Medium-term Hydro-scheduling in Iberdrola

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Introduction

Hydro power is a renewable source of energy that plays a key role in electric power systems, especially due to its flexibility and to its ability to allow the integration of other intermittent renewable sources.

The medium-term hydro-scheduling is a very complex task that involves a great variety of processes and variables, some of which are considered stochastic, because of their uncertainty in the medium term. Two combined methods are used by Iberdrola in medium-term hydro-scheduling: stochastic optimization and simulation.

This paper briefly describes these processes and shows two examples of applications to hydro management. One is referred to the continuous task of scheduling, and the other is an example of maintenance planning. Nevertheless these models have also been used for designing and upgrading of hydropower plants, international river agreements, analysis of ecological flows, etc.

1. Background

Iberdrola is a Spanish multinational company with more than 150 years of experience in the electricity sector, with a workforce of around 33000 employees in over 40 countries.

Iberdrola has an installed capacity of hydropower plants of 9731 MW with an average net yearly production of 17732 GWh. It is the owner of a lot of reservoirs ranging in sizes of up to 3162 hm^3, dedicated to electricity production, but some of them are also oriented to irrigation, water consumption, cooling thermal units, etc.

The management of the hydroelectric system in Iberdrola has the objective of optimizing the value of water, taken into account the constraints from different aspects: environment, irrigation, flood safety and others. Stochastic nonlinear programming techniques are used for this optimization, considering a scope of around two years. Object Oriented Programming is used in the simulation tool, to facilitate its utilization in very different hydroelectric schemes. The output will be used in a cascade of decisions, up to the day-ahead market, and the power plants operation.

Iberdrola and Institute for Research in Technology (IIT) have developed two tools that cover the requirements of medium-term hydro-scheduling in Iberdrola: a hydrothermal optimizing model [1], and a hydro simulator [2] [3]. These models provide to Iberdrola a successful management tool that helps in the hydro management process [4].

2. Models description

2.1 Scope

The most common approaches to medium-term hydro-scheduling are optimization and simulation techniques.

--Optimization techniques are used to obtain the optimal operation. Perhaps the most common methodology to solve stochastic optimization problems is currently Stochastic Dual Dynamic Programming (SDDP) [5] and [6] researched this concept approximating the nonlinear function by discrete envelopes, resulting in a mixed integer linear problem to consider the full detail of a basin. A state-of-the-art review can be seen in [7]

--Simulation techniques try to reproduce as close as possible the actual performance of a system, allowing more detailed description compared to optimization methods, with regards to the elements of the basins, the power plants and their constraints. [8] focus on long term simulation, oriented to irrigation, while [9] focus on short term simulation of energy generation with hourly detail for a week.

MHE is a stochastic hydro-thermal optimization model that is focused on the whole Iberian Electricity system. The stochasticity is related to the consideration of multiple scenarios of inflows. It considers in high detail hydraulic elements of river and water uses, but some simplifications are made to reduce the size and complexity of the problem. The time step is one week, divided into peak and off-peak periods.

Each hydro simulator is dedicated specifically to a hydroelectric scheme, uses a fixed time step of one day, and adapts to the guidelines obtained from MHE model. The modelling possibilities include generating and pumping units, rivers and canals. Linking hydro simulators with MHE allows an emulation of the actual operation of the basins without neglecting the optimization scope.

2.2 Medium Term Stochastic Hydrothermal Scheduling Model

This tool determines the optimal operation of the reservoirs and hydro power plants and the optimal flow tables for the main basins operated by Iberdrola. Optimal flow tables are multidimensional functions that establish the optimal outflow of each reservoir in each week as a function of the stored water volume of this reservoir, of a reference reservoir of the same basin and of the stochastic water inflows. These tables are used as input by the hydro simulator to optimally guide the operation of the reservoirs. The use of the level of another reservoir is due to the fact that the main rivers managed by Iberdrola usually have more than one reservoir that highly affects the whole behaviour of the system. Fig. 1 shows an example of a 3D plot of one of these optimal solutions.

The scope of the model is two hydrological years, beginning in October, divided in weeks, a total of 104. Every thermal power plant is considered individually and the Iberdrola hydro system is modelled with all the hydro power plant cascades representing the topological relations. The remaining hydro systems from other companies are represented by energy equivalents.

The medium term operation model is stated as a stochastic optimization model solved by a state-of-the-art and efficient stochastic dual dynamic programming algorithm. The stochastic natural hydro inflows are represented by a multivariable recombining scenario tree for the whole model scope. Five scenarios in each stage are considered enough to define the variability of the inflows.

The model is implemented in GAMS with Microsoft Excel as interface for inputting the data and gathering and representing the output results.

MHE considers in high detail the reservoirs and the hydropower plants, including maintenance periods and topology of several elements of a basin.

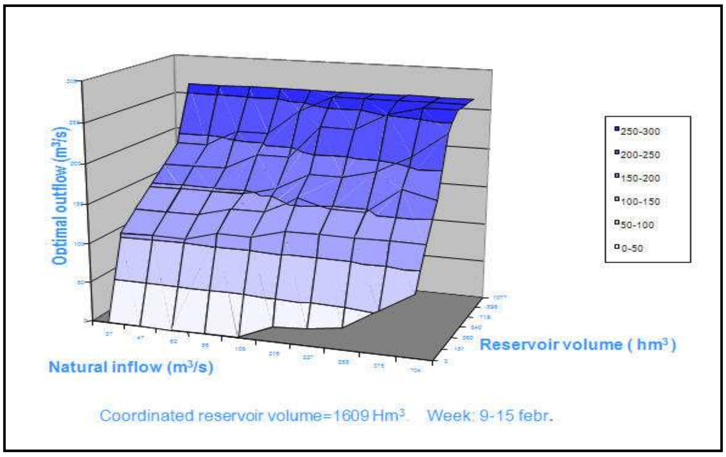

Fig. 1. Plot of an example matrix generated by MHE that shows the optimal outflow of a power plant for a certain week

2.3 Hydro Simulator

The simulation tool is designed to follow the long term guidelines provided by the MHE model, while taking into account the full complexity of the operation of hydro units. These details cannot be considered in MHE because of its longer time scope and due to the increase in size such details might mean.

The difference in modelling detail between MHE and the simulation tool might lead to situations such as spillages or lack of water to fulfill water release agreements. To avoid it, the simulation is organized around four simulation stages that aim at reducing these situations by coordinating the basin operation. These four stages are:

- First, each river element computes its output independently of the rest of elements. It also computes if the elements run into problems such as spillages or lack of water, and if not, how much it can change this operation before it runs into these problems.
- In the second stage, the operation of the elements is coordinated to avoid the problems using the available modification ranges.
- In the third stage, once water use is decided, final power production is computed.
- The fourth and last stage gathers final results for the whole river basin, such as the energy reserve available for the power system.

The implantation of this simulation tool is done in a set of Visual Basic for Applications macros consisting of more than 33000 lines of code under Excel. In order to be flexible, it uses the Object Oriented Programming paradigm to abstract the general behaviour of the basin elements. This allows including new elements (or even new river basins) more easily, providing its describing data without the need to modify any code.

3. Study cases

This section includes two applications of these models to realistic cases, even though there are several other significant uses, as designing and upgrading of hydropower plants, international river agreements, analysis of ecological flows, and others.

MHE performs a stochastic optimization of the generation mix in Spain, but it also may be done for the whole Iberian Electricity system. The main outputs are the optimal flow tables, which are the guidelines of the stochastic planned management for the main reservoirs and hydro power plants of Iberdrola, within a period of one or two years.

The two following applications in this paper do not correspond exactly to a real river basin, although it has been created to be very similar to real river Duero scheme. The main hydroelectric reservoirs in this basin are managed by Iberdrola, with 11 big dams and a total volume of 4708 hm^3, 17 power stations with 3327 MW of generation capacity and 1185 MW of pumping capacity. It consists primarily of a main river, with two more tributaries that join at the middle and end of it.

3.1 Application to scheduling

The main aim of this set of models is the scheduling of the hydro generation in Iberdrola, which is based on optimization and simulation processes.

The first step is to get the optimal flow tables of the reservoirs, as a result of MHE model for the optimization of balancing the energy demand and the whole generation mix. The main management constraints are taken into account: ecological flows, international agreements flows, irrigation, safety guides, etc. Some minor constraints could be ignored in this step, in order to avoid a huge calculation time. The time slice is one week, divided into peak and off-peak levels.

Once the optimal flow tables are obtained, the following step is the simulation process, to be performed for every hydroelectric scheme. In this process, all the management constraints are considered, including some of the neglected in the optimization process. The time slice is now one day, also divided into peak and off-peak levels.

For the simulation of the hydroelectric scheme of this application, a series of 24 hydro inflows have been performed. Each series comprises of daily values for one whole year, although the beginning of the simulation has been set to Mar-31. For previous dates, the reservoir volume graph presents data that has been fixed to provide an initial trajectory.

The output of a hydro simulator comprises a big amount of daily data of all the relevant variables for each reservoir. The daily variables of the power plants, as pumping or generation, are also divided into peak and off-peak levels.

The results of the MHE model and hydro simulators are then compared. If the changes are large, MHE has to be run again. If the required changes are not so large, hydro simulators can use several parameters or guiding curves, in order to tune the management in some reservoirs or power plants, and MHE has not to be run again.

In Fig. 2, the evolution of the volume for an annual reservoir is shown, for each of the simulated series. From Jan-1 to Mar-31, it corresponds to the period prior to the start of the simulation, and hence the figure shows only one trajectory. The thick line indicates the mean of the simulated evolutions, and it can be seen that it is initially descending, even though there is a variety of trajectories due to the diversity of inflows.

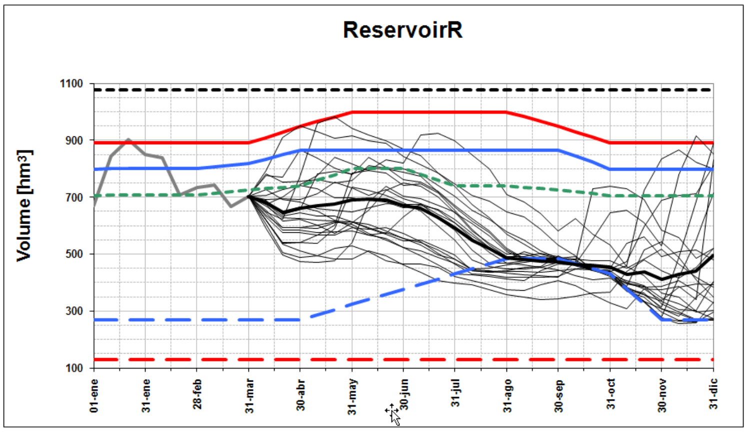

Fig.2. ReservoirR simulated evolutions with guiding curves, from Mar-31 to Dec-31

As a sensibility analysis, it has been made a new MHE run, with much less energy demand in April. A new release table is obtained and used in the hydro simulator. In Fig. 3, it is shown a new evolution of the volume of the same reservoir. In this case, the mean of the simulated evolutions is initially ascending, because the water is stored for months with higher energy demands.

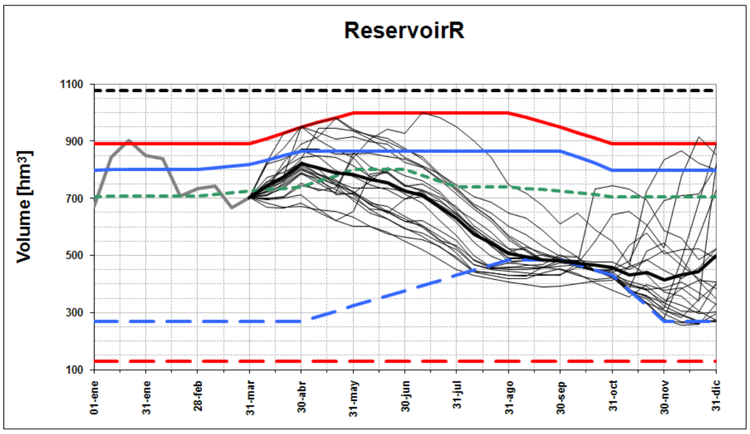

Fig. 3. Sensibility analysis. ReservoirR simulated evolutions with guiding curves, from Mar-31 to Dec-31

Following with the main study case, in Fig. 4 it is shown the discharge corresponding to the hydropower station of the previous annual reservoir. In summer, as the inflows are smaller, the releases are lesser, dedicated to peak generation and to give ecological and irrigation flows. A certain break can be seen in October, when the wet season begins in this basin.

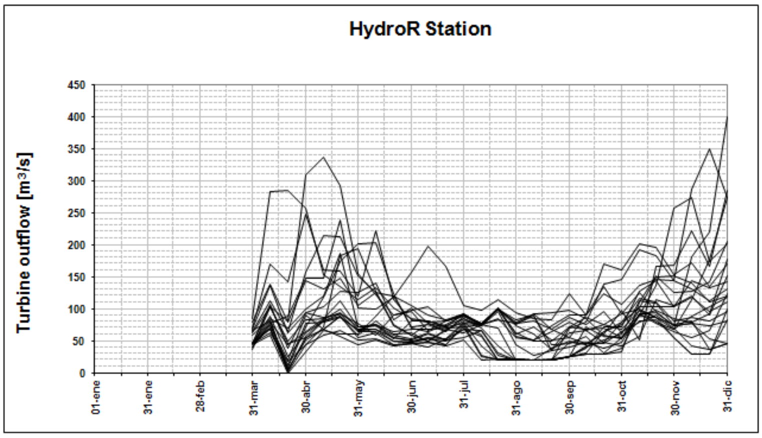

Fig. 4. HydroR simulated power plant outflow from Mar-31 to Dec-31

Fig. 5 shows the generation of the whole scheme, where a big variety of values can be observed, mainly out of summer. This information is also available for each reservoir, and it can be distinguished between different types of generation, such as mandatory for irrigation or completely free for generation. These outputs could also be used for risk management, even to restart the optimization model if needed.

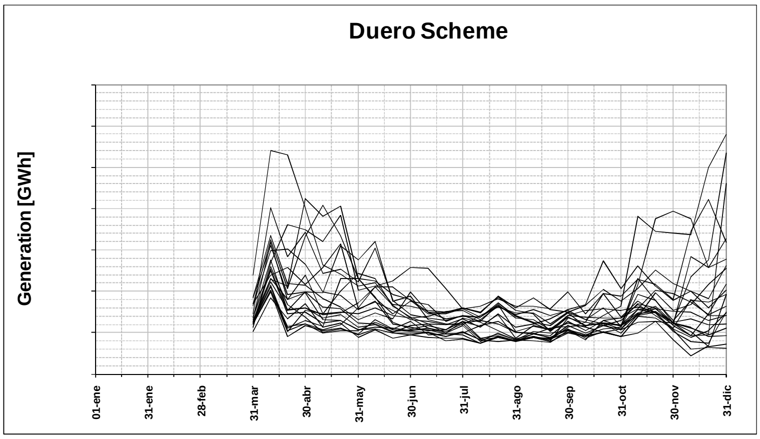

Fig. 5. Duero scheme simulated generations from Mar-31 to Dec-31

3.2 Application to hydro units maintenance planning

Scheduling of maintenances under a market framework is one of the key issues of the hydro planning, since they limit the power production available in a specific moment which can have a great impact on the economic results. There are many factors to consider, for instance, optimizing the available capacity on the periods with higher prices may result in spilling water if a flash flood happens during such maintenance works. Other factors to be taken into account are, for instance, the minimum river flows and irrigation flows.

Techniques of optimizing provide good results establishing dates for maintenances. Simulation techniques can complete the study assessing these results in terms of energy and measuring the risk of spilling water.

It is shown through an example how it is possible to get valuable information by means of the optimization and the simulation tools in order to decide the period of maintenance works.

The example analyzes two possibilities of allocating a maintenance work of one of the main power plants on the analyzed basin. The maintenance work need to take month and a half, and the possible options of starting are Aug-15 and Sep-15.

On Fig. 6 it is shown the mean of the simulated evolutions of the reservoir whose power plant is going to have the maintenance works, in both cases.

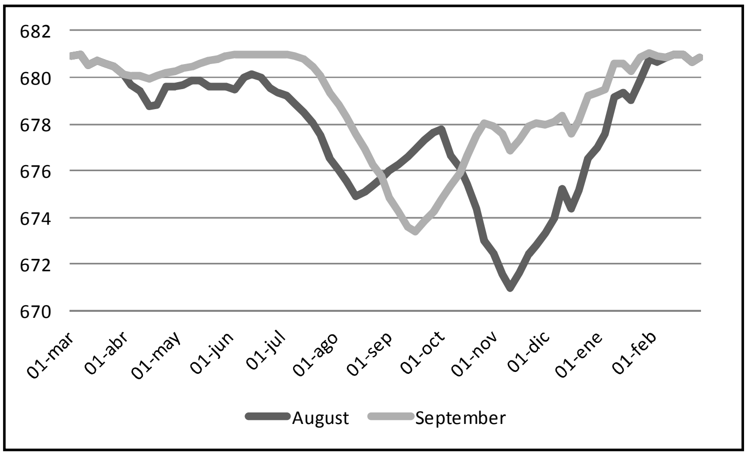

Fig. 6. Mean of the simulated evolutions of the level of the reservoir in two optional periods

Fig. 6. shows that in the case of August the optimization process decides to decrease the level of the reservoir dam in spring, in order to avoid spills during the unavailability of the power plant. When the maintenance is in September, the highest decrease of the level of the reservoir is in summer, and the level is lower than in the case of August, because of the higher inflows on the period of maintenance. It can be seen that, in both cases, after the maintenance period, the reservoir tends slowly to the same level, which is reached around March of the next year.

A series of 24 hydro inflows have been performed by the simulator to study the outputs of both cases. Fig 7. shows the average difference of energy produced in the power station with the maintenance and all the downstream power stations as well. However, the rest of its basin and the rest of the basins should be also analyzed, because they also would modify their evolution, although to lesser extent.

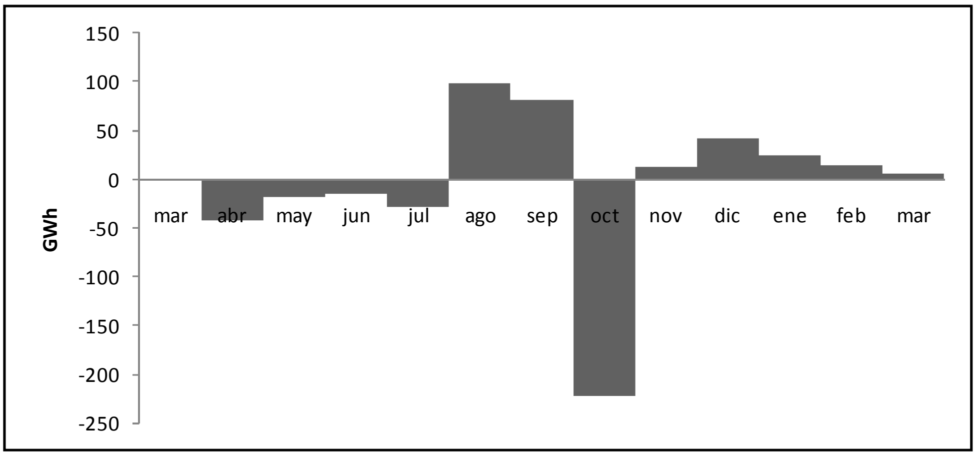

Fig. 7. Simulated differences of energy production between the two options. The difference is calculated as the energy produced in the case when the maintenance is in September minus the one produced when the maintenance is in August.

Table 1 shows a summary of the results obtained for the simulation of the two options. Both simulations are performed for the period since April to March of the following year. The values of spill, spilled energy and delivered energy are referring only to the power plant whose maintenance is under analysis.

This information is only a small part of the data to be considered. Of course, the results of the remaining reservoirs have to be analyzed, and a huge amount of data is available after the simulations for that issue. It is also important to consider data referring to price levels, evaluation of damage from spills, etc.

TABLE 1
AVERAGE OUTPUT OF SIMULATIONS FOR RESERVOIR_R

Unavailability Period	Reservoir Spill (hm^3)	Spilled Energy (GWh)	Delivered Energy (GWh)
Aug-Sep	218	33	604
Sep-Oct	244	37	600

4. Conclusions

Optimization models are necessary to obtain guidelines for hydro scheduling. However, the size of the optimization problem tends to be huge, especially considering the stochastic variables, and some simplifications are due to perform the calculations in a reasonable time.

Simulation models can represent in great detail the characteristics of a hydroelectric system and its operation, including reservoirs, channels, power plants, rivers, and a big amount of constraints.

The link between the simulation and optimization models is achieved through the optimal flow tables, which are the main result of the optimization process. These tables are used to guide the simulation of the daily operation of the reservoirs and power plants, in coordination with other guidelines and constraints.

Iberdrola and the Institute for Research in Technology (IIT) have developed two tools, a hydrothermal optimizing model and a hydro simulator, that are used to support the decision making process regarding the hydro scheduling in Iberdrola. They are also used for different kinds of analysis like maintenance planning, works, ecological flows, international agreements regarding river flows, droughts, and other similar issues that may arise in the management of a hydroelectric scheme.

Two realistic study cases have been shown. The first one describes the process of scheduling a hydroelectric scheme in Iberdrola, presenting graphics with some of the most significant results. The other one describes an application to hydro units maintenance planning.

Continual improvements to these models arise after new suggestions on their use. For instance, introducing randomness in the optimal flow tables allows considering the daily variability of the energy market, and randomness in outages allows being realistic in the simulation of hydro units, which is very useful in maintenance planning or designing new power plants.

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