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A New Approach to Economic Dispatch Problem with Valve Point Loading Using Evolutionary Programming

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Abstract: Economic Load Dispatch (ELD) is one of the main functions of modern Energy Management System (EMS), which determines the optimal real power settings of generating units with an objective of minimizing the total fuel cost. In all practical cases, the fuel cost of generators can be represented as a quadratic function of real power generation. In fact, discontinuity may also be observed in thermal power plants due to valve point loading. The conventional optimization methods require the objective functions in continuous differentiable form, therefore they fail to provide global minima. The Evolutionary Computation (EC) methods can handle non-differentiable and non-convex objective functions and give global or near global optimum solutions. Evolutionary Computation methods such as Genetic Algorithm (GA), Evolutionary Programming (EP) are applied to economic dispatch problem. By avoiding the coding and decoding process of transformations in GA, use of EP among other EC methods resulted in less population size and number of iterations. A MATLAB program has been developed for Evolutionary Programming to solve economic load dispatch problem. In this paper EP based ELD problem is solved with stochastic method for competition and selection.

Key words: Power systems, optimization, evolutionary programming, economic dispatch, valve-point loading

INTRODUCTION

Economic Load Dispatch (ELD) is a sub-problem of the Optimal Power Flow (OPF) forms a part of modern Energy Management System (EMS) functions and is used to determine optimal power output of generators in view of minimizing total fuel cost. To solve effectively, the Economic Dispatch problem require the incremental cost curves to be of monotonically increasing nature. However, 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. This give rise to the non-smooth type of heat input and discontinuities type of incremental heat rate characteristics.

The classical Lambda iteration method is the basis for many online ELD problems. Many other methods such as lagrangian and dynamic programming have also been applied in ELD problems (Wood and Wollenberg, 1996). However, all these above methods are based on the assumption of continuity and differentiability of cost functions. Hence, the cost functions have been approximated in the differentiable form, mostly in quadratic (Chowdhury and Rehman, 1990). Practically the cost functions are not in quadratic form. Therefore ELD problems lead to non-convex solutions. In fact, discontinuity may also be observed in thermal power plants due to valve point loading. The modeling of valve point loading effect, is by adding the rectified sinusoidal contribution to the conventional quadratic cost curve. When fuel cost characteristic are represented by higher order polynomials instead of quadratic, by accounting turbine valve point loading effect (Lai, 1998). The classical algorithms are not giving feasible solutions. Dynamic programming method has been employed for higher order polynomial problem and this method is suffering from the problem of large dimensionality, due to search for solution space.

There are currently three main areas of research in applying Evolutionary Computation (EC) such as Genetic Algorithms (GA) and Evolutionary Programming (EP). Each method emphasizes on natural evolution in different directions. Each of these techniques represented their data structures in binary (or) real coded (or) in both forms. Operators such as binary crossover, binary mutation and Gaussian mutation were used in EC techniques. Genetic Algorithms are devoted to solve the complex non-linear ELD problems, which are independent of the shape of fuel cost functions. Evolutionary Programming was applied to ELD problem with non-smooth fuel cost functions. Binary crossover and mutation operations need to be performed in case of GA. However, it was avoided in case of EP and it was found that the performance of EP was better than GA. Both GA and EP can provide a near global solution.

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But the encoding and decoding schemes essential in the GA approach are not needed in Economic Dispatch (ED) problem. The EP, therefore, is faster in speed than GA in ED case.

A Genetic based algorithm is used to solve the ELD problem for valve point loading. This algorithm uses the payoff information of candidate solution to evaluate the optimality. The difficulty is the effort required to find the algorithm parameters required several runs in the initial to determine the settling time and will vary slightly as models and constraints are changed (David *et al*., 1993). An efficient general ED algorithm for units with non smooth fuel cost functions was developed and this algorithm is capable of determining the global optimal dispatch solutions in the cases where, the classical Lagrange based algorithm ceases to be applicable (Hong *et al*., 1996). A reliable EP based algorithm with load demand specifications in multiple intervals of generation scheduling is discussed (Kit and Jason, 1998). The ELD problem with multiple fuel options, ramp rate limits and prohibited operating zones has been solved with EP and tested for a three generators and capital IEEE 30 bus systems (Ven katesh *et al*., 2003). A goal attainment method which is then handled by the EP programming technique can offer near global non inferior solutions for the Decision Maker (DM) (Basu, 2005).

Gnanadass *et al*. (2005) propose a EP based solution to ELD with line flow constraints and the line flows in MVA are computed directly by NR method. Kulharni *et al*. (2000) developed a algorithm using improved back propagation neural network for the combined economic and emission dispatch problem. Dipti *et al*. (1997) developed a algorithm which employs a heuristics-guided EP to solve this multi objective problem and provides a DM a whole range of alternatives along the Pareto-optimal frontier. This study proposes a EP based ELD problem using stochastic method for competition and selection of off spring.

PROBLEM FORMULATION

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:

Fuel cost: The fuel cost functions of the generating units are usually described by a quadratic function of power output as:

$$F_i(P_i) = a_i + b_iP_i + c_iP_i^2 \ \$/hr \tag{1}$$

Where a_i, b_i and c_i are the cost co-efficient of unit i.
The objective is to minimize the cost function

$$\min F_t = \sum_{i=1}^{N} F_i(P_i) \tag{2}$$

Where N is the number of generating units,
$F_i(P_i)$ is the individual fuel cost function of i^{th} generating units.

Power balance constraints

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

Where P_D is the total load demand
P_i is the power output of i^{th} generating unit.

Capacity limits constraints:

$$P_{i,min} = P_i = P_{i,max} \quad i = 1, \ldots\ldots N \tag{4}$$

Where, $P_{i,min}$ is the i^{th} generating unit minimum output
$P_{i,max}$ is the i^{th} generating unit maximum output
To model the effects of non-smooth fuel cost functions, a recurring rectified sinusoid contribution is added to the second order polynomial functions to represent the input-output equation as follows,

$$F_i(P_i) = a_i + b_iP_i + c_iP_i^2 + |e_i \sin(f_i(P_{i,min} - P_i))| \tag{5}$$

Where e_i and f_i are non-negative constants.
The objective function of ED is to minimize the above non-smooth function by regulating the active power outputs of the generators, subject to the power balance constraints and capacity limits constraints.

EVOLUTIONARY PROGRAMMING BASED ELD ALGORITHM

The step by step algorithm of the proposed method (EPELD) is given as follows,

Representation: For the N generating units, control variables of this problem are the generating output from all units. An array of these variables vector S can be shown as,

$$S = \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ \vdots \\ P_N \end{bmatrix} \tag{6}$$

Initialization: Generate the parent population of chromosome is uniform randomly initialized within the operation range of the generator.

The equality constraint must be handled carefully. This constraint can be handle by the following equations,

$$\text{if } \sum_{i=1}^{N} P_i > P_D, \text{ then } P_i^{new} = P_i^{old} - \frac{\sum_{i=1}^{N} P_i^{old} - P_D}{N} \quad (7)$$

$$\text{if } \sum_{i=1}^{N} P_i < P_D, \text{ then } P_i^{new} = P_i^{old} + \frac{P_D - \sum_{i=1}^{N} P_i^{old}}{N} \quad (8)$$

Fitness evaluation: The fitness is calculated directly from the objective function. The cost for all the parent vectors are calculated after satisfying the above equations. Then find the minimum optimal cost as f_{min} for the corresponding population.

Find the standard deviation using the relation given below,

$$\sigma_i = \beta \times \frac{f_s}{f_{min}} (P_{i,max} - P_{i,min}) \quad (9)$$

Creation of offspring: A new population of solutions (offspring) is produced from the existing population by adding a Gaussian random number with zero mean and a predefined standard deviation to each individual as

$$P_i^{'} = P_i + N(0, \sigma_i^2) \quad (10)$$

Calculate the cost of generations with offspring generation vectors after satisfying the equality constraints and capacity limits constraints.

Competition and selection: The selection technique used here is the stochastic method. The 2P individuals compete with each other for selection. A weight value is assigned to each individual as follows.

$$W_S = \sum_{j=1}^{2P} W_j \quad (11)$$

$$W_j = 1 \text{ if } f_S < f_r$$
$$W_j = 0, \quad \text{otherwise}$$

RESULTS AND DISCUSSION

The proposed Evolutionary Programming approach was tested by its application on 3 units system. The minimum fuel cost found by this method is 8234.2 $. This result matches with the complete enumeration approach. The execution time for this approach is less compared to that of the complete enumeration method (Table 1 and 2).

Table 1: Unit data for three units system with valve-point loading

	P_{min}	P_{max}	a	b	c	e	f
Unit 1	100	600	0.001562	7.92	561	300	0.0315
Unit 2	100	400	0.00194	7.85	310	200	0.042
Unit 3	50	200	0.00482	7.97	78	150	0.063

Table 2: Solution for three units systems with valve-point loading

	Generated powers (MW)				Execution time
Methods	Unit 1	Unit 2	Unit 3	Cost ($)	(in sec)
Complete enumeration	300	400	150	8234.2	1107.1
Evolutionary programming	499	251	100	8234.2	12.2

CONCLUSION

This study has projected a new approach and it was developed in such a way that a stochastic optimization technique evolutionary programming is used to solve economic dispatch problem with non-smooth fuel cost functions. The advantage of the EP algorithm lies in its ability to handle any type of unit characteristics, whether smooth or not. The EP algorithm approach yields solutions, which are very near to optimal. The result shows that the EP algorithm is a powerful optimization tool in which the computational time is reduced when compared to the complete enumeration method.

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