Pumping Scheduling in Object Oriented Simulation of Hydroelectric Power Systems

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Content

• Introduction
• Data representation
• Simulation method
• Results
• Conclusions
Introduction (i)

- Hydro scheduling is very important:
  - Very low variable cost of energy (only O&M)
  - Large regulation capability
  - Allows the storage of energy for reliability purposes (specially by the recent increasing penetration of wind power)

- Hydro production in Spain ranges from 15 % to 20 % of the energy demand of the ordinary regime (except renewable resources)
Introduction (ii)

- **Objective:**
  - Analyze and test different management strategies of hydro and pumped-storage plants

- **Simulation** is the method chosen to model them
  - because of its **flexibility** and
  - the **complex characteristics** of hydro basins
Introduction (iii)

• Key features of simulation models:
  – **Time**: Static vs. Dynamic
  – **Stochasticity**: Deterministic vs. Stochastic
  – **Time step**: Fixed vs. Event-oriented

• This hydro simulation model is
  – **Dynamic** (up to one year)
  – **Stochastic hydro inflows**
  – **Fixed** (one day)
Introduction (iv)

Model aims:
- Economic planning of hydro operation:
  - Yearly and monthly planning
- Update the yearly forecast:
  - Operation planning up to the end of the year
- Short term detailed operation:
  - Detailed operation analysis of floods and droughts, changes in irrigation or recreational activities, etc.
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Data representation (i)

- Basin topology is represented by a **graph of nodes** where each **node** is an **element**:

  ![Diagram](image)

- Connections among nodes are physical junctions through the river.
- This structure induces the use of
  - Object Oriented Programming (OOP)
Data representation (ii)

- Five **types of nodes (objects)** are needed:
  - Reservoir
  - Canal
  - Plant
  - Inflow point
  - River junction

- Each node is **independently “operated”** although it may require information from other elements
Data representation (iii)

- **Reservoir:**
  - Manages the water
    - One or more natural inflows
    - One outflow
  - May have associated:
    - Minimum outflow
    - Volume curves that guide its operation:
      - Minimum/maximum target curves
      - Lower/upper guiding curves
      - Avoiding spillage curve
    - Minimum and maximum volume
    - Optimal production table (input from long term hydrothermal models)
Data representation (iv)

- **Canal:**
  - Doesn’t manage the water
  - Flow transportation between nodes with a limit
Data representation (v)

- **Plant:**
  - Produces electric energy from hydro inflow
  - Coefficient of efficiency depending linearly on the head
  - May also pump
Data representation (vi)

• **Natural inflow point:**
  – Introduces water into the system
  – Uses historical series or synthetic inflows
Data representation (vii)

- **River junction:**
  - Groups elements in a river junction
  - Limits the **maximum joint outflow**
  - Management determined in the steps:
    1. Independent initial decision
    2. Reduction of the initial value following a priority order up to the maximum flow
       - Production that can not be retained
       - Pumping that can not be retained
       - Production and pumping that can be retained
Tagus-Tiétar river junction

It is just one hydro plant
Two hours are needed for changing from one mode to the other

Pumping is used to avoid spillage, maximize hydro production

Algorithm

- Production that can not be retained at Tiétar / Pumping that can not be retained at Tiétar
- Production that can not be retained at Tagus
- Production that can be retained at Tiétar / Pumping that can be retained at Tiétar
- Production that can be retained at Tagus
Reservoir operation strategies

a) Optimal outflow decision taken from a precalculated optimal production table depending on:
   - Week of the simulated day
   - Hydrologic index of the basin inflows (type of year)
   - Volume of the own reservoir
   - Volume of a reference reservoir of the same basin
     - Table calculated by a long term hydrothermal model
     - Usually for the main reservoirs of the basin

b) Outflow equals incoming inflow (usually for small reservoirs)

c) Go to minimum target curve (spend as much as possible)

d) Go to maximum target curve (keep water for the future)
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Simulation method (I)

- **Main objective:**
  - Maximize hydro production following the reservoir operation strategies
  - **Other objectives:**
    - Avoid spillage
    - Satisfaction of minimum outflow (irrigation)

- The proposed method requires **three phases**:
  1. Decides the initial management
     - Blind decision for each element
  2. Modifies it to avoid spillage and produce minimum outflows
  3. Determines the electricity output for previous inflows
Simulation method (II) – Phase 1

- **Downstream**
- **Each element is individually operated according to its own operation and strategies**
- **Additional information is collected:**
  - In reservoirs
    - Spillage and non served minimum flow
    - Additional volume to spend or to keep
  - In all the elements:
    - Accumulates those values for the own element and those located upstream
Simulation method (III) – Phase 1

Additional vol to keep

Additional vol to spend
Simulation method (III) – Phase 2

- **Upstream** from the end of the basin
- **Modifies the Phase 1 operation**
  - To avoid spillage forces the reservoirs to keep water
  - To serve a minimum flow increases the production of reservoirs
  - **Pumping** can be used for both purposes
- Splits the changes proportionally to the capacity of each element with respect to all the remaining elements located upstream
Simulation method (IV) – Phase 3

• Determines the plant output
  – By using a coefficient of efficiency
  – Depending on the average water head of the day

• Splits the production between peak and off-peak hours:
  – Put as much energy as possible in peak hours
  – The rest in off-peak hours
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Case study

- Application to the Tagus basin belonging to Iberdrola with:
  - 9 reservoirs of different sizes
  - 8 hydro plants
  - 6 natural inflow points
  - 27 historical series of daily inflows
Results (i)

**Large reservoir**

- **Maximum curve**
- **Real curve**
- **Maximum target curve**
- **Minimum target curve**

**Graph Details:**
- The graph shows the volume (in millions of cubic meters, [Hm^3]) over time from January 1st to December 31st.
- The curves indicate the target and actual volumes for different periods:
  - **2.5%**
  - **20.0%**
  - **ME DIA**
  - **80.0%**
  - **97.5%**
  - **MÁXIMA**
  - **RESGUARDO**
  - **GARANTÍA**
  - **REAL**

**Legend:**
- The graph includes a legend that explains the significance of each line.
- The x-axis represents the months from January to December.
- The y-axis represents the volume in millions of cubic meters.

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**Title:**
- Pumping Scheduling by Simulation
Results (ii)

Small reservoir

Volume [Hm³]

- 2.5%
- 20.0%
- MEDIA
- 80.0%
- 97.5%
- MÁXIMA
- RESGUARDO
- GARANTÍA
- REAL

Embalse 2

0 20 40 60 80 100 120 140 160 180

01-ene 21-ene 10-feb 02-mar 22-mar 11-abr 01-may 21-may 10-jun 30-jun 20-jul 09-ago 29-ago 18-sep 08-oct 28-oct 17-nov 07-dic 27-dic

Volúmenes

2.5% 20.0% MEDIA 80.0% 97.5% MÁXIMA RESGUARDO GARANTÍA REAL
Results (iii)
Results (iv)
Results (v)
Results (vi)
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Conclusions

• A **general simulation method** for hydro basins has been proposed
• A **three phase method** implements the maximization of hydro production objective including pumped-storage and hydro plants
• **Object Oriented Programming** paradigm has been used
• A **flexible computer application** implements this method
• Validated with a case study
• It is **currently been used** for hydro operation
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