Optimal Scheduling of Hydro-Wind-Solar Hybrid Systems

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In order to establish a hydro-wind-solar hybrid system, the control of multiple power sources and the coordination and real-time scheduling between multiple power sources must be solved. The realization of a multi-energy complementary system first needs to pay attention to the form in which dozens or even hundreds of wind and solar power plants participate in power generation scheduling, how to predict and describe their power generation laws, and the risks brought about by their uncertainties, in addition to to paying attention to the coordinated operation of hydropower stations and large-scale wind power stations on multiple time scales.

Keywords: hydro-wind-solar system ; energy complementary ; risk management

1. Prediction and Description of Wind and Solar Power Generation

Affected by the natural environment, climatic conditions, and geographical space, wind speed and light intensity have great variability and uncontrollability in time series, resulting in strong volatility, intermittent, and uncertainty in the time and space distribution of wind power and photovoltaic power generation [1][2][3][4][5]. How to accurately predict and describe the output law of wind and solar power plants is one of the core issues in promoting new energy consumption and speeding up the development and operation of multi-energy complementary, involving the identification of power generation-influencing factors [6][7][8][9]. There are many factors that affect the output power of wind and solar power generation systems. If each influence is considered, then this will increase the complexity and difficulty of prediction. It is necessary to accurately analyze the factors that are closely related to the output power and find the corresponding relationship to construct a mathematical index so as to provide a premise for the prediction of wind and solar power generation. Accurate renewable power generation forecasting is very important for the scheduling optimization of hydro-wind-solar hybrid systems. The problems of medium- and long-term forecasts and uncertainty are currently intractable. How to reasonably select and improve the corresponding forecasting methods for different loads to ensure energy output efficiency is still an issue worthy of in-depth discussion.

2. Risk Management of Hydro-Wind-Solar Hybrid Systems

Due to the uncertainty of wind and solar power generation, large-scale direct grid connection of new energy will disrupt the balance of a power system and cause a serious impact on the power grid. Quantifying the uncertainty of the output of water, wind, and photovoltaic power generation can allow one to directly analyze the characteristics of power generation or study the error law of the predicted output [10]. Uncertainty is very important in the operation of a hybrid energy system, and the uncertainty of a hybrid energy system is basically considered in the usual research [11][12], but the risks brought by uncertainty are mostly ignored. Hydro-wind-solar hybrid systems often face risks such as load curtailment, no water for power generation at the end of the dry season, power curtailment, output shortages, and spilled water [13][14][15][16].

The power balance of the power system is the basis for stable operation of the power grid. However, the starting, stopping, and changing of power sources and loads, as well as the interruption of transmission lines, can lead to power imbalances in the grid. When the power grid is unbalanced, the voltage and frequency fluctuate, which may cause the grid frequency and node voltage to exceed the limit and even cause serious accidents such as grid oscillation and disconnection. When power is redundant, generation shedding is a proven method for controlling the power system and returning to stable operation [17]. In a power system with high penetration rates of wind power and photovoltaic power, wind and photovoltaic shedding are gradually applied to maintain the power balance of the power system. In a power system with high penetration rates of wind power and photovoltaic power, both are also gradually applied to maintain the power balance of the power system. When the power is insufficient, because the short-term power boosting capacity of the synchronous generator is limited, the load shedding method is often used to balance the power [18][19]. However, generation shedding is not conducive to the restoration of the power grid, and the reconnection of generators to the grid may also cause shocks. Load shedding has economic and reliability problems, and increasing the reserve capacity of synchronous generators can reduce load shedding. However, its cost is high, especially in a power system with a high proportion of new energy. The installed capacity of synchronous generators has difficulty meeting the demand for a reserve. Accordingly, it is of great practical significance to ensure the effective management and control of risks while maximizing the benefits by using new energy to connect to the grid and adjust in a random environment.

3. Optimal Dispatching of Hydro-Wind-Solar Hybrid Systems

The power station of the water-solar hybrid system has a large scale, and the power generation scheduling of large-scale power station groups faces both technical problems, such as unified management and maintenance of massive operation information, as well as basic theoretical problems, such as the accuracy of large-scale system optimization modeling and calculation efficiency. However, with a single power station as the control point, the interactions of direct dispatching of instructions will greatly affect the power generation dispatching model’s construction and solution efficiency, and it is difficult to accurately control the power generation law, which also brings great uncertainty to the power generation planning and dispatching operation of a power grid. In this case, cluster scheduling of power stations is an effective way to reduce the number of directly dispatched power stations [20], but how to determine the appropriate number of clusters and the power stations they contain is the main problem faced by this method. The specific cluster division method is closely related to the actual engineering characteristics, such as power supply composition, and the installed capacity, as well as the power generation characteristics, so practical and effective methods are needed.

The key to the complementary operation of hydro and wind power lies in that the reservoir has the regulation and storage capacity and hydropower has strong regulation properties [21][22]. The power transmission characteristics of hydropower at “non-peak regulation” and “anti-peak regulation” will increase the difficulty of peak regulation and trough consumption pressure in a power grid. Therefore, how to rationally utilize the storage capacity of a reservoir will be directly related to the long-term operation effect and efficiency of a complementary system [23]. In this operation mode, not only should the uncertainty of the flow be considered but also the short-term flexibility adjustment needs and long-term power consumption needs of wind and solar power. Reconstructing the long-term operation mode of the main stream cascade-controlled reservoir group and the water level control rules of the key nodes before and at the end of the flood season is another key problem in the complementary operation of water and wind power. The essence is a stochastic optimization problem of large-scale multi-type power station groups under the conditions of long, medium, and short multi-time scale coupling, runoff, and wind and solar power generation with multiple uncertainties. Compared with the scheduling rule optimization of a single-type hydropower system, this is more complex and difficult. It is necessary to explore innovative ideas and solutions in model construction.

When the proportion of new energy installed reaches a certain degree, the influence of power fluctuations increases significantly in the power grid load trough and peak periods, which increases the demand for flexible adjustment of day-ahead and real-time dispatching. This aggravates the difficulty of power balance in the whole cycle and the pressure of power grid peak shaving and frequency modulation [24], which can easily cause the problem of system stability [25]. From the perspective of short-term operation, the problem of hydro-wind-solar complementarity and coordination is prominent. On the one hand, the complementarity between hybrid energy sources cannot be ignored [26]. It is necessary to consider the uncertainty of wind and solar power generation to accurately describe the flexibility adjustment requirements of the system [27] (i.e., how much adjustable capacity is needed to stabilize the fluctuation of new energy output). The flexibility index and its characterization method need to be studied. On the other hand, it is necessary to study the day-ahead joint dispatch model and real-time coordinated control strategy of large-scale new energy and adjustable hydropower stations, considering the target requirements of system flexibility, new energy consumption, etc. to realize the efficient solution of the model and determine day-ahead and real-time start-stop methods and the output plans of a complementary system and its units.

Essentially, multi-energy coupling makes the operation of hydro-wind-solar hybrid systems more complicated and increases the complexity of decision making during system operation, such as the increase in the dimension of decision variables, multiple constraints on optimization problems, and possible non-convex nonlinearity. In the scheduling of hydro-wind-solar hybrid systems especially, the analysis and finding solutions to the problem will become more difficult. The design of an energy scheduling framework under multi-energy technology, the physical constraint modeling of multi-energy scheduling, the establishment of a multi-energy elastic demand characteristic model, and the solution of non-convex nonlinear energy scheduling optimization problems have become challenges for the operation research of hydro-wind-solar hybrid systems.

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