Bee Hive Algorithm to Optimize Multi Constrained Piecewise Non-Linear Economic Power Dispatch Problem in Thermal Units

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Abstract: This paper presents application of a Bee Hive Algorithm to Economic Load Dispatch which considers practical constraints and non linear characteristics. The proposed ED formulation includes ramp rate limits, valve loading effects, multiple fuels, equality and inequality constraints, which usually are found simultaneously in realistic power systems. Conventional methods such as Lambda iteration and Base point participation are not able to obtain optimal solution for units having discontinuous fuel cost functions. Bee Hive Algorithm can overcome the difficulties and provides an almost global optimal solution, since they don't get stuck up at local optimum.

Keywords: Economic load Dispatch, Bee Hive Algorithm, Valve-point loading, Ramp rate limits, Multiple Fuels

1. Introduction

ECONOMIC Load Dispatch (ELD) seeks "the best" generation for the generating plants to supply the required demand plus transmission losses with the minimum production cost. Improvement in scheduling the units output can lead to significant cost savings. In traditional ELD problems, the cost function of each generator is approximately represented by a simple quadratic function and is solved using mathematical programming based on several optimization techniques such as dynamic programming, Linear programming, homogenous linear programming and quadratic programming methods[2],[3],[4]. However none of these methods may be able to provide an optimal solution and they usually get stuck at a local optimum. Normally the input-output characteristic of modern generating units are highly non-linear in nature due to valve-point effect [1],[14], [15], [16], [18], [19] ramp-rate limits, Fuel switching [11], [20] etc, having multiple local minimum points in the cost function.

To overcome such difficulties many heuristic search algorithms, such as Genetic algorithm [1], [5], Differential Evolution [6], Tabu search [7], [19], etc., have been proposed to solve ELD problem. These techniques can be used to search the global optimum with any type of objective function and constraints [22]. In this paper, two ED problem for 3 and 10 thermal units with a non smooth fuel cost function [8] are employed to demonstrate the performance of the proposed method with BHA and the results were compared with GA.

The rest of this paper is organized as follows: Section II describes the formulation of an ED problem; while section III explains the standards in BHA. Section IV then details the procedure of handling the BHA. Section V gives the flow chart. Section VI gives the Data and gives the results of the optimization. Section VII outlines our conclusion and future research.

2. Problem Description

The objective of ED is to determine the generation levels for all on-line units which minimize the total fuel cost, while satisfying a set of constraints. It can be formulated as follows:

A. Economic Dispatch (Ed) Problem Formulation

The fuel cost functions of the generating units are usually described by a quadratic function of power output [13].

Thus the objective function is to minimize:

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \tag{1}$$

Where

a_i, b_i, c_i - the fuel cost coefficients of the ith unit

N- Number of generating units in the system

P_i - output generation of ith unit.

1. Power balance constraint:

$$\sum_{i=1}^{N} P_i = P_D + P_L \tag{2}$$

Where

P_D – Total power demand

P_L – Total network losses

2. Capacity limits constraints:

$$P_i^{min} \le P_i \le P_i^{max} \tag{3}$$

Where

P_i^{min} – minimum generation limit

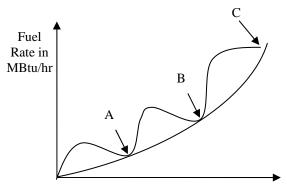P_i^{max} – maximum generation limit

B. Valve Point Effect

Large steam turbine generators will have a number of steam admission valves that are opened in sequence to obtain ever–increasing output of the unit. As the unit loading increases the input to the unit increases and the incremental heat rate decreases between the opening points for any two valves [9], however, when a valve is first opened, the throttling losses increases rapidly and the incremental heat rate rises suddenly. This is "valve point" effect which leads to non-smooth, non-convex input-output characteristics [12], to be solved using the heuristic techniques[1].

The valve point effect is incorporated in ED problem by superimposing the sine component model on the quadratic cost curve which is given below,

$$F_i*(P_i) = F_i(P_i) + e_i \sin(f_i[P_i^{min} - P_i]) \tag{4}$$

Where

$F_i*(P_i)$ – fuel cost if ith unit with valve point effect

e_i, f_i – the fuel cost coefficients of the ith unit with valve point effect.

Figure 2.1. Valve point curve

C. Ramp Rate Limits:

The Ramp-Up and Ramp-Down rate limits of ith generator are given by
As generation increases,

$$P_i - P_{i0} \le UR_i \qquad (5)$$

As generation decreases

$$P_i - P_{i0} \le DR_i \qquad (6)$$

and

$$\max(P_i^{min}, P_{i0} - DR_i) \le P_i \le \min(P_i^{max}, P_{i0} + UR_i) \qquad (7)$$

Where Pi is the current output power and Pi0 is the output power in the previous interval of the ith generator unit. UR$_i$ is the up-ramp rate limit of the ith generator and DR$_i$ is the down-ramp rate limit of the ith generator.

D. Multiple Fuels:

Some generating units are capable of operating using different types of fuels. The use of multiple fuel types may result in multiple cost curves that are not necessarily parallel or continuous. The lower region of the resulting cost curve determines which fuel type is most economical to bum.
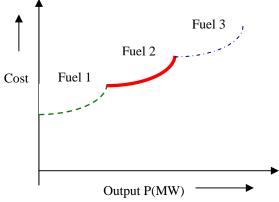

Figure 2.2. Fuel Cost Function Supplied with Multiple Fuel Types

This cost function can be represented by a piecewise curve (see Fig 2.2), and the segments are defined by the range in which each fuel is used. The ED problem with piece wise quadratic cost curves is very difficult to solve by standard techniques. Piecewise quadratic cost functions have as many segments as fuel types.

$$F_i(P_{G,i}) = \begin{cases} a_{i,1} + b_{i,1}P_{G_i} + c_{i,1}P_{G_i}{}^2, & \underline{P}\,^1_{G_i} < \overline{P}^1_{G_i} \\ a_{i,2} + b_{i,2}P_{G_i} + c_{i,2}P_{G_i}{}^2, & \underline{P}\,^2_{G_i} < \overline{P}^2_{G_i} \\ \quad\vdots \\ a_{i,k} + b_{i,k}P_{G_i} + c_{i,k}P_{G_i}{}^2, & \underline{P}\,^3_{G_i} < \overline{P}^k_{G_i} \end{cases} \tag{8}$$

Where $P_{G_i}^k$ and $\overline{P}_{G_i}^k$ are the lower and upper bound respectively of the kth fuel of unit-I, and $a_{i,k}, b_{i,k}., c_{i,k}$ are the kth fuel cost coefficient of unit-i.

3. Optimization Using Bee Hive Algorithm

Bee Hive algorithm, proposed by Karaboga in 2005 for real parameter optimization, is a recently introduced optimization algorithm and simulates the foraging behavior of bee colony [2] for unconstrained optimization problems [1]–[5]. For solving constrained optimization problems, a constraint handling method was incorporated with the algorithm [7]. The ABC algorithm is developed by inspecting the behaviors of the real bees on finding food source, which is called the nectar, and sharing the information of food sources to the bees in the nest.

Biological Inspiration

In a real bee colony, there are some tasks performed by specialized individuals. These specialized bees try to maximize the nectar amount stored in the hive by performing efficient division of labour and self-organization. The minimal model of swarm-intelligent forage selection in a honey bee colony, that bee hive algorithm adopts, consists of three kinds of bees: employed bees, onlooker bees, and scout bees. Half of the colony comprises employed bees and the other half includes the onlooker bees. Employed bees are responsible from exploiting the nectar sources explored before and giving information to the other waiting bees (onlooker bees) in the hive about the quality of the food source site which they are exploiting. Onlooker bees wait in the hive and decide a food source to exploit depending on the information shared by the employed bees. Scouts randomly search the environment in order to find a new food source depending on an internal motivation or possible external clues or randomly. The bee decides for one of the possibilities using the mechanism based on the characteristics of the food source (quality, quantity and distance from the hive). The described process continues constantly, while the bees from a hive collect nectar and investigate new areas with possible food sources.

4. Implementation Of Bee Hive Algorithm

Main steps of the Bee Hive algorithm simulating these behaviors are given below, here the food represents the economic generation and the food source represents the limits of each generator.
1. Initialize the food source positions.
2. Each employed bee produces a new food source in her food source site and exploits the better source.
3. Each onlooker bee selects a source depending on the quality of her solution, produces a new food source in selected food source site and exploits the better source.
4. Determine the source to be abandoned and allocate its employed bee as scout for searching new food sources.

5. Memorize the best food source found so far.
6. Repeat steps 2-5 until the stopping criterion is met.

The process of the Bee hive algorithm is presented as follows:

Step 1. Initialization: Spray *ne* percentage of the populations into the solution space randomly, and then calculate their fitness values, which are called the nectar amounts, where *ne* represents the ratio of employed bees to the total population. Once these populations are positioned into the solution space, they are called the employed bees.

Step 2. Move the Onlookers: Calculate the probability of selecting a food source, select a food source to move to by roulette wheel selection for every onlooker bees and then determine the nectar amounts of them.

Step 3. Move the Scouts: If the fitness values of the employed bees do not be improved by a continuous predetermined number of iterations, which is called "*Limit*", those food sources are abandoned, and these employed bees become the scouts.

Step 4. Update the Best Food Source Found So Far: Memorize the best fitness value and the position, which are found by the bees.

Step 5. Termination Checking: Check if the amount of the iterations satisfies the termination condition. If the termination condition is satisfied, terminate the program and output the results; otherwise go back to the Step 2.

$$P_i = \frac{F(\theta_i)}{\sum_{k=1}^{S} F(\theta_k)} \tag{9}$$

where θ_i denotes the position of the ith employed bee, S represents the number of employed bees, and P_i is the probability of selecting the ith employed bee.

$$x_{ij}(t+1) = \theta_{ij} + \phi(\theta_{ij}()t - \theta_{kj}(t)) \tag{10}$$

where x_i denotes the position of the ith onlooker bee, t denotes the iteration number, θ_k is the randomly chosen employed bee, j represents the dimension of the solution and $\phi(\cdot)$ produces a series of random variable in the range $[-1, 1]$.

$$\theta_{ij} = \theta_{ij\,min} + r.(\theta_{ij\,max} - \theta_{ij\,min}) \tag{11}$$

where r is a random number and $r \in [0, 1]$.

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5. Flowchart
The diagrammatic representation of the Bee Hive algorithm is given below:
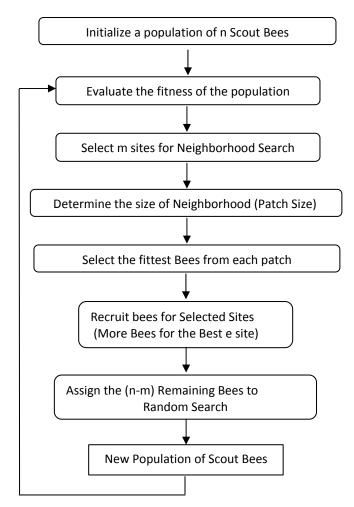

Figure 5.1. Bee Hive Algorithm

6. Data And Results
A. *TEST CASE I*
3-generator System:

The unit characteristics data are given [1]. The load demand is 850MW. The constraints which have been included are Valve point loading, Ramp Rate Limits, Prohibited Operating zones and transmission losses.

The output power for each generator among the three and Fuel cost for the same has been represented below and also the total power along with the fuel cost has been calculated. Comparison has been made for the calculated result in Bee Hive Algorithm with Genetic Algorithm.

Table 1. Convergence Results for 3 Generating Units With Valve Point Effect & Losses

Quantities	Optimal Values	
	BHA	GA
P1(MW)	145.56	146.56
P2(MW)	293.42	293.12
P3(MW)	422.36	421.87
F1($/hr)	1365.4	1379.4
F2($/hr)	2287.5	2584.3
F3($/hr)	4357.1	4377.7
Ploss(MW)	11.139	13.139
Total Gen(MW)	861.34	861.55
Total Fuel Cost ($/hr)	8010	8341.4

B. TEST CASE II

10-generator systems:

The unit characteristics data are given [1]. The load demand is 2000MW. System data of units considering b loss coefficients are given in [27].

The constraints which have been included in this ten unit system was Valve point loading, Ramp-Rate limits, Prohibited Operating Zones along with Multiple Fuel Switching.

Table 2. Convergence Results for 10 Generating Units With Valve Point Effect

Quantities	Optimal Values	
	BHA	GA
P1(MW)	195.193	225.6242
P2(MW)	286.109	233.7826
P3(MW)	340	330
P4(MW)	300	300
P5(MW)	243	242
P6(MW)	160	160
P7(MW)	130	130
P8(MW)	120	118
P9(MW)	80	80
P10(MW)	223.236	245.9484
Total Power Output(MW)	2057.53	2056.8752
Ploss(MW)	57.53	56.872
Total Generation Cost($/h)	123916.573	125975.5063

7. Conclusion

In this paper, a comprehensivs ED model including ramp rate limits, valve loading effects, Multiple Fuels and transmission losses together is presented. In this method, the Bee Hive algorithm method is found best suited for the fuel cost functions of non-smooth, multiple fuel curves when compared with GA. The proposed BHA can provide a more diverse search of solution space and so better optimum solutions with low computation burden can be found. The research work is under way in order to incorporate more security issues of power system in the ED model with other constraints.

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