CHAPTER 1

INTRODUCTION

1.1 GENERAL

In an electric power system, the total load on the system is generally higher during the daytime and early evening when industrial loads are high and lower during the late evening and early morning (Wood and Wollenberg 1996). Due to the fluctuations in the loads, the thermal generating plants start-up and shutdown decision are to be considered to minimize the fuel cost. The Unit Commitment (UC) problem in a power system involves determining a start-up and shutdown schedule of generating units to meet the forecasted demand over a short-term (24 - 168 hours) period. In solving the UC problem, generally two basic decisions are involved. The UC decision involves determining which generating units are to be running during each hour of the planning horizon, while considering constraints that includes the power balance, spinning reserve, generation limit and minimum up-time and down-time constraints. The related Economic Dispatch (ED) decision involves the allocation of system demand, generation limit and spinning reserve capacity among the operating units during each specific interval of operation. As these two decisions are interrelated, the UC problem generally embraces both these decisions and the objective is to obtain an overall least cost solution for operating the power system over the scheduling horizon.

Short term hydrothermal scheduling is one of the important planning tasks in optimal operation of power system whereby the generations
of hydroelectric and thermal plants are so allocated as to minimize total operating cost of the thermal plants in a time horizon of one day or one week while satisfying various constraints on hydro, thermal and power system network. In a dominantly fossil unit power system, hydro units are usually scheduled for peak load periods and are generally considered as a replacement for more expensive thermal units as they can be started up and shut down more efficiently. If most of the capacity in a power system is hydro, these units are also considered for base load demands. In this regard, in a hydrothermal system, it is necessary to coordinate the thermal and hydro units in order to obtain the minimum operation cost.

The short term hydrothermal scheduling with pumped-hydro plants are designed to save the fuel cost by serving the peak load with hydro energy and then pumping the water back into the reservoir at light load periods. Pumped-hydro units are also used as a spinning reserve unit under the forced outage of the thermal unit to safeguard the system if the reserve availability is marginal. A pumped storage unit has many advantages as peaking units and spinning reserve units: quick response, relatively low capital cost, etc.

1.2 LITERATURE SURVEY

A survey of literature on UC problem reveals that various numerical optimization techniques have been employed to obtain the solution of the UC problem. Specifically, they are Priority List (PL) methods, Dynamic Programming (DP), Mixed Integer Programming (MIP), Branch and Bound (BB) and Lagrangian Relaxation (LR) methods. Literature survey on short-term hydrothermal scheduling reveals that, several methods have been developed to solve the problem including DP, LR, Network Flow Programming (NFP), Decomposition and Linear Programming (LP) methods.
Recently, with the emergence of artificial and computational intelligence technology, attention has been gradually paid to solve power system problems like unit commitment, economic dispatch, hydrothermal scheduling etc. Artificial Intelligence (AI) techniques like Tabu Search (TS), Simulated Annealing (SA), Expert Systems (ES), Fuzzy Systems (FS), Artificial Neural Networks (ANN), Genetic Algorithms (GA) and Evolutionary Programming (EP) have been used for obtaining the solution of the UC problem. Hydrothermal scheduling problem is also solved using TS, SA, GA and EP techniques.

1.2.1 Literature Review on Unit Commitment Method

**Priority Listing:** Wood and Wollenberg (1996) presented a PL method to solve the UC problem, in which the generating units are committed based upon the strict priority order. PL could be obtained by noting the full-load average production cost of each unit. Tomonobu et al (2003) proposed a fast technique for UC problem by extended priority list method. Though the operating time of the extended priority list method is less, the operational cost is high. The PL method is simple and fast but the quality of final solution is approximate.

**Dynamic Programming:** Pang et al (1981) compared the performance of four methods, three of which are based on DP approach and the other is the complete priority order method. The Three DP methods are DP-Sequential combinations, DP-Truncated combinations and DP Sequential/Truncated combinations. The common feature of all these DP methods is that they are based on a priority list. As a result, the solution is suboptimal. Li et al (1997) presented a new UC method based on a decommitment procedure for solving the power systems resources scheduling
problem. From an initial schedule of all available units committed over the study period, a ‘one at a time’ unit decommitment is accomplished by DP according to some specified economic criteria. The advantage of DP is its ability to maintain solution feasibility. Its disadvantage is the “curse of dimensionality”, which results in unacceptable solution time.

**Branch and Bound:** Cohen et al (1983) presented a new approach for solving the UC problem based on BB techniques. This method incorporates time-dependent constraints and does not require a priority ordering of units. The difficulty of this method is exponential growth in the execution time for systems of a practical size. Hunag et al (1998) proposed a constraint logic programming along with depth-first BB search technique to provide an efficient and flexible approach to the UC problem. The system loss and the line flow constraints were not included in the proposed approach.

**Lagrangian Relaxation:** Bertsekas et al (1983) described a solution methodology based on Lagrangian relaxation. The duality gap decreases in relative terms as the number of units increases and as a result algorithm tends to perform better for problems of large size but the computational requirements typically grow linearly with the number of generating units. Cheng et al (2000) proposed a Lagrangian Relaxation and Genetic Algorithm (LRGA) method to solve the UC problem, which incorporates GA into LR to update the Lagrangian multipliers and improve the performance of LR method. The drawback of the proposed method is its large computational time. Fu et al (2005) introduced an efficient security constrained UC approach with ac network constraints that obtains the minimum system operating cost while maintaining the security of power systems. The proposed approach applies the Benders decomposition for separating the UC problem. The master problem applies the augmented LR
method and DP to solve UC and the subproblem checks the ac network security constraints.

**Genetic Algorithm:** Kazarlis et al (1996) presented a genetic algorithm solution to the UC problem. A simple GA algorithm implementation using the standard crossover and mutation operators could locate near optimal solutions. With the addition of problem specific operators the UC solution could be improved. Maifeld et al (1996) presented a new UC scheduling algorithm, using GA with domain specific mutation operators. The disadvantage of GA is that, since they are stochastic optimization algorithms, the optimality of the solution they provide cannot be guaranteed. Another disadvantage is their high execution time. Huang et al (1997) proposed a new approach using GA based neural network and DP to solve power system UC. A set of feasible generator commitment schedule is first formulated using genetic-enhanced neural networks. These pre-committed schedules are then optimized by the DP technique. A common drawback existed in neural network applications is on the dependency of test systems and the training set should be sufficient enough to tackle various problem demands, this may become a laborious task. Swarup et al (2002) presented a solution methodology of UC using GA. This approach is described as gradual consideration constraints and objectives in the total problem formulation. Though the computational time is less, it failed to converge to the optimal solution. Damousis et al (2004) presented a new solution to the thermal UC problem based on an integer-coded GA. The GA chromosome consists of a sequence of alternating sign integer numbers representing the sequence of operation/reservation times of the generating units. Though the execution time is comparatively reduced it fails to obtain the global minimum. Line flow constraints and transmission losses were not considered in any of these GA based UC problems.
Genetic algorithms have been used to solve constrained optimization problems. Although different methods to handle constraints have been suggested, penalty function methods have been mostly used. In penalty function method, a penalty term corresponding to the constraint violation is added to the objective function. However, it imposes the problem of building a suitable penalty function for the specific problem, based on the violation of the problem constraints.

Evolutionary Programming: Juste et al (1999) proposed an EP technique to solve the UC problem. The proposed algorithm operates on a system, which is designed to encode each unit operating schedule with regard to its minimum up/down time restrictions. The drawback of the proposed algorithm is its large computational time and it fails to reach the global optimum solution. Rajan et al (2004) presented a new approach to solve the short-term UC problem using an EP based TS method. TS method is incorporated in to EP to avoid the entrapment in local minima. Rajan et al (2007) presented a new approach to solve the short-term UC problem using an EP based SA method. The offspring obtained from the EP algorithm is given as input to SA and the refined status is obtained and evolutionary strategy selects the final status. Though the hybrid algorithm guarantees the near optimum solution it takes more computational time.

1.2.2 Literature Review on Hydrothermal Scheduling

Dynamic Programming: Yang et al (1989) used multi-pass DP method combined with successive approximations, which is an iterative procedure beginning with coarse time and state grids and refining the grid pass by pass. Line flow constraints and transmission loss were not considered in this formulation. Contaxis et al (1990) formulated the hydrothermal scheduling by decomposing the optimization problem into three subproblems
viz. maintenance scheduling problem, dispatch of thermal units and dispatch of hydro units. These subproblems were solved using levelized risk criterion, probabilistic techniques and discrete dynamic programming respectively.

**Lagrangian Relaxation:** Rashid et al (1991) formulated the short-term scheduling by forming a Lagrangian function consisting of an objective function augmented with the equality constraints on power balance and water availability using Lagrangian multipliers. The scheduling problem in each interval was solved through iterative method by linearizing the coordination equations. The transmission loss was included using loss coefficients and the network constraints were not enforced. Salam et al (1998) presented an improved LR based hydrothermal coordination algorithm. Lagrangian multipliers are used to relax system-wide demand and reserve requirements. The problem is decomposed into thermal and hydro subproblems. The thermal subproblem is solved using DP and hydro subproblem is solved using modified LR. Extensive constraints are considered such as power balance, spinning reserve, minimum up/down time, capacity limits, ramp rate and hydro constraints. Transmission losses are also incorporated.

**Network Flow Programming:** NFP is the most widely used method for the hydropower scheduling since, comparing to other approaches, it is more effective in dealing with the water traveling time between stations in a river, especially when the river is branched. Li et al (1993) implemented NFP to the hydrothermal coordination in an energy management system. Oliveira et al (1995) presented a second-order network flow algorithm specially designed for hydrothermal scheduling problems. The algorithm is based on the Truncated Newton method and takes the advantages of the particular layout of the hydro scheduling network. However, the computational effort drastically increases when there exist some convex branches in the flow network.
**Decomposition and Linear Programming method:** Bonaert et al (1972) decomposed the problem into hydro and thermal subproblems. The hydro subproblem was solved using an adaptation of successive approximations of DP method and the thermal subproblem was solved using gradient method. Mohan et al (1992) presented an effective algorithm for short term hydrothermal scheduling, which decomposes the problem in hydro and thermal subproblems and solves them alternatively. The hydro subproblem is solved using the local variation method and the thermal subproblem is solved using participation factors/Linear Programming method. The proposed algorithm was very effective in enforcing security constraints and able to give an optimal generation schedule which could be readily implemented for the next day.

**Genetic Algorithm:** Orero et al (1998) applied GA to the hydrothermal scheduling. A multi-reservoir cascade hydroelectric system with non-linear relationship between water discharge rate, net head and power generation is considered. The water transport delay between connected reservoirs is also taken into account. Line flow constraints are not included in this approach. Rudolf et al (1999) presented a two-layer approach to solve the UC problem of a hydrothermal power system. The first layer uses a GA to decide the on/off status of the units. The second layer uses a non-linear programming formulation solved by a LR to perform the ED while meeting all plant and system constraints. Line flow constraints and transmission losses were not considered in this formulation. Wu et al (2000) proposed a diploid genotype based GA to solve the short-term scheduling of hydrothermal systems. The proposed GA uses a pair of binary string with the same length to represent a solution to the problem. This algorithm improves the overall performance and avoids premature convergence. Line flow constraints are not included in this approach. Gil et al (2003) proposed a GA based model, which handled simultaneously the subproblems of short-term hydrothermal
coordination (yearly, monthly and weekly), UC (weekly or daily) and economic load dispatch (hourly). Line flow constraints and transmission losses were not considered in this formulation. Zoumas et al (2004) presented a GA solution to the hydrothermal coordination problem. The generation scheduling of the hydro production system is formulated as a mixed-integer, nonlinear optimization problem and solved with an enhanced GA featuring a set of problem-specific genetic operators. The thermal subproblem is solved using priority list method. Line flow constraints and transmission losses were not considered in this formulation.

1.2.3 Literature Review on Hydrothermal Scheduling with Pumped-Hydro Plant

Nanda et al (1986) solved the hydrothermal scheduling problem for systems with pumped-hydro plant using progressive optimality algorithm. In this algorithm the hydro generations and pumping powers are treated as injections and loads respectively at the appropriate buses and the optimal thermal generations were obtained using gradient method. The transmission loss was included through loss coefficients and the network constraints were not enforced.

Tang et al (1992) developed an algorithm based on LR. The problem is decomposed into a hydro subproblem and a thermal subproblem by using LR. The hydro subproblem is solved using mixed coordination and the thermal subproblem is solved analytically. A method is developed based on Lagrangian multipliers in deciding the operation of the pumped storage plants. Line flow constraints and transmission losses were not considered in this formulation.
Mohan et al (1993) presented a new problem formulation by including the generator outage induced security constraint on water storage level to operate the pumped-hydro plant as a spinning reserve unit and a method for the selection of the initial trajectory for the pumped-hydro plant. Hydro subproblem is solved using the local variation method and the thermal subproblem is solved using the participation factors and LP method.

Liang (2000) proposed a neural network based approach for the hydroelectric generation scheduling with pumped storage units. The neural network employed in this work is a stochastic neural model called noise annealing neural network. Though the proposed method has the ability to determine the global optimum solution, the line flow constraints and transmission losses were not considered in this formulation.

1.3 OBJECTIVES OF THE THESIS

The limitations of the GA based algorithms presented in the previous Section are summarised as follows:

i) In Genetic algorithm, penalty function method is mostly used to solve the constrained optimization problem. In penalty function method, a penalty term corresponding to the constraint violation is added to the objective function. Improper selection of penalty functions of different nature for each of the constraints may lead to local convergence and large computational time.

ii) The GA based algorithms have not considered the line flow constraints and the line losses, which are important for practical implementation of the solution of UC problem and hydrothermal scheduling.
The objectives of this thesis are to address the above limitations and develop methods to overcome the limitations as given below:

i) To develop an enhanced GA based algorithm to solve the UC problem.

ii) To develop an enhanced GA based algorithm to solve the UC problem with security constraints.

iii) To develop a GA based algorithm to solve the hydrothermal scheduling problem with security constraints.

iv) To develop a GA based algorithm to solve the hydrothermal scheduling problem with pumped-hydro plant for the operational benefits such as peak load plant and as spinning reserve unit.

1.4 SCOPE OF THE THESIS

A brief outline of various chapters is given below:

In Chapter 2, an enhanced GA is developed to solve the UC problem. In this proposed algorithm, feasible initial populations are generated randomly. The populations evolved in the consecutive generations are repaired and approximated regarding the constraint violation of minimum up/down time constraints and demand/spinning reserve constraints, which totally avoids the penalty functions. A two level crossover genetic algorithm is also introduced i.e. unit level and population level crossover to get a better scheduling. Other than the standard GA operators, swap mutation operator is also introduced.
In this Chapter, a hybrid EP technique is also proposed to solve the UC problem in which PL method is used to generate the initial population. The initial solution goes under a corrective procedure to obtain a feasible solution while satisfying the minimum up/down time constraints. The feasible solution is considered as an initial population to EP technique to obtain the optimal solution to the UC problem.

An Improved Lambda Iteration (ILI) technique is also proposed to solve the complicated ED problem. In AI based unit commitment problems, populations are created randomly with binary code 1’s and 0’s, which shows the on-off status of the generating units. Each generating unit has different fuel cost coefficients. Finding the optimum incremental cost for the randomly committed units is difficult.

In this Chapter, GA based algorithm for solving the UC problem with security constraints (line flow constraints) is proposed. UC problem is solved using enhanced GA and Optimal Power Flow (OPF) with power balance equality constraints, limits on the active power generations and limits on line phase angle as inequality constraint have also been included.

Chapter 3 presents the security constrained short-term hydrothermal scheduling, which has been solved using decomposition approach. Initial feasible water storage trajectory is obtained using Discharge Proportional to Demand Method (DPDM). This water storage trajectory is perturbed using local variation approach and lambda iteration technique to improve the hydrothermal schedule. Line flow constraints are enforced to check the overloading of lines and GA based OPF is applied only to the intervals at which line flow constraints violate the limit.
This Chapter also presents the security constrained short-term hydrothermal scheduling using GA. The hydro subproblem is solved using proposed GA and thermal subproblem is solved using lambda iteration technique without line losses. Both the hydro and thermal subproblems are solved alternatively. In the proposed GA, to get the new patterns of genetic strings during the evolution process, two levels of crossover operation, i.e. string level crossover and population level crossover are introduced. Total fuel cost is calculated including line losses for the best hydrothermal schedule obtained using proposed GA. Line flow constraints are checked for its limits at each interval. GA based OPF is implemented only for the constraints violated intervals.

Chapter 4 presents the security constrained short-term hydrothermal scheduling with pumped-hydro plant using GA. Two case studies are presented. In case 1, the pumped-hydro plant is used to serve the peak loads in the system with pumped-hydro by pumping the water into the reservoir at light loads and generating power during peak loads. In case 2, the pumped-hydro plant is used as a spinning reserve unit under the forced outage of the thermal generating unit. Line flow constraints are checked for its limits and GA based OPF is applied only to the intervals at which line flow constraints violate the limit.

In Chapter 5, a review of work done, major conclusions reached and contributions made are presented. Scope for future line of research is also outlined.