Scenario analysis for energy optimization of pumping plants in complex water supply systems

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Introduction

The management of complex water supply systems needs a close attention to economic aspects concerning high costs related to energetic management (Pasha and Lansey 2014). Specifically, the optimization of water pumping plants activation schedules is an important issue, especially managing strategic and costly water transfers under drought risk (Asefa et al. 2014; Matheus and Tullos 2016). In such management context and under uncertainty conditions, it is crucial to assure simultaneously energy savings and water shortage risk alleviating measures. The model formulation needs to highlight these requirements duality: to guarantee an adequate water demands fulfilment respecting an energy saving policy.
The obtained results should allow the water system's Authority to get a robust decision policy, defining optimal rules and, specifically, the definition of optimal activation triggers for water pumping stations.

Modelling approach

This problem modelling approach has been developed using a two stages scenario analysis (Pallottino et al. 2004) with a cost-risk balancing approach (Gaivoronski et al. 2012; Napolitano et al. 2016), achieving simultaneously an energetic and operative costs minimization and assuring an adequate water demand level fulfilment for users. The water supply system has been schematized through a single-period flow network graph (basic graph) (Diestel 2005) and by its replicates obtaining the multi-period graph (Pallottino et al. 2004).

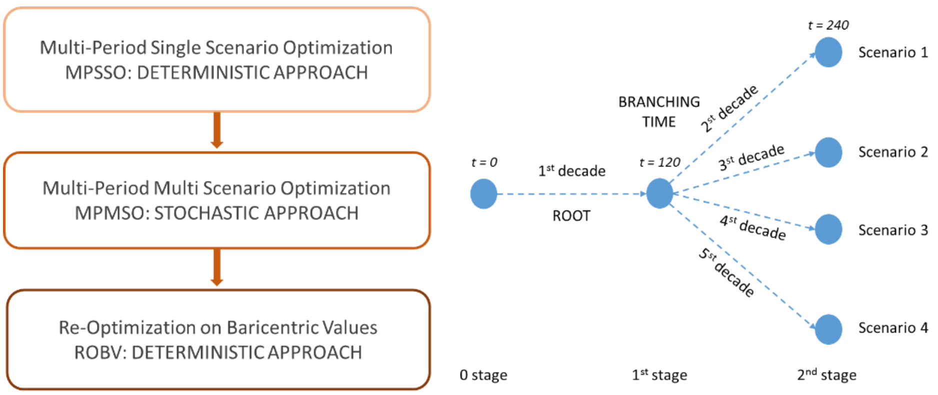

Figure 1: Main modelling steps and scenario tree aggregation

The optimization procedure (summarized in the flowchart shown in Figure 1) aims to identify the pump activation thresholds, mainly using reservoirs' storage volumes as trigger values in the pumps-activation decision. For each pump station, two seasons' activation thresholds should be identified, in order to define a barycentric seasonal value. These trigger values refer specifically to the dry (in Mediterranean countries months from April to September) and the wet (months from October to March) hydrological semester.

The scenario optimization model has been implemented using the software GAMS (2008) interfaced with CPLEX solvers specifically designed for modelling mixed integer optimization problems.

Results and concluding remarks

An application of the proposed optimization approach has been tested considering the draft of a real supply system located in a drought-prone area in South-Sardinia (Italy).

By applying the scenario-optimization process, a robust decision strategy for seasonal trigger values of pumps activation was retrieved. Reference scenarios were settled considering the regional hydrological database (RAS 2006) modified in order to take into account climatological trends in last decades and water resource reductions. As drafted in Figure 1, the database has been organized considering 4 hydrological scenarios of different criticism, where each one has been of 20 years, 240 monthly periods with the branching time located at the 120th period.

The scenario-optimization methodology confirmed its potentiality when applied to the real-case. It allowed identifying two seasonal optimal activation thresholds for each pumping plant located in the water system. Moreover, the cost-risk balancing approach minimized the O&M costs and contextually restricted risks and conflicts between users in shortage conditions.

Costs and penalties have been evaluated in a simulation phase through an economic post-processor taking into account water shortages penalties and pumping costs. Deficit occurrences could remain into "planned shortages", which the user is asked to accept under drought conditions or into "unplanned shortages", which could occur in very critical scenarios, due to severe and not expected lack of resource.

In order to build a model more adherent to the reality, the effectiveness of the obtained results has been tested interacting with the regional water system's Authority by comparison with the occurred management behaviour.

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