APPLICATIONS OF SEMIDEFINITE PROGRAMMING TECHNIQUES FOR SOLVING SOME NON-CONVEX POWER DISPATCH PROBLEMS

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ABSTRACT

This study formulated the non-convex economic dispatch (ED) problems as convex ones. The formulation was then extended to handle the multi-objective economic emission dispatch problem, and the resulting convex problems were solved using semidefinite programming (SDP) techniques. The performance of the SDP techniques in solving the problems was also evaluated. This was done with a view to obtaining globally optimal solutions of the real-world non-convex power dispatch problems.

Non-convex ED problems which consider the effects of valve point loading (VPL), multiple fuel options (MFO), and combined cycle co-generation power plants (CCCP) in the operation of modern power plants were formulated as convex problems by performing decomposition of the fuel cost function, followed by convex relaxation of the decomposed ED problems. Two formulations were considered. In the first formulation (called sSDP), the non-convex ED problem was represented as an optimization problem having polynomial fuel cost objective function and constraints with vector variables. In the second formulation (called qmSDP), the problem was reformulated as a quadratic matrix programming problem. In order to extend the problem formulation to the multi-objective case, minimization of pollutant emissions from the power plants was considered as an additional objective function. Both objectives were aggregated using the adaptive weighted sum method. The resulting convex ED problems were modelled in MATLAB/CVX/YALMIP environments and solved using the SDPT3 and SEDUMI SDP solvers. Datasets used included the modified IEEE 30-bus, six generator test system incorporating CCCP and MFO units, the MFO ten unit system, the three unit, thirteen unit and forty-unit systems with VPL effects, and the multi-objective forty-unit system with VPL and emission coefficients. The solutions obtained for the different systems were evaluated by comparing them with the results reported in the literature.

The results showed that for the CCCP problem, both sSDP and qmSDP techniques returned better fuel costs of 946.6858 and 946.6851 $/h, respectively compared to 949.1428 $/h which is the best reported value in the literature. For the modified IEEE 30-bus MFO problem, sSDP and qmSDP techniques obtained better fuel costs of 647.5894 and 647.5341 $/h, respectively compared to the best reported value of 647.7900 $/h. In solving the ten unit MFO problem, qmSDP gave the best minimum solution of 481.7226 $/h. sSDP however returned a fuel cost of 481.8281 $/h. Results for the VPL problem showed that sSDP and qmSDP obtained best minimum fuel costs of 8234.0717, 17963.9848 and 121412.5355 $/h for the three, thirteen and forty-unit test systems, respectively. For the multiobjective economic emission dispatch problem, the SDP techniques obtained a set of Pareto-optimal solutions that completely dominated those obtained by the Non-dominated Sorting Genetic Algorithm (NSGA-II). The spacing and extent metric values for the SDP solution set were 2.0321×10^3 and 1.8320×10^5 while the corresponding values for NSGA-II were 85.4675 and 5.0408×10^4, respectively.

This study concluded that SDP techniques can obtain globally optimal solutions of non-convex power dispatch problems. This would help power system operators to make better decisions regarding the economical cost and environmentallyfriendly operation of power system networks.

Keywords: Semidefinite,Programming Techniques,Non-Convex Power,Dispatch Problems,CCCP

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CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Optimal Power Flow (OPF) solution methods were developed over the years to ensure that electric power systems operate economically and efficiently (Acha *et al.*, 2004). The most basic OPF problem is the Economic Dispatch (ED) problem. The objective of an economic dispatch is to minimize the total generation cost by adjusting the power output of each of the generators while meeting the load demand and satisfying the system's equality and inequality constraints (Jeyakumar *et al.*, 2006; Saadat, 2002). Traditionally, the total power generation cost is modeled as the sum of the cost of each generating unit, with each generator's cost curve represented by a single quadratic function. Although this quadratic model has been widely used in practice, it fails to describe the highly nonlinear characteristics of modern generating units such as multiple fuel options (Lin and Viviani, 1984; Chiang, 2005), valve-point loading effects (Walters and Sheble, 1993) and prohibited operating zones (Zhan *et al.*, 2014). This often results in inaccurate non-optimal dispatches causing loss of revenue and time-consuming computations (Chaturvedi *et al.*, 2008; Reddy and Vaisakh, 2013). The practical ED with the above-mentioned nonlinearities translates into a complicated optimization problem having complex and non-convex characteristics, with multiple minima, making the challenge of obtaining the global minima difficult.

Various methods have been used to solve the ED problem. The conventional methods include the lambda-iteration method, the base point and participation factor method, and the gradient method (Bakirtzis *et al.*, 1994; Lee and Breipohl,

1993; Gaing, 2003). The fundamental assumption in these methods is that the incremental cost curves of the units are monotonically increasing piecewise-linear functions. This assumption renders these methods infeasible because of the nonlinear characteristics of practical systems. Furthermore, these solution methods are faced with the problem of convergence resulting in long solution time (Gaing, 2003; Coelho and Mariani, 2009). Liang and Glover (1992) presented a dynamic programming method for solving the ED problem. The method does not depend on the shape of the cost function. However there is increased difficulty in obtaining an optimal solution as the problem dimension increases, especially in dealing with modern power systems with a large number of generators (Niknam, 2010).

Various heuristic and computational intelligence approaches have been used in solving the economic dispatch problem. Such methods include evolutionary programming (EP) (Yang *et al.*, 1996; Sinha *et al.*, 2003; Wong and Yuryevich, 1998), simulated annealing (SA)(Wong and Fung, 1993), tabu search (TS)(Lin *et al.*, 2002), pattern search (PS) (Al-Sumait *et al.*, 2007), genetic algorithm (GA) (Walters and Sheble, 1993), differential evolution (DE) (Coelho and Mariani, 2006), and particle swarm optimization (PSO) (Park *et al.*, 2005). Although these heuristic methods do not always guarantee obtaining globally optimal solutions, they often provide an acceptable solution in finite time.

Another approach that is being increasingly used in solving various power system optimization problems is the semidefinite programming (SDP) approach. In SDP, one minimizes a linear function subject to the constraint that an affine combination of symmetric matrices is semidefinite. Semidefinite programming