CHAPTER 1

INTRODUCTION

1.1 GENERAL

In the growing scenario, each and every day electricity networks deliver hundreds of Giga Watt hour energy from the generating units to the consumers. Based on the utilization of power by the consumers, it is understood that the demand varies predictably throughout the day, but it is also noted to fluctuate significantly in real time. At this juncture, to protect and ensure that the system remains secure and that the delivery of power is reliable, careful planning is required. The daily ‘ON’ and ‘OFF’ scheduling of the energy resource of the systems is called as unit commitment. This is a large scale optimization problem which determines the operating status of hundreds of generating units with respect to a set of specified constraints. Considering the scale of the problem and the frequency with which it has to be solved, unit commitment problem (UCP) has become a major research area in the power sector during the past few decades. The following sections of this chapter provide a better understanding of the need for unit commitment and its importance in power sector. The existing methodologies employed for solving unit commitment problem with their advantages and limitations are also outlined. The importance and the need for finding solution to UCP employing various proposed optimization algorithms are highlighted, and the objectives of this research work are listed.
1.2 NEED TO SOLVE UNIT COMMITMENT PROBLEM

UCP is fundamentally an optimization problem that aims to determine the operation schedule of the generating units at every interval with varying loads under different constraints and environments. Unit commitment aims to schedule the most cost effective combination of generating units to meet the forecasted load and the reserve requirements, considering generator and transmission constraints. Basically, UC completed for a scheduled horizon of one day to one week determines the operation schedule of the generator and the time interval. The problem of unit commitment involves determining the minimum – cost dispatch of available generation resources to meet the electrical load. This commitment schedule considers the inter – temporal parameters of each generator and does not specify the production levels, which are determined five minutes before delivery. The ultimate need to solve UCP is to appropriately schedule the generators to meet the growing power demand with minimal cost. The importance of UCP is increasing constantly with the varying demands. Henceforth, there is an immediate need in the power sector to keep track of the methodologies adopted for solving UCP to further optimize the specified criterions of the generating units.

1.3 LITERATURE REVIEW OF METHODS ADOPTED TO SOLVE UCP

Over the past few decades, numerous algorithms have been developed for optimization of the unit commitment problem, but still researchers working in this field propose new hybrid algorithms for making the problem more realistic. Generally, UCP is referred as a mixed combinatorial and non – linear optimization problem. It is highly tedious to solve these UCPs, because of their enormous dimension, non – linear objective function and coupling constraints. A number of researchers have studied this
A complex problem for decades and several traditional and meta-heuristic techniques have been developed. A few of these techniques include integer programming, mixed integer linear programming, dynamic programming, branch and bound, Lagrangian relaxation and so on. Similarly, meta-heuristic approaches like simulated annealing, tabu search, genetic algorithms and so on have been applied to solve UCP. This section presents the past literature studies available in the literature for solving UCP employing traditional and meta-heuristic approaches.

Johnson et al. (1971) performed unit commitment method and its implementation in program form on a 100 machine system and realized substantial savings in system operations over manual methods of commitment. Cohen & Yoshimura (1983) presented a solution using branch-and-bound techniques for unit commitment problem. The decision variables are the start and stop times and the generation levels of the units. Zhuang & Galiana (1990) performed simulated annealing based solution for unit commitment problem. The performance of this method was verified by using it on up to 100 units and the results indicate better flexibility in handling unit commitment constraints and outperform the other earlier methods.

Su & Hsu (1991) pointed out a solution based on the fuzzy dynamic programming for UCP. The performance of this method was compared with that of the Taiwan power system. The results show that fuzzy dynamic programming outperform the conventional dynamic programming method. Ouyang & Shahidehpour (1992) carried out a work using hybrid dynamic programming-artificial neural network to solve the unit commitment problem. The system is prescheduled based on input load profile generated by ANN. The result proves that when compared to the traditional dynamic programming the suggested method outperform with reduced execution time.
Sasaki et al. (1992) performed a work using artificial neural network to solve the unit commitment problem. The designed Hopfield neural network was used to determine the generators to be stored up at each period and a conventional algorithm was adapted to adjust the network output. Sheblé & Maifeld (1994) suggested genetic algorithm based solution for unit commitment scheduling problem and applied this for six-generator 24-hour scheduling period.

Kazarlis et al. (1996) proposed a solution problem using genetic algorithm (GA) incorporating Varying Quality Function technique and adding problem specific operators. Mantawy et al. (1998) suggested a solution using Simulated Annealing Algorithm (SAA) and quadratic programming routine to solve the nonlinear programming problem. Mantawy et al. (1999) pointed out a solution using integrating genetic algorithms, tabu search and simulated annealing methods. New population members for GA reproduction phase are generated by tabu search and the convergence of the GA is accelerated by simulated annealing method. The premature convergence of the genetic algorithm and fall in to local optimum is avoided by adapting simple short-term memory procedure.

Cheng, Chuan-Ping et al. (2000) suggested Genetic Algorithms (GA's) and Lagrangian Relaxation (LR) method based solution for unit commitment problem. Lagrangian multipliers are updated by Genetic Algorithms. The result confirms that the proposed approach obtain highly near-optimal solution to the UC problem because of faster convergence and easy implementation than LR and GA separately. Chen & Wang (2002) presented a solution using Cooperative Coevolutionary Algorithm (CCA), Lagrangian multipliers optimized by adapting subgradient-based stochastic optimization method and unit commitment sub-problems are solved by GA. Compared to the conventional LR and traditional Gas, this method handles
more complicated time-dependent constraints and provides better quality solution.

Cheng, C-P et al. (2002) solved unit commitment problem using annealing-genetics (AG) algorithms in order to improve the performance. Compared to SA, GA, DP and LR, the result reveals that the use of AG provides with highly near-optimal solution to the UC problem, better convergence and easy implementation. Padhy (2003) analyzed general backgrounds of research and developments in the field of unit commitment problem under deregulated environment in order to reduce the difficulty for the new researchers in carrying out research in the area of next-generation unit commitment problem.

Ting, T-O et al. (2003) proposed Hybrid Particle Swarm Optimization (HPSO) based solution for unit commitment problem and validated with 10 generator-scheduling problem and the result proves satisfactory performance. Damousis et al. (2004) pointed out integer-coded genetic algorithm (GA) based solution for unit commitment problem. The generating unit’s minimum up and minimum downtime constraints are directly coded in the chromosome. Padhy (2004) reviewed mathematical formulations and general backgrounds of research and developments in the field of UC problem in both the regulated and deregulated environment.

Rajan & Mohan (2004) carried out a work based on an evolutionary programming-based tabu search (TS) method. Unit commitment problem is handled by evolutionary programming and evolutionary strategy is adapted to choose the best population and prevention of local minima and the status improvement is done by Ting et al. (2006) performed hybrid particle swarm optimization (HPSO) approach which is a combination of binary PSO and real coded PSO in order to solve the unit commitment problem.
Chen & Wang (2007) suggested integrated PSO/GA approach based solution for unit commitment problem and as well repeating the process of ED with modified PSO. Rajan, CCA & Mohan (2007) pointed out a solution for short-term unit commitment problem based on evolutionary programming based simulated annealing method. Unit commitment problem is handled by evolutionary programming, where in evolutionary strategy is adapted to choose the best population, status improvement is done by SA and random recommitment is performed with respect to the unit’s minimum down times. Dang & Li (2007) identified a solution using floating-point genetic algorithm (FPGA), which enhanced to reduce the complexities in handling the minimum up/down time limits. The exploration and exploitation of FPGA in the non-convex solution space and multimodal objective function is obtained by formulation of dynamic combination scheme of genetic operators.

Lee & Chen (2007) presented iteration particle swarm optimization (IPSO) algorithm based solution for unit commitment with probabilistic reserve problem, and applied it for 48 unit power systems. Rajan, C & Mohan (2004) suggested a solution based on Neural-Based Tabu Search (NBTS) for utility system unit commitment problem. Rajan, CCA & Mohan (2007) carried out a work using genetic algorithm-based simulated annealing method to solve the unit commitment problem. Status improvement is done by SA and random recommitment performed with respect to the unit's minimum down times.

Saber et al. (2007) performed fuzzy adaptive particle swarm optimization (FAPSO) based solution for unit commitment problem, with a balance between global and local searching abilities improved by fuzzy IF/THEN rules based dynamical inertia weight adjustment. Saber, AY et al. (2007), suggested two-fold simulated annealing (twofold-SA) approach for
fuzzy unit commitment formulation. Dieu & Ongsakul (2008) presented a solution for ramp rate constrained unit commitment problem based on improved priority list (IPL) and augmented Hopfield Lagrange neural network (ALH). Unit scheduling problem is solved by IPL and ramp rate constrained economic dispatch (RED) problem is solved by ALH respectively. Patra et al. (2008) pointed out a solution for unit commitment problem with ramp constraints using differential evolution algorithm, binary code and integer code based implementation.

Saber & Alshareef (2008) presented a solution for scalable unit commitment problem using memory-bounded ant colony optimization (MACO) and the local searching ability is improved by A* heuristic method and estimation of pheromone intensity for the forgotten value is done by probabilistic nearest neighbour method. Belede et al. (2009) analyzed the past 20 year nature and biologically inspired computing techniques based solution for unit commitment problem in order to assist the new researchers working in this field. Eslamian et al. (2009) provided a solution for unit commitment problem using bacterial foraging (BE), directly coding minimum up/down-time constraints and reducing the computation time by integer coding. Lau et al. (2009) proposed a novel method to solve unit commitment problem using quantum-inspired evolutionary algorithm (QEA), where in economic dispatch problem is handled by Lambda-iteration method and unit-scheduling problem is solved by QEA.

Yuan et al. (2009) suggested a solution based on improved binary PSO (IBPSO) pointed out a solution based on new Three-Stage (THS) approach: first stage achieves solution in a feasible duration of time obtained by simple procedure, second stage performs ED by adapting hybrid serial algorithm of AI with PSO and NM and the third stage helps in reaching more appropriate solution by solution modification process (SMP).
Pappala & Erlich (2010) presented a solution for unit commitment problem using variable-dimension optimization approach and implemented it in particle swarm optimization. The optimization process begins with an arbitrary problem dimension, incorporates it with respect to the swarm progress and lastly chooses the optimal dimensional space. The results confirm that the suggested method improve the solution quality, reduce the problem dimension with better convergence. Chung et al. (2011) proposed a solution for unit commitment problem based on advanced quantum-inspired evolutionary algorithm, incorporating multi-observation, single-search, and group-search techniques.

Dimitroulas & Georgilakis (2011) presented a solution for price based unit commitment problem using advanced memetic algorithm (MA), CPU time is reduced by two-level tournament selection mechanism. Ebrahimi et al. (2011) proposed a shuffled frog leaping algorithm based solution for unit commitment problem. Total energy dispatch cost over the scheduling period is reduced by integer-coded algorithm and the minimum up/down-time constraints are directly coded.

Singh & Rajan (2011) carried out a work based on hybrid approach combination of Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). Yen et al. (2011) performed solution to unit commitment problem using modified hybrid particle swarm optimization (MHPSO), in which particle stagnation is prevented by modifying the velocity equation of particle. The performance of this approach was evaluated for 10, 20, 40 and 60 unit systems, and the results confirm that compared to other prior methods MHPSO achieve better performance.

Yuan et al. (2011) pointed out an enhanced PSO (EPSO) based on DBPSO with the Lambda-iteration method for unit commitment problem.
When eliminating minimum up/down time constraints unit scheduling is done by DBPSO, decommitment of excess spinning reserve units and minimum up/down time constraints is handled by heuristic search strategies and economic load dispatch based on the unit schedule is solved using Lambda-iteration method. Chandrasekaran & Simon (2012) carried out a work using hybrid search algorithm (CSA) incorporating fuzzy system in order to solve multi-objective unit commitment problem (MOUCP). The requirement of expertise needed for setting the variables avoided by tuning the fuzzy design variables. ON /OFF status of the generating units are obtained by binary coded CSA and the solution for economic dispatch problem (EDP) and tuning of the fuzzy design boundary variables is performed by real coded CSA.

Datta & Dutta (2012) suggested a solution for unit commitment problem based on the binary- real- coded differential evolution and applied for power systems up to 100 units over 24-h time horizon. Govardhan & Roy (2012) suggested a solution based on hybrid Priority List (PL) method and the effectiveness of the EP, HEP, ABC algorithm was validated with 10 units. Hadji & Vahidi (2012) proposed a solution based on imperialistic competition algorithm (ICA), scheduling variables are coded as integers in order to directly handle the minimum up/down-time constraints. Datta (2013) presented binary real coded genetic algorithm to solve unit commitment problem; integer and real parts including ramp rate constraints are solved.

Govardhan & Roy (2013) analyzed three evolutionary techniques such as PSO, DE and GABC algorithms in order to solve unit commitment problem. Performance was evaluated with 10 and 20 unit test system over a 24 hour scheduling period. Lakshmi & Vasantharatha (2013) proposed a solution for profit based unit commitment problem using hybrid artificial immune system. Pourjamal & Ravadanegh (2013) carried out a work employing harmony search algorithm (HSA).
Roy (2013) performed gravitational search algorithm (GSA) for unit commitment problem and verified using 10, 20, 40, 60, 80 and 100 units over a scheduling period of 24 h. The result proves that compared to SA, GA, EP, DE, PSO, IPSO, HPSO, BCPSO, QEA, IQEA, QM, ILA and BRCFF, this method shows better & effective performance. Viana & Pedroso (2013) pointed out a solution for unit commitment problem in power generation planning using MILP. Optimum converging and faster solution is obtained by piecewise linear approximations of the quadratic fuel cost function that are dynamically updated in an iterative way.

Saravanan et al. (2014) performed invasive weed optimization algorithm (IWO) for unit commitment problem. Minimum up/down time constraints have been coded in a direct manner and are evaluated using 10 units and 24 h system. Rahman et al. (2014) presented two algorithms: local branching and hybridization of particle swarm optimization with a mixed integer programming solver for unit commitment problem. Jiang et al. (2014) pointed out a solution for unit commitment problem under uncertainty based on two-stage robust optimization model. This technique provides tight lower and upper bounds for the general network constrained robust unit commitment problem.

Mallipeddi & Suganthan (2014) analyzed and compared conventional and nature inspired algorithms based solution for unit commitment problem in order to assist the new researcher to carry out research in this field. Mandal & Kumar Roy (2014) suggested teaching learning based optimization (TLBO) algorithm in order to solve multi-objective optimal power flow (MOOPF) problems; quasi-oppositional based learning (QOBL) is adopted to improve the quality of solution and convergence speed. Morsali et al. (2014) carried out a work on a novel version
of harmony search (HS) algorithm for unit commitment problem. In this, two important control parameters are adjusted to obtain the optimal solution.

Niknam et al. (2014) pointed out a solution for unit commitment problem using self-adaptive Bat-inspired algorithm (BA). Population diversity and exploration power of BA are improved by self-adaptive method, hence achieve better solution and faster convergence. Niknam et al. (2014) suggested a solution for unit commitment problem based on self-adaptive learning charged system search algorithm (SACSS) and applied for 10, 20, 40 and 100 units over 24-h time horizon. Quan et al. (2014) presented second-order cone programming (SOCP) and valid inequalities (VIs) based tighter relaxation method (RM) for unit commitment problem.

Roy & Sarkar (2014) presented quasi-oppositional teaching learning based algorithm (QOTLBO) for unit commitment problem and validated using 10, 20, 60, 80 and 100 units over 24h scheduling period. Vamsi Krishna Tumuluru et al. (2014) carried out a work based on new formulation and solution method, where feasible path of ON–OFF states for each generator searched by formulation and Lagrangian relaxation (LR) based solution method was obtained to perform optimal solution for the UCP.

Yuan et al. (2014) presented integrated binary gravitational search algorithm (BGSA) with Lambda-iteration method based solution for unit commitment problem. Yu & Zhang (2014), suggested Lagrangian relaxation and particle swarm optimization (ELRPSO) algorithm for unit commitment problem. Adaptive sub gradient heuristic help multipliers were obtained from the LR as they tend to be close to the optimal multipliers and have a large potential to lead to a feasible near-optimal UC schedule.
Marrouchi & Chebbi (2015) pointed out Gradient-Genetic algorithm and Fuzzy logic based solution for unit commitment problem. pointed a solution for unit commitment problem using improved priority list and neighbourhood search (IPL-NS) method, unit status for UC without ramp rate constraints is obtained by IPL based MILP and unit status for RUC is obtained by neighbourhood search (NS) algorithm. Ramesh Kumar & Premalatha (2015) suggested adaptive real coded biogeography-based optimization (ARCBBO) algorithm for optimal power flow (OPF) problem in a power system in order to obtain optimal settings of control variables.

Singhal et al. (2015) proposed a solution for unit commitment problem using hybrid method based on novel binary artificial bee colony (NBABC) algorithm and local search (LS). Yang et al. (2015) carried out a work to solve the unit commitment problem using projected mixed integer quadratic programming (P-MIQP), two mixed integer linear programming (MILP) formulations obtained from traditional MIQP and CPLEX solver. Yuan et al. (2015) presented a solution for hydro thermal unit commitment problem using hybrid method based on chaotic backtracking search optimization algorithm and binary charged system search algorithm (CBSA-BCSS).

The detailed review of the early literature studies elucidates the applicability of evolutionary optimization techniques adopted to solve UCP with the specified constraints being satisfied. Thus the present research focused on developing hybrid modified variants of evolutionary based optimization techniques to solve UCP.
1.4 MOTIVATION FOR THE RESEARCH STUDY

From the above extensive literature study on solving unit commitment problem employing evolutionary optimization techniques over the past decades, it has been noted that the following problems are observed when solving UCP for the specified constraints:

- Scalability not attained
- Premature convergence of the algorithms
- Getting trapped in local and global optima
- Fluctuations in the power demand
- Stagnation
- Elapsing more computational time
- Increased computational burden of the algorithms
- No guarantee on interpretability of the system

This research work proposed adaptive, flexible and scalable algorithms that utilize the advantages of proposed population based evolutionary optimization algorithms and a discrete neural network architectures for improving exploration and exploitation needs and the training learning process. The proposed work gives the highest probability for minimizing the fuel operating cost of 10, 20, 40, 60, 80 and 100 units systems for the specified constraints compared to the existing works due to the following factors:

- Faster convergence of the algorithms developed
- Feasible location of optimal solution
- Set constraints are being met
- Solution for avoidance of premature convergence
- Improvement in cost incurred
- Improvement of the exploration and exploitation capabilities of the search process.
- Reduction in the number of generations of the process and the fuel cost of the generating system.
- Reduction of time complexity of the system model
- Improvement of the general ability to solve power sector issues.

In general, this research is carried out to propose appropriate optimization technique to perform effective minimization of fuel running cost, and in turn the fuel operating cost for the considered unit commitment system. The contribution leads to the development of new hybrid evolutionary optimization and novel variants of stochastic algorithms to offer quality solutions in solving UCP. In precise, this research work contributes to power system research by developing effective and scalable proposed approaches that are based on population based stochastic evolutionary algorithms to meet out the equality and inequality constraints and to solve UCP. The proposed algorithms are used to facilitate the process of solving UCP with complete guarantee on constraints in a responsive and efficient way. Besides the contribution to power system research, the study also contributes to the evolutionary optimization algorithm development research. The effectiveness based on the simulation results computed for minimum cost incurred is compared with a few of the other existing and proposed algorithms for its proper validation.

1.5 OBJECTIVES OF THE RESEARCH WORK

It is imperative that finding a solution to unit commitment problem employing effective optimization algorithms is of prime concern in the growth of power system sector. In this scenario, it is necessary to analyze and develop evolutionary optimization algorithms to determine optimal
solution to UCP with the specified equality and inequality constraints met. Thus, in this research, certain hybrid evolutionary optimization approaches are proposed to produce optimal solutions with a guarantee on constraints and minimal cost. This research is based on the applicability of the proposed evolutionary optimization algorithms which have proven its efficiency to compute optimal solution with better convergence rate. The following algorithms are proposed for solving UCP with respect to 10, 20, 40, 60, 80 and 100 units system in this research work:

- Hybrid Cuckoo Search and Imperialist Competitive Algorithm for solving Unit Commitment Problem with respect to the considered systems.
- Development of a Unified Momentum Gravitational Search Algorithm (UMGSA) to find optimal solutions to 10, 40, 40, 60, 80 and 100 units system along with the equality and inequality constraints defined.
- A new variant of charged system search algorithm called as Refined Charged System Search Algorithm (RCSSA) to explore the combinatorial power search space resulting in better solutions to avoid the occurrence of optimization problems.
- A novel stochastic based evolutionary optimization technique which is a variant of Charged System Search Algorithm (CSSA); called Hybrid Differential Evolution - Charged System Search Algorithm (HDE – CSSA) is developed by hybridizing the proposed differential evolution with that of the original CSSA to minimize the fuel running cost and in turn the operating cost of unit commitment problem.
- A Discrete Hopfield Neural Network (DHNN) is chosen to solve unit commitment problem and the weights of the Hopfield network is optimized employing the Biogeography based optimization (BBO). A neural network modelling is carried out with their weights being optimized by BBO which acts based on its habitat suitability index to
compute optimal operating cost for UCP with the specified constraints met.

Each one of the proposed approaches contributes a distinct methodology for solving UCP effectively and efficiently in a cooperative manner rather than a competitive manner. The results of the UCPs employing these proposed approaches are more intelligent, accurate and human-interpretable as compared to the results of the other proposed models available in the literature. MATLAB mathematical software is employed for simulation of the proposed population – based stochastic evolutionary optimization algorithms. Detailed numerical simulation experiments are carried out to analyze the performance and validity of all the proposed approaches. The results computed employing the proposed algorithmic approaches are compared with some of the existing methods to prove their level of accuracy and validity.

1.6 ORGANIZATION OF THE THESIS

The thesis is organized into seven chapters including the introductory chapter 1. An outline of the forthcoming chapters is given below:

Chapter 2 discusses the importance of unit commitment problem in power system sector. In this chapter, a hybrid cuckoo – imperialist competitive algorithm (HCICA) is proposed to solve UCP with the given constraints being met. The tests are performed for 10, 20, 40, 60, 80 and 100 units for a scheduling period of 24 hours. The results obtained after employing the proposed HCICA approach prove significant while compared to the earlier methods for the same test bed in solving UCP.
Chapter 3 proposes a new modified variant of Gravitational Search Algorithm (GSA) to find solutions to unit commitment problems with the considered equality and inequality constraints met. The proposed unified momentum GSA (UMGSA) resulted in exploring the search space and avoiding the stagnation problem as well to improve the exploration process. The simulation results computed during the implementation of small scale and large scale systems are discussed in detail in this chapter.

Chapter 4 presents a variant of CSSA called as Refined Charged System Search Algorithm (RCSSA) which invokes the exploitation process to a greater extent enhancing the convergence of solutions to solve UCP. The proposed RCSSA is applied to UCP with 10, 20, 40, 60, 80 and 100 units system with specified constraints and the cost solutions computed using the proposed approach is noted to be better than the existing techniques.

Chapter 5 details a novel stochastic based evolutionary optimization technique which is a variant of CSSA; called Hybrid Differential Evolution - Charged System Search Algorithm (HDE – CSSA) developed by hybridizing the proposed hybrid differential evolution with the original CSSA. Detailed simulation results for large scale and small scale systems are presented to elucidate the applicability of proposed technique for solving UCP.

Chapter 6 presents a hybrid version of biogeography based optimization (BBO) based discrete Hopfield neural network (DHNN) to solve UCP. The proposed technique is presented in this chapter with the features of an evolutionary optimization approach and neural network brought out to minimize the fuel operating cost for unit commitment problem.

Conclusions of the research work and suggestions for future scope are presented in the Chapter 7.
List of references and a list of papers published based on this research work are given at the end of the thesis.

1.7 SUMMARY

An introduction to the need for finding solutions to unit commitment problem in the growing power sector domain is presented in this chapter. It provided an in-depth justification for the motivation towards this research work and the need to solve UCP based on hybrid intelligent evolutionary optimization algorithms. It also discussed the need for the research work and an extensive literature review on the various methods adopted to solve UCP. This chapter also presented the major contributions towards the research problem undertaken in the area of unit commitment and sketches the details on the outline of this thesis.