

ALLIEVI as a Tool for Simulating Hydraulic Transients in Energy Recovery Systems [†]

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Abstract: ALLIEVI is a software developed by the Universitat Politècnica de València to model and analyze hydraulic transients in pressurized water systems. ALLIEVI allows for the modeling of valve and pump maneuvers, including pressure reducing valves (VRPs) and energy recovery elements such as turbines and pumps operating as turbines (PATs). In this work, two practical cases are presented in which ALLIEVI is used as a tool, either to adjust the energy recovery potential of a system or to calculate the hydraulic transient generated by maneuvers of an energy recovery system.

Keywords: ALLIEVI; hydraulic transients; energy efficiency; pressurized water networks

1. Introduction

The various maneuvers in hydraulic systems generate transient effects that can lead to cavitation, among other effects. The complexity of their calculation requires specialized software such as ALLIEVI, which simulates the system's behavior. ALLIEVI is a free software, used internationally for the calculation and simulation of hydraulic transients [1].

This program can model different devices and stages of a system, from the design stage to verification. ALLIEVI enables the simulation of transient behavior by Francis turbines, installed in the system, when a regulation maneuver or sudden disconnection of the generator takes place.

The software also allows for the modeling of pumps working as turbines (PATs). In this case, the pumps' characteristic curves are obtained from the Marchal, Flesch and Suter universal curves [2]. These curves enable the characterization of the pump's behavior in whichever functioning conditions are present.

In this work, two practical cases are presented in which ALLIEVI is used as a tool, either to adjust the energy recovery potential of a system or to calculate the hydraulic transient generated by maneuvers of an energy recovery system.

2. Case 1: Implementation of a PAT at the Entrance of a Water Supply System

The first case involves a study of the implementation of a PAT at the entrance of a water supply system [3]. The water supply for this municipality is directly connected to a bulk water supply network, resulting in excess head pressure. This excess pressure is dissipated through a PRV, which adjusts the pressures to meet the municipality's requirements, as seen in Figure 1. To improve the energy efficiency of the system, the installation of a PAT in parallel with the VRP is proposed. ALLIEVI is employed for modeling this potential energy recovery scenario. The software allows for the modeling of the pump functioning as a turbine, utilizing the default implementation of universal curves by Marchal, Flesch, and Suter [2]. Once the network model is created with ALLIEVI, various operating points of the PAT are studied to identify the optimal point for maximizing energy recovery while



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ensuring proper system functionality. This study explores different installation alternatives for the PATs.

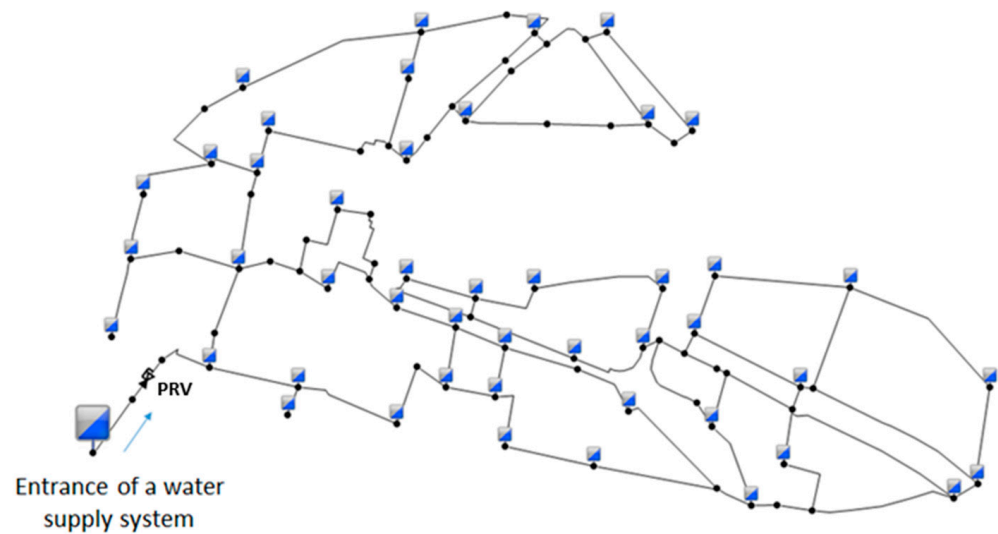


Figure 1. Allievi's model of the water supply system.

It is estimated that the pumping height in turbine mode will be equal to the pressure drop introduced by the PRV, namely 12.5 m during the day (from 06:00 to 24:00) and 18.5 m during the night (from 00:00 to 06:00), with the flow rate varying between a minimum value of 4.89 L/s during the night and a maximum value of 43.12 L/s during the day. Based on five different theoretical expressions relating the pump operating point to turbine mode [4], 30 possible operating points of the PAT are studied with the intention of selecting the one that recovers the most energy while ensuring the proper functioning of the network. Subsequently, from the selected point, nearby operating points are bounded with the aim of improving energy recovery, both in the daytime and night-time scenarios.

Finally, starting from the point of maximum energy recovery, a real pump is selected and installed in the model functioning as a turbine. After studying different operating modes of the PAT, it is concluded that the best option for installing a pump functioning as a turbine in the municipality distribution network is to install two PATs in parallel with the pressure reducing valve, as seen in Figure 2.

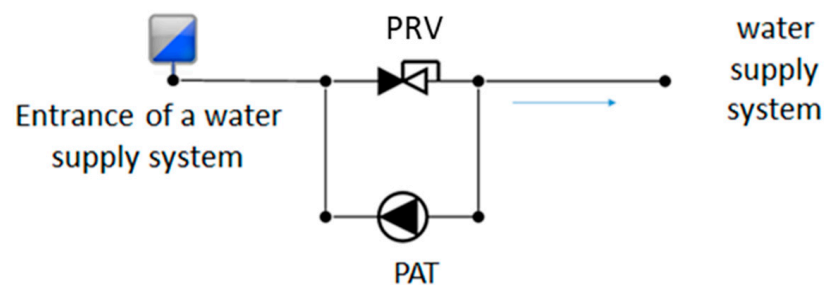


Figure 2. Installation of the PAT in parallel with the VRP.

Two different PATs are installed, one for the daytime scenario and another for the night-time scenario. The night-time scenario from 00:00 to 06:00 allows for the recovery of 4.85 kWh/day, while the daytime scenario from 06:00 to 24:00 allows for the recovery of 14.75 kWh/day. Therefore, it can be concluded that the energy recovery produced in one day by the installed PATs is close to 20 kWh/day, as shown in Table 1.

Table 1. Summary of the energies recovered.

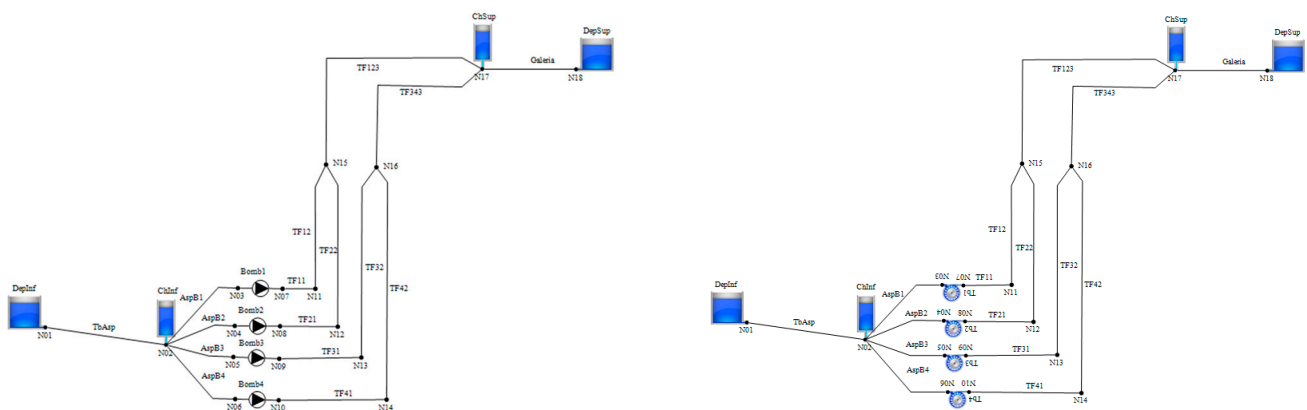
	Recovered Energy (kWh/día)		
	Day Stage (06:00–24:00)	Night Stage (00:00–06:00)	Total
Theoretical optimal point obtained from theoretical equations	7.29	2.96	10.25
Real optimal point obtained from actual manufacturer curves	14.75	4.85	19.60

As seen in Table 1, this study began with an energy recovery of 10.25 kWh obtained with estimated theoretical optimal operating points based on supply conditions and theoretical equations, resulting in a final system energy recovery of 19.60 kWh with the installation of two real pumps operating as turbines.

This study streamlines the selection of pumps for turbine operation via simulations on ALLIEVI. Addressing gaps in manufacturer catalogs, it provides insights into pump behavior beyond the first quadrant.

3. Case 2: A Power Station Equipped with Four Reversible Groups

The second case study involves the concept of reversible pumping. Reversible power stations utilize electrical energy produced during off-peak hours (typically night-time and weekends) to pump water from a lower reservoir to an upper one. Subsequently, this water is turbinated during peak hours (typically daytime on weekdays) [5]. These power stations operate with pressurized conduits. In this second case, a power station equipped with four reversible groups is simulated. Each group is equipped with a hydraulic machine that operates as either a pump or a turbine and an electric machine that functions as either a motor or a generator. Figure 3 shows the model created with ALLIEVI describing the two operating modes.

**Figure 3.** Allievi model in pumping mode (left) and in turbine mode (right).

The transients resulting from the abrupt disconnection of the four groups, in both scenarios, require the presence of protection devices at the inlet and outlet of these groups. In this case, the installation of a surge tank at these points is analyzed, assessing the system's protection against the abrupt disconnection of these elements.

On the left side of Figure 4, the envelopes of maximum (green line) and minimum (red line) piezometric head between the lower and upper reservoirs are observed after the abrupt shutdown of the pumps. The blue line represents the steady flow. Similarly, the right side of Figure 4 shows the envelopes of maximum and minimum piezometric head between the lower and upper reservoirs after the abrupt disconnection of the four turbine groups.

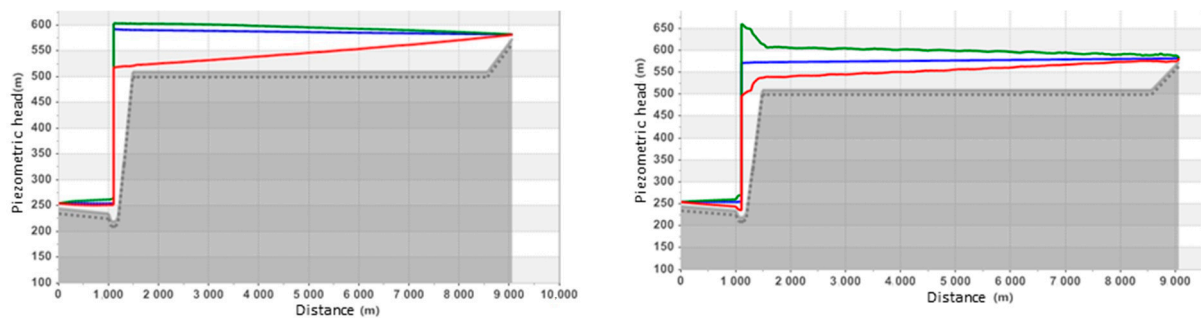


Figure 4. Envelope of piezometric heights after pump shutdown (**left**) and after abrupt turbine disconnection (**right**).

In both cases, the surge tank protects the installation from the effects of both overpressure and depression, without reaching negative pressures.

4. Conclusions

This study highlights the importance of using ALLIEVI to address transient effects in hydraulic systems. Simulations conducted with ALLIEVI provide valuable insights into energy recovery potential and help predict and mitigate hydraulic transients, which are crucial for optimizing hydraulic system performance.

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