Dynamic Economic Dispatch Considering Emission Using Multi-Objective Flower Pollination Algorithm

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***Abstract*— This paper presents dynamic economic dispatch considering emission constraint using multi-objective flower pollination algorithm (MOFPA) method. Minimizing the operating cost in economic dispatch is no longer permitted to be the only criterion for dispatching the electric power due to environmental and health consideration. Besides, dynamic constraints such as output power ramp rates have to be considered to avoid excessive fatigue in plant structure, which leads to the necessity of solving this problem using improved economic dispatch called dynamic economic emission dispatch (DEED). In this paper, fuel cost and NOx emission functions are considered as a single-objective optimization problem and both of them can be formulated by using multi-objective optimization. This multi-objective optimization function will be solved using Flower Pollination Algorithm (FPA). This algorithm is a new nature-inspired algorithm, based on the characteristics of flowering plants. Based on the literature survey, the cost function is taken as a quadratic function and solved for economic and emission dispatch problem. The IEEE 30-bus system with 6-generation units is presented as a plant to illustrate the application of the proposed problem.**

***Keywords*— Dynamic Economic Emission Dispatch, Flower Pollination Algorithm, Ramp Rate,** *Multi-Objective Optimization*

I. INTRODUCTION

Dynamic Economic Dispatch (DED) is one of the major optimization issues in power system operations. The objective of DED is to minimize the total production cost of a power system over the dispatch period by determining an optimal combination of the unit output power, while satisfying various constraints such as physical and operational constraints. Dynamic constraints such as output power ramp rates have to be considered to avoid excessive fatigue in plant structure, which leads to the necessity of solving this problem using improved economic dispatch called Dynamic Economic Dispatch (DED).

Nowadays, minimizing the operating cost in economic dispatch is no longer permitted to be the only criterion for dispatching the electric power due to environmental and health consideration**.** *Electrical* power is generated using various conventional and renewable sources. In fact, The major part of the electric power is still produced by thermal plants that use fossil-based fuel to generate electricity. The nature of thermal power plants makes them one of the main sources of gaseous emission and air pollution.

There are several methods in order to solve the DED problem presented in the literature. Some of the classical methods have been implemented to solve the DED problem, such as Langrangian Relaxation method [1] and Dynamic Programming [2]. Yet, most of these methods cannot lead to the optimal solutions due to their shortcomings in terms of problem formulation, accuracy of their solution or computation efficiency.

The heuristic optimization methods in the DED problem are intended to use by many of recent research in the area. One of the example of the heuristic search method is Tabu Search, which is employed in [3] to solve the DED problem. The heuristic methods impose no limitation on formulation of the problem. On the other hand, obtaining the global optimal solution cannot be guaranteed by these methods but they find more acceptable solutions than the classical methods. The main problem related with these methods refers to the premature phenomenon which happens when the dimensions and the simulation time of the problem are increased. In order to remove these deficiency, proposed method is introduced.

In this paper, a Multi-Objective Flower Pollination Algorithm (MOFPA) is presented and applied to solve the DEED including the ramp-rate limits. The reminder of the paper is organized as follows: Section 2 provides the formulation of the problem formulation. In Section 3, Flower

Pollination Algorithm is described. Simulation results are demonstrated in Section 4. The conclusion of this paper is drawn in Section 5.

II. PROBLEM FORMULATION

The objective of the Dynamic Economic Emission Dispatch (DEED) problem is to determine the optimum loading of all generation units so that both the cost and emission functions are minimized subject to specified constraints [4].

C. Objective Function

The DEED is formulated as a multi-objective optimization problem for all-thermal plants. This formula is calculated considering the emission in addition to the operating cost. These objective functions can be represented mathematically as follows [5]:

$$F = \sum_{i=1}^{Ng} (a_i P_{gi}^2 + b_i P_{gi} + c_i) \quad \$/h \qquad (1)$$

$$E = \sum_{i=1}^{Ng} (d_i P_{gi}^2 + e_i P_{gi} + f_i) \quad kg/h \qquad (2)$$

where,
F : the fuel cost function of the thermal units
E : the amount of emission (*NOx*)
Pgi : Power generation of unit *i*
ai, bi, ci : The fuel cost coefficients for unit *i*
di, ei, fi : The emission coefficients
Ng : Number of generation units.

D. Constraints

These objective functions represented by are subject to a number of constraints, represented as follows :

1. Load Balance

$$\sum_{i=1}^{Ng} P_{gi} = P_D \qquad (3)$$

which *Pgi* is the total power generated and *PD* is the total of system load demand.

2. Generating Unit Capacity Limits

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \qquad (4)$$

which P_{gi}^{min} and P_{gi}^{max} are the minimum and maximum power generation for unit *i*.

3. Ramp Rate

$$P_i^t - P_i^{t-1} \le UR_i \qquad (5)$$

$$P_i^{t-1} - P_i^t \le DR_i \qquad (6)$$

which URi and DRi are the ramp-up and ramp-down-rate limits of generator i, respectively.

E. Multi-Objective Optimization

Multi-objective optimization is an area of multiple criteria decision making that is concerned with mathematical optimization problems involving more than one objective function to be optimized simultaneously. Sum weighted [6], one of the multi-objective optimization method, combines two or more unrelated single-objective problem into a new multi-objective function. The combined economic and emission problem is converted into single optimization problem by introducing price penalty factor h [7].

This combined objective function is represented as follows:

$$M = w \sum_{i=1}^{Ng} F(P_{gi}) + (1-w)\, P_F \sum_{i=1}^{Ng} E(P_{gi}) \qquad (7)$$

where *w* is a weighting factor that satisfies $0 \le w \le 1$.

$$P_F = \frac{\sum_{i=1}^{Ng} F(P_{gi}^{max})}{\sum_{i=1}^{Ng} E(P_{gi}^{max})} \qquad (8)$$

The price penalty factor P_F, is the ratio between the maximum fuel cost and maximum emission of corresponding generator.

III. FLOWER POLLINATION ALGORITHM

Flower pollination is the process where pollen is transferred from the anther (male part) to the stigma (female part) of the plant enabling fertilization and reproduction. There are two pollination process, biotic and abiotic, with over with 90% of them being biotic. Pollinators transmit pollen in biotic pollination. Whereas, abiotic pollination does not require pollinators, instead it is done by wind and water and other natural causes. The following are the four rules of the flower pollination characteristics [8]:

1. Biotic and cross-pollination are considered as process of the global pollination and pollen is carried by a movement which is represented mathematically as Levy flight movement.
2. Abiotic and self-pollination are equivalent to process of local pollination
3. Flower constancy can be developed by pollinators, which is like probability of reproduction and proportional to the similarity of two flowers involved.
4. Changing from local pollination to global pollination can be controlled by a probability which the value of is a uniform distribution from 0 to 1.

In global pollination step, flower pollen is carried by pollinators over longer distances. This ensures pollination and reproduction of the most optimal (best fitness value) and the fitness value is represented as $x*$.The mathematical equivalent of first rule can be represented as follows:

$$x_i^{t+1} = x_i^t + \gamma L(\lambda)(x_i^t - x_*) \qquad (9)$$

where, $x\ it$+1 is the pollen i or solution vector xiat iteration *t*, $x*$is the current best solution, *L* is the power of the pollination, which essentially is the step size. Since insects may move over a long distance with different distance steps, a Levy flight is used to represent these characteristic. Levy distribution, L > 0,

$$L = Z \frac{R\left(\frac{\Gamma(1+\beta)\sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left(\frac{1+\beta}{2}\right)\beta \, 2^{\frac{\beta-1}{2}}}\right)^{\frac{1}{\beta}}}{|R|^{\frac{1}{\beta}}} \quad (10)$$

Here, Γ is the standard gamma function, R is a normal random number, $\beta$is a levy step scalling factor and Z is a Levy step constant. At the local pollination, both the second and third rule can be represented mathematically as follows:

$$x_i^{t+1} = x_i^t + \epsilon(x_j^t - x_k^t) \quad (11)$$

where $xjt$and xkt are pollen from another flowers of the same plant species. Mathematically, if $xjt$and xktcome from the same species or selected from the same population, this equivalently becomes a local random step if the value is a uniform distribution from 0 to 1.

Most flower pollination activity can occur on a local and global scale. In practice, adjacent flowers are more often pollinated by its local pollen. A switch probability, the fourth rule, is used through a proximity probability p to switch between global pollination and local pollination. A preliminary parametric showed that p=0.8 might work better for most applications. Yang has observed that, the value of p = 0.8 works better in most applications for the simulation [9].

IV. SIMULATION RESULTS

The proposed MOFPA method is implemented to solve an DEED problem. This case study is the IEEE 30 bus system with 6 generators with a total load demand of 1800, 2000 and 2200 MW. The cost functions, emission functions, generation capacity limits and ramp rate of the thermal units are given in Table 1 [11]. In this DEED problem, two conflicting objectives are considered, the cost and emission functions.

The MOFPA method is implemented to solve this two-objective problem. The problem is solved first by optimizing the fuel cost neglecting the emission objective functions individually using the Lambda Iteration, PSO and FPA method. Then, the problem is solved by optimizing the fuel cost considering the emission objective functions simultaneously using MOFPA. To generate the non-inferior solution, the weighted-sum method is applied.

A. Economic Dispatch (ED) Neglecting Emission

In this case, the Lambda Iteration, PSO and FPA method are compared in solving the ED problem. The calculation is performed within one level of load demand. The results show that the FPA method is more optimal and more effective than the PSO method in solving the ED problem as shown in Table 2. It shows that the result from FPA method is closer to the numerical method's result than the result obtained from PSO method.

B. Dynamic Economic Emission Dispatch (DEED)

In this case, the MOFPA method is implemented to solve the DEED problem. The emission is considered in addition to the fuel cost and the calculation performed within 3 levels of load demand for 3 hours. The multi-objective optimization problem is converted into a single one by utilizing the weighting factors w_1 and w_2. A combination of these 2 weights is applied each time to obtain the set of non-dominant solutions. These solution sets for the economic cost and emission are obtained using MOFPA method as shown in Table 3 for hour-1, Table 4 for hour-2, and Table 5 for hour-3.

TABLE 2. ED RESULT

	Lambda Iteration	**PSO**	**FPA**
Cost ($)	17459.62666	17459.65289	17459.62666
Unit 1 (MW)	172.06534	174.54232	172.06534
Unit 2 (MW)	352.10760	352.22402	352.10759
Unit 3 (MW)	390.44590	389.81529	390.44591
Unit 4 (MW)	309.02079	306.12776	309.02080
Unit 5 (MW)	390.44590	390.97593	390.44589
Unit 6 (MW)	185.91447	186.31468	185.91446

TABLE 3. COST AND EMISSION RESULT FOR HOUR-1 (LOAD =1800)

Case	**Weight**		**Objective**	
	w1	***w2***	***Cost ($)***	***Emission (kg)***
1	1.00	0.00	17459.6267	2013.1210
2	0.75	0.25	17523.5781	1814.0785
3	0.50	0.50	17562.5961	1795.7435
4	0.25	0.75	17583.9155	1792.2769

TABLE 4. Cost and Emission Result for Hour-2 (Load =2000)

Case	**Weight**		**Objective**	
	w1	***w2***	***Cost ($)***	***Emission (kg)***
1	1.00	0.00	19301.7046	2406.4524
2	0.75	0.25	19370.4221	2188.9312
3	0.50	0.50	19411.5608	2169.5852
4	0.25	0.75	19433.9013	2165.9513

TABLE 1. GENERATORS DATA

Unit	**Cost Function**			**Emission Function**			**Pmin (MW)**	**Pmax (MW)**	**Ramp Down (MW)**	**Ramp Up (MW)**
	a	***b***	***c***	***d***	***e***	***f***				
1	0.002035	8.432500	85.634800	0.006323	-0.381280	80.901900	150	600	50	100
2	0.003866	6.410310	303.778000	0.006480	-0.790270	28.824900	150	600	50	100
3	0.002182	7.428900	847.148400	0.003174	-1.360610	324.177500	150	600	50	100

4	0.001345	8.301540	274.224100	0.006732	-2.399280	610.253500	150	600	50	100
5	0.002182	7.428900	847.148400	0.003174	-1.360610	324.177500	150	600	50	100
6	0.005963	6.915590	202.025800	0.006181	-0.390770	50.380800	150	600	50	100

TABLE 5. Cost and Emission Result for Hour-3 (Load =2200)

Case	Weight		Objective	
	w1	*w2*	*Cost ($)*	*Emission (kg)*
1	1.00	0.00	21174.8162	2886.3275
2	0.75	0.25	21253.0286	2628.6181
3	0.50	0.50	21298.0178	2607.4349
4	0.25	0.75	21322.2177	2603.4967

The power generated solution set in order to fulfill the power demand yet considering cost and emission is calculated within 3 levels of load demand for 3 hours. The calculation apply a combination of these 2 weights each time to obtain the set of non-dominant solutions, as shown in Table 6-9.

Results obtained by MOFPA method in this case study demonstrate a good performance in solving DEED problem regardless of the non-linear and non-smooth shape of the input-output characteristics of the thermal generating unit.

TABLE 6. POWER GENERATED FOR CASE-1 (*W1* = 1, *W2* = 0)

Unit	Hour 1 (Load =1800 MW)			Hour 2 (Load = 2000 MW)			Hour 3 (Load = 2200 MW)		
	Pmin (MW)	*Pmax (MW)*	*Pgen (MW)*	*Pmin (MW)*	*Pmax (MW)*	*Pgen (MW)*	*Pmin (MW)*	*Pmax (MW)*	*Pgen (MW)*
1	150	600	172.0653	150.0000	272.0653	210.1902	160.1902	310.1902	248.3150
2	150	600	352.1076	302.1076	452.1076	372.1759	322.1759	472.1759	392.2442
3	150	600	390.4459	340.4459	490.4459	426.0023	376.0023	526.0023	461.5586
4	150	600	309.0208	259.0208	409.0208	366.7041	316.7041	466.7041	424.3873
5	150	600	390.4459	340.4459	490.4459	426.0023	376.0023	526.0023	461.5586
6	150	600	185.9145	150.0000	285.9145	198.9254	150.0000	298.9254	211.9363
Total			1800.0000			2000.0000			2200.0000

TABLE 7. POWER GENERATED FOR CASE-2 (*W1* = 0.75, *W2* = 0.25)

Unit i	Hour 1 (Load =1800 MW)			Hour 2 (Load = 2000 MW)			Hour 3 (Load = 2200 MW)		
	Pmin (MW)	*Pmax (MW)*	*Pgen (MW)*	*Pmin (MW)*	*Pmax (MW)*	*Pgen (MW)*	*Pmin (MW)*	*Pmax (MW)*	*Pgen (MW)*
1	150	600	167.38380	150.00000	267.38380	196.57414	150.00000	296.57414	225.76449
2	150	600	242.70013	192.70013	342.70013	267.13035	217.13035	367.13035	291.56057
3	150	600	453.16287	403.16287	553.16287	500.79804	450.79804	600.00000	548.43320
4	150	600	306.42391	256.42391	406.42391	336.02188	286.02188	436.02188	365.61986
5	150	600	453.16288	403.16288	553.16288	500.79804	450.79804	600.00000	548.43320
6	150	600	177.16641	150.00000	277.16641	198.67754	150.00000	298.67754	220.18868
Total			1800.00000			2000.00000			2200.00000

TABLE 8. POWER GENERATED FOR CASE-3 (*W1* = 0.5, *W2* = 0.5)

Unit	Hour 1 (Load =1800 MW)			Hour 2 (Load = 2000 MW)			Hour 3 (Load = 2200 MW)		
	Pmin (MW)	*Pmax (MW)*	*Pgen (MW)*	*Pmin (MW)*	*Pmax (MW)*	*Pgen (MW)*	*Pmin (MW)*	*Pmax (MW)*	*Pgen (MW)*
1	150	600	166.1440	150.0000	266.1440	192.9958	150.0000	292.9958	219.8476
2	150	600	213.8211	163.8211	313.8211	238.4572	188.4572	338.4572	263.0933
3	150	600	470.5488	420.5488	570.5488	519.8715	469.8715	600.0000	569.1941
4	150	600	305.6521	255.6521	405.6521	331.6049	281.6049	431.6049	357.5577
5	150	600	470.5489	420.5489	570.5489	519.8715	469.8715	600.0000	569.1941
6	150	600	173.2851	150.0000	273.2851	197.1992	150.0000	297.1992	221.1132
Total			1800.0000			2000.0000			2200.0000

TABLE 9. POWER GENERATED FOR CASE-4 ($w1$ = 0.25, $w2$ =0.75)

Unit	Hour 1 (Load =1800 MW)			Hour 2 (Load = 2000 MW)			Hour 3 (Load = 2200 MW)		
	Pmin (MW)	*Pmax (MW)*	*Pgen (MW)*	*Pmin (MW)*	*Pmax (MW)*	*Pgen (MW)*	*Pmin (MW)*	*Pmax (MW)*	*Pgen (MW)*
1	150	600	165.58163	150.00000	265.58163	191.40494	150.00000	291.40494	217.22825
2	150	600	200.49014	150.49014	300.49014	225.13858	175.13858	325.13858	249.78703
3	150	600	478.73293	428.73293	578.73293	528.69481	478.69481	600.00000	578.65670
4	150	600	305.30163	255.30163	405.30163	329.79851	279.79851	429.79851	354.29538
5	150	600	478.73293	428.73293	578.73293	528.69481	478.69481	600.00000	578.65670
6	150	600	171.16074	150.00000	271.16074	196.26834	150.00000	296.26834	221.37594
Total			1800.00000			2000.00000			2200.00000

V. CONCLUSIONS

In this paper, the Dynamic Economic Emission Dispatch (DEED) problem is discussed and tackled considering the environmental aspects. The difference between the normal EED problem is the dynamic constraints such as output power ramp rates have to be considered to avoid excessive fatigue in plant structure, which leads to the necessity of solving the problem using improved economic dispatch called Dynamic Economic Dispatch (DED). In addition to the fuel cost, the emission also minimized simultaneously which finally solve the DEED problem. The MOFPA method has been implemented in this paper to solve the DEED problem. This method is a new nature-inspired method, based on the characteristics of flowering plants. Based on the literature survey, the cost function is taken as a quadratic function and solved for economic and emission dispatch problem. The Multi-Objective optimization problem is converted to a single one by utilizing the weighted-sum method. This paper also shows the effectiveness of the MOFPA method in solving the Multi-Objective DEED problem.

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