Hybrid MODE/TS for Environmental Dispatch and Economic Dispatch

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ABSTRACT

The economic dispatch and environmental dispatch are used as problem formulas for this paper. The problem formulations are formulated as multi-objective problems. The hybrid Multi-Objective Differential Evolution/Tabu Search (MODE/TS) is developed to solve these multi-objective problems. The proposed method is applied to 2 test systems. The first test system which contains 6 generations is used as a test system without any losses. Another test system which contains 10 generations is used as a test system with non-flat losses by using losses coefficiency. The constraints are used to control the power of each generation in all test systems. Test results from hybrid MODE/TS are compared with test results from original MODE under the same constraints and parameter settings. The test results indicate that the hybrid MODE/TS can determine better optimal pareto solutions and average solution than those from original MODE. Moreover, the hybrid MODE/TS gives the outstanding solution which is far away from original DE.

Keywords: Differential Evolution, Tabu Search, Economic Dispatch, Environmental Dispatch, Optimization

1. INTRODUCTION

From past to present, the problems of power system are well-known. There are many types of problems. Examples of related problems are economic dispatch (ED), environmental dispatch, losses minimizing, and enhance power transfer capability. Most solutions of these problems are formulated as single-objective optimization. The modern heuristic methods such as evolutionary programming (EP) [1, 2], genetic algorithm (GA) [3], tabu search (TS) [4, 5], simulated annealing (SA) [6], particle swarm optimization (PSO) [7] are used to solve these problems [8, 9]. These modern heuristic methods have been proved that they can provide optimal values which are in feasible search spaces [10].

However, these methods have their advantages and limitations. An idea for improving efficiency by combining these methods is proposed and applied. The aim is to use these methods in a combination such that disadvantages are reduced. Moreover, the advantages of each method are increased. In [11, 12], the hybrid PSO is developed to enhance power transfer capability by integrating the sub methods of EP and TS into PSO. In [13], the sub method of EP, TS and SA are integrated into PSO, along with the subpopulation technique. In [14], TS is integrated into the bee algorithm (BA) to solve ED. In [15], hybrid TS/SA is developed to solve power flow problem with FACTS device. However, these method can be determined only single objective function. This is their limitation.

Due to the limitation of these heuristic methods, the multi-objective determining methods are developed. Examples of multi-objective solving methods are VEGA [16], SPEA [17], NSGA [18], NSGA-II [19, 20], NSGA-III [21] and MODE [22]. It has been proven that these methods can solve multi-objective problems.

In addition, these methods still content the general disadvantages. The main limitation is their convergences have a chance to be stuck in local search space. This means the solutions of these methods may be the global solutions or not.

In this paper, the new method is developed by integrating TS to original MODE. MODE is selected as the main method for the developed hybrid. The MODE is an interesting method due to its advantages, which are the ability to apply for multi-objective function, handle non-differentiable, nonlinear and multimodal cost functions, and good convergence properties. TS is integrated. The mechanism of TS is anti-back tracking which can deny backtracking to previous movement. The hybrid method is named hybrid MODE/TS. The economic and environmental dispatch (EED) are formulated as a multi-objective function. The 6 and 10 units test systems are used as the test system. The pareto optimal frontier is used to test the optimal objective values. The experimental results from hybrid MODE/TS are compared with the result from original MODE.

2. PROBLEM FORMULATIONS

In this paper, the multi-objective function is formulated. This multi-objective function includes economic dispatch and environmental dispatch. The details of each objective functions are as follows.

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2.1 Economic dispatch

The general purpose of ED problem is to minimize total fuel cost of generations. The equation of ED problem with non-losses is Eq. (1) [23].

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

where F is the total generation cost (\$/h), F_i is the cost function of the ith generation, P_i is the electrical power output of the ith generation, m the number of generations in the electrical power system, and a_i, b_i, c_i, d_i, and e_i are the cost coefficients of the ith generation.

2.2 Environmental dispatch

The general purpose of environmental dispatch is to minimize total emission of generations. The objective function of environmental dispatch is named as emission objective function. The equation of emission objective function is Eq. (2) [24].

$$\min E = \sum_{i=1}^{m} E_i(P_i) = \sum_{i=1}^{m} (\alpha_i P_i^2 + \beta_i P_i + \gamma_i) \quad (2)$$

where E is the total generation emission (kg/h), E_i is the emission of the ith generation, and α, β, and γ are the emission co-efficient of the ith generation.

2.3 Power Balance

In this paper, the power balance constraint is formulated as Eq. (3). Power loss is calculated by Eq. (4).

$$\min \left(\sum_{i=1}^{m} P_i - (P_D + P_L) \right) > LD \quad (3)$$

$$\min P_L = \sum_i \sum_j B_{ij} P_i P_j \quad (4)$$

where P_D is total load demand, P_L is total power losses, LD is load demand, B_{ij} is power loss coefficient, and P_i is the electrical power output of the ith generation.

2.4 Generations limit

Each generation has its limit which is expressed in Eq. (5)

$$P_{i,\min} \leq P_i \leq P_{i,\max} \quad (5)$$

where $P_{i,\min}$ is minimum power of generation ith, P_i is power of generation ith, and $P_{i,max}$ is maximum power of generation ith.

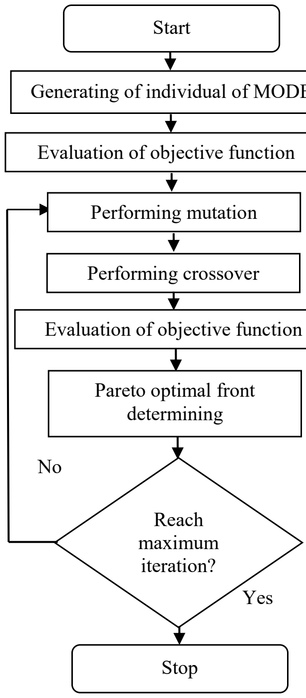

Fig.1: *The flowchart of original MODE.*

3. PROPOSED METHOD

3.1 Multi-Objective Differential Evolution

Differential Evolution (DE) is proposed by R. Storn and K. Price in 1997 [25]. After that, MODE is developed to fulfill the ability to handle multimodal function, parallelizability, ease of use, and good convergence. This MODE is called original MODE for this paper.

The original MODE has its mutation technique which is different from other general mutation techniques of GA or EP. The mutant vector is generated by using Eq. (6).

$$v_{i,G+1} = x_{r1,G} + F \cdot (x_{r2,G} - x_{r3,G}) \quad (6)$$

where $v_{i,G+1}$ is the offspring vector, $x_{r1,G}$, $x_{r1,G}$ and $x_{r3,G}$ are the random parents, and F is scaling factor which value 0.5.

After the mutation is finished. All offspring are sent to a crossover technique, and evaluate the objective function values. After that, the optimal pareto frontier is calculated The flowchart of original MODE is shown as Fig. 1.

3.2 Tabu search

Tabu search is a well known meta-heuristic method. This meta-heuristic represents a modification of basic local search. Tabu search has its identification mechanism which can describe the former paths of searching and solution that are stored in a list, which is named tabulist. The list of this approach is used to maintain a short term memory and act as

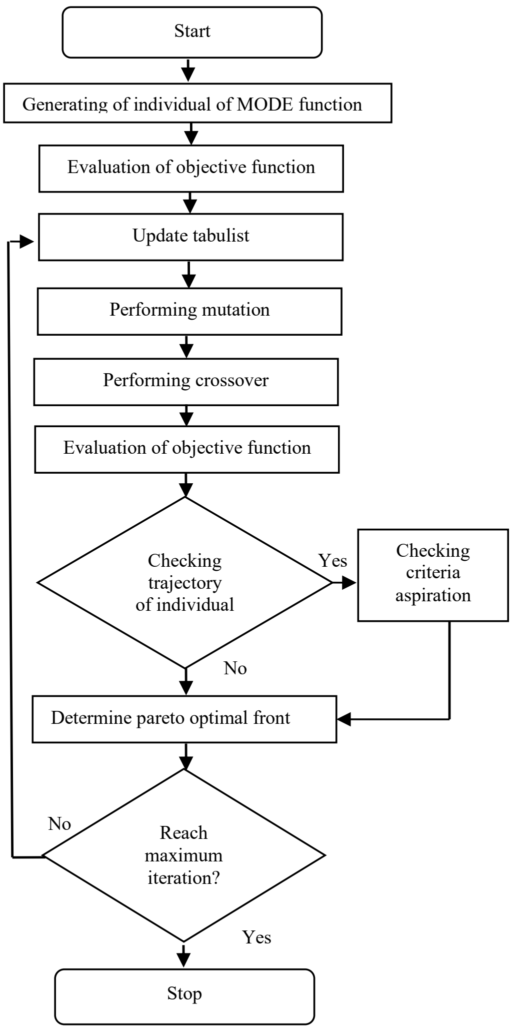

Fig.2: *The flowchart of hybrid MODE/TS.*

a trajectory. After that, it is used to check that the previous vector has travelled through this trajectory or not. This ability can prevent future moves from undoing those changes and can deny backtracking to previous movement in its list [26, 27].

3.3 Hybrid MODE/TS

This hybrid is developed by merging original MODE and TS. The aim of developing it is to use the advantage of original MODE and TS. The advantages of original MODE are described in Section 1. Moreover, the anti-back tracking of TS is used to prevent the sticking chance in local search space area. The flowchart of hybrid MODE/TS is as Fig. 2.

4. EXPERIMENTAL RESULTS

The original MODE and hybrid MODE/TS are used to determine objective function. The individual size of both methods is 100. The maximum iteration of both methods is 200. Each method is set for batch evaluating. Each batch contains 10 runs. Test results

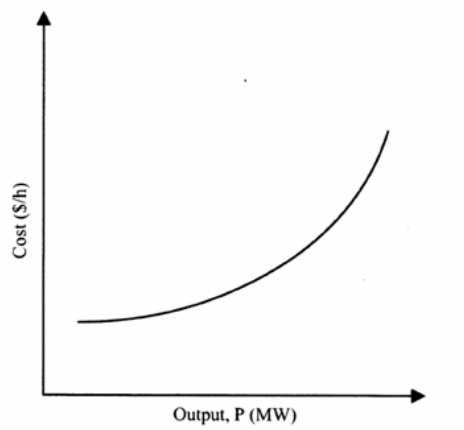

Fig.3: *The plot of flat fuel cost function.*

Table 1: *Generations data of 6 units system with flat fuel cost.*

Unit	$P_{i,\min}$ (MW)	$P_{i,\max}$ (MW)
1	10	125
2	10	150
3	35	225
4	35	210
5	130	325
6	125	315

from hybrid MODE/TS are compared with original MODE.

4.1 6 units system

The 6 units system with flat fuel cost and non-losses is used as the test system [28]. The plot of flat fuel cost function is shown in Fig. 3.

The load demand is set to 800 MW. The generated data of the 6 units system with flat fuel cost and fuel cost co-efficiency and emission co-efficiency data of each generation are shown in Tables 1 and 2, respectively.

Due to the number of generations in the test system, the number of permutations is the factorial of six which equals 720. The tabulist of this test system is set to 180 which considers 25% of the total 720 permutations .The number 180 is determined by trial and error to find the optimal number of tabulist. The aim of reducing is to reduce the time usage of tabu search method. The number 720 makes it use less time overall. The objective function values of the first iteration are shown in Fig. 4.

According to Fig. 4, the result from the first evaluation shows that the separating of objective function values is found. The minimum of generation cost is 41188.1925 $/h. The minimum generation emission is 571.6615 kg/h. In addition, almost all of the objective function values are high.

After that, the calculation is continued to reach

Table 2: *Fuel cost co-efficiency and emission co-efficiency data of each generation.*

Unit	a_i (\$/MWh)^2	b_i (\$/MWh)	c_i (\$/h)	α (kg/MWh)^2	B (kg/MWh)	γ (kg/h)
1	0.1525	38.540	756.800	0.0042	0.3277	13.8593
2	0.1060	46.160	451.325	0.0042	0.3277	13.8593
3	0.0250	40.400	1050.000	0.0068	–0.5455	40.2669
4	0.0355	38.310	1243.570	0.0068	–0.5455	40.2669
5	0.0211	36.328	1658.570	0.0046	–0.5112	42.8955
6	0.0180	38.270	1356.660	0.0046	–0.5112	42.8955

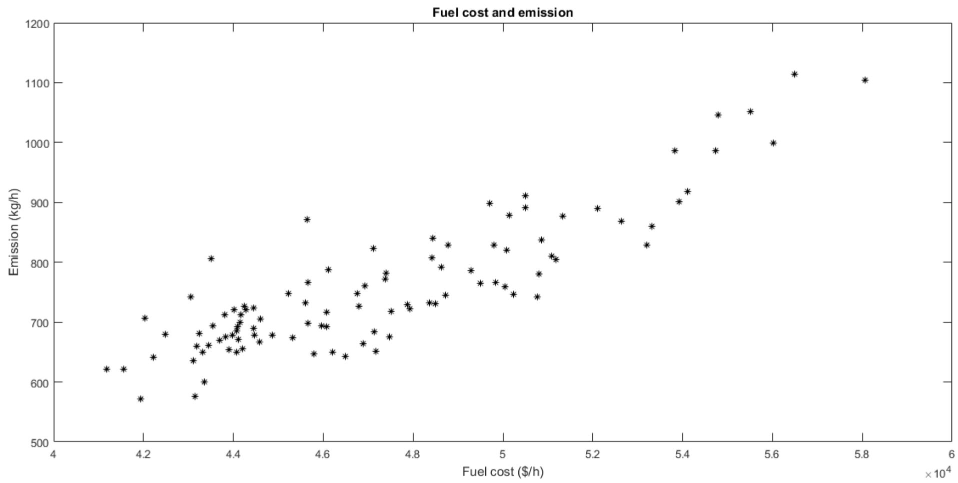

Fig.4: *The objective function values of first iteration.*

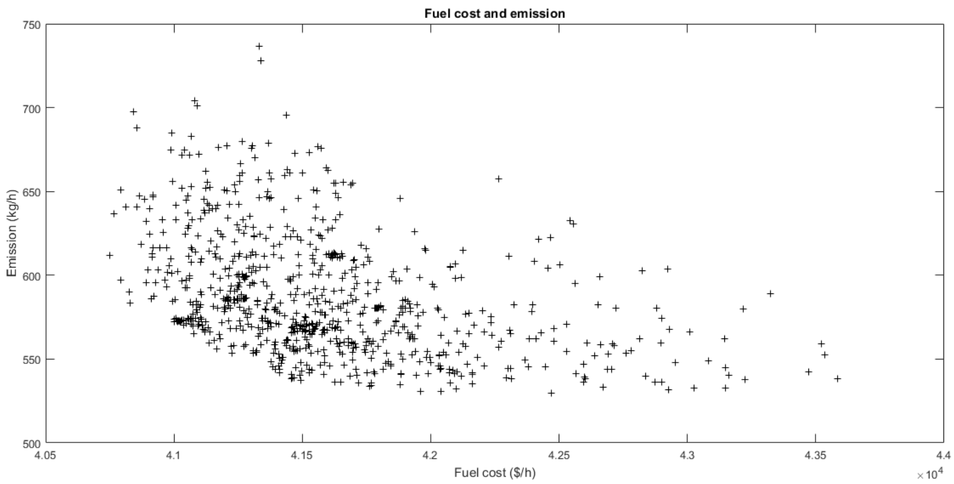

Fig.5: *The all objective function values from 10 runs of original MODE.*

maximum iterations. The convergences for minimizing objective function values are found by the mechanism of original MODE and hybrid MODE/TS. The convergences are converged to the pareto optimal set. Moreover, the diversity of solutions is maintained. Finally, the optimal pareto front is evaluated. All the objective function values from 10 runs of original MODE and hybrid MODE/TS are shown in Figs. 5 and 6, respectively.

Due to the different values of fuel cost and emissions, the normalization method is used to normalize Eq. (7).

$$n_{i,norm} = \frac{n_i}{|n_{\max}|} \quad (7)$$

where $n_{i,norm}$ is ith normalized value of objective function, n_i is ith value of objective function, and

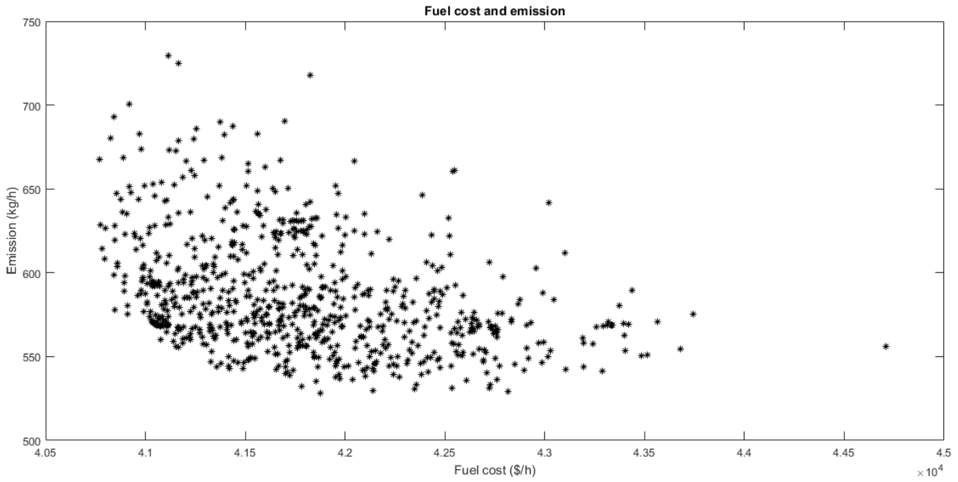

Fig.6: *The all objective function values from 10 runs of hybrid MODE/TS.*

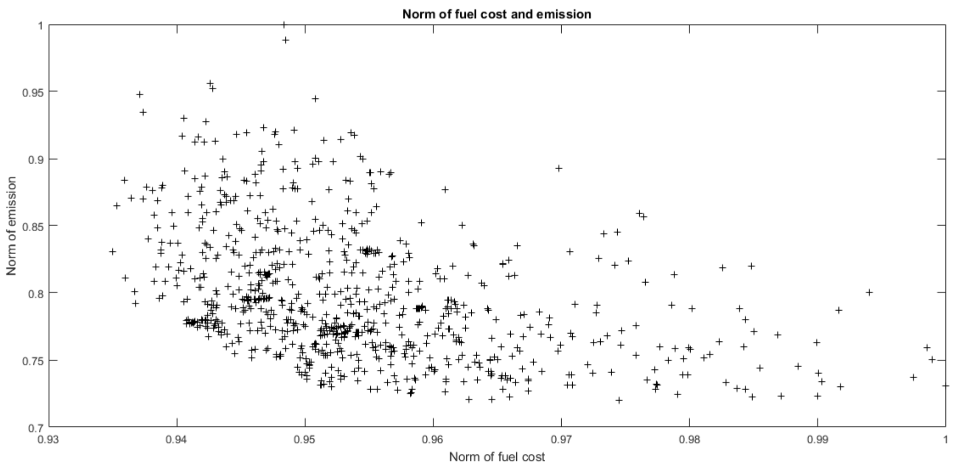

Fig.7: *Normalized objective function values of original MODE.*

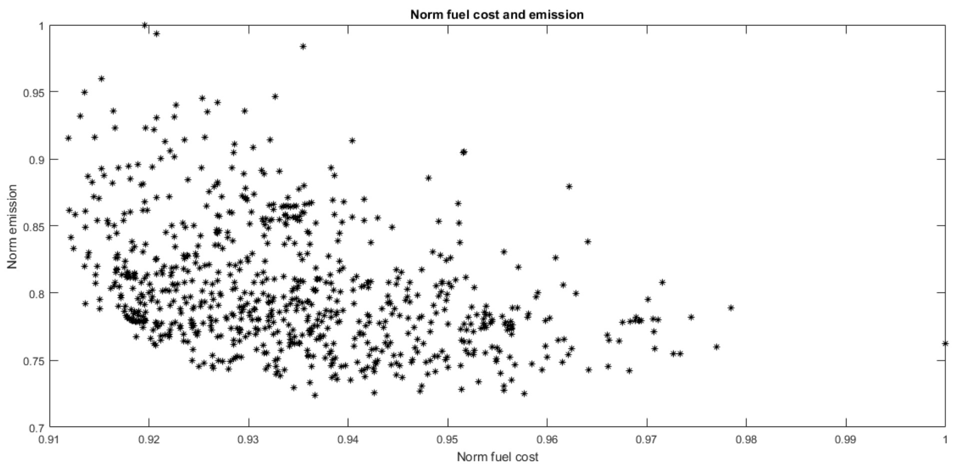

Fig.8: *Normalized objective function values of hybrid MODE/TS.*

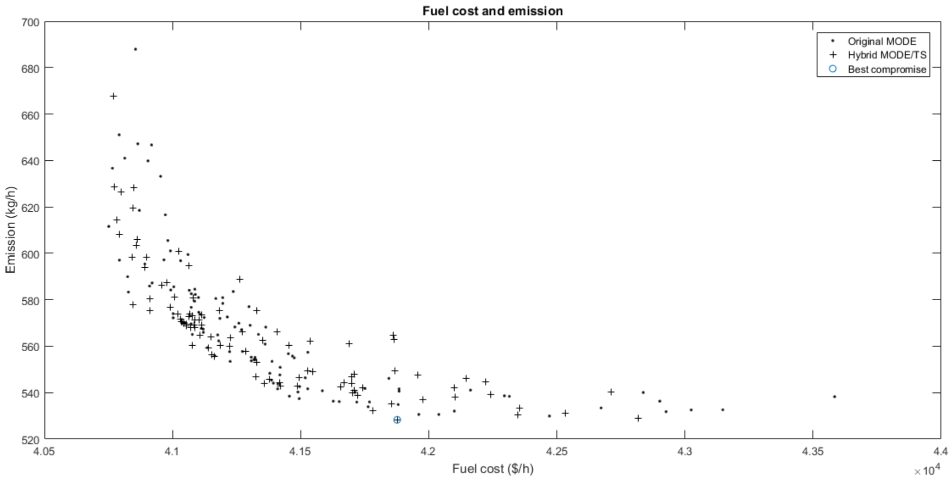

Fig.9: *The best pareto front objective function values from 10 runs of original MODE and hybrid MODE/TS with best compromise objective function values.*

Table 3: *Power of each generation by using hybrid MODE/TS of compromise individual.*

Total Power (MW)	800.0709
P1 (MW)	88.3593
P2 (MW)	73.6555
P3 (MW)	125.6644
P4 (MW)	128.3698
P5 (MW)	186.7974
P6 (MW)	197.2245

Table 4: *The best compromise objective functions.*

Fuel cost ($/h)	Emission (kg/h)
41876.6126	528.2822

$n_{\max}$ maximum value of the objective function.

After the objective function values are normalized, the Euclidean distance calculation method is used to determine the best compromise individual. The individual which contains the minimum distance is promoted as the best compromise individual.

Figs. 7 and 8 show the normalized objective function values of original MODE and hybrid MODE/TS, respectively.

Fig. 9 shows the best pareto front objective function values from 10 runs of original MODE and hybrid MODE/TS with best compromise objective function values. The best compromise individual is evaluated from hybrid MODE/TS. The power of each generation by using hybrid MODE/TS of compromise individual and best compromise objective functions are shown in Tables 3 and 4, respectively. The average values of each objective function by using original MODE and hybrid MODE/TS are shown in Table 5.

Table 5: *The average value of each objective function by using original MODE and hybrid MODE/TS.*

Method \Objective function	Fuel cost ($/h)	Emission (kg/h)
Original MODE	41404.7060	567.6375
Hybrid MODE/TS	41364.8479	565.7846

Table 6: *Generations data of 10 units system with non-flat fuel cost.*

Unit	$P_{i,\min}$ (MW)	$P_{i,\max}$ (MW)
1	10	455
2	20	80
3	47	120
4	20	130
5	50	160
6	70	240
7	60	300
8	70	340
9	135	470
10	150	470

4.2 10 units system

The 10 units system is used as the second test system in this paper [28]. The problem of this test system is ED with non-flat fuel cost. The demand load of this test system is 1500MW. The generations data of 10 units system with non-flat fuel cost, the losses co-efficiency of 10 units system with non-flat fuel cost function, and emission co-efficiency data of each generation are shown in Tables 6, 7, and 8, respectively.

The losses co-efficiency of generations of 10 units system is as followed [28].

Table 7: *The losses co-efficiency of 10 units system with non-flat fuel cost function.*

Unit	a_i (\$/MWh)^2	b_i (\$/MWh)	c_i (\$/h)	d_i (\$/h)	e_i (rad/MW)
1	0.1524	38.5379	786.7988	450	0.041
2	0.1058	46.1591	451.3251	600	0.036
3	0.028	40.3965	1049.9977	320	0.028
4	0.0354	38.3055	1243.5311	260	0.052
5	0.0211	36.3278	1658.5696	280	0.063
6	0.0179	38.2704	1356.6592	310	0.048
7	0.0121	36.5104	1450.7045	300	0.086
8	0.0124	36.5104	1450.7045	340	0.082
9	0.109	39.5804	1455.6056	570	0.098
10	0.1295	40.5407	1469.4026	380	0.091

Table 8: *Emission co-efficiency data of 10 units system.*

α (kg/MWh)^2	B (kg/MWh)	γ (kg/h)
360.0012	-3.9864	0.04702
350.0056	-3.9524	0.04652
330.0056	-3.9023	0.04652
330.0056	-3.9023	0.04652
13.8593	0.3277	0.0042
13.8593	0.3277	0.0042
40.2669	-0.5455	0.0068
40.2669	-0.5455	0.0068
42.8955	-0.5112	0.0046
42.8955	-0.5112	0.0046

$$B = 1e^{-6} \times \begin{bmatrix} 49 & 14 & 15 & 15 & 16 & 17 & 17 & 18 & 19 & 20 \\ 14 & 45 & 16 & 16 & 17 & 15 & 15 & 16 & 18 & 18 \\ 15 & 16 & 39 & 10 & 12 & 12 & 14 & 14 & 16 & 16 \\ 15 & 16 & 10 & 40 & 14 & 10 & 11 & 12 & 14 & 15 \\ 16 & 17 & 12 & 14 & 35 & 11 & 13 & 13 & 15 & 16 \\ 17 & 15 & 12 & 10 & 11 & 36 & 12 & 12 & 14 & 15 \\ 17 & 15 & 14 & 11 & 13 & 12 & 38 & 16 & 16 & 18 \\ 18 & 16 & 14 & 12 & 13 & 12 & 16 & 40 & 15 & 16 \\ 19 & 18 & 16 & 14 & 15 & 14 & 16 & 15 & 42 & 19 \\ 20 & 18 & 16 & 15 & 16 & 15 & 18 & 16 & 19 & 44 \end{bmatrix} \tag{8}$$

Due to the number of generations in the test system, the number of permutations is the factorial of 10 which equals 3628800. The tabulist of this test system is set to 2000 which uses trial and error to find the optimal number of tabulist. Numbers bigger or smaller than 2000 cannot determine the better optimal objective values. The objective function values of this test system are normalized by using Eq. (6). After that, the best compromise individual is determined by using normalization method and Euclidean distance calculation method.

The best compromise of this test system is found by hybrid MODE/TS. This means the mechanism of the proposed method still performs better than original MODE. The best pareto front objective function values from 10 runs of original MODE and hybrid MODE/TS with best compromise objective function values are shown in Fig. 10. The power of each generation by using hybrid MODE/TS of compromise individual and best compromise objective functions values are shown in Tables 9 and 10, respectively.

The average value of each objective function by using original MODE and hybrid MODE/TS are shown in Table 11.

Table 9: *Power of each generation by using hybrid MODE/TS of compromise individual.*

Total Power (MW)	1500.2088
P1 (MW)	54.3506
P2 (MW)	67.2784
P3 (MW)	67.4719
P4 (MW)	58.6190
P5(MW)	133.4321
P6 (MW)	122.6497
P7 (MW)	182.5507
P8 (MW)	199.6965
P9 (MW)	326.5838
P10 (MW)	287.5758

Table 10: *The best compromise objective functions values.*

Fuel cost (\$/h)	Emission (kg/h)
80756.3325	2378.7650

Table 11: *The average value of each objective function by using original MODE and hybrid MODE/TS.*

Method \Objective function	Fuel cost (\$/h)	Emission (kg/h)
Original MODE	79935.3856	2461.1381
Hybrid MODE/TS	79848.4188	2471.2881

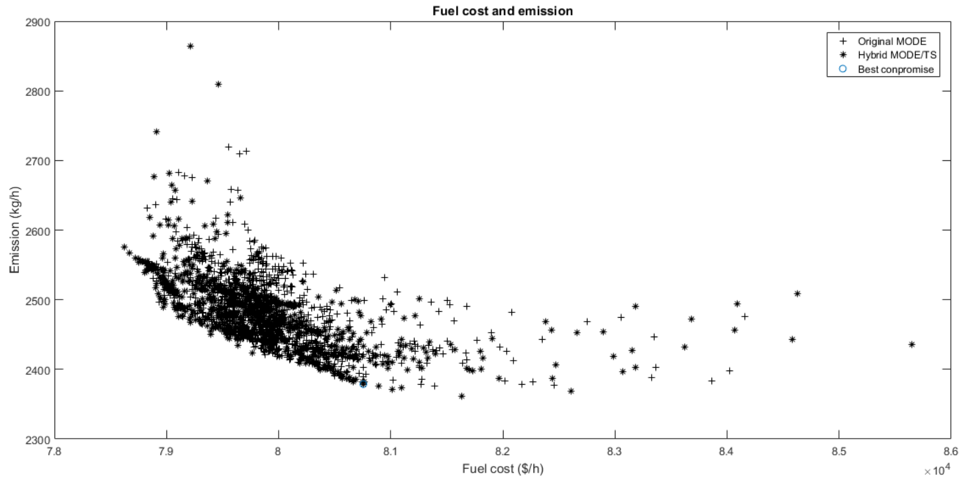

Fig.10: *The best pareto front objective function values from 10 runs of original MODE and hybrid MODE/TS with best compromise objective function values.*

5. CONCLUSION

This paper proposed the hybrid MODE/TS which is a merge of MODE and TS. The 2 objective functions are formulated as a multi-objective function. The 6 units system with economic and emission co-efficiency and 10 units system with non-flat fuel cost and losses co-efficiency are used. Test results comparing original MODE and hybrid MODE/TS show that hybrid MODE/TS can be determined to provide better results by using the anti-back tracking ability of TS. This ability can protect the back tracking of parameters. The parameters are forced to go forward to new values and step over the local search space. The global answer can be found. This proposed method can be used to determine the optimal objective function values which can use their generations data for the optimal operations. These optimal operations will reduce cost and increase efficiency of operation of the electrical power system.

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