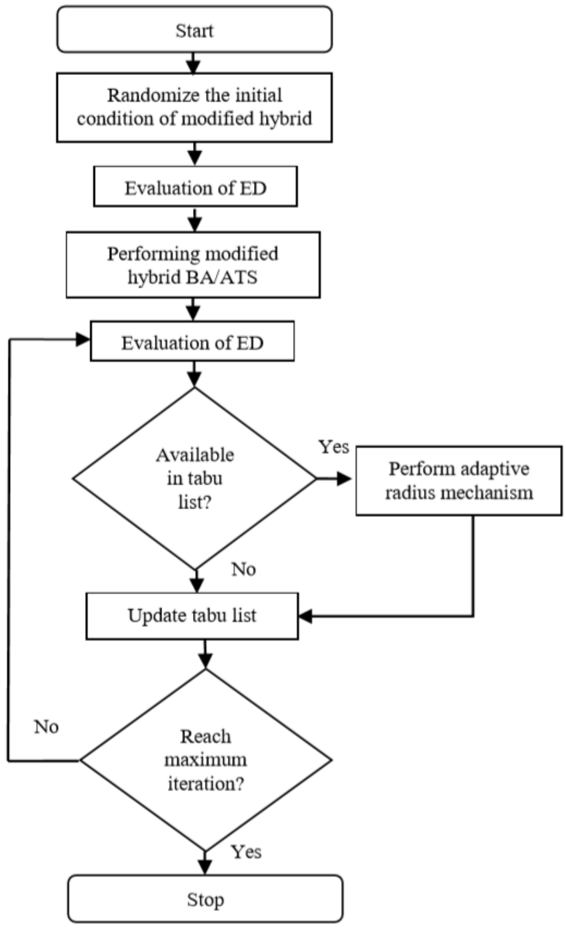

Fig.1: *The flowchart of the modified hybrid BA/ATS to evaluating ED problem.*

4. EXPERIMENTAL RESULTS

The practical TPC 15 unit system [14], and practical TPC 40 unit system [15] are used for the comparing of the GA, PSO, original BA, hybrid BA/TS, and proposed algorithm. Number of the population is 50 and others parameters are shown in table 1.

Table 1: *The parameters of used algorithm.*

	Number of sites	Number of selected sites	Number of best site	Number of bees around the best sites	Number of bees around other selected sites
GA	-	-	-	-	-
PSO	-	-	-	-	-
Original BA	30	30	5	20	10
Hybrid BA/TS	30	30	5	20	10
Modified hybrid BA/ATS	30	30	5	20	10

The evaluation of each algorithm is set as a batch. Each batch contains 10 sub-evaluations for the minimum value, average value, maximum value, and coefficient of variation.

4.1 Practical Taiwan power company 15 unit system

The first test system of this paper is a practical TPC 15 unit system [14]. The ED with flat fuel cost and without loss is set for this test system. The load demand for this test system is 2600MW. The tabu list size of this test system is 5000. In this test system, the 4 prohibited operating zones are used and shown in Table 2.

The data of TPC 15 unit system with flat fuel cost is shown in table 3.

The minimum cost, average cost, maximum cost and co-efficient of variation of TPC 15 unit system comparing modified hybrid BA/ATS and competing algorithms are shown in table 4.

The results from the TPC15 unit system indicate that modified hybrid BA/ATS gives a better minimum fuel cost of operation ($/h) than the other compared algorithms. Although the average fuel cost and maximum fuel cost are higher than the results of Hybrid BA/TS, these values are still lower than the results from GA, PSO, and original BA. The total fuel cost, total power, and power of each generator of the TPC 15 unit system using modified hybrid BA/ATS and the other compared algorithms are shown in table 5.

Table 2: *Prohibited zones of TPC 15 unit system.*

Unit	Zone 1 (MW)	Zone 2 (MW)	Zone 3 (MW)
2	[185,225]	[305,335]	[420,450]
5	[180,200]	[260,335]	[390,420]
6	[230,255]	[360,395]	[430,455]
12	[30,55]	[65,75]	

Table 3: *Data of TPC 15 unit system with flat fuel cost.*

Unit	ai ($/MW)^2 h	bi ($/MWh)	ci ($/h)	$P_{i,min}$(MW)	$P_{i,max}$(MW)
1	0.000299	10.07	671.03	150	455
2	0.000183	10.22	574.54	150	455
3	0.001126	8.80	374.59	20	130
4	0.001126	8.80	374.59	20	130
5	0.000205	10.40	461.37	150	470
6	0.000301	10.10	630.14	135	460
7	0.000364	9.87	548.20	135	465
8	0.000338	11.50	227.009	60	300
9	0.000807	11.21	173.72	25	162
10	0.001203	10.72	175.95	20	160
11	0.003586	11.21	186.86	20	80
12	0.005513	9.90	230.27	20	80
13	0.000371	13.12	225.28	25	85
14	0.001929	12.12	309.03	15	55
15	0.004447	12.41	323.19	15	55

Table 4: *Minimum fuel cost, average fuel cost, maximum fuel cost and co-efficiency variation of cost of TPC 15 unit system by competing algorithms and modified hybrid BA/ATS.*

Value/ Algorithm	Minimum fuel cost ($/h)	Average fuel cost ($/h)	Maximum fuel cost ($/h)	Co-efficient of variation
GA	125418.7861	131726.0931	145797.6982	0.0598098
PSO	124347.1194	130920.2793	136075.7061	0.0287794
Original BA	119476.9652	132429.4328	140843.3734	0.0518447
Hybrid BA/TS	87679.0713	98396.1344	107798.0255	0.0814923
Modified hybrid BA/ATS	87553.0516	117670.5192	129035.1257	0.105993

Table 5: *Best of the total fuel cost, total power, and power of each generator of TPC 15 unit system using the other compared algorithms and modified hybrid BA/ATS.*

Value/ Algorithm	GA	PSO	Original BA	Hybrid BA/TS	Modified hybrid BA/ATS
Total fuel cost ($/h)	125418.7861	124347.1194	119476.9652	87679.0713	87553.0516
Total Power (MW)	3125.7109	3076.5189	3018.2216	2696.6251	2659.3042
P1 (MW)	385.0772	401.3470	376.6764	133.7904	203.1099
P2 (MW)	376.7234	375.4470	378.1822	364.0002	226.2309
P3 (MW)	111.8623	129.6142	105.7314	110.8106	119.3311
P4 (MW)	121.2500	117.4798	117.3985	105.3153	118.7939
P5(MW)	403.0129	398.8761	389.3135	376.2651	467.3252
P6 (MW)	450.8022	376.8905	382.5793	368.0623	418.9479
P7 (MW)	396.4503	381.2205	393.6212	372.4926	419.4026
P8 (MW)	254.8466	254.7579	286.0592	270.2752	224.9989
P9 (MW)	157.9616	154.6706	135.0072	139.0365	73.6774
P10 (MW)	144.3562	159.7730	155.1990	135.5966	129.8800
P11 (MW)	77.4988	75.7158	68.2492	71.6811	48.9021
P12 (MW)	68.9743	78.8339	71.0162	71.8016	76.9914
P13 (MW)	81.2660	68.5890	69.1949	76.1474	59.2600
P14 (MW)	45.3114	48.9605	44.0384	49.2434	22.2338
P15 (MW)	50.3177	54.3431	45.9550	52.1068	50.2192

4.2 Practical Taiwan power company 40 unit system

The second test system of this paper is the practical TPC 40 unit system [15]. This problem of this test system is ED with flat fuel cost and without loss. In this test system, the prohibited operating zones are released. The load demand for this test system is 8900 MW. The tabu list size of this test system is 8000. The losses co-efficient of the TPC 40 unit system with flat fuel cost function are shown in table 6.

Table 6: *Data of TPC 40 unit system with flat fuel cost.*

Unit	a_i ($/MW)^2 h	b_i ($/MWh)	c_i ($/h)	$P_{i,min}$ (MW)	$P_{i,max}$ (MW)
1	0.03073	8.3360	170.44	40	80
2	0.025028	7.0706	309.54	60	120
3	0.00942	8.1817	369.03	80	190
4	0.08482	6.9467	135.48	24	42
5	0.09693	6.5595	135.19	26	42
6	0.01142	8.0543	222.33	68	140
7	0.00357	8.0323	287.71	110	300
8	0.00492	6.9990	391.98	135	300
9	0.00573	6.6020	455.76	135	300
10	0.00605	12.908	722.82	130	300
11	0.00515	12.986	635.20	94	375
12	0.00569	12.796	654.69	94	375
13	0.00421	122.504	913.40	125	500
14	0.00752	8.8412	1760.40	125	500
15	0.00708	9.1575	1728.30	125	500
16	0.00708	9.1575	1728.30	125	500
17	0.00708	9.1575	1728.3	125	500
18	0.00313	7.9691	647.85	220	500
19	0.00313	7.9550	649.69	220	500
20	0.00313	7.9691	647.83	242	550
21	0.00313	7.9691	647.81	424	550
22	0.00298	6.6313	785.96	254	550
23	0.00298	6.6313	785.96	254	550
24	0.00284	6.6611	794.53	254	550
25	0.00284	6.6611	794.53	254	550
26	0.00277	7.1032	801.32	254	550
27	0.00277	7.1032	801.32	254	550
28	0.52124	3.3353	1055.10	10	150
29	0.52124	3.3353	1055.10	10	150
30	0.52124	3.3353	1055.10	10	150
31	0.28095	13.052	1207.80	20	70
32	0.16766	21.887	810.79	20	70
33	0.26350	10.244	12.47.70	20	70
34	0.30575	8.3707	1219.20	20	70
35	0.18362	26.258	641.43	18	60
36	0.35563	9.6956	1112.80	18	60
37	0.00722	7.1633	1044.40	20	60
38	0.23915	16.339	832.24	25	60
39	0.23915	16.339	834.24	25	60
40	0.23915	16.339	1035.2	25	50

The minimum fuel cost, average fuel cost, maximum fuel cost and co-efficiency of variation of TPC 40 unit system comparing between modified hybrid BA/ATS and other compared algorithms are shown in table 7.

The results from the TPC 40 unit system indicate that modified hybrid BA/ATS gives a better overall total cost of operation ($/h) than the other compared algorithms. Especially, the minimum fuel cost is lower than the lowest result from the compared algorithms by about 2.17%. This means the mechanism of the proposed algorithm can perform well. This mechanism can give a better objective function value.

The total fuel cost, total power, and power of each generator of the TPC 40 unit system using modified hybrid BA/ATS and the other compared algorithms are shown in table 8.

5. CONCLUSION

According to the experimental results, the results from modified hybrid BA/ATS show that the overall total cost of operation of generators is lower than those from GA, PSO, original BA, and hybrid BA/TS. The modified equation of BA and the adaptive radius of ATS improve the performance compared to plain hybrid BA/TS. Also, the algorithm of modified hybrid BA/ATS can push the parameter forward resulting in non-duplicate values by using anti-back tracking of ATS. By using this mechanism and generator constraints, the suitable value of any parameters in a feasible search space can be found. New and better answers can be evaluated. For economic dispatch problems, the modified hybrid BA/ATS algorithm is more effective for the ED problem than the other compared algorithms. Future work would be to integrate the multi-objective function solving into the BA/ATS algorithm.

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Table 7: *Minimum cost, average cost, maximum cost and co-efficient variation of cost of TPC 40 unit system comparing between other compared algorithms and modified hybrid BA/ATS.*

Value/ Algorithm	**Minimum fuel cost (\$/h)**	**Average fuel cost (\$/h)**	**Maximum fuel cost (\$/h)**	**Co-efficiency variation**
GA	148409.7348	148694.9487	148896.5905	0.00102676
PSO	149671.8809	149942.6141	150186.8391	0.00116543
Original BA	151997.1436	161469.7742	174413.6699	0.0420747
Hybrid BA/TS	144143.1207	146693.0412	149409.9144	0.0118104
Modified hybrid BA/ATS	141001.9598	142144.7558	142908.6029	0.00433793

Table 8: *Best of the total fuel cost, total power, and power of each generator of TPC 40 unit system by using compared algorithms and modified hybrid BA/ATS.*

Value/ Algorithm	**GA**	**PSO**	**Original BA**	**Hybrid BA/TS**	**Modified hybrid BA/ATS**
Total fuel cost (\$/h)	148409.7348	149671.8809	151997.1436	149649.0835	141001.9598
Total Power (MW)	9000.7604	9004.0885	9136.4970	9003.1893	9006.3419
P1 (MW)	58.7542	60.0132	177.4344	61.6262	54.1346
P2 (MW)	102.7210	105.2806	96.5394	97.5440	84.2052
P3 (MW)	139.5562	157.4645	166.6773	157.1399	183.7015
P4 (MW)	31.1409	34.3565	28.4775	35.4303	25.8905
P5 (MW)	31.5243	33.6079	33.6506	37.1005	30.3992
P6 (MW)	122.4404	119.7957	106.5369	105.2766	114.6353
P7 (MW)	271.2250	228.4411	204.5996	227.3278	220.2041
P8 (MW)	220.8069	225.1184	239.4308	225.3657	187.7040
P9 (MW)	246.3506	238.2982	296.6910	225.2751	194.1401
P10 (MW)	220.2298	225.3881	243.5040	225.0929	249.7423
P11 (MW)	286.6444	281.5438	297.3507	282.0700	287.5553
P12 (MW)	275.1570	281.9553	346.4599	282.6250	272.7527
P13 (MW)	412.7977	379.0468	371.7032	375.8001	309.1612
P14 (MW)	366.5028	388.3166	332.2306	375.2783	340.3030
P15 (MW)	372.6690	375.2566	376.7835	375.0538	325.4064
P16 (MW)	368.8997	375.6078	311.5548	392.8036	436.9524
P17 (MW)	367.8824	375.7368	367.3033	375.2495	315.7000
P18 (MW)	370.8300	383.5533	303.9885	445.3560	444.9003
P19 (MW)	438.7717	447.0332	368.1377	375.7956	327.9012
P20 (MW)	441.5195	413.1159	380.2607	456.5184	431.9973
P21 (MW)	409.7549	413.6756	438.8088	467.7457	479.6636
P22 (MW)	402.9833	487.2516	544.8428	414.8584	502.1133
P23 (MW)	490.0043	412.8194	505.8595	416.9520	510.3524
P24 (MW)	408.9050	458.9811	414.9816	413.0876	526.8585
P25 (MW)	403.9089	413.0354	503.5252	434.2198	450.8715
P26 (MW)	476.3457	443.6007	405.7365	461.3983	464.5521
P27 (MW)	449.0320	413.1398	439.8245	434.5188	502.8982
P28 (MW)	109.9440	112.6190	103.1733	112.7793	91.4339
P29 (MW)	110.3144	112.7383	111.1607	112.5886	92.4504
P30 (MW)	110.6863	112.5301	123.6477	112.6528	91.3734
P31 (MW)	51.6006	52.5660	54.2473	52.5578	49.2190
P32 (MW)	51.3393	52.7517	58.9144	52.6525	44.3284
P33 (MW)	58.5758	52.6751	47.5852	52.7017	60.1674
P34 (MW)	51.7693	52.6102	54.1632	52.6206	45.1905
P35 (MW)	44.9235	45.0410	44.5138	50.4520	36.3898
P36 (MW)	44.1690	45.0055	42.3110	46.8908	41.5354
P37 (MW)	44.7387	45.0449	48.8045	45.1893	46.8684
P38 (MW)	44.3791	50.0173	53.2938	45.3405	39.9672
P39 (MW)	44.3838	45.2566	53.2071	45.0502	39.6792
P40 (MW)	46.5792	53.7992	38.5818	45.2031	53.0425

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