International Journal of Science and Engineering Applications
Volume 14-Issue 03, 04 – 06, 2025, ISSN:- 2319 - 7560
DOI: 10.7753/IJSEA1403.1002

The Overview of Optimization Methods for Water Power Scheduling in Cascade Small Hydropower Stations

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Abstract: Hydropower is currently one of the most widely used renewable clean energy sources in power systems. When scheduling and optimizing hydropower plants, operators need to pay attention to metrics such as power generation and minimum output. Constantly monitoring power generation enables the scientific and rational utilization of water resources, allowing enterprises to achieve optimal benefits. The maximum model for minimum output can improve the performance of hydropower systems, enhancing the minimum output, making it easier for cascade small hydropower stations to effectively adjust during wet and dry periods, and achieving the goal of compensation and regulation. The hydropower industry is an essential sector for driving social and economic development, and cascade small hydropower stations are a crucial part of this industry. These stations, located within the same river basin, need to not only operate normally but also coordinate the dual functions of power generation and water usage to improve overall efficiency.

Keywords: Cascade small hydropower stations; Hydropower scheduling; Optimization methods

1. INTRODUCTION

Cascade small hydropower stations, as a key component of the power system, require enterprises to effectively manage their scheduling and optimization processes to resolve various operational issues and ensure stable operation. Currently, many scholars have conducted in-depth research in this area, often using single-objective optimization scheduling models. These models typically prioritize goals such as maximizing power generation, minimizing water consumption, and increasing total storage capacity, which have shown some success. However, due to the close interconnection between the hydraulic and electrical aspects of cascade small hydropower stations, there are certain constraints and challenges in their operation, making the creation of an optimization scheduling model a major difficulty. Additionally, the dynamic characteristics of water power scheduling in these stations are quite evident, which demands continuous improvement in solution methods. With the ongoing development of the electricity market, hydropower optimization scheduling must actively pursue innovative improvements to meet the demands of the new era.

2. OPERATING CHARACTERISTICS OF CASCADE SMALL HYDROPOWER STATIONS

(1) Undertaking Corresponding Social Functions: Hydropower stations primarily have multiple functions, such as flood control, irrigation, and ecological water use. Cascade small hydropower stations are no exception and exhibit this multifaceted characteristic. Their operation not only needs to meet the requirement of safe operation but also needs to achieve comprehensive utilization by incorporating various parameter indicators into the power generation optimization scheduling model. This makes the scheduling and optimization process subject to various constraints, with numerous conditions to address, and in a diversified form.

(2) Hydraulic Interconnection: Cascade small hydropower stations are usually located within the same river basin, with two main connection types: intermittent and connected. The power generation and water flow discharge from upstream stations have a significant impact on downstream stations, directly affecting their operation. Therefore, a comprehensive water usage plan needs to be developed based on the actual conditions. Additionally, the discharge from a hydropower station in one period can greatly influence the electricity and water plans for subsequent periods. This indicates a hydraulic coupling relationship between the various stations and the time periods of each station. As a result, during the operational scheduling process, cascade small hydropower stations exhibit complexity in terms of time-space relationships, energy transfer, and scheduling.

(3) Electric Power Connection: When conducting unified scheduling for cascade small hydropower stations, attention must be paid to the operational speed and mode of each station. This allows for the proper understanding of the storage capacity, hydrological compensation, and other benefits of the stations. However, because a large number of hydropower stations are located within the same river basin, each with its own adjustment capabilities, various issues arise during short-term scheduling. The most obvious issue is load distribution. When multiple hydropower stations are connected to the same grid and share the same transmission channel, capacity shortages are common, and mutual constraints may occur between stations. The electric power connections between the cascade small hydropower stations and the power grid, as well as the inter-station electric power relationships, make the optimization and scheduling process considerably challenging.

3. THE SCHEDULING DIFFICULTY OF CASCADE SMALL HYDROPOWER STATIONS

3.1 Classic Optimization Methods

Up to now, the optimization and innovation of hydropower scheduling methods have always been a key focus of research for relevant personnel, directly affecting the safe and stable operation of cascade small hydropower stations. In the hydropower scheduling optimization process, classic optimization methods are commonly used, which include linear programming, nonlinear programming, and dynamic programming.

Linear programming, based on the fundamentals of operations research, is typically applied in cascade small hydropower stations as an extension of the operations research field. Compared to other algorithms, linear programming emerged earlier and has developed rapidly in recent years. With the continuous optimization and improvement of the related theoretical system, this method has been widely applied and its usage is deepening. Additionally, linear programming can be viewed as a quantitative method, providing a reference for technological optimization and innovation.

Next, nonlinear programming, which emerged in the mid-20th century, also has operations research at its core, but in practical applications, it is often constrained by various factors. This method takes the objective function as the starting point for implementation, analyzing data and calculating results to derive a nonlinear function.

Finally, dynamic programming, which is a mathematical tool derived from operations research theory, focuses on optimizing decision-making processes at various stages. The dynamic programming algorithm divides the problem to be solved into multiple subproblems, solving each subproblem individually to obtain the actual answer. Dynamic programming links decision problems across multiple stages, formulating targeted decisions based on the actual situation of each stage.

In the hydropower scheduling optimization process, operators should consider the entire system to make the whole operation process more systematic. The optimal results achieved at different stages depend on the current state of the hydropower station, which in turn has a significant impact on future development. The stages are interrelated, existing in a chain-like structure, to ensure that the objective function in the decision process reaches its extreme value. The above methods can all be represented by various mathematical models, and their calculation processes differ, leading to noticeable differences in the optimized values. Operators need to analyze and consider the specific situation to choose the most suitable scheduling method..

3.2 Modern Intelligent Optimization Methods

(1) Simulated Annealing Algorithm (SA): This method is based on the principle of solid annealing. When a solid material is heated, the particles begin to undergo Brownian motion, which intensifies as heating continues, eventually leading to a disordered state. When the internal energy reaches a certain strength, annealing begins, and the thermal motion of the particles reduces, making the movement more orderly and structured until the system reaches equilibrium. The internal energy decreases and ultimately tends toward its minimum value. Simulated annealing is an algorithm that iteratively seeks the optimal solution using a probabilistic "jump" mechanism to explore the objective function, ensuring that the algorithm considers the best global solution rather than getting stuck in a local minimum.

(2) Genetic Algorithm (GA): The genetic algorithm is inspired by the principles of biological evolution and genetics. It is a computational model that treats individuals in a population as research subjects and utilizes randomization techniques to guide the exploration of the encoded parameter space and efficiently search for solutions. The algorithm involves many components, including parameter encoding, fitness function design, and initial population selection, as well as genetic operators such as selection, crossover, and mutation. The main feature of genetic algorithms is their global optimization search capability. They are simple, universal, robust, capable of parallel processing, and highly practical. The genetic algorithm has seen significant application across various industries and continues to evolve as an indispensable intelligent optimization tool.

(3) Tabu Search (TS): This method marks previously searched optimal solutions and uses a flexible and efficient storage structure along with clearly defined tabu rules to avoid backtracking during the search process. By applying the "aspiration criterion," some solutions that are usually forbidden are exempted if they satisfy specific requirements. The primary characteristic of tabu search is its global nature, which simulates human thinking and uses the optimal solution's tabu search to achieve global optimization. This allows the algorithm to explore diverse paths and obtain more accurate data.

(4) Artificial Neural Network (ANN): The basic idea behind artificial neural networks is to model biological neural networks using mathematical models that simulate their structure and functions. ANN typically operates on known data, learns from it, and makes adjustments based on relationships such as excitation and inhibition between neurons. The main components of ANN are different artificial neurons, and because these networks contain a large number of neurons, they can store substantial amounts of data, including uncertain information. This allows them to process data quickly and effectively. Moreover, artificial neural networks can analyze local conditions, making them capable of reasoning and identifying patterns in data, thus supporting systems with automatic recognition functionality to derive conclusions based on inference.

3.3 Selecting the Corresponding Scheduling Period and Scheduling Objectives through Mathematical Models and Optimization Algorithms

In the process of scheduling for cascade small hydropower stations, understanding the actual demand and supply is essential to ensure the safe and stable operation of the power system. The application of mathematical models and optimization algorithms can be used to model the system according to the demand, and based on the power generation capacity of the cascade small hydropower stations, appropriate generation plans can be formulated. At the same time, the optimization strategy for hydropower scheduling must consider the coordination of each hydropower station in the cascade to ensure the balance between supply and demand in the power system.

During practical implementation, close attention must also be paid to factors such as the load generated by the power system, line capacity, and transmission losses to ensure the safe and stable operation of the power grid. By using mathematical models and optimization algorithms to simulate the system’s operation, real-time data can be used to predict demand and set corresponding generation plans, thus enhancing the stability and reliability of the power system.

Furthermore, when scheduling cascade small hydropower stations, it is crucial to manage water resources scientifically to prevent ecological damage. Mathematical models and optimization algorithms can effectively manage water resources by adjusting the scheduling based on demand, minimizing waste, and protecting the environment from severe damage. Additionally, appropriate scheduling strategies should be developed based on actual conditions to reduce greenhouse gas emissions, follow sustainable development principles, and meet the requirements of green energy and environmental protection.

3.4 Achieving good coordination with the electricity market.

Currently, fluctuations in electricity market prices and load demand changes significantly affect the scheduling and generation planning of cascade small hydropower stations. To ensure that these stations achieve ideal benefits and meet development requirements, it is essential to have a detailed understanding of the actual demand in the electricity market. Based on this understanding, adjustments to the power generation should be made to achieve a balanced development goal.

If the market price is too high, the cascade small hydropower stations need to increase their generation to maximize their revenue. Conversely, if the market price is too low, they should reduce generation to avoid excessive production costs. Adjusting to market price fluctuations ensures that the hydropower stations can achieve ideal benefits.

Additionally, in accordance with the actual load conditions in the electricity market, the stations must adjust their generation accordingly. For example, if demand is high during a certain period, generation should be increased to meet usage requirements. Conversely, if demand is low, generation should be reduced to prevent oversupply.

When optimizing hydropower scheduling, market demand and the specific conditions of the cascade small hydropower stations must be considered. In practice, there are several challenges, such as significant market price fluctuations that require immediate responses, incomplete market understanding, and poor forecasting, which may adversely affect scheduling plans. Moreover, if the market mechanism is not well-developed, economic benefits cannot be maximized.

4. COMPARISON OF OPTIMIZATION METHOD PERFORMANCE

Classical optimization methods struggle to effectively handle complex and high-difficulty scheduling optimization problems, resulting in limited feasibility. Linear programming algorithms, as an advanced implementation method, offer a unified algorithm that can solve various linear programming problems. However, the main drawback of this method is that it only plays an important role in scenarios involving linear relationships. Compared to linear programming, nonlinear programming also has a unified algorithm for handling different types of problems, but it has its limitations, as there is currently no algorithm that can be applied to all nonlinear programming problems.

Dynamic programming algorithms, on the other hand, can obtain optimal solutions from a global perspective during the solving process. By using a dynamic approach, the evolution process is demonstrated, enhancing the connections between different stages and allowing for a better understanding of specific features. When combined with theoretical knowledge and the experience of practitioners, dynamic programming can improve solution efficiency. However, due to the lack of a unified standard in dynamic programming models, the process of solving with numerical methods may encounter the "curse of dimensionality," which complicates the computation.

5. DISCUSSION

In conclusion, under the context of the new era, optimizing the hydropower scheduling of cascade small hydropower stations is crucial. It is a systematic and complex issue that can significantly improve energy utilization efficiency, protect the natural ecological environment, and contribute to the sustainable and stable development of society. Therefore, relevant personnel need to place greater emphasis on this matter, conduct in-depth research on the theories related to cascade small hydropower station scheduling, and adjust plans and strategies based on the specific circumstances of these stations. By developing appropriate models, they can ensure that the stations achieve both sustained stable development and ideal economic benefits, while keeping pace with the development of the times.

6. REFERENCES

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