METHODS OF SOLVING OPTIMAL SCHEDULING PROBLEM IN POWER-GENERATIONS SYSTEM

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Резюме.
Маджики Ф., Ткаченко В.Н. Методы решения задачи оптимизации расписания нагрузки энергоблоков. Статья посвящена анализу большого разнообразия различных подходов к решению задач оптимизации расписания нагрузки энергоблоков, которые развиты и опубликованы в настоящее время.

GENERAL PROBLEM STATEMENT.

The unit commitment problem (UCP) in a power system involves determining the start up and shut down schedule of the power generating units to meet the forecasted demand over a short term period [1,17]. The problem deals with the unit generation schedule in a power system, with the objective of minimizing the operating cost, and satisfying the prevailing constraints such as, load balance, system spinning reserve, ramp rate limits, fuel constraints, multiple emission requirements as well as minimum up and down time limit over a set period of time [2]. With the UC schedule, the generating companies (GENCO) satisfy customer load demands and maintain transmission flows and bus voltage within the limits. In solving the UCP, two basic decisions are involved, namely the "UC" decision and the "economic dispatch" decision. The "UC" decision involves the determination of the generating units to be running each hour of the planning horizon, considering system capacity requirements including the reserve, and the constraints on the start up and shut down of units. The "economic dispatch" decision involves the allocation of the system demand and spinning reserve capacity among the operating units during each specific hour of operation [18].

Different methods for solving the unit commitment (UC) problem have been developed. This paper seeks to summarize the different methods that have been used in the literature to solve the UCP.

MODEL FORMULATION AND RESEARCH PROBLEM STATEMENT.

The unit commitment problem can be formulated as:
minimize operational cost (OC):

$$FT = \sum_{t=1}^{I} \sum_{i-1}^{N} FC_{it}(P_{it}) + ST_{it} \qquad (1)$$

where $FC_{it}(P_{it})$ (Fuel Cost) ~ is the input/output curve that is modeled with a curve (normally quadratic):

$$FC_{it}(P_{it}) = a * P_{it}^2 + b * P_{it} + c\,. \qquad (2)$$

The start up cost is described by:

$$ST_{it} = TS_{it} + (1 - e^{(D_{it} / AS_{it})}\ BS_{it}), \qquad (3)$$

where P_{it} - power output of a generating unit;
i - index of the thermal unit;
t - time index;
TS_{it} - turbine start up cost;
BS_{it} - boiler start up cost;
D_{it} - number of hours down;
AS_{it} - boiler cool down coefficient.

Subject to-:

1) Demand constraint

$$\sum_{i=1}^{N} P_{it} U_{it} = PD_t \quad ,$$

where PD_t - system peak demand per hour;
U_{it} - commitment state, when $U_{it} = \begin{cases} 1, \text{ if unit is on} \\ 0, \text{ if unit is off} \end{cases}$;
N - number of available generating units.

2) Spinning reserve $\sum_{i=1}^{N} P_{\max_i} U_{it} \geq (PD_t + R_t), 1 \leq t \leq T,$

where $P_{\max_i}$ - maximum generation limit of unit i,
R_t - spinning reserve at time,
T - scheduled time horizon.

3) Rated maximum and minimum capacities of units

$$P_i^{\min} \leq P_i \leq P_{\mathrm{i}}^{\max}, \quad i = 1,2,\ldots\ N; \quad t = 1,2,\ldots T.$$

4) Minimum up/down time limits of units

$T_{oni} \geq T_{upi}$ and $T_{offi} \geq T_{downi}$,

where
T_{oni} – duration on for which unit i is continuously ON;
T_{upi} - unit i maximum up time;
T_{offi} - duration for which init i is continuously OFF;
T_{downi} - unit i minimum down time.

METHODS OF SOLUTION.

This section summarizes the some of the different methods of solution of the UCP, which have been reported in the literature.

CLASSICAL OPTIMIZATION METHODS

Lagrangian Relaxation. The approach concentrates on finding an appropriate coordinate technique for generating feasible primal solutions while minimizing the dual gap [8]. It involves two steps, the dual optimization and feasible solution construction. The dual optimization has the crucial role in determining the overall computational efficiency solution quality of the algorithms. In Lagrangian Relaxation the cost function (primal objective function) of the UC problem is related to the power balance, the generating constraints via two sets of Lagrangian dual function [19] . The dual problem is then decoupled into smaller sub problems which are solved separately with the remaining constraints. At the same time the dual function is maximized with respect to the Lagrangian multipliers usually by a series of iterations based on the sub gradient method [9]. It has the advantage of solving large scale problems and also enables handling of various constraints more easily.

Integer and linear programming. Integer programming involves partitioning the UC problem into non linear economic dispatch problems and pure integer non linear UC problem based and Benders approach [4]. The mixed integer approach solves the UC problem by reducing the solution search space through rejecting infeasible subsets. Linear programming UC problem can be solved by either decomposing the whole problem into sub problems and then apply linear programming to solve each sub problem or it can be solved directly by revised simplex techniques [4].

Dynamic programming. It was the earliest optimization based method to be applied to the UC problem [4]. Dynamic programming has the ability to solve problems of a variety of size and to be easily modified to model characteristics of specific utilities [4].

Particle swarm optimization with Lagrangian relaxation. Particle Swarm Optimization (PSO) is motivated from the social behaviors of birds flocking and fish schooling. It was introduced by Kennedy and Eberhat [14]. In the unit commitment problem (UCP), the Lagrangian Relaxation (LR) is applied to relax coupling constraints. The UCP is then split into independent optimization functions for each generating units. Each of the sub problems is solved using dynamic programming. PSO is then used to involve lagrangian multipliers. The PSO and LR approach is efficient in terms of computational times while providing good solutions [14].

HEURISTIC METHODS.

Priority list. With this approach, the units are committed in ascending order of the units' full load cost so that the most economic base loads are committed first and the peaking units last in order to meet the load demand. They are highly fast but are highly heuristic and give schedules with relatively high operation cost [8].

Fast extended priority listing. Priority listing method initially arranges the generating units based on the lowest operational cost characteristics [4]. Fast extended priority listing method makes use of the priority list. First, the priority list method yields rapidly an initial solution. Then plurality of solutions is produced based on derived one before. Finally, among all solutions, only potential solutions of improvement are implemented some fast heuristics, which can reduce the cost. Therefore, the method provides a satisfactory solution in terms of accuracy and computational effort [8].

Branch and bound. Lauer and Cohen presented a new approach for solving the UC problem based on the Branch and Bound [4]. This method incorporates all time dependent constraints and does not require a priority ordering of units [4]. It consists of a repeated application of the following steps :

step 1.. Mutually exclusive and collectively exhaustive sub problems of the original problem that is partitioned subsets in which the optimal solution is known to lie [4], [5].

step 2. If all the elements in a subset violate the constraints of the minimization problem, then that subset is eliminated from further consideration [2].

step 3. On upper bound on the minimum value of the objective function is computed [4].

step 4. Lower bounds are computed on the value of the objective function is computed when the decision variables are constrained to lie in each subset still under consideration [4]. A subset is then discarded if it fails to satisfy the constraints of the minimization problems. Finally, convergence will occur when only one subset of the decision variables remains and the upper and lower bounds are equal for that subset.

Tabu search. This proposed method was applied to a unit commitment problem [4]. Tabu search is one of the efficient combination optimization methods. It avoids becoming trapped in local optima by exploiting memory and data structures that prevent immediately moving back to a previously examined solution, and more generally, prevent moving to solutions that share certain attributes with previous solutions [5]. The method has the advantage that the process of evaluating the same solution is avoided to find out better solutions efficiently [11].

Simulated annealing. Kirkpatrick, Gela and Vecchi in 1982 and Cerny in 1985 independently introduced simulated annealing. Annealing physically refers to the process of heating up a solid to a high temperature followed by slow cooling achieved by decreasing the temperature of the environment in step [4]. The steps are as follows:

1. The temperature of the system is raised to a sufficient level,
2. while cooling , the temperature of the system is maintained for prescribed amount of time at each of the predetermined temperatures,
3. the system is allowed to cool under controlled conditions until the desired energy state is attained [5].

Thus, simulated annealing is a computational process, which attempts to solve hard combinatorial optimization problems like the UCP, through controlled randomization. It emulates the process of annealing which attempts to force a system to its lowest energy state through controlled cooling [5]. Simulated annealing takes long CPU time but has strong features like being independent of the initial solution and mathematical complexity.

Primal and dual methods. The primal method to the UC problem relies on solving the underlying large scale mixed integer optimization problem by adapted branch and bound techniques possibly enriched by cutting planes derived from the convex hall of feasible points [6]. The dual approach has also commonly been used in solving the UC problem. It uses Lagrangian relaxation, which aims at incorporating loosely coupling constraints linking operation of different units into the objective function by use of Lagrange multiplier [6]. The main problem is subdivided into subproblems. The solution of relaxed problem provides a lower bound on the optimal solution of the original problem. This approach can be applied for large systems because it works fast due tot the dual problem into essentially smaller problems and it reduces the duality gap for large number of units.

Ant colony search algorithm. Ant colony is the natural metaphor on which ant colony search algorithm (ACSA) is based. ACSA is a proposed method that solves the thermal UC problem. A cooperative approach inspired by the observation of the behaviors of real ant colonies on the topic of ant trail formation and foraging method [7]. It is believed that real ants are capable of finding the shortest path from a food source to their nest without using visual cues by exploiting phenomenon formation [4]. In the UC problem the set agents referred to, as ant will cooperate to find a good solution. The strength of this approach are the various parallel search and optimization capabilities.

Exhaustive enumeration. Exhaustive enumeration involves solving the UC problem by finding all possible combination of generating units and then the one with the least cost of operation is considered as the optimum solution [4]. The method is capable of providing an accurate solution though it is not suitable for a large-scale size electric utility.

A fuzzy logic approach. Fuzzy logic is a mathematical theory, which encompasses the idea of vagueness when defining a concept or a meaning. For example, there is uncertainty or 'fuzziness' in an expression like 'large' or 'small', since these expressions are imprecise and relative. Variables considered are termed 'fuzzy' as opposed to ‘crisp’. Fuzziness is simply one means of describing uncertainty. Fuzzy logic represents an effective alternative to conventional solution methods. It attempts to quantify linguistic terms so that the variables can be treated as continuous rather than as discrete. In this process, the qualitative behavior of a system, the system's characteristics and the response may be described without the need for exact mathematical formulation [3]. Thus, the fuzzy logic employs linguistic terms, which deals with the causal relationship between the input, and the output variable [3]. Thus, the approach makes it easier to manipulate and solve many problems, particularly where the mathematical model approximates reasoning, while allowing decisions to be made efficiently. An advantage of the fuzzy approach is that the crisp output can be further used in developing a qualitative interpretation.
Sanerfard et al [3] demonstrated the application of fuzzy logic approach to the UCP.

ARTIFICIAL INTELLECT METHODS.

Expert system. Expert system based approach to short term UC which is intended to process large generating schedules in real time are used for this investigation [4]. The method is intelligent computers program that use knowledge and reference procedures to solve problems that are difficult enough to require significant human expertise for their solution [4]. Its knowledge base is the human experts in the domain and it emulates their methodology and performance. Thus, skilled humans, have knowledge in both theoretical and practical and made perfect through experience in the domain.

Artificial neural network. The artificial neural network approach determines the discrete variables correspond to the state of each unit of the time interval [12]. They model the behavior of biological neural network [4]. The gist behind the development of artificial neural network was to take advantage of parallel processors computing than traditional serial computation.

Genetic algorithm. It is a general purpose search technique based on principles inspired from genetic evolution mechanisms observed in natural system of living being [8]. It achieves the objective by generating successive populations of alternative solutions until a solution is obtained that yields acceptable results [5]. The process occurs in such a way that within each successive operation, improvements in the quality of the individual solutions are gained. Thus, genetics algorithm can quickly move to the best solution without determining all possible solutions to the problem [4]. The benefits of using genetic algorithm are a robust optimization technique, easy implementation into concurrent processing and production of multiple UC schedules [10].

Seeded mimetic algorithm. The mimetic algorithm (MA) combines a genetic algorithm with LR with local search. A genetic algorithm (GA) is an adaptive search based on natural selection, reproduction and mutation [15]. A modified Lamarckian approach was used to augment the GA, creating a MA. MA requires fewer generations to converge than the convention GA. This hybrid approach solves the large problems better and uses less computational time [15].

HYBRID MODELS.

It is vital to note that improvement is necessary on existing UC algorithms. The need to implement various algorithms has led to the emergence of hybrid models. A hybrid model consists of two or more algorithms blended together in order to meet industrial requirements [4]. Some of the hybrid models are discussed below.

Hybrid Genetic algorithm . Genetic algorithms are adaptive search techniques that derive their model from the genetic processes of biological organisms and are based on evolution theory [13]. The UC problem is first tackled by incorporating a fast priority list heuristic generator ordering scheme to speed up the genetic algorithm search process. A hybrid genetic algorithm incorporates existing convectional solution methods into the genetic algorithm solution technique. The main limitation of genetic algorithm in solving large scale problem is the long computational times and associated difficulty both of which can be overcome by use of a hybrid technique [13]. The method of the hybridization process has the following advantages:

- simple to implement,
- computationally fast,
- results are predictable,
- most widely used techniques by electricity utilities.

Hybrid neural network and simulated annealing. This approach uses the artificial neural network to determine the discrete variables corresponding to the interval [12]. Then simulated annealing is applied to generate the continuous variables corresponding to the power output of each unit of the production cost [12]. This method yield reduced computational time.

ABSOLUTELY STOCHASTIC SIMULATED ANNEALING METHOD. This method has been adopted for the solution of the UCP [16]. Appropriate probability distributions are applied for both higher and lower cost new feasible solutions. Variable numbers of bits are flipped at different temperatures. Besides, logarithmic probability distribution for excess units and sign vector help to avoid the use of penalty functions and overhead calculation. This method lead to the improvement of robustness solution quality and execution time of simulated annealing [16].

Greedy randomized adaptive search procedure (GRASP). This is a Meta heuristic that takes into account decisions made in previous iterations for choosing the current movement and is a positive way of tackling true multi-period problem. GRASP has adaptability property. The decisions taken by the method, when building a solution are some how adapted according to decision previously taken. This dynamic “learning-process” often leads to very good solutions. The advantage of this method is that it is robust and effective in handling centralized UCPs.

Conclusion.

The paper highlighted different methods of solution to the UCP giving a brief overview of each of the algorithms. Some hybrid models were also discussed, of which most of the researchers are targeting on in solving the complex UCP.

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