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Decision Support System for Large-Scale Hydropower System Operations

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Abstract China's gross installed hydropower generating capacity has surged 500% since 1980 and exceeded 100 GW in 2004, making up one quarter of gross installed electric power capacity and providing about e 20 percent of the country's total electric power. China's hydropower system, after nearly 20 years development, has formed a trans-basin, large-scale hydropower stations operation system, with complex scheduling relations and requiring a variety of methods and techniques to solve. One of the biggest challenges facing power grids of China today is how to construct a large scale operation hydropower system which is scientific, efficient, convenient, and available for practical system. The paper is a summary of the outcome of the decision support system for large-scale hydropower system operations oriented to provincial or municipal power grids. The background, objectives, challenges and contents of the decision support system are presented. The main focus is on the key technologies to the system, the design of the flowchart and its core components. The current system has been applied to the hydropower systems in the South China Grid Company, the East China Grid Company, the Fujian Province Power Grid, the Yunnan Province Power Grid and the Guizhou Province Power Grid, where the total of hydropower installed generation capacity has exceeded 30 GW at the end of 2009 and a total of 1500 hydropower stations. Some techniques are also beneficial for other systems.

***Keywords**:* Large-scale hydropower system operations; Optimization; Decision support system; Generation scheduling;

INTRODUCTION

Hydroelectric power is low cost, near-zero pollution emissions, and ability to quickly respond to peak loads make it a valuable renewable sources. It has been accurately calculated that hydropower energy of 2MWh can save about 1t coal. Hydropower plays a significant role in replacing some non-renewable mineral resources such as coal and reducing emissions for environmental sustainability.

Since the economic reform in 1980, China has experienced unprecedented economic growth. The continuing economic development of the nation requires sustainability in electric energy supply and the demand is tremendous. During past 20 years, China has put priority on hydroelectric projects to meet the rising energy demand of the country's booming economy. The recently released "renewable energy and long-term development plan" put forward the ambitious hydropower development goals: by 2010 the national hydropower installed capacity will reach 190 GW, and 300 GW by 2020, the degree of development will be close to the level of developed countries. China's hydropower system, after nearly 20 years development, has formed a trans-basin, large-scale hydropower stations operation system, with complex scheduling relations and requiring a variety of methods and techniques to solve. One of the biggest challenges facing power grids of China today is how to construct a large scale operation hydropower system which is scientific, efficient, convenient, and available for practical system. However, developing such a decision support system for large-scale hydropower system operations will inevitably encounter many difficulties, they are summarized as follows:

- The large-scale hydro system should involve lots of hydropower plants built, being built and to be built. When a new power plant or generating unit is put into operation, how to easily add it to the system and automatically update the topology without any adjustment of procedures and models will pose a great challenge to the system. Also, the issue is put top priority on developing decision support system.

- Optimal operation models and optimization techniques have become increasingly important in the past decades. Because of different actual running situation of power grids or hydropower plants, several models based on different objective functions should be available in the decision support system. Mario et al. [2003] developed a successive linear programming model on the basis of linear programming model and nonlinear programming model in view of a few objectives such as minimizing the loss of the stored potential energy, minimizing storage deviations from targets and maximizing total energy production. Wang et al. [2004] described an operation model to maximize hydro energy production for 27 hydropower plants. Naresh et al. [2000] presented a two-phase artificial neural network approach for finding optimal scheduling of interconnected hydropower plants with the objective of maximizing hydropower generation and satisfying the irrigation requirement as far as possible. And Shawwash et al. [2000] proposed the B.C. hydro short term optimization model to determine the optimal hourly generation and trading schedules in a competitive power market.
- Considering reasonably time delay of cascade hydropower plants is indispensable in short-term operation scheduling. It was shown by Ramesh et al. [2000] that proposed a brief model of time delay neglecting attenuation factor, and Yeh et al. [1992] also introduced additional complications of hydraulic time delays for cascaded hydropower plants.
- Users or decision makers often need to make a few appropriate changes for optimal operation results according to their own experience or the running demands, so it has significant impacts on the decision support system how to design a flexible and user-friendly human-computer interaction.
- In the hydro system, lots of inputs are extremely complex including basic information (e.g., reservoir characteristics, power plant generating units), initial operation conditions (e.g., initial water level upstream before schedule, reservoir inflow) and constraints setting (e.g., minimum and maximum storages, energy demand, turbine capacity). Many of the above inputs and constraints are taken into account by Johannesen et al. [1990], Khalil et al. [1991], NAJMAII et al. [1992], El-Hawary et al. [1992], Rekutowski et al. [1994], Georgakakos et al. [1997], and Esteban et al. [2003]. As such large amounts of data have to be required or set in the process of making an operation schedule; practicability such as response speed will be greatly reduced if data acquisition and constraints setting can not be properly dealt with.
- It is also necessary for a perfect hydro system to ensure data integrity. So the present system has to interact with other systems including data platform of hydro system which can provide the actual running results of hydropower plants, flood forecasting system which can provide reservoir inflow. At the same time, the present system is also asked to send the operation results of hydropower plants these above systems. It is crucial what technique will be utilized in order to achieve automatic interaction between different systems.

How to reasonably deal with all of issues or difficulties above will be introduced in detail in other sections of the paper.

The decision support system for large-scale hydropower system operations has been developed to operate and manage the hydropower systems of provincial or municipal power grids. The system adopts three-layer B/S framework of the database/server/browser, by the use of Java technology platform for models and screens, oracle database management system, and integrated development environment called JBuilder9.0. The paper is a summary of the outcome of the decision support system for large-scale hydropower system operations oriented to provincial or municipal power grids. The background, objectives, challenges and contents of the decision support system are presented.

CALCULATION FOR POWER OUTPUT

In order to meet different situations, two types of calculation for power output can be available in the system:

- **By formula:**

$$N = A * H_t * Q_t \qquad (1)$$

Where N =power output during time period t(kW); A = output coefficient of power plant, which is less than 1.0 and related to g, hydraulic turbine efficiency, unit efficiency, etc.; Q_t =total discharge of all generating units during time period t(m^3/s).

The formula method is often applied to mid- and long-term operation, and also used in the short-term operation when all of the needed curves are not complete.

- **By the relation curve of net head, unit output and discharge in the generating unit:**
  Using the relation curves of generating units is the best choice for real-time or short-term operation. This solution is with high accuracy, as the relation curves can exactly represent the running situations for generating units. In order to improve optimization efficiency, dynamic programming, one of the most promising techniques, is used to convert units' curves into power plant's curves considering the vibration bounds of generating units. As a result, the calculation time is not only greatly reduced, but also the accuracy of optimization result is kept.

MODULES OF DECISION SUPPORT SYSTEM

The decision support system is designed to provide more flexibility and consistency in supporting the decision-making process for operation of hydropower plants considering a variety of inputs and constraints of reservoirs or hydropower plants. And a few nonpower requirements (e.g., navigation) are also taken into account in developing operating policies. The system consists of the following four modules, which are briefly explained in the following paragraphs.

- Medium- and long-term operation module, making yearly, monthly or weekly operation scheduling plans of hydropower plants;
- Short-term operation module, making daily operation scheduling plans of hydropower plants during one day or several days;
- Data management module, defining some new data (e.g., a hydropower plant that will be put into operation) or editing basic information and curves of reservoirs or hydropower plants.

Medium- and Long-Term Operation Module

Different operation schedules for hydropower plants can be developed in this module with three kinds of time period steps available including one month, tendays and one day. Completing an operation scheduling is roughly divided into three parts.

- **Data preparation:** In the data preparation, the first step is responsible for the selection of power plants and schedule time range. In the second step, most of inputs and constraints are implemented. Among them, reservoir inflows, as the most important input for operation, can be obtained in many ways, including frequency forecasting, model forecasting as well as others. The frequency forecasting is on the basis of historical inflows. It asks the user to enter a frequency which will be utilized in curve interpolation for the demanded inflow series. The model forecasting is based on some types of mathematical statistical methods such as non-stationary time series, fuzzy pattern recognition and multiple linear regressions. So users can make use of one of the above ways to predict reasonable reservoir inflows for the next operation. Additionally, it sets different constraints as system load, variable constraints on the minimum and maximum power output, discharge over each period of time, and several ramping constraints.

- **Optimal calculation:** After all input data are entered, the most important step is to start optimal operation. In order to meet different actual demands, users are able to choose a suitable one of optimal operation models that are summarized as follows:
  1) Conventional operation model, a non-optimization model, which operates on basis of reservoir operation rule curves.
  2) Maximum generated energy of hydro system model, which maximizes generated

energy of hydro system fully utilizing water resources, and it's often used.
Objective function

$$\max E = \sum_{t=1}^{T}\sum_{m=1}^{M} p_{m,t} \times \Delta_t \tag{2}$$

Where E =total energy during schedule (MWh); $p_{m,t}$ =average power output of the m th power plant during time period t(MW); Δ_t =total hours during time period t(h).

3) Minimum purchasing power cost model, which is mainly used in the context of electricity market, and considers price differences between power plants to reduce the power purchase cost.
Objective function

$$\min C = \sum_{t=1}^{T}\left(\sum_{m=1}^{M} p_{m,t} \times v_{m,t}\right) \times \Delta_t \tag{3}$$

Where C =total purchasing cost(￥); $v_{m,t}$ =average electricity price of the m th power plant during time period t(￥).

- **Human-computer interaction:** Above all, the system provides a flexible human-computer interaction, users can not only directly modify the data (water level, power output or power release) in tabular form, but also drag and drop curves according to own experience and the actual running situation of hydropower plant, then all of associated hydropower plants will automatically calculate again from the upstream power plants to the downstream ones.

Short-Term Operation Module

Its main task is to implement daily generation schedule for hydropower plants in this module. It involves three main aspects including plans management, plants selection, constraints setting, optimal calculation, scheduling submission and comparison that are essential to complete an operation scheduling.

Data preparation: A new daily schedule plan firstly need to choose hydropower plants that will participate in optimal operation, therefore a number of shortcuts are available to users in the present system, such as all of power plants, a single cascade, a single station and a user-defined virtual power plant that means a combination of a number of hydropower plants with the same features or purposes.

A few intractable inputs that are different from long-term operation are summarized as follows:

- **Reservoir level at the first period**

In order to prevent from the spill risk, it's necessary to ensure the accuracy of initial water level for run-of-river power station with poor regulation. Therefore, the relation curves, net head ~ unit output ~ discharge in the generating unit, are used to calculate accurately reservoir level at 24 point today based on the latest reservoir level, daily operating schedule and real-time forecasting inflows.

- **Upstream reservoir discharge**

The term "discharge" represents the sum of power release and spill of reservoir in view of time delay of cascade reservoirs before schedule. It involves two parts: the actual total discharge that has already happened, scheduling discharge in the coming hours that are estimated by daily generation scheduling.

Optimal calculation: The key step in optimal operation is to select an appropriate model from the model library that is proposed by different objective functions. Fig.1 presents the optimal operation screen of the short-term operation module. In this graphical user interface, it can be well known that there are a few concerned statistics of single plant scheduling on the top, including reservoir inflow, reservoir spill and daily power generation. Its interface style is in line with the output screen of long-term operation by using object-oriented technology.

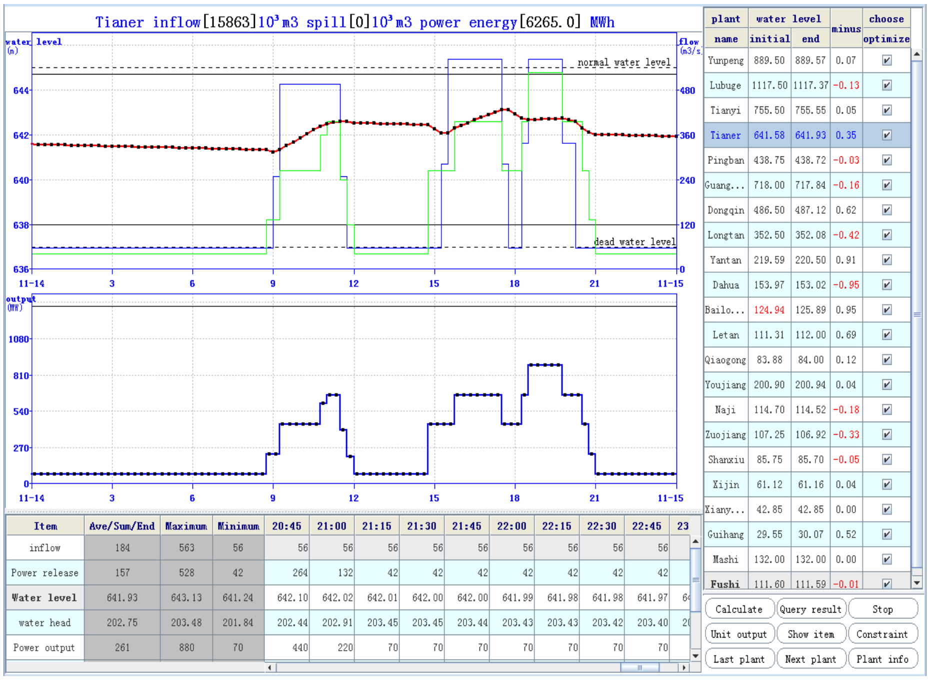

Fig. 1. Optimal operation screen of short-term optimal operation system

Analysis of the results: Firstly, the users are able to review their own operation scheduling, and compare the scheduling data with the actual running data. The next step is to choose a suitable scheduling which will be submitted to hydro-thermal power system for power grid's daily work. Moreover, it is also demanded that other operation results such as inflow, water level and reservoir releases are provided with flood forecasting system and automatic operating platform of hydropower stations. All of the above relations with other systems are got through by Web Service technique that will be described in the next part of this paper.

Data Management Module

In the data management module, users can add, edit or delete amounts of data about reservoirs or power plants including the following:

1) Adding a new hydropower plant or basin, deleting an existing one; 2) Basic information management of reservoir or hydropower plant such as characteristic reservoir level; 3) Generating units and relative attribute management of hydropower plants such as turbine capacity, number of units and type of turbine; 4) Data about time delay of cascade hydropower stations; 5) The relation curve including reservoir level and storage, tailrace water level and reservoir discharge, the net head, unit output and discharge in the generation unit; 6) The operation lines of reservoirs; 7) The actual running data;

The module is significantly improved by graphical and tabulated technique which makes it easier for users to deal with a wide range of inputs and constraints of reservoirs or power plants, and every user is able to manage own default setting and the actual running results such as reservoir inflow, water level, average power output and the power energy each time period. Moreover, a excel template about required information of hydropower station is allowed to download, and a statistics form about data integrity of all reservoirs and power plants is also presented to users.

Reservoir or power plant definition: In order to deal with dynamical launch of a new reservoir or power plant, a sound reservoir or power plant definition guide like software installation guide is available. Fig.2 shows the procedure of defining a new reservoir or power plant including nine steps, so the user can readily complete the definition of a new object without good professional knowledge, and the information lacking for optimal operation is also effectively reduced.

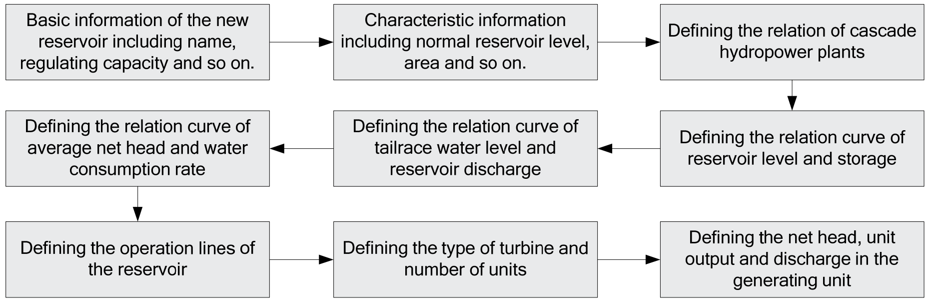

Fig.2 The flowchart of defining a new reservoir or power plant

KEY TECHNIQUES

It plays a vital role in the system's practicality and timeliness what techniques are used to deal with aforementioned issues. The key techniques have been summarized as follows:

Automatic Relation of Cascade Hydropower Plants

The optimal operation for cascade hydropower plants depends on strict rules because of the complexity of hydraulic connection. Above all, the calculation order must be right, as it may have a significant effect on calculation structure when different hydropower plants will be put into operation, and the wrong order may lead to invalid operation scheduling or the ending that convergent results are unavailable. The present system makes use of the depth-first search (DFS) principle to automatically obtain the correct calculation order. Firstly, the DFS has to choose a starting node, then performs the next criteria: (1) if possible, visit an adjacent node visited, mark it and put it into the stack; (2) if the last criterion can not be completed and the stack is not empty, a new node should be got from the stack; (3) if the last two criteria can not be completed, then search process will finish. Fig.3 shows the calculation order obtained by DFS from 0 to 23; the whole calculation process is in line with the routine from the upstream power plants to the downstream ones.

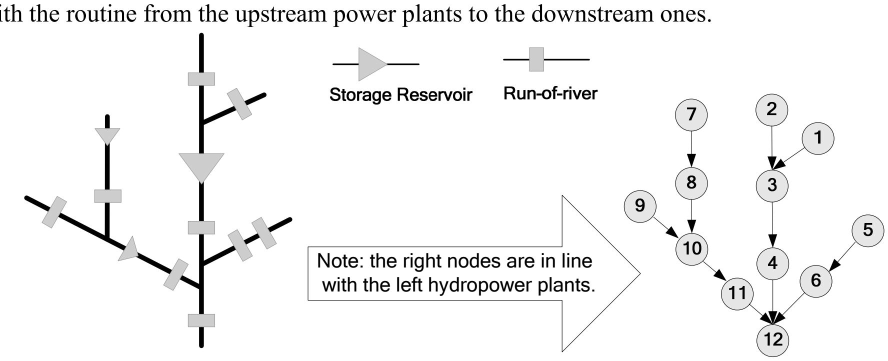

Fig. 3. The calculation order obtained by DFS

Automatic Setting Technique Based on intelligent Memory and Script Control

In the decision support system for large-scale hydropower system operations, lots of calculation conditions and constraints setting are extremely complex because of the size of plants when a new operation plan is made, so both intelligent memory technique and script control technique are introduced in order to make scheduling makers avoid hands-on preparatory work as much as possible. Fig.4. shows the processing procedure of techniques above. In the basis of these techniques, large amounts of data about reservoirs or plants can be automatically set up according to dispatching mode and time range. In this way, the efficiency of making a new operation scheduling is greatly enhanced as the trouble and possible errors caused by a large number of manual inputs and setting are effectively reduced.

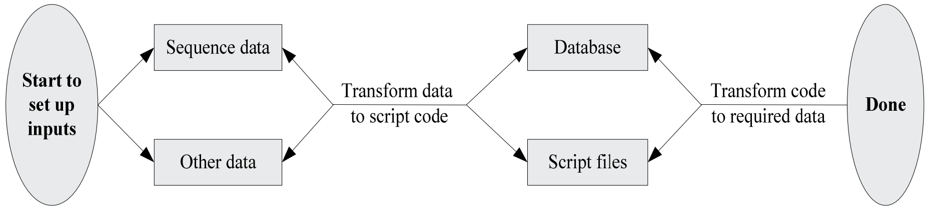

Fig.4. The processing procedure of the intelligent memory and script control technique

Seamless Data Interaction with Other Systems

Using a self-contained, self-describing and modular Web Service applications which is based on the already existing and well-known HTTP protocol, and uses XML as the base language, the decision support system achieves perfect interaction with data platform of hydro system, hydro-thermal system, dispatch management information system, device maintenance system and flood forecasting system between different platforms and programming. Also, an advanced transaction processing technique that resembles the Microsoft Task Scheduler is introduced together. It is not to make the present system send operation scheduling to a few of the above systems mentioned, but to make sure that the actual data, real-time information, forecasting inflow and daily scheduling of power grid or power plants are effectively got from other systems. Detailed interactive information can be seen from fig.5.

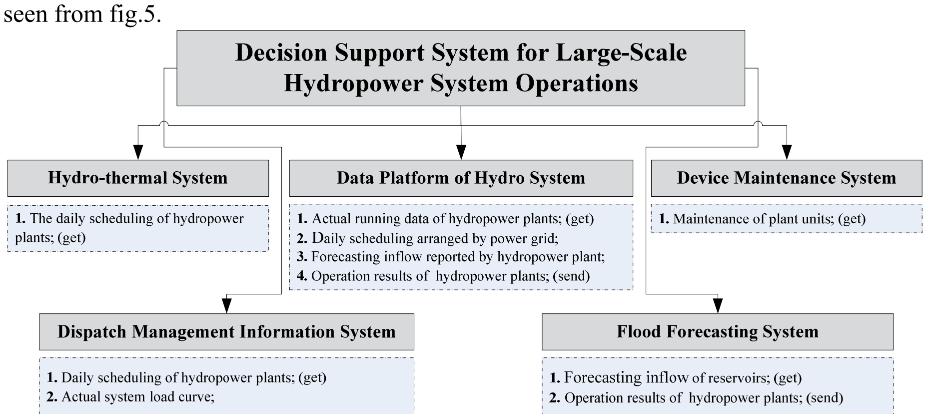

Fig. 5. Data interaction diagram with other systems

SUMMARY AND CONCLUSIONS

This paper has presented an efficient decision support system for large-scale hydropower system operations. The proposed system has been applied to the hydropower systems in the South China Grid Company, the East China Grid Company, the Fujian Province Power Grid, the Yunnan Province Power Grid and the Guizhou Province Power Grid since January 2006 as a demonstration of its capabilities and eventual implementation as an operation scheduling decision tool. By involvement of operators in the running process of the decision support system, the system has been enhanced in many aspects to solve real-world problems. With the application, the decision support system is successfully tested promising in solving the medium- and long-term and short-term operation scheduling problems for large-scale hydropower systems. Moreover, during the past few years, the present system has produced significant performance and played an important role in replacing some non-renewable mineral resources such as coal, reducing emissions and promoting informationization and networking of smart power grid.

Overall, it is apparent that the successful applications of the proposed decision support system in multi-layered power generation companies show its wide generability. A few key techniques such as depth-first search principle and script control technique are introduced to accomplish dynamic reconfiguration of cascade hydropower plants and large amounts of inputs, respectively. Also, a user-friendly graphical user interface facilitates the specification and modification of all kinds of information. Furthermore, The optimization models and algorithms are site specific and can be extended to hydro systems in different regions with little readjustment. Therefore the system presented is a general and convenient decision support tool that allows dispatch operators to make hydro scheduling and analyze complicated optimization problems for hydropower plants.

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