# Simulation Applications to Hydropower Systems Management and Design

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## 1. Introduction

Hydro power plants play a key role in electric power systems, due to their low operating costs and their flexibility in real time operation. In addition, sustainability and environmental concerns support their use in current power systems, jointly with other renewable sources of energy, like wind and solar energy. The ecological impact of reservoirs can be overcome by the benefits of a good hydro production scheduling.

Simulation allows considering complex behavior in hydro plant operation at low computational costs compared with other approaches. For instance, mathematical modeling may involve integer or nonlinear programming that requires increased solution times over the simpler linear programming models. In our simulation model, nearly optimal results are obtained by following the guide of longer term hydrothermal mathematical programming models to propose initial reservoir management that is later adapted to fit the peculiarities of the river basin.

In this paper we describe a simulation model based on discrete time step. This model may have different purposes: a common use is to obtain near-optimal production schedules that are physically feasible, without performing an explicit optimization; another approach is to use simulation to evaluate the costs of performing maintenance duties in different periods; it can be used to carry out reliability analysis; and finally, simulation can also be used to test different design options when considering river basin construction or expansion.

**Keywords:** Hydroelectric power plants, discrete simulation, hydro reservoirs management, electric power scheduling.

## 2. Simulation model

The simulation model described in this section is a medium term model included in the general set of models used in the electric power plant scheduling. This means it receives longer term instructions about the optimal way to allocate water use through the year, and it transmits daily hydro production to shorter term models that may prepare the corresponding market bids. The longer term model has to take into account the whole hydrothermal power system, so as to be able to properly schedule each hydro section.

The simulation model consists of two main parts: the basin representation and the simulation algorithm, which are described in the following two sections.

### *A. Data representation*

River basin elements can be divided into three main categories: reservoirs, power plants and channels. Reservoirs are by far the most important elements in the management of the basin from a hydrological point of view and thus they are fully explained further in this section.

The power plants associated with the reservoirs are independently modeled to allow more flexibility in the river basin representation. For instance, a power plant may draw water from either of two different reservoirs, depending on the choice of the operator. Although electric power generation is the main result regarding power system operation, for a simulation seeking a rational schedule of water use, it is a byproduct. Hence, they transport water from the upstream reservoir to downstream elements delivering the corresponding power, but no special management is required for these elements.

Channels are used to model non-natural water flows that may exist in the basin. During simulation, water flows from the power plants to the downstream reservoirs, then to their corresponding power plants and so on. This continues until the river mouth is reached, unless there is an artificial outflow to other elements, which physically does not follow the natural river path. These situations are modeled by means of channels.

For the reservoir management, an outflow proposal is initially made, and this computation process can be divided into two steps:

- An initial outflow is obtained according to longer term instructions. Depending on the reservoir size, the detail used to compute this outflow changes. For the more relevant reservoirs, a longer term mathematical programming model provides an optimal outflow, whereas for the less relevant ones simpler approaches are used (for instance, targeting the reservoir volume to a monthly curve objective). The outflow provided by longer term models also include pumping flows, which may operate on a weekly or daily basis, depending on the capacity of the reservoir.

- This initial outflow is later modified to fit pre-specified behaviors for the different volume areas. These volume areas have corresponding outflow limits that are intended to soften the reservoir operation, driving their volumes more smoothly to safe areas that avoid spillages and not supplying outflow agreements.

### *B. Simulation method*

The general idea of the simulation method is to carry on reservoir management as close to longer term instructions as possible. Bearing this in mind, the algorithm has been split into three passes, where each one covers the whole river basin computing different concepts:

- In the first pass, the basin is simulated in downstream order, computing the outflow proposal (mentioned in the previous section) for each reservoir independently of the overall basin situation. This proposed outflow is then transmitted downstream through power plants and channels. This may cause spillages or the inability to fulfill outflow agreements in some reservoirs.

- In the second pass, performed from the river mouth upstream, the outflow proposal for each reservoir is modified to avoid spillages and breaking outflow agreements. These undesired situations are communicated to the elements upstream for them to help avoiding these situations, by modifying their outflows and even preventing spillages by increasing upstream pumping flows, if this is needed.

- Finally, the third pass computes final power productions once the water flows are as close as they can be to the optimal ones (computed by the longer term hydrothermal model) while causing as little problems as possible.

These simulations use two different types of hydro series as water inflow: on the one hand, historical data from the past years can be used to recover past situations that may happen; on the other hand, synthetical series can be computed based on a subset of the historical series (for instance, the series corresponding to the most dry years), applying monthly coefficients that modulate the year inflow profile.

## 3. Simulation tool

For the analysis presented in this paper, a simulation tool is used. This tool is based on Object Oriented Programming, due to the fairly independent computations required for each basin element. This allows the representation of the basin as a set of objects that interact with each other in each pass in a very limited way: the water flows, and the spillages and lack of agreed outflows.

With this abstract representation of a river basin, the consideration of a new one is greatly simplified. It consists of building the objects representing the new river structure, but the basic object management remains the same.

## 4. Case study

In this section a real case study is analyzed. This case is based on a real basin, where it will be demonstrated in the usual tasks that a utility performs. These tasks include common management ones like yearly planning of the hydro production, or more rare short scope analysis in presence of exceptional circumstances like water floods or droughts. Simulation can also be used to locate the best period of time to carry out maintenance or enlargement works. Finally, outflow agreements and design of new reservoirs can be evaluated employing this simulation approach that provides a measure to support the decision process.

## 5. Conclusions

This paper describes a simulation model that provides a physically feasible production scheduling for river basins, based upon the solution of longer term models and taking into account the special features of real river basins.

This model is applied to a case study where its effectiveness can be assured in practical terms, considering the management needs of an electric utility.

## References

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