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Viewpoint

Hybrid solution and pump-storage optimization in water supply system efficiency: A case study

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ABSTRACT

Environmental targets and saving energy have become ones of the world main concerns over the last years and it will increase and become more important in a near future. The world population growth rate is the major factor contributing for the increase in global pollution and energy and water consumption. In 2005, the world population was approximately 6.5 billion and this number is expected to reach 9 billion by 2050 [United Nations, 2008. www.un.org, accessed on July]. Water supply systems use energy for pumping water, so new strategies must be developed and implemented in order to reduce this consumption. In addition, if there is excess of hydraulic energy in a water system, some type of water power generation can be implemented.

This paper presents an optimization model that determines the best hourly operation for 1 day, according to the electricity tariff, for a pumped storage system with water consumption and inlet discharge. Wind turbines are introduced in the system. The rules obtained as output of the optimization process are subsequently introduced in a hydraulic simulator, in order to verify the system behaviour. A comparison with the normal water supply operating mode is done and the energy cost savings with this hybrid solution are calculated.

1. Introduction

Energy, environment and hydraulic efficiency are important goals for the sustainable development of water supply systems (Ramos and Covas, 1999). The needs for water consumption, environmental targets and saving energy have become ones of the world's main concerns over the last years and they will grow to be more and more important in a near future (Refocus, 2006). The objective of these systems is to guarantee the delivery of enough water with good quality to populations. Although, in order to achieve that, energy for pumping is needed, representing the main cost for water companies who operate the systems. The evaluation of the energetic potential in water supply systems is expected to become a common procedure to achieve improvement of these systems. This can be done by taking advantage of the possible environmental and economical benefits from the instalation of a water turbine as a clean energy converter (United Nations, 2008).

The optimization of pump/turbine-operation with energy consumption/production has been investigated over the last decade (Allen et al., 2006; Anagnostopoulos and Papantonis, 2006). The interest in this area is not only related to the complexity of the problem but mainly by the environmental, economical and social benefits by adopting this type of solution. The implementation of energy production components in water supply systems is a solution that intends to increase the energy efficiency by using local available renewable resources. With this kind of systems the external energy dependence and their costs can be reduced. The adaptation of water supply systems to produce energy is an advantageous solution because most of the system components already exist (e.g. reservoirs, pipe system, valves) and there is a guaranteed discharge continuous flow along each day.

These days, pump hydro storage systems are used as energy and water storage on systems' networks. These systems consist of two reservoirs, where one is located at a low level and the other at a higher elevation, with pump and hydropower stations for energy injection or conversion. During off-peak hours the water is pumped from the lower to the upper reservoir where it is stored. During peak hours the water is released back to the lower reservoir, passing through hydraulic turbines generating electrical power (Bose et al., 2004).

When a wind park is combined with a pumped-hydro system, several advantages can be achieved:

- during low consumption hours, the wind energy that otherwise would be discarded, can be used to pump water to the

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upper reservoir and discharged whenever there is a need to produce energy;

- when the wind has high variability, these storage systems can be used to regulate the energy delivery;
- the energy stored in the pumped-hydro system can be utilized to generate electricity when wind power is not available;
- when there is a variable tariff applied, it is possible to achieve significant economical benefits by deciding optimal pumping/turbine schedules (Papathanassiou et al., 2003).

An optimization problem is a mathematical model in which the main goal is to minimize or maximize a quantity through an objective function constrained by certain restrictions. The optimization models can use several methods which nowadays are becoming more efficient due to the computer technology evolution. In Firmino et al. (2006) an optimization model using linear programming (LP) was developed to improve the pumping stations' energy costs in Brazil. The study revealed that the energy costs can be reduced by 15%. In Castronuovo and Lopes (2004) a model for the daily operation of a wind-hydro plant was developed using LP. They concluded that, for the test case presented, the predicted yearly average economic gain of including a pumped-hydro station in a wind farmer, is between 425.3 and 716.9 k€.

In this paper, an hourly discretized optimization model for the determination of operational planning in a wind pumped-hydro system is presented. Comparisons are made between cases with and without complementary wind energy. The economical profit for each case study is presented.

2. System description

A real case is analysed based on the "Multi-purposes Socorridos system" located in Madeira Island, Portugal. This system was designed to supply water to Funchal, Câmara de Lobos and Santa Quitéria, as well as to regularize the irrigation flows and produce electric energy. In this system there is a pumping and a hydropower station located at Socorridos. It is a reversible type system which enables pumping (in one station) and power production (in a parallel station) of 40,000 m^3 of water per day. Fig. 1 depicts a scheme of Socorridos system.

The system includes an upper reservoir (Covão) at 540 m, with storage tunnels capacity for 40,000 m^3. The Covão reservoir is used to supply water for the Câmara de Lobos population. In addition to the tunnels, the Covão reservoir is used as storage for the water that flow from the mountains. In Socorridos, there is a tunnel located at 81 m that has the same capacity as the upper one.

The pump station is located at a height 85 m and has four pumps with an installed power of 3750 kW each. The hydropower station is located at a topographic height of 89 m and has Pelton turbines installed with a nominal power of 8000 kW and a maximum flow of 2 $m^3\,s^{-1}$ each. In Fig. 2 the characteristic curves of the Pelton turbines and the pumps are presented.

The penstock between Covão and Socorridos has a total length of 1266.25 m. The characteristics are presented in Table 1.

This pumping station was designed to pump 40,000 m^3 of water stored in Socorridos reservoir during 6 h, for the electricity low peak hours (from 0 to 6 a.m.). In the remaining hours of the day, the water is discharged from Covão reservoir to Socorridos

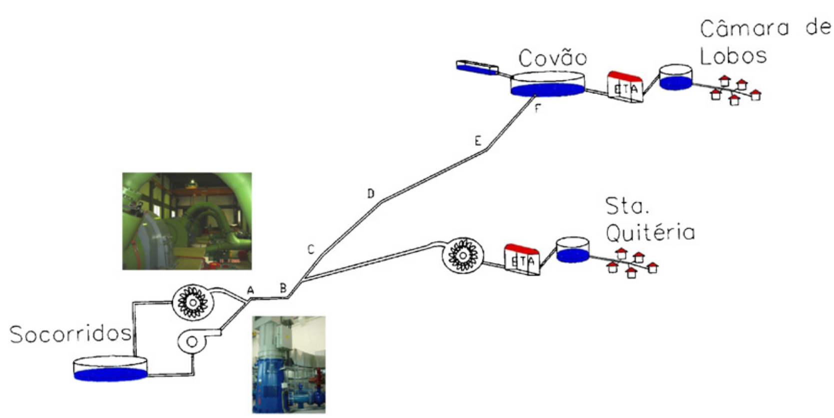

Fig. 1. Multi-purposes scheme of Socorridos system.

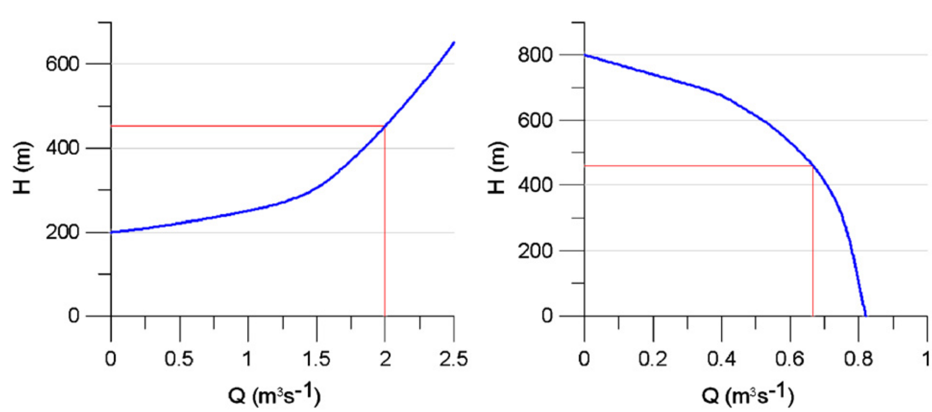

Fig. 2. Turbine (left) and pump (right) characteristic curves and operating conditions.