Economic Load Dispatch Using Linear Programming:
A Comparative Study
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ABSTRACT
This paper presents an optimum solution of the economic dispatch (ED) problem without considering transmission losses using linear programming (LP). In the ED problem, several on-line units (generators) are available, and it is needed to determine the power to produce by each unit in order to meet the required load at minimum total cost. To apply LP, the nonlinear cost functions of all generators are approximated by linear piecewise functions. To examine the effectiveness of this linearization method, a comprehensive set of benchmark test problems is used consisting of 3, 6, 18, 20, 38, and 40 generators. Using this set, LP solutions of linearized ED problems are compared with several other techniques available in the literature. The LP technique with piecewise linearization shows an overall competitive advantage in terms of total cost, solution time, and load satisfaction accuracy. The impact of varying the width of the linearized pieces (segments) is also discussed. All the computational analysis is performed using MATLAB software environment.

KEYWORDS
Comparative Literature Review, Economic Dispatch, Linearization, Linear Programming, MATLAB

INTRODUCTION
The economic dispatch (ED) problem involves the determination of the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities. Many techniques have been proposed in the literature to solve this problem. Ciornei and Kyriakides (2013) present a comprehensive review of ED models and techniques since 1991, and provide a database of ED test systems commonly used in the literature.

One type of these techniques is the classical techniques category that includes Lambda-Iteration Algorithm (LIA), Gradient method, Newton’s method and Lagrange multiplier method. In addition, heuristic approaches are becoming very popular in solving the ED problem. These techniques include Genetic Algorithms (GA), Tabu Search (TS), Simulated Annealing (SA), Differential Evolution (DE) and Particle Swarm Optimization (PSO). Other solution categories include Quadratic Programming (QP), cost composite function, sequential approach with matrix framework, and Dynamic Programming (DP). In addition, hybrid methods, which are combinations of more than one method to solve ED problem, are also used.

Currently, the ED problem is still under the investigation and attention by many researchers. A recent literature search has found several works published on ED optimization using both established...
and innovative methods. Some of the techniques used recently to solve ED problems include PSO (Lin et al., 2015), Grey Wolf Optimization (GWO) (Tung & Chakravorty, 2015), Mixed Integer Quadratic Programming (MIQP) (Absil et al., 2015), Fast Lambda Iteration (FLA) (Zhan et al., 2014), Artificial Neural Networks (ANN) (Momoh & Reddy, 2014), Flower Pollination Algorithm (FPA) (Vijayaraj & Santhi, 2016), Ant Lion Optimization (ALO) (Nischal & Mehta, 2015), and Gravitational Search Algorithm (GSA) (Hota & Sahu, 2015).

Advancements in smart grid and Distributed Generation (DG) have wide ED applications in optimizing power generation from several energy sources instead of only one conventional source. Examples of these sources include wind, solar, and battery storage. Combining these different sources, including their respective constraints, and trying to optimize the power generated from each source is not an easy task. The authors of Zhu (2014), Liu et al. (2014), Lorca and Sun (2015), Mudumbai and Dasgupta (2014), Su and Chuang (2014), Zhang and Giannakis (2014), Shen et al. (2014) and Jose (2014) show various approaches in smart grid environment to optimize the generated power from each DG.

In the area of LP applications on ED, Hoke et al. (2013) apply a fast and reliable LP approach to the ED of grid-tied micro-grids containing several DGs such as conventional generators, energy storage, and wind turbines. Their simulations have shown quick and reliable results. In Jabr et al. (2000), a simplified homogeneous and self-dual LP interior point algorithm is presented. The algorithm is applied to the security constrained economic dispatch (SCED) problem. A method for solving the economic power dispatch problem in the presence of renewable energy sources is described in Elsaiah et al. (2014). The proposed method uses LP because of flexibility, reliability and speed. Chamba and Ano (2013) propose an innovative hybrid methodology that integrates LP within a meta-heuristic algorithm to calculate the optimal power flow and the reserve assigned to each unit.

In this paper, quadratic and cubic cost functions are linearized using piecewise linear segments. After formulating the linearized model, several benchmark ED test problems are solved using LP. The paper presents a novel, concise formulation of the LP model for the economic load dispatch problem, assuming piece-wise linearization with equal-width segments. Compared to previous literature, the paper presents a more comprehensive numerical comparison of LP with other techniques for solving the economic load dispatch problem. This comparison is based on a larger number of solution techniques and a larger number of benchmark test problems. The paper also includes an explicit convergence analysis of the LP solution in terms of the width of the piece-wise linear segments.

The paper is organized as follows. Section II briefly explains the ED problem, while section III discusses the linearization approach and how LP is used to solve the ED. Comparative results and conclusions are presented in sections IV and V, respectively. All the computational analysis in this paper is performed using MATLAB 7.10 software in 2.4 GHz PC, 64-bit operating system.

**THE ECONOMIC DISPATCH PROBLEM**

A power system has several power plants. Each power plant has several generating units. At any point of time, the total load in the system is met by the generating units in different power plants. ED determines the power output of each power plant, and the power output of each generating unit within a power plant, to minimize the overall cost of fuel needed to serve the system load (Wood & Wollenberg, 2012). Therefore, the objective of the ED problem in a power system is to determine the optimal combination of power outputs for all generating units that will minimize the total cost while satisfying the load and capacity constraints.
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