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DYNAMIC ECONOMIC EMISSION DISPATCH OPTIMIZATION INTEGRATED WIND AND SOLAR ENERGY SYSTEMS

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ABSTRACT

This paper focuses on economic emission dispatch, this dispatching is able to determine the optimum operating strategy to minimize energy costs, enable reduced emissions, and better utilization of renewable energy resources such as wind and solar power. Many countries have made great efforts to save energy and make efficient use, by the development and exploitation of renewable energy such as wind and solar energy, which is a very important alternative to reduce gas emissions, reduce the bill for power generation. In this paper an algorithm (MOALO) called multi-objective ant lion optimizer, is used to solve the dynamic economic environmental dispatch problems with and without ramp rate considering the integration of wind and solar energy. This applied approach is used optimal solutions for power generations and then calculates emission and cost functions. The combined dynamic economic emission dispatch problem (Combined dynamic economic emission dispatch problem) is employed as a muti-objectives problem in this work, respecting many equality and inequality constraints. The proposed algorithm was applied to a 10-units test power system including wind and solar power. A comparison of the results is made with those in literature. The simulations are executed in MATLAB®-Simulink.

Disciplinary: Electrical Engineering Technology, Energy Technology Management, Renewable Energy, Sustainability.

1 INTRODUCTION

Scientific research and technological development, although they seek to solve all the problems associated with electrical networks are finding the best solution. It is in this context that our work takes place which is the continuation of this paper and which revolves around the dynamic economic emission dispatch problem (CDEEDP) includes DEcDP and EEmDP. DEcDP takes into

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consideration ramp rate limits, and EEmDP considers not only the economy but also the environment. CDEEDP has two objectives: the optimal total amount of pollution gas emission and the optimal total cost of the thermal power units during the total scheduling periods, which are mutually competing, namely, a decrease of one objective with an increase of another one[1]. Nowadays, scholars around the world mainly study CDEEDP on the aspect of solving the multi-objective non-convex and nonlinear problem. optimization

The problem of CDEED is more difficult to solve the problems EECD and DEMD [2], because it adds at the same time the constraints ramp to rate unit of production and the function of emission to the problem of distribution of the economic load of origin. Also, all outputs power must be appropriately calculated to obtain a better compromise solution that satisfies all constraints [3]. The conception of the strategy respecting all constraints of equality and inequalities and the improvement of the performance of the heuristic algorithm are taken into consideration in order to guarantee a high quality of the solutions for the CDEED problem. It is in this context that our main contribution in this work is expressed using this optimization algorithm (MOALO).

Many literatures solve the CDEED problem. There were many approaches to solve the present problem. In summary, particle swarm optimization (PSO) [3], hybrid differential evolution (DE) and sequential quadratic programming (DE-SQP) [4], particle swarm optimization (PSO) and sequential quadratic programming (PSO-SQP) [4], multiobjective differential evolution (MODE) [5], multi-elite guide hybrid differential evolution with simulated annealing technique (MOHDE-SAT) [5], harmony search (HS) method with a new pitch adjustment (NPAHS) [6], Evolutionary Programming (EP) [7], simulated annealing (SA) [8] and pattern Search method (PS) [8], new enhanced harmony search (NEHS) [9], chemical reaction optimization (CRO) [10] and hybrid CRO (HCRO) [10], in reference [11] a (MAMODE) approach is detailed , improved bacterial foraging algorithm (IBFA) [12], nondominated sorting genetic algorithm-II (NSGA-II) and real-coded genetic algorithm (RCGA)[19], modified real-genetic algorithm (MRGA) and modified NSGA-II (MNSGA-II) [20], This work presents an algorithm (MOALO) proposed to solve DEcDP, DEmDP and CDEEDP.

2 OBJECTIVE FUNCTIONS

2.1 THERMAL COST AND TOTAL EMISSION FUNCTIONS

Equation (1) represents a mathematical expression of the cost fuel function

$$F1 = Min\, Fu_{it}(P_{gi,t}) = \sum_{t=1}^{T} \sum_{i=1}^{Nn} Fu_{it}(P_{gi,t})$$

$$F1 = \sum_{t=1}^{T} \sum_{i=1}^{Nn} a_i P_{gi,t}^2 + b_i P_{gi,t} + c_i \qquad (1)$$

In the CDEED problem, when the VPLE is taken into consideration, the cost function of unit generation is [12]

$$F1 = Min\, Fu_{it}(P_{gi,t})$$

$$F1 = a_i P_{gi,t}^2 + b_i P_{gi,t} + c_i + \left| d_i \sin\left(e_i\left(P_{gi}^{\min} - P_{gi,t}\right)\right)\right| \qquad (2)$$

Equation (3) illustrates the emission function

$$F2 = Min\ E_{m_{it}}(P_{gi,t}) = \gamma_i P_{gi,t}^2 + \beta_i P_{gi,t} + \alpha_i + \xi_i \exp(\lambda_i P_{gi,t}) \qquad (3).$$

Currently, electricity companies are oriented towards the use of renewable energies to reduce environmental pollution [13].

2.2 WIND POWER MODEL AND COST FUNCTION

The model given to wind speed using (PDF) [14], can be expressed by Equation (4) [1]

$$PDF(v_{win}) = \frac{k}{c}\left(\frac{v_{win}}{c}\right)^{k-1}.\exp\left(-\left(\frac{v_{win}}{c}\right)^{k}\right), \quad (v_{win} > 0) \qquad (4).$$

The calculation of wind power is based on Equation (5) [13]

$$Pwin = \begin{cases} 0, & \text{for } vwin,t \le v_{in}\ and\ vwin,t > v_0 \\ pr\left(\frac{v_{win,t} - v_{in}}{v_r - v_{in}}\right), & \text{for } v_{in} \le vwin,t \le v_r \\ pr, & \text{for } v_r \le vwin,t \le v_0 \end{cases} \qquad (5).$$

The cost wind expressed by Equation (7) [31]

$$F3(P_{win,k,t}) = \sum_{k=1}^{Nw} K_{win,k} P_{win,k,t} \qquad (6).$$

2.3 PV POWER MODEL AND COST FUNCTION

Equation (7) gives the mathematical expression of solar irradiation of PV solar [16]:

$$P_S(G) = \begin{cases} P_S\left(\frac{G^2}{G_{std}.R_c}\right) & for\ 0 < G < R_c \\ P_S\left(\frac{G}{G_{std}}\right) & for\ G > R_c \end{cases} \qquad (7),$$

where it is noted that PV cell temperature is neglected. The maximum penetration of PV, the system is given by

$$P_{S,k} \le P_{S,k}^{\max} \qquad (8)$$

The Weibull distribution function is given by [17]

$$f_G(G) = \omega\left(\frac{k_1}{c_1}\right).\left(\frac{G}{c_1}\right)^{K_1-1} \exp\left[-\left(\frac{G}{c_1}\right)^{K_1}\right] + (1-\omega)\left(\frac{k_2}{c_2}\right).\left(\frac{G}{c_2}\right)^{K_2-1} \exp\left[-\left(\frac{G}{c_2}\right)^{K_2}\right] \qquad (9)$$

$$\text{for } 0 < G < \infty$$

A cumulative distribution n function (CDF) corresponding to the Weibull PDF Equation (9), is given by Equation (10)

$$F_G(G) = \omega\left[1 - \exp\left\{-\left(\frac{G}{c_1}\right)^{K_1}\right\}\right] + (1-\omega)\left[1 - \exp\left\{-\left(\frac{G}{c_2}\right)^{K_2}\right\}\right] \qquad (10)$$

According to the transformations of random variables, given by Equations (11) and (12):

$$p_s = aG + b = g(G) \qquad (11)$$

$$f_{p_s}(p_s) = f_G[g^{-1}(ps)]\left|\frac{dg^{-1}(ps)}{dp_s}\right| = f_G(G) * \left|\frac{1}{a}\right| = f_G\left(\frac{p_s - b}{a}\right) * \left|\frac{1}{a}\right| \qquad (12)$$

$$p_s\left(\frac{P_{Sr}}{G_{std}}\right)G = aG,\ for\ G > R_c \tag{13}$$

and

$$a = \left(\frac{P_{Sr}}{G_{std}}\right) \tag{14}$$

$$f_{p_s}(p_s) = f_G\left(\frac{ps}{a}\right) * \frac{1}{a} = f_G\left(\frac{psG_{std}}{P_{Sr}}\right) * \frac{G_{std}}{P_{Sr}} \tag{15}$$

Where G is given by

$$p_s = \left(\frac{P_{Sr}}{G_r R_c}\right)G^2 = aG^2, \quad \text{for } 0 < G < R_c \tag{16}$$

And

$$a = \left(\frac{P_{Sr}}{G_r R_c}\right) \tag{17}$$

$$f_{p_s}(p_s) = \frac{1}{2\sqrt{ap_s}}\left[f_G\left(\sqrt{\frac{ps}{a}}\right) + f_g\left(-\sqrt{\frac{ps}{a}}\right)\right] \tag{18}$$

Therefore, the PDF of solar PV output power is

$$f_{p_s}(p_s) = \frac{1}{2\sqrt{\frac{P_{Sr}p_s}{G_{std}R_c}}} * \left[f_G\left(\sqrt{\frac{p_s G_{std} R_c}{P_{Sr}}}\right) + f_G\left(-\sqrt{\frac{p_s G_{std} R_c}{P_{Sr}}}\right)\right] \tag{19}.$$

The cost PV solar expressed by Equation (7) [31]

$$F4\left(P_{PV,m,t}\right) = \sum_{m=1}^{N_{PV}} K_{pv,k}\, P_{PV,m,t} \tag{20}.$$

2.4 LOAD DEMAND UNCERTAINTY MODEL

This function is given by [18]

$$f_l(l) = \frac{1}{\partial\sqrt{2\pi}} * \exp\left[-\left(\sqrt{\frac{(l-\mu)^2}{2\partial^2}}\right)\right] \tag{21},$$

Where:
σ: standard deviation of the uncertain load.
μ: mean value of the uncertain load.

2.5 MULTI OBJECTIVE FUNCTION

In the multi-objective CDEED dispatch, the problem can be expressed as :

$$Min\ F\left(P_{gi,t}\right) = \left[F1\left(P_{gi,t}\right), F2\left(P_{gi,t}\right), F3\left(P_{win,k,t}\right), F4\left(P_{PV,m,t}\right),\right] \tag{22}.$$

In [4], we can formulate the CDEED problem with these multi-objective and these non-linear constraints into a mono-objective problem using the weighting method

$$Min\ F = w\,F1 + pf\,(1-w)\,F2 \tag{23}.$$

Where pf is the price penalty factor as in Equation (24)

$$pf_i\left(P_{ig}^{max}\right) = \frac{F1\left(P_{ig}^{max}\right)}{F2\left(P_{ig}^{max}\right)}\ \$/ton \tag{24}.$$

Where $w \in [0, 1]$ is a weighting factor. It will be noted that when w = 1, the dynamic economic dispatch problem (DEcD) look Equation (2) finds the optimal amount of the power generation by minimization of the cost. If = 0, then the dynamic emission dispatch problem (DEmD) problem gives the optimal amount of power generation by minimization of the emission. If $w = 0.5$, then DEED determines power generation by minimization simultaneously of the economic and emission [12].

2.6 PROBLEM CONSTRAINTS

The active power equilibrium equation

$$\sum_{i=1}^{N_n} P_{gi,t} + P_{win} + P_{PV} = P_{Dt} + P_{Lt} \;;\; t = 1,2,\ldots,T \tag{25}$$

Or

$$P_{Lt} = \sum_{t=1}^{T} \sum_{i=1}^{N_n} P_{gi,t} B_{ij} P_{gj,t} \quad ;\; t = 1,2,\ldots,T \qquad (26).$$

Generator limits

$$P_{gi}^{min} \le P_{gi,t} \le P_{gi}^{max} \qquad (27).$$

2.6.1 GENERATING UNIT RAMP-RATE LIMITS

At a well-determined time interval, the output power of a unit can be decreased (ramp down) or increased (ramp-up) according to the specified maximum ramp rates. This Violation of the unit ramp rates makes it possible to reduce the lifespan of electrical generations. These ramp rate limits must respect the variation in the load request [30].

$$P_{gi,t} - P_{gi,t-1} \le UR_{gi} \qquad (28.1),$$

$$P_{gi,t-1} - P_{gi,t} \le DR_{gi} \qquad (28.2),$$

for $i \in N_n \; et \; t = 2, 3, \ldots\ldots T,$

where (28.1) when generation increases, (28.2) when generation decreases. If the limits of unit ramp-rate are taken into account, the real generated power limits (9) can be modified as the following Equation:

$$\max\left(P_{gi}^{\min}, P_{gi,t-1} - DR_{gi}\right) \le P_{gi,t} \le \min\left(P_{gi}^{\max}, P_{gi,t-1} + UR_{gi}\right) \tag{29}$$

3 STUDY DETAILS MULTI-OBJECTIVE ANT LION OPTIMIZER (MOALO)

An algorithm called Ant Lion Optimizer (ALO) was inspired by nature, proposed by Seyedali Mirjalili in 2015. The fundamentals and steps are detailed in reference [19, 20, 21, 22]. This is one of the algorithms that are also used for the economic emission load dispatch problem (EELDP it is one of the significant recent research [23, 24].

The original random walk utilized in the ALO algorithm to simulate the random walk of ants follows Equation (28) [25].

$$X(t) = [0, cumsum\,(2r(t1) - 1) - 1), cumsum\,(2r(t2) - 1), \ldots .\, cumsum\,(2r(tn) - 1) \tag{30}$$

where $r(t)$ expressed by Equation (31)

$$r(t) = \begin{cases} 1 \text{ if } rand > 0.5 \\ 0, \ otherwise \end{cases} \qquad (31),$$

where (rand) random number generated with uniform distribution in the interval of [0,1], and t shows the step of random walk (iteration in this study).

Equation (32) is used in the normalization of random walks, in order to prevent the ants from in research space [24]

$$X_i^t = \frac{(X_i^t - a_i) \times (d_i^t - c_i^t)}{b_i - a_i} + c_i^t \qquad (32).$$

Equations (33) and (34) represent the mathematical expressions of trapping ants used in simulation [23]

$$c_m^t = Ant - lion_n^t - c^t \qquad (33)$$

$$d_m^t = Ant - lion_n^t - d^t \qquad (34)$$

The method of the roulette wheel is used in the selection of the lion ant stronger for the construction of the trap.

In the simulation of ants sliding towards, the limits of random walks should be adaptively reduced as follows Equations (35) and (36) [26]:

$$c^t = \frac{c^t}{I} \qquad (35)$$

$$d^t = \frac{d^t}{I} \qquad (36)$$

Where $I = 10^w(t/S)$, t is the courant iteration, S is the maximum number of iterations and w is a constant whose value is given by system (19) [23]

$$w = \begin{cases} 2 \ \ if \ \ t > \ 0.1S \\ 3 \ if \ \ t > \ 0.5S \\ 4 \ if \ t > \ 0.75S \\ 5 \ \ if \ t > \ 0.9S \\ 6 \ \ if \ \ t > \ 0.95S \end{cases} \qquad (37)$$

To catch ant lion ants and re-construction of the pit can be described mathematically by Equation (38) [21]:

$$Antlion_j^t = Ant_i^t, \text{ if } f(Ant_i^t) > f(Antlion_j^t) \qquad (38),$$

where $Antlion_j^t$ indicates shows the selected position of jth ant lion at ith iteration, Ant_i^t indicates the position of ith ant at ith iteration, at the current iteration t.

Equation (39) indicates that the roulette wheel is used in the calculation of the last operator in ALO, that is elitism [26]

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \qquad (39),$$

where R_A^t : random walk nearby the ant lion.

R_E^t : random walk nearby the elite at tth iteration,

Ant_i^t: location of ith ant at tth iteration

4 IMPLANTATION OF MOALO TO SOLVE CDEEDP

The MOALO contains the following steps [27]:

Step 1: Initialization of random walks by Equation (28), ant position generation saved using a matrix

$$M_{Ant} = \begin{bmatrix} Ant_{1,1} & Ant_{1,2} & Ant_{1,3} & \dots & Ant_{1,d} \\ Ant_{2,1} & Ant_{2,2} & Ant_{2,3} & \dots & Ant_{2,d} \\ \dots & \dots & \dots & & \dots \\ Ant_{n,1} & Ant_{n,2} & Ant_{n,3} & \dots & Ant_{n,d} \end{bmatrix}_{n\times d} \quad (40),$$

where

M_{Ant}: matrix to save the position for each ant.

d: number of variables.

$Ant_{\,i,j}$: the value of the jth variable for ith ant.

n is an ant number.

Step 2: evaluation of each ant, the following matrix (41) presents the fitness value of all ants during optimization

$$M_{OA} = \begin{bmatrix} f([Ant_{1,1} & Ant_{1,2} & Ant_{1,3} & \dots & Ant_{1,d}]) \\ f([Ant_{2,1} & Ant_{2,2} & Ant_{2,3} & \dots & Ant_{2,d}]) \\ & & & \ddots & \\ f([Ant_{n,1} & Ant_{n,2} & Ant_{n,3} & \dots & Ant_{n,d}]) \end{bmatrix} \quad (41)$$

where M_{OA}: fitness of each ant, saved in this matrix.

$Ant_{\,i,j}$: jth dimension for ith ant,

f: objective function.

Step 3: the previous matrices (40) and (41) described below (42) used to save the optimal generation power and the optimal corresponding cost:

$$M_{AL} = \begin{bmatrix} AL_{1,1} & AL_{1,2} & AL_{1,3} & \cdots & AL_{1,d} \\ AL_{2,1} & AL_{2,2} & AL_{2,3} & \cdots & AL_{2,d} \\ \dots & \dots & \dots & \dots & \vdots \\ AL_{n,1} & AL_{n,2} & AL_{n,3} & \cdots & AL_{n,d} \end{bmatrix} \quad (42),$$

where M_{AL} : matrix to save the position of each ant lion,

n: ant lions number, d: variables (generators) number.

Where M_{OAL}matrix saves the fitness for each ant lion.

AL_{ij} jth dimension's value of ith ant lion,

$$M_{OAL} = \begin{bmatrix} f([AL_{1,1} & AL_{1,2} & AL_{1,3} & \dots & AL_{1,d}]) \\ f([AL_{2,1} & AL_{2,2} & AL_{2,3} & \dots & AL_{2,d}]) \\ & & & \ddots & \\ f([AL_{n,1} & AL_{n,2} & AL_{n,3} & \dots & AL_{n,d}]) \end{bmatrix} \quad (43)$$

5 FRONT PARETO AND BEST COMPROMISE SOLUTION

The membership function evaluated by the Decision-maker (DM), μF_k in a subjective manner [28, 29] and is defined strictly monotonic decreasing and continuous function as

$$\mu_{F_k}(i) = \begin{cases} \frac{F_k^{Max} - F_k(i)}{F_k^{Max} - F_k^{Min}}, & F_k^{Max} \leq F_k \leq F_k^{Min} \\ 0, & Otherwise \end{cases} \quad (44).$$

The procedure is first to find and save the maximum for each objective, second Addition one of the objective functions (emission function F_2) to constraints

$$F2 = Min\ E_{m_{it}}(P_{gi,t}) \leq \varepsilon \quad (45).$$

The ε value will be varied from $F2^{max}$ to $F2^{min}$ and then $F1$ (cost function) is minimized.

The final optimal solution reached, after a decision taken according to the conditions of the procedure described in the steps of the algorithm.

Where nS number of the total solution and nF number of objective functions

$$\underset{1:nS}{\text{Max}}\left(\underset{1:nF}{\min}(\mu \text{F}_\text{k})\right) \quad (46).$$

6 ANALYZE AND DISCUSSION OF RESULTS

In this paper, 10-units test power systems to demonstrate the performance of the proposed approach with the three following cases:

Case#1: DEcD: *DEcDP* dynamic economic dispatch problem.

Case#2: DEmD: *DEmDP* dynamic emission dispatch problem.

Case#3: CDEEDP: Combined dynamic economic emission dispatch problem.

Test Ten-unit power system, the generators' input data, price penalty factors for hourly load demands, and the transmission power losses coefficients of this system are given in Tables 10, 11, and 12, respectively.

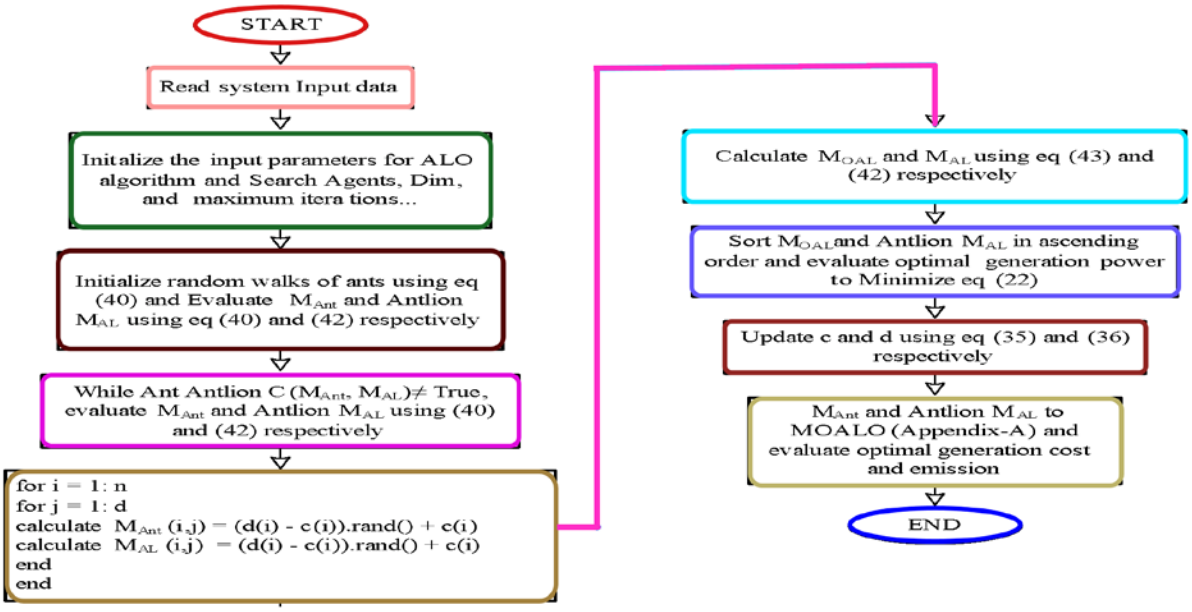


Figure 1: Flow-chart of combined environmental economic dispatch using the MOALO algorithm.

All the simulations results are done using MATLAB R2013a and executed with i3-2310M CPU @ 2.10 GHz and 6 GB RAM PC. The system data is the same for all cases. The proposed algorithm was employed with the population size is 100 and the maximum iteration number max 100 for the 10-units test system under consideration.

For each value power demand, this well is the algorithm turned in order to obtain a better result. The convergence characteristic of the proposed MOALO algorithm for the 10-units test system is depicted in Figure 2. We can see that 100 iterations take by MOALO to converge towards the best solution nearby. This proves the complexity of the CDEED problem when considering the transmission power losses and the effect of the valve point.

The numerical results for the Pareto front and compromise solution for DEEDP of the 10-unit system are given in Table 1. When the best cost is 2592900 $ and the best emission is 292100 lb. Figures 3 show the Pareto and compromise solution for the case#3 obtained from the proposed method.

Similarly, Tables 2 and 3 give the results of dynamic economic dispatch, dynamic emission dispatch, and combined economic emission dispatch and power losses for the 24-h period for a 10-unit system, with and without ramp rate.

6.1 CASE#1: 10-UNIT SYSTEM DECDP

With a comparison of the minimum total fuel cost firstly obtained by different approaches. The minimum fuel cost obtained by MOALO (2455700$) is the best value than the value obtained by different approaches. Secondly, with a comparison of the minimum emission obtained by different approaches. The minimum emission obtained by MOALO (17853 lb) is the same value obtained by the better approach in the literature, the same remark for the value of power losses.

6.2 CASE#2: 10-UNIT SYSTEM DEMDP

Case# 2 concerns a 10-unit system where w= 0 and variable values of pf for 24 hours, the transmission loss is not considered with the valve point effect. Table 3 gives a comparison between the obtained result and the literature approach in this situation case. It gives the best results for the employed method after comparison to that in literature. The emission is 291610 lb less than NEHS approach. Compared with the last situation in this case the cost increased.

6.3 CASE#3: 10-UNIT SYSTEM CDEEDP

Equation (5) is used in this case situation where the price penalty factor pf is computed using Equation (22). The minimum function cost given by the employed MOALO algorithm is $2529000/h among 100 trials in economic dispatch can be taken into consideration as the ever-better solution. It is also observed from the simulation results that the employed algorithm gives the best statistical simulations results in comparison with other available results given in Table 3. The corresponding emission and loss are found to 18434 lb and 189,2309 MW respectively.

6.4 EXTENDED OF DEEDP BY RAMP RATE CONSTRAINT

Respect Equations (28.1) and (28.2) to solve DDP with the 10-units test system with the three cases. Table 3 gives summary results, and then the corresponding results are presented in Tables 4, 5, and 6 for the test system. Results of simulation demonstrate that when the better total fuel cost dispatch is taken into consideration, the system is facing the minimum amount of cost for a 24h time interval, where without ramp rate, it is 2455700 $. On the other hand with consideration of the better pollutant emission, the system operating at its lowest amount of emission, 291610 lb. Concerning the combined dispatch minimum emission and total fuel cost case, pollutant emission and the total fuel cost obtained by the proposed algorithm can be scaled down about 2529000$ and 295490 lb.

Then with the ramp rate, it is 2462400 $. On the other hand with consideration of the better pollutant emission, the system operating at its lowest amount of emission, 303920 lb. For the combined minimum fuel cost and emission case, the fuel cost and pollutant emission obtained by the proposed method can be reduced by about 2546000 $ and 293440 lb. The ramp-up/ramp-down values of each unit for each hour in the optimization problem of the DEED is shown in Figure 4. It can be seen that the unit ramp rate constraints and in particular the constraint (10) have been respected. However, for the conventional DEED problem, from the obtained simulation results of the ten-unit system using CRO [10], HCRO [10], DE-SQP [4], PSO-SQP [4], MAMODE [11], IBFA [12], RCGA [13], MRGA [1], NEHS [9] methods, it is clearly seen that the proposed method given the best solution for the ten units systems than those reported in the literature.

The generation of each unit over 24h for the best compromise solution is shown in Figure 4. It can be seen that the generators 5, 6, 7, 8, 9, and 10 reach their maximum production from a total load demand greater than or equal to 1258 MW since they are the least powerful machines, but the generated power by the committed units 1, 2, 3 and 4 follow the profile of load demand PD and work with their full capacities in peak demand times.

6.5 INTEGRATED WIND AND SOLAR ENERGY SYSTEMS FOR DYNAMIC DISPATCH WITH RAMP RATE CONSTRAINT

Solar PV generator (SPVG) rating and wind power generator (WPG) rating are PS=150 MW and pr =150MW respectively. Kwin = 3.25 and Kpv = 3.5 are respectively the direct cost coefficient of WPG and SPVG. The values 150 W/m^2 and 1000 W/m^2 are taken by Rc and Gstd for solar radiation in certain and standard environments respectively. vr=15 m/s, vo=25 m/s and vin=4m/s are the rating value respectively of wind speeds, cut-out and cut-in. Table 13 [32] contains solar radiation and wind velocity. Tables 7, 8, and 9 illustrate the best solutions for multi-objective wind, solar, and thermal dispatch with ramp rate using MOALO for the 10- test system. The effect of the integration of renewable energy is influential, the cost and the emission for case#1, case#2, and case#3 equal 2307100 $, 283100 lb; 2501000 $, 257230 lb; 22415600 $, 253580 lb respectively, are lower than without energy renewable.

Table 1: The numerical results for Pareto front and compromise solution for DEEDP of 10-unit system

Sn	ε (10^6)	Fu (10^6)	Em (10^6)	μ_{Fu}	μ_{Em}	min (μ_{Fu}, μ_{Em})
1	0.31	2.66	0.29	0	1.00	0
2	0.31	2.63	0.29	0.26	0.95	0.26
3	0.31	2.62	0.29	0.36	0.90	0.36
4	0.31	2.61	0.29	0.43	0.85	0.43
5	0.31	2.60	0.29	0.50	0.80	0.50
6	0.31	2.60	0.29	0.55	0.75	0.55
7	0.31	2.59	0.29	0.60	0.70	0.60
8	0.31	**2.59**	**0.29**	0.64	0.65	**0.64**
9	0.31	2.58	0.29	0.68	0.60	0.60
10	0.31	2.58	0.29	0.72	0.55	0.55
11	0.31	2.58	0.29	0.75	0.50	0.50
12	0.31	2.57	0.29	0.78	0.45	0.45
13	0.31	2.57	0.29	0.81	0.40	0.40
14	0.31	2.57	0.29	0.84	0.35	0.35
15	0.31	2.56	0.29	0.86	0.30	0.30
16	0.31	2.56	0.29	0.89	0.25	0.25
17	0.31	2.56	0.29	0.91	0.20	0.20
18	0.31	2.56	0.29	0.93	0.15	0.15
19	0.32	2.55	0.29	0.96	0.10	0.10
20	0.32	2.55	0.29	0.98	0.05	0.05
21	0.32	2.55	0.29	1.00	0	0

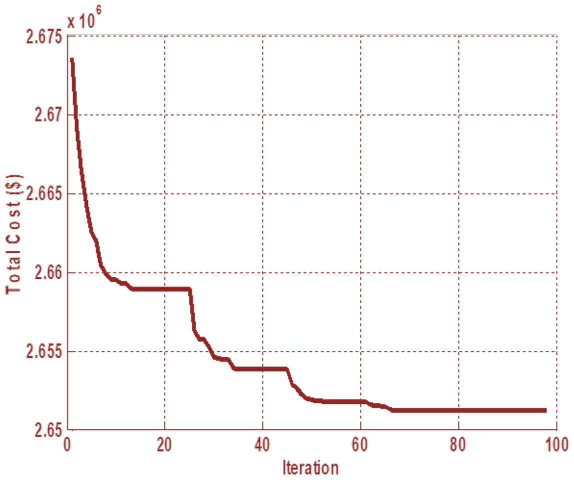


Figure 2: Convergence characteristic of MOALO for case#3.

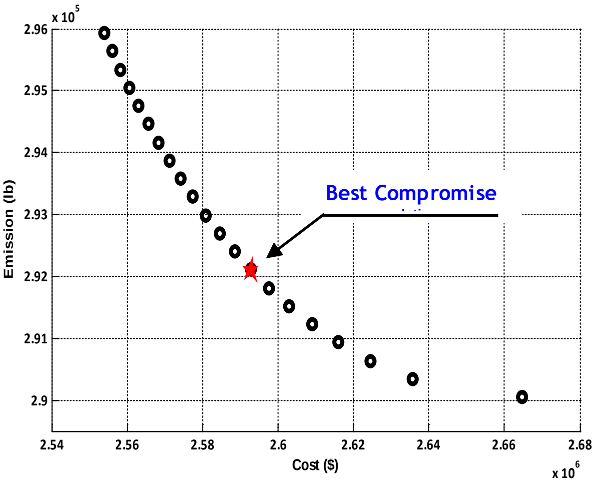


Figure 3: Pareto and compromise solution of MOALO for case#3.

Table 2: Best solutions for multi-objective wind, solar and thermal dispatch with ramp rate using MOALO

	Without wind and solar			With wind and solar		
	DEcD	DEmD	DEEDP	DEcD	DEmD	DEED
Cost ($)	2462400	2658900	254600	2307100	2501000	2415600
Emission (lb)	322740	303920	293440	283100	257230	253580
Total cost ($)			2633400			2368600
Ploss	1282.8	1315.3	1299.6	1089.7	1129.4	1112.5

Table 3: The DEcD, DEmD, and CDEED results of different algorithms for with and without ramp rate

Problem type	Method	without the ramp rate		with ramp rate		P Loss (MW)
		function values				
		Cost ($)	Emission (lb)	Cost ($)	Emission (lb)	
DEcDP	CRO [10]	2 481 613.38	--	--	--	1292.96
	HCRO [10]	2 479 931.38	--	--	--	1292.53
	DE-SQP [4]	2.46×10^6	--	--	--	1289.7
	PSO-SQP [4]	2.46×10^6	--	--	--	1289.7
	MAMODE [11]	--	--	2 492 451	315119	1297.6
	IBFA [12]	--	--	2 481 733.25	327501	1295.26
	RCGA [13]	--	--	2.51×10^6	317400	--
	MRGA [1]	2.49×10^6	--	--	--	
	NEHS [9]	2 463 500.84	--	--	--	
	MOALO	**2 455 700**	**337360**	**2462400**	**322740**	**1282.8**
DEmDP	CRO [10]	--	298 664.48	--	--	1300.28
	HCRO [10]	--	298 456.27	--	--	1300.27
	MAMODE [11]	--	295 244	--	295 244	--
	IBFA [12]	--	295 833.03	--	295 833.03	1319.95
	RCGA [13]	--	3.04×10^5	--	3.04×10^5	--
	MRGA [1]	--	2.92×10^5	--	--	--
	NEHS [9]	--	291 849.47	--	--	--
	MOALO	**2592900**	**291 610**	**2658900**	**303920**	**1315.3**
CDEEDP	CRO [10]	2 517 821.03	301 941.92	--	--	1298.47
	HCRO [10]	2 517 076.39	299 065.50	--	--	1299.87
	DE-SQP [4]	2.46×10^6	3.15×10^5	--	--	1290.0
	PSO-SQP [4]	2.47×10^6	3.15×10^5	--	--	1290.3
	MAMODE [11]	--	--	2 514 113	302742	--
	IBFA [12]	--	--	2 517 116.74	299 036.71	1299.88
	NSGA-II [13]	--	--	2.52×10^6	3.09×10^5	--
	RCGA [13]	--	--	2.52×10^6	3.12×10^5	--
	MRGA [1]	2 555 180.88	299 140.86	--	--	1305.4
	MNSGA-II [1]	2 517 711.43	308 674.15	--	--	1299.3
	NEHS [9]	2 533197.20	295 120.86	--	--	--
	MOALO	**2 529 000**	**295 490**	**2546000**	**293440**	**1299.6**
		Total cost = **2633800 $**		Total cost =**2633400 $**		

Table 4: The best solutions obtained by MOALO for case#1 with ramp rate without wind and solar.

PD	Dynamic Economic Dispatch (DEcD)										PLoss
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	
1036	150.00	135.00	73.00	78.67	178.86	156.57	130.00	120.00	20.00	12.87	19.62
1110	150.00	135.00	85.61	97.25	210.03	160.00	130.00	120.00	25.73	17.95	22.37
1258	150.00	135.00	137.59	141.42	243.00	160.00	130.00	120.00	39.08	29.19	28.43
1406	150.00	135.00	208.53	191.42	243.00	160.00	130.00	120.00	57.31	44.53	35.38
1480	150.00	135.00	242.39	227.90	243.00	160.00	130.00	120.00	61.25	47.84	39.24
1628	150.00	135.00	322.39	277.90	243.00	160.00	130.00	120.00	80.00	55.00	47.87
1702	150.00	173.60	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	52.72
1776	172.83	229.56	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	58.12
1924	251.43	309.56	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	70.10
2022	287.98	378.81	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	78.98
2106	325.35	432.64	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	87.17
2150	344.98	460.91	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	91.68
2072	337.84	383.15	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	83.74
1924	257.84	303.15	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	70.10
1776	179.24	223.15	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	58.11
1554	150.00	143.15	270.74	250.00	243.00	160.00	130.00	120.00	73.29	55.00	43.43
1480	150.00	135.00	241.16	220.95	243.00	160.00	130.00	120.00	65.69	51.58	39.25
1628	150.00	158.25	306.08	270.95	243.00	160.00	130.00	120.00	80.00	55.00	47.94
1776	214.44	238.25	312.88	277.01	243.00	160.00	130.00	120.00	80.00	55.00	58.49
1972	294.44	318.25	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	74.34
1924	266.00	295.00	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	70.10
1628	186.00	215.00	260.00	250.00	243.00	160.00	130.00	120.00	61.14	48.35	48.54
1332	150.00	135.00	180.00	200.00	234.25	160.00	130.00	120.00	31.14	21.90	31.69
1184	150.00	135.00	100.00	150.00	217.01	160.00	130.00	120.00	27.08	19.09	25.22
Total	Cost= 2462400 $, Em=322740 lb										1282.8

Table 5: The best solutions obtained by MOALO for case#2 with ramp rate without wind and solar.

PD	Dynamic Emission Dispatch (DEmD)										P_{Loss}
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	
1036	150.00	135.00	90.48	90.48	130.16	130.16	97.25	97.25	80.00	55.00	19.67
1110	150.00	138.32	100.75	100.75	145.35	145.35	108.48	108.48	80.00	55.00	22.43
1258	167.36	167.36	118.55	118.55	171.69	160.00	127.97	120.00	80.00	55.00	28.92
1406	204.47	204.47	141.30	141.30	205.35	160.00	130.00	120.00	80.00	55.00	36.63
1480	223.37	223.37	152.88	152.88	222.48	160.00	130.00	120.00	80.00	55.00	40.88
1628	264.44	264.44	178.05	178.05	243.00	160.00	130.00	120.00	80.00	55.00	50.26
1702	290.29	290.29	193.90	193.90	243.00	160.00	130.00	120.00	80.00	55.00	55.43
1776	314.87	314.87	208.97	208.97	243.00	160.00	130.00	120.00	80.00	55.00	60.90
1924	364.28	364.28	239.26	239.26	243.00	160.00	130.00	120.00	80.00	55.00	72.75
2022	397.33	397.33	259.51	259.51	243.00	160.00	130.00	120.00	80.00	55.00	81.27
2106	425.91	425.91	277.03	277.03	243.00	160.00	130.00	120.00	80.00	55.00	89.00
2150	440.98	440.98	286.27	286.27	243.00	160.00	130.00	120.00	80.00	55.00	93.21
2072	414.29	414.29	269.91	269.91	243.00	160.00	130.00	120.00	80.00	55.00	85.82
1924	364.28	364.28	239.26	239.26	243.00	160.00	130.00	120.00	80.00	55.00	72.75
1776	314.87	314.87	208.97	208.97	243.00	160.00	130.00	120.00	80.00	55.00	60.90
1554	242.29	242.29	164.48	164.48	239.65	160.00	130.00	120.00	80.00	55.00	45.40
1480	223.37	223.37	152.88	152.88	222.48	160.00	130.00	120.00	80.00	55.00	40.88
1628	265.77	265.77	178.87	178.87	243.00	160.00	130.00	120.00	80.00	55.00	50.26
1776	314.87	314.87	208.97	208.97	243.00	160.00	130.00	120.00	80.00	55.00	60.90
1972	380.44	380.44	249.16	249.16	243.00	160.00	130.00	120.00	80.00	55.00	76.85
1924	356.51	356.51	258.60	235.45	243.00	160.00	130.00	120.00	80.00	55.00	72.47
1628	276.51	276.51	178.60	185.45	215.20	160.00	130.00	120.00	80.00	55.00	50.51
1332	196.51	196.51	119.16	135.45	172.59	160.00	128.64	120.00	80.00	55.00	32.84
1184	152.18	152.18	109.24	109.24	157.92	157.92	117.78	117.78	80.00	55.00	25.50
Total	Em=303920 lb, Cost= 2658900$										1326,5

Table 6: The best solutions obtained by MOALO for case#3 with ramp rate without wind and solar.

PD	Economic Emission Dispatch (CDEED)										PLoss
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	
1036	150.00	135.00	84.40	86.28	133.58	129.83	108.05	108.05	65.61	55.00	19.67
1110	150.00	135.00	93.86	95.43	148.03	143.94	119.18	119.18	72.89	55.00	22.44
1258	150.00	135.00	129.04	129.44	198.03	160.00	130.00	120.00	80.00	55.00	28.51
1406	150.00	152.25	176.36	175.30	243.00	160.00	130.00	120.00	80.00	55.00	35.56
1480	159.89	175.43	199.22	197.47	243.00	160.00	130.00	120.00	80.00	55.00	39.62
1628	219.26	237.20	214.88	213.66	243.00	160.00	130.00	120.00	80.00	55.00	49.19
1702	240.33	261.02	234.30	232.75	243.00	160.00	130.00	120.00	80.00	55.00	54.21
1776	260.37	283.66	252.76	250.91	243.00	160.00	130.00	120.00	80.00	55.00	59.50
1924	311.74	336.66	280.26	278.44	243.00	160.00	130.00	120.00	80.00	55.00	71.26
2022	343.55	370.08	301.00	299.07	243.00	160.00	130.00	120.00	80.00	55.00	79.65
2106	380.63	406.79	318.49	300.00	243.00	160.00	130.00	120.00	80.00	55.00	87.58
2150	397.46	425.09	331.95	300.00	243.00	160.00	130.00	120.00	80.00	55.00	91.86
2072	361.86	390.24	316.30	300.00	243.00	160.00	130.00	120.00	80.00	55.00	84.21
1924	311.74	336.66	280.26	278.44	243.00	160.00	130.00	120.00	80.00	55.00	71.26
1776	259.17	280.82	254.79	252.91	243.00	160.00	130.00	120.00	80.00	55.00	59.42
1554	179.17	200.82	216.23	213.97	243.00	160.00	130.00	120.00	80.00	55.00	44.06
1480	159.89	175.43	199.22	197.47	243.00	160.00	130.00	120.00	80.00	55.00	39.62
1628	220.35	238.43	215.88	214.64	243.00	160.00	130.00	120.00	80.00	55.00	49.19
1776	260.37	283.66	252.76	250.91	243.00	160.00	130.00	120.00	80.00	55.00	59.50
1972	329.07	354.13	288.89	287.11	243.00	160.00	130.00	120.00	80.00	55.00	75.36
1924	310.00	326.98	298.52	271.61	243.00	160.00	130.00	120.00	80.00	55.00	71.15
1628	230.00	246.98	218.52	221.61	215.20	160.00	130.00	120.00	80.00	55.00	49.39
1332	150.00	166.98	138.52	171.61	191.80	160.00	130.00	120.00	80.00	55.00	32.02
1184	150.00	135.00	102.42	121.61	159.87	156.69	129.24	120.00	79.47	55.00	25.36
Total	Cost =2546000 $, Em = 2933400 lb, , Total Cost=2633400 $										1299,6

Table 7: The best solutions obtained by MOALO for case#1 with ramp rate with wind and solar

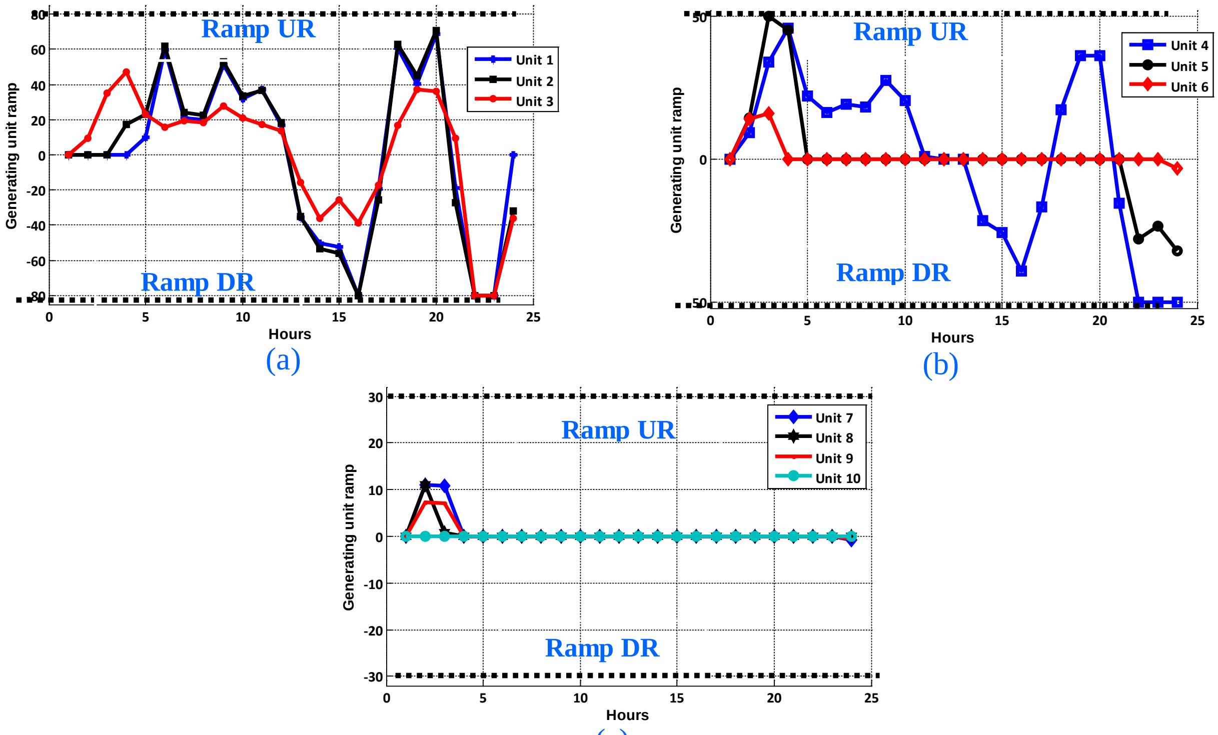
PD	Dynamic Economic Dispatch (DEcD)												PLoss
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{wind}	P_{solar}	
1036	150.00	135.00	73.00	78.68	178.87	156.58	130.00	120.00	20.00	12.88	0	0	18.97
1110	150.00	135.00	85.62	97.26	210.03	160.00	130.00	120.00	25.74	17.96	0	0	21.59
1258	150.00	135.00	137.60	141.42	243.00	160.00	130.00	120.00	39.09	29.19	0	0	27.32
1406	150.00	135.00	208.53	191.42	243.00	160.00	130.00	120.00	57.31	44.53	0	0	33.77
1480	150.00	135.00	242.40	227.90	243.00	160.00	130.00	120.00	61.25	47.85	0	0	37.35
1628	150.00	135.00	322.40	277.90	243.00	160.00	130.00	120.00	80.00	55.00	0	0	45.25
1702	150.00	160.48	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	0	12.32	48.84
1776	155.61	197.04	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	0	46.65	51.28
1924	223.51	277.04	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	0	56.25	60.80
2022	254.61	330.74	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	0	75.45	66.75
2106	284.19	373.36	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	0	92.55	72.11
2150	299.13	394.87	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	0	102.90	74.90
2072	288.03	318.82	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	0	105.45	68.31
1924	208.03	238.82	302.81	269.04	243.00	160.00	130.00	120.00	80.00	55.00	60.00	110.40	53.14
1776	150.00	158.82	297.06	257.86	243.00	160.00	130.00	120.00	80.00	55.00	80.45	87.90	44.11
1554	150.00	135.00	217.06	207.86	243.00	160.00	130.00	120.00	50.00	27.95	83.18	63.75	33.76
1480	150.00	135.00	196.55	191.64	232.53	160.00	130.00	120.00	49.51	25.00	77.72	43.65	31.56
1628	150.00	135.00	276.55	241.64	243.00	160.00	130.00	120.00	79.51	55.00	70.90	7.40	40.96
1776	156.97	207.71	316.55	279.91	243.00	160.00	130.00	120.00	80.00	55.00	76.36	0	49.50
1972	236.97	287.71	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	81.81	0	62.47
1924	230.00	243.18	340.00	300.00	243.00	160.00	130.00	120.00	80.00	55.00	81.81	0	58.95
1628	150.00	163.18	260.00	250.00	243.00	160.00	130.00	120.00	64.75	53.17	75.00	0	41.12
1332	150.00	135.00	180.00	200.00	193.00	112.63	130.00	120.00	34.75	23.17	80.45	0	27.04
1184	150.00	135.00	100.00	150.00	149.58	122.05	130.00	120.00	20.00	10.00	117.27	0	19.89
Total	Cost =2307100 $, Em = 283100 lb												1089.7

Table 8: The best solutions obtained by MOALO for case#2 with ramp rate with wind and solar.

PD	Dynamic Economic Dispatch (DEcD)												
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{wind}	P_{solar}	Ploss
1036	150.00	135.00	90.37	90.37	129.99	129.99	97.12	97.12	80.00	55.00	19.02	0	18.97
1110	150.00	138.15	100.64	100.64	145.19	145.19	108.37	108.37	80.00	55.00	21.62	0	21.58
1258	167.19	167.19	118.45	118.45	171.54	160.00	127.86	120.00	80.00	55.00	27.66	0	27.31
1406	204.20	204.20	141.13	141.13	205.10	160.00	130.00	120.00	80.00	55.00	34.81	0	33.77
1480	223.05	223.05	152.69	152.69	222.20	160.00	130.00	120.00	80.00	55.00	38.74	0	37.35
1628	265.15	265.15	178.49	178.49	243.00	160.00	130.00	120.00	80.00	55.00	47.28	0	45.25
1702	285.48	285.48	190.95	190.95	243.00	160.00	130.00	120.00	80.00	55.00	51.18	12.32	48.84
1776	298.58	298.58	198.98	198.98	243.00	160.00	130.00	120.00	80.00	55.00	53.78	46.65	51.28
1924	344.46	344.46	227.10	227.10	243.00	160.00	130.00	120.00	80.00	55.00	63.41	56.25	60.79
2022	370.72	370.72	243.20	243.20	243.00	160.00	130.00	120.00	80.00	55.00	69.27	75.45	66.75
2106	393.07	393.07	256.90	256.90	243.00	160.00	130.00	120.00	80.00	55.00	74.48	92.55	72.10
2150	404.33	404.33	263.81	263.81	243.00	160.00	130.00	120.00	80.00	55.00	77.17	102.90	74.90
2072	377.38	377.38	247.28	247.28	243.00	160.00	130.00	120.00	80.00	55.00	70.81	105.45	68.31
1924	306.60	306.60	203.89	203.89	243.00	160.00	130.00	120.00	80.00	55.00	55.40	110.40	53.13
1776	258.44	258.44	174.38	174.38	243.00	160.00	130.00	120.00	80.00	55.00	46.04	87.90	44.11
1554	204.49	204.49	141.31	141.31	205.36	160.00	130.00	120.00	80.00	55.00	34.87	63.75	33.76
1480	192.16	192.16	133.75	133.75	194.18	160.00	130.00	120.00	80.00	55.00	32.42	43.65	31.55
1628	240.86	240.86	163.60	163.60	238.35	160.00	130.00	120.00	80.00	55.00	42.64	7.39	40.95
1776	288.75	288.75	192.96	192.96	243.00	160.00	130.00	120.00	80.00	55.00	51.83	0	49.50
1972	351.94	351.94	231.69	231.69	243.00	160.00	130.00	120.00	80.00	55.00	65.05	0	62.46
1924	330.05	330.05	236.33	219.23	243.00	160.00	130.00	120.00	80.00	55.00	61.52	0	58.95
1628	250.05	250.05	159.50	169.23	222.05	160.00	130.00	120.00	80.00	55.00	42.91	0	41.11
1332	170.05	170.05	111.87	119.23	172.05	160.00	120.66	120.00	80.00	55.00	27.35	0	27.03
1184	150.00	135.00	94.82	94.82	136.58	136.58	102.00	102.00	80.00	55.00	20.08	0	19.89
Total	Cost =2501000 $, Em = 257230 lb												1129.4

Table 9: The best solutions obtained by MOALO for case#3 with ramp rate with wind and solar

PD	Dynamic Economic Dispatch (DEmD)												
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	P_{wind}	P_{solar}	Ploss
1036	150.00	135.00	83.33	85.25	134.36	130.63	108.03	108.03	65.35	55.00	0.00	19.01	21.64
1110	150.00	135.00	92.78	94.38	148.85	144.70	119.13	119.13	72.61	55.00	0.00	27.38	33.96
1258	150.00	135.00	128.05	128.49	198.85	160.00	130.00	120.00	80.00	55.00	0.00	37.68	46.52
1406	150.00	158.74	172.09	171.16	243.00	160.00	130.00	120.00	80.00	55.00	0.00	50.32	52.84
1480	164.01	180.38	193.43	191.86	243.00	160.00	130.00	120.00	80.00	55.00	0.00	62.46	68.28
1628	226.20	245.04	208.18	207.07	243.00	160.00	130.00	120.00	80.00	55.00	0.00	73.57	76.21
1702	242.74	263.74	223.43	222.06	243.00	160.00	130.00	120.00	80.00	55.00	0.00	69.78	54.64
1776	253.39	275.78	233.24	231.72	243.00	160.00	130.00	120.00	80.00	55.00	0.00	45.31	34.01
1924	301.86	325.71	258.10	256.57	243.00	160.00	130.00	120.00	80.00	55.00	0.00	31.71	41.94
2022	327.81	352.74	273.94	272.34	243.00	160.00	130.00	120.00	80.00	55.00	0.00	50.94	64.15
2106	354.73	378.63	283.55	282.11	243.00	160.00	130.00	120.00	80.00	55.00	0.00	60.63	42.23
2150	364.59	389.35	291.43	289.91	243.00	160.00	130.00	120.00	80.00	55.00	0.00	27.12	20.09
2072	333.52	359.03	278.72	277.06	243.00	160.00	130.00	120.00	80.00	55.00	0.00	19.01	21.64
1924	269.81	290.19	230.68	229.51	243.00	160.00	130.00	120.00	80.00	55.00	60.00	27.38	33.96
1776	220.75	238.88	203.16	202.14	243.00	160.00	130.00	120.00	80.00	55.00	80.45	37.68	46.52
1554	150.00	159.10	172.45	171.51	243.00	160.00	130.00	120.00	80.00	55.00	83.18	50.32	52.84
1480	150.00	142.85	156.42	155.96	240.07	160.00	130.00	120.00	80.00	55.00	77.72	62.46	68.28
1628	205.25	221.36	188.88	188.09	243.00	160.00	130.00	120.00	80.00	55.00	70.90	73.57	76.21
1776	245.41	266.75	225.88	224.48	243.00	160.00	130.00	120.00	80.00	55.00	76.36	69.78	54.64
1972	311.74	335.05	260.51	259.07	243.00	160.00	130.00	120.00	80.00	55.00	81.81	45.31	34.01
1924	298.42	305.85	266.55	243.94	243.00	160.00	130.00	120.00	80.00	55.00	81.81	31.71	41.94
1628	218.42	225.85	186.55	193.94	225.41	160.00	130.00	120.00	80.00	55.00	75.00	50.94	64.15
1332	150.00	145.85	114.69	143.94	179.15	160.00	130.00	120.00	80.00	55.00	80.45	60.63	42.23
1184	150.00	135.00	86.60	93.94	139.13	135.50	111.87	111.87	67.86	55.00	117.27	27.12	20.09
Total	Cost = 2415600$, Em= 25358 lb, Total cost = 2368600 $												1112.5



(a) (b)

(c)

Figure 4: The ramp up/ramp down values of case#3
(a) units 1, 2, 3; (b) units 4, 5, 6; (c) units 7, 8, 9, 10

Table 10: Ten-unit power system -generators Characteristics.

Unit	Pmin	Pmax	a	b	c	d	e	α	β	γ	ζ	λ	UR	UD
1	(MW)	(MW)	($/MW^{2}h)	($/MWh)	($/h)	($/h)	(rad/MW)	(lb/h)	(lb/MWh)	(lb/M^{2}Wh)	(lb/h)	(MW-1)	(MW)	(MW)
1	150	470	0.15	38.54	786.79	450	0.04	103.39	-2.44	0.03	0.50	0.02	80	80
2	135	470	0.10	46.15	451.32	600	0.03	103.39	-2.44	0.03	0.50	0.02	80	80
3	73	340	0.02	40.39	1049.99	320	0.02	300.39	-4.07	0.05	0.49	0.02	80	80
4	60	300	0.03	38.30	1243.53	260	0.05	300.39	-4.07	0.05	0.49	0.02	50	50
5	73	243	0.02	36.32	1658.57	280	0.06	320.00	-3.81	0.03	0.49	0.02	50	50
6	57	160	0.01	38.27	1356.65	310	0.04	320.00	-3.81	0.03	0.49	0.02	50	50
7	20	130	0.01	36.51	1450.70	300	0.08	330.00	-3.90	0.04	0.51	0.02	30	30
8	47	120	0.01	36.51	1450.70	340	0.08	330.00	-3.90	0.04	0.51	0.02	30	30
9	20	80	0.10	39.58	1455.60	270	0.09	350.00	-3.95	0.04	0.54	0.02	30	30
10	10	55	0.13	40.54	1469.40	380	0.09	360.00	-3.98	0.04	0.54	0.02	30	30

Table 10: Price penalty factors for hourly load demands a 10-unit system.

Hr (h)	1	2	3	4	5	6	7	8	9	10	11	12
PD (MW)	1036	1110	1258	1406	1480	1628	1702	1776	1924	2022	2106	2150
Pf	3.69	3.69	3.69	4.11	4.11	8.06	8.06	8.06	10.39	11.34	13.67	13.67
Hr (h)	13	14	15	16	17	18	19	20	21	22	23	24
Pf	11.34	10.39	8.06	4.11	4.11	8.06	8.06	11.34	10.39	8.06	4.11	3.69
PD (MW)	2072	1924	1776	1554	1480	1628	1776	1972	1924	1628	1332	1184

Table 11: B-coefficients (B) Transmission losses of 10-unit power system (1.e-04), B_{ij} where : column: i=1 to 10. and line : j=1 to 10.

	B_{i1}	B_{i2}	B_{i3}	B_{i4}	B_{i5}	B_{i6}	B_{i7}	B_{i8}	B_{i9}	B_{i10}
B_{j1}	0.4900	0.1400	0.1500	0.1500	0.1600	0.1700	0.1700	0.1800	0.1900	0.2000
B_{j2}	0.1400	0.4500	0.1600	0.1600	0.1700	0.1500	0.1500	0.1600	0.1800	0.1800
B_{j3}	0.1500	0.1600	0.3900	0.1000	0.1200	0.1200	0.1400	0.1400	0.1600	0.1600
B_{j4}	0.1500	0.1600	0.1000	0.4000	0.1400	0.1000	0.1100	0.1200	0.1400	0.1500
B_{j5}	0.1600	0.1700	0.1200	0.1400	0.3500	0.1100	0.1300	0.1300	0.1500	0.1600
B_{j6}	0.1700	0.1500	0.1200	0.1000	0.1100	0.3600	0.1200	0.1200	0.1400	0.1500
B_{j7}	0.1700	0.1500	0.1400	0.1100	0.1300	0.1200	0.3800	0.1600	0.1600	0.1800
B_{j8}	0.1800	0.1600	0.1400	0.1200	0.1300	0.1200	0.1600	0.4000	0.1500	0.1600
B_{j9}	0.1900	0.1800	0.1600	0.1400	0.1500	0.1400	0.1600	0.1500	0.4200	0.1900
B_{j10}	0.2000	0.1800	0.1600	0.1500	0.1600	0.1500	0.1800	0.1600	0.1900	0.4400

Table 13: Forecast solar radiation and wind velocity.

Hr (h)	1	2	3	4	5	6	7	8	9	10	11	12
Gt(W/m^2)	0	0	0	0	0	0	111	311	375	503	617	686
Vwint(m/s)	3.5	3.6	1.5	1.4	0.1	1.8	1.3	2.2	3.8	3.7	2.0	0.6
Hr (h)	13	14	15	16	17	18	19	20	21	22	23	24
Gt(W/m^2)	703	736	586	425	291	86	0	0	0	0	0	0
Vwint(m/s)	0.4	8.4	9.9	10.1	9.7	9.2	9.6	10.0	10.0	9.5	9.9	12.6

7 CONCLUSION

This paper presents a MOALO algorithm used to solve a combined dynamic economic emission dispatch problem (CDEED) including transmission power losses, non-smooth cost functions associated with the point valve-point effect, ramp rate constraint, and the correlated PDF of wind power for the system consisting of thermal, wind and solar energy. We can conclude that the proposed multi-objective ant lion optimizer (MOALO) algorithm will provide valuable information and suggestions for safe, reliable, and economic operation of the power system. The DEED problem for the 10-units test system is carried out to determine the hourly generation schedule using MOALO for the optimum total fuel cost case#1, minimum pollutant emission case#2, and combined minimum fuel cost and emission case#3. Simulation results demonstrate that MOALO gives the best solution than the other method for the DEmD, DEcD, and CDEED systems and can give desirable solutions for 100 iterations. The reduction of cost and emission function, calculation efficiency, and able to convergence property of MOALO are demonstrated. Therefore MOALO algorithm optimization is a promising technique to solve complex problems in electrical power systems. Applications of the proposed algorithm to multi-objective problems in power systems including renewable energy such as the wind farms, PV system, hydro, and ESS operation are future work.

8 AVAILABILITY OF DATA AND MATERIAL

Information can be made available by contacting the corresponding author.

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