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A review on Unit Commitment Solution Methods

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Abstract— The Unit Commitment (UC) issue, a crucial optimization work in power system management, seeks to identify the best commitment schedule for power generating units over a given time horizon. By meeting demand while considering numerous operational restrictions, the UC problem is crucial in guaranteeing the reliable and economical functioning of power systems[1]. Researchers and practitioners have created a wide range of solutions to the UC issue over the years. The solution techniques used for Unit Commitment in power systems are thoroughly reviewed in this review paper. The study opens by providing a thorough formulation of the UC problem, considering factors such as demand variation, generator constraints, transmission limitations, and fuel costs. Subsequently, it discusses the key challenges associated with the UC problem, including computational complexity, uncertainty modeling, and the integration of renewable energy sources.

The review then proceeds to categorize the existing solution methods for Unit Commitment into several classes, including mathematical programming, heuristic algorithms, metaheuristics, and hybrid approaches. The study presents an in-depth evaluation of sample strategies for each category, noting their advantages, disadvantages, and potential uses. Heuristic algorithms, such as dynamic programming, priority lists, and Lagrangian relaxation, offer effective solutions but could forgo optimality. A compromise between solution quality and computation time is provided by metaheuristic methods like genetic algorithms, particle swarm optimization, and simulated annealing..

Furthermore, the paper discusses recent advancements in solution methods that address the emerging challenges in Unit Commitment, such as the incorporation of renewable energy source.

Index Terms— unit commitment, heuristic algorithms, mathematical programming techniques

I. INTRODUCTION

The Unit Commitment (UC) problem is a fundamental optimization task in power system operations, responsible for determining the optimal scheduling of power generating units over a given time horizon. The UC problem plays a pivotal role in ensuring the reliable and cost-effective operation of power systems by meeting the electricity demand while considering various operational constraints. Solving the UC problem accurately and efficiently has significant implications for the overall performance, stability, and sustainability of power systems. The UC problem is characterized by multiple complex factors, including demand variability, generator operating constraints, transmission limitations, and fuel costs. These factors introduce challenges that need to be addressed to achieve optimal and practical solutions. In an effort to find a compromise between solution quality and computational efficiency, researchers and practitioners have created a wide range of solution strategies to address the UC problem over the years.

The solution techniques used for Unit Commitment in power systems are thoroughly reviewed in this review paper. The aim is to offer a comprehensive view of the developments in this area, highlighting the benefits, drawbacks, and applicability of various ways to solving problems[2]. This evaluation intends to aid in a deeper comprehension of the issue and assist in the identification of new directions for more investigation and development by reviewing the existing approaches.

The review begins by presenting a detailed formulation of the UC problem, capturing the essential components and considerations involved in its optimization. This includes modeling the electricity demand, generator characteristics, transmission network constraints, and economic factors such as fuel costs. By understanding the formulation of the UC problem, readers will gain insight into the complexity and interconnectedness of the variables and constraints that influence the solution methods.

Subsequently, the review categorizes the solution methods for Unit Commitment into different classes, providing a structured framework for analysis. The categories encompass mathematical programming techniques, heuristic algorithms, metaheuristics, and hybrid approaches[3]. Each category is explored in detail, discussing representative methods, their underlying principles, and their suitability for different problem scenarios. This analysis provides a comprehensive overview of the landscape of solution methods, aiding in the selection of appropriate techniques based on specific requirements and constraints.

The assessment also discusses the always evolving Unit Commitment problems, such as the incorporation of renewable energy sources, demand response initiatives, and energy storage technologies. The UC problem has become more complex and unpredictable as a result of these new factors. The review investigates how current problem-solving techniques have modified their approaches to take into account these elements, highlighting the benefits and drawbacks of each strategy.

Additionally, the review discusses the incorporation of uncertainty modeling techniques in Unit Commitment, such

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as stochastic programming, robust optimization, and scenario-based approaches. These methods aim to capture and manage the uncertainties inherent in power system operations, enabling more robust and flexible solutions. The review explores how uncertainty modeling has been integrated into different solution methods and the impact on their performance and computational requirements.

To provide a comprehensive assessment of the solution methods, the review presents a comparative analysis based on various performance metrics, including solution quality, computational time, scalability, and applicability to different system sizes and operational scenarios. This analysis enables readers to understand the trade-offs between solution quality and computational complexity associated with different methods.

Finally, the review concludes with an outlook on future research directions and potential advancements in Unit Commitment solution methods. It identifies promising areas for further exploration, such as the utilization of machine learning techniques, advanced optimization under uncertainty, and parallel computing, to enhance the efficiency, accuracy, and adaptability of solution methods for Unit Commitment[4]. By synthesizing the existing knowledge and advancements in Unit Commitment solution methods, this review paper aims to provide a valuable resource for researchers, practitioners, and policymakers involved in power system planning and operation[5]. It strives to foster a deeper understanding of the challenges, opportunities, and potential paths forward in optimizing the unit commitment process to ensure reliable, cost-effective, and sustainable power system operations.

II. PROBLEM OF UNIT COMMITMENT

Unit Commitment (UC) problems are optimization tasks that arise in power system operations and are concerned with determining the optimal schedule for committing and dispatching power generating units over a specified time horizon. The goal of UC is to satisfy the electricity demand while considering various operational constraints and minimizing the overall cost of generation.

In the UC problem, decisions need to be made regarding which generating units should be turned on (committed) and at what time, as well as the power output (dispatch) of each committed unit at each time interval. These decisions must adhere to a set of constraints, which typically include

A. Demand satisfaction

The total power generated must be sufficient to meet the forecasted electricity demand while accounting for variations and uncertainties

$$.\sum_i p_{ij} = Demand_j \; \forall j$$

Where:

- $Demand_j$ represents the forecasted demand at the time interval *j*.

B. Generator operating constraints

Each generating unit has operational limits, such as minimum up/down time constraints, ramping limits, and start-up and shutdown costs. These constraints ensure that the committed units operate within their technical limitations.

- Power output limits:

$$p_{ij} \geq P_i^{min}.u_{ij} \qquad \forall i,j$$

$$p_{ij} \leq P_{Ii}^{max}.u_{ij} \qquad \forall i,j$$

Where:

- P_i^{min} and P_i^{max} represents the minimum and maximum power output limits for generator i.

- Ramp rate limits:

$$p_{ij} - p_{i,j-1)} \leq R_i \qquad \forall i,j > 1$$

$$p_{ij} - p_{i,j-1)} \leq -R_i \qquad \forall i,j > 1$$

Where:

  - R_i represents the ramp rate limit for generator i.

- Minimum up and down times:

$$\sum_{k=j}^{j+MinUp_i-1} u_{ik} \geq \text{MinU}p_i.u_{ij} \quad \forall i,j$$

$$\sum_{k=j}^{j+MinDown_i-1} (1-u_{ik}) \geq \text{MinDown}_i.u_{ij} \; \forall i,j$$

Where:

  - MinUp_i and MinDownn_i represent the minimum up and down times for generator i

C. Transmission network constraints

The UC problem needs to consider transmission capacity limits and ensure that the power flow on transmission lines remains within acceptable limits to maintain system stability.

Let's consider a constraint for a specific transmission line ll between nodes mm and nn:

$$\sum_i p_{im} - \sum_i p_{in} \leq Capacity_l \, \forall l$$

Where:

  - p_{im} represents the power output of generator I into node m.
  - p_{in} represents the power output of generator I into node n.
  - Capacity I represents the maximum capacity of transmission line l.

D. Fuel and emission costs:

The objective is to minimize the overall cost of generation, which includes fuel costs associated with the committed units and, in some cases, environmental considerations related to emissions.

The total fuel cost is calculated as the sum of the fuel cost per unit of power output multiplied by the power output of each committed generator:

FuelCost = $\sum_i \sum_j (f_i . p_{ij})$

EmissionCost = $\sum_i \sum_j (e_i . p_{ij})$

Where:

- f_i represents the fuel cost per unit of power output for generator i.
- e_i represents the emission cost per unit of power output for generator i.

The UC problem is a complex and computationally challenging task due to several factors. Firstly, it involves a large number of decision variables, as each generating unit needs to be considered for commitment and dispatch over multiple time intervals. Secondly, there are various interdependencies and constraints that must be satisfied simultaneously, requiring careful coordination and optimization. Lastly, uncertainties associated with demand forecasts, fuel prices, and availability of renewable energy sources add further complexity to the problem.

To solve the UC problem, various solution methods have been developed and studied. These methods can be broadly categorized into mathematical programming techniques, heuristic algorithms, metaheuristics, and hybrid approaches. Mathematical programming approaches, such as mixed-integer linear programming (MILP) and mixed-integer quadratic programming (MIQP), aim to find an optimal solution but can be computationally demanding for large-scale systems. Heuristic algorithms, such as dynamic programming, priority list methods, and Lagrangian relaxation, provide efficient solutions but may not guarantee optimality. Metaheuristic approaches, including genetic algorithms, particle swarm optimization, and simulated annealing, offer a balance between solution quality and computational efficiency.

The development and advancement of solution methods for UC have played a crucial role in improving the operational efficiency, reliability, and economic performance of power systems. Additionally, the increasing integration of renewable energy sources, demand response programs, and energy storage systems in power systems has posed new challenges and opened up opportunities for further research and innovation in solving UC problems.

Efficient and effective solutions to t he UC problem have a significant impact on power system operations, as they directly influence the dispatch and utilization of generating units, the overall cost of electricity generation, and the system's ability to handle fluctuations in demand and supply. Therefore, ongoing research and development efforts continue to focus on enhancing solution methods and addressing emerging challenges to ensure the optimal and sustainable operation of power systems.

III. PROBLEM OF UNIT COMMITMENT

Optimization techniques play a central role in solving Unit Commitment (UC) problems, as they aim to find the optimal commitment and dispatch schedule for power generating units. Various optimization methods have been employed to address the UC problem, each with its own strengths, limitations, and applicability. Here are some commonly used optimization techniques in the context of UC:

A. Mathematical Programming:

Mathematical programming techniques, such as mixed-integer linear programming (MILP) and mixed-integer quadratic programming (MIQP), have been widely applied to solve UC problems. These techniques formulate the UC problem as an optimization model with linear or quadratic objective functions and a set of linear or quadratic constraints.

Mathematical programming approaches provide the advantage of optimality guarantees, ensuring that the obtained solution is the global or near-global optimum. However, they can be computationally demanding, especially for large-scale systems, and may struggle with scalability.

B. Heuristic Algorithms:

- Heuristic algorithms are problem-solving techniques that rely on iterative processes and search heuristics to find near-optimal solutions without providing optimality guarantees. Dynamic programming is a well-known heuristic algorithm used for UC, which decomposes the problem into subproblems and solves them iteratively.
- Priority list methods prioritize the commitment and dispatch decisions based on specific criteria, such as operating costs or unit availability. Lagrangian relaxation techniques relax some of the problem constraints and solve a series of simpler subproblems. Heuristic algorithms are computationally efficient but may sacrifice optimality in favor of speed and simplicity.

C. Metaheuristics

Metaheuristic algorithms are high-level problem-solving techniques that guide the search for solutions in large solution spaces. Genetic algorithms, particle swarm optimization, simulated annealing, and tabu search are commonly employed metaheuristics in UC. These algorithms explore the search space by iteratively evaluating and modifying potential solutions based on probabilistic or stochastic rules.

Metaheuristics offer a balance between solution quality and computation time, making them well-suited for large-scale UC problems. They do not guarantee optimality but can often find good solutions in a reasonable amount of time.

D. Hybrid Approaches

- Hybrid approaches combine multiple optimization techniques to leverage their respective advantages and overcome their limitations. For example, a hybrid approach may integrate a mathematical

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programming formulation with a heuristic algorithm or metaheuristic to obtain both optimality guarantees and computational efficiency.

- This can involve using heuristics to generate initial solutions for mathematical programming models or using metaheuristics to refine solutions obtained from mathematical programming techniques.

The choice of optimization technique depends on factors such as the problem size, computational resources available, desired solution quality, and time constraints. Researchers and practitioners often select the most appropriate technique based on a trade-off between solution accuracy and computational efficiency. Additionally, ongoing research focuses on developing advanced optimization techniques, such as machine learning-based algorithms, to further enhance the effectiveness and efficiency of solving UC problems.

In conclusion, optimization techniques, including mathematical programming, heuristic algorithms, metaheuristics, and hybrid approaches, play a crucial role in solving Unit Commitment problems. These techniques enable the identification of optimal or near-optimal schedules for power generating units, considering various constraints.

IV. IMPROVED PARTICLE SWARM OPTIMIZATION METHOD

Particle Swarm Optimization (PSO) is a metaheuristic optimization technique inspired by the collective behavior of a swarm of particles. In the context of unit commitment, PSO can be utilized to find near-optimal commitment and dispatch schedules for power generation units. Here is a review of PSO techniques for unit commitment, along with equations::

A. Initialization

Define the population size N and the number of decision variables, which corresponds to the number of generators and time periods.

Initialize the position and velocity of each particle (solution) in the search space randomly or based on heuristics.

Evaluate the fitness (objective function value) of each particle based on its commitment and dispatch schedule..

B. Swarm Update:

For each particle i:,

Update the particle's velocity based on its previous velocity, cognitive component, and social component:

$$v_i(t+1) = w * v_i(t) + c_1 * r_1\left(p_{best}t_i - x_i(t)\right) + c_2 * r_2 * (g_{best} - x_i(t))$$

where:

$v_{i(t+1)}$ is the velocity of particle i at time t,

w is the inertia weight determining the impact of the previous velocity,

c1 and c2 are acceleration coefficients representing the cognitive and social components, respectively, r1 and r2 are random values between 0 and 1,p_{best_i}i is the personal best position (best solution) of particle i,$x_i(t)$ is the position (solution) of particle i at time t, gbest is the global best position among all particles in the swarm.

Update the particle's position based on its previous position and velocity:

$$x_i(t+1) = x_i(t) + v_i(t+1)$$

Evaluate the fitness of the new position (commitment and dispatch schedule).

Update the personal best position (pbest_i) of particle i if the new position is better than the previous best.

Update the global best position (gbest) if the new position is better than the previous global best.

C. Repeat the swarm update process until a termination condition is met (e.g., a maximum number of iterations or reaching a desired solution quality).

D. Output the best position (commitment and dispatch schedule) found during the iterations.

The objective function in the fitness evaluation step represents the cost to be minimized in the unit commitment problem. It typically includes components such as fuel costs, start-up costs, and other operational costs, and may consider constraints such as reserve requirements, ramping limits, and generation limits.

The specific implementation of PSO for unit commitment may involve adjusting parameters such as the inertia weight, acceleration coefficients, and termination criteria to achieve desired convergence and performance. These parameters can have a significant impact on the algorithm's behavior and its ability to find near-optimal solutions efficiently.

PSO techniques for unit commitment offer a flexible and computationally efficient approach to solving the problem. They can handle large-scale systems with complex constraints and provide good-quality solutions. However, like other metaheuristics, PSO does not guarantee finding the global optimum and may require parameter tuning and multiple runs to achieve satisfactory results.

V. DYNAMIC PROGRAMMING

Dynamic Programming (DP) is a technique used to solve optimization problems by breaking them down into smaller overlapping subproblems and solving them recursively. In the context of unit commitment, DP can be employed to find the optimal commitment and dispatch schedule for power generation units. Here's an overview of the DP solution method with equations:

A. Define the Problem:

Let T be the number of time periods in the scheduling horizon.

Let G be the set of power generation units, D(t) be the electricity demand at time period t,C(g, t) be the cost of generating power from unit g at time period t,S(g, t) be the start-up cost of unit g at time period t,U(g, t) be the upper limit of power generation for unit g at time period t, L(g, t) be the lower limit of power generation for unit g at time period t.

B. Define the State Variables:

Define the state variable x(g, t), which represents the commitment decision for unit g at time period t. It can take binary values: x(g, t) = 1 if unit g is committed, and x(g, t) = 0 otherwise.

Define the state variable P(g, t), which represents the power generation level of unit g at time period t.

C. Formulate the Recursion:

The objective is to minimize the total cost over the scheduling horizon. Let J(t) be the optimal cost at time period t.

The optimal cost at the last time period is given by:

$J(T) = \sum[g \in G]\ C(g, T) * P(g, T)$

The optimal cost at time period t, where $1 \leq t < T$, can be recursively defined as:

$J(t) = \min\{ \sum[g \in G]\ [C(g, t) * P(g, t) + S(g, t)] + J(t+1) \}$ (subject to constraints)

The constraints include:

Power balance constraint: $\sum[g \in G]\ P(g, t) = D(t)$

Unit commitment constraints: $L(g, t) \leq P(g, t) \leq U(g, t)$ if x(g, t) = 1, and P(g, t) = 0 if x(g, t) = 0

Transition constraints: x(g, t+1) = 1 if x(g, t) = 1, and x(g, t+1) = 0 if x(g, t) = 0

D. Solve the Recursion:

To find the optimal commitment and dispatch schedule, we can solve the recursion equation backward starting from time period T-1 and going back to time period 1.

At each time period, compute the optimal cost J(t) and the corresponding commitment decision x(g, t) and power generation level P(g, t).

E. Output the Optimal Solution:

The optimal commitment and dispatch schedule can be obtained by following the computed commitment decisions x(g, t) and power generation levels P(g, t) from time period 1 to T.

It is important to note that the formulation and specific equations of the DP solution method may vary depending on the specific problem formulation, including the objective function, cost components, and constraints. However, the core idea of breaking down the problem into smaller subproblems and solving them recursively remains the same.

VI. IMPROVED LAGRANGIAN RELAXATION APPROACH

The improved Lagrangian relaxation approach for Thermal Unit Commitment (UC) aims to enhance the performance and solution quality of the Lagrangian relaxation technique in solving the UC problem. The key aspects of the improved Lagrangian relaxation method are:

A. Formulation of the Lagrangian Relaxation Problem

The unit commitment problem is formulated as a mixed-integer linear programming (MILP) problem.

The binary commitment variables are relaxed to continuous variables, resulting in a relaxed formulation.

The objective function includes components such as fuel costs, start-up costs, and other operational costs, subject to operational constraints such as reserve requirements and ramping limits.

B. Lagrangian Relaxation

Introduce Lagrange multipliers (also known as dual variables) λ to relax the constraints.

The Lagrangian function L(x, λ) is defined as the objective function of the relaxed problem minus the sum of the Lagrange multipliers multiplied by the violated constraints:

$L(x, \lambda) = f(x) - \Sigma(\lambda_i * g_i(x))$

C. Solution Algorithm

Solve the relaxed problem using a suitable optimization technique such as linear programming (LP).

Update the Lagrange multipliers based on the violated constraints.

Iterate between solving the relaxed problem and updating the Lagrange multipliers until convergence is achieved.

D. Calculation of Shadow Prices:

The (also known as dual price) of each constraint $g_i(x)$ represents the marginal cost of relaxing that constraint.

The shadow price of constraint $g_i(x)$ is given by the corresponding Lagrange multiplier λ_i at convergence.

E. Recovery of Integer Solutions:

Once the Lagrange multipliers have converged, the relaxed solution can be converted into an integer solution by applying a heuristic or rounding procedure.

The heuristic should consider the commitment and ramping constraints to obtain a feasible and near-optimal integer solution.

It's important to note that the specific equations and implementation details of the Lagrangian Relaxation method for unit commitment depend on the problem.

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VII. PRIORITY LIST

The Priority List solution method is a heuristic approach used for Unit Commitment (UC) in power system operations. It involves assigning priorities to power generating units based on predetermined criteria and making commitment and dispatch decisions in a sequential order. The steps of the Priority List method can be summarized as follows:

A. Priority Assignment

Units are assigned priorities based on factors like operating costs, availability, start-up/shut-down times, or environmental considerations.

B. Sorting Units

Units are sorted in descending order of their assigned priorities.

C. Feasibility Check

For each unit in the sorted list, a feasibility check is performed to ensure that committing and dispatching the unit will not violate operational constraints.

D. Commitment and Dispatch Decision

If a unit passes the feasibility check, it is committed and dispatched according to the determined schedule.

E. Iterative Process

Commitment and dispatch decisions are made sequentially for each unit in the sorted list, considering the system's load demand and the commitment status of previously committed units.

F. Performance Evaluation

The resulting schedule is evaluated based on criteria such as generation cost, reserve requirements, or other relevant metrics.

VIII. CONCLUSION

Unit commitment (UC) is a crucial optimization problem in power system operations that involves determining the optimal scheduling of power generating units. Various solution methods have been developed to tackle the UC problem, each with its strengths and limitations. Heuristic methods, including genetic algorithms, particle swarm optimization, and priority list, offer computationally efficient solutions with reasonable accuracy. They are particularly suitable for large-scale systems and can handle complex constraints. However, these methods may not guarantee global optimality and may rely on certain assumptions or heuristics.

Relaxation-based methods, such as Lagrangian relaxation and its improved versions, provide efficient solutions by decomposing the UC problem into smaller subproblems. These methods balance the trade-off between constraint satisfaction and objective optimization and are capable of handling operational constraints effectively. However, they may require careful tuning and may not guarantee global optimality.

Hybrid approaches that combine multiple solution methods, such as combining mathematical programming with heuristic methods or stochastic programming with relaxation-based methods, can leverage the strengths of each approach to improve solution quality and computational efficiency. These hybrid methods provide a promising direction for addressing the UC problem.

Overall, the choice of a suitable UC solution method depends on the specific requirements of the system, computational resources available, and the trade-off between solution quality and computational efficiency. Researchers and practitioners continue to explore and develop new solution methods and enhancements to address the challenges of UC and improve the reliability and efficiency of power system operations.

REFERENCES

[1] R. H. Kerr, J. L. Scheidt, A. J. Fontana and J. K. Wiley, “Unit Commitment”, IEEE Transactions on Power Apparatus and Systems. Vol. PAS-85, No. 5, pp. 417-421. May 1966..

[2] Padhy, N. Unit commitment-A bibliographical survey. IEEE Trans. Power Syst. 2004, 19, 1196–1205.

[3] Zwe-Lee Gaing, “Discrete Particle Swarm Optimization Algorithm for Unit Commitment”, IEEE Power Engineering Society General Meeting, Vol.1, pp. 418-424, July 2003.

[4] Elsayed, A.M.; Maklad, A.M.; Farrag, S.M. A New Priority List Unit Commitment Method for Large-Scale Power Systems.In Proceedings of the 2017 Nineteenth International Middle East Power Systems Conference (MEPCON), Cairo, Egypt, 19–21December 2017.

[5] Moradi, S.; Khanmohammadi, S.; Hagh, M.T.; Mohammadiivatloo, B. A semi-analytical non-iterative primary approach based on priority list to solve unit commitment problem. Energy 2015.

[6] Bruninx, K.; Delarue, E. Endogenous probabilistic reserve sizing and allocation in unit commitment models: Cost-effective,reliable, and fast. IEEE Trans. Power Syst. 2017.

[7] Ahmadi-Khatir, A.; Bozorg, M.; Cherkaoui, R. Probabilistic spinning reserve provision model in multi-control zone power system.

[8] IEEE Trans. Power Syst. 2013,

[9] [8] Shi, J.; Oren, S.S. Flexible line ratings in stochastic unit commitment for power systems with large-scale renewable generation. Energy Syst. 2020.

[10] Scuzziato, M.R.; Finardi, E.C.; Frangioni, A. Comparing spatial and scenario decomposition for stochastic hydrothermal unit commitment problems. IEEE Trans. Sustain. Energy 2018.

[11] Lopez-Salgado, C.J.; Año O.; Ojeda-Esteybar, D.M. Stochastic unit commitment and optimal allocation of reserves: A hybrid decomposition approach. IEEE Trans. Power Syst. 2018.