Multi-Objective Dispatch of Wind-Thermal System using Moth-Flame Algorithm

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***Abstract*— Most of electricity generated on the globe is produced by thermal power plants. Thermal power plants are main source of generation of harmful gases like SO2, CO2 and NO2. Serious concerns towards reduction of pollution is taken by authorities which lead to economic load dispatch to economic load dispatch Optimization. In economics emission dispatch both objectives, that is minimization of fuel cost and minimization of emission are satisfied at same time. Multiobjective load dispatch is difficult optimization process of gaining generation schedule with minimization of fuel cost and reduced emission.**

This paper illustrates the solution of multi objective load dispatch problem of wind-thermal system using Moth flame algorithm. Moth Flame Optimizer is a new metaheuristic technique based on hunting behavior of living beings, this algorithm is tested on 6- unit thermal system using matlab 2016 platform .This dispatch model have both the thermal and wind farms. Weighted sum method is used in this paper to get the best combination of both the objectives. Valve point effect is also considered in the paper to show the real constants of thermal system. The complex nature of wind is calculated using weibull distribution equation and over estimation/under estimation cost is calculated using closed integral function. In the first case moth flame algorithm is implemented on 6-unit thermal system having 1200MW of load demand. In the second case same technique is implemented on Wind-thermal system having 6-Thermal generating units and a wind farm without considering emissions. Load demand in this case is also 1200MW. In third case this algorithm is implemented on wind-thermal system with 6-units of thermal system and one wind farm considering emissions. This case has load demand of 1600MW. All these cases are compared with other algorithms. Comparison shows that Moth flame algorithm has better convergence and effective in achieving global optimal solution and ignores local minima problem.

Keywords*: *Combined economic emission dispatch, Moth flame optimizer (MFO), Differential Evolution (DE), Multiobjective Differential Evolution (MODE), Wind Energy Conversion System (WECS), Wind Energy.

1. INTRODUCTION

Electricity produced by thermal power plants emits oxides of Sulphur, Nitrogen, carbon (SOx, NOx, COx). These oxides harm environment and living life badly. The problem was addressed throughout the globe and nations were made to change their energy generation policies to minimize emissions from thermal power plants. Multiobjective load dispatch is a complex problem in which general load dispatch problem with emissions are considered to achieve environmental protection aim. Thermal generators are set in such a way that maximum fuel cost economy is achieved, while satisfying load demand and other constrains. Minimization of fuel cost is always given higher priority and emissions are not minimized in Economic Load Dispatch (ELD). While generators are scheduled according to Economic Load Dispatch they have more emissions.

When generators are set to minimize emissions, fuel cost will be more. Hence both these objectives are inverse to each other. The main goal of Multiobjective optimization is to find the best optimal solution so that fuel cost with emissions is globally minimized while satisfying equality and inequality constrains.

Many conventional optimization techniques were implemented in past to solve Combined Economic Emission dispatch (CEED) problem. These techniques are lengthy and time consuming. Also these techniques are unable to handle non-linear constrain of objective function. To solve these problems metaheuristic techniques are developed. These techniques are able to solve Combined Economic and Emission Dispatch (CEED) problem more effectively. These techniques are based on the hunting methods of living insects and are capable of handling constrains effectively. The objective of each living being is to survive. These methods are able to avoid local optima problem.

Many metaheuristic methods are implemented on Combined Economic and Emission Dispatch of Wind-Thermal system which includes Multiobjective Differential Evolution (MODE)[1], Differential Evolution (DE)[2], Multiobjective Evolutionary Programming (MOEP)[3], and Non Dominated Sorting Genetic Algorithm (NSGA)[4]. Strength Pareto Evolutionary Algorithm-2 (SEPA-2)[5]. Weighted sum is used to obtain the best optimal solution of both the objectives. By changing the values of weights, the preference of objective function can be fixed.

Mothflame optimizer is a new nature inspired metaheuristic technique proposed by Mirjalili in 2015[6]. It is a population based metaheuristic technique tested on single and Multiobjective test function. The algorithm has been implemented in the field of Engineering, Science and Proven efficient.

2. OBJECTIVE FUNCTION

In this paper Mothflame optimizer is applied on two objectives simultaneously. The objective functions are to minimize fuel cost of wind thermal system and emission at

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same time. Optimization is subjected to fulfill various equality and inequality constrains. Multiobjective optimization of thermal system can be expressed as[7].

$C_i(p_i) = a_i + b_i p_i + c_i p_i^2 + | d_i \sin(e_i (P_{i\,min} - P_i)) |$ Rs/hr (1)

a_i, b_i, c_i are fuel cost coefficients and d_i, e_i are valve point coefficients. the fuel cost of each thermal generator is expressed as addition of quadratic equation and sinusoidal function. to show real factors of thermal power plant, valve point effect has been considered.

The cost function of wind farm is calculated as follows [10][8]

$$C_i w_i = \sum_{j=1}^{N} C_{w,j}(w_{j,av}) + \sum_{j=1}^{N} C_{u,j}(W_{j,av} - w_j) +$$

$$\sum_{j=1}^{N} C_{o,j}(w_j - W_{j,av}) - \sum_{j=1}^{N} C_{s,j}(W_{j,av}) \quad (2)$$

Where $C_{w,j}$ is the direct cost coefficient

Total operating cost= Ci(pi) + Ciwi

Direct cost of wind power that a power system operator has to pay to wind farm operator is represented by first component of equation 2, over estimation cost is represented by second component and underestimated imbalance cost is represented by third component. Subsidy cost is given by forth component of equation that is given to wind farm operator and is directly proportional to wind power generated.

If forecasted power is less than actual genetated power over estimation occurs and power system operator needs to buy power from other sources to fulfill the load demand. Over estimation cost can be divided into two components S1 and S2[10].

$$\sum_{j=1}^{N} C_{o,j}(w_j - W_{j,av}) = C_{o,j}(S1+S2)$$

Where

$$S1 = w1 \left\{ 1 - exp\left(-\left(\frac{v_{in}}{c}\right)^k\right) + exp\left(-\left(\frac{v_{out}}{c}\right)^k\right) \right\}$$

$$S2 = \int_0^{w_1} (w_1 - w) f_w(w) d(w) \quad (3)$$

If forecasted power is more than generated power under estimation occurs. In this case system operator needs to relieve other thermal units which are connected to supply, for overestimated wind power reserve requirements are considered. Where Cuj is cost of penalty for over estimation of wind power[10].

$$\sum_{j=1}^{N} C_{u,j}(W_{j,av} - w_j) = C_{u,j}(S3 + S4)$$

$$\text{Where } S3 = w1 \left\{ 1 - exp\left(-\left(\frac{v_{in}}{c}\right)^k\right) + exp\left(-\left(\frac{v_{out}}{c}\right)^k\right) \right\} \quad (4)$$

$$S4 = \int_{w_i}^{w_r} (w - w_i) f_w(w) d(w) \quad (5)$$

Emissions

Emissions are caused by thermal power plants in the form of oxides of NOx, Cox, Sox. All these three emissions can be generalized using single equation. These emissions can be generalized using single equation. These emissions are also expressed in the form of active power generation. The emissions have quadratic function with exponential function and can be expressed as,

f2(x) =(αi+βi Pi + γiPi2+ η iexp (δiPi) Kg/hr

Also, mathematical expression for Multiobjective optimization for economic load dispatch is [8]

Min F(x) = [f1(x), f2(x)] (6)

The economic load dispatch of Wind-Thermal system have following constrains.

Power Balance Constrain:

This is also known as equality constrain. This gives power balance between generation and load. The generation of wind-
thermal collaboration should be enough to fulfill load demand with compensating power losses [9]

$$\sum_{i=1}^{M} P_i + \sum_{j=1}^{N} w_j = P_d + P_{loss} \quad (7)$$

Inequality Constrains: This defines the upper limit and lower limit of thermal power plant to generate electricity.

$$P_{i,min} \le P_i \le P_{i,max} \quad (8)$$

Wind power plant have generation capacity from zero. This is subjected to inequality constrain defined by their operating limits

$$0 \le w_j \le w_{r,j}$$

Weighted Sum Method[10]

Weighted sum method is simple method used to obtain the best solution between various combinations of solutions. In this work weighted sum method is used to get the best optimal solution between two objectives. In this method both objectives are assigned with different weights related to their importance. Multiobjective optimization is turned into single objective with this method. Then both the objectives are added together to get objective function as

Min f = ωF1 + (1-ω) F2 (9)

Subjected to

$$\sum^{n=2} \omega = 1$$

Where F1 represents objective 1 and F2 represents objective 2 (i.e. Minimization of emissions) of generators. the value of ω lies between 0 and 1[10]. Value 0 assigned to a objective function indicates that the objective function is not considered and other objective function is taken for

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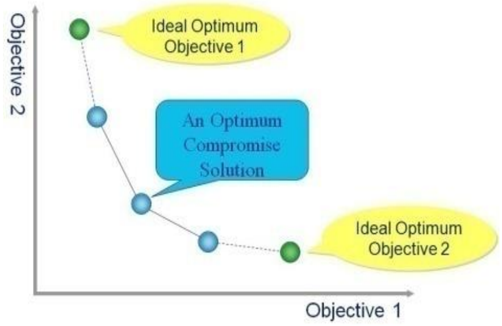
optimization (ie emission function). When ω=1 is considered it indicates that only objective function that represents fuel cost is considered while neglecting emissions. By varying the value of ω, optimum best value of both the objectives can be calculated.



3. MOTH FLAME ALGORITHM

MFO algorithm is a new metaheuristic technique proposed by Mirjalili in 2015[6]. This technique is based on hunting mechanism of Mothflies it is a nature inspired algorithm. Mothflies travel during night by maintaining a fixed angle with respect to moon which allows them to travel in a straight path. Mothflies converges towards artificial light or flames through spiral movement. This spiral movement led to mathematical optimization of this technique. In this algorithm, candidate solution is considered to be moths and position of mothflies in space is considered as problem`s variable. Mothflies can fly in 1D 2D 3D or hyperdimension in space, by changing their position vector. Steps of MFO algorithm is shown below.

Step 1
The number of generators in Economic Load Dispatch (ELD) and Combined Economic and Emission Dispatch (CEED) is equal to number of dimension of each moth and flame, this specifies the upper bond and lower bond values of each generator and maximum number of iterations.

Step 2
MFO algorithm is represented by position matrix having M moths and F flames. The mothflies can fly in any direction in space by setting variables for each moth and flame.
Set of moths can represented by following matrix:

$$M = \begin{bmatrix} m_{1,1} & m_{1,2} & \cdots & \cdots & m_{1,d} \\ m_{2,1} & m_{2,2} & \cdots & \cdots & m_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ m_{n,1} & m_{n,2} & \cdots & \cdots & m_{n,d} \end{bmatrix}$$

Here n = number of moths
d = number of variables (dimension)
A similar matrix for flames can be represented as:

$$F = \begin{bmatrix} F_{1,1} & F_{1,2} & \cdots & \cdots & F_{1,d} \\ F_{2,1} & F_{2,2} & \cdots & \cdots & F_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ F_{n,1} & m_{n,2} & \cdots & \cdots & F_{n,d} \end{bmatrix}$$

Fitness values of moths and flames are given by:

$$OM = \begin{bmatrix} OM_1 \\ OM_2 \\ \vdots \\ OM_n \end{bmatrix}$$

$$OF = \begin{bmatrix} OF_1 \\ OF_2 \\ \vdots \\ OF_n \end{bmatrix}$$

Where n = number of moths.

For position matrix M and F initialization can be calculated by equation:
M(a,b) or f(a,b) = (ub(a)-lb(a)*rand+lb(a))

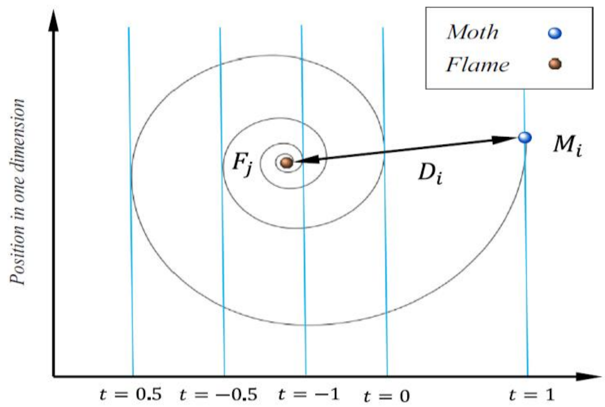
Where a = number of moths or flames
b = number of variables or dimensions
ub = upper limits
lb = lower limits
rand = random no. generated in range between 0 to 1

Step 3
Initialization of iterations
MFO algorithm is defined by a logarithmic spiral function which is represented as

$$S(M_i, F_j) = D_i \cdot e^{bt} \cdot \cos(2\pi t) + F_j$$

Where Di = Distance of ith moth from jth flame
b = constant of shape of logarithmic spiral
t = random number in range from 0 to1
Here D is calculated as

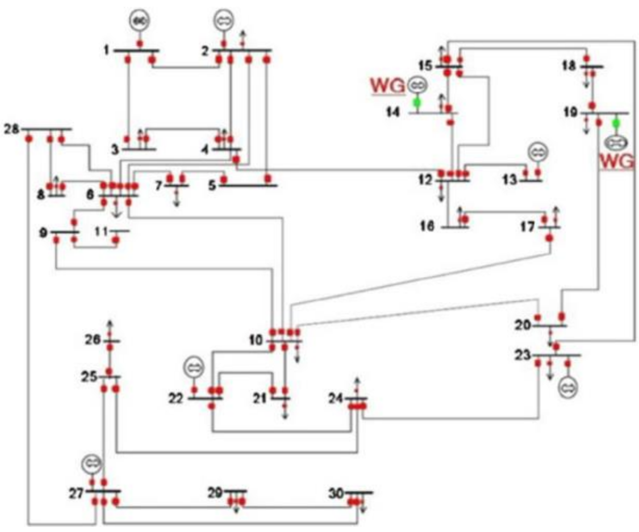
$$D_i = |F_j - M_i|$$



Logarithmic spiral, space around a flame and position with respect to t

Economic Dispatch Problem formulation

Moth flame algorithm is applied on modified IEEE-30 bus system having 6-generating units. The benchmark platform (1st) have six thermal units, two wind based units and twenty-one loads. Thermal units comprises of three coal, two, gas and one oil-based unit.



Modified IEEE-30 Bus System

4. CASE STUDY

Case 1: Economic Load Dispatch with Valve point Effect.

In this case the load demand is 1200MW and system losses are considered to be nil. The basic Economic load Dispatch model without wind generator is optimized through the platform. The output of each generating unit with their cost of generation is tabulated in table 1. Its comparison with other existing meta-heuristic technique is tabulated in table 2

Table: 1 Solution of ELD without wind generator.

Unit	Generation(MW)	Fuel Cost($)	Emission Cost($)
G1	110.0	2576.87	3365.089
G2	85.97	2013.15	3718.569
G3	600.0	14050.23	6622.236
G4	149.58	3500.84	810.116
G5	214.43	5020.60	327.133
G6	40.00	939.68	456.145
Total	1200.0	28101.0	15300.0

Table: 2 Comparison of MFO with other techniques.

Unit	Moth-Flame Algorithm	Gbest ABC[8]	SQO-PSO[9]	QPSO[10]
G1	110.0	98.7	96.9	107.7
G2	85.97	99.9	99.4	99.9
G3	600.0	592.1	593.6	582.5
G4	149.58	259.3	259.1	259.0
G5	214.43	110.0	110.6	110.4
G6	40.00	40.0	40.3	40.4
Total	1200	1200	1200	1200
Total cost	28101.0	29147.0	29538.6	29555.7

Case 2: Economic Load Dispatch Considering Wind Generator.

In this case load demand is 1200MW and system losses are considered to be zero. Economic load dispatch model with integrated wind generator is optimized on the platform. The output of each generating unit with their cost of generation is tabulated in table 3. Its comparison with other existing meta-heuristic technique is tabulated in table 4

Table: 3 solution of ELD considering wind power.

Unit	Generation(MW)	Fuel Cost($)
G1	110	2933
G2	63.0104	3156
G3	600	11661
G4	110	2942
G5	110	3189
G6	200	4940
G7	6.9896	1053.6
Total	1200	29875

Table: 4 Comparison of MFO with SQO-PSO.

Unit	Moth-flame algorithm	SQO-PSO
G1	110	94.93
G2	63.0104	99.97
G3	600.00	592.03
G4	110	258.99
G5	110	110.01
G6	200	40.55
G7(wind)	6.98	3.86
Total Generation(MW)	1200	1200
Total Cost($)	29875	31115.63

Case 3: Multi objective Economic Load Dispatch for 6-unit System.

In this case the load demand is 1600MW and system losses are considered to be nil. The Combined Economic Emission load Dispatch model with wind generator is optimized through the altered IEEE-30 bus system. The output of each generating unit with their cost of generation is tabulated in table 5. For best optimal solution value of ω is considered as 0.4 and 0.6 for objective 1 and objective 2 respectively. Its comparison with existing meta-heuristic technique SQO-PSO is tabulated in table 6

Table: 5 Solution for CEED with wind generator for 6-unit system

Unit	Power(MW) T5	Operation Cost($)	Emission Cost($)
G1	57.83	2592	2784
G2	41.82	2924	3373
G3	305.90	8522	6406
G4	520.0	11039	870
G5	430.40	10053	753
G6	80.33	2085	867
G7(W)	163.69	2305.0047	0
Total	1600	39520	15054
Overall Cost	54574.00		

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Table: 6 Comparison of MFO with SQO-PSO

Unit	Moth Flame Algorithm		SOQ-PSO	
	Power(MW)	Operation Cost($)	Power(MW)	Operation Cost($)
G1	57.83	2592	95.34	2980.80
G2	41.82	2924	21.35	2835.68
G3	305.90	8522	569.05	11708.60
G4	520.00	11039	507.65	10885.02
G5	430.40	10053	296.03	7159.18
G6	80.33	2085	40.06	1068.30
G7(wind)	163.69	2305.0047	70.49	3230.97
Total	1600	39520	1600	39868.55
Emission Cost($)	15054.00		16498.57	
Overall Cost($)	54574.00		56367.12	

5. CONCLUSION

In this paper Mothflame algorithm is implemented on IEEE-30 bus system having six thermal and one wind unit. Mothflame algorithm is implemented on Economic Load Dispatch for Wind-thermal system and Multiobjective wind-thermal system, further results obtained from Mothflame optimization were compared with existing metaheuristic techniques in table 2,4 and 6. Load demand for case 1 and case 2 were 1200MW and for case 3 load demand is considered 1600MW. To get best optimal solution of both the objectives weighted sum method is used and the value of ω is considered 0.4 and 0.6 for objective 1 and objective 2 respectively.

Hence Mothflame optimizer has better convergence rate and optimizes wind-thermal system in such a way that the objectives of fuel economy and reduced emissions has achieved. Comparison shows that Mothflame algorithm is better than other existing metaheuristic techniques.

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