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A Review on Thermal Unit Commitment using Optimization Techniques

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ABSTRACT

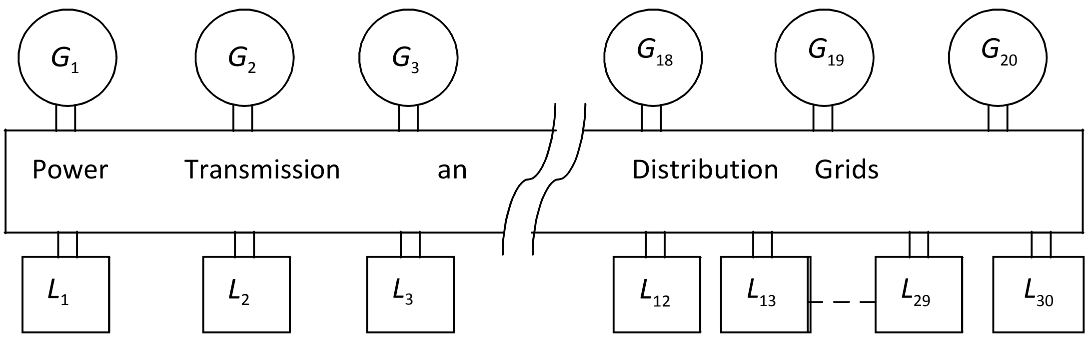
In an interconnected power system, the power requirement is mainly supplied by thermal power plants. Load patterns exhibits utmost variation between peak and off-peak hours. So, there is need of sufficient energy generation to meet the exacerbate energy demand. The problem confronting the system operator is to determine which unit should be taken offline and for how long or in other words scheduling of thermal units.

Therefore, thermal unit commitment problem (TUCP) is defined as committing some enough units to supply a power to network or a system with respect to load demand optimally. It is mixed integer non-linear optimization problem subjected to various constraints. In this paper, various conventional and random search techniques are discussed for the solution of TUCP

Keywords: Power Requirement, Thermal Unit Commitment, Optimum Commitment

I.INTRODUCTION

In power industry fuel expenses constitute a significant part of overall generation cost. So, it's being necessary put some limitation on the usage of fuel for generating power. This can be achieved by proper scheduling of generating of units termed as unit commitment (UC). Therefore, unit commitment is an essential step in scheduling and dispatching of electric power [1]. So, UC is forward positive step to make a balance between generating power and load demand. So broadly UC is defined as committing an enough unit to supply a power to network or a system with respect to load demand. Consider a simple power system coupled to generating station or units at one end and consumer end or load end on the other end as shown in figure (1).



G1 - G20 – Generators

L1 - L30 -- Load

Figure 1 A Simple Power System

It means that power system operation is continuously varying with respect to the consumers demand. The demand varies between weekdays and weekends and also between peak and off-peak hours. So therefore, it is not economical to run all the generating units all the time i.e. keeping them online all the time as it gives high impact to economics [2]. So, UC provides a proper coordination between generating power and its demand. Ultimately, it's been concluded that load demand and power reserve requirement are considered as global constraints and rest all the operating characteristics are the local constraints. It means that unit commitment is time dependent problem. So therefore, UC is the problem of scheduling of the generating units to keep online or offline as per the demand of electricity but subjected to various constraints. Various optimization techniques are applied to solve this problem deterministic techniques branch and bound method (BABM), priority list method (PLM) and dynamic programming (DP), lagrangian relaxation method (LRM) [3-4]. Out of these PLM, DP and LRM techniques are mostly used in power plants to solve unit commitment problem. But having a drawback of being more computational and expensive as the optimization problem grown in both dimensionality and complexity [5]. Advancement in computation and the searching for better results for complex optimization problems leads to the development of random search techniques like evolutionary programming (EP), ant colony search method (ACSM), particle swarm optimization (PSO), genetic algorithm (GA) and simulated annealing (SA) [6]. Evolutionary programming method has convergence rate to find the global optimum solution for optimization problems is much better as it than earlier optimization techniques. Moreover, it also provides fast and more accurate results as close to conventional methods in a reasonable time [7]. So, it can be easily implemented to practical problems. In Electrical power system unit commitment is nonlinear mixed integer optimization problem of deciding that which unit should be running to satisfy a demand of electricity requirement [8]. At one extreme nuclear power plants can provide electricity at low incremental cost for additional megawatt hour of energy but it has high start-up cost as it is once shutdown it will take a while to bring back it to a full power. Hydro power plants have high capital cost but low operating cost. So therefore, it is optimum to make the proper utilization of optimum mix of generation unit to generate electricity but taking into consideration the local as well as global constraints [9]. Therefore, UC is the problem of determining the schedule of the generating units to keep online or offline as per the demand of electricity but subjected to the device as well as the constraints. Unit commitment problem (UCP) resolved by lot of techniques and number of papers were presented by various researchers pertaining the solution to UCP. Happ, *et al***.** [10] presents a approach of sub optimizer and optimizer for obtaining the online optimal solution for UCP and require less computation time with satisfaction of operating constraints. Cohen and Yoshimura [11] presented a technique of branch and bound to find the feasible optimal solution to UCP with decision variables as start, stop times and generation level of the generating units and implemented without the incorporation of priority ordering criteria for the generating units. Snyder, *et al.* [12] suggested dynamic programming approach to UCP with incorporating of special feature of controlling the optimization problem size and provides an economic allocation of fuel cost to generating units. Huang, *et al.* [13] proposed a combination of logic programming with operating constraints satisfaction and branch bound technique to provide a flexible and efficient approach to UCP. Chowdhury and Billinton [14] develops a probabilistic approach involving system reliability and reserve requirement evaluation as two

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risks criteria for the feasible solution of UCP for continually varying load demand. Bender decomposition method for obtaining the feasible optimal solution to UCP and reactive power and voltage constraints for confirmed convergence to optimality discussed by Ma and Shahidehpour [15]. Dillon, *et al.* [16] provides the method for determining the optimum generating schedule by incorporating some alternations in branch and bound method for integer programming approach and considering satisfaction of power reserve constraint. Unit commitment problem can be solved by linear programming approach (LP) [17-18]. Gray and Sekar [17] discussed a unified approach of LP with direct current network model (DCNM) for solving UCP and considering power security constraint. Tight description of feasible generating schedules for solving UCP with LP considering ramp constraint proposed by Ostrowski, *et al*. [18]. Chang, *et al.* [19] presented a mixed integer linear programming (MILP) for solution to UCP of a simple combined cycle generating model prevailing all the operating constraints satisfaction.

Short term UCP leads to feasible optimum solution considering satisfaction of all operating constraints using PLM approach suggested by Keong and Teshome [20]. A solution to UCP considering the satisfaction of all the operating constraints using LRM are discussed [21-28]. Virmani, *et al*. [21] provides an LRM approach to most feasible optimize solution to UCP and discussed LRM implementation aspects to realistic UCP. A transmission constrained UCP of DCNM leads to the optimal solution using LRM Tseng, *et al.* [22]. Bertsekas, *et al.* [23] and Merlin and Sandrin [24] provides a reliable optimal solution to large scale UCP within the realistic time constraints by LRM implementation. A three phase i.e. maximized and find optimal solution to UCP and economic load dispatch (ELD) using LRM presented by Zhuang and Giliana [25].

Conventional techniques for solving thermal unit commitment problem are

Classical

1. Exhaustive Enumeration
2. Priority Listing
3. Dynamic Programming
4. Branch and Bound
5. Integer Programming
6. Linear Programming
7. Simulated Annealing
8. Lagrangian Relaxation
9. Tabu Search
10. Interior Point Optimization

Non-Classical

1. Expert Systems
2. Fuzzy Systems
3. Artificial Neural Networks

4. Genetic Algorithms
5. Evolutionary Programming
6. Particle Swarm Optimization

Hybrid Models Methods based on Artificial Intelligence(AI) like Neural Network (NN), Genetic Algorithms (GA), Simulated Annealing (SA), Ants Algorithms, Taboo Search (TS), Particle Swarm Optimization (PSO) etc. are advanced growing methods

II.FORMULATION OF UNIT COMMITMENT PROBLEM

Objective function: -

To minimize the cost as under

$$F\cos t[J,I]=[P\cos t(J,I)+S\cos t(J-1,L;J,I)+F\cos t(J-1,L)] \tag{1}$$

where

$F\cos t[J,I]$ = Least total cost at state (J,I)

$F\cos t(J-1,L)$ = Minimum total cost to arrive at state (J,I)

I = No of successful combinations

J = Total no of hours.

L = Reduced number of strategies that depends on the experimenting with a particular program (discarding the highest cost schedules at each time interval and saving only the lowest N paths or strategies).

N = No of strategies, or paths, to save at each step = $(2^{\text{no of units}} - 1) = 2^N - 1$

$P\cos t(J,I)$ = Production cost for state (J,I).

$S\cos t(J-1,L;J,I)$ = Transition cost from state $(L-1,L)$ to state $(J-1,I)$.

State (J,I) = I^{th} combination at hour J.

Subjected to various constraints which are required to be satisfied for electric power generation and power flow are as under: -

Spinning Reserve constraint describes the total amount of generation available from all units synchronised on power syste, subtracting the present load supplied and losses being incurred during that period.

$$\sum_{i=1}^{NG} U_{ij} P_i^{\max} \geq PD_i + P_j^r \tag{2}$$

where

NG = Total number of generating units.

$P_i^{\max}$ = Maximum power generated by i^{th} unit.

P_i^r = Spinning reserve requirement at j^{th} hour.

PD_i = Total power demand at j^{th} hour.

U_{ij} = Commitment by i^{th} unit at j^{th} hour.

Thermal unit constraint can be treated with two approaches as first approach is cooling and second approach is banking or hot start-up cost.

Start-up cost when cooling is given as under

$$F_c\left(1-e^{-t/\alpha}\right)\times F+F_f \tag{3}$$

where

F_c = Cold start cost.

F = Fuel cost.

F_f = Fixed cost (Crew cost & Maintenance cost).

t = Time (h) the unit was cooled.

α = Thermal time constant for the unit.

It may be economical to keep the unit in hot standby. The choice between shutting down and hot standby is depending on the two cost curves and length of the time a unit is to be out of service. Generally constant fuel is required to maintain the temperature and pressure in the boiler. Thus, standby cost is assumed to be linear function of shut down time [27].

Start-up cost when banking or hot start-up is considered is

$$F_c\left(1-e^{-t/\alpha}\right)\times F+F_t \tag{4}$$

where

F_t = Cost of maintaining a unit at operating temperature

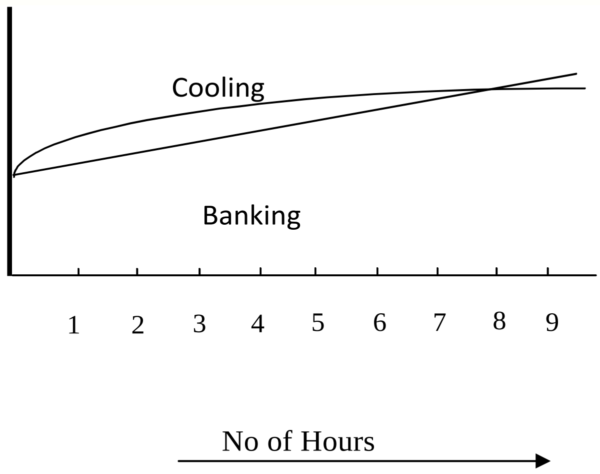

Figure 2 Time dependent start-up cost curve.

Fuel Constraint - A system in which some units have limited fuel, or else have constraints that require them to burn a specified amount of fuel in a given time, presents a most challenging unit commitment problem. In case of unit commitment fuel cost is subdivide into two categories as production cost or generation cost for power generation and transitional cost. The transitional cost is generally associated with starting and shutdown of a generating unit. Production cost is the cost incurred for the generation of power depends upon the load demand [16].

Transitional cost is the cost associated with shutdown and starting of a particular generating unit. Normally shutdown cost is considered as fixed cost which is independent of length of time for which the unit is running before shutdown. So ultimately transitional cost is considered as time dependent cost i.e. minimum down time and cold start-up time. It depends upon two cost curves i.e. hot startup cost and cold startup cost $\left(S\cos t_{ij}^{k}\right)$ and length of time a unit is out of service. So, it is preferable to unit on hot standby instead of shutdown as cost curve for hot standby is linear function of shutdown time [27, 28].

$$H_i^{off} = MDT_i + T_i^{cold} \quad (5)$$

where

T_i^{cold} = Cold start-up time for unit i.

MDT_i = Minimum downtime for unit i.

Then a start-up cost can be hot start-up cost or cold start-up cost as under.

$$\text{if} \quad \left\{MDT_i \le T_i^{off} \le H_i^{off}\right\} \text{ then } S\cos t_{ij}^{k} = S_{hi} \;\; ; \;\; \left\{T_{ij}^{off} > H_i^{off}\right\} \text{ then } S\cos t_{ij}^{k} = S_{ci} \quad (6)$$

where

S_{hi} = Hot start-up cost for unit i.

S_{ci} = Cold start-up cost for unit i.

T_i^{off} = Unit i off time during j^{th} hour.

Production cost is the cost incurred on fuel for the generation of power by the generating cost to meet the load demand. So main overall objective of unit commitment is to minimize the production cost. Numerous methods of economic dispatch are there to minimize production cost. Units are assumed to have linear piece wise linear generation cost curves and loading is being carried with unit having lowest incremental cost and dispatch continues until demand fulfill. Dispatching of power is carried out within the limit of generation limits and satisfied all the operating constraints and also power reserve constraint [12,29].

$$F_i\left(P_{ij}\right) = a_i + b_i P_{ij} + c_i P_{ij}^2 \quad (7)$$

where

a_i, b_i and c_i = Cost coefficients.

$F_i\left(P_{ij}\right)$ = Total fuel cost incurred for generating the power by i^{th} unit in j^{th} hour.

P_{ij} = Power generated by i^{th} unit in j^{th} hour.

Power equality constraint deals with total power generated at each hour should be equal to the load of the corresponding hour.

$$\sum_{i=1}^{NG} P_{ij} U_{ij} = PD_j + P_L \quad (8)$$

where

P_{ij} = Real power generation by i^{th} unit in j^{th} hour.

PD_j = Total Power demand at j^{th} hour.

P_L = Transmission losses at j^{th} hour.

U_{ij} = Unit commitment by i^{th} unit in j^{th} hour.

Power inequality constraint of generating unit is as under.

$$P_i^{\min} \le P_{ij}U_{ij} \le P_i^{\max} \tag{9}$$

where

$P_i^{\max}$ = Maximum real power generation limit of i^{th} unit.

$P_i^{\min}$ = Minimum real power generation limit of i^{th} unit.

Minimum up/Minimum down time constraint indicates that a unit must be on/off for a certain number of hours before it can be shut off or brought online, respectively. It means a unit cannot be shut or start immediately as it required some minimum period of time to shut down from commit state or to start from decommit state.

$$T_{ij}^{off} \ge MUT_i \tag{10}$$

$$T_{ij}^{off} \ge MDT_i \tag{11}$$

where

MUT_i = Minimum up time.

MDT_i = Minimum down time.

T_{ij}^{off} = Time duration during which the i^{th} unit is continuously off in j^{th} hour.

T_{ij}^{on} = Time duration during which the i^{th} unit is continuously on in j^{th} hour.

III.OPTIMIZATION TECHNIQUES

Dynamic Programming: it is a mathematical optimization technique which split the complex problem into simpler problems, solving each problem and stores its solution. If same subproblem occurs again then previous solution can be referred to save computation time. Therefore, this technique works in recursive manner.

Branch and Bound Technique: It is mathematical optimization technique which enumerates the optimal solution of problem by means of state space search method. In this technique a rotted tree of solutions is created. With the help of this technique tree is explored to an upper and lower bounded limit for optimal solution of problem.

Particle Swarm Optimization: In this technique an optimal solution of a problem is evaluated iteratively using state search method around a population of candidates' solution in regard to given measure of quality. In this every particle's movement is influenced by its local best-known position, but it guides toward the best-known positions in the search-space, which are updated as better positions are found by other particles leads to move the swarm toward the best solutions.

Genetic Algorithm: It is metaheuristic technique to get a high-quality solution of complex problem by relying on bio-inspired operators as mutation, crossover and selection. Best solution is selected by evaluating its fitness level. It is an iterative method to generated population of solution which are evaluated on the basis of fitness to optimize the objective function. This technique is terminating to best solution if required fitness level achieved.

Evolutionary Programming: Evolutionary programming is a stochastic optimization strategy, which places emphasis on the behavioral linkage between parents and their offsprings. It is powerful optimization technique which does not first and second derivates of objective function [30]. The main stages of EP are initialization, creation of offspring vectors by mutation and finally competition and selection to evaluate the optimal solution, so common underlying idea that come out is given a population of individuals or parents, environmental pressure causes the natural selection based on survival of fittest and finally reach the global optimum point [31]. In EP recombination or mutation is applied to each candidate or parent resulted into one or more new candidates (offspring) which competes with main parents on the basis of their fitness values and selected to undergo mutation for the next generation. This process repeats until search reaches the global optimal point.

<u>Algorithm for Evolutionary Programming</u>

1. Initially generates the population of individuals randomly.
2. Evaluate the fitness of each individual in that population (time limit, sufficient fitness achieved, etc.)
3. Repeat the above steps until termination:
4. Select the best-fit individuals for reproduction. (Parents)
5. Breed new individuals through crossover and mutation operations to give birth to offspring.
6. Re-evaluate the individual fitness of new individuals.
7. Replace least-fit population with new individuals.

IV.RELATED WORK

S.M.Hassan Hosseini, H.Siahkali and Y.Ghalandaran (2012) [32] Unit Commitment problem consists of two decisions: “Unit Scheduled” decision and “Economic Dispatch” decision. Unit Scheduled is a combinational programming optimization problem. In this paper PSO is hybridised with GA for optimal unit commitment. Results are presented in this work.

Aditya parashar, Kuldeep Kumar Swankar (2013) [33]: In this a genetic algorithm based approach to resolve the thermal unit commitment (UC). The model during this study contains four-generation units and also the 8-hour daily load demand. The results are compared between the dynamic programming (DP) and genetic algorithm the achieved results obtained using MATLAB tool box prove the effectiveness, and validity of the planned approach to unravel the large-scale UC. In the results indicating comparison of the cost solutions is using the genetic algorithm and the Dynamic Programming.

D.P. Kadam, S.S. Wagh & P. M. Patil (2007) [34]: This paper describes the application of genetic algorithm and fuzzy logic for determining short-term commitment of thermal units in electrical power generation. Feasibility of these methods is examined and preliminary results to determine near optimal commitment order of thermal units in studied power system over short term are reported. The results obtained from genetic algorithm and fuzzy logic based approach are compared with the priority list method solution to unit commitment problem. The comparison proves that genetic algorithm and fuzzy logic based approach are powerful tools for solving such highly non-linear, multi constrained optimization problems in electrical power systems.

Yun-Won Jeong , Jong-Bae Park , Joong-Rin Shin & Kwang Y. Lee (2009) [35]: In this article a new approach for solving unit commitment problems using a quantum-inspired evolutionary algorithm. Unit commitment problem is a complicated non-linear and mixed-integer combinatorial optimization problem with heavy constraints. An improved quantum evolutionary algorithm to effectively solve unit commitment problems. The quantum-inspired evolutionary algorithm is considered a novel evolutionary algorithm inspired by quantum computing, which is based on the concept and principles of quantum computing such as the quantum bit and the superposition of states. Proposed improved quantum evolutionary algorithm adopts both the simplified rotation gate and the decreasing rotation angle approach in order to improve the convergence performance of the conventional quantum-inspired evolutionary algorithm. The suggested simplified rotation gate can determine the rotation angle without a lookup table, while the conventional rotation gate requires a predefined lookup table to determine the rotation angle. In addition, the proposed decreasing rotation angle approach provides the linearly decreasing magnitude of rotation angle along the iteration. Furthermore, it also includes heuristic-based constraint treatment techniques to deal with the minimum up/down time and spinning reserve constraints in unit commitment problems. The excessive spinning reserve can incur high operation costs, the unit de-commitment strategy is also introduced to improve the solution quality. This technique is tested on large-scale power systems of up to 100-unit with 24-hr demand horizon.

V.CONCLUSION

This paper presents a review of work done by various innovative optimization techniques for solving unit commitment problem. However, in today's platform various advance techniques are already developed to minimize the cost of generating units and maximize the profit.

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