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Application of Grasshopper Optimization Algorithm to Solve Multi-Objective Combined Economic Emission Load Dispatch Problem

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Abstract- The most important condition is to generate sufficient electricity to meet the variable load demand of consumers at lowest cost. The generation of power by each generator in a generating station must be done in such a way that the total generation cost which is the function of fuel cost is minimized while satisfying various constraints. This is called economic load dispatch (ELD). Generating plants which are generally the thermal power plants use coal as an input fuel which emits harmful pollutants like the oxides of carbon, sulfur & nitrogen that causes atmospheric pollution. The biggest challenge is to reduce these pollutants emitted from thermal power plants during power generation. It is required that the optimal quantity of power is to be generated simultaneously by thermal power generators in the system with minimum generation cost & emission levels, which is known as combined economic and emission dispatch (CEED). In this work, swarming behavior of the grasshopper is used an optimization tool to solve the complex CEED problem. Intellectually grasshopper has two inviting habits. One is by exploring the food and another is by exploiting the food. The grasshopper move instinctively in exploration and move locally in exploitation. This technique of exploration and exploitation is main searching aspects in Grasshopper Optimization Algorithm (GOA).

Keywords - CEED, GOA, Grasshopper Optimization Algorithm, Economic emission dispatch load dispatch, power plant

I. INTRODUCTION

One of the complex systems that play a crucial part in the functioning of contemporary culture is the electric power system. Electrical energy generation, transmission and distribution must be carried out economically in order to fulfill this function. The most significant situation is to produce enough electricity at the lowest price to satisfy consumer variable demand. This situation is called the Economical Load Dispatch (ELD). The issue with ELD in the energy scheme is to schedule the energy production for each dedicated generator unit to minimize operating costs while maintaining load demand, operating power limits and stability [1]. Thermal power plant utilizes coal as an input gas that emits damaging pollutants such as carbon dioxide, sulfur dioxide, atmospheric pollution causing nitrogen oxides. One of the causes of global warming is these thermal power plants. This is a significant issue in contemporary culture today. It is therefore necessary to minimize these pollutants emitted during energy generation from heat energy plants, which have a severe impact on the environment. Therefore, the generating station has two difficulties: one is economic load dispatch and the other is emission reduction. Both issues conflict with each other. It can therefore be concluded that each generator energy distribution depends on the price of generation and pollutant emission level. Combined Economic Emission Dispatch (CEED) is regarded as the optimal amount of energy to be produced concurrently by heat power generators in the scheme with minimal expense of generation & emission concentrations [2]. Because of the nonlinear features of the mathematical formulation used to represent emissions, environmental problems add complexity to solving the financial load dispatch issue. Therefore, dealing with multi-objective CEED issue through standard methods that usually optimize a single goal is very hard. Different researchers have created a lot of optimization techniques to solve the CEED issue. In [3], authors suggested Lagrangian method of relaxation to fix the ecologically restricted economical load dispatch issue. In their suggested work, they regarded nitrogen and sulfur oxides to be pollutants. This method was tested on 101 dispatchable units including 73 coal units, 19 oil units, 6 nuclear units and 3 units were the combination of coal and oil. Also, in this test system there were 36 hydro units and 39 combustion turbine units. The test results were obtained under different constraints conditions. Using the Newton Raphson method [4], Shin and Jiann created a fresh technique for solving the economic emission dispatch issue. This technique was based on the matrix of Jacobian. Using the DC load flow model, sensitivity variables were also acquired. On Taiwan Power Company, composed of

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288 buses, the suggested technique was introduced. The simulation findings were also contrasted with another technique mentioned in their literature and the final result confirmed the precision and rapid response efficiency of this technique. In [5], authors suggested a simulated annealing technique to address the multi-objective issue of the economical load dispatch of fixed hydro and thermal plants while taking into account the emission coefficients. With the assistance of the goal achievement technique, the multi-objective function was transformed into a single objective optimization issue in their suggested work. On a scheme composed of two hydro plants and four thermal plants, the suggested technique was tested. The test findings showed that this suggested work was valid and effective. Using the bacterial foraging algorithm [6], authors proposed a fresh approach for solving financial and emission dispatch problems. The valve point loading effect was regarded by the authors in their job. On IEEE 3 bus six generator system and Taiwan 40 generating units, the suggested approach was enacted. It has been found that the simulation findings are better than other existing methods. Ant lion optimization algorithm (ALO) to fix the issue of multi-objective mixed economical and emission dispatch. This algorithm is based on ant-lion hunting style. Test system simulation findings showed better worldwide convergence and a good optimal solution. Authors suggested an adaptive immune algorithm inspired by immunology under multiple limitations to fix the issue of mixed economical emission dispatch [7]. The proposed algorithm has been introduced with six generating units on the IEEE 30 bus scheme. Results of simulation endorsed this algorithm's adoption to fix CEED issue. In [8], is proposed to solve the complex economic emission load dispatch problem of thermal generators of power systems. On IEEE 30 bus scheme, this hybrid algorithm is tested. The simulation findings showed that the suggested hybrid algorithm provides the EED issue with an efficient and precise solution. Authors proposed a new hybrid algorithm based on Differential Evolution (DE) and Biogeography-based Optimization (BBO) algorithm in [9] to fix a multi-objective economical load dispatch issue. In their suggested work, the authors regarded nitrogen, sulfur and coal oxides as emission elements. In the suggested work, they also considered loading of the valve point. The hybrid algorithm was tested with distinct combinations of emission parts on three and six generator systems. The results of the simulation showed in all cases the effective and better solutions. In the proposed work, Grasshopper Optimization Algorithm (GOA) has been discussed and implemented to solve the aforesaid problem. GOA is based on the behavior of grasshopper swarms in nature. Nature-inspired algorithms logically divide the search process into two tendencies: exploration and exploitation. In exploration, the search agents are encouraged to move abruptly, while they tend to move locally during exploitation [10]. These two functions, as well as target seeking, are performed by grasshoppers naturally. To show the effectiveness of GOA, this technique has been implemented on test system.

II. GRASSHOPPER OPTIMIZATION ALGORITHM (GOA)

GOA is based on the nature conduct of grasshopper swarms and was created by Seyedali Mirjali [10] to solve issues with optimization. Grasshopper is regarded as a plague as it damages plants. Grasshoppers life cycle is shown in fig. 1.

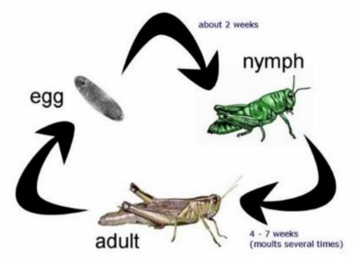

Fig. 1 Life cycle of Grasshopper

The distinctive element of the grasshopper swarm is that both nymph and adulthood find swarming behavior. Millions of nymph grasshoppers, like rolling cylinders, jump and move. They consume nearly all the vegetation on their route. After this behavior, they form a swarm in the air when they become adults. This is how big distances of grasshoppers migrate. Slow motion and tiny moves of the grasshoppers are the primary feature of the swarm in the larval stage. In comparison, the vital characteristic of swarm in adulthood is long range and abrupt motion. Food source searching is another significant feature of grasshoppers swarming. In comparison, the vital characteristic of swarm in adulthood is long-range and abrupt motion. Food source searching is another significant feature of grasshoppers swarming. The search method is logically divided into two tendencies by nature-inspired algorithms: exploration and exploitation. In exploration, the search agents are urged to move suddenly, while during exploitation they tend to relocate locally. These two functions, as well as target seeking, are performed by grasshoppers naturally. These two tasks, as well as the search for targets, are obviously carried out by grasshoppers. Therefore, the grasshopper's swarming conduct is sought to address the issues of optimization. Hence, the swarming behavior of the grasshopper is procured to solve the optimization problems. In GOA, grasshoppers change their positions by flying around in a multi-dimensional search space until an objective has been encountered, or until the computational limitations are exploded.

Grasshoppers can choose the path in the network through group recognition. There are two kinds of forces among them: repulsive and attractive forces, the first allowing them to explore search space and then revitalizing them in

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order to destroy the promising areas. The zone of comfort is the zone in which two forces are equal. The location of the grasshopper with the highest fitness value will be regarded as the closest to the goal as the target position is unknown. Updating grasshopper's place in the social interaction network to balance worldwide and local search will move grasshopper along the goal and converge to the best solution.

III. MATHEMATICAL MODEL OF GOA

The swarming behavior of grasshoppers can be written as [10]:

$$X_i = r_1 S_i + r_2 G_i + r_3 A_i \qquad (1)$$

Where

X_i defines the position of the i^{th} grasshopper

S_i = social interaction.

G_i = gravity force on i^{th} grasshopper.

A_i = shows the wind advection.

r_1, r_2, and r_3 are random number in [0, 1]

$$S_i = \sum_{\substack{j=1 \\ j \neq 1}}^{N} S(d_{ij})\hat{d}_{ij} \qquad (2)$$

Where,

d_{ij} = distance between the i^{th} and j^{th} grasshopper and can be calculated as $d_{ij} = |X_j - X_i|$.

$\hat{d}ij$ is a unit vector from the i^{th} grasshopper to the j^{th} grasshopper and is given by $\hat{d}ij = \frac{x_j - x_i}{d_{ij}}$

'S' is a function to define the strength of social forces between two grasshoppers and is given by

$$S(r) = fe^{-r/l} - e^{-r} \qquad (3)$$

Where, f is the intensity of attraction and l is the attractive length

Another important feature of swarming conduct is the social attraction that includes grasshopper attraction and repulsion when they move in search space together and apart. The parameters l and f significantly alter the area of convenience, attraction, and repulsion. Function S will separate the room explicitly between the region of repulsion, the comfort zone and the region of appeal.

The gravity force (G_i), is computed as follows

$$G_i = -g\hat{e}_g \qquad (4)$$

Where g is gravitational constant and $\hat{e}_g$ shows a unity vector towards the center of earth.

The wind advection (A_i), is computed as follows

$$A_i = u\hat{e}_w \qquad (5)$$

where u is a is a constant drift and $\hat{e}_w$ is a unity vector in the direction of wind.

There is no swing in the nymph grasshopper, so their moment is extremely linked with wind direction.

Substituting S_i, G_i and A_i in equation 1, we get

$$X_i = \sum_{\substack{j=1 \\ j \neq 1}}^{N} S(|X_j - X_i|)\frac{X_j - X_i}{d_{ij}} - g\hat{e}_g + u\hat{e}_w \qquad (6)$$

Where, N is the number of grasshoppers.

To simulate the interaction between grasshoppers in the swarm, above equation is used. However, because of improper convergence, the above model can not be used straight for simulation purposes because either the grasshoppers achieve the comfort zone quickly or the swarm does not move to the designated stage. The modified equation used for optimization is depicted as below

$$X_i^d = C\left\{\sum_{\substack{j=1 \\ j \neq 1}}^{N} C\frac{ub_d - lb_d}{2} S(|X_j^d - X_i^d|)\frac{X_j - X_i}{d_{ij}}\right\} + \hat{T}_d \qquad (7)$$

Where,

C is a decreasing coefficient to shrink the comfort zone, repulsion zone and attraction zone.

ub_d is the upper bond in the D^{th} dimension.

Lb_d is the lower bond in the D^{th} dimension.

$\hat{T}_d$ is the main goal (best solution).

This phenomenon is presented in Fig 2.

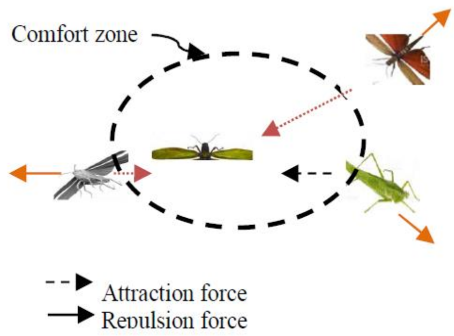

Fig.2 Corrective patter of individual Grasshopper in swarm

Where none of the other particles contributes to the updating of the particle position above equation indicates that the grasshopper's next position is defined based on its present situation, GOA needs all search officers to participate in the definition of the next place of each search officer, which is the primary benefit of the GOA over the PSO.

In order to balance between exploration and exploitation, coefficient c must be reduced as proportional to the amount of progressions of iterations and calculated as follows:

$$C = C_{max} - iter\,\frac{C_{max} - C_{min}}{iter\_max} \qquad (8)$$

Where,

C_{max} is the maximum value.

C_{min} is the minimum value.

iter indicates the current iteration and

iter_max is the maximum number of iterations.

In this work, it is assumed that $C_{max} = 1$ and $C_{min} = 0.0001$

In GOA, the most fit grasshopper is presumed to be the target during optimization. During each iteration, this will help GOA save the most promising destination in the search space and require grasshoppers to move towards it. This is done with the hope that a better and more accurate target will be found as the best approximation in the search space for the real global optimum. The debates above

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show the GOA algorithm's efficiency in finding the global optimum in a search space.

IV. MATHEMATICAL MODEL OF PROBLEM FORMULATION

The multi-objective CEED problem in a power system is to plan the power output for each dedicated generator unit in such a way that both the operating cost of generation and emission level of pollutants are minimized simultaneously while maintaining equality and non equality constraints in their respective limits. The multi-objective function *F* to express CEED problem consists of two sub functions namely fuel cost function and emission level function. Here, the multi objective function *F* is the total cost of generation of a station and named as total cost function. The main objective of the dissertation work is to minimize total cost of the generation i.e *F* while satisfying certain constraints and this function *F* is expressed as:

$$Min\ F(CEED) = f(C, E) \qquad (9)$$

Where,

C is fuel cost function
E is emission level function
Both the functions are different which results in a multi-objective function. Mathematically, this multi-objective function can be converted into a single objective function with the help of cost weight factors *k*. Hence, the objective function under the study is redefined as:

$$Min\ F(CEED) = f(C, k * E) \qquad (10)$$

Mathematically, fuel cost function C is given by:

$$C = \sum_{i=1}^{N} (a_i P_{gi}^2 + b_i P_{gi} + c_i) \qquad (11)$$

Where,
a_i, b_i, c_i are fuel cost coefficients
P_{gi} *is* power generated by i^{th} generator.
Mathematically, emission level function *E* is given by:

$$E = \sum_{i=1}^{N} \left(d_i P_{gi}^2 + e_i P_{gi} + f_i \right) \qquad (12)$$

Where, *di*,*ei* and *fi* are emission coefficients.
Mathematically, cost weight factor *k* is given by $k\,[i] =$

$$\frac{\sum_{i=1}^{N} (a_i P_{gi\,max}^2 + b_i P_{gi\,max} + c_i)}{\sum_{i=1}^{N} (d_i P_{gi\,max}^2 + e_i P_{gi\,max} + f_i)} \qquad (13)$$

Hence, mathematically objective function *F* is given as:

$$\text{Min } F = \sum_{i=1}^{N} (a_i P_{gi}^2 + b_i P_{gi} + c_i) + [\frac{\sum_{i=1}^{N} (a_i P_{gi\,max}^2 + b_i P_{gi\,max} + c_i)}{\sum_{i=1}^{N} (d_i P_{gi\,max}^2 + e_i P_{gi\,max} + f_i)} * \sum_{i=1}^{N} \left(d_i P_{gi}^2 + e_i P_{gi} + f_i \right) \qquad (14)$$

The constraints which are considered in the work are given by:
a) Equality constraint
In this, total generation generated by the all the units must be equal to the sum of total power demand & transmission power loss.

$$\sum_{i=1}^{N} P_{gi} - P_d - P_L \qquad (15)$$

where,
N is the total number of generators
P_{gi} is the power generated by ith generator
P_d is the total demand
P_L is the total transmission loss
The power loss using B coefficients can easily by calculated by the following formula:

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{0i} P_i + B_{00} \qquad (16)$$

b) Inequality constraint
Power generated by each generator must be within its upper and lower limits.

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \qquad i = 1,2 \ldots..N \qquad (17)$$

where, P_{gi}^{min} is lower operating limit of i^{th} generator , P_{gi}^{max} is upper operating limit of i^{th} generator

V. METHODOLOGY

Algorithm of GOA technique is formulated in MATLAB and steps involved in it are discussed below:

Step1: Initialize population size , max number of iterations, C_{max}, C_{min} number of generators, generator limits, load demand, cost coefficients and emission coefficients.
Step2: Define initial total cost function F using equation 5.6.
Step3: Randomly generate the initial positions of all the grasshoppers in the search space.
Step4: Evaluate fitness of each grasshopper of current population by using the fitness function while satisfying all the constraints and store the solution corresponding to the best-fit.
Step5: Sort the population from best to worst fitness value.
Step6: Assign the overall best fitness and the corresponding positions.
Step7: Initialize the iteration counter as 1.
Step8: Update the position of search agent by updating the value of C by using equation ……..
Step9: Evaluate fitness value corresponds to updated position while satisfying all the constraints.
Step10: Update overall best fitness value and the correspondingly position of grasshoppers.
Step11: Now check, if number of iteration is less than maximum iteration then go to step7 else terminate the program to find the optimal solution.

VI. SIMULATION RESULTS

In this case, three generator systems is considered whose fuel cost coefficients, emission cost coefficients & B loss coefficients of all the generators are taken from reference [11]. In this case, only NOx emission component is considered. The proposed algorithm is tested for the load demand of 700 MW. Table I shows the simulation result for 700 MW load demand when GOA technique is implemented on three generator system. Results obtained by GOA are also compared with other techniques and shown in table II. Looking into the results of table II, it can be concluded that GOA gives better results than FFA and GWO techniques.

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TABLE I SIMULATION RESULTS FOR THREE GENERATOR SYSTEM USING GOA

Parameters	Proposed GOA
P1 (MW)	210
P2 (MW)	209.99
P3 (MW)	191.52
Power Loss (MW)	16.2798
Fuel Cost (Rs/hr)	35425
NOx Emission (Kg/hr)	312.70
Total Cost (Rs/hr)	50379

TABLE II COMPARISON OF RESULTS OBTAINED WITH PROPOSED SCHEMES FOR 700 MW

Parameters	FFA [12]	GWO [11]	Proposed GOA
Power Loss (MW)	23.36	23.33	16.2798
Fuel Cost (Rs/hr)	35464	35462.78	35425
NOx Emission (Kg/hr)	651.5	651.50	312.70
Total Cost (Rs/hr)	66622.7	66619.07	50379

VII. CONCLUSIONS

GOA technique has been successfully applied to find the optimal solution of multi-objective combined economic emission dispatch problem. In this dissertation, Grasshopper optimization algorithm has been discussed and implemented to solve CEED problem. Swarming behavior of the grasshopper is used an optimization tool to solve the complex problem. Intellectually grasshopper has two inviting habits. One is by exploring the food and another is by exploiting the food. The grasshopper move instinctively in exploration and move locally in exploitation. This technique of exploration and exploitation is main searching aspects in GOA. The similar methodology is adopted in the formulation of GOA and is proposed in this dissertation to solve the multi-objective CEED problem. Here, the multi-objective CEED problem is converted into single objective problem by converting emission level into equivalent cost by multiplying the emission level by cost weight factor. The test system consists of three generators is simulated by proposed GOA in MATLAB under various load conditions where only oxides of nitrogen as emission pollutant is considered. From the results obtained, it is found that the total generation cost, emission level and power loss is lesser in case of proposed GOA technique than earlier technique. Hence, GOA is very effective in solving multi-objective CEED problem.

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