FPA APPLIED TO THE RESOLUTION OF THE ECONOMIC DISPATCH PROBLEM WITH OPERATIONAL LIMITS OF MAXIMUM AND MINIMUM POWER OF THE GENERATING UNITS

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ABSTRACT

This paper presents the application of a Computational Intelligence technique based on Flower Pollination Algorithm (FPA) to solve an Economic Dispatch (ED) problem. Aiming to minimize the total generation costs and considering operational constraints of each generating unit and the power balance. The algorithm was tested using the case study with fifteen generating units available in the current literature. Finally, the data obtained were compared to others already published, in which the authors applied Directional Search Genetic Algorithm (DSGA) to solve the pointed problem. The good results achieved demonstrate the applicability of the proposed technique.

Keywords: Economic Dispatch, FPA, Generation Units, Metaheuristic

Introduction

The origin of Economic Dispatch (ED) problem dated to the 1920, when engineers became concerned with the problem of economic allocation of generating units or the most appropriate division of load among available generating units [1].

According to Jeronymo [2] ED problem deals with the distribution of the total power demand requested by the electrical power system for available generation units, so that the cost of energy generation is minimized. Another point mentioned by author is the importance of respecting the system power balance as well as the physical and operational limits.

To solve the DE problem, several techniques can be implemented that are deterministic or stochastic. Deterministic algorithms are in search of the locally optimal solution (except for linear programming and convex algorithms), they are traditional algorithms and are normally not effective for non-linear problems. The most stochastic algorithms, known as heuristics or meta-heuristics, are bioinspired, that is, they are inspired by nature and are in search of a global solution [3]. Therefore, stochastic algorithms explore a wide space searching by global solution while deterministic algorithms searching by the local solution.

Bioinspired optimization methods have been widely used to solve economic dispatch problems due to their ability to offer efficient solutions to complex problems, as described by Oliveira [4]. In this context, several methods using metaheuristics have already been studied, including Genetic Algorithm (GA) [5], Particle Swarm Optimization (PSO) [6] and Ant Colony [7]. Some of them have been modified and/or improved, as Directional Search Genetic Algorithm (DSGA) case, becoming an improved version of the conventional genetic algorithm [8].

FPA was applied in this paper due to be a technique promising and with wide possibilities of study to solve ED problem, as described in [9]. An example is the Yang study [10] that presented an excellent performance for FPA when compared to other widely studied meta-heuristics such as PSO and GA. Another study that corroborates for the fact of FPA is a promising technique and collaborates with the motivation of this work to expand this kind of research is the presented by Suman and Sakthivel [11]. One of results obtained justifying the application of FPA is that it has only one key input parameter p (probability of switching), which makes the algorithm easier to implement and faster to reach the ideal solution. Furthermore, the alternation between local and global pollination contributes to the algorithm escaping the local minimum solution. As well as in a more recent study by Tahir et al [12], which includes renewable generation, solar and wind.

Following this context, this paper aims to study the problem of ED with operational limits by applying FPA to evaluate if the technique presents satisfactory results and to compar its results with the results of the DSGA presents in the study of Adhinarayanan and Sydulu [8]. These two algorithms are bioinspired and the optimization is based on populations. The difference between the two is that DSGA is a modified and deterministic algorithm based on local directional search and genetics, and FPA is swarm-based and targets flower pollination behavior to search for the global solution.

Problem Modeling

As described by Souza, Oliveira and Silva [13] to solve this problem is required to minimize the generation cost function of all available generating units represented by Equation 1. One of the constraints applied to the active power balance of the system, as described by Equation 2, and other constraint established between the minimum and maximum limits of generation for each plant as describes by Equation 3.

$$Minimize \sum_{i=1}^{N} F_i(P_i) \tag{1}$$

Subject to:

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

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

Where: i : Thermoelectric plant (unit); N : Total of the thermoelectric plant of the system (unit); F_i : Total cost of the thermoelectric plant ($/h); P_i : Total power generated by the thermoelectric plant (MW); P_D : Demand of the system (MW); P_i^{min} : Minimum power generated by the thermoelectric plant (MW); P_i^{max} : Maximum power generated by the thermoelectric plant (MW);

A. Traditional Formulation

For Souza, Oliveira and Silva [13] a traditional formulation follows the characteristics presented in Equation 4, due to "the approximation of the cost function by a simple quadratic function is the classic approach". This classic formulation is represented by a non-linear function and restrict according to equations 2 and 3 and described in items B and C.

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 \tag{4}$$

Where a_i, b_i and c_i are operating cost coefficients referring to generating unit i.

B. Active Power Balance Constraint

According to Oliveira [4] this constraint refers to the load required by the system and must be satisfied by generating units. Therefore, the active power balance is a constraint described by Equation 2.

C. Operating Limits Constraint

These are the operating limits of the generating unit which delimits the generation capacity between the minimum and maximum values. This limitation is formulated by Equation 3 which represent the operating constraint of the generating unit. Therefore, the value to be generated by unit i for the ED problem must be within this range.

Flower Pollination Algorithm

In this paper, FPA optimization technique was applied to minimize the total operating cost function. As defined by Yang [14] in a simplified form, four rules are used to implement FPA algorithm:

1. Biotic and cross-pollination is considered the overall pollination process. With pollinators moving obeying Lévy flights;
2. Abiotic and self-pollination are considered as local pollination or local search;
3. Pollinators such as insects can develop a constancy in the search for the same flowers, which is equivalent to the probability of reproduction that is proportional to the similarity of the flowers involved;
4. The variation in the search for solutions through abiotic or biotic pollinations can be controlled by an exchange probability $p \in [0,1]$.

As noted by Yang [10], for implementation it is necessary to transform these rules into equations due to that the algorithm follows two main steps, global and local pollination.

A. Global Pollination Step

In the global pollination step, flower pollens are carried by pollinators such as insects, and pollens can travel over a long distance because insects can often fly and move in a much longer range. This ensures the pollination and reproduction of the fittest. In the formulation is represented by variable g_*. The first rule and flower constancy can be represented mathematically by Equation 6.

$$x_i^{t+i} = x_i^t + L\left(x_i^t - g_*\right) \tag{6}$$

Where: x_i^t - Pollen i or vector solution x_i; t - Number of iterations; g_* - Best solution option found among all solutions in the current generation/iteration; L - Step vector obeying the Lévy flights.

B. Movement of pollinators using Lévy flights

Since insects may move over a long distance with various distance steps, can use a Lévy flight to imitate this characteristic efficiently. In this context, the drawing $L > 0$ from a Levy distribution is described by Equation 7.

$$L \sim \frac{\lambda\Gamma(\lambda)\sin(\pi\lambda/2)}{\pi}\frac{1}{s^{1+\lambda}},\ (s \gg s_0 > 0) \tag{7}$$

Where: $\Gamma(\lambda)$ - Standard gamma function; whose distribution is valid for large steps $s > 0$.

C. Local Pollination Step

Then, to model the local pollination, both Rule 2 and Rule 3 can be represented by Equation 8.

$$x_i^{t+i} = x_i^t + \epsilon\left(x_j^t - x_k^t\right) \tag{8}$$

Where: ϵ - Local random walk from a uniform distribution in [0,1]; x_j^t, x_k^t - Pollens from different flowers of the same plant species.

An additive penalty strategy was to apply the equality constraints of the ED problem. A penalty factor is introduced to guarantee that the fitness of infeasible solutions is always worse than any feasible one. Kohler, Vellasco and Tanscheit [15] added the penalty to the objective function of disabled individuals according to Equation 9 such that $p(x) = 0$ if x satisfies all constraints of the problem.

$$F(x) = f(x) + p(x) \tag{9}$$

Where: $F(x)$ - the expanded objective function to be minimized; $f(x)$ - the original objective function; $p(x)$ - the amount of the penalty.

Results and Comparatives

Applying FPA through the MATLAB® tool, a resolution was sought for the case study with fifteen generating units, as well as a comparison of the results of the total generation costs obtained through FPA in relation to the DSGA presented by Adhinarayanan and Sydulu [8]. It is important to emphasize that the prohibited operation zone constraint was not applied.

First, data entry were performed, then several configurations were tested for flower population n, local search probability p and number of maximum iterations $tmax$. After the tests, the following parameters were defined: $tmax$=500 (% Maximum Iterations); n=100 (% Flower Population); p=0.4 (% Local Search Probability [0;1]).

A. Study Case – 15 Units

Using the same input data from the study by Adhinarayanan and Sydulu [8], the technique for solving the ED problem was applied to the system composed of fifteen generating units with load required by the 2,650 MW generation system.

Table 1 presents the results of the optimal generation obtained for each generating unit, as well as the total cost of operation, and in column 3, the results obtained by DSGA [8]. The results were obtained from the objective function and problem modeling constraints, after 20 simulations of the problem using FPA.

Table 1 - Optimal Generation Levels

Unit	Optimal Generation by FPA	Optimal Generation by DSGA [8]
1	455	437.8
2	455	455
3	130	130
4	130	130
5	317.8032	335
6	460	460
7	465	465
8	60	60
9	25	25
10	20	20
11	20	20
12	57.19668	57.1
13	25	25
14	15	15
15	15	15
Total Cost ($/h)	32,542.44	32,545

In Table 1, satisfactory comparative results are observed when the cost obtained via FPA is compared with the cost obtained by DSGA [8]. The cost obtained by FPA was 0.79% lower when compared to that obtained by DSGA. This demonstrates the feasibility of applying FPA to resolve other cases of the comparative study or related studies.

Conclusions

After accomplishment of the study, it is possible to conclude that the results obtained show that FPA when compared with the DSGA has the potential to satisfactorily solve ED problems with operating

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limits and active power balance. FPA was necessary to parameterize the maximum number of iterations, the flower population, and the local search probability for the minimum possible simulations to be able to find the feasible solution whereas in deterministic algorithms the result does not change between simulations.

Future studies are valid to improve the analysis, carrying out tests in cases with a larger number of generating units and including challenges related to real operating conditions such as prohibited zones of operation, for generating units that do not operate within some power, multiple fuels, when the operation has more than one type of fuel, and aspects of the transmission network, that is, including the value of transmission losses in the power balance, thus making the more realistic problem, especially in relation to the total cost of operation.

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Authorship statement

The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been herein included as part of the present paper is either the property (and authorship) of the authors or has the permission of the owners to be included here.

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