Pumping Scheduling in Object Oriented Simulation of Hydroelectric Power Systems

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Introduction (I)

- Hydro plant characteristics:
  - Low variable costs
  - No pollutant emissions
  - Large regulation capability
  - Allow energy storage
    - Pumping units
- Objective:
  - Analyze and test different management strategies of hydro plants

Introduction (II)

- Two approaches for comparison:
  - Simulation model:
    - Dynamic
    - Stochastic
    - Discrete
  - Optimization model:
    - Multi-objective MIP problem
    - Objectives' weights reflect management priorities
    - Benchmark for comparison

Simulation model (I)

- Two main objectives:
  - Represent the wide variety of management strategies

    Simulation approach
  - General representation of river basins

    Object Oriented Programming
    - Represents topology by means of a graph
    - Each node in the graph is an object
- Five object types
- Three passes simulation algorithm

Simulation model (II) – data

- Reservoir
  - Water management
  - Management strategies:
    - Pre-calculated decision tables
    - Target to maximum or minimum operating levels
    - Produce inflows
  - Guiding volume curves
  - Minimum outflows
- Channels
  - Upper limit to the water flow

Simulation model (III) – data

- Power plant
  - Energy production, but no water management
  - Water pumping
  - Conversion coefficient depending on water head
- Natural inflows
  - Uses historical or synthetic series of inflows
- River junctions
  - Group of elements sharing a common penstock
  - First individual independent management
  - Later reduction of outflows to fit the common outgoing flow

Simulation model (IV) - method

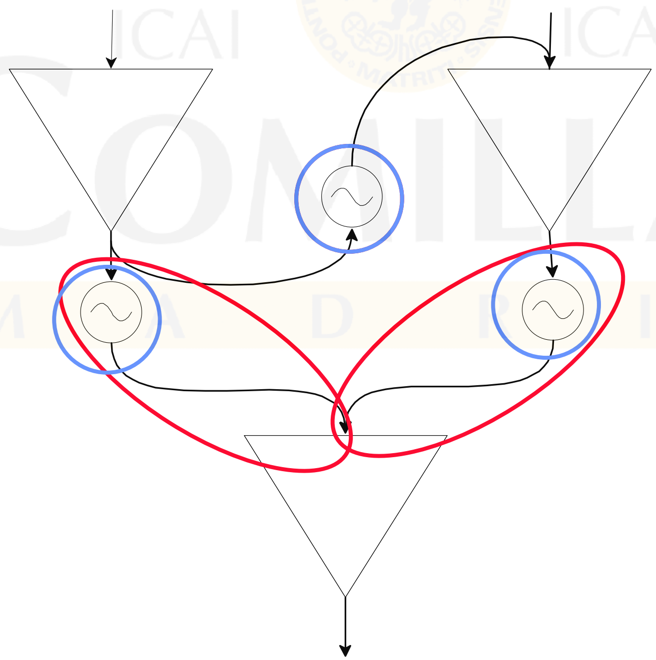
- Main objectives:
  - Follow longer term directions
  - Reduce spillages
  - Provide of committed minimum flow
- Three passes
  - Share whole ability to help to reduce:
    - Spillages
    - Not supplying minimum outflows

Simulation model (V) - method

- First pass
  - Individual management
  - Compile information about element's capability to help reduce unwanted situations:
    - Capability to provide additional water
    - Capability to retain water
- Second pass
  - Transmit the problematic situation upstream
  - Each element contribute to reduce problems
- Third pass
  - Calculate productions and reserves

Simulation model (VI) - pumping

- Two ways:
  - Additional capability to retain water
  - Expressly modeling the pumping groups



Optimization model (I)

- Multi-objective optimization model
- Objective function weights express priorities of management
  - Avoid not supplying committed water flows
  - Stay in usual operation ranges
  - Avoid spillages
  - Deviations from initial management proposal

Optimization model (II)

- Objective function:

$$
\begin{aligned}
z = \quad & K_i \cdot irrigation\_deviation + \\
& K_v \cdot volume\_deviation + \\
& K_s \cdot spillages + \\
& K_f \cdot proposed\_flow\_deviation
\end{aligned}
$$

- Reservoir's water balance:

$$
\begin{aligned}
volume = \; & starting\_volume + \\
& + natural\_inflows + inflows + pumped\_inflows - \\
& - outflows - pumped\_outflows
\end{aligned}
$$

Optimization model (III)

- Minimum operation level:

$$volume < min\_op\_volume \rightarrow \alpha = 1$$

$$outflow \leq (1-\alpha) \cdot max\_outflow$$

$$volume + volume\_deviation \geq min\_op\_volume$$

- Maximum operation level:

$$volume > max\_op\_volume \rightarrow \beta = 1$$

$$spillage \leq \beta \cdot M$$

- Minimum outflows:

$$irrigation + irrigation\_deviation = commited\_irrigation$$

Optimization model (IV)

- Reservoir management:
  - Pre-calculated table:

$$outflow = objective\_flow + proposed\_flow\_deviation$$

  - Inflows production:

$$natural\_inflows + inflows + pumped\_inflows - \\ -outflows - pumped\_outflows = proposed\_flow\_deviation$$

  - Towards minimum / maximum operation level

$$natural\_inflows + inflows + pumped\_inflows - \\ -outflows - pumped\_outflows + starting\_volume = \\ target\_volume + proposed\_flow\_deviation$$

Numerical results (I)

- Test case:
  - Real river basin from Spain

Reservoirs	9
Pre-calculated tables	2
Hydro power plants	10
River junctions	1
Inflows	6

  - Analyzed for 24 inflow series
  - Synthetic series: dry (60% inflows), medium and wet (140% inflows)

Numerical results (II)

- Simulation model:

	All series	Dry	Medium	Wet
Production	2315.3	1275.9	2289.2	3258.5
Pumping	0.2	0	0	0
Reserves	330.1	214.1	307.1	401.1
Execution time	848''	43''	43''	43''

- Optimization model:

	All series	Dry	Medium	Wet
Production	2531.2	1537.0	2672.4	3751.8
Pumping	13.1	10.9	18.1	20.9
Reserves	219.9	139.9	166.0	231.1
CPLEX time (x8)	387''	27''	18''	11''

Conclusions

- Management assessment approaches:
  - Generic simulation model
    - Object Oriented Programming
    - Three phase simulation method
  - Multi-objective programming model
    - Prioritizes management objectives
- Real test case presented
  - Better results for optimization model
  - Longer solution times implied

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Optimization model (II)

- Objective function:

$$z = \sum_{i\in T} \mathrm{Pt}_i \cdot \left(defw_i + excw_i\right) + \sum_{i\in M} \mathrm{Pm}_i \cdot \left(defw_i + excw_i\right) + \\ + \sum_{i\in I} \mathrm{Pf}_i \cdot \left(deff_i + excf_i\right) + \sum_{i\in I} \mathrm{Ps}_i \cdot s_i + \sum_{i\in I} \mathrm{Pr}_i \cdot defr_i$$

- Reservoir's water balance:

$$w_i = \mathrm{W}_i^{\mathrm{d-1}} + 0.0864 \cdot \left[\begin{array}{c} \mathrm{In}_{i,d} + \sum_{i'\in Up(i)} \left(f_{i'} + s_{i'} - ir_{i'} + ff_{i'} \right) + \sum_{i'\in PumpIn(i)} pf_{i',i,d} \\ - f_i - s_i - ir_i - ff_i - \sum_{i'/i\in PumpIn(i')} pf_{i',i,d} \end{array} \right]$$

Optimization model (III)

- Minimum operation level:

$$w_i \leq \left(1 - u_i^{\min}\right) \mathrm{W}_i^{\min} \quad i \in I$$

$$f_i \leq \left(1 - u_i^{\min}\right) F_i^{\max} \quad i \in I$$

$$w_i + defw_i \geq \mathrm{W}_i^{\min} \quad i \in I$$

- Maximum operation level:

$$w_i \geq \left(1 - u_i^{\max}\right) \mathrm{W}_i^{\max} \quad i \in I$$

$$s_i \leq \left(1 - u_i^{\max}\right) \cdot M \quad i \in I$$

- Minimum outflows:

$$ir_i = IR_i - defr_i \quad , i \in I$$

Optimization model (IV)

- Reservoir management:
  - Pre-calculated table:

$$\mathrm{In}_i + \sum_{i' \in Up(i)} \left(f_{i'} + s_{i'} - ir_{i'} + ff_{i'} \right) + \sum_{i' \in PumpIn(i)} pf_{i',i} -$$
$$-\mathrm{OF}_i - s_i - ir_i - ff_i - \sum_{i' / i \in PumpIn(i')} pf_{i',i} = excf_i - deff_i$$

  - Inflows production:

$$\mathrm{In}_i + \sum_{i' \in Up(i)} \left(f_{i'} + s_{i'} - ir_{i'} + ff_{i'} \right) + \sum_{i' \in PumpIn(i)} pf_{i',i} -$$
$$- f_i - s_i - ir_i - ff_i - \sum_{i' / i \in PumpIn(i')} pf_{i',i} = excf_i - deff_i$$

  - Towards minimum / maximum operation level

$$\mathrm{In}_i + \sum_{i' \in Up(i)} \left(f_{i'} + s_{i'} - ir_{i'} + ff_{i'} \right) + \sum_{i' \in PumpIn(i)} pf_{i',i} -$$
$$- f_i - s_i - ir_i - ff_i - \sum_{i' / i \in PumpIn(i')} pf_{i',i} = \frac{\mathrm{W}_i^{\mathrm{TARGET}} - \mathrm{W}_i^{\mathrm{d\text{-}1}}}{0.0864} + excf_i - deff_i$$