MOALO Algorithm applied to Dynamic Economic Environmental Dispatch including renewable energy

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Summary
The purpose in this present work, consists to use the multi-objective ant lion optimizer (MOALO) algorithm to solve dynamic economic environmental dispatch problems with and without ramp rate. The proposed method repository in first used to search for optimal solutions of the generated powers and then calculate the cost, emission functions. The dynamic problem of economic distribution (CDEED) is a major problem in power systems. This consists of a valve point effect, transmission losses, a load, a power balance and generator constraints. The proposed method was applied to 5-units test systems with different constraints. The results are compared with those of the literature. All simulations are performed on the MATLAB-Simulink platform.

Key words:
Dynamic economic emission dispatch problem; ramp rate; solar power; wind power; MOALO; power systems; transmission losses; valve point effect.

1. Introduction

The Combined dynamic economic emission dispatch problem (CDEEDP) includes DEcDP and EEmDP. DEcDP takes into consideration ramp rate limits, and EEmDP considers not only the economy but also the environment. CDEEDP has two objectives: the minimum total amount of pollution gases emission and the minimum total cost of the thermal power units during the total scheduling periods, which are mutual competing, namely, decrease of one objective with increase of another one[1]. Nowadays, scholars around the world mainly study CDEEDP on the aspect of solvers to solve the multi-objective non-convex and nonlinear optimization problem.
Dynamic economic dispatch (DEcD) is a method to schedule the online generator outputs with the predicted load demands over a certain period of time so as to operate an electric power system most economically [1–2]. It is a dynamic optimization problem taking into account the constraints imposed on the system operation by generator ramping rate limits. The DEcD is not only the most accurate formulation of the economic dispatch problem but also the most difficult to solve because of its large dimensionality. Normally, it is solved by dividing the entire dispatch period into a number of small time intervals, then a static economic dispatch has been employed to solve the problem in each interval. Since DEcD was introduced, several methods have been used to solve this problem. Several strategies to reduce the atmospheric pollution have been proposed and discussed [2]. These include installation of pollutant cleaning, switching to low emission fuels, replacement of the aged fuel burners with cleaner ones, and emission dispatching [2].
The CDEED problem is more intractable then the EEcD and DEmD problems [2], since it adds both the generating unit ramp-rate constraints and the emission function to the original economic load dispatch problem. Moreover, all the power outputs should be suitably determined so as to achieve the best compromise solution while keeping all the constraints satisfied [3]. To obtain high quality CDEED solutions, both the performance improvement of heuristic algorithm and the design of constraint handling strategy are involved in this paper. The main contribution of our work can be stated using Multi-objective ant lion optimizer (MOALO).
Many works are in literature to solve the CDEED problem. There were a many methods to solve this present problem such as 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], modified adaptive multiobjective differential evolution (MAMODE) algorithm [11], 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], In this present work multi-objective ant lion optimizer (MOALO) is proposed to solve for solving DEcDP, DEmDP and CDEEDP.

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2. Dynamic economic emission dispatch

The traditional EED problem assumes that the amount of power to be delivered by a given set of units is constant for a given interval of time and attempts to minimize the cost as well as the emission of supplying this energy subject to various constraints on the static behavior of the generating units. The CDEED problem can be distinguished from the traditional, static EED by the ramp rate limit constraints.

The CDEED cannot be solved for a single value of the load as these ramp rate constraints involve the evolution of the output of the generators [10].

3. Objective function

3.1 Thermal cost and total emission functions.

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The equation (1) represents the fuel cost minimization: The traditional fuel cost function is assumed to be quadratic function and may mathematically be expressed as:

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

The sequential valve-opening process for multi-valve steam turbines produces ripple-like effect in the heat rate curve of the generator. To analyze CDEED problem with this effect, a rectifed sinusoidal component superimposes the basic quadratic fuel cost characteristics to give the completeness of the CDEED problem. Then, the fuel cost function of each generating unit is expressed in the sum of quadratic and sinusoidal form with the value point effect taken into account. The inclusion of the valve point loading effects makes the representation of the incremental fuel cost function of the generating units more practical [12]. Thus, the total generation cost is expressed as follows (2):

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

Equation (3) illustrated emission minimization: The total emission of atmospheric pollutants such as SOx and NOx caused by fossil-fueled thermal units can be expressed as follows: $F2 = Min\, E_{m_{it}}(P_{gi,t}) = \gamma_i P_{gi,t}^2 + \beta_i P_{gi,t} + \alpha_i + \xi_i \exp(\lambda_i P_{gi,t})$ (3)

Concerning the Model of renewable sources, in recent years, development of Renewable Energy Generation (REG) has received great attention by the power engineers. In power system, the conventional generating stations are nowadays integrated with REG in order to decrease the use of fossil fuel. [13]

3.2 Wind power model and cost function

Wind power generation is mainly dependent on the variation in wind speed. Various techniques have been used to describe the uncertain behaviour of wind speed characteristics. In this paper, Weibull Probability Density Function (PDF) [14] is used to model the wind speed characteristics. Generally, the Weibull Probability Density Function method is commonly used to describe the stochastic characteristic of wind speed profile. The PDF can be expressed by equation (4) [15]:

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

The shape factor k changes the look of the PDF. The large-scale factors shift the curve towards higher wind speeds. Once the uncertain nature of the wind is characterized as a random variable, the output power of the wind DG may also be characterized as a random variable through a transformation from wind speed to output power. The output power of wind is calculated based on the wind velocity and can be determined using its speed–power curve can be expressed by equation (5) [13]

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

From Eq. (5), it is seen that wind DG has:

* No power output up to cut-in wind speed.
* A linear power output relationship between cut-in and rated wind speeds.
* A constant rated power output between the rated wind speed and cut-out wind speed.
* No power output with wind speed greater than the cutout speed.

The cost wind expressed by equation (6) [31]

$$F3\left(P_{win,k,t}\right) = \sum_{k=1}^{Nw} K_{win,k} P_{win,k,t} \quad (6)$$

3.3 PV power model and cost function

The solar irradiation to energy conversion function of the PV generator or power output from PV cell is given by [16].

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

Where it is noted that PV cell temperature is neglected.
The solar PV active power generation can either be controlled by the power tracking control scheme or to be charged into batteries. Therefore, the maximum penetration of PV to system is given by

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

The output of PV mainly depends on irradiation. The distribution of irradiation at a particular location usually follows a bimodal distribution, which can be seen as a linear combination of two unimodal distribution functions. The unimodal distribution functions can be modeled by Beta, Weibull, and Log-normal PDFs [17]. Here, the Weibull distribution is employed and is explained by equation (8):

$$f_G(G) = \omega\left(\frac{k_1}{c_1}\right).\left(\frac{G}{c_1}\right)^{K_1-1} \exp\left[-\left(\frac{G}{c_1}\right)^{K_1}\right] + \quad (9)$$
$$(1-\omega)\left(\frac{k_2}{c_2}\right).\left(\frac{G}{c_2}\right)^{K_2-1} \exp\left[-\left(\frac{G}{c_2}\right)^{K_2}\right],\ 0 < G < \infty$$

Where ω is the weighted parameter, and its range is $0 < \omega < 1$; k_1, k_2, c_1, and c_2 are the shape factors and scale factors. For the Weibull PDF equation (8), the corresponding cumulative distribution function (CDF) is given by equation (10)

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

According to the transformations of random variables, the linear transformation accomplished with G as the solar irradiation random variable is given by equations (11) and (12):

$$p_S = aG + b = g(G) \quad (11)$$

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

Where g is a transformation function, p_s is a solar power random variable. That is

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

Where

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

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

The quadratic transformation accomplished with solar irradiation random variable (G) is given by

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

Where

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

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

Therefore, using (17), the Weibull PDF of solar PV power output random variable then takes the form equation (19)

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

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

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

3.4 Load demand uncertainty model

The future system load is uncertain at any given time. Two commonly used PDFs are the normal PDF and uniform PDF. Here, normal PDF is used to model demand distribution. The PDF of the normal distribution for uncertain load l is given by [18]

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

Where μ is the mean value of the uncertain load. It is also called the location parameter. σ is the standard deviation of the uncertain load. It is also called the scale parameter.

3.5. Multi-objective function.

The multi-objective CDEED problem can be formulated by considering more than one objective simultaneously and it can be expressed as (4):

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

The EED problems determine optimal real power generations that minimize the two conflicting objectives of fuel cost and emissions while satisfying several equality and inequality constraints. The EED problem becomes CDEED problem when it is solved for a given time interval, which is divided into discrete subintervals [12].
Aggregating the objectives and constraints, the CDEED problem can be mathematically formulated as a nonlinear constrained multi-objective optimization problem, which can be converted into a single-objective optimization using the weighting method as (5), where F1 from equation (2) subject to constraints [4]:

$$Min\,F = wF1 + pf(1-w)F2 \quad (23)$$

Where *pf* is the price penalty factor is as flows equation (24).

$$pf_1(P_{ig}^{max}) = \frac{F1(P_{ig}^{max})}{F2(P_{ig}^{max})} \$/\,ton \quad (24)$$

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

3.6. Problem constraints

The problem of unit commitment is subject to many constraints depending on the nature of the power system under study. The constraints taken into account can be classified into two main groups: system constraints and unit constraints. System constraints, sometimes referred to as coupling constraints, also include two categories: the load demand and the spinning reserve constraints [12].

3.6.1 Real power balance equation:

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

Or

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

3.6.2. Real power generation limit

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

3.6.3. Generating unit ramp-rate limits

Ramp rates are the maximum rates specified for each unit at which the power output of a unit can be increased (ramp up rate) or decreased (ramp down rate) at a time interval. Violation of the unit ramp rates will shorten the life of the power generation facilities. Thus, ramp rate limits should be satisfied as the power load demand changes [30].

$$\left.\begin{array}{ll} P_{gi,t} - P_{gi,t-1} \le UR_{gi} & (28.1) \\ P_{gi,t-1} - P_{gi,t} \le DR_{gi} & (28.2) \end{array}\right\} \quad i \in N_n \;\; et \;\; t = 2,3,\ldots..T \quad (28)$$

Where (28.1) if generation increases and (28.2) if generation decreases. If the unit ramp-rate limits are taken into account, the real power generation limits (9) can be modified as equation (29):

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

4. Multi-objective ant lion optimizer (MOALO)

A algorithm called Ant Lion Optimizer (ALO) inspired by nature, proposed by Seyedali Mirjalili in 2015.
The fundamentals of this algorithm should be discussed first. An algorithm should follow the same search behaviour to be considered as an extended version of the same algorithm. The ALO algorithm mimics the hunting mechanism of antlions and the interaction of their favourite prey, ants, with them [19].
The Ant Lions belongs to the class of insects with wings and nerves (neuroptera). The life cycle of the ants includes two main phases: larvae and adults. A natural shelf life can take up to three years, which occurs mainly in larvae (3 to 5 weeks into adulthood). The Lion Ant undergoes a metamorphosis into a cocoon to become an adult [20, 21, 22]. They hunt primarily on larvae and the adult period is for breeding. A larva of lion ant massive jaw. After digging the trap, the larvae hide under the bottom of the cone and wait for the insects (preferably ants) to be trapped in the well. The edge of the cone is sharp enough so that the insects fall easily into the bottom of the trap. Once the ant realizes that a prey is in the trap, it tries to catch it. This is one of the algorithms that are also used for EELD, and it is one of the most recent discoveries [23, 24].

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

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

Where r(t) expressed by equation (13)

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

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).

To keep the random walk in the boundaries of the search space and prevent the ants from overshooting, the random walks should be normalized using the following equation (14) [24]:

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

To simulate the trapping of ants the mathematical expression of the trapping of the ants to the given by following equations (15) and (16) [23]:

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

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

To construction of trap, the fittest ant lion is selected using the roulette wheel method.

To simulate the sliding ants towards ant lions, the boundaries of random walks should be reduced adaptively as follows equations (17) et (18) [26]:

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

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

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]:

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

To catching the ants by ant lion and re-building the pit can be mathematically described by equation (20) [21]:

$$Antlion_j^t = Ant_i^t \; if \; f(Ant_i^t) > f(Antlion_j^t) \quad (38)$$

Where $Antlion_j^t$ indicates the position of selected *j*th antlion at *i*th iteration and Ant_i^t shows the position of *i*th ant at *i*th iteration. *t* shows the current iteration.

Finally the last operator in ALO, that is elitism, calculated using roulette wheel as follows equation (21) [26]:

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

Where R_A^t the random walk nearby the ant lion is chose by means of the roulette wheel at *i*th iteration, R_E^t is the random walk nearby the elite at *t*th iteration, Ant_i^t is the location of *i*th ant at *t*th iteration.

4.1. Implantation of MOALO to solve CDEEDP

The steps for an ant lion optimization application are as follows [27]:

Step 1: Initialize random walks on ants using Eq (28) and save generation scheduling of generating units as ant position using matrix (38) described below:

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

Where M_{Ant} , is the matrix for saving the position of each ant, $Ant_{i,j}$ shows the value of the *j*th variable (dimension) of *i*th ant, n is the number of ants, and *d* is the number of variables.

Step 2: For evaluating each ant (i.e., generating units), the following objective functions described in equation (2) and equation (3) are utilized during optimization and following matrix (23) stores the fitness value of all ants :

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

Where M_{OA} is the matrix for saving the fitness of each ant, $Ant_{i,j}$ shows the value of *j*th dimension of *i*th ant, *n* is the number of ants, and *f* is the objective function.

Step 3: Save the optimal cost and generation scheduling using matrix (40) and (41) described below:

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

Where M_{AL} is the matrix for saving the position of each ant lion, $AL_{i,j}$ shows the *j*th dimension's value of *i*th ant lion, *n* is the number of ant lions, and *d* is the number of variables (generators).

Where M_{OAL} the matrix for saving the fitness of each ant lion is, $AL_{i,j}$ shows the *j*th dimension's value of *i*th ant lion, *n* is the number of ant lions, and *f* is the objective function.

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

4.2 Front pareto and best compromise solution

Decision maker (DM) may presume fuzzy or imprecise goals for each objective function. The fuzzy sets are defined by equations called membership functions. The DM evaluates the membership function, μF_k in a subjective manner [28, 29] and is defined strictly monotonic decreasing and continuous function as defined below:

$$\mu_{F_k}(i) = \begin{cases} 0 & , Otherwise \\ \dfrac{F_k^{Max} - F_k(i)}{F_k^{Max} - F_k^{\min}} & , F_k^{Max} \le F_k(i) \le F_k^{\min} \end{cases} \quad (44)$$

The procedure is as follows:

First find the maximum of each objective function and save them, second Add one of the objective functions (here emission function F_2) to the constraints as follows:

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

The ε value will be varied from F_2^{Max} to $F_2^{\min}$ and then F_1 (cost function) is minimized.

A conservative decision maker tries to maximize minimum satisfaction among all objectives or minimize the maximum dissatisfaction. The final solution can then be found as equation (44).

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

$$\underset{1:nS}{\mathrm{Max}}\left(\underset{1:nF}{\min}(\mu F_k)\right) \quad (46)$$

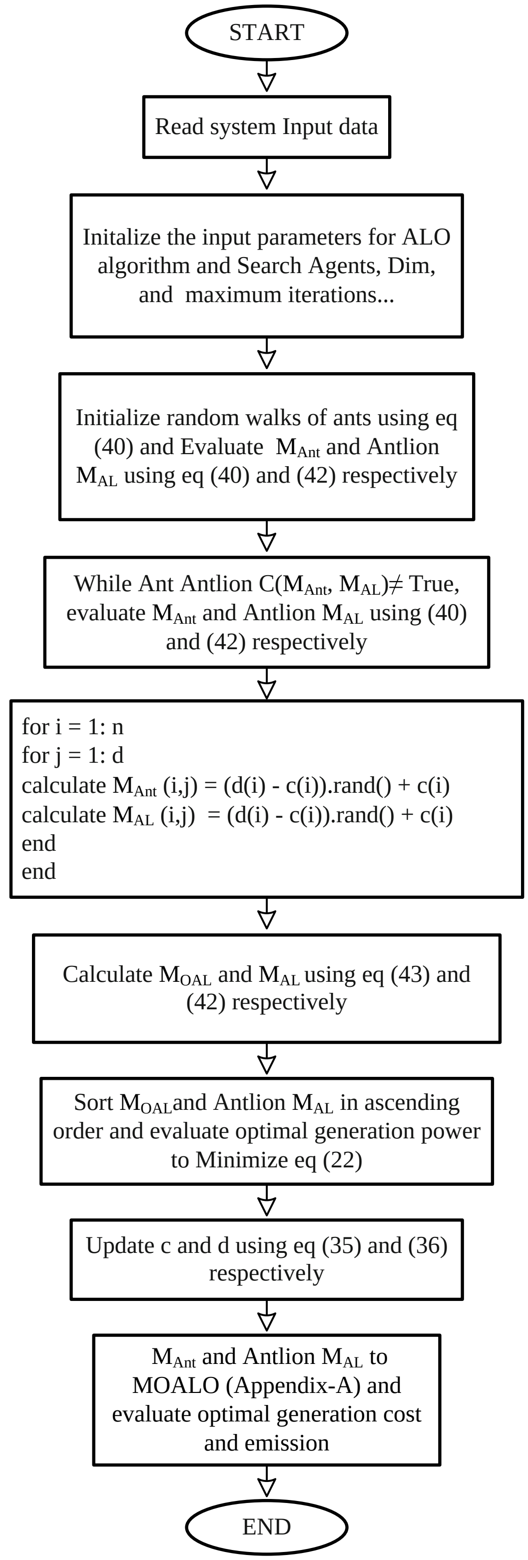

Fig. 1 Flow-chart of combined environmental economic dispatch using MOALO algorithm.

5. Analysis and discussion of results

In this work, the 5 units test system with the valve point effects, with different numbers of generating units are used to comprehensively measure the performance of the proposed algorithm with three cases.
Case 1: DEcD (dynamic economic dispatch problem).
Case 2: DEmD (dynamic emission dispatch problem).
Case 3: CDEED (Combined dynamic economic emission.
The Test 5-unit system, the generators' input data, load demand for 24 hours and the transmission loss coefficients of this system are given at reference [4].
All the simulations are done using in MATLAB R2013a and executed with i3-2310M CPU @ 2.10 GHz 2.10 GHz and 6 GB RAM PC. The system data for all cases are given from. The proposed algorithm was employed with the population size is 100 and the maximum iteration number max 100 for the 5-units test system under consideration.
To have a better result, we turned algorithm for each power demand value. The convergence characteristic of the proposed MOALO algorithm for case 3 is depicted in fig. 2. It can be observed that MOALO only takes 100 iterations to converge to the best solution nearby. This reflects the complexity of the CDEED problem especially when we take into account the transmission loss and valve point effect.
The numerical results for Pareto front and compromise solution for DEEDP of 5-unit system is given by fig.3. When for case 3 the best cost is 51731 $ and the best emission is 27576 lb. Figures 3 shows the Pareto and compromise solution for the CDEED problem obtained from the proposed method.
Similarly Table 2 gives the results of dynamic economic dispatch, dynamic emission dispatch, and combined economic emission dispatch and power losses for 24-h period for the 5-unit system, with and without rampe rate.

5.1. Case 1 : DEcDP

In this case the DEcDP is considered to minimize only the fuel cost where w =1 and pf =1. To test the effectiveness of the proposed method, table 3 presents the dispatching results (MW) and the power losses using MOALO, for verification, and Table 2 shows the summary results obtained by MOALO and literature methods, its show that The DEcD solution obtained by MOALO gives the best total cost among all methods. Comparing the proposed method MOALO with that (NEHS) and (NPAHS) for example we notice that MOALO takes more time of calculation, but it realizes a much better total cost ($763.0731 of less than the best method in the literature NEHS). The total emission not minimize is equal to 23837 Ib. But the power losses is more than the other method (SA) with 3,9721 MW, where this method have a $47 356 in cost function.

5.2. Case 2 : DEmDP

In this situation we taking into account the transmission loss and valve point effect, the total emission only is minimize where w =0 and pf =1.Table 4 illustrate the dispatch results and the power losses using MOALO. It is clear that the proposed method gives the best solution compared to the other method with a fable minimum difference of cost and losses. Compared to case 1 the total cost in this situation worth $ 51982 it's absolutely this value is higher than, because we minimize only emission. But the emission value 17853lb is lower by 5984lb.

5.3. Case 3 : CDEEDP

The case 3 we used the equation (5) where w =0.5 and pf is computed using Equation (6), minimizing simultaneously the economic and emission. The cost value obtained by MOALO equal $ 44 942 it's best than literature methods. As a consequence, MOALO can better equalize fuel cost but more pollutant emission, by 41,66284 lb, as the multi-objective functions than the NEHS method. The dispatch results and the power losses using MOALO are illustrated by table 5.

5.4 Extended of DEEDP by ramp rate constraint.

Respect the equations (28.1) and (28.2) to solve DDP for the 5-units test systems with the three cases. Tables 2 gives summary results, and then the corresponding results are listed in Tables 3, 4 and 5. Results show that when the best cost dispatch is taken into account, the system is faced with the minimum amount of cost for a 24h time interval, where without ramp rate, it is 42303$ for case 1. On the other hand by considering the best emission, the system is operated at its lowest amount of emission, 17853 lb for case 2. For the combined minimum fuel cost and emission case, the fuel cost and pollutant emission obtained by the proposed method can be reduced about 44942$ and 18434 lb for case 3.
Then with ramp rate it is 50781 $ for case 1. On the other hand by considering the best emission, the system is operated at its lowest amount of emission, 17885 lb for case 2. For the combined minimum fuel cost and emission case, the fuel cost and pollutant emission obtained by the proposed method can be reduced about 51664 $ and 17956 lb for case 3. 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

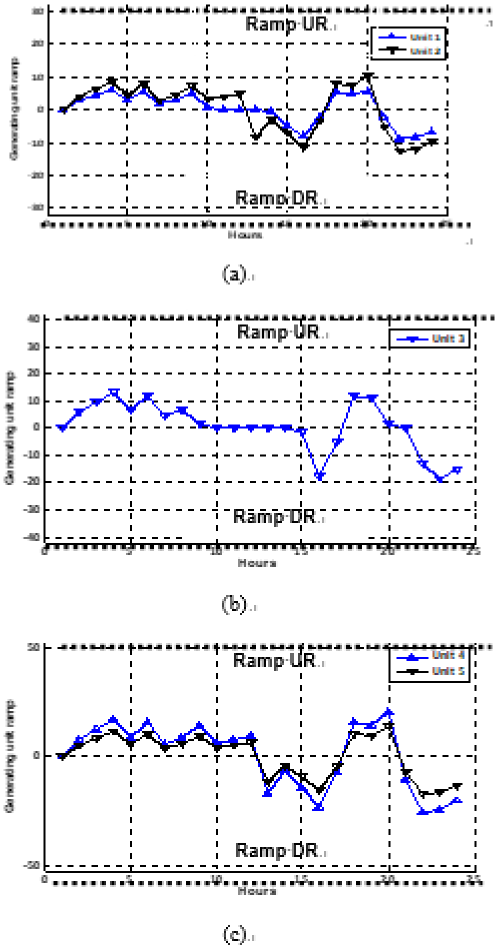

Fig. 3 The ramp up/ramp down values of case 1 situation 3:

(a) units 1, 2 ; (b) units 3; (c) units 4,5

constraints and in particular the constraint (10) have been respected. However, for the conventional DEED problem, from the obtained simulation results using PSO [3], DE-SQP [4], PSO-SQP [4], MODE [5], MOHDE-SAT [5], NPAHS [6], EP [7], SA [8], PS [8], NEHS [9] methods, it is clearly seen that the proposed method given the best solution for the 5-units systems than those reported in literature.

The generation of each unit over 24h for the best compromise solution is shown in Figure 3. It can be seen that the generators 3, 4 and 5 reach their maximum production from a total load demand. The generated power by the committed units 1 and 2 follow the profile of load demand PD and work with their full capacities in peak demand times.

5.5 Integrated Wind and Solar Energy Systems for dynamic dispatch with ramp rate constraint.

The rating of wind power generator is pr =150MW. The cut-in, cut-out and rated wind speeds are vin=4m/s, vo=25 m/s and vr=15 m/s respectively. The direct cost coefficient Kwin for the wind power generator is taken 3.25. The rating of solar PV generator is PS=150 MW. The direct cost coefficient Kpv for the solar PV generator is taken 3.5. The solar radiation in the standard environment Gstd and a certain radiation point Rc are taken as 1000 W/m2 and 150 W/m2. The forecasted wind velocity and solar radiation table 6 are taken from [32].

Tables 2 illustrates the best solutions for multi-objective wind, solar and thermal dispatch with ramp rate using MOALO for case 1. From case 1 it's clear that the cost with renewable energy increase but the emission values decreases, so the integration of renewable energy in this case is useless, to because the cost wind and PV solar added increases the global cost look equations (6) and (20).

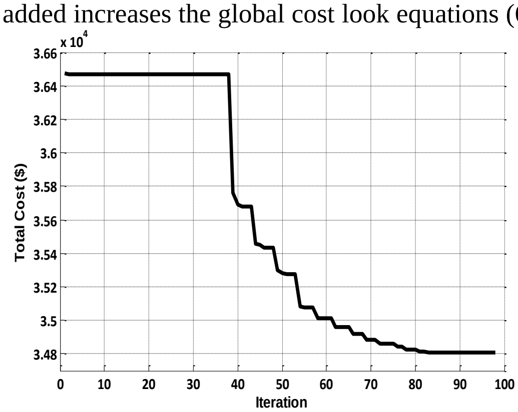

Fig. 2: Convergence characteristic of MOALO for case3

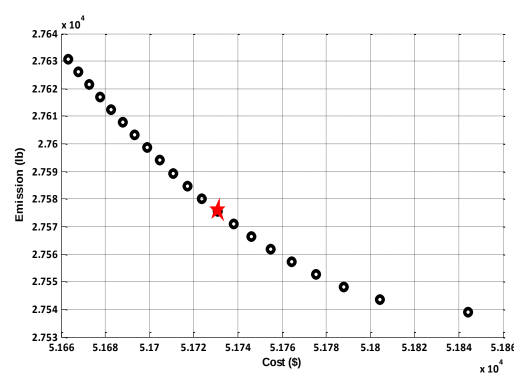

Fig.4: Pareto and compromise solution for case 3

Table 1: 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 (**$**)	50781	51877	51664	52479	55860	55624
Emission (lb)	31189	17885	17956	17854	13916	14022
Total cost (**$**)			34810			37670
Ploss	196.1821	188.1285	189.2309	147.7911	143.0931	143.0622

Table 2: The DEcD, DEmD and CDEED results of different algorithms with and without ramp rate

Problem type	Method	function values: without ramp rate		function values: with ramp rate		P Loss (MW)
		Cost ($)	Emission (lb)	Cost ($)	Emission (lb)	
DEcDP	PSO [3]	47 852	--	--	--	--
	DE-SQP [4]	43 161	--	--	--	194,1988
	PSO-SQP [4]	43 263	--	--	--	193,3194
	MODE [5]	46 747	--	--	--	--
	MOHDE-SAT [5]	46 478	--	--	--	--
	NPAHS [6]	43 072,99	--	--	--	194,6059
	EP [7]	46 777	--	--	--	--
	SA [8]	47 356	--	--	--	192,21
	PS [8]	46 530	--	--	--	--
	NEHS [9]	43066,0731	--	--	--	--
	MOALO	**42303**	**23728**	**50781**	**31189**	**196,1821**
DEmDP	PSO [3]	--	19 094	--	--	--
	MODE [5	--	17 944	--	--	--
	MOHDE-SAT [5]	--	17 884	--	--	--
	NPAHS [6]	--	17 853	--	--	188.1340
	EP [7]	--	17 966	--	--	--
	PS [8]	--	18 192	--	--	--
	NEHS [9]	--	17 853,0029	--	--	--
	MOALO	**51982**	**17853**	**51877**	**17885**	**188.1285**
CDEEDP	PSO [3]	50 893	20 163	--	--	--
	DE-SQP [4]	44 450	19 616	--	--	192,6101
	PSO-SQP [4]	44 542	19 772	--	--	191,7028
	MODE [5]	47 330	18 116	--	--	--
	MOHDE-SAT [5]	48 214	18 011	--	--	188,4360
	NPAHS [6]	45 196	18 630	--	--	190,0686
	EP [7]	48 628	21 154	--	--	--
	SA [8]	48 621	21 188	--	--	--
	PS [8]	47 911	18 927	--	--	191.73
	NEHS [9]	45 398,0163	18 392,3371	--	--	--
	MOALO	**44 942**	**18434**	**51664**	**17956**	**189,2309**
		Total cost = **31688 $**		Total cost = **34810 $**		

Table 3: The best solutions obtained by MOALO for case 1 without wind and solar

PD	Dynamic Economic Dispatch (DEcD)										PLoss
	Without ramp rate					With ramp rate					
	P_1	P_2	P_3	P_4	P_5	P_1	P_2	P_3	P_4	P_5	
410	11.6383	20.0000	112.6735	40.0000	229.5196	15.0048	73.3463	58.3656	120.0388	146.6925	3.6242
435	51.2609	98.5398	30.0000	209.8158	50.0000	16.0797	76.2125	65.5311	128.6374	152.4249	3.8314
475	75.0000	23.1604	32.4635	209.8159	139.7598	17.8017	80.8047	77.0116	142.4140	161.6093	4.6165
530	55.4691	98.5398	112.6735	40.0000	229.5196	20.1744	87.1317	92.8292	161.3950	174.2633	5.1996
558	10.0000	92.8437	112.3382	209.8157	139.7598	21.3844	90.3584	100.8960	171.0752	180.7168	6.2020
608	50.2066	98.5398	112.6735	124.9079	229.5196	23.5488	96.1301	115.3252	188.3902	192.2601	6.7574
626	67.0809	98.5398	30.0000	209.8158	229.5196	24.3292	98.2113	120.5282	194.6339	196.4226	7.8474
654	12.7090	98.5398	112.6735	209.8158	229.5196	25.5442	101.4512	128.6279	204.3535	202.9023	8.9561
690	49.6196	98.5398	112.6735	209.8158	229.5196	27.1089	105.6236	139.0590	216.8708	211.2472	9.2577
704	64.0108	98.5398	112.6735	209.8158	229.5196	27.7184	107.2492	143.1229	221.7475	214.4983	10.1683
720	18.0402	98.5398	175.0000	209.8158	229.5196	28.4155	109.1081	147.7703	227.3243	218.2162	10.5595
740	75.0000	124.7110	112.6735	209.8159	229.5196	29.2875	111.4334	153.5836	234.3003	222.8669	10.9154
704	64.0108	98.5398	112.6735	209.8158	229.5196	27.7184	107.2491	143.1228	221.7474	214.4983	11.7200
690	49.6196	98.5398	112.6735	209.8158	229.5196	27.1090	105.6240	139.0600	216.8720	211.2480	10.5595
654	12.7090	98.5398	112.6735	209.8158	229.5196	25.5442	101.4513	128.6283	204.3539	202.9026	10.1683
580	26.4485	98.5399	112.6735	209.8158	139.7598	22.3361	92.8964	107.2409	178.6891	185.7927	9.2577
558	10.0000	91.8849	108.4107	124.8934	229.5169	21.3844	90.3584	100.8960	171.0752	180.7168	7.2375
608	50.2066	98.5398	112.6735	124.9079	229.5196	23.5488	96.1300	115.3250	188.3900	192.2600	6.7059
654	12.7090	98.5398	112.6735	209.8158	229.5196	25.5443	101.4515	128.6286	204.3544	202.9029	7.8474
704	64.0108	98.5398	112.6735	209.8158	229.5196	27.7185	107.2493	143.1232	221.7478	214.4985	9.2577
680	39.3529	98.5398	112.6735	209.8158	229.5196	26.6740	104.4639	136.1598	213.3918	208.9278	10.5595
605	52.0076	98.5398	112.6735	209.8158	139.7598	23.4188	95.7835	114.4587	187.3504	191.5669	9.9016
527	56.8895	98.5398	112.6735	124.9079	139.7598	20.0448	86.7862	91.9655	160.3586	173.5724	7.7965
463	10.0000	78.5142	30.0000	209.8149	139.7596	17.2848	79.4262	73.5654	138.2785	158.8523	5.7705
Total	Cost= 42303 $, Em= 23728 lb					Cost=50781 $, Em= 31189 lb					196.1821

Table 4: The best solutions obtained by MOALO for case 2 without wind and solar

PD	Dynamic Economic Dispatch (DEmD)										PLoss
	Without ramp rate					With ramp rate					
	P_1	P_2	P_3	P_4	P_5	P_1	P_2	P_3	P_4	P_5	
410	54.6786	58.2355	116.5717	110.5982	73.3640	54.6457	57.2415	119.8688	110.1403	71.5518	3.4480
435	58.0671	62.3835	121.8514	117.9819	78.6016	57.9646	61.2242	125.5584	117.6079	76.5303	3.8855
475	63.5261	69.0803	130.2208	129.7502	87.0639	63.2823	67.6054	134.6744	129.5726	84.5067	4.6413
530	71.1205	78.4297	141.5516	145.8017	98.8901	70.6087	76.3972	147.2340	146.0572	95.4965	5.7936
558	75.0000	83.2690	147.2412	153.9049	105.0157	74.3452	80.8809	153.6394	154.4642	101.1011	6.4308
608	75.0000	93.3123	158.9125	170.4455	117.9841	75.0000	89.9865	166.6474	171.5373	112.4832	7.6544
626	75.0000	97.5459	162.3634	176.6156	122.6003	75.0000	93.3125	171.3988	177.7734	116.6406	8.1252
654	75.0000	102.5107	169.1904	185.4430	130.7349	75.0000	99.4101	175.0000	189.2064	124.2626	8.8790
690	75.0000	110.8922	175.0000	197.2456	141.7717	75.0000	108.3872	175.0000	206.0384	135.4839	9.9095
704	75.0000	115.4648	175.0000	202.9722	145.8994	75.0000	111.8846	175.0000	212.5961	139.8557	10.3364
720	75.0000	120.2594	175.0000	209.2192	151.3559	75.0000	115.8841	175.0000	220.0952	144.8552	10.8345
740	75.0000	125.0000	175.0000	217.3084	159.1633	75.0000	120.8871	175.0000	229.4758	151.1088	11.4717
704	75.0000	115.1651	175.0000	203.2749	145.8961	75.0000	111.8845	175.0000	212.5960	139.8556	10.3361
690	75.0000	111.5158	175.0000	197.5302	140.8671	75.0000	108.3880	175.0000	206.0400	135.4850	9.9131
654	75.0000	103.0427	169.3807	185.1830	130.2740	75.0000	99.4104	175.0000	189.2070	124.2630	8.8804
580	75.0000	87.7312	152.3940	161.2011	110.6290	75.0000	84.8189	159.2650	161.8479	106.0236	6.9553
558	75.0000	83.2637	147.2404	153.9097	105.0169	74.3452	80.8809	153.6394	154.4642	101.1011	6.4307
608	75.0000	92.8525	158.9007	170.7970	118.1036	75.0000	89.9864	166.6473	171.5371	112.4830	7.6538
654	75.0000	104.0180	169.0839	184.4714	130.3084	75.0000	99.4107	175.0000	189.2076	124.2634	8.8817
704	75.0000	115.5785	175.0000	203.0639	145.6948	75.0000	111.8848	175.0000	212.5965	139.8560	10.3372
680	75.0000	108.7826	175.0000	193.5898	137.2449	75.0000	105.8921	175.0000	201.3601	132.3651	9.6173
605	75.0000	92.8398	158.1106	169.4912	117.1367	75.0000	89.4326	165.8562	170.4987	111.7908	7.5783
527	70.7033	77.9150	140.9393	144.9310	98.2388	70.2087	75.9171	146.5482	145.1570	94.8964	5.7274
463	61.8832	67.0629	127.7207	126.2266	84.5139	61.6860	65.6899	131.9379	125.9811	82.1124	4.4073
Total	Em= 17850 lb, Cost=51982 $					Em= 17885 lb, Cost=51877 $					188.1285

Table 5: The best solutions obtained by MOALO for case 3 without wind and solar

PD	Dynamic Economic Dispatch (DEED)										PLoss
	Without ramp rate					With ramp rate					
	P_1	P_2	P_3	P_4	P_5	P_1	P_2	P_3	P_4	P_5	
410	27.5030	98.5398	112.6735	124.9079	50.0000	43.1392	60.9232	115.0955	113.2353	81.2310	19.6037
435	60.6073	90.8126	112.6735	124.9079	50.0000	45.8156	64.7893	121.0433	120.9674	86.3857	22.5181
475	75.0000	98.5413	115.6561	125.9360	64.6147	50.1132	70.9968	130.5933	133.3825	94.6624	28.5796
530	72.1679	86.3011	112.6735	124.9079	139.7598	56.0260	79.5375	143.7329	150.4639	106.0500	35.4408
558	75.0000	98.8632	122.2839	128.5479	139.7598	59.0471	83.9013	150.4465	159.1915	111.8684	39.5279
608	75.0000	98.5927	175.0000	127.2736	139.7598	64.4440	91.6969	162.4397	174.7828	122.2626	48.0139
626	73.5279	98.5397	112.6735	209.8158	139.7598	66.4153	94.5443	166.8204	180.4776	126.0591	52.9470
654	75.0000	98.5408	139.8574	209.8158	139.7598	69.4377	98.9101	173.5369	189.2090	131.8801	58.3973
690	75.0000	100.3389	175.0000	209.8159	139.7599	74.3250	105.9694	175.0000	203.3277	141.2926	70.5512
704	75.0000	114.7841	175.0000	209.8158	139.7598	75.0000	109.1471	175.0000	209.6831	145.5295	79.6379
720	75.0000	125.0000	175.0000	210.0807	145.7794	75.0000	112.9549	175.0000	217.2987	150.6065	88.0681
740	75.0000	98.5398	175.0000	209.8158	193.0103	75.0000	117.6870	175.0000	226.7629	156.9160	92.4355
704	75.0000	114.7840	175.0000	209.8159	139.7598	75.0000	109.1471	175.0000	209.6831	145.5295	84.5157
690	75.0000	100.3389	175.0000	209.8159	139.7599	74.3250	105.9694	175.0000	203.3277	141.2926	70.5512
654	75.0000	98.5408	139.8574	209.8158	139.7598	69.4377	98.9101	173.5369	189.2090	131.8801	58.3973
580	74.9999	98.5395	112.6753	161.0533	139.7599	61.4278	87.3402	155.7370	166.0693	116.4536	43.6277
558	75.0000	98.8632	122.2839	128.5479	139.7598	59.0471	83.9013	150.4465	159.1915	111.8684	39.7190
608	75.0000	98.5927	175.0000	127.2736	139.7598	64.4440	91.6969	162.4397	174.7828	122.2626	48.0501
654	75.0000	98.5408	139.8574	209.8158	139.7598	69.4377	98.9101	173.5369	189.2090	131.8801	58.3973
704	75.0000	114.7841	175.0000	209.8158	139.7598	75.0000	109.1471	175.0000	209.6831	145.5295	74.8699
680	66.7042	98.5398	174.8135	209.8158	139.7598	72.9086	103.9236	175.0000	199.2361	138.5648	70.5512
605	75.0000	98.5422	163.9459	135.2974	139.7598	64.1191	91.2276	161.7177	173.8441	121.6368	48.1273
527	56.8895	98.5398	112.6735	124.9079	139.7598	55.7054	79.0744	143.0205	149.5377	105.4325	31.7705
463	75.0000	98.5418	114.6977	124.9097	54.3867	48.8252	69.1363	127.7311	129.6615	92.1818	25.2377
Total	Cost = 44942 $, Em= 18434 lb, Total cost = 31688 $					Em= 17956 lb, Cost=51664$, Total cost = 34810 $					189.2309

6. Conclusions and perspectives

In this work, Multi-objective ant lion optimizer used to solve combined dynamic economic emission dispatch problem with valve point effect and transmission loss. To tackle this non-convex problem, linear approximation is applied to the non-smooth cost function and the transmission loss, and consequently the original CDEED problem is converted into MOALO problem.

The DEED problem for the test system is carried out to determine the hourly generation schedule using MOALO for the minimum fuel cost case 1, minimum emission case 2 and combined minimum fuel cost and emission case 3 . Simulation results show that MOALO is more efficient than the other method for the DEcD, DEmD and CDEED problems and has the potential to find desirable solutions in 100 iterations.

The economic emission effect, computation efficiency and convergence property of MOALO are demonstrated. Therefore MOALO optimization is a promising technique for solving complicated problems in power systems. Applications of the proposed algorithm to multi-objective problems in power system integrated with wind farms, PV system, hydro and ESS operation are a future work.

Appendix

Table 6: Forecast solar radiation and wind velocity.

Hr (h)	1	2	3	4	5	6	7	8	9	10	11	12
Gt(W/m2)	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/m2)	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

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