ESD.S30
Electric Power System Modeling for a Low Carbon Economy

*Hydrothermal scheduling. A case study*

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1. Introduction

2. Long-term stochastic hydrothermal scheduling model

3. Medium-term simulation model
Introduction
Long-term stochastic hydrothermal scheduling model
Medium-term simulation model
Introduction

• Relevance of hydroelectric power
  – Reduces electric system operation cost
  – High flexibility to integrate intermittent generation
  – Important role in the generation mix

• Objectives of hydro scheduling
  – To optimize the water value in an stochastic environment, fulfilling all the operation constraints (to minimize the operation cost)
  – To analyze and test different scheduling strategies of storage hydro and pumped storage hydro plants
Procedure in two steps

1. Stochastic Hydrothermal Coordination Model (MHE) to deal with a large-scale electric system and with the dimensionality of stochastic hydro inflows
   - Based on Stochastic Dual Dynamic Programming (SDDP)
   - Scope: 2 years. Time step: week. Load levels: peak and off-peak
   - Some hydro details must be simplified in order to reduce the size of the problem

2. Simulation-based model to deal with hydro cascades in a more detailed way
   - Receives the main outputs from the optimization model and performs daily simulations
Introduction

Long-term stochastic hydrothermal scheduling model

Medium-term simulation model

Long-term stochastic hydrothermal scheduling model
MHE model creates DISCHARGE, PUMPING and PRICE TABLES

- Hydrothermal model (Spanish or Iberian Electricity Market)
- Detailed modeling of the hydro system
- Less detailed modeling of demand and the rest of the generation mix
- Representation of inflows through weighted scenario trees

Data for generating the scenario tree:
- Starting date
- Current inflows
- Tree structure
Two-year scope case study

- **Spanish electric system**
  - 118 thermal units
  - 3 main basins with 57 hydro plants and 7 pumped storage hydro plants that operate 39 hydro reservoirs

- **Inflows uncertainty**
  - Recombining tree with 5 branches every 4 weeks: $5^{25}$ scenarios

![Map of Spain highlighting SIL, DUERO, and TAGUS areas](image_url)
Historical natural hydro inflows in an small reservoir
Historical natural hydro inflows in a medium reservoir
Historical natural hydro inflows in a large reservoir
Optimization process of MHE

Input data
- Demand forecast
- Non dispatchable renewable energy
- Thermal units and their variable costs
- Hydro plants and their cascaded topologies
- Scenario tree with probabilities of inflows

STOCHASTIC OPTIMIZATION

Output results
- For each node it obtains the optimal solution
- Through interpolation methods it obtains multidimensional tables that show the optimal output of hydro power plants depending on
  - Week of the year
  - Level of the reservoir
  - Natural inflows
  - Water reserve in the basin

Hydrothermal scheduling. A case study
Volume and water head in an small reservoir

Hydrothermal scheduling. A case study
Volume and water head in a medium reservoir

Hydrothermal scheduling. A case study
Volume and water head in a large reservoir

![Graph showing volume and water head in a large reservoir]
Volume in an small reservoir

Hydrothermal scheduling. A case study
Volume in a medium reservoir
Volume in a large reservoir
**Water release table**

**Result: water release**
for a volume of reservoir 2 = 1609 hm\(^3\)
for week February 9-15.

<table>
<thead>
<tr>
<th>Q(m(^3)/s)</th>
<th>2</th>
<th>181</th>
<th>360</th>
<th>540</th>
<th>719</th>
<th>898</th>
<th>1077</th>
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</table>

**Input: natural inflow**

**Input: volume of reservoir 1**
Water release table (for week 52)
Water release table (for week 7)
System marginal cost

Peak (in red) and off-peak (in blue)
Introduction
Long-term stochastic hydrothermal scheduling model
Medium-term simulation model

Medium-term simulation model
Introduction

- Simulation allows full detail modeling of hydro plant operation
  - Nonlinearities in the production function
  - Specific behavior of river basin elements
- Simulation can produce scheduling plans
  - Closer to real operation
  - With lower computational requirements
Object oriented programming simulation

Five types of nodes (objects) are needed:

- Reservoir
- Canal
- Plant
- Inflow point
- Special objects

Hydro topology is represented by a graph of nodes where each node is an element.
Two kinds of strategies

a) Discharge decision taken from a pre-calculated optimal water release table depending on:
   - Week of the simulated day
   - Natural inflow
   - Volume of the own reservoir
   - Volume of a coordinated reservoir, if needed
   - Table calculated by MHE stochastic hydrothermal model (usually for the main reservoirs of the basin)

b) Discharge decision taken from guiding curves (usually for small reservoirs) depending on:
   - Week of the simulated day
   - Volume of the own reservoir
   - Guiding curves & associated discharges
Water release table

Result: water release for a volume of reservoir 2 = 1609 hm³ for week February 9-15.

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Guiding curves
Application case to hydro scheduling (i)

- Two effects studied:
  - Variation of peak and off-peak hourly prices spread
  - Variation of installed thermal capacity
- Realistic case of 9 reservoirs
- Simulation for 24 yearly series
  - Previous generation of production/pumping water release tables for each case
- Results for reservoir yearly operation
Application case to hydro scheduling (ii)

- Effect of the increased price spread among peak and off-peak hours:
  - Narrower reservoir volume evolutions

![Graph showing reservoir volume evolutions over time with real, maximum, upper limit curve, lower limit curve, upper guide, and lower guide lines highlighted.](image-url)
Application case to hydro scheduling (iii)

- Effect of the increased installed thermal capacity
  - Allows free allocation of hydro production
  - Does not need to keep a reservoir volume during summer
Application case to hydroelectric scheme design (i)

- Analysis of investment in new power plants in Douro river
- Example case:
  - Simulation of 24 historical series
  - Unplanned outage rate of 5%
- Assessment of the maximum outflow
  - Power plant with up to 4 units of 200 m$^3$/s and 48 MW
  - Analysis of generation and spilled outflows

<table>
<thead>
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Application case to hydroelectric scheme design (ii)

- Assessment of the maximum outflow
  - Power plant with up to 4 units of 200 m³/s and 48 MW
  - Analysis of results:
    - Generation increase and spillage reduction
    - Allocation of more energy in peak hours

<table>
<thead>
<tr>
<th>Case</th>
<th>Generation energy</th>
<th>Spilled energy</th>
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<tr>
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<td>Total [GWh/year]</td>
<td>Peak [GWh/year]</td>
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<tr>
<td>4a</td>
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</table>
Application case to hydroelectric scheme design (iii)

- Assessment of the number of units (1 to 4):
  - For a fixed outflow of 600 m$^3$/s
  - Should be combined with the economic valuation of investment costs
  - The increase from 1 to 2 units is more significant than the rest of new units installation

```
<table>
<thead>
<tr>
<th>Case</th>
<th>No. of units</th>
<th>Generated flow [hm$^3$/year]</th>
<th>Spilled flow</th>
<th>Generation energy [GWh/year]</th>
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Conclusions

• Medium term simulation model
  – Connected to long-term stochastic hydrothermal model
  – Considers detailed operation
  – Stochastic inflows and outages

• Application case to hydro scheduling
  – Provides feasible operation
  – Different operation criteria

• Application case to hydro scheme design
  – Considering several options about installed units
  – Unplanned outage sampling