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OPTIMAL UNIT COMMITMENT SOLUTION IN COMPETITIVE MARKET USING MODERN OPTIMIZATION TECHNIQUES

A Thesis
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ABSTRACT

Unit commitment (UC) problem plays major role in power system since the improvement of commitment schedule results in the reduction of operating cost. However, unit commitment problem is one of the most difficult optimization problems in power system, because this problem has many constraints. Further, these constraints vary with each unit.

In solving the unit commitment problem, generally two basic decisions are involved, namely the 'unit commitment' (UC) decision and the 'optimal dispatch' (OD) decision. The UC decision involves the determination of the generating units to be running during each hour of the operation and planning horizon, considering system capacity requirements, including the reserve, and the constraints on the start up and shut down of units. The OD decision involves the allocation of the system demand and spinning reserve capacity among the operating units during each specific hour of operation.

This thesis proposes two approaches for optimal scheduling of unit commitment (UC) considering reserve generating for regulated and deregulated power system in competitive market. The particle swarm optimization (PSO) technique is used to find out the solution of both optimal UC and power generation problems, simultaneously. The two proposed approaches depend on various sigmoid functions to obtain the binary values of PSO. The first proposed approach takes the fuzzification of generation costs as a sigmoid function; while the second proposed approach takes the fuzzification of power generation as sigmoid function. A proposed objective function is presented dependent on the exponential form which leads to fast convergence of PSO solution. This objective aims to minimize

the generation costs as well as maximize their own profit while all load demand and generation reserve constraints are satisfied. Hence, the generations companies (GENCO) schedule their generators with maximize profit regard to system social benefit. The proposed objective function helps GENCO to make a decision, how much power and reserve should be sold in markets and how to schedule generators in order to receive the maximum profit. Different comparisons are carried out using various standard test systems to show the capability of the two proposed sigmoid approaches and the proposed objective function compared with other techniques.

The UC problem is solved by proposed HPSO approaches for different conditions (normal, predicted and emergency conditions). A multi-objective function is prsented to obtain the optimal preventive control actions to overcome any emergency conditions. The proposed multi-objective functions are: minimizing the generation cost function, maximizing the generation reserve at certain generator, maximizing the generation reserve for all generation system.

The proposed algorithm is applied on 5-bus, 14-bus and 30-bus systems for the OPD problem and 3-, 4-, 10-generating unit systems for the unit commitment to illustrate.

The qualities of the proposed approaches are that ability to solve the security-constraint UC problem, profit-based UC problem and to find the optimal preventive control action for UC at predicted emergency condition.

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CHAPTER 1
INTRODUCTION

One of the main objectives when controlling large power production systems is to make the best use of available resources. To do that considerable planning is needed. On an hourly basis, this involves determining the production output of individual units in the production system in order to meet the requirements of a given load demand.

In the past, utilities had to produce power to satisfy their customers with the minimum production cost. That means utilities run unit commitment (UC) with the condition that all demand and reserve must be met. After the structure changed; however, they are more competitive under deregulation. The objective of UC is not to minimize costs as before, but to make the maximum profit for company. Generation companies (GENCO) can now consider the amount of power is sold on the market as well as generator scheduling plan that create the maximum profit without regard that demand and reserve have been completely met or not.

The UC problem is defined as determining the mix of generators and their estimated output level to meet the expected demand of electricity over a given time horizon (a day or a week), while satisfying constraints such as ramp rate limits, up-time and down-time constraints, reserve and energy requirements. Ramp rate limits reflect the time it takes to turn the generators on/off, while up-time and down-time constraints ensure that once a generator is up/down, it stays at that state for at least a given length of time. Reserve requirements ensure that the system has a minimum amount of surplus power at each time period in order to respond to load spikes or equipment breakdowns. Energy requirements ensure the system has enough supply to satisfy the load for each time period.

The UC may not be capable to keep the system in normal state after a major disturbance (sudden increase of load, generator and / or line outages). In power systems, two kinds of security actions can be defined. Preventive security actions ensure that in the event of a contingency enough resources are available for the quick execution of corrective security actions that guarantee the normal operation of the system once the contingency has taken place.

1.1. Literature Review

A survey of literature on UC methods reveals that various numerical optimization techniques have been employed to address the UC problems. Specifically, there are priority list method [1], integer programming [2], dynamic programming [3], mixed-integer programming [4], branch-and-bound methods [5], and Lagrangian relaxation methods [6]. There is another class of numerical techniques applied to the UC problem Meta-heuristic approaches include expert systems (ES) [7], fuzzy logic (FL) [8], artificial neural networks (ANNs) [9], genetic algorithm (GA) [10], evolutionary programming (EP) [11], simulated annealing (SA) [12], and tabu search (TS) [13]. These methods can accommodate more complicated constraints and are claimed to have better solution quality.

Among these methods, the priority list method is simple and fast, but the quality of final solution is not guaranteed and the quality of solution is low. Dynamic programming method which is based on priority list method is flexible. This method has many advantages such as its ability to maintain solution feasibility. Nevertheless, this method has dimensional problem with a large power system because the problem size increases rapidly with the number of generating units to be committed, which results in an unacceptable solution time. Branch-and-bound adopts a linear function to represent the fuel consumption and time-dependent start cost and obtains the required lower and upper bounds. The disadvantage of the branch-and-bound method is the exponential growth in the execution time with the size of the UC problem. The integer and mixed-integer methods adopt linear programming technique to solve and check for an integer solution. These methods have only been applied to small UC problems and have required major assumptions that limit the solution space. The Lagrangian relaxation method provides a fast solution, but it may suffer from numerical convergence and solution quality problems.

SA is a powerful, general-purpose stochastic optimization technique, which can theoretically converge asymptotically to a global optimum solution. One main drawback of SA is that it takes a large CPU time to find the near-global minimum. GA is a general-purpose stochastic and parallel search methods based on the mechanics of natural selection and natural genetics. It is a search method and has the potential of obtaining a near-global minimum.

The PSO approach is motivated from the social behavior of bird flocking and fish schooling. Kennedy and Eberhart introduced PSO in 1995 in terms of social and cognitive behavior. The PSO has been widely used as a problem-solving method in engineering and computer science. The PSO has been used to solve the optimal power flow problem [14], the reactive power and voltage control problem [15], and the distribution state estimation problem [16].

1.2. Aims of the Thesis

This thesis aims to determine the generating units which be running during each hour of the planning horizon, considering system capacity requirements, including the reserve, and the constraints of the minimum up/down time and start-up of units.

The solutions of optimal power dispatch (OPD) are used to guide the modern optimal techniques that solve the combinatorial part of the unit commitment problem (UCP). A comparison between FLP, GA and PSO techniques are presented to interact between OPD and UC problems.

In this thesis, two proposed approaches of a hybrid particle swarm optimization (HPSO) to solve the UC problem is introduced. The proposed algorithm uses the real-code PSO method to generate a pre-schedule of thermal generating units according to the load profile. Then, the binary-code PSO search is performed to find the commitment states of the units which may be on or off.

In this thesis modern power systems have been moved from a formerly vertically integrated and highly regulated industry to one that has been horizontally integrated (deregulated integrated). The objective of UC is not to minimize costs as before, but to make the maximum profit for company for competitive market. Generation companies (GENCOs) can now consider the amount of power and reserve sold on the market as well as generator scheduling plan that create the maximum profit. The generation companies (GENCO’s), and consumers interact via contracts. Electricity traders make bids and offers that are matched subject to the approval of an independent contract administrator (ICA) who ensures that the system is operating safely within their limits.

In this thesis the UC problem is solved using the proposed HPSO approaches for different conditions (normal, predicted and emergency conditions). The multi-objective function is used to obtain the optimal preventive control actions for unit committed to overcome any emergency conditions.

1.3. Organization of Thesis

This thesis consists of seven chapters and one appendix. The chapters content can be summarize as:

In chapter 1, presents an explanation of what is meant by the UC problem and a short review of the solution methods. The main objective of this research and the thesis organization are also presented.

In chapter 2, the construction and implementation of a modern heuristic methods (methods which can be guaranteed to converge to the optimal solution) to solve the optimal power dispatch problem. Particle swarm optimization (PSO), genetic algorithm (GA) and fuzzy technique are presented, which solve the optimal power dispatch (OPD) problem. The performance of such method with respect to time and solution convergence is a crucial part in the solution process of solving the UC problem. The objectives of this chapter are satisfying the minimization of generation cost as well as keeping the power flows in transmission lines within their maximum permissible limits.

In chapter 3, focuses on the problem of scheduling thermal generating and problem formulation. It reviews the basic features of some optimization techniques currently available to solve the UC problem.

In chapter 4, the basic concept of hybrid particle swarm optimization (HPSO) and two proposed approaches are presented for solving the security-constrained unit commitment (SCUC). A proposed objective function is presented dependent on the exponential form which leads to fast convergence of PSO solution. The objectives of this chapter are satisfying the generation cost minimization and keeping all constraints within permissible limits. This chapter presents also a comparison between three proposed approaches with other methods.

In chapter 5, the proposed approaches are presented for solving the profit-based unit commitment (PBUC) for maximizing the total profit of GENCO. A proposed objective function is presented dependent on the exponential form which leads to fast convergence of PSO solution.

Chapter 6 presents a proposed approaches that depends on the multi-objective function to obtain the optimal preventive control actions, for unit committed and power generation, to overcome any emergency conditions. The proposed multi-objective functions are: minimizing the generation cost function, maximizing the generation reserve at certain generator, maximizing the generation reserve for all generation system.

Chapter 7 gives the conclusions of this thesis and presents the recommendations for future work.

CHAPTER2
OPTIMAL POWER DISPATCH FOR UNIT COMMITMENT

2.1. Introduction

The optimal power dispatch problem objective is to minimize production cost while satisfying demand within power system constraints for a given combination of active units. The solutions of the optimal power dispatch OPD problem are used to guide the solution method that solves the combinatorial part of the unit commitment problem. Figure 2-1 shows the connection between the combinatorial part and the OPD problem for the unit commitment problem. When the combinatorial part is solved, solutions from the OPD problem are used to estimate the quality of different unit combinations.

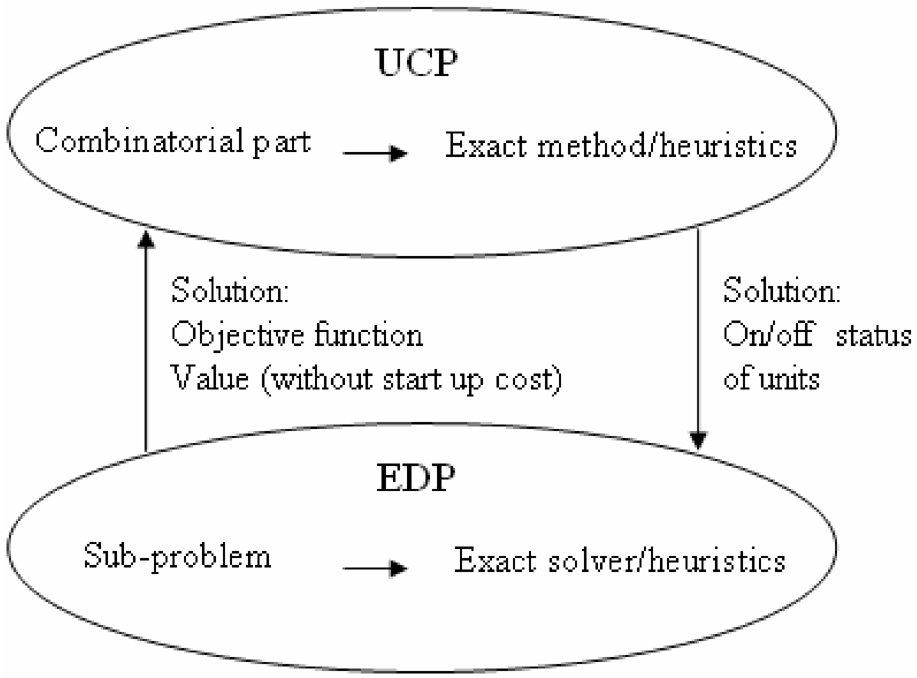

Figure 2-1 Connection between the combinatorial part of the UCP and the OPD problem.

If the unit commitment problem is solved by exact methods, the OPD problem should also be solved by exact methods. If not, there is a risk that the method might not converge to the optimal solution.

Previous efforts on solving OPD problems have employed various mathematical programming methods and optimization techniques. These conventional methods include the linear programming (LP) [17] and quadratic programming (QP) [18].

In these numerical methods for solution of OPD problems, an essential assumption is that the incremental cost curves of the units are monotonically increasing piecewise-linear functions. Unfortunately, this assumption may render these methods infeasible because of its non-linear characteristics in practical systems. These non-linear characteristics of a generator include discontinuous prohibited zones, ramp rate limits, and cost functions which are not smooth or convex. Furthermore, for a large-scale mixed-generating system, the conventional method has oscillatory problem resulting in a longer solution time. A dynamic programming (DP) method for solving the OPD problem with valve-point modeling had been presented in [19,20]. However, the DP method may cause the dimensions of the OPD problem to become extremely large, thus requiring enormous computational efforts.

In order to make numerical methods more convenient for solving OPD problems, artificial intelligent (AI) techniques, such as the fuzzy linear programming (FLP) [21] and the Hopfield neural networks (HNN) [22]. The Hopfield neural networks have been successfully employed to solve OPD problems for units with piecewise quadratic fuel cost functions and prohibited zones constraint. However, an unsuitable sigmoidal function adopted in the Hopfield model may suffer from excessive numerical iterations, resulting in huge calculations.

The fuzzy linear programming (FLP) is a natural and appropriate tool to represent inexact relations. The advantages of fuzzy systems over conventional systems are the actual implementation of fuzzy systems, which, are also increasing towards better and more reliable solutions for problems in power systems. The fuzzy systems have been increasingly used to develop more efficient schemes for the power system operation, planning, control and management.

In the past decade, a global optimization technique known as genetic algorithms (GA) [20,23], Tabu search (TS) [24], simulated annealing (SA) [25], and recently-introduced particle swarm optimization (PSO) are considered as realistic and powerful solution schemes to obtain the global or quasiglobal optimums in power system optimization problems [26]. These techniques have been successfully used to solve power optimization problems such as feeder reconfiguration and capacitor placement in a distribution system [23-26].

The GA method is usually faster than the SA method because the GA has parallel search techniques, which emulate natural genetic operations. Due to its high potential for global optimization, GA has received great attention in solving OPD problems. In some GA applications, many constraints including network losses, ramp rate limits, and valve-point zone were considered for the practicability of this method. For an efficient GA method, the real-coded representation scheme, arithmetic crossover, mutation, and elitism in the GA to solve more efficiently the OPD problem, and it can obtain a high-quality solution with less computation time [27].

Particle swarm optimization (PSO) is one of the modern heuristic algorithms. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous non-linear optimization problems [26,28–30]. The PSO technique can generate high-quality solutions within shorter calculation time and stable convergence characteristic than other stochastic methods. Although the PSO seems to be sensitive to the tuning of some weights or parameters, many researches are still in progress for proving its potential in solving complex power system problems [31].

In this chapter, the construction and implementation of modern methods such as: the PSO, GA and FLP which solves the OPD problem. The performance of such method with respect to time and solution convergence is a crucial part in the solution process of solving the unit commitment problem (UCP).

2.2. Problem Formulation

The standard OPD problem can be described mathematically as an objective with three constraints as:

$$Min\ F_t = \sum_{i=1}^{NG} F_i(P_i) \tag{2.1}$$

Where, F_t is the total generation cost (\$/hr);

P_i is the power output of unit i (MW);

$F_i(P_i)$ is the fuel cost of unit i when its output power is P_{it} (\$/hr).

Subject to the following constraints:

1) **Demand Constraints**:

$$\sum_{i=1}^{NG} P_i = \sum_{j=1}^{Nb} PD_j \tag{2.2}$$

Where, PD_j is the power demand of bus j (MW);

NG is the number of generators;

Nb is the number of buses;

2) Power generation Limits:

$$P_{i\min} \le P_i \le P_{i\max} \qquad i = 1,2,....,NG \tag{2.3}$$

Where, $P_{i\max}$ is the maximum generation limit of generator i (MW);

$P_{i\min}$ is the minimum generation limit of generator i (MW).

3) Power flow constraints:

$$PF_{l\min} \le PF_l \le PF_{l\max} \qquad l = 1,2,....,NL \tag{2.4}$$

Where, $PF_{l\max}$ is the maximum power flow limit of line l (MW);

$PF_{l\min}$ is the minimum power flow limit of line l (MW).

The line flow constraint is important for any practical implementation of OPD problem, is tacking into consideration.

The fuel cost function or input-output characteristic of the generator may be obtained from design calculations or from heat rate tests. Many different formats are used to represent this characteristic. The data obtained from heat rate tests or from the plant design engineers may be fitted by a polynomial curve. It is usual that, quadratic characteristic is fit to these data. A series of straight-line segments may also be used to represent the input-output characteristic [30]. The fuel cost function of a generator, which usually used in power system operation and control problem, is represented with a second-order polynomial.

$$F_i(P_i) = a_i + b_i.P_i + c_i.P_i^2 \tag{2.5}$$

Where, a_i, b_i and c_i are the cost coefficients of the i^{th} generating unit.