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Hybrid integer coded differential evolution – dynamic programming approach for economic load dispatch with multiple fuel options

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Abstract

This paper presents a novel and efficient approach through a hybrid integer coded differential evolution – dynamic programming (ICDEDP) scheme to solve the economic dispatch (ED) problem with multiple fuel options. A dynamic programming (DP) based simplified recursive algorithm is developed for optimal scheduling of the generating units in the ED problem. The proposed hybrid scheme is developed in such a way that an integer coded differential evolution (ICDE) is acting as a main optimizer to identify the optimal fuel options, and the DP is used to find the fitness of each agent in the population of the ICDE, which makes a quick decision to direct the search towards the optimal region. The hybrid ICDEDP decision vector consists of a sequence of integer numbers representing the fuel options of each unit to optimize quality of search and computation time. A gene swap operator is introduced in the proposed algorithm to improve its convergence characteristics. In order to show the efficiency and effectiveness, the proposed hybrid ICDEDP approach has been examined and tested with numerical results using the ten generation unit economic dispatch problem with multiple fuel options. The test result shows that the proposed hybrid ICDEDP algorithm has high quality solution, superior convergence characteristics and shorter computation time.

Keywords: Economic dispatch; Multiple fuel options; Integer coded differential evolution; Dynamic programming

1. Introduction

The main objective of the economic dispatch problem is to determine the optimal combination of power outputs for all generating units that minimizes the total fuel cost while satisfying load demand and operating constraints. This makes the ED problem a large scale nonlinear constrained optimization problem. Conventional techniques offer good results, but when the search space is nonlinear and has discontinuities, they become very complicated with a slow convergence ratio and do not always seek the optimal solution. New numerical methods are needed to cope with these difficulties, especially those with high speed search for the optimal and not being trapped in local minima.

The stochastic search algorithms such as genetic algorithm (GA) [1], evolutionary programming (EP) [2,3], simulated annealing (SA) [4] and PSO [5,6], may prove to be very effective in solving nonlinear ED problems without any restriction on the shape of the cost curves. Although these heuristic methods do not always guarantee discovering the globally optimal solution in finite time, they often provide a fast and reasonable solution (sub-optimal, nearly global optimal). SA is applied in many power system problems, but setting the control parameters of the SA algorithm is a difficult task, and the convergence speed is slow when applied to a real system [7]. Though GA methods have been employed successfully to solve complex optimization problems, recent research has identified some

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deficiencies in GA performance. This degradation in efficiency is apparent in applications with highly epistatic objective functions. Moreover, the premature convergence of GA degrades its performance and reduces its search capability that leads to a higher probability of obtaining a local optimum [8]. EP seems to be a good method to solve optimization problems. When applied to problems consisting of more numbers of local optima, the solutions obtained from the EP method is just near the global optimum one. Also, the GA and EP take long simulation times in order to obtain a solution for such problems. Therefore, hybrid methods combining two or more optimization methods were introduced [9,10].

The generation cost function for fossil fired plants can be represented as a segmented piecewise quadratic function. The generating units, particularly those that can be supplied with multi-fuel sources (coal, natural gas, or oil), lead to the problem of determining the most economic fuel to burn. Lin and Vivani [11] have discussed such a problem using the hierarchical approach of Lagrangian multipliers (λ) method to find the incremental fuel cost for subsystems comprising groups of units. The solution searches for the optimal λ for various choices of fuel and the generation range of the units iteratively. Park et al. [12] proposed to apply a Hopfield neural network (HNN) to the ED problem for a piecewise quadratic cost function. Lee et al. [13] presented an improved adaptive Hopfield neural network approach for finding the solution for ED with multiple fuel options. It is well known that the HNN converges very slowly and normally takes a large number of iterations. Baskar et al. [14] discussed a hybrid real coded GA method for solving the ED problem with multiple fuel options.

In this paper, a hybrid ICDEDP algorithm that combines a heuristic optimization technique and a mathematical algorithm is proposed to solve the ED problem with multiple fuel options. Differential evolution (DE), developed by Storn and Price, is one of the most excellent evolutionary algorithms. DE is a robust statistical method for cost minimization, which does not make use of a single nominal parameter vector but instead uses a population of equally important vectors. The fittest of an offspring competes one to one with of the corresponding parent, which is different from the other evolutionary algorithms [15]. By using a simple and direct evolution process, the convergence speed of DE becomes very fast. However, the faster convergence may lead to a higher probability of obtaining a local optimum. Generally, this drawback can be overcome by using a large population size but which leads to increased computation time in evaluation of the fitness function. In order to overcome this drawback a hybrid method is presented to solve the ED problem with multiple fuel options by integrating the integer coded DE with the dynamic programming (DP) method. A DP [16] based recursive algorithm that minimizes fuel cost has been developed in a simple form to evaluate the fitness of each individual in the population of the hybrid ICDEDP algorithm. The main advantages of the proposed method for solving the ED problem with multiple fuel options are its simple concept, great robustness, high quality solution and better computation efficiency.

2. Problem formulation

The main objective of economic dispatch (ED) is to find the optimal combination of power generations that minimizes the total generation cost while satisfying equality and inequality constraints. A piecewise quadratic function is used to represent the input–output curve of a generator with multiple fuel options. For a generator with k fuel options, the cost curve is divided into k discrete regions between lower and upper bounds. The economic dispatch problem with piecewise quadratic function is defined as

$$\text{Minimize } \sum_{i=1}^{n} F_i(P_i)$$

$$F_i(P_i) = \begin{cases} a_{i1}P_i^2 + b_{i1}P_i + c_{i1}, & \text{fuel } 1, \quad P_i^{\min} \leqslant P_i \leqslant P_{i1} \\ a_{i2}P_i^2 + b_{i2}P_i + c_{i2}, & \text{fuel } 2, \quad P_{i1} < P_i \leqslant P_{i2} \\ \vdots \\ a_{ik}P_i^2 + b_{ik}P_i + c_{ik}, & \text{fuel } k, \quad P_{ik-1} < P_i \leqslant P_i^{\max} \end{cases} \tag{1}$$

where $F_i(P_i)$ is the fuel cost function of the ith unit, P_i is the power output of the ith unit, n is the number of generating units in the system and a_{ik},b_{ik}, and c_{ik} are cost coefficients of the ith unit using fuel type k.

Minimization of the generation cost is subjected to the following constraints:

(i) The power balance constraints

$$\sum_{i=1}^{n} P_i = P_{\mathrm{D}} \tag{2}$$

where P_{D} is the total system demand in MW.

(ii) Generating capacity constraints

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

where $P_i^{\min}$ and $P_i^{\max}$ are the minimum and maximum power outputs of the ith unit.

3. A simplified recursive approach for economic dispatch problem with multiple fuel options

The dynamic programming technique decomposes a multi-stage decision problem as a sequence of single stage decision problems. For the mth stage, the input state vector is denoted by s_{m-1}, and the output state vector as s_m. The output from stage $m-1$ must be equal to the input to stage m. The output of each stage in a multi-stage decision problem is given by