CHAPTER I

INTRODUCTION

1.1 Research Motivation

Optimal power flow (OPF) plays a very important role in power system operation and planning. The OPF solves a power flow problem, simultaneously scheduling the system controls to minimize the selected objective function, while ensuring that the power system static operating limits are not violated. In a vertically integrated system, the OPF can be used for many applications, e.g. generation cost minimization, real power (MW) loss minimization, reactive power (MVAR) loss minimization, minimum deviation or minimum control shift, minimize the cost of installation of new capacitors or reactors, minimize the cost of MVARs supplied, maximize MW transfers, minimize the time to correct the violations, and minimize the total emission. In addition, the OPF is also of importance for the deregulated environment of power sector. It can be used as a tool to determine electricity prices, and also for the congestion management to ensure security and reliability of the power systems.

Generally, the OPF is a large dimension nonlinear, nonconvex and highly constrained optimization problem. It is nonconvex due to existence of nonlinear AC power flow equations, nonconvex fuel cost functions, e.g. quadratic function with rectified sine component (valve-point effects) [1, 2], piecewise quadratic function (multiple fuels) [1, 2], combined cycle cogeneration (CCCP) plants [3], or FACTS (Flexible Alternating Current Transmission System) devices in power systems.

Solutions of the OPF problem give optimal settings of the generators' active power output and voltage, shunt capacitors/reactors, transformer tap-settings and other control variables to minimize total generator fuel costs, while keeping the load bus voltages, generator reactive power outputs, network power flows and all other state variables in their operational and secure limits. However, one primary limitation of the OPF solution for system planning and operation is the lack of system security or contingency constraints pertaining to credible outages of transmission circuits and/or generating plants. Security of the system requires that optimal operation of the system is not only feasible for the intact system (N-0) but also for the contingency cases (N-1). Therefore, in order to ensure security of the system, contingency constraints for a few severe contingencies should be identified and OPF schedule should be corrective rescheduling to eliminate limit violation [4].

Conventional gradient based optimization techniques, e.g. linear programming, nonlinear programming, quadratic programming, and interior point method, have been used to solve OPF problems [5, 6]. These methods rely on convex and continuous fuel cost function to obtain the global optimum solution, and as such, these curves must be approximated by continuous and monotonic functions. Therefore, the drawback of conventional gradient based method usually converges to sub-optimal solution when nonconvex characteristics of fuel cost function is considered [7]. Many heuristic algorithms, e.g. genetic algorithm (GA) [8], tabu search (TS) [9], hybrid tabu search and simulated annealing (TS/SA) [10], improved tabu search (ITS) [11], evolutionary programming (EP) [7, 12, 13], and improved evolutionary programming (IEP) [14], have been proposed to solve the OPF problem. In addition, EP has been applied to solve security constrained optimal power flow (SCOPF) problems [13]. All these techniques search for the global or quasi-global optimum for any types of objective function and constraints without any requirement of gradient information, and the reported results were promising and encouraging for further research in this direction.

Differential evolution (DE) has gain increasing attention for a wide variety of engineering application including power engineering [1, 2, 15, 16]. DE is an evolutionary algorithm (EA) that uses rather greedy selection and less stochastic approach to solve optimization problems than other classical EAs such as genetic algorithm (GA), evolutionary programming (EP), and evolutionary strategies (ES). The potentialities of DE are its simple structure, convergence property, quality of solution, and robustness [17-22]. However, tuning the DE's parameters – mutation factor (F), crossover constant (CR), and population size (NP) – is a tedious task due to complex relationship among parameters. The optimal parameter settings may never be found, and the final result may be trapped at a local optimum [1, 23]. Recently, a self-adaptive differential evolution method with augmented lagrange multiplier (SADE_ALM) [1, 2] has been proposed for solving the economic load dispatch for units with two types of nonconvex fuel cost characteristics, i.e. piecewise quadratic function (multiple fuels), and combined piecewise quadratic function with rectified sine components (multiple fuels with valve-point effects). Numerical results have been shown that the SADE_ALM is very effective and provides promising capability for solving the complicated economic load dispatch problems compared with previous reports [1, 2].

Parallel processing is a promising technology for power system computation since the scale and complexity of power system has been increased drastically in the past few decades. Most parallel computers are relatively expensive and some others are not easy to be upgraded and extended, which limits the widely use of parallel processing technology. PC cluster is a parallel processor system, which consists of PCs and a high-speed network. With the advantages of low cost, upgradability, and scalability, PC cluster is an interesting option for parallel processing on power system computation [24-27]. C. H. Lo *et. al.* [24] applied parallel evolutionary programming for solving the OPF problem via PC cluster arranged in master-slave structure with 31x2.66 GHz Pentium IV processors. Numerical results showed that parallel EP had accurately and reliably converged to the global optimum solution, while the quality of the solution was comparable to the sequential EP.

1.2 Objectives

The main purpose of this dissertation is to develop both sequential and parallel algorithms of an enhanced version of the conventional differential evolution (DE) called self-adaptive differential evolution with augmented lagrange multiplier method (SADE_ALM) for solving the optimal power flow (OPF) and security constrained optimal power flow (SCOPF) problems. The parallel processing technique is employed to increase the search capability of the sequential algorithm via PC Cluster. The main objective is to achieve through fulfilling the following specific objectives:

1) To develop the sequential and parallel program of SADE_ALM for solving the OPF and SCOPF problems.
2) To analyse and compare the effectiveness of the proposed algorithms in terms of the solution quality and computational time.
3) To compare the effectiveness of the proposed algorithms with other approaches, e.g. GA, TS, TS/SA, ITS, EP, parallel EP, IEP etc.

1.3 Scope and Limitation

The scope and limitation of this dissertation are outlined as follows:

1) The proposed algorithms will be implemented on a small PC cluster 3x2.8 GHz Pentium IV processors arranged in master-slave structure.

2) The objective function of the OPF and SCOPF problems for this study is to minimize the generator fuel cost.

3) Four types of the generator fuel cost function will be used to verify the ability and robustness of the proposed algorithms to solve the OPF problems. They are composed of

   - Quadratic cost curve model,
   - Piecewise quadratic cost curve model (multiple fuels),
   - Quadratic cost curve with rectified sine component model (valve-point effects)
   - Combined multiple fuels, valve-point effects, and combined cycle cogeneration plant (CCCP) model.

4) The SCOPF problems for units with quadratic cost curve models will be implemented to verify the ability and robustness of the proposed algorithms.

5) The proposed algorithms will be implemented to solve the OPF and SCOPF problems and studied their performance based on the IEEE 30, 57, and 118 bus test systems.

1.4 Organization of the Dissertation

This dissertation is divided into 7 chapters. An introduction of the OPF and SCOPF problems is briefly described in chapter 1. Research motivations, objectives, scope and limitation of the dissertation are presented in the same chapter. Chapter 2 introduces the fundamental of the evolutionary algorithms. The general structure of a typical differential evolution and the proposed algorithm called self-adaptive differential evolution with augmented lagrange multiplier method (SADE_ALM) are also descibed in this chapter. Chapter 3 introduces the problem of optimal economic operation of electric power system. This chapter discusses the mathematical formulation of the economic dispatch problem. Several variations on the representation of fuel-cost characteristics of thermal generating units with numerical examples are provided in this chapter. Chapter 4 presents the solution procedure of the optimal power flow (OPF) problems. The OPF problem formulation is introduced in this chapter. Then, the sequential and the parallel of SADE_ALM for solving the OPF problems are described with numerical examples. In chapter 5, the solution procedure of the proposed algorithm for solving the security constrained optimal power flow (SCOPF) problems is described. The methodology of the sequential and parallel SADE_ALM for solving the SCOPF problems are presented. Simulation results are also provided in this chapter. In chapter 6, another variance of the SADE_ALM called the mixed-integer SADE_ALM (MISADE_ALM) is described with numerical simulations. Since, in practical situation of the OPF problems, the optimal settings of control variables (e.g., shunt capacitors/reactors and transformer tap-settings) are discrete in nature. The SADE_ALM may possibly provide the local optimal solutions after the continuous control variables are modified to the nearest discrete control variables. Finally, conclusion and recommendation are given in the last chapter.