HYDROELECTRIC POWER DAMS NETWORK SIMULATION

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Abstract

A simulation system was developed to build simulation models for evaluating and testing control rules and personal training in the operation of sets of interdependent hydroelectric power dams under flood conditions. The project was developed for the company Electricity of Portugal (EDP) by three members from the University of Porto (Guimarães, R. C., Moreira da Silva, C., Brito, A. C.). A discrete event simulation approach was used based on numerical methods to model the system state variables. A configuration stage allows the user to define the hydroelectric power dams network and to enter the required data to characterize each of the power dams. Graphics were used to show the hydroelectric power dams network so that the user could easily check the input data. After defining all the required data the user can generate the simulation model. For running the simulation the user needs also to choose one of the downstream water flow data series previously defined. These series were based on historical data from the most significant floods registered by EDP. During the simulation run the user can interactively control the turbines power and the floodgates aperture. During the model execution icons are used in a pictorial representation of the dams. A zoom interaction allows to observe the functioning of a particular dam. At this level of detail it is possible with special conceived dynamic XY graphics to follow the behavior of some of the most important state variables. This was essential for the analyst to be able to control the dams under flood conditions. The simulation system can be used for training purposes and to test control rules without any risk, that can be used later in severe flood conditions allowing a better use of the water resources.

Keywords: Simulation, Modelling, Hydroelectric power dams simulation

Presenting Author's biography

António Carvalho Brito. Was born in Porto, Portugal and went to Universidade do Porto, where he studied mechanical engineering and obtained his degree in 1981, staying in the same institution as Lecturer where he did his M.S. thesis in 1985. He obtained his Ph.D. in Simulation from the School of Management at the University of Cranfield (U.K.) in 1993. Currently he is a Professor at Universidade do Porto, where he leads research in the field of Simulation and Information systems.

1 Introduction

Computer simulation has become widely used in the analysis of complex problems and is now an important tool in decision making. Since the 1960s simulation has been used with success in solving real problems.

In 1976 the concept of Visual Interactive Simulation (VIS) was introduced by Hurrion [1]. With VIS a picture of the model running is displayed on the screen and the user can interrupt the model running, at any time, and interact with it in a way that he can influence the future behavior of the model.

Visual Interactive Simulation aggregates a set of graphics, visual and interactive techniques which can be incorporated with different levels of extension in a simulation system. In the past years, there have been a large number of situations where simulation and VIS were successfully applied to different areas as in [2], [3], [4], [5], [6], [7] and [8].

Using these techniques a system was developed to build simulation models for evaluating and testing control rules and personal training in the operation of sets of interdependent hydroelectric power dams under flood conditions. The project was developed for the company Electricity of Portugal (EDP) by three members [9] from the University of Porto.

2 The problem

EDP's engineers had difficulties in defining and testing rules to control hydroelectric dams under flood conditions. The amount of water that should be release during a major flood was critical because in any circumstances it was admissible the water level to go above the safety limit. If this happens would affect the integrity of the dam and put in danger the facility workers and the population living along downstream river banks.

Another issue was the time needed to prepare the personal to control the hydroelectric power stations, because they need to work at the physical installations and most of the time they were not able to operate without proper supervision.

EDP needs a tool that could address these problems so it was decided to develop a simulation system. As the system was intended to be used by EDP personal without simulation expertise it must had certain characteristics such as: user friendly interface with hydroelectric power dams terminology; interactive controls similar to the real ones; graphical interface for helping users in the decision making process.

3 Configuration

The information collection and analysis phase were essential to provide an accurate image of the hydroelectric power dams. Fortunately EDP had already developed models to characterize the work of the dams. Numerical methods were used to compute the state variables at fixed intervals. The time interval was chosen in order to obtain the required precision.

The configuration stage allows the user to define the hydroelectric power dams network and to enter the required data to characterize each of the power dams. Due to the large amount of data the user is allowed to edit and store the dams network information at anytime and independently from the simulation model, by navigating through the menu tree.

The hydroelectric power dams network can be represented graphically so that the user can easily check the input data. The user needs also to enter the downstream water flow data series. These series are based on historical data from the most significant floods registered by EDP.

After defining all the required data the user can generate and store the simulation model and run it whenever he needs, with different downstream water flow data series.

EDP run two types of dams that were considered in the model: water reservoirs, where a large amount of water is stored for later use, and water flow, in fast-flowing rivers where the water cannot be stored for later use. Each power dam is characterized by the following curves:

- backwater curves (water flow dams)

- reservoirs water curves (water reservoirs dams)

- turbine water flow curves

- floodgates water flow curves

- downstream water flow curves

The backwater curves are used to compute de upstream water level in the water flow dams. The water level depends on the amount of upstream water flow and on the distance of the dam as shown in Fig.1.
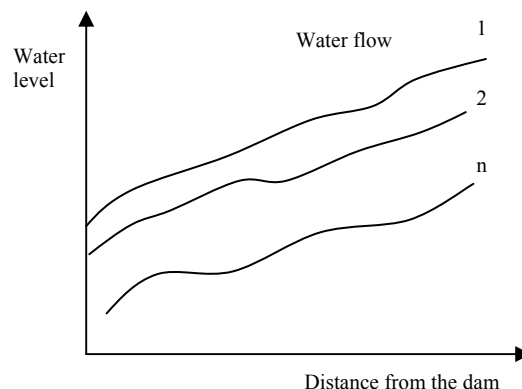

Fig. 1 Backwater curves

The reservoirs water curves are used to compute the water level near the dam depending on the volume of the water stored in the reservoir (see Fig. 2).
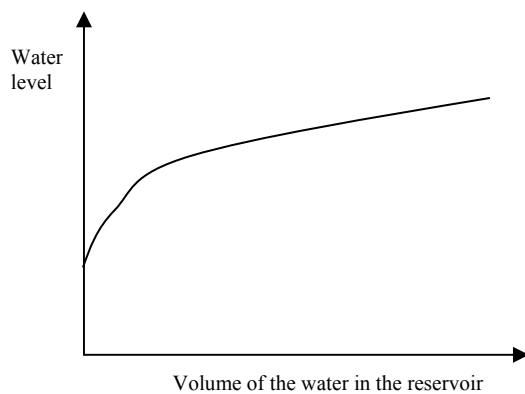

Fig. 2 The reservoir water curve

Each power group is characterized by the turbine water flow curves. The power of the group depends on the amount of water flow and on the difference in height (head) between the source and the water's outflow (see Fig. 3). If the power groups share the incoming water tunnel, a set of curves must be defined for each different combination of working groups.
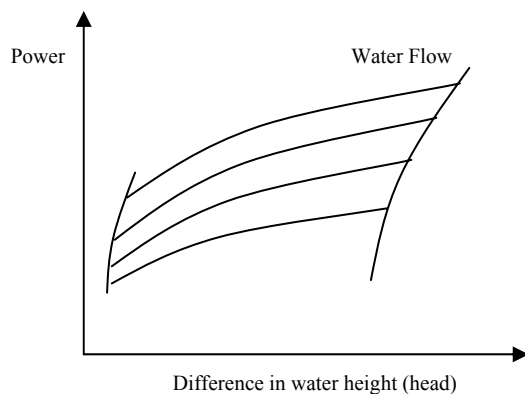

Fig. 3 The turbine water flow curves

The floodgates water flow curves are used to compute the amount of water that is released through the floodgates. That depends on the gates aperture and on the water level near the dam (see Fig. 4).

In the case where floodgates aperture cannot be controlled (open or close state only) the amount of water released depends only on the water level near the dam.
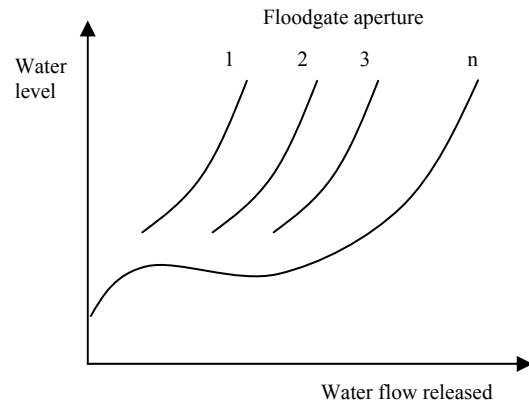

Fig. 4 The floodgates water flow curves

The downstream water flow curves are used to compute the downstream water level that depends on the amount of water released (see Fig. 5).
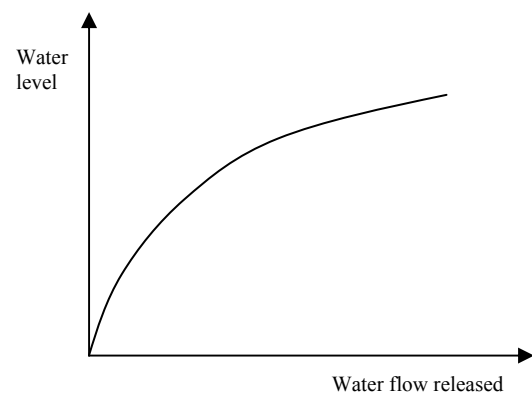

Fig. 5 The downstream water flow curve

At the configuration stage input data describes each power dam, such as the number and type of power groups, the number and type of floodgates, the parameters of the different curves described above, etc.

It is also necessary to define at this stage the information related to the power dam network. A maximum of five power dams can be configured to be part of a network. Each power dam can be placed in serial or in parallel in the network and the model internally automatically defines the logic associated with the layout.

A complex and large amount of data has to be defined at the configuration stage. As an example, Fig. 6 shows a small part of the input data flow diagram that displays the power group characterization.
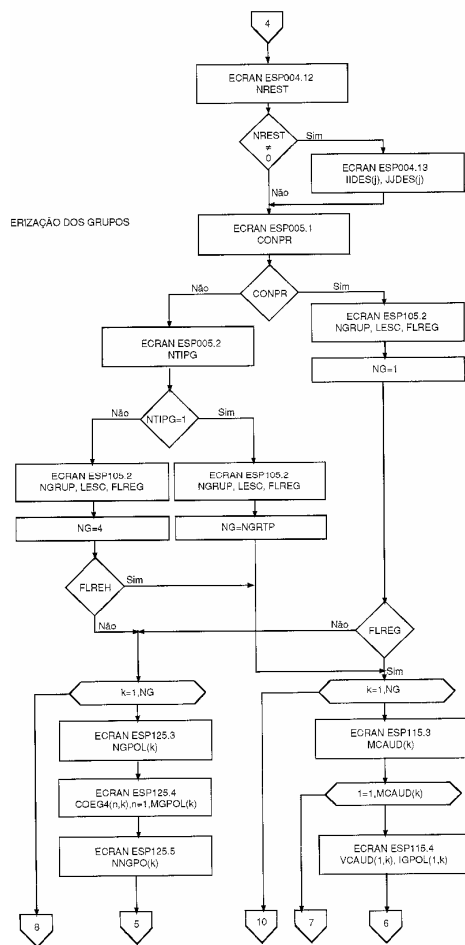
Fig. 6 Part of the input data flow diagram

Another important data is the water flow time series. Each series can be linked to one or more of the network power dams at the initialization stage. The input data is usually imported from files corresponding to significant flood situations. Two of them are called the century flood, that can occur once every 100 years, and the millennium flood that can occur once every 1000 years.

The initialization stage set the initial conditions for the simulation of a power dam network. This module allows to set different initial conditions without having to go through the configuration stage. At this stage the initial values for some of the state variables are defined, such as the upstream water levels, turbine power, floodgates aperture, etc.

At the initialization stage it is also possible to choose what state variables values and graphs will be displayed during the simulation. Nevertheless, during the simulation the user can change the initial settings choosing what he wants to see displayed on the screen.

4 Model

A discrete event simulation approach was used, instead of continuous simulation approach, due to the previous experience and available tools and because it was considered to be a good representation of the system to be modeled.

The model follows the general structure for discrete simulation. The executive is implemented using the next event technique and the event approach modeling. Special logic was included to handle user interrupts. However the simulation run can only be interrupted between the occurrence of events. After the simulation has been interrupted the user has access to a set of available commands called interactions.

At regular time intervals, that can be set by the user, the model computes the state variables values. In most of the cases a numerical polynomial approach is used. As an example, the reservoir water curve (see Fig. 2) is represented by the following expression:

$$N = a_0 + a_1V + a_2V^2 + a_3V^3 + a_4V^4 + a_5V^5$$

where V is the volume of the dam, N is the upstream water level nears the dam and $a_0 \dots a_5$ are parameters that are defined for each power dam.

The dynamic of the model is set by the water flow time series that can only be connected to dams with external (EXT) water sources (see Fig. 7). A specific logic was created to propagate the water through time and along the links between power dams. The power dams network can be quite complex (see Fig. 7) with water flow junctions and with turbine water flow being redirected to other stream (PD1, PD2).
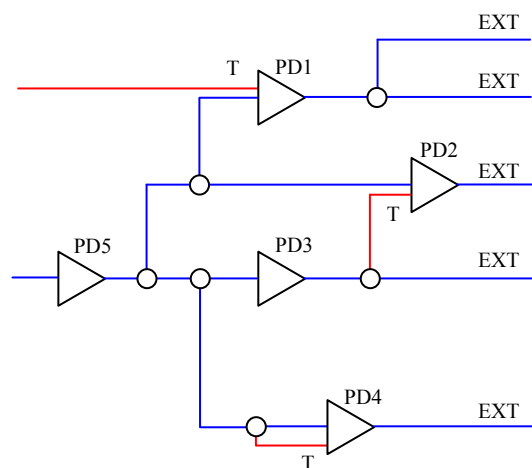

Fig. 7 Power dam network diagram

Special simulation elements were created to implement the water junction logic. That was necessary to represent some more complex power dams network.

5 Simulation System

At the simulation model execution stage icons are used in a pictorial representation of the hydroelectric power dams network as shown in Fig.8.
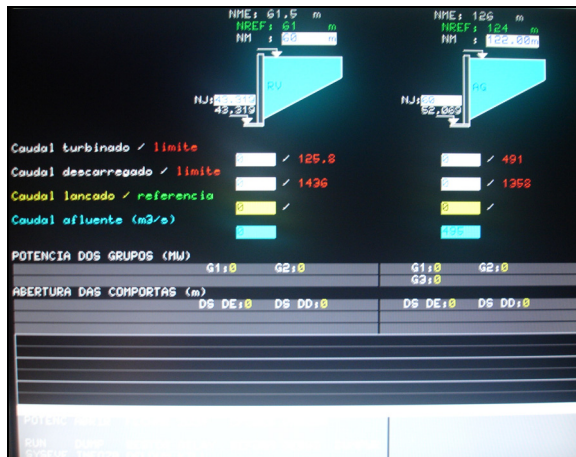

Fig. 8 The simulation screen

Several commands, called interactions, are available to the user. One of this commands, zoom interaction, allows to observe the functioning of a particular dam. At this level of detail it is possible with special conceived dynamic XY graphics to follow the behavior of some of the most important state variables as shown in Fig. 9.

Other commands allows the user to interactively control the power of the turbines and the amount of water released (floodgates aperture). This was essential for the user to be able to control the dams under flood conditions.
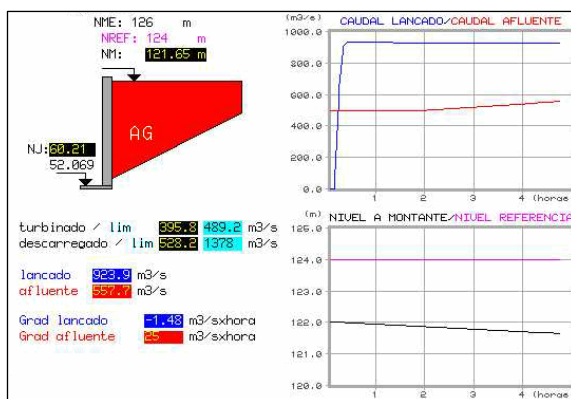

Fig. 9 The simulation screen (zoom)

During the running of the simulation model it is possible to watch some useful information on the screen. On the top right corner is displayed the current simulation date and time. Several information from the model can also be displayed along the simulation run such as incoming flow rate, turbines flow rate and floodgates flow rate as well as their variation with time (gradient). Also water levels from the upstream and downstream flow can be represented. Alarm events are programmed as in real life to alert the user to critical situations.

6 Conclusions

The model was oriented to people without simulation experience. It was developed a front end, with a friendly interface, within which the user can define the problem in his own technical language without a significant simulation knowledge.

The model is automatically generated, based on the user input data, so that complex simulation details can be hidden from the user.

Colors, graphics and animation are used so that visual aspects can help the user to validate the model and see why problems arise during its running and interpreting the simulation results.

Interactive facilities are used to quickly change model parameters, obtain further information about the state of the model and to display statistical reports.

The simulation system objectives were fulfilled. The use of common terminology and familiar interface makes the system easy to use. It can be useful for training purposes allowing the personal to be prepared before going to work at the facilities. They can make learning mistakes without the risk of jeopardize the installations.

New control rules can be tested to be used later in severe flood conditions without any risk, allowing a better use of the water resources.

The system interface allows the creation of new hydroelectric power dams networks by editing existing ones or starting from scratch without the need of simulation or programming expertise.

7 References

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