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Tournament-based harmony search algorithm for non-convex economic load dispatch problem

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ABSTRACT

This paper proposes a tournament-based harmony search (THS) algorithm for economic load dispatch (ELD) problem. The THS is an efficient modified version of the harmony search (HS) algorithm where the random selection process in the memory consideration operator is replaced by the tournament selection process to activate the natural selection of the survival-of-the-fittest principle and thus improve the convergence properties of HS. The performance THS is evaluated with ELD problem using five different test systems: 3-units generator system; two versions of 13-units generator system; 40-units generator system; and large-scaled 80-units generator system. The effect of tournament size (t) on the performance of THS is studied. A comparative evaluation between THS and other existing methods reported in the literature are carried out. The simulation results show that the THS algorithm is capable of achieving better quality solutions than many of the well-popular optimization methods.

1. Introduction

In power system, economic load dispatch (ELD) problem is an important optimization and operations task. The main aim of solving ELD is to distribute the required generation among the generating units in such a way to minimize the fuel costs of each unit subject to satisfying equality constraints related to the power balance and inequality constraints related to the power output [27,65]. Therefore, ELD problem is considered as a non-convex and highly non-linear optimization problem which can not be easily tackled using traditional calculus-based optimization methods [65,28]. Indeed, the calculus-based methods require smoothing and differentiable objective function when applied to tackle the ELD problems [34].

Recently, the emergence of the approximation methods for ELD revealed very successful stories in the operations and planning of the power system. These approximation methods can be grouped into (i) swarm-based algorithms such as shuffled frog leaping algorithm [70], firefly algorithm [28,87], artificial bee colony [43,44], bacterial foraging algorithm [35], cuckoo search [17,84], particle swarm optimization [73], ant colony optimization [45,24,68], honey bee mating optimization [61], chemical reaction optimization [71], (ii) evolutionary-based algorithms such as genetic algorithm [29,80], harmony search algorithm [27], biogeography-based optimization [69,21,19], and (iii) trajectory-based algorithms such as simulated annealing [66], tabu search [67]. The approximation methods have the ability to find potential solutions when employed to tackle the problem of high dimensionality such as ELD.

However, due to the complexity nature of ELD search space, recent studies modified or hybridized the approximation methods in order to improve their performance. For example, the evolutionary programming and genetic algorithm are incorporated for the ELD in [77,29] while the performance of particle swarm optimization is enhanced with sequential quadratic programming (PSO-SQP) in [83]. And many other improvements related to ELD can be found in [73,20,48,51,18,15,42].

The most important issue related to adaptation of any optimization algorithm to constrained problems is how the algorithm handles the constraints relating to the problem. Over the years, several methods are proposed to handle the problem constraints. These methods include those that preserve the feasibility of solutions, penalty-based methods, methods that clearly distinguish between feasible and infeasible solutions, and hybrid methods [32]. When ELD-based methods handle the equality and inequality

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constraints, they choose to work in a feasible search space region or infeasible one. In case, if the method is employed to search the feasible region of the search space (like the one adapted in this paper), the feasibility of each generated solution is maintained using a special repair strategy that guaranteed the satisfactions of all constraints [33,54]. In contrast, when the method is utilized to search the infeasible region of the search space, an error rate that reflects the violation in the constraints is incorporated in the fitness function (which penalizes infeasible solutions). Thus, this converts the constrained to unconstrained optimization problem. By means of modifying the fitness function to include the constraint violations (normally with high penalty value), the method obtains a solution with no constraint violations as well as with a minimum fuel cost at the final stage of run [23,47].

In the recent years, several harmony search (HS) algorithms have been proposed to tackle ELD problems [30,27,47,65,63]. The HS, which is the recent evolutionary algorithm proposed in [40], is considered to be an efficient approximation technique due to its derivative-free characteristics [53]. Literatures have shown the usability of HS algorithm have been increasing over the year to address a wide range of optimization problems [76,12,39,37,38,46]. Similarly, the HS algorithm has been modified and hybridized with other efficient methods to cope with the combinatorial nature of highly constrained optimization problems [4,7,1,10,11,14]. Furthermore, the parameter-free HS [41] and population structured of HS are proposed to improve the theoretical aspects of the algorithm [2,5].

Procedurally, HS as an evolutionary algorithm begins with a population of individuals generated randomly. At each generation, a new individual called "new harmony" is generated in accordance with three operations: "memory consideration" concerned with a recombination process; "random consideration" concerned with diversification aspects; and "pitch adjustment" concerned with local intensification. The new individual is evaluated and replaced the worst individual in the entire population, if superior. This generation process is repeated until a certain stop criterion is reached.

One of the main shortcomings of the HS algorithm raised is in the area of memory consideration selection process where the natural selection of survival-of-the-fittest principle is omitted [3]. Thus, the investigations of novel selection methods in the memory consideration for the HS algorithm are proposed in [3,13] and analyzed in [6], where five selection schemes were investigated: proportional, tournament, global best, linear rank, and exponential rank. Interestingly, the tournament-based HS algorithm achieved the best performance for the global optimization problems and adopted by other researchers as an efficient variant of the HS algorithm [25,75,49].

In this paper, the tournament-based HS (THS) algorithm is investigated for the ELD problem. The performance of THS is better than HS because it utilized the survival-of-the-fittest principle of the natural selection in memory consideration process. Note that the memory consideration is the main operator of THS which responsible for constructing the new solutions from the accumulative search and therefore, improving its selection process will improve the convergence property directly. However, time complexity in each iteration of the THS algorithm might be marginally affected because new data structure will be added to operate the tournament concepts in memory consideration. The THS algorithm is experimented with five ELD test systems with valve point loading effect instances for diverse power systems and different cost curve natures. These include 3-units generator system; two versions of 13-units generator system; 40-units generator system; and a large-scaled 80-units generator system. In all experimented ELD cases, the proposed THS competitively produced comparable results.

The remainder of this paper is organized as follows: Section 2 provides the formulations of ELD problem. The description of THS algorithm for ELD is given in Section 3. Experimental results and analysis of the findings are presented in Section 4 while the conclusion and possible future research directions are provided in Section 5.

2. Economic load dispatch problem

The economic load dispatch problem could be traditionally formulated as a minimization of the fuel costs summation of the individual dispatchable generating power units subject to the balance of real power with the total load demand in addition to limits on power generating system outputs. Mathematically, the objective function of ELD problem can be formulated in Eq. (1) as:

$$F(\boldsymbol{P}) = \sum_{i=1}^{N} F_i(P_i). \tag{1}$$

where $F(\boldsymbol{P})$ is a system-wide total cost functions of N generating units; F_i is generating cost function of generating unit i; and P_i is the generation output of the active generating unit i. The incremental cost functions of the power generating systems with valve-point loading effects are represented using Eq. (2) as follows:

$$F_i(P_i) = \lfloor a_i P_i^2 + b_i P_i + c_i + |e_i \sin(f_i(P_i^{(\min)} - P_i))| \rfloor. \tag{2}$$

Subject to

$$\sum_{i=1}^{N} P_i - P_D - P_L = 0 \tag{3}$$

$$P_i^{(\min)} \leq P_i \leq P_i^{(\max)}, \quad i \in N_s \tag{4}$$

In Eq. (2), (a_i, b_i, c_i) and (e_i, f_i) are the smooth and non-smooth cost fuel coefficients of generating unit i respectively. Note that Eq. (3) represents the equilibrium state between total system generation $(\sum_{i=1}^{N} P_i)$ and the summation of total system loads (P_D) with losses (P_L). Finally, the lower and upper bound $(P_i \in [(P_i^{(\min)}), (P_i^{(\max)})])$ of the output of each active generating unit is inequality constrained in Eq. (4).

The total transmission losses of the system is expressed as a quadratic function of outputs of the power generating system as shown in Eq. (5)

$$P_L = \sum_{k=1}^{N}\sum_{i=1}^{N} P_k B_{ki} P_i + \sum_{k=1}^{N} B_{0k} P_k + B_{00} \tag{5}$$

where B_{ki} is the $k$ith component of the loss coefficient square matrix while B_{0k} and B_{00} are the ith component of the loss coefficient vector and the constant of the loss coefficient respectively.

The fuel cost function together with sinusoidal function which models the effect of valve-point generates waves in the heat-rate curve creates additional local optima to the solution search space [8]. As experimented by other comparative studies reported in Table 1 [23,8,22,54,82,58], the total transmission losses are ignored for all the test arrangements for sake of simplicity sought in this paper(i.e., $P_L = 0$).

3. Tournament harmony search for ELD

Procedurally, the THS has five main steps pseudo-coded in Algorithm 1 and described as follows: