A review on solving economic dispatch problem with multiple fuel option using various techniques

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Abstract - The economic dispatch (ED) problem is one of the important optimization tasks in power system. Improvements in scheduling the unit outputs can lead to significant cost savings. The economic dispatch problems with multi-fuel option (MFO) is represented as a nonsmooth optimization problem with equality and inequality constraints. In this work various techniques adopted to solve the ED problem with MFO is thoroughly reviewed.

Key Words: Economic dispatch, fuel, fossil fuel, soft computing, optimization

1. INTRODUCTION

In the economic operation of power systems, economic dispatch (ED) problem with multiple fuel option is one of the important optimization problem. The objective is to find the optimum number of units to meet the power demand in most economical way by satisfying the physical and operational constraints. In the ED problem, the cost function for each generating unit is usually represented by single quadratic function. But it is more realistic, if the cost curve of each generating fossil fired unit can be represented as a segmented piece-wise quadratic functions. For piece-wise quadratic cost function, the generating units are supplied with multiple fuel sources such as gases, coal and oil. Hence the cost function of any fossil-fired unit can be divided into different parts for multiple fuels. Each part for multi-fuel cost function is being associated with different types of fuel. The units with multiple fuel sources faces the problem of determining which is the most economical fuel to burn. In this work, the piece-wise quadratic function is used to represent multi-fuel which is available to each generating unit. The segmented-piecewise quadratic function is used to represent the cost function of power generation using these fossil thermal units. Conventional method yields good results, but they are complicated and its convergence ratio is slow. Also they always give the optimal solution when the search space is non-linear and has discontinuities. Hence it is necessary to adopt artificial intelligence to overcome these difficulties, especially those with high speed search to the optimal and not being trapped in local minima. In this chapter, various soft computing techniques adopted for solving ED with MFO problem is reviewed.

2. PROBLEM FORMULATION

The main objective of ED problem is to evaluate the combination of power generation that will minimize the total generation by satisfying all the constraints. The economic dispatch problem with MFO is written in terms of piecewise quadratic function as

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

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

Where $F_i(P_i)$ is the Fuel cost function; P_i is the Power output of the i^{th} unit; N_g is the Number of generating units in the system; a_{ik}, b_{ik} and c_{ik} is the fuel cost coefficients of the i^{th} unit using fuel type k.

Minimization of the generation cost is subjected to the following constraints

The power balance constraint is

$$\sum_{i=1}^{N_g} P_i = P_D$$

Where P_D - Total system demand in MW

The generating capacity constraint is

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

Where P_i^{min} and P_i^{max} – Minimum and maximum power outputs of the i^{th} unit

3. LITERATURES IN ECONOMIC DISPATCH PROBLEMS WITH MFO

Lin and Vivani [2] presented a method to solve the ED problem with piecewise quadratic cost functions. The solution approach is hierarchical, which allows for decentralized computations. An advantage of this approach is the capability to optimize over a greater variety of operating conditions. Traditionally, one cost function for each generator is assumed. In this formulation multiple intersecting cost functions are assumed. This method has application to fossil generation units capable of burning gas and oil, as well as other problems which result in multiple intersecting cost curves for a particular unit. The results show that the solution method is practical and valid for real time application.

Park *et al* [3] employed Hopfield neural network method to solve the ED problem with piecewise quadratic cost function. They used multiple intersecting cost functions for each unit. Through case studies, they have shown the possibility of the application of the Hopfield neural network to the ED problem with general non-convex cost functions. This approach is much simpler and the results are very close to those of the numerical method. Lee *et al* [4] developed two different methods viz. slope adjustment and bias adjustment methods, to speed up the convergence of the Hopfield neural network system. The results are compared with those of a numerical approach and the traditional Hopfield neural network approach. To guarantee and for faster convergence, adaptive learning rates are also developed by using energy functions and applied to the slope and bias adjustment methods. The results of the traditional, fured learning rate, and adaptive learning rate methods are compared in ED problem.

Jayabarathi and Sadasivam [5] applied evolutionary programming (EP) to solve ED problem having piecewise quadratic cost functions. The proposed EP algorithm determines the global or near global optimum without any restrictions on the shape of the cost functions. The method is applied to a system with piecewise cost functions and the results are compared with the adaptive Hopfield neural network method. The test results prove that the EP method is simpler and more efficient for solving ED problems with multiple cost curves than many existing techniques. Lee and Kim [6] employed a Lagrangian artificial neural network (ANN) to the power system ED problems with piecewise quadratic cost functions (PQCFs) and nonlinear constraints. By restructuring the dynamics of the modified Lagrangian ANN, stable convergence characteristics are obtained even with the nonlinear constraints. The convergence speeds are enhanced by employing the momentum technique and providing criteria for choosing the learning rate parameters.

Baskar *et al* [7] developed a two-phase hybrid real coded genetic algorithm (GA) based technique to solve ED problem with MFO. This hybrid scheme is developed in such a way that a simple real coded GA is acting as a base level search, which makes a quick decision to direct the search towards the optimal region, and local optimization by direct search and systematic reduction in size of the search region method is next employed to do the fine tuning. Constraint satisfaction technique has been employed to improve the solution quality and reduce the computational expenses. In order to validate the effectiveness of the proposed hybrid real coded genetic algorithm, the result of 10-generation unit ED problem with MFO is considered. The result shows that the proposed hybrid algorithm not only improves the solution accuracy and reliability but also makes the algorithm more efficient in terms of number of function evaluations and computation time.

An improved genetic algorithm with multiplier updating (IGAMU) was proposed to solve ED problems of units with valve point effects and multiple fuels [8]. The IGAMU integrates the improved genetic algorithm (IGA) and the multiplier updating (MU). The IGA equipped with an improved evolutionary direction operator and a migration operation can efficiently search and actively explore solutions, and the MU is employed to handle the equality and inequality constraints of the ED problem. This algorithm was compared with previous methods and the conventional genetic algorithm (CGA) with the MU (CGAMU), revealing that the proposed IGAMU is more effective than previous approaches, and applies the realistic ED problem more efficiently than does the CGAMU.

Liu and Cai [9] applied Taguchi method to solve the ED problem with non-smooth cost functions. In this approach, the Taguchi method that involves the use of orthogonal arrays in estimating the gradient of the cost function is used. The use of the Taguchi method for the ED problem is a novel idea, and it leads to efficient algorithms that can find a satisfactory solution by minimizing the cost function in a few iterations. Simulation results show that the Taguchi method is less sensitive to initial values of parameters and is more effective than other previously developed algorithms. In addition, this algorithm is suitable for parallel implementations. Jeyakumar *et al* [10] successfully adapted particle swarm optimisation (PSO) algorithm to solve various types of ED problems. The results obtained show that the proposed PSO based ED algorithm can provide comparable dispatch solutions with reduced computation time for all types of ED problems.

A Self-Adaptive Differential Evolution (SDE) algorithm [1] is employed to solve ED problem of generating units with valve point effects and multiple fuel options. The key parameters of control in DE algorithm such as the crossover constant CR and weight applied to random differential F are self-adapted in their study. The ED problem formulation takes into consideration of non-smooth fuel cost function due to valve point effects and multi fuel options of generator. The proposed approach has been examined and tested with the numerical results of ED problems with thirteen generation units including valve point effects, ten generation units with multiple fuel options neglecting valve point effects and ten generation units including valve point effects and multiple fuel options. The test results are promising and show the effectiveness of SDE approach for solving ED problems.

Balamurugan and Subramanian [11] developed a hybrid integer coded differential evolution – dynamic programming (ICDEDP) scheme to solve the 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. This 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 hybrid ICDEDP algorithm has high quality solution, superior convergence characteristics and shorter computation time.

An evolutionary programming with Levenberg-Marquardt optimization technique was developed to solve EDP with valve point effect and MFO [12]. The method is developed in such a way that a simple EP is applied as a base level search to find the direction of the optimal global region and Levenberg-Marquardt Optimization (LMO) method is used as a fine tuning to determine the optimal solution. The applicability and validity of the proposed approach on MFO are presented and compared with other methods. Park *et al* [13] presented an approach for solving ED problems with non-convex cost functions using an improved particle swarm optimization (IPSO). Although the PSO approaches have several advantages suitable to heavily constrained non-convex optimization problems, they still can have the drawbacks such as local optimal trapping due to premature convergence, insufficient capability to find nearby extreme points, and lack of efficient mechanism to treat the constraints. They proposed an improved PSO framework employing chaotic sequences combined with the conventional linearly decreasing inertia weights and adopting a crossover operation scheme to increase both exploration and exploitation capability of the PSO. In addition, an effective constraint handling framework is employed for considering equality and inequality constraints. The IPSO is applied to three different non-convex ED problems with valve point effects, prohibited operating zones with ramp rate limits as well as transmission network losses, and multi fuels with valve point effects.

Quantum-behaved particle swarm optimization (QPSO) is inspired by the conventional particle swarm optimization (PSO) and quantum mechanics theories. An improved QPSO named SQPSO, which combines QPSO with a selective probability operator is applied to solve the economic dispatch (ED) problems with valve-point effects and multiple fuel options [14]. To show the performance of the proposed SQPSO, it is tested on five standard benchmark functions and two ED benchmark problems, including a 40-unit ED problem with valve-point effects and a 10-unit ED problem with multiple fuel options. The results are compared with differential evolution (DE), particle swarm optimization (PSO) and basic QPSO, as well as a number of other methods reported in the literature in terms of solution quality, convergence speed and robustness. The simulation results confirm that the proposed SQPSO is effective and reliable for both function optimization and ED problems.

Firefly algorithm has been examined and tested with the numerical results of ED problems with ten generation units including valve point effects and multiple fuel options [15]. The test results clearly show the effectiveness of proposed approach for solving ED problems. A novel and improved method for solving the Non Convex Economic Dispatch (ELD) problems with valve-point effects and Multiple Fuels, by integrating the particle swarm optimization (PSO) with the chaotic sequences and Cross over Operations was developed [16]. The results of the IPSO were compared with previous methods and the conventional Genetic Algorithm (GA), revealing that the results clearly show that the IPSO outperforms other state-of-the-art algorithms in solving ELD problems with the valve-point effect.

4. CONCLUSIONS

In this work, the solution of different types of ED problems with multiple fuel option has been reviewed. Unlike the traditional algorithms and dynamic programming, the stochastic algorithms may prove to be very effective in solving nonlinear ED problems with MFO without any restrictions on the output.

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