Decision support system for integrated management of hydro-thermal-wind-solar hybrid energy system

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Abstract. A decision support system is presented for integrated management of hydro-thermal-wind-solar hybrid energy system. Three main modules are included, data management module, operation conditions and constraints input module, and generation schedule optimization module. The DSS is designed based on an advanced technical framework and implemented using Java program. Many user-friendly interfaces are available to enhance the usability and flexibility of all modules. Since 2016, the DSS has been used to make everyday quarter-hourly generation schedules of 170 hydropower plants, 150 wind plants, 80 solar plants, and 11 thermal plants operated by the dispatching center of Yunnan Power Grid. More than 1000 operational schemes have been carried out by all power plants.

1. Introduction

In the past two decades, the construction of renewable power plants and power grids in China has experienced rapid development. The installed capacity of renewable energy power generation has expanded rapidly. By the end of 2018, the hydropower, wind and solar generation capacities have reached 352 million kW, 184 million kW and 174 million kW, respectively, ranking first in the world [1,2]. These plants are extensively connected through inter-provincial and -regional ultra-high voltage ac/dc network grid, and constitute a huge and complex regional/provincial power grid multi-source hybrid energy system.

At present, a single provincial power grid is in charge of more than 400 large and medium-sized power plants [3,4]. This number may be larger for a regional power grid that usually has several subordinate provincial power grids. The management and generation scheduling of such large-scale hybrid energy systems requires a practical and efficient tool to provide information and technique for obtaining rational operational decisions [5]. Therefore, most power grids of China have accelerated the informatization construction for managing and scheduling various power plants. Many operation software systems were thus developed, such as operation management system, operation control system, load forecasting system, new energy power prediction system, energy-saving power generation dispatching system, runoff forecast system, maintenance management system, and so on. Among them, the integrated management of hydro-thermal-wind-solar hybrid energy system is usually performed by the energy-saving power generation dispatching system. This decision support system (DSS) is one of the most important operation systems, which is used to make multiple time-scale generation schedules of all power plants.

Yunnan Power Grid (YNPG) is taken as an example. Currently, the provincial dispatching center of
the YNPG is managing more than 400 power plants that cover hydropower, wind, solar, and thermal power. It is responsible for making yearly, monthly, weekly, daily, quarter-hourly power generation schedules. Such a large-scale hybrid energy system involves many operation constraints and conditions [6-8]. In everyday generation scheduling, how the system operators accurately and efficiently prepare and determine these constraint boundaries and conditions is very tedious and difficult. A suitable decision support tool can help to complete the task within reasonable time. Moreover, this system produces a bulk of historical data, operation scheme data, and analysis data in daily generation operations. How the system operators effectively manage large-scale power plants and their data, as well as efficiently optimize their generation schedules are also challenging technique problems. The conventional excel-based simple analysis tool is very hard even impossible to provide elaborative operation analysis and efficient planning and management of large-scale power plants. There is an urgent need for decision support tools of large-scale hybrid energy systems and key techniques. In fact, this is a common problem and need in many provincial and regional power grids of China. Therefore, depending on the actual needs of power system operations, this study focuses on an elaborate design for a decision support system for integrated management of hydro-thermal-wind-solar hybrid energy system.

The past three decades have seen the advancements of the DSS for electrical power system planning and management because it can facilitate this task using computer technology. Some DSSs have been applied to specific engineering, such as RiverWare [9]. The literatures have presented a detailed review about the development of DSSs [10,11]. However, it should be noted that different hybrid energy systems usually have discrepant requirements for the modules of the DSS. None of a DSS is universal for all real-world engineering. Moreover, managing large-scale power plants and solving complex generation scheduling problem on a hydro-thermal-wind-solar hybrid energy system may be very hard with these DSSs based on standard commercial solvers such as Cplex [12], Minos [13], and Lingo [14]. This is because it is difficult to dynamically and frequently change operation conditions and constraints in practical engineering. Also, the whole optimization process is usually invisible for users so that they may need much effort to find the reason of unreasonable optimization results. The main objective of this study is to develop a DSS to provide flexibility and calculation platform for integrated management of hydro-thermal-wind-solar hybrid energy system that is operated by a provincial power grid. More importantly, the presented DSS will allow dynamic change of operation conditions and constraints and provide flexible interactive functions for users. The whole calculation process is also visible. Some commonly used models and methods, such as power balance model and dynamic programming method, are integrated in this DSS.

The rest of this study is organized as follows. Section 2 describes the framework of the DSS. The section 3 shows the detail of main modules of the DSS. In section 4, the application of the developed system to Yunnan Power Grid is briefly introduced. Section 5 concludes the study.

2. The framework of DSS

According to practical operation requirements and the characteristics of the electric power industry, the DSS of hybrid energy system is designed based on a mature data platform. There are four layers, including data access and validation, data storage layer, service layer, analysis and application layer, as shown in figure 1.

- The data access and verification layer is responsible for the data acquisition and accuracy verification of the whole system. This layer integrates the Webservice, JDBC and other classical data interaction technologies and the big data technologies such as Flume and Sqoop to realize the seamless connection with other operation software systems mentioned above. The automatic transaction method is incorporated to ensure the timeliness of data access. Multi-source data verification technology based on professional characteristics is proposed to intelligently analyse and clean all access data by using various data characteristics and correlation relations of power generation scheduling.
- The data storage layer is composed of relational database, distributed database and Hadoop
file system, which can efficiently store massive heterogeneous historical records and operation scheme data through multi-platform collaboration.

- The service layer provides unified data access services and defines uniform data interfaces by standardizing data demand parameter sets. Multi-source and multi-dimensional data integration processing technology, the structured query language, Hadoop cluster technology and data caching technology, are coupled to provide a fast response to various data requests. This layer can meet complex requirements of real-time extraction of large-scale data in the generation scheduling and operation analysis.

- Analysis and application layer is designed to fully employ a large number of operation data and efficiently determine the generation schedules through using the clustering analysis, regression analysis, correlation analysis, space-time series analysis technique. This layer help identify the key factors that influence the operational decision, and then develop a power generation decision-making model based on data driven. The main user interfaces for managing and scheduling power plants are also included in this layer.

Figure 1. Framework of the DSS.

3. Main modules of DSS

The DSS is developed for hydro-thermal-wind-solar hybrid energy system that satisfies power demands of one provincial power grid when the daily energy target or reservoir storage target for each power plant is given. Note, power balance at each period must be met in developing operating policies. The DSS consists of three modules, data management module, operation conditions and constraints input module, and generation schedule optimization module. These three modules are necessary and important in making generation schedules. The first module manages and provides basic data for generation scheduling. The second module is responsible for setting all operation constraints and conditions. The third module utilizes suitable optimization model and method to determine rational operation decisions. They are respectively shown in the following subsections.

3.1. Data management module

This module provides five components, including hydro data management, thermal data management, wind data management, solar data management, and data interface management. The first four components can add or edit various data about each type of plants and units. The fifth component manages the data interface between the DSS and other operation software systems, where the WebService technology is used for securing the data transmission. Figure 2 depicts the detailed functions of these components. Additionally, the data management module is improved by the
graphical and tabulated capabilities. In other words, the user can easily query or modify data by graphic or tabular form.

**Figure 2.** Detailed functions of data management module.

In this module, the dynamic programming method is utilized for determining the unit commitment of hydropower units. With a fixed head and a predetermined power generation, this problem can be formulated as minimizing turbine discharge for a hydropower plant, shown as equation (1). The detailed procedure can refer to our previous work [15].

\[
\text{Min } q = \sum_{i=1}^{N} q_i(p_i, h)
\]  

where stage variable \( i \) = index of unit; \( h \) = fixed head; state variable \( \bar{p}_i \) = remaining generation from units \( i \) to \( N \); decision variable \( p_i \) = generation for unit \( i \); \( q_i \) = turbine discharge of unit \( i \) in \( p_i \).

### 3.2. Operation conditions and constraints input module

The generation scheduling of hydro-thermal-wind-solar hybrid energy system involves large amounts of operation conditions and constraints, which are usually time-varying. This module provides the input interfaces of these data. Moreover, to efficiently complete data input, all default values are automatically set when a new operation scheme is created. In this case, the user just needs to modify a few boundary parameters depending on the current operation requirements.

All the conditions and constraints are composed of load demands, local inflow, control target for each plant, minimum and maximum of reservoir level, maintenance schedules of hydro, thermal, wind, and solar units, minimum and maximum of power generation, minimum and maximum of reservoir release, maximum ramping capacity, continuous time periods of operation and shut down. Here, the load demands and inflow are obtained from the load forecast system and inflow forecast model, respectively. Figure 3 shows these information. The control target is usually represented as daily energy demands and reservoir storage target at the ending of time horizon. It is dependent on the long-term operation schedules.
3.3. Generation schedule optimization module
The power balance model and peak-shaving model are available in the generation schedule optimization module. They are used to optimize the quarter-hourly generation schedules. The optimization procedure consists of two main steps. The first step is to determine the generation schedules of thermal power plants, wind plants and solar plants. The thermal schedules usually refer to the schedules of the last day because the thermal unit commitment usually remains unchanged between two adjacent days. When large changes occur, the initial schedules can be modified according to the energy target and load demands. The wind and solar schedules are first obtained from the renewable energy power prediction system. Then, the forecast errors of wind and solar power are estimated in this step to determine reasonable capacity reserve for hydropower scheduling. The second step utilizes one of the aforementioned two models to optimize the schedules of hydropower plants. A multi-step progressive optimality algorithm, which was developed in our previous work [16], is used to solve the model. It should be mentioned that several hydropower plants are usually chosen as the balanced plants to smooth the power fluctuation and secure power balance at each period. The chosen plants need to have the capability of automatic generation control.

4. Application
The DSS for integrated management of hydro-thermal-wind-solar hybrid energy system has been applied to the generation scheduling of Yunnan Power Grid (YNPG) since 2016. YNPG is one of hydropower-dominated provincial power grid in our country, which also contains a lot of wind and solar power plants. The number of all power plants directly operated by YNPG exceeds more than 400 in 2018. Correspondingly, the total installed capacity of hydro, thermal, wind, and solar reaches 87.05 million kW, which includes 62.42 million kW hydropower, 8.32 million kW wind power, 2.44 million kW solar power, and 12.48 million kW thermal power, respectively. In the actual operation, the dispatching center of YNPG needs to make daily power generation schedules of all power plants. This task involves a lot of data query, processing, analysis, calculation and other work. These factors bring great complexity and real challenges to the daily generation operation.

The present DSS provides a practical and convenient tool for system operators to manage large amounts of power plants and their historical records, as well as scheduling the quarter-hourly generation schedules of all power plants. During the past three years, more than 1000 daily generation schemes have been produced using the DSS. Each scheme was directly released to each power plant for their actual operation of the next day. Figure 4 presents two main user interfaces related to the generation scheduling. The first user interface provides the function of setting all operation constraints.
Figure 4. Main components included in three modules of the DSS. (Note: The DSS is developed using Chinese language). (a) Set operation conditions and constraints of power plants and (b) The optimized generation schedules.

and conditions. This user interface consists of seven components. In the first component, the load curve can be automatically obtained from the load forecast system. The operators can also refer to historical records. The maintenance component presents unit maintenance schedules uploaded by each power plant. In the third component, the local inflows are predicted by any one of several commonly used methods, including model forecast, frequency forecast, annually average inflow, and artificial experience approach. The forth component is the previous outflow which means delay flow from the upstream reservoir into the immediate reservoir with time delays. Here, the water time delay between two reservoirs is considered as a constant. The maximum and minimum reservoir levels are given in the next component. This constraint ensures that each hydropower plant will operate within a reasonable range. The control section module presents network security constraints of some important grid nodes. In the last module, the operation mode of each power plant can be determined from several alternative modes. It should mentioned that this DSS uses a script processing technique to rapidly determine the default values of all constraints and conditions while a new operation scheme is created. Thus, the system operators can modify only a few unreasonable conditions and constraint boundaries according to the current actual operation needs. The second user interface gives the quarter-hourly generation schedules that are respectively determined or optimized in terms of power source type.
above subsection 3.3 introduces the detail of determining the generation schedules for each type of power plants. Through using the present DSS, the system operators of YNPG could usually complete the generation scheduling task within 30 minutes. The work efficiency has been enhanced substantially, saving much time for other operation analysis works of the hydro-thermal-wind-solar hybrid energy system.

5. Conclusions
This study shows a decision support system for short-term generation scheduling of hydro-thermal-wind-solar hybrid energy system of Yunnan Power Grid in southwest China. The DSS is composed of three main modules for data management, operation condition and constraints input, and generation schedule optimization. An advanced framework is designed for the DSS to secure the usability of these modules. The DSS allows the user to efficiently make a daily generation schedules for more than 400 power plants operated by YNPG. Some practical and effective models and methods are also available in the DSS. In real-world operation, the system operators can select proper model to schedule power plants according to the operation requirements. It should be mentioned that this software can be extended to similar energy management systems of other provincial power grids in China. Note that the extension of the software require minor modification because many interfaces are open and reserved in the system design.

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