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Efficient Optimization Methods for Short Term Unit Commitment Scheduling with Influence of Major Constraints

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Abstract: In power system, the scheduling for hourly load variation is main task for power system engineers. The solution for Unit Commitment(UC) helps to select the unit and that should be start up and shut down over a planning time horizon. Generally, many conventional and non-conventional methods have been used to solve the UC problem with various useful constraints. This paper deals with different optimization techniques for Unit Commitment under dissimilar constraints for both stochastic and deterministic loads. This paper focus to give a basic idea about the various mathematical solution for UC problem with help of (30) number of research articles published in last 30 years and it is useful to new power system researchers in the field of Unit Commitment problem.

Keywords: Computing Methodologies, Unit Commitment (UC), Economic Dispatch, Priority List, LR, DP, Evolutionary computing methods and Artificial Intelligence techniques.

1. INTRODUCTION

Unit Commitment (UC) is the problem of determining the schedule of generating units within a power system subject to devices and operating constraints. The resultant schedule should minimize the system production cost during the period while simultaneously satisfying the load demand, spinning reserve, physical and operational constraints. UC is an important optimization task in the operation planning of modern power systems. The principle objective of the UC of power systems is to schedule the generation units in order to determining a startup and shutdown schedule of units to meet the forecast demand over a short-term period.

Numerous solutions have been proposed to solve the unit commitment problem, such as Priority List (PL), Dynamic Programming (DP), Lagrangian Relaxation (LR), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony search algorithm, Tabu Search, Bacterial Foraging Algorithm(BFA), Shuffled Frog Leaping Algorithm (SFLA) and various Evolutionary computing, Artificial Intelligence techniques.

The organization of the paper is organized as follows: Section 2 presents formulation of UC problem with various constraints, Section 3 presents the detailed Conventional approaches for UC problem solution, and Non-conventional approaches are given in Section 4 followed by a conclusion and references in Section 5 and 6.

2. MATHEMATICAL UC PROBLEM FORMULATION

The main objective of Unit Commitment problem is to allocate the thermal generating units in order to minimize the total operating cost of the system. It can be mathematically formulated by the following equation.

$$TC = \sum_{t=1}^{T} \sum_{i=1}^{N} F_i(P_{it})U_{it} + ST_{it}U_{it}(1 - U_{it-1}) \quad (1)$$

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$$F_i(P_{it}) = A_i + B_iP_{it} + C_iP_{it}^2 \tag{2}$$

$$ST_i = \sigma_i + \delta_i\left(1 - \exp\left(\frac{-T_i^{OFF}}{\tau_i}\right)\right) \tag{3}$$

The objective function is subjected to the following constraints.

2.1. Equality Constraints:

A. Power Balance Constraint

$$\sum_{i=1}^{N} P_{it}U_{it} = PD_t \quad (t = 1, 2, \ldots T) \tag{4}$$

2.2. Inequality Constraints:

A. Generation limit constraint

$$P_{i\,min} \le P_t \le P_{i\,max} \tag{5}$$

$$0 \le R_{it} \le P_{i\,max} - P_{i\,min} \tag{6}$$

B. Minimum up time constraint

$$T_i^{ON} \ge MU_i \tag{7}$$

C. Minimum down time constraint

$$T_i^{OFF} \ge MD_i \tag{8}$$

D. Spinning reserve constraints

$$\sum_{i=1}^{N} P_{it}U_{it} \ge PD_t + SR_t \tag{9}$$

E. Ramp up constraint

$$P_{it} - P_{it-1} \le K.\ UR_i \tag{10}$$

F. Ramp down constraint

$$P_{it-1} - P_{it} \le K.\ DR_i \tag{11}$$

Where, K = 60 min is the UC scheduling time step.

3. CONVENTIONAL APPROACHES FOR UC PROBLEM SOLUTION

A. Priority List Method

Lee (1989) have presented a short-term fuel constrained thermal unit commitment method designed for Oklahoma Gas & Electric Co. (OG&E) which has significant fuel constraints including take-or-pay gas contracts and limitations associated with the gas delivery system. These fuel constraints are explicitly considered in determining the short-term (e.g. daily, weekly) thermal unit commitment strategy. In this approach, each iteration consists of two phases - the sequential commitment phase and the parameter adjustment phase. The starting point used by the author was determined by sequentially committing the available units according to their respective Average Full Load Cost (AFLC) until the system hourly capacity obligation is fulfilled. In the initial trajectory, the hourly on-off status of each committed unit was determined fully according to the system's need and the unit's physical constraints (e.g. initial condition, minimum-up-time, minimum-down-time), and no attempt was made to satisfy the associated fuel constraints. As a result, the starting point was well defined and can be easily determined without dynamic optimization.

B. Lagrangian Relaxation

Chung-Li Tseng et al., (1999) presented a transmission-constrained unit commitment method using a Lagrangian relaxation approach. Based on a DC power flow model, the transmission constraints are formulated as linear constraints. The transmission constraints, as well as the demand and spinning reserve constraints, are relaxed by attaching Lagrange multipliers. A three-phase algorithmic scheme is devised including dual optimization, a feasibility phase and unit decommitment. A large-scale test problem with more than 2200 buses and 2500 transmission lines was tested along with other test problems.

C. Benders Decomposition Method

Yong Fu et al., (2005) have introduced an efficient Security Constrained Unit Commitment (SCUC) approach with ac constraints that obtains the minimum system operating cost while maintaining the security of power systems. The proposed approach applies the Benders decomposition for separating the Unit Commitment (UC) in the master problem from the network security check in sub problems. The master problem applies the augmented Lagrangian Relaxation (LR) method and dynamic programming (DP) to solve UC. The sub problem checks ac network security constraints for the UC solution to determine whether a converged and secure ac power flow can be obtained. If any network violations arise, corresponding Benders cuts will be formed and added to the master problem for solving the next iteration of UC. The iterative process will continue until ac violations are eliminated and a converged optimal solution was found. In this paper, a six-bus system and the IEEE118–bus system with 54 units are analyzed to exhibit the effectiveness of the approach.

D. Mixed Integer Programming

Frangioni A et al., (2009)have proposed a new way for constructing Mixed Integer Linear Programming (MILP) approximated formulations for hydrothermal unit commitment problems. Implement than previously proposed formulations, the new approach significantly improves the performances of MILP-based heuristics to the problem, either in terms of required running time or in terms of quality of the obtained solutions. With a limited additional implementation effort dynamic versions of the approach can be implemented which may lead to further significant improvements of the results. While the formulation is tested only on a “standard” form of the UC problem, the underlying concept can be applied to many other variants of the problem, where analogous results should be expected. All in all, these results show that appropriate formulations of UC problems can be used to find good-quality solutions in relatively short time by using off-the-shelf, general-purpose optimization software.

E. Dynamic Programming

Snyder W.L., Jr et al., (1987) have presented a field-proven dynamic programming formulation of the unit commitment problem. This approach features the classification of generating units into related groups so as to minimize the number of unit combinations which must be tested without precluding the optimal path. Programming techniques which maximize efficiency are described. Considerations are discussed which determine when generating units must be evaluated and when they may be ignored. The heuristic procedures described in this paper are concerned with supplying all a priori information to the program thereby minimizing its execution time. Results are presented from field testing on a medium size utility. Composite generating unit formulation is described for the economic allocation of constrained fuel to a group of units. Dynamic programming is a methodical procedure which systematically evaluates a large number of possible decisions in a multi-step problem. This algorithm incorporates a number of special features and effectively deals with the control of problem size. The discussion includes practical considerations and design techniques. This approach has been field proven on a medium size utility for which sample results were presented. A Unit Commitment program based on the approach described in this paper is presently in operation on the San Diego Gas & Electric System and presently deals with 30 generating units, 21 of which are peakers.

Joon-Hyung Park et al., (2010) proposed a modified dynamic programming solution to the Unit Commitment (UC) problem. The priority list method, The Lagrange Relaxation and the Mixed Integer Linear Programming (MILP) are possible to apply to a real power system for performing the UC. So far, by using these methods, only a suboptimal solution could be achieved. A base set of 5 units was chosen along with their 24 hour demand schedules. When the 100 paths were chosen to perform the modified dynamic programming it was impossible to solve this problem because there are no solutions to satisfy the minimum up/down constraints. By using the modified unit commitment, the optimal solution could be achieved which was the same with dynamic programming solution.

4. NON-CONVENTIONAL APPROACHES FOR UC PROBLEM SOLUTION

A. Genetic Algorithms

Genetic Algorithm (GA) solution to the Unit Commitment problem was proposed by Kazarlis et al., (1996). A simple GA algorithm implementation using the standard crossover and mutation operators could locate the near optimal solutions but in most cases failed to converge to the optimal solution. However, using the Varying Quality Function technique and adding problem specific operators, satisfactory solutions to the Unit Commitment problem were obtained. Test results for systems of up to 100 units and comparisons with results obtained using Lagrangian Relaxation and Dynamic Programming are also reported. Genetic Algorithms are general-purpose search techniques based on principles inspired from the genetic and evolution mechanisms observed in natural systems and populations of living beings. The simulations included test runs for 10, 20, 40, 60, 80and 100 unit systems respectively. A base set of 10 units was initially chosen along with a 24-hour demand schedule. A disadvantage of the GAs is that, since they are stochastic optimization algorithms, the optimality of the solution they provided cannot be guaranteed. Another disadvantage of GA-UC algorithms is their high execution time. However with the progress in the hardware of parallel computing, both disadvantages of the GA-UC algorithms can soon be eliminated.

Hong-Tzer Yang et al., (1997) proposed a Parallel Genetic Algorithm (PGA) approach to solve the thermal unit commitment (UC) problem. The search process becomes very inefficient for the GA to achieve the optimal or near optimal solution. In the UC problem, the decision variables of the cost function are decomposed into integer on-off variables, which are coded into binary strings, and the continuous real power outputs, which are determined by economic dispatch sub program based on the string under evaluation. The binary strings after processing by the GA can be easily decoded back to the actual decision variables. The basis of our parallel implementation of the GA is to divide a population into several sub-populations. The transputer network is arranged in structures of master-slave and dual-direction ring. Two numerical examples for the UC problem, one with 4 units over 8-hour period and the other with 38 units over 24 hours were presented by using this PGA approach. In particular, the parallel processing topology of dual-direction ring was shown to be able to achieve a near linear reduction in computation time when compared with its sequential form. In this study, the easiness of programming, debugging, and modifying the software of PGA have been experienced. The portability of the PGA software further makes feasible the PGA in solving diverse optimization problems of power systems within reasonable execution time.

Swarup and Yamashiro (2002) have planned a Solution methodology of Unit Commitment (UC) using Genetic Algorithms (GA). Problem specific operators are proposed for the satisfaction of time dependent constraints. Genetic algorithms (GA) are adaptive search techniques based on the principles and mechanisms of natural selection and "survival of the fittest" from natural evolution. GA operates as an iterative procedure on a fixed size of population or pool of candidate solutions. The candidate solutions represent the encoding of the problem into a form that is analogous to the chromosomes of biological systems. Each chromosome represents a possible solution for a given objective function. Associated with each chromosome is a fitness value, which determines its ability to survive and produce offspring. The program is tested on a 10-generator system. The performance of the GA for 300 iterations in terms of convergence of the Total Objective Function (TOF) was obtained. This ensures a feasible solution during every stage of the GA simulation. The spinning reserve is treated as an objective with minimization in the total objective function.

Rajan et al., (2002) have proposed the Improved Genetic Algorithm (IGA) Solution to UC problem. The objective of this paper was to find the generation scheduling such that the total operating cost could be minimized, when subjected to a variety of constraints. Neyveli Thermal Power Station - 11 in India, demonstrates the effectiveness of the proposed approach. At a crossover of 95% and mutation of 0.5% to get the optimal solution. For that optimal solution, the unit commitment schedule is obtained. The proposed algorithm differs from other GA implementations in three aspects. First, it can consistently find good UC schedules in a reasonable amount of computer time. Second, it could produce many different UC schedules in one run. Multiple UC schedules provided data for an analysis tool that could be used for spinning reserve compression, securing analysis and transaction evaluation and solution. Third, GA is an information algorithm. The more information given to the GA solution to UC (spinning reserve, crew constraints, emission constraints, etc.) by the true costing approach, the better the GA solution to UC would be able to understand the problem and be able to come up with a good UC schedule.

Damousis et al., (2004), have presented a new solution to the thermal Unit Commitment (UC) problem based on an Integer-Coded Genetic Algorithm (ICGA). The GA chromosome consists of a sequence of alternating sign integer numbers representing the sequence of operation/reservation times of the generating units. The proposed coding achieves significant chromosome size reduction compared to the usual binary coding. As a result, algorithm robustness and execution time are improved. In addition, generating unit minimum up and minimum downtime constraints are directly coded in the chromosome, thus avoiding the use of many penalty functions that usually distort the search space. A base set of ten units was initially used, along with a 24-h load curve. For the 20-unit configuration, the base set has duplicated and the load demand was doubled. The 40-unit to 100-unit systems was created in the same way. The reserve requirement was 10% of the hourly load in all cases. The ICGA solutions were compared to the solutions of the LR and the Binary-Coded GA (BCGA). For each case, an ICGA consisting of 50 chromosomes run for 300 generations. The result is a GA that produced better results than the popular LR method that was used as a benchmark, while the execution time is reduced compared to binary GA implementations. Finally, the new algorithm showed remarkable robustness since it did not require heuristic changes to the population size or the number of generations in order to converge, regardless of the system's size.

B. Simulated Annealing

The new UC problem formulation solved using the Simulated Annealing (SA) technique has proposed by Boris et al., (2006). In the 4-state model, the banking, minimum and maximum statuses consider that the unit is operational. Therefore, in any of these three statuses, an up time is considered. The SA strategy starts with a ''high'' temperature giving a high probability to accept non-improving movements. The temperature and probability levels diminish as long as the algorithm advances to the optimal solution. In this way, a diversification procedure in the search algorithm is performed with care in the system energy. The main key to obtain good solutions in the usage of SA is the cooling criterion. In order to validate the model is an application to the Chilean Northern Interconnected System, a 5-unit system. The results obtained via this method are compared to the optimal solution manually found (analytic solution) for a 24-h demand curve (out of 1023UC combinations per hour) and the classical On/Off unit model. Finally, the use of the SA as an optimization algorithm permits, without any implementation difficulty, to solve the UC in its complete formulation giving excellent results and having low simulation times. With the use of SA, linear approximations of the UC formulation are not required.

C. Particle Swarm Optimization

Tiew-on Ting et al., (2003) presented a Hybrid Particle Swarm Optimization (HPSO) to solve the Unit Commitment (UC) problem. Application of HPSO is a new approach in solving the Unit Commitment problem. Results demonstrated that HPSO is a competent method to solve the UC problem. The total objective was sum of objectives and constraints, which are fuel cost, start up cost, spinning reserve and power demand. For better solution, powers generated by N unit of generators are constantly checked so that feasible particles that meet the power demand are always generated. This reduces the pressure of the constraint violation of the total objective function. The minimum up and down time are treated separately by forcing the generator to turn on or off in order to fulfill this constraint.

Ting et al., (2006) presented a new approach via Hybrid Particle Swarm Optimization (HPSO) scheme to solve the Unit Commitment (UC) problem. HPSO proposed in this paper is a Blend of Binary Particle Swarm Optimization (BPSO) and Real Coded Particle Swarm Optimization (RCPSO). The UC problem is handled by BPSO, while RCPSO solves the economic load dispatch problem. Both algorithms are run simultaneously, adjusting their solutions in search of a better solution. PSO is inspired by particles moving around in the search space. The particles in a PSO thus have their own positions and velocities. The result obtained from the simulation is most encouraging in comparison to the best known solutions so far.

A new Improved Binary Particle Swarm Optimization (IBPSO) method to solve the Unit Commitment problem (UCP) was proposed by Xiaohui Yuan (2009), which is integrated Binary Particle Swarm Optimization (BPSO) with lambda-iteration method. The IBPSO was improved by priority list based on the unit characteristics and heuristic search strategies to repair the spinning reserve and minimum up/down time constraints. The IBPSO method for solving UCP consists of three stages. In the first stage, combination discrete binary particle swarm optimization with priority list is used to commit units to satisfy spinning reserve neglecting the minimum up and down time constraints. In the second stage, a heuristic search algorithm is applied to repair violations of the minimum up and down time constraints as well as decommit excessive spinning reserve units based on the unit schedule from the first stage. In the last stage, the equal lambda-iteration method is used to solve the economic load dispatch problem. The proposed IBPSO method is tested on a basic system of 10 units. The scheduling time horizon T is chosen as one day with 24 intervals of an hour each. The spinning reserve requirement is set to be 10% of the total load demand. The total production costs over the scheduled time horizon by IBPSO are less expensive than any other optimization methods reported in the literature especially on the large-scale UCP.

Yun-Won Jeong et al., (2010) proposed a new Quantum-inspired Binary Particle Swarm Optimization (QBPSO) approach to solve UC problem. The BPSO algorithm has some drawbacks such as premature convergence when handling heavily constrained problems. The proposed QBPSO combines the conventional BPSO with the concept and principles of quantum computing such as a quantum bit and superposition of states. The QBPSO adopts a Q-bit individual for the probabilistic representation, which replaces the velocity update procedure in the particle swarm optimization. To improve the search capability of the quantum computing, a new rotation gate was also introduced, which is, a coordinate rotation gate for updating Q-bit individuals combined with a dynamic rotation angle for determining the magnitude of rotation angle. The QBPSO is applied to 10, 20, 40, 60, 80, and 100 units along with 24-hour load demands.

D. Ant Colony Search Algorithm

Saber et al., (2008) have proposed a Memory-bound Ant Colony Optimization (MACO) solution to unit commitment problem. Inspired by the food-seeking behavior of real ants. As a result, an initially irregular path from nest to food will eventually contract to a shorter path in Ant Colony Optimization (ACO). A significant drawback of the ACO is that the amount of memory required to store the pheromone matrix is exponential of the number of units N for the UC problem. Input data of 6-unit system, which consists of 26 buses and 46 transmission lines. The MACO has better information sharing and conveying mechanisms, and thus may possess less randomness than GA and EP and the cost per unit power was little bit higher for larger system, as the allocated memory was fixed for all the systems and larger systems suffer more than that of the smaller systems.

The Ant Colony Search Algorithm (ACSA) is a meta-heuristic technique for solving hard combinatorial optimization problems, a class of problems like the UC problem. El-Sharkh et al., (2010) proposed a fuzzy comparison technique and generated a fuzzy range of the cost that reflects problem uncertainties. ACSA mimics the behavior of real ants and uses an artificial ant colony as an optimization tool. The fuzzy ACSA-based UC solution approach was tested on a 10-unit system considering a time horizon of 24 hours. The average cost of the fuzzy solution using the Fuzzy ACSA approach and the best crisp solutions using the Lagrangian Relaxation (LR), Genetic Algorithms (GA), Memetic Algorithms (MA), and the crisp Ant Colony Search Algorithms (ACSA) were analyzed. The generated optimal solution was a fuzzy range that reflected the problem uncertainties. Test results were quite encouraging and indicated the viability of this technique to solve the UC problem and other power system optimization problems considering problem uncertainties.

E. Tabu Search

Rajan (2009) has proposed to solve the short-term unit commitment problem using the genetic algorithm based tabu search method with cooling and banking constraints. A power station in India with seven generating units, each with a capacity of 210 MW has been considered as a case study. In this proposed work, the parents have been obtained from a pre-defined set of solution's i.e. each and every solution is obtained from the TS method. Then a random recommitment was carried out with respect to the unit's minimum down times. In comparison with the results produced by the referenced techniques (GA, DP, LR, TS), the Genetic Algorithm Tabu Search (GATS) method obviously displayed a satisfactory performance. There was no obvious limitation on the size of the problem that must be addressed for its data structure such that the search space is reduced to a minimum. No relaxation of constraints is required, instead populations of feasible solutions are produced a teach generation and throughout the process, a GA was inherently parallel this proposed method was found suitable for parallel and distributed implementation.

F. Evolutionary Strategies

Uyar et al., (2008) have compared three evolutionary computation techniques, namely Steady-State Genetic Algorithms, Evolutionary Strategies and Differential Evolution for the Unit Commitment Problem. The comparison was based on a set of experiments conducted on benchmark datasets as well as on real-world data obtained from the Turkish Interconnected Power System. The results of the two state-of-the-art evolutionary approaches, namely a Generational Genetic Algorithm and a Memetic Algorithm for the same benchmark datasets are also included in the paper for comparison. The tests show that Differential Evolution is the best performer among all approaches on the test data used in the paper. The first test problem has 4 power generating units and a time horizon of 8 hours. The use of EAs for the Unit Commitment Problem (UCP) is explored in this study. These experimental results show that EAs, especially DE, are very suitable for the UCP.

G. Bacterial Foraging Algorithm

Morteza Eslamian et al., (2009) have presented a new evolutionary algorithm known as Bacterial Foraging (BF) for solving the UC problem. This new integer-code algorithm is based on the foraging behavior of E-coli Bacteria in the human intestine. By integer coding of the problem, computation time decreases and the minimum up/down-time constraints may be coded directly, and therefore, there is no need to use penalty functions for these constraints. The idea of BFA was based on the fact that natural selection tends to eliminate animals with poor foraging strategies and favor those having successful foraging strategies. After many generations, poor foraging strategies are either eliminated or reshaped into good ones. The E. coli bacteria that are present in our intestines have a foraging strategy governed by four processes, namely, chemotaxis, swarming, reproduction, and elimination and dispersal. The simulation includes runs for 10, 20, 40, 60, 80, and 100 unit systems. The Scheduling period is 24 hours. Results show that the proposed BF method converges very fast to the LR solution and also locates a significantly better solution. This shows the superiority of BF method over LR and GA methods for practical and large-scale applications.

H. Neural Networks

Rajan et al., (2003) proposed an approach to solveing the short-term Unit Commitment Problem (UCP) using a Neural Based Tabu Search (NBTS). Tabu search is a powerful optimization procedure that has been successfully applied to a number of combinatorial optimization problems. It has the ability to avoid entrapment in local minima by employing a flexible memory system. The neural network combines good solution quality for tabu search with rapid convergence for an artificial neural network. The neural based tabu search method is used to find the unit commitment. By doing so, it gives the optimum solution rapidly and efficiently. A NTPS in India with seven generating units, each with a capacity of 210 MW, has been chosen for case study. A time period of 24 hours was considered and the unit commitment problem was solved for these seven units and it was also compared with 10, 26 and 34 generating unit power systems. It was shown that the results obtained from the proposed method were far superior to those obtained from conventional methods.

I. Fuzzy Logic-Based Methods

Saber (2006) has formulated a Fuzzy Adaptive Particle Swarm Optimization (FAPSO) for Unit Commitment (UC) problem. FAPSO reliably and accurately tracks a continuously changing solution. By analyzing the social model of standard PSO for the UC problem of variable resource size and changing load demand in deregulated market, the fuzzy adaptive criterion is applied for the PSO inertia weight based on the diversity of fitness. In this method, the inertia weight is dynamically adjusted using the fuzzy IF/ THEN rules. To increase the knowledge, the globally best location is moved instead of a fixed one in each generation. To avoid the method to be frozen, stagnated/idle particles are reset from time to time. Velocity is digitized (0/1) by a logistic function for the binary UC schedule. Finally, the benchmark data and methods are used to show the effectiveness of the proposed method. The proposed fuzzy adaptive PSO has better information sharing and conveying mechanisms than the other evolutionary methods. A standard input data set, base 10 unit systems is used to compare with other popular methods.

A dynamic programming technique with a fuzzy and simulated annealing based unit selection procedure for the solution of the UC problem has been proposed by Patra et al., (2009). The curse of dimensionality of the dynamic programming technique is eliminated by minimizing the number of prospective solution paths to be stored at each stage of the search procedure. Heuristics like priority ordering of the units, unit grouping, fast economic dispatch based on priority ordering, avoidance of repeated economic dispatch through memory action have been employed to make the algorithm fast. This method has produced comparable results with the best performing methods found in the literature. Memory based ED along with unit clustering mechanism has made the computation fast whereas fuzzy based start-up/shut-down cost prediction help reducing the number of prospective solution paths to be stored. The proposed method can produce results which are comparable with the best of the UC solution procedures available in the current technical literatures. Since only a few solution paths need to be stored at each stage, the so called the curse of dimensionality of the dynamic programming approach has been eliminated and at the same time best quality of solutions are obtained in the proposed method.

J. Straightforward Method

Hosseini et al., (2007) have presented a novel fast straightforward method for the scheduling of thermal generating units. This method decomposes the solution of the Unit Commitment (UC) problem into three sub problems. In the first sub problem, the quadratic cost functions of units are line arised and hourly optimum solution of UC was obtained considering all constraints except the minimum up/down time constraints. In the second sub problem, the minimum up/down times ware enforced through a novel optimization process by modifying the schedule obtained in the first step. Finally, in the third sub problem, the extra reserve was minimized using a new recommitment algorithm. This method was implemented in the Iranian national power grid model to illustrate the performance of this method. The salient feature of this approach was extremely short execution time that makes it applicable and efficient for large scale practical power systems generation scheduling.

K. Evolutionary Programming and PSO

Pappala et al., (2010) have proposed a variable-dimension optimization approach to address the high dimensionality issues in solving the unit commitment problem. This method introduces the concept of adaptive search space dimension. This approach was implemented in particle swarm optimization algorithm. The optimization process starts with an arbitrary problem dimension, adapts with respect to the swarm progress and finally selects the optimal dimensional space. The efficiency of this method was tested on a ten-unit test system. The results are compared with binary programming and fixed duty cycle approaches. The motive behind the new version of PSO is to develop a black box optimization tool. The algorithm should involve minimum human assistance and should provide good solutions to a wide variety of real-time applications. The simulation results on a ten generator test problem imply that nearly 88% reduction in problem dimension was possible. The advantage of the reduced search dimension was reflected in the improved quality of the final solution. Due to a few decision making UC variables, the swarm was able to effectively optimize the scheduling of various generation units. This research has proved that it was possible to define the optimization problem even without declaring the problem dimension.

L. Harmony Search Algorithm

M. Afkousi-Paqaleh et al., (2010) have presented a Harmony Search Algorithm Harmony Search Algorithm (HSA) to solve Unit Commitment (UC) problem. HSA was conceptualized using the musical process of searching for a perfect state of harmony, just as the optimization process seeks to find a global solution that was determined by an objective function. HSA can be used to optimize a non-convex optimization problem with both continuous and discrete variables. In this paper it was shown that HSA, as a heuristic optimization algorithm, may solve power system scheduling problem in a better manner in comparison with the other evolutionary search algorithms that are implemented in such complicated issue. Two case studies were conducted to facilitate the effectiveness of this method. One on the conventional 10-unit test system and its multiples while the other was on a 26-unit system, both of which were with a 24-hour scheduling horizon.

M. L-shaped algorithm

XiongPeng et al., (2010) have proposed a convergence acceleration technique for UC problem. The objective of this problem is to minimize the expected operating cost for the decision time horizon under load uncertainty. The problem was solved using a standard L-shaped algorithm. They suggested some acceleration techniques to improve the convergence behavior. These techniques were tested on a 9-bus system to determine computing efficiency. Results showed that the proposed acceleration techniques reduced the number of iterations as well as the algorithm convergence time. The L-shaped algorithm was employed to treat problems with a greater number of scenarios. Furthermore, two simple convergence acceleration techniques were presented. The first one selected a better initial solution which as already close to the optimal point, while the second one appended additional constraints to the first stage problem so that the solution procedure approached optimal point in a better path. Empirically, both techniques can help to improve the convergence characteristics and a combination of them greatly reduced the computing time. Besides, since the decision time horizon was not sufficiently long, minimum up and minimum down time constraints were not included.

N. Shuffled Frog Leaping Algorithm

JavadEbrahi et al., (2011) proposed shuffled frog leaping algorithm for UC problem. The integer-coded algorithm was developed to minimize the total energy dispatch cost over the scheduling horizon while all of the constraints should be satisfied. In addition, minimum up/down-time constraints have been directly coded not using the penalty function method. The proposed algorithm was applied to ten up to 100 generating units, considering one-day and seven-day scheduling periods. The most important merit of this method is its high convergence speed. The simulation result of this algorithm was compared with the results of algorithms such as Lagrangian relaxation, genetic algorithm, particle swarm optimization and bacterial foraging. The comparison results showed the efficiency of this method. The SFLA has been tested on the 10, unit systems over a scheduling period of 24 hours. The spinning reserve is assumed to be 10% of the load demand. The operating cost of 10 unit systems for a seven-day scheduling period was compared with the result of the BF algorithm which results in lower costs as compared to the BF algorithm in the seven-day scheduling period. The simulation results show that the computation times and production costs of SFLA are less than other algorithms such as LR, GA, PSO and BF.

O. Quantum-Inspired Evolutionary Unit Commitment

Chung et al., (2011) have developed an advanced Quantum-Inspired Evolutionary Unit Commitment (QIEA-UC) algorithm by developing a new initialization method based on unit priority list and a special Q-bit expression for ensuring diversity in the initial search area for improving the efficiency of solution searching. Different techniques such as multi-observation, single-search, and group-search are also proposed for incorporation in to the advanced algorithm. QIEA-UC was tested on 10, 20, 40, 60, 80 and 100-unit test systems. The greatly improved ability of the QIEA-UC algorithm is due to the use of priority lists in the initialization of the Q-bit individuals at the beginning of the QIEA-UC process and the employment of better search strategies including the single-search, group-search and multi-observation technique in the QIEA-UC process. The study results have also confirmed that the QIEA-UC algorithm proposed outperforms many other earlier methods and possesses a large capability in solving large-scaled unit commitment problems.

5. CONCLUSION

This paper presents the literature review of research work based on various methodologies used to solve Unit Commitment Problem in Power System. Around 30 selected research articles published in the last 30 years are taken for this review. This bibliographic survey on this topic will be useful for new researchers in the field of Power System Unit Commitment.

References

1. Chung-Li Tseng; Oren, S.S.; Cheng, C.S.; Li, C.; Svoboda, A.J.; Johnson, R.B., "*A transmission-constrained unit commitment method*", Proceedings of the Thirty-First Hawaii International Conference on System Sciences, 1998., Vol. 3, pp. 71–80, 1998.
2. Yong Fu, Shahidehpour, M. and Zuyi Li, "*Security-constrained unit commitment with AC constraints*", IEEE Transactions on Power Systems, Vol. 20, Issue. 2, pp. 1001-1013, 2005.
3. Frangioni, A., Gentile, C., Lacalandra, F., "*Tighter Approximated MILP Formulations for Unit Commitment Problems*", IEEE Transactions on Power Systems, Vol. 24, Issue.1, pp. 105-113, 2009.
4. Joon-Hyung Park, Sun-Kyo Kim, Geun-Pyo Park, Yong-Tae Yoon and Sang-Seung Lee, "*Modified dynamic programming based unit commitment technique*", 2010 IEEE Power and Energy Society General Meeting, pp. 1-7, 2010.
5. Joon-Hyung Park, Sun-Kyo Kim, Geun-Pyo Park, Yong-Tae Yoon and Sang-Seung Lee, "*Modified dynamic programming based unit commitment technique*", 2010 IEEE Power and Energy Society General Meeting, pp. 1-7, 2010.
6. Kazarlis, S.A., Bakirtzis, A.G. and Petridis, V., "*A genetic algorithm solution to the unit commitment problem*", IEEE Transactions on Power Systems, Vol. 11, Issue.1, pp. 83-92, 1996.
7. Hong-Tzer Yang, Pai-Chuan Yang and Ching-Lien Huang, "*A parallel genetic algorithm approach to solving the unit commitment problem: implementation on the transputer networks*", IEEE Transactions on Power Systems, Vol. 12, Issue. 2, pp. 661-668, 1997.
8. Swarup, K.S. and Yamashiro, S., "*Unit commitment solution methodology using genetic algorithm*", IEEE Transactions on Power Systems, Vol. 17, Issue.1, pp. 87-91, 2002.
9. Rajan, C.C.A., Mohan, M.R. and Manivannan, K., "*Improved genetic algorithm solution to unit commitment problem*," Asia Pacific. IEEE/PES Transmission and Distribution Conference and Exhibition 2002, Vol. 1, pp. 255-260, 2002.
10. Damousis I. G., Bakirtzis A. G., and Dokopoulos S., "*A solution to unit commitment problem using integer coded genetic algorithm*" IEEE Transactions on Power Systems, Vol. 19, No. 2, pp. 1165-1172, May 2004.
11. Boris J. Pavez-Lazo and Claudio A. Roa-Sepulveda, "*A 4-state unit definition for the unit commitment problem*", International Journal of Electrical Power & Energy Systems, Vol. 29, Issue. 1, pp. 21–27, January 2007.
12. Tiew-On Ting, M.V.C. Rao, C.K. Loo, S.S. Ngu, "*Solving Unit Commitment Problem Using Hybrid Particle Swarm Optimization*", Journal of Heuristics, Vol. 9, Issue. 6, pp. 507-520, December 2003.
13. Ting, T.O., Rao, M.V.C. and Loo, C.K., "*A novel approach for unit commitment problem via an effective hybrid particle swarm optimization*", IEEE Transactions on Power Systems, Vol. 21, Issue.1, pp. 411-418, 2006.
14. Xiaohui Yuan, HaoNie, Anjun Su, Liang Wang, and Yanbin Yuan, "*An improved binary particle swarm optimization for unit commitment problem*", Expert Systems with Applications, Vol. 36, Issue 4, pp. 8049–8055, May 2009.
15. Yun-Won Jeong, Jong-Bae Park, Se-Hwan Jang and Lee, K.Y., "*A New Quantum-Inspired Binary PSO: Application to Unit Commitment Problems for Power Systems*", IEEE Transactions on Power Systems, Vol. 25, Issue. 3, pp. 1486-1495, 2010.
16. Ahmed Yousuf Saber and Abdulaziz Mohammed Alshareef, "*Scalable unit commitment by memory-bounded ant colony optimization with a local search*", International Journal of Electrical Power & Energy Systems, Vol. 30, Issue. 6–7, pp. 403–414, July–September 2008.
17. El-Sharkh, M.Y., Sisworahardjo, N.S., El-Keib, A.A. and Rahman, A., "*Fuzzy unit commitment using the Ant Colony Search Algorithm*", IEEE Electric Power and Energy Conference (EPEC), pp. 1-6, 2010.
18. Rajan, C.C.A, "*Genetic Algorithm Based Tabu Search Method for Solving Unit Commitment Problem with Cooling — Banking Constraints*", Journal of Electrical Engineering, Vol. 60, No. 2, pp. 69–78, 2009.
19. Uyar AS and B Turkay, "*Evolutionary algorithms for the unit commitment problem*", Turkish Journal of Electrical Engineering, Vol. 2, pp. 236-243, 2008.

20. Morteza Eslamian, Sayed Hossein Hosseinian and Behroozvahidi, "*Bacterial Foraging - Based Solution to the Unit Commitment Problem*", IEEE Transaction on Power System, Vol. 24, No. 3, pp.1478-1488, Aug 2009.

21. Rajan, C.C.A, M. R. Mohan, K. Manivanan, "*Neural Based Tabu Search Method for Solving Unit Commitment Problem*", IEE Proc. On Generation, Transmission and Distribution, UK, Vol. GTD-150, No. 4, pp. 469-474, 2003.

22. Saber, A.Y., Senjyu, T., Miyagi, T., Urasaki, N. and Funabashi, T., "*Fuzzy unit commitment scheduling using absolutely stochastic simulated annealing*", IEEE Transactions on Power Systems, Vol. 21, Issue. 2, pp. 955-964, 2006.

23. Parta.S, Goswami, S.K. Goswami, B. "*Fuzzy and simulated annealing based dynamic programming for the unit commitment problem*", expert systems with applications, Vol. 36, pp. 5081-5086, 2009.

24. Lee, F.N., "*A fuel-constrained unit commitment method*," IEEE Transactions on Power Systems, Vol. 4, Issue. 3, pp. 1208-1218, Aug. 1989.

25. Hosseini, S.H., Khodaei, A. and Aminifar, F., "*A Novel Straightforward Unit Commitment Method for Large-Scale Power Systems*", IEEE Transactions on Power Systems, Vol. 22, Issue. 4, pp. 2134-2143, 2007.

26. Pappala, V.S. and Erlich, I., "*A Variable-Dimension Optimization Approach to Unit Commitment Problem*", IEEE Transactions on Power Systems, Vol. 25, Issue. 3, pp. 1696-1704, 2010.

27. M. Afkousi-Paqaleh, M. Rashidinejad, M. Pourakbari-Kasmaei, "*An implementation of harmony search algorithm to unit commitment problem*", Electrical Engineering, Vol. 92, Issue. 6, pp. 215-225, November 2010.

28. XiongPeng and Jirutitijaroen, P., "*Convergence acceleration techniques for the stochastic unit commitment problem*", IEEE 11th International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), pp. 1196–1205, 2010.

29. Javad Ebrahi, Seyed Hossein Hosseinian, and Gevorg B. Gharehpetian, "*UC Problem Solution Using Shuffled Frog Leaping Algorithm*," IEEE Transactions on Power Systems, Vol. 26, No. 2, pp. 573-581, May 2011.

30. Chung, C.Y. ,Han Yu and Kit Po Wong, "*An Advanced Quantum-Inspired Evolutionary Algorithm for Unit Commitment*", IEEE Transactions on Power Systems, Vol. 26, Issue. 2, pp. 847-854, 2011.