CHAPTER-1
INTRODUCTION

1.1 INTRODUCTION

Today's power system has grown up to high proportions due to a large number of inter-connections. Also its operating characteristics are highly non-linear. Size of the power system is growing exponentially due to heavy demand of power in all the sectors viz. agricultural, industrial, residential and commercial ones. Increase in the electrical energy demand and trends in privatization and deregulation result in overloading impact on electrical grids. The situation requires the development of electrical grid at the same pace as the increase in demand, but economical commitment and scheduling has the ability to tackle the time-varying power demand, environmental constraints and leads to the full exploitation of accessible grid.

Modern power system consists of various power generating units like nuclear, thermal, hydro etc. Further, power demand attends different values during a day. Thus, it is necessary to decide, which generating unit should be kept on for particular hour and for what hour, it should be kept off to meeting time varying power demand, so that optimal generation cost can be achieved. The complete procedure of making this intelligent decision is termed as unit commitment (UC) and the unit, which is programmed to be connected to power system network, is known as *committed unit*.

Unit commitment with respect to power system optimization refers to the determination of ON/OFF schedule of power generating units to minimize the operating cost at a given time horizon [222, 311]. Generators cannot be immediately turned on to meet up power demand. So, it is required that the planning of generating units must be so done that there is enough generation available to fulfill the load demand along with an ample reserve generation to avoid mal-effect of failures and malfunctions under adverse situations.

1.2 ECONOMIC LOAD DISPATCH

Electrical power is very crucial in today's world. Almost every modern activity is dependent on electricity in one way or the other way. Therefore efficient generation, transmission, distribution and utilization of electrical power are essential. To achieve this purpose, there is a need to plan the operational schedule of the generators in an optimal possible way called the *economic load dispatch* (ELD) in power system [40].

Economic dispatch in electric power system refers to the short-term discernment of the optimal generation output of various electric utilities, to satisfy the system power requirement, subject to system's operational and transmission limits. It is called the economic load dispatch Problem. The ultimate aim of the ELD problem is to generate and distribute the electrical power at the minimum possible cost while satisfying various equality and inequality constraints of the system. The problem of ELD is usually multimodal, discontinuous and highly nonlinear due to the effect of valve-point openings, which limit the operating zones. Although the cost curves of thermal generating units is generally modeled as a smooth curve. Noteworthy economical benefits can be achieved by searching a better solution to the economic load dispatch problem [40].

1.3 UNIT COMMITMENT PROBLEM

The *unit commitment* (UC) is an important daily task in the planning and operation of modern electric power systems. Because the power demand of the system keeps on varying daily, the management has to decide in advance the operational schedule of generators in the network. This evaluation procedure is called unit commitment. The units that are to be turned on and connected to the system are said to be committed [236] and the units turned off are called de-committed.

The decision for turning on and off of units to satisfy the time varying power demand should be so taken so as to minimize the cost of generation while operating within practical limits of generators and power system components. The major component of cost would be incurred due to fuel cost. Also costs are involved during starting up and shutting down of units. Even cost is involved during no-load if the generator is on line. The main operational constraints to be considered are:

- The generated power must be equal to the net power requirement including system losses.
- There should be adequate spinning reserve to cover any unavoidable shortage in generation.

- The each unit must operate within its minimum and maximum capacity.
- The each unit must follow its minimum up and down time limit.

The unit commitment problem for a power system is usually solved over a set of time periods [311]. UCP is a non-linear, large scale, mixed integer constrained optimization problem [188] and happens to belong to combinatorial optimization problems. There are many constraints involved in UCP and hence it is quite a complex and tedious task to compute or to find the optimal solution.

There is a variety of generating units and each unit has different characteristics. A nuclear power unit has very low incremental cost for each additional megawatt hour (MWh) of energy, but it has a high start up cost and also it takes some time to come up to its full capacity. On the other hand, a gas turbine generator can be started up quickly, but its incremental cost is much more. Efficient but costly to start generators are turned on earlier as base load generators and the cheap to start generators are turned on later on with increase in load demand. As demand decreases, units are shut down in the reverse order. If there is a short duration peak in demand, then it may be economical to turn on a cheap-to-start unit, even if it is inefficient for the duration of the short spike. Solution of the UC problem for large power systems is computationally more involved and it grows exponentially to the number of generating units.

Our industries, agriculture and software companies require consistent and uninterrupted power supply for toeing the needs of continuous customer demand. It therefore drew the attention of researchers to determine the optimal and most economic condition for generation units to operate in each period so as to satisfy a predictably varying demand for electricity. Further due to complexity of multi area generation system, the determination of economic condition for committed units along with economic dispatch and minimum emission is most important. Thus, there is urgent need to implement a trusted and foolproof algorithm to solve unit commitment of electric power system in single and multi-objective framework.

1.4 LITERATURE REVIEW ON UNIT COMMITMENT

Unit commitment is an important optimization problem, which is used to obtain the optimal schedule for operating the generating units in the most economic manner to meet the required load demand and at the same time to accomplish the constraints' requirements. Unit commitment has attracted many researchers over past few years. Most of the researchers had explored the solution of single area unit commitment problem. The researchers are looking forward to find new techniques and methodologies for solving unit commitment problem. Also, optimization is another vast area in which the research is going on rapidly. The researchers are trying to implement various techniques on different problems and are able to find the solutions successfully. The work is going on to find new algorithms and also the hybrid forms of the algorithms to rectify any drawbacks in the existing techniques. This chapter deals with the literature survey of various techniques successfully applied on various real world problems including the unit commitment problem. The techniques covered here include (i) conventional methods; viz Priority list method [207,227, 254, 276] , De-commitment method [169], Dynamic programming method [183, 202, 246, 266], Branch and Bound method [30], Integer and Mixed Integer programming [172, 201, 224], Lagrangian relaxation (LR) method[44, 51, 236, 245], Straight forward method [271], Secant method [289], Simulated annealing method[68, 151, 152, 161, 379], Expert system[48, 53, 79, 90, 95, 183] , (ii) non-conventional methods; viz Genetic algorithm [104, 110, 117, 118, 120, 121, 132], Tabu Search [148, 181], Artificial Neural Network (ANN) [86, 87, 135, 141, 259], Memetic algorithm [190, 362, 392, 401, 412], Differential evolution (DE) [220, 221, 228, 235, 273, 294, 330, 374], Harmony search algorithm (HSA) [297, 317, 352, 356, 365, 366, 383], Shuffled frog leaping algorithm (SFLA) [292, 370, 371, 385, 387] , Snake algorithm[369], Biogeography based optimization (BBO) [296, 325, 326, 327, 341, 364, 388, 391] , Particle swarm optimization (PSO) [112, 113, 146, 200, 384, 390], Fuzzy Logic method [226, 239, 246, 255, 267, 270], Evolutionary programming (EP) [216, 314, 321], Ant Colony Optimization (ACO) [191, 205, 213, 291, 316, 350, 399, 403], Greedy randomized Adaptive Search Procedure [28, 213, 331] and Hybrid methods [84, 135, 161, 171, 181, 188, 200, 216, 244, 266, 349, 351, 394] .

The first paper in the field of unit commitment was introduced by Baldwin [4] in 1959. Since 1959, appreciable research work has been done in the area of single area multi-objective unit commitment problem. Lots of research papers are available related to single-objective and multi-objective or multi-criterion optimization problems and single area unit commitment problem. Literature review for the study at hand has been divided according to various methodologies like conventional, non-conventional and hybrid and is being presented under different sections in ensuing sections:

1.4.1 Conventional Optimization Methods

Kerr *et al.* [8] have explained the need of unit commitment problem in power system with respect to economic aspects of generating units and elaborated the method to formulate the solution of single area unit commitment problem. Hara *et al. [10]* have elaborated a technique for scheduling integrated operations of thermal power system and formulated an objective function, which consist of reliability aspects of generating units along with operational cost. Guy [13] had demonstrated constrained search technique to determine the ON/OFF status of generating units to minimize fuel cost along with start-up cost. The simulation results obtained by constrained search technique meets power system reliability requirement and along with minimum fuel costs.

Lauer *et al.* [29] have developed a solution methodology to solve large-scale unit commitment problem of electric power system. In developed solution methodology, two unique features were taken into consideration. First, computational requirements vary linearly with the number of generating units. Second, the performance of the algorithm can be thoroughly improved as the number of generating unit increases. Lee *et al.* [36] have discussed unit commitment problems allied with uncertainty in loads, production costs, and in the countenance of increasingly complicated operational constraints and had focused industry consideration on current problems faced by electric utility operators. Snyder *et al.* [43] have developed heuristic procedures for supplying a priori information to the program for deciding when generating units must be committed and when it may be ignored to minimize simulation time. Nieva *et al.* [44] have formulated the solution for large-scale unit commitment problem and discussed the results for very large and complex unit commitment problems of thermal power system.

Cohen *et al*. [45] have applied a method to solve unit commitment problem in the presence of fuel constraints. The developed method was applied to a production-grade program, which was appropriate for energy executive systems applications. Lee [49, 50] had developed an algorithm for short term thermal unit commitment problem and demonstrated algorithm for satisfactory performance. In simulation results, it was found that the computation time in developed method was approximately linear with respect to the number of hours in the unit commitment horizon. Hobbs *et al.* [52] have demonstrated an algorithm which saves forerunner options and applied the proposed algorithm for on-line energy management system.

Aoki *et al.* [59] have developed a variable metric approach for dual maximization, another method for solving long-term single area unit commitment problem off large scale power system. Tong *et al.* [58] have elaborated a method for scheduling power generating units which operates under fuel utilization constraints. Numerical results presented in the proposed method describe the effectiveness and expediency of the algorithm. Chowdhury *et al.* [66] have formulated probabilistic schedules for frequently changing loads in an interconnected power system configuration for a specified time period. Handschin *et al.* [67] have demonstrated a method for the unit commitment problem considering energy constraints obtained from a long-term optimization. Hussain [72] had elaborated the limitations of the existing unit commitment algorithm against different constraints and accomplished that limitations of existing unit commitment algorithm can be overcome by applying simple techniques rather than spending money and time for ordering extraordinary new software. Ma *et al.* [134] have considered reactive power and voltage constraints for single area unit commitment problem and tested IEEE-30 bus system to reveal the performance of the algorithm.

Burns et al. [17] proposed a dynamic priority list which varies with the system power demand. Tingfan and Ting [286] proposed a methodological priority list method to overcome the drawback of less efficient conventional priority list. Lee et al. [62, 88] developed the priority list based on commitment utilization factor in association with the average full load cost and claimed that the commitment utilization factor can imitate the impact of multi-area transmission interconnection constraints and experimentally found that the priority list(PL) based on commitment utilization factor and average full load cost yields better results. Shoults et al. [23] incorporated the average start-up cost along with average full load cost, for determining unit priority list for multi-area unit commitment with area import/export constraints. Senjyu, *et al.* [207] have applied extended priority list (EPL) method for the solution of single area unit commitment problem of electric power system, which consists of two steps. In first step, initial commitment schedules of generating units was determined by priority list approach and initial status of units was modified using problem specific heuristics to fulfill various constraints requirements of generating units. Also, Senjyu, et al. [254] proposed another improved priority list method known as stochastic priority list (SPL). In proposed SPL technique, feasible unit commitment schedules for single area unit commitment problem are generated with the help of priority list approach and priority based stochastic window system. Heuristics procedures are used to diminish search space and computational time. Lee [74] has presented an approach for determining the priority list for single area thermal unit commitment problem and applied the proposed technique for a mid-western utility system. Experimental results had shown that additional modification in priority listing significantly improved the performance of priority-order-based model without noticeable penalty in the computational requirements. Tseng *et al.* [150] have applied Lagrangian relaxation method to find unit commitment schedule of generating units having identical fuel cost characteristics. To improve the cost, heuristics de-commitment procedure was combined with Largrangian relaxation method. Heuristic de-commitment method was applied as post unit commitment process to minimize the excessive spinning reserve.

Tseng *et al.* [169] have demonstrated that de-commitment method is an efficient, reliable, and quick approach for solving unit commitment problem and considered unit ramp rate constraints along with others operational constraints, which was not taken into consideration by various researchers. Li *et al.* [119] have applied a commitment method based on de-commitment process for solving resource scheduling problem of electric power system and demonstrated the results of proposed method with Lagrangian relaxation method and Fred Lee's sequential unit commitment (SUC) method and concluded that proposed method had potential benefits for power system operations planning. Ouyang and Shahidehpour [77] have applied a heuristic procedure for improvement of truncated window dynamic programming and used a variable window size according to forecast load demand increments. To fine tune the optimal solution, an iterative process for the number of strategies saved in every stage was incorporated. Lowery [9] applied dynamic programming for the solution of unit commitment problem.

The major concern for applying this method was to determine the feasibility of dynamic programming for the solution of unit commitment problem. Experimental results of study show that simple, straightforward constraints are adequate to produce a usable optimum operating policy. Also, the method was proved to be feasible as required computational time to produce a solution was small. Bond *et al.* [40] developed a dynamic programming algorithm, which is capable of solving the unit commitment and generation scheduling problem of electric power system. Su et al. [76] has elaborated fuzzy dynamic programming. Fuzzy set notation was used to derive membership functions for the load demand, the total cost, and the spinning reserve. The errors in the forecasted load were also taken into consideration, while deriving fuzzy membership functions. The developed fuzzy DP algorithm was tested to solve the unit commitment problem of Taiwan power system consisting of 6 nuclear, 48 thermal and 44 hydro generating units and it has been experimentally found that fuzzy dynamic programming approach requires more computer time than the classical dynamic programming approach.

Pang *et al.* [25] have compared the performance of four dissimilar types of unit commitment approached, three of which was based on the dynamic programming approach. Bosch *et al.* [35] have proposes decomposition and dynamic programming techniques for the solution of a high dimensional non-linear, mixed-integer unit commitment optimization problem. Experiments showed that the proposed methods were able to locate a better solution in less time than many other existing techniques. Kusic *et al.* [37] have applied dynamic programming technique to determine an optimal schedule for start up and shutdown of available generating units in addition to unit base generation and production costs. The proposed approach was presented for the problem of dispatch and unit commitment of wholly owned and commonly owned units. Cohen *et al.* [30] proposed a new approach based on branch-and-bound techniques. The method incorporates start-up costs, load demand, spinning reserve, minimum up time and minimum down time constraints. Juste *et al.* [160] proposed an algorithm using evolutionary programming technique in which initial population is generated randomly and then the solutions are evolved through selection, competition, and random changes. The performance of the proposed algorithm was tested for 10-100 generating units systems and simulation results are compared with Lagrangian relaxation method, genetic algorithm and dynamic programming approach. Dillon *et al.* [22] proposed an extended and modified version of integer programming by applying branch and bound technique. The proposed method was tested to find unit commitment solution for hydro and thermal systems. The proposed method had constituted a basis for the development of unit commitment programs using integer programming for practical use in electric utilities and proven to be computationally practical for realistic system.

Li et al. [245] applied mixed integer programming approach for price-based unit commitment problem. The proposed approach was tested for solution of price-based unit commitment problem for a power generating company having cascaded-hydro, thermal, pump storage and combined-cycle units. The results was compared with Lagrangian relaxation method and it has been found that the major obstacles of using mixed integer programming approach are more computation time and memory requirement to solve large UC problems. Venkatesh et al. [275] have formulated fuzzy linear optimization model for unit commitment using a mixed integer linear programming routine and demonstrated the advantages of using fuzzy optimization model for unit commitment problem. The proposed model was tested on 5 and 104-generating unit system for 24-hours load demand and it had been elaborated that using linear programming proposed model had gained speed and robustness. Guan et. al [201] have observed that Lagrangian relaxation is one of the most successful approaches. Poommalee et al. [285] obtained the unit commitment considering security-constrained optimal power flow by using Lagrangian relaxation along with genetic algorithm.

Bavafa et al. [314] have proposed a hybrid Lagrangian relaxation with evolutionary programming and quadratic programming for ramp rate constrained unit commitment problem. Merlin et al. [31] proposed Lagrangian relaxation method for solution of unit commitment problem. Numerous developments such as simultaneous management of pumping units, probabilistic determination of the spinning reserve were envisaged, to make the algorithm more flexible. The practical demonstration reveals that the proposed decomposition method was flexible and Lagrange multiplier provides a new solution to the conventional problem. Zhuang, et al. [51] demonstrated Lagrangian relaxation method for large scale unit commitment problem and tested a 100-generating unit model over time horizon of 168 hours for scheduling the units and experimentally found that the proposed method gives low execution time and reliable performance. Virmani et al. [61] demonstrated the practical aspects of the Lagrangian relaxation methodology for solving the thermal unit commitment problem.

Baldick [106] has demonstrated the generalized formulation and solution of unit commitment problem using Lagrangian relaxation method. The proposed technique was tested for ten units system for a time period of 24 hours. In proposed methodology, algorithm approximately solves the dual optimization problem. Practical demonstration of algorithm reveals that the performance of algorithm was slower in solving the special cases of the generalized unit commitment problem as compared with others methodologies. Lagrangian decomposition method with reference to a simple model system. Peterson et al. [107] proposed a Lagrange relaxation to solve unit commitment problem by incorporating unit minimum capacity and unit ramp rate constraints. The proposed methodology was used to find the feasible unit commitment schedule considering a new approach for ramping constraints. In proposed algorithm, the special practical features are incorporated such as boiler fire-up characteristics and non-linear ramp up sequences. Bakirtzis et al. [170] have applied Lagrangian relaxation method to demonstrate the difference between the unit commitment problem based on economic interpretation of the Lagrangian relaxation solution framework and the lambda values of the economic dispatch. In proposed LR methodology, two sets of lambdas are used, which represent marginal cost of electricity. The first lambda is assigned as a Lagrange multiplier to the unit commitment power balance equations and second lambda is assigned as Lagrange multiplier of the power balance equation in the economic dispatch problem.

Ongsakul et al. [217] demonstrated an enhanced *adaptive Lagrangian relaxation* (ALR), which consists of heuristic search and adaptive Lagrangian relaxation. The proposed adaptive Lagrangian relaxation was enhanced by introducing new 0-1 decisions and the heuristic search was used to fine tune the commitment schedule. Experimental demonstration of ALR for large scale power system reveals that production cost and computational time is much less compared with others approaches and methodology approaches to a feasible solution. Murtaza et al. [237] applied Lagrange relaxation method for unit commitment scheduling problem by consideration of transmission losses.

A two stage Lagrange relaxation was provided for better convergence and faster calculation. Ruic *et al*. [73] have presented an original approach of Lagrangian relaxation for solving extended unit commitment problem of electric power system.

Walsh *et al.* [138] have elaborated augmented neural network architecture with interconnection between neurons giving a more general energy function containing both discrete and continuous terms. The proposed method was applied to unit commitment problem consisting of thermal, hydro and pumped storage units and results are compared with Lagrangian relaxation approach. Takriti *et al.* [172] have applied branch-and-bound approach, which is an integer program with nonlinear constraints for refining the unit commitment solution obtained by Lagrangian relaxation approach. The obtained numerical results have indicated a significant improvement in the quality of the solution obtained.

Hosseini et al. [271] has applied a novel fast straightforward method (SF) to solve unit commitment problem. The proposed approach has decomposes the unit commitment problem into three sub-problems. In first part, the quadratic cost functions of generating units was linearized and hourly operating cost of unit commitment was obtained considering all constraints except minimum up time and minimum down time constraints and then the MUT/MDT constraints are introduced by modifying the schedule obtained in the first step through a proposed novel optimization processing. Finally, the extra spinning reserve is reduced by using a newly developed de-commitment procedure. Chandram et al. [289] has applied Secant method for the solution of unit commitment problem and improved pre-prepared power demand (IPPD) table using concept of low minimum incremental cost. In proposed Secant method, the unit commitment problem was divided into two sub-problems, the unit ON/OFF scheduling and economic dispatch sub problem. In proposed method, firstly, ON/OFF status information of IPPD table is obtained and then the optimal solution is achieved by Secant method. Mokhtari et al. [53] has formulated an expert system based on consultant, which combines the knowledge of the unit commitment programmer and an experienced operator. The proposed expert system had leaded an inexperienced operator to a better unit commitment schedule. In proposed expert system, 56 rules were used for the experiments and it was estimated that

300 rules would be required to satisfy all operational requirements of unit commitment problem.

Tong et al. [78] developed a new expert system approach to handle short term unit, in which priority list based heuristic was applied to form initial unit commitment schedules for given forecasted load. Li et al. [95] has applied a graphics package and a new heuristic method for the solution of unit commitment problem. The simulation results are elaborated by considering unit status in three different categories of base, medium and peak and it has been found that the computational time was less than two seconds. Also, it has been concluded that the principles of proposed method can be expanded to consider more complicated cases with additional constraints. Mukhtari *et al.* [48] have elaborated expert system to help power system operators for scheduling the operation of power generating units. Numerical examples and simulation results of proposed method has demonstrated that proposed can obtain a better and operationally more acceptable unit commitment solution.

Viana et al. [180] proposed a resolution approach based on Simulated Annealing. Rajan [218] have presented a new approach to solve the short term unit commitment problem using an Evolutionary programming based simulated annealing method with cooling and banking constraints. Simopoulos and Contaxis [225] have proposed some rules concerning the cooling schedule and the random generation of the initial solution of the system. Zhuang, et al. [68] developed simulated annealing method to solve unit commitment and generation scheduling problem. In proposed method, feasible solutions are generated randomly and simulated annealing was used to apply moves among these solutions using a strategy leading to a global minimum with high probabilities. The method assumed no specific problem structures and was highly flexible in handling unit commitment operational constraints. The method was tested for numerical results up to 100-generating units test systems. Wong [152] applied an enhanced simulated annealing algorithm for the solution of unit commitment problem by adopting mechanisms to ensure that the candidate solutions produced are feasible and satisfy all the constraints. Simopoulos et al. [264] had combined dynamic economic dispatch method with enhanced simulated annealing approach. In proposed solution methodology, simulated annealing was used for generation scheduling and dynamic economic dispatch method was used to incorporate the ramp rate constraints in the unit commitment problem. For tuning of the control parameters of the simulated annealing algorithm, revised rules were developed. Saber et al. [255] presented fuzzy UCP using the absolutely stochastic simulated annealing method.

Mantawy *et al.* [151] applied modified rules for randomly generated feasible solutions in simulated annealing algorithm for the solution of unit commitment problem. In proposed approach, the unit commitment problem was divided into two sub-problems: a combinatorial optimization problem and a nonlinear programming problem. The former was solved using the simulated annealing algorithm while the later was solved using a quadratic programming algorithm. Numerical results have demonstrated an improvement in the operation costs compared to others methodologies.

1.4.2 Non-Conventional Methods for Unit Commitment

Saneifard et al. [136] formulated the fuzzy logic to the UCP. They demonstrated that if the process of unit commitment could be described linguistically then such linguistic descriptions could be translated to a solution using fuzzy logic that yields similar results compared to dynamic programming. Kadam et al. [312] has applied fuzzy logic algorithm for the solution of short-term commitment problem of electric power system. The performance of the proposed algorithm was compared with priority list method and it has been found that proposed algorithm is much powerful for solving multi constrained and non-linear optimization problems of electric power system. Wang et al. [363] has applied fuzzy logic approach, in which fuzzy value at risk is employed as a technique to evaluate the power demand and reserve for each period and fuzzy variable are introduced to more accurately describe the future power load. Pandian et al. [226] presented a fuzzy logic approach that is very useful to consider the uncertainty in the forecasted load curve, derating and line losses. For validation of the approach in respect of total production cost and computational time, case studies on 10, 26 and 34 units have been performed and the obtained simulation results were compared with dynamic programming and Lagrangian relaxation.

Maojun and Tiaosheng [179] proposed a complementary genetic algorithm for unit commitment and constructed three kinds of genetic operators. In order to obtain a near optimal solution in less computational time with all specified unit commitment constraints. Jalilzadeh and Pirhayati [313] have presented an improved genetic algorithm for unit commitment problem with lowest cost. Ademovic et al. [344] have documented a genetic algorithm using real-coded chromosomes instead of using binary coded chromosomes scheme. Dasgupta et al. [94] applied genetic algorithm to determine the priority order of thermal generating units. In proposed methodology, genetic algorithm was used to evaluate the priority of the generating units dynamically considering the system characteristics and operational constraints along with load profile at each time period in the scheduling horizon. In proposed research, feasibility of genetic algorithms was examined and simulation results of thermal generating units were reported in near optimal scheduling conditions.

Ma et al. [110] applied a forced mutation operator instead of classical mutation operation to improve the efficiency of genetic algorithm. In proposed methodology, two different algorithms were developed and tested on a 10-generating unit model and it has been experimentally found that the two-point crossover operation is more efficient than the single-point crossover operation, which was commonly used in classical GA’s. Also, the effects of GA’s control variables on convergence were extensively studied and experimental results reveal the robustness of the algorithm. To improve the search mechanism of genetic algorithm. Orero et al. [118] has developed an enhanced genetic algorithm, in which sequential decomposition logic is used for faster search operation. The proposed method was tested on a 26-generating unit system and ramp rate was considered along with system operational constraints.

Kazarlis et al. [120] applied varying quality function technique and added problem specific operators in genetic algorithm. The algorithm was implemented in a binary form. By applying varying quality function, the genetic algorithm was able to locate the exact global solution. For fitness scaling, a nonlinear transformation was used. Swap-mutation and swap-window hill-climb was used to develop modified operators of genetic algorithm. The proposed algorithm was tested for 100-units test system. Senjyu et al. [192] have developed a genetic algorithm for unit commitment problem, which uses genetic operator based on unit characteristic classification and intelligent technique for generating initial populations. The initial population in proposed algorithm was generated depending on load curve. To handle minimum up/down time constraints, modified mutation operators were introduced. Also, modified crossover operator, shift operator, and intelligent mutation operators were proposed in the algorithm. MUT/MDT constraints are taken into consideration to categorize generating units several groups. Violated constraints in the proposed technique were prevail over by adding a penalty term to the total generation cost. Gil et al. [208] developed a genetic algorithm using specialized operators for hydrothermal systems. The proposed method has demonstrated excellent performance in dealing with hydro-thermal scheduling problem and for obtaining near-optimal solutions in reasonable computational time.

Dang et al. [256] proposed a floating-point genetic algorithm (FPGA), which uses a floating-point chromosome representation based on the forecasted load curve. Encoding and decoding schemes were used to handle minimum up-time and minimum down-time constraints. The fitness function, selection, crossover and mutation probabilities along with constraints has been characterized and formulated in detail and it has been concluded that the proposed floating-point genetic algorithm is also applicable for non-convex cost function. Sun et al. [250] introduced a matrix real-coded genetic algorithm (MRCGA), which uses a real number matrix representation of chromosome to solve unit commitment problem through genetic operations. In proposed MRCGA method, search performance is improved through a window mutation. The proposed mechanism of chromosome repair guarantees that the unit commitment schedule satisfies unit and system constraints.

Dasgupta *et al.* [104] have applied genetic algorithm to determine ON/OFF states of power generating units to meet the load demand and spinning reserve constraints requirement at each time period, such that the overall cost of generation has been minimized. Maifeld *et al.* [121] have presented a genetic algorithm with domain specific mutation operators for unit commitment scheduling problem. Experimental results showed that the proposed algorithm finds good unit commitment schedules in a reasonable computation time. Richter *et al.* [174] have applied genetic algorithm to a price/profit-based unit commitment problem, which considers the softer demand constraint and allocates fixed and transitional costs to the scheduled hours. Swarup *et al.*

[193] have developed a genetic algorithm for the solution of unit commitment problem and presented the solution for a 10-generatorscheduling problem.

Senjyu et al. [209] presented a solution to the thermal UCP using Genetic Algorithm (GA). They have classified the units according to minimum up or minimum down time constraints. The small units are scheduled for operation by numerical calculation depending on cost characteristics and GA is used for commitment of other units. The simulation results show the proposed method is satisfactory for committing the units in reasonable time. Damousis et al. [224] developed a genetic algorithm based solution for unit commitment problem. The integer coding used in new GA differentiates it from previous binary GA and the test performed on 100- unit system showed better results compared to the LR method. The new GA reduces the execution time and showed more robustness. Ouiddir et al. [241] used the genetic algorithm to find the solution of an economic dispatch problem in the Western part of the Algerian power network. The results indicated that the proposed method is very effective for the determination of optimum control for power generation with minimum fuel cost and reduced transmission losses, along with the advantage of short span of time taken for giving accurate results. Mantawy et al. [148] developed Tabu search method for the solution of single area unit commitment problem. In proposed technique, initial solution was generated randomly and quadratic programming was used to solve dispatch the committed generating units.

Ouyang et al. [89] and Daneshi et al. [202] presented that artificial neural networks and dynamic programming method, which can avoid unnecessary calculations for similar load demand profiles while the eminence of the optimization is not deteriorated. Chung et al. [149] combined genetic algorithms with artificial neural network for better training of ANN. Sasaki et al. [86, 87] applied Hopfield neural network (HFNN) for unit commitment problem to handle large inequality constraints. The proposed neural network model has been tested for 30-generating units and it has been found that the obtained results were very encouraging. Yalcinoz *et al.* [158] demonstrated an improved Hopfield neural networks method to solve unit commitment problem and considered transmission losses and transmission capacity along with minimum up time and minimum downtime constraints for calculation of start-up and shutdown costs. The proposed HFNN model was applied for testing of 3-unit and 10-generating units systems. Liang *et al.* [173] has applied extended mean field annealing neural network approach for the solution of short-term thermal unit commitment problem of Taiwan power system.

Yare et al. [324] proposed the differential evolution (DE) approach for generator maintenance scheduling (GMS) and economic dispatch of the Indonesian power system to optimize the cost of operation of 19-units. The simulation results indicated the fitness of the application of the proposed technique and also offered an effective option for solving such problems in power system as GMS and ED. Chakraborty et al. [328] presented a fuzzy modified differential evolution approach for solving thermal UC problem integrated with wind power system. The proposed methodology is applied to make a comparison of the performances in two different power systems and the results prove the effectiveness of the methodology accurately. Sharma *et al*. [375] developed a new method to solve the economic dispatch problem known as Self-Realized Differential Evolution. The projected approach, after getting tested for 10-unit and 40-unit system, outperformed the solutions given by the existing algorithms showing robustness, fast convergence and improved efficiency. Hardiansyah et al. [389] investigated the features of three different optimization techniques i.e. artificial bee colony (ABC) algorithm, particle swarm optimization (PSO) and differential evolution algorithm and by doing a comparative study on 3-units and 6-units systems. The results of simulation showed that the DE algorithm converges faster than ABC and PSO. Ravi and Rajan [400] used differential evolution (DE) optimization algorithm to solve optimal power flow (OPF) problem. Standard IEEE-30 bus system had been considered to perform the testing and study and the results shows that DE algorithm gives the best solution for an OPF problem.

Lee and Geem [242] developed a new harmonic search (HS) optimization algorithm which is a global search method and an improvement of the HS optimization technique for various kinds of engineering problems related to optimization. The HS algorithm yielded improved solutions than current algorithms and the study here proved to give more efficient results to accomplish that the HS algorithm carried the potential of a better optimization technique. Coelho and Mariani [317] improvised the already established harmony search algorithm using exponential distribution to solve economic dispatch problems into improved harmony search (IHS) optimization algorithm. The tests have been performed on a 13-unit system and the numerical results prove the effectiveness of IHS method because of its good convergence and lower generation costs than those resulted in classical HS. Coelho et al. [349] proposed a customized HS algorithm united with differential evolution (DE) and chaotic sequences which had been named as CHSDE algorithm for solving the ELD problem. A test system consisting of 10-generating units had been considered to test the solution quality of the proposed method and from the simulation results, it had been shown that the CHSDE algorithm is more efficient for solving an economic dispatch problem in power generating systems.

Shukla and Anand [365] applied harmony search (HS) technique for the multi-objective optimization of a styrene reactor. The objective functions to be minimized in order to get variables for a styrene reactor are selectivity, productivity and yield. The results turn out to be the proof that HS algorithm gives better optimization solutions under considered operating conditions than other techniques. Arul et al. [366] attempted to apply harmony search algorithm to solve ELD problem with transmission losses under the changing patterns of consumer load. The HS algorithm is tested on the standard IEEE-6 bus system, IEEE-14 bus system and IEEE-30 bus system and the test results revealed that HS algorithm better than the improved fast evolutionary program (IFEP) and PSO for finding solutions to ELD problems along with the benefit of reduced transmission losses and relatively lower computation time. Tuo and Yong [383] presented an enhanced harmony search with chaos (HSCH). The test results show that the HSCH algorithm is a convincing algorithm and it is much better than the classical HS technique and *HS algorithm with differential evolution* (HSDE). Also, on average the explorative power of HSCH is greater than the explorative power of HS and HSDE, which means improved accuracy.

Xue-hui et al. [292] adapted a meta-heuristic algorithm, the shuffled frog-leaping algorithm (SFLA), and applied to solve travelling salesman problem (TSP). The results of the experiment revealed that SFLA is capable to find the most favorable for small scale problem or near optimal result with more cities. Reddy et al. [370] improvised the SFLA into a *modified shuffled frog-leaping algorithm* (MSFLA) for solving the *economic-emission load dispatch* (EELD) problem. The test has been carried on a standard IEEE-30 bus system and the test results verify that the proposed algorithm is more reliable and robust to attain a better quality solution for such problems of power system networks. It is comparable to other techniques and happens to give better solutions with enhanced quality. Pourmahmood et al. [371] proposed a *modified shuffled frog- leaping* (MSFL) algorithm. The modifications resulted in a faster convergence, a speedy adaptive algorithm and avoidance of local optima in comparison to the original SFLA technique. Jebaraj et al. [387] applied SFLA to optimize the location and the size of the two FACTS devices i.e. TCSC and SVC, which has been incorporated to enhance the voltage stability margin and to minimize the losses. The test had been carried out on a standard IEEE-30 bus system under certain considered conditions. Anita et al. [385] presented the application of SFLA optimization algorithm to find the solution of UCP of thermal units. The proposed algorithm was applied to a 10- unit system over a scheduling period of one day and the results of the proposed algorithm has also been compared with the LR method and ICGA method, which showed that the production cost in case of SFLA in less than that in the other two methods.

Fang et al. [369] presented a snake algorithm which is demonstrated to overcome the drawbacks of traditional snake/ contour algorithms for contour tracking of multiple objects more effectively and efficiently. The experimental results of the tests carried out have proved that the proposed method is robust, effective and accurate in terms of finding the boundary solutions of multiple objects. Simon [296] considered biogeography and its mathematics as the base of the new optimization technique named as, *biogeography-based optimization* (BBO) and discussed the development of BBO. The test have been carried out by taking 14 benchmark functions, applying BBO and comparing the results with those of GA, PSO, DE, ES, *stud genetic algorithm* (SGA), PBIL and ACO. BBO had been found to have some features that are exceptional amongst the other methods. Du [325] demonstrated the modifications of BBO in certain different ways to exploit the performance of the new technique. The BBO technique is modified using evolutionary strategy (ES) techniques. Secondly, the modified BBO technique had been applied to the travelling salesman problem and the results are compared to those obtained by applying GA to the same problem which proved that BBO is better in operation than GA. Lastly, BBO had been modified to function in noisy environment by addition of Kalman filter.

This modification resulted into a much better BBO technique to operate in a noisy environment.

Kundra et al. [367] proposed a new optimization method combining the features of BBO and PSO to improve the reliability. The proposed technique, PBBO, had been applied to underground water penetration and it's been proved to be a better method for such problems and yields better results than PSO. Khokhar et al. [388] used BBO algorithm to solve the ED problem of optimal scheduling taking certain cases over 24-hour time. The test results has been compared with those of the Lagrange multiplier method and the PSO method and it has been proved that BBO provides reasonably better solutions along with the improvements like enhancing the global search potential and avoidance of premature convergence. Scheidegger et al. [368] extended the standard BBO technique to a new algorithm which had been named as distributed BBO (DBBO). Both the traditional and modified BBO methods are considered and applied to test for 14 benchmark functions. Also, optimization of robot control systems is done using BBO and DBBO. The centralized BBO had been proved to be better than DBBO.

Du et al. [326] incorporated features of ES for modifying BBO and a refusal approach is also included in BBO. The results obtained by applying BBO had been compared with other heuristic optimization techniques. The modified BBO had been tested for 14 benchmarks and had been proved to be better than the original BBO. After these tests, some standard test has been implemented to check the performance of modified BBO. Rarick et al. [327] applied BBO algorithm and GA to the same power flow problem taking the IEEE 30-bus system as the test system to make a comparison between the two heuristic techniques. The results showed that BBO constantly proved to be better than GA for finding out optimal solution for such kind of problems. Simon et al. [364] showed that BBO is generalized form of GA with *global uniform recombination* (GUR) often known as GA/GUR. BBO had been compared with GA/GUR taking certain benchmark problems/ cases and analyzing the results obtained from the Markov models of the two techniques. It has been shown that BBO has some distinctive features that makes it better for solving optimization problems and generate better solutions. BBO and GA/GUR had also been for combinatorial problems like TSP, graph colouring etc.

1.4.3 Hybrid Optimization Methods

Babu et al. [348] described a hybrid genetic algorithm in which, they have used for constructing a departmental class timetable. The results of their study confirmed that the proposed algorithm has the ability to produce much better solutions for such a problem reducing the time also. They also concluded that data organization is an important aspect in the operation of hybrid genetic algorithm. Kushwaha et al. [382] proposed a genetic algorithm based bacterial foraging algorithm for optimization of a function. The proposed method gives an emphasis on mutation, crossover, step sizes and the lifetime of bacteria. Bilolikar et al. [393] presented a hybridized approach using simulated annealing and genetic algorithm to solve multi mode resource constrained project scheduling problem. The results of the tests showed the competitive performance of this algorithm compared to other heuristic based techniques. Mafteiu et al. [392] developed a memetic algorithm (MA) for the solution of linear system of equations by converting into an optimization problem. The proposed MA determines the solutions of any given linear system of equations better than any other similar technique. Mafteiu-Scai [401] proposed a technique using memetic algorithm for the improvement of convergence of iterative methods to solve linear or nonlinear systems of equations. This hybridized method uses memetic algorithm as the basis of finding the solution and its take lesser time to find a value as a single iteration showed the accurate results.

Sanusi et al. [362] investigated the performance of GA and memetic algorithm for a constrained optimization. The simulation results indicated that memetic algorithm converges quicker than GA and produces more optimal results but the time taken by iteration in GA is less than that in memetic algorithm. Sriyanyong and Song [240] combined particle swarm optimization algorithm with Lagrangian relaxation method for optimal settings of Lagrange multipliers for the solution of unit commitment problem. The performance of proposed hybrid method was tested for 4 and 10 generating unit system. Xiong et al. [287] have applied multi particle swarm to parallel arithmetic to produce particle to enhance the convergence speed and found the more efficient results than genetic algorithm. Jeong et al. [335] have discussed binary particle swarm optimization-based approach for solving the UC problems. Ge [343] has proposed a new approach to solve ramp rate constrained unit commitment problem by improving the method of particle swarm optimization.

Borghetti et al. [181] have demonstrated Tabu search method and suggested that it is not promising that Tabu search method will yield global optimal solution for large scale power system. Rajan et al. [188] proposed Neural based Tabu search algorithm for the unit commitment problem and developed an improved version of Neural based Tabu search approach. Gaing [203] developed binary particle swarm optimization (BPSO) to solve combinatorial unit commitment problem of electric power system. In proposed algorithm, the ON/OFF schedule of generating units was obtained by BPSO and lambda iteration method was used to solve economic dispatch sub-problem for obtaining the total production cost. Yuan et al. [323] has developed an improved version of binary particle swarm optimization algorithm known as improved binary PSO (IBPSO). In proposed approach, the standard particle swarm optimization algorithm was improved by using the priority list. The heuristic search procedure was applied to improve the minimum up time and minimum down time constraints. To validate the proposed algorithm, generating unit model of 10-100 unit were taken into consideration and it was found that proposed approach was superior in terms of low total production cost and short computational time compared with others methods.

Zhao et al. [257] has applied an improved particle swarm optimization algorithm (IPSO) to solve single area unit commitment problem. In proposed IPSO model, LR technique are combined to 0-1 variable to improve the performance of standard PSO algorithm. Lee et al. [268] presented a new approach for UCP named the iteration particle swarm optimization. The proposed method has improved the eminence of solution in terms of total production cost and computation efficiency. A standard 48 unit system has been tested for validation. Samudi *et al.* [288] have presented the solution of short term hydro thermal scheduling problems using particle swarm optimization algorithm and it has been elaborated that the proposed PSO algorithm was appropriate for hydro economic dispatch problems, hydro-thermal co-ordination problems, thermal economic dispatch problems, and scheduling of hydraulically coupled plants along with unit commitment problem.

Chen et al. [189] have presented a conjunctive co evolutionary algorithm for unit commitment. Rajan et al [216] have applied Evolutionary programming method in conjunction with the Tabu search method for solving economic dispatch problem for units with “non smooth” fuel cost functions. Rajan *et al.* [249] has also presented Evolutionary programming based Tabu search method for the solution of short-term unit commitment problem with due consideration of cooling and banking constraints. Sum-im et al. [205] developed ant colony search algorithm (ACSA) for the solution of unit commitment problem. The performance of the proposed algorithm was tested for 10-generating unit system and results are compared with genetic algorithm, Evolutionary programming, Lagrangian relaxation and combined Lagrangian relaxation and genetic algorithm. Saber et al. [291] developed memory-bounded ant colony Optimization (MACO) for the solution of large scale unit commitment problem. To enhance local search a heuristic procedure was adopted. Sisworahardjo et al. [191] presented the ant colony search algorithm (ACSA)-based technique for solving the unit commitment problem and demonstrated its efficiency in solving the UCP using a 10-generating unit system. The results had been compared with the results obtained using traditional methods like dynamic programming and Lagrangian relaxation and other meta heuristic techniques like genetic algorithm and memetic algorithm which indicated the feasibility of the presented technique to solve power system optimization problems.

Chusanapiputt et al. [293] proposed a new methodology called hybrid ant system/priority list method (HASP) to solve UCP with operating constraints. The proposed technique has speedy access for committing generating units directly as is done in a priority list method, provides more intelligent approach and has more flexibility to change itself iteratively to achieve improved UC solution. Proposed technique was tested for 100 unit test system and it has been found that proposed algorithm was able to achieve better economical saving in total operating cost as compared to others reported methods. Also, computational time can be greatly saved with respect to others reported methods.

Yu *et al.* [350] projected a hybrid algorithm composed of ant colony optimization algorithm and Lambda-iteration method for solving UCP. Operation encoding had been done to reduce the space complexity of ACO algorithm. The simulation results show

HACO is more efficient and effective for UCP in the range of 10 to 60 generating units, and the production costs are less pricey as calculated by HACO. Chitra *et al.* [403] focused on power quality improvement in autonomous micro grid considering voltage frequency regulation and harmonic analysis as the main parameters. They have developed a special design of a power controller based on real- time optimization and have used the ant colony optimization for self tuning of control parameters. The results prove that the proposed power controller shows a great response to improve the power quality of an autonomous micro grid.

In 2003, Viana et al. [204] presented greedy randomized adaptive search procedure, which was an adaptive algorithmic framework based on another meta-heuristic principle. Ouyang *et al.* [85, 100] proposed a multi-stage neural network-expert system approach. Through inference the feasible UC schedule is obtained. A load pattern matching scheme is performed at the pre-processor stage. The trained network performs adjustments in the schedule to achieve the optimal solution at the post processor stages. Ouyang *et al.* [84] have discussed a hybrid dynamic programming-artificial network algorithm (DP-ANN). The experimental results indicate that the proposed algorithm can significantly reduce the execution time of the traditional dynamic programming approach without degrading the quality of the generation schedule. Kothari *et al.* [111] applied a hybrid expert system dynamic programming approach for the solution of single area unit commitment problem. Shyh-Jier et al. [135] elaborated genetic algorithm based neural network and dynamic programming approach for solution of single area unit commitment problem.

Wong *et al.* [168] has hybridized genetic algorithm with ANN to intelligently decide the initial weights and the connections in the ANN and to prevent stagnation during training. Three selection methods Roulette wheel, tournament and ranking were used as well as two options for weight and connections were combined for running the GA. It have been observed that Roulette wheel has the best performance. Nayak *et al.* [171] proposed a hybrid of feed forward neural network and the simulated annealing. The ANN is used to solve the unit scheduling sub problem and the SA is used to solve the ED sub problem. A set of inputs based on the forecasted load curve and corresponding UC schedules as outputs satisfying the system and unit constraints are used to train the network. A reduction in computational time is achieved by this approach. Cheng et al. [175] presented an application of genetic algorithms and Lagrangian relaxation method. The proposed approach incorporates GA into LR method to improve the performance of LR and to update the Lagrangian multipliers. The method is easy to implement, better in convergence. Cheng *et al.* [178] proposed the application of the annealing–genetic (AG) algorithm. The AG algorithm was a hybrid of GA into the SA to improve the performance of the SA approach. The method improves the computational time of the Simulated Annealing and the quality of solution of genetic algorithm and gives near optimal solution of a large scale system. Valenzuela *et al.* [190] presented a memetic algorithm, which was a hybrid of genetic algorithm and Lagrangian relaxation. The proposed hybrid algorithm was efficient and effective for solving large scale unit commitment problems. The comparison results with other techniques showed that memetic algorithm combined with Lagrangian relaxation came out to be a superior method of optimization for solving large problems much better and consuming less computational time along with reduced fuel costs.

Ting *et al.* [253] proposed a hybrid particle swarm optimization (HPSO). Problem formulation, representation and the numerical results for a 10-unit system was presented. Results shown are acceptable at this early stage. Srinivasan *et al.* [227] proposed an efficient algorithm for aiding unit commitment decisions. To solve the UCP an evolutionary algorithm with problem specific heuristic and genetic operators has been employed. Shi *et al.* [213] developed and demonstrated a novel ant colony optimization algorithm with random perturbation behavior. The approach is based on the combination of colony optimization and stochastic mechanism is developed for the solution of optimal UC with probabilistic spinning reserve. Balci et al. [214] presented a hybrid of PSO and LR. UCP is divided into sub problems and each sub problem is solved using DP. PSO is used to update the Lagrangian multipliers. The comparison of results shows that the proposed approach uses less computational time and gives good quality solutions.

Victoire [244] introduced an application of hybrid-PSO and sequential-quadratic programming technique (SQP) guiding the Tabu search. The unit scheduling problem is solved using an improved random-perturbation scheme. A simple procedure for generating initial feasible UC schedules is proposed for the TS method. The nonlinear ED subproblem is solved using the hybrid PSO-SQP technique. Chusanapiputt et al. [236] presented parallel relative particle swarm optimization (PRPSO) and LR for a large-scale system. To reduce the dimensionality problem and to improve the UC schedules the neighborhood solutions are divided into sub-neighborhoods.

Aruldoss *et al.* [239] applied Hybrid combination of simulated annealing, particle swarm optimization and sequential quadratic programming technique (hybrid SA-PSO-SQP) along with fuzzy logic to solve singe area unit commitment problem. Dieu *et al.* [258] proposed augmented Lagrange Hopfield network (ALHN) and enhanced merit order (EMO) for the solution of hydrothermal scheduling problem with pumped-storage units. Saber, et al. [367] presented a twofold simulated annealing (twofold-SA) method. A hybrid of SA and fuzzy logic is used to obtain SA probabilities from fuzzy membership function. The initial feasible UC schedules are generated by a priority list method and are modified by de-composed SA using a bit flipping operator. Results indicate a low total production cost and low execution time compared with other approaches.

Nasser et al. [269] presented hybrid particle swarm optimization based simulated annealing (PSO-B-SA) approach. The unit scheduling sub problem is solved by using binary PSO and ED sub problem is solved by using real valued PSO. Numerical results demonstrated show that the PSO-B-SA approach can perform well compared with the other solutions. Saber et al. [270] proposed a fuzzy adaptive particle swarm optimization (FAPSO) for UCP. FAPSO precisely tracks a changing schedule. Based on the diversity of fitness the fuzzy adaptive criterion is used for the PSO inertia weight. Using fuzzy IF/THEN rules the weights are dynamically adjusted. Kumara et al. [266] developed DP based direct Hopfield computation method. The proposed approach solves the UCP in two steps. The generator scheduling problem is solved using DP and generation scheduling problem is solved using Hopfield neural network. Hung *et al.* [153] have applied proposed a constraint logic programming (CLP) algorithm for the solution of thermal unit commitment problem of electric power system. The performance of proposed CLP algorithm was compared with dynamic programming, simulated annealing and Lagrangian relaxation method. Mantawy *et al.* [161] applied integrating genetic algorithms, tabu search and simulated annealing algorithm for the solution of unit commitment problem and performance of purposed integrated method was compared with standard genetic algorithm, simulated annealing and tabu search methods.

1.4.4 Multi Area Optimization

Chitra [251] demonstrated economic load dispatch and multi-area unit commitment (MAUC) for market pool operation. Venkatesan and Rajan [399] presented ant colony search algorithm for the solution of multi area unit commitment problem and practically found that ant colony search algorithm have the potential to solve multi area unit commitment problem with smaller computation time. Selvi *et al.* [319] applied particle swarm optimization algorithm to solve multi-area unit commitment problem of electric power system. In proposed methodology, dynamic programming method was used to solve multi area unit commitment requirement and particle swarm optimization was applied to compute the generation assigned to each area and the power allocation to all committed units**.** To demonstrate the performance of proposed algorithm, four area test system consisting of 26 units, which was connected through tie lines was taken into consideration and it has been found that the performance of proposed algorithm was promising and proposed method was much efficient than conventional dynamic programming and evolutionary programming Method with respect to operating cost and computation time. Also, Selvi et al. [384] implemented an algorithm to solve the multi-area unit commitment problem using evolutionary iteration particle swarm optimization algorithm. The performance of the proposed algorithm was demonstrated on IEEE test systems consisting of four areas and it has been found that proposed methodology was efficient as compared to other algorithms.

Selvi *et al.* [320] presented multi-area unit commitment with bilateral contract approach in deregulated electricity market. The performance of the proposed algorithm was tested for IEEE test system consisting of four areas and it has been experimentally found that proposed method was reliable, fast and computationally efficient for multi area unit commitment problem. Venkatean *et al.* [386] implemented an improved version of bilateral contract approach to solve multi-area unit commitment problem in deregulated electricity market and experimentally tested for IEEE test system consisting of four areas having 26-generating units and connected through tie-line and it has been experimentally found that proposed method was reliable for the solution of multi area unit commitment problem in deregulated electricity market and require less computation time and have more computational efficiency.

1.5 SCOPE OF RESEARCH

A survey of existing literature on the problem reveals that various numerical optimization techniques have been employed to solve the complicated unit commitment problem. Although no optimization algorithm can perform general enough to solve all optimizations problems, each optimization algorithm has its own advantages and disadvantages. Particle swarm optimization has simple concept, easy implementation, and relative robustness to control parameters and has computational efficiency [16]. Although it has numerous advantages, it gets trapped in a local minimum, when handling heavily constrained problems due to the inadequate local/global searching capabilities [17, 18]. The limitations of the numerical techniques [19, 20, 21] and dynamic programming method [19, 23] are the size or dimensions of the problem, large computational time and complexity in programming. The mixed integer programming methods [24,25] for solving the economic load dispatch problem fail when the participation of number of units increases, because they require a large memory and suffer from great computational delay. Gradient descent method [26] is distracted for Non-differentiable search spaces.

The Lagrangian relaxation approach [22] fails to obtain solution feasibility and solution quality of problems and becomes complex if the number of units are more. The branch and bound method [35] employs a linear function to represent fuel cost and start-up cost and obtains a lower and upper bounds. The difficulty of this method is the exponential growth in the execution time for systems of a large practical size. An expert system algorithm [48] rectifies the complexity in calculations and saving in computation time. But it faces the problem if the new schedule is differing from schedule in database. The fuzzy theory method [136] using fuzzy set solves the forecasted load schedules error but it suffers from complexity. The Hopfield neural network technique [23] considers more constraints but it may suffer from numerical convergence due to its training process.

The simulated annealing [28] and Tabu search [34] are general-purpose and powerful stochastic optimization technique, which has ability to converge asymptotically to a global optimum solution. But, requires much time to achieve near-global minimum solution. Gravitational search algorithm has the advantages to explore better optimized results, but masses get heavier and heavier over the course of time due to the cumulative effect of the fitness function on mass. This causes masses to remain in close proximity and neutralize the gravitational forces of each other in later iterations, preventing them from rapidly exploiting the optimum [25]. Therefore, increasing effect of the cost function on mass, masses get greater over the course of iteration and search process and convergence becomes slow. Differential evolution algorithm [31, 32] has the ability to find the true global minimum regardless of the initial parameter values and requires few control parameters. It has parallel processing nature and fast convergence as compared to conventional optimization algorithm. Although, it does not always give an exact global optimum due to premature convergence and may require tremendously high computation time because of a large number of fitness evaluations. To overcome the limitation of conventional DE, a hybrid combination of differential evolution and random search algorithm is presented in the proposed research. Harmony search has the ability to escape from local minima, does not require differential gradients and initial value setting for the variables and free from divergence and has strong ability on exploring the regions of solution space in a reasonable time. However, it has lower exploitation ability in later period and it easily gets trapped into local optima and converges very slowly. To improve the exploitation ability of harmony search algorithm in later stage and provide global optimal solution, a novel and hybrid version of harmony search combined with random search and differential evolution algorithm (i.e. Integrated DE-HS and hybrid HS-RS) is presented in the proposed research to solve single and multi area unit commitment problem of electric power system under single and multi-objective framework.

1.6 RESEARCH OBJECTIVES

The intent of the proposed research is to solve the unit-commitment optimization problem using memetic algorithm approach for solution methodology in the multi-objective framework with due consideration to operational and physical constraints and security of a realistic power system. The objectives of the research work undertaken are outlined as below:

- To solve *single objective unit commitment problem* by applying any suitable modern soft computing technique or by integrating more than one technique out of Differential Evolution, Harmony Search and Random exploratory search methods.
- To solve *multi-objective unit commitment problem* by applying any suitable modern soft computing technique or by integrating more than one technique out of Differential Evolution, Harmony Search and Random exploratory search methods.
- To solve *multi-objective and multi-area unit commitment problem* by applying any suitable modern soft computing technique or by integrating more than one technique out of Differential Evolution, Harmony Search and Random exploratory search methods. To achieve aforementioned research objectives, hybrid solutions methodologies like hybrid differential evolution - harmony search algorithm, hybrid harmony search - random search algorithm and hybrid differential evolution-random search algorithms are proposed and adopted to solve UCP

Above defined objectives have been achieved by implementing the systematic approach as detailed herewith. Study of the existing practices for unit commitment problem to meet the forecasted load requirement has been carried out. Scalar-objective unit commitment problem considering system and physical constraints is formulated. Attempt to formulate and solve scalar objective unit commitment problem to meet the forecasted demand has been made by applying integrated differential evolution and harmony search, hybrid and harmony search and random search and hybrid differential evolution and random search algorithms. Formulation and solution of multi-objective unit commitment problem to meet the required load demand has been obtained by using applying integrated differential evolution and harmony search, hybrid and harmony search and random search and hybrid differential evolution and random search algorithms. Multi-objective and multi-area unit commitment problem to meet the load power demand has been formulated and solved by applying integrated differential evolution and harmony search, hybrid and harmony search and random search and hybrid differential evolution and random search algorithms. Analysis and validation of the results obtained by integrated DE-HS, hybrid HS-random search and hybrid DE-random search algorithms.

1.7 OUTLINES OF THE THESIS

The present research study is dedicated to investigate the novel techniques to define, extend and establish optimal unit commitment strategies in single and multi-objective framework for single and multi area unit commitment problem while considering various system and physical constraints explicitly in the input-output characteristics of thermal power generation units. To solve the multi-objective and multi-area unit commitment problem conventional and non-conventional search techniques are explored. Random search algorithm is exploited to improve the exploration ability and global performance of conventional Harmony search and Differential evolution algorithms. The work undertaken in the present study has been arranged in this thesis in the following manner.

Chapter-1 deals with introductory aspects of economic load dispatch and unit commitment problem and their significance for modern electric power system. Also, this chapter contains the significant contribution of various researchers/authors in the field of economic load dispatch and unit commitment problem. As unit commitment deals with the economic operation of the generating units and leads to a minimized cost of generation, it has attracted many researchers over past few years. The researchers are trying to implement numerous techniques on various types of problems and are able to find the solutions successfully. The work is going on to find new algorithms and also the hybrid forms of the algorithms to rectify any drawbacks in the existing techniques. This chapter deals with the literature survey of various techniques successfully applied on various real world problems including the unit commitment problem. The chapter covers a general review of the related research papers starting from 1939 and a vast review of unit commitment problem from 1959-2015 along with advantages and disadvantages of various algorithms applied for different kinds of optimization problems.

Chapter-2 is dedicated to explain various methodologies to solve unit commitment problem. Since unit commitment is a large, non-linear, non-convex, and mixed integer problem, the attempt to receive the optimal schedule of committed generating units is challenging. Various methods have been developed to achieve the UC table and generations while minimizing the cost in a reasonable computational time. The aim of this chapter is to discuss in brief some existing optimization methods those are useful to solve unit commitment problem and to explore and explain in detail the proposed hybrid solution methodologies that further implemented to find the solution of single-objective and multi-objective unit commitment problem for single area and multi-area power systems. The algorithms viz. proposed integrated differential evolution and harmony search (DE-HS), hybrid harmony and random search (HS-RS) and hybrid differential evolution-random search (DE-RS) algorithms are presented in this chapter.

Chapter-3 represents the solution of single area, single-objective unit commitment optimization problem of electric power system. Commencement of the chapter simulates integrated DE-HS and hybrid harmony and random search algorithm to solve the unit commitment problem to obtain the optimal schedule for operating the generating units in the most economic manner to meet the load demand and at the same time accomplish the system and physical constraints' requirements. The integrated DE-HS and hybrid HS-random search algorithms are tested on 5-, 6-, 7-units and sample systems consisting of 10-, 20- and 40 -generating units. The effectiveness of proposed hybrid algorithms is authenticated by performing comparison with other well-known evolutionary, heuristics and meta-heuristics search algorithms. It has been found that performance of proposed hybrid HS-RS algorithm is much better than classical harmony search algorithm, improved harmony search algorithm and integrated DE-HS algorithm as well as recently developed algorithms. Sensitivity analysis on proposed hybrid HS-RS algorithm shows that low value of pitch adjustment rate results in better cost and parametric test on proposed algorithm shows the rejection of the null hypothesis at the alpha significance level. Subsequent section of this chapter explores the solution of single area, scalar objective unit commitment problem using a novel hybrid DE-Random Search algorithm. This algorithm is tested for 5-unit, 6-unit, 7-unit system and IEEE benchmark systems consisting of 10, 20 and 40 generating units. The effectiveness of proposed hybrid algorithm is compared with other well known evolutionary, heuristics and meta-heuristics search algorithms. By performing analysis, it has been observed that proposed algorithms yields global results for the solution of unit commitment optimization problem.

In Chapter-4, hybrid HS-Random search and hybrid DE-Random search algorithms are extended to exploit multi-objective unit commitment optimization problem. Operating cost and gaseous pollutant emission (CO_2) are undertaken into consideration to formulate the objective function for multi-objective unit commitment problem. Multi-objective unit commitment optimization problem is tested for 5-, 6- and 7-units system and it has been found that performance of hybrid DE-Random Search algorithm is better than conventional differential evolution, harmony search and hybrid harmony-search random search algorithm.

In chapter-5, multi-area unit commitment strategies are employed, whose objective is to establish optimal commitment and generation schedule for multi-area power system for momentous outfitted cost savings. Modern power system network has high proportions, large number of interconnections and high nonlinearities. Challenge of supplying the nation with high quality and reliable electrical energy at a reasonable cost has converted the government policy into deregulation and restructuring environment. To achieve significant cost savings, hybrid harmony-search random and hybrid differential-random search optimization techniques have been explored to solve multi-objective and multi-area unit commitment optimization and scheduling problem of electric utility system. The performance of the proposed hybrid algorithms is tested with two different benchmarks of multi area power system. The first benchmark has two area interconnected system, each area consist of 5-generating units. Another benchmark has three area interconnected system, in which each area consist of 6-generating units. Simulation results show that proposed algorithms have prospective to solve multi area unit commitment and scheduling problem in deregulated power market with import and export constraints.

The last chapter summarizes the significant conclusions of the research carried out for the preparation of the present thesis. Both the contribution and utilization of integrated differential evolution and harmony search, hybrid harmony search -random search and hybrid differential evolution -random search algorithms for single and multi-objective and multi-area unit commitment problem in power system operation studies are systematically presented and summarized. Suggestions for further possible research work are also speculated.