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Proceeding Paper

Pressure Management in Water Distribution Networks by Means of Pumps as Turbines: A Case Study in Northern Italy †

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Abstract: Pressure control by means of pressure-reducing valves (PRVs) is a possible strategy to reduce water losses in water distribution networks (WDNs). However, PRV replacement with energy-harvesting devices—such as pumps as turbines (PATs)—can lead to a more sustainable management of water systems. This study analyzes the case study of a WDN located in Northern Italy, of which the layout is supposed to be upgraded by installing a PAT for both pressure reduction and energy recovery. To identify the optimal PAT to install (i.e., the one that maximizes energy recovery), a fleet of forty-five turbomachines is hypothetically employed. The study reveals that the hydraulic regulation of the optimal PAT allows recovering over 50% of the hydraulic energy available in the WDN.

Keywords: pumps as turbines; water distribution networks; sustainability; energy recovery

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1. Introduction

In this era of challenges posed by both climate crisis and a growing population, efficient management of water distribution networks (WDNs) is needed to save resources, water, and energy. Traditionally, an excess of water pressure-head in WDNs has been dissipated by means of the installation of pressure-reducing valves (PRVs) in order to limit water pressure and thus reduce leakages. However, to pursue sustainable energy policies, water utilities are also required to convert energy dissipation into energy production [1]. Thus, pressure-head excess can represent a significant opportunity for potential power production. In this context, several studies suggest replacing PRVs with energy-harvesting devices, such as turbines, for a more sustainable management of water systems. In fact, an excess of pressure-head is dissipated with the former application, whereas hydraulic energy—which instead would be unexploited—is recovered with the latter solution. Among the different devices that can be coupled with low and variable power, pumps as turbines (PATs)—i.e., pumps used in turbine mode by reversing flow direction with the engine acting as a generator—can be considered a promising alternative, due to the limited installation costs along with an acceptable energy production [2,3]. However, the exploitation of PATs is still limited since (i) PAT characteristic curves have to be predicted, as made in [4,5]; and (ii) identifying the most suitable turbomachine and defining its optimal control strategy is still a challenging task [6]. Thus, specific studies are needed to fill this gap. This paper tackles the second challenge highlighted above, by investigating the case study of a District Metered Area (DMA) located in Northern Italy, where a PRV currently reduces the excess of pressure-head at the inlet point. The potential benefits of PAT installation are evaluated by identifying the optimal PAT among a fleet of forty-five turbomachines, of which the field characteristic curves are available in the literature. Two relevant goals are achieved in this study: (i) the definition of a new layout for the DMA inlet point to harvest energy; and (ii) the evaluation of the actual potential of the optimal PAT, based on WDN field data and experimental PAT characteristic curves.

2. Materials and Methods

2.1. PAT Selection and Control

In this study, the most suitable turbomachine (i.e., the one that maximizes energy recovery) is selected among the forty-five PATs considered in [7], of which the characteristic curves were derived from the literature.

The control strategy adopted in this study is denoted as "hydraulic regulation". On the one hand, this strategy requires that the PAT—of which the rotational speed is kept constant over time—is installed in series with a first PRV, by dissipating the exceeding head (i.e., *throttle control*). Moreover, a second PRV is placed on a bypass line, along which the exceeding flowrate passes through (i.e., *bypass control*) (Figure 1a). From an operational standpoint, the hydraulic regulation is defined for each hydraulic condition (i.e., head-drop and flowrate, hereinafter denoted as *operation point*) of the WDN. Specifically:

- if a given operation point of the WDN falls outside the PAT operation range (e.g., points A and B in Figure 1b), the entire hydraulic energy of WDN is wasted (i.e., the flowrate is fully bypassed).
- if a given operation point of the WDN falls above the head-drop characteristic curve of a given PAT (e.g., point C in Figure 1b), throttle control is applied [8]. The PAT swallows the entire available flow rate in the WDN, while the PRV dissipates the exceeding head-drop (ΔH_{ex} in Figure 1b), by wasting a fraction of WDN hydraulic energy [7].
- if a given operation point of the WDN falls below the head-drop characteristic curve of a given PAT (e.g., point D in Figure 1b), bypass control is applied [8]. In this case, PAT's head-drop is equal to the WDN's head-drop, while the exceeding flowrate (ΔQ_{ex} in Figure 1b) is delivered through the bypass line, by wasting a fraction of WDN hydraulic energy [7].

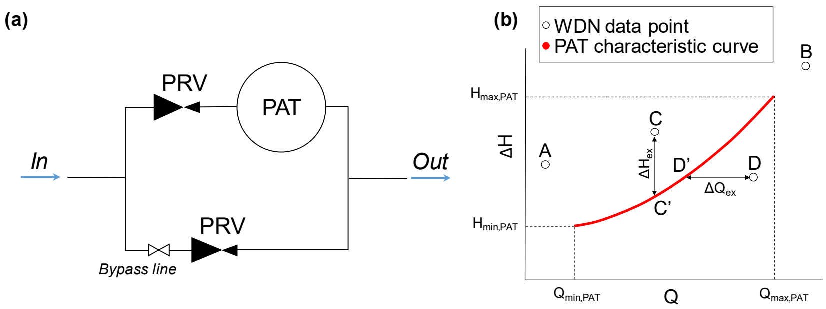

Figure 1. (**a**) System layout; (**b**) H-Q representation of throttle and bypass control.

In both cases of throttle and bypass control, power generation is estimated from the PAT power–flowrate characteristic curve, i.e., by evaluating PAT power output as a function of the swallowed flowrate. Energy recovery is then calculated based on power generation over time, whereas the energy-recovery rate is quantified by dividing the total energy recovery (i.e., the sum of each contribution) by the total hydraulic energy available at the inlet point of the WDN.

2.2. Case Study

The WDN considered as a case study is a DMA located in Northern Italy (Figure 2a), supplying about 5000 residential users by means of two inlet points. Downstream the main inlet point of the DMA, a PRV currently dissipates the excessive pressure head to limit water losses. From an operational standpoint, the PRV upstream-downstream head (H_U and H_D, respectively) and PRV flowrate were observed over a period of nearly five months (from 16 May to 15 October 2019), and recordings were collected at 15-min temporal resolution. A representative week (i.e., from Monday 20th to Sunday 26th May 2019) is reported in Figure 2b. The dissipated head $\Delta H = H_U - H_D$ (hereinafter denoted as *head-drop*) varies throughout the day from a minimum of about 10 m to a maximum of over 25 m, whereas the flowrate Q entering the DMA varies between 20 L/s and 80 L/s. Figure 2b also reveals that the flow-rate trend does not follow the typical pattern of residential DMAs. This is mainly due to the fact that the DMA also includes an outflow point (supplying a downstream tank), of which the outflow-discharge values affect the current PRV regulation strategy. To recover energy at the inlet point, the layout of the major DMA inlet is supposed to be revised by installing (i) a PAT in series with the existing PRV and (ii) a bypass line with a second PRV, as in Figure 1a.

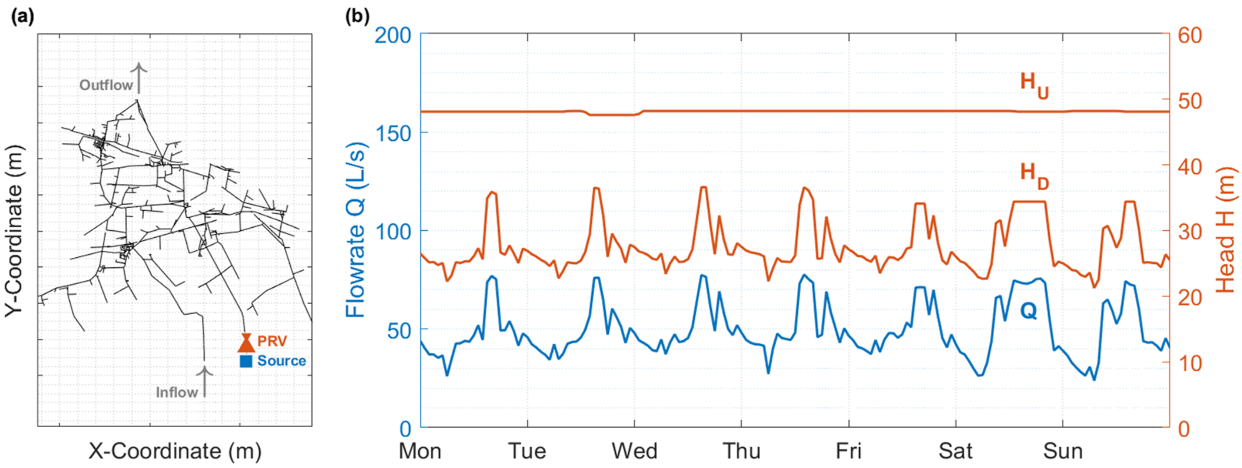

Figure 2. (**a**) DMA layout; and (**b**) trend of flowrate Q, PRV upstream head H_U, and PRV downstream head H_D during a representative week.

3. Results

The energy-recovery rate associated with each PAT is reported in Figure 3a, which reveals that PAT #36 is the optimal turbomachine to install, since it recovers 50.1% of the DMA hydraulic energy. The residual 49.9% is dissipated through hydraulic regulation and PAT operation. The head-drop characteristic curve of PAT #36 (red markers in Figure 3b) is in the range from 28.2 L/s to 55.3 L/s and from 9.5 m to 20.1 m. Thus, if the head-drop and flow rate of the DMA falls outside the PAT #36's field of operation, the entire flowrate of the DMA is bypassed, PAT #36 does not operate, and energy recovery is null (grey markers in Figure 3b). Such a scenario occurs only in 9% of the operation points, while in most cases throttle and bypass controls are applied (light-blue and blue markers in Figure 3b). It is worth noting that most of the dissipated energy due to the hydraulic regulation is wasted by the bypass control (i.e., approximately 49%), followed by the throttle control (i.e., approximately 37%), whereas approximately 14% of hydraulic energy is wasted given that PAT #36 cannot operate.

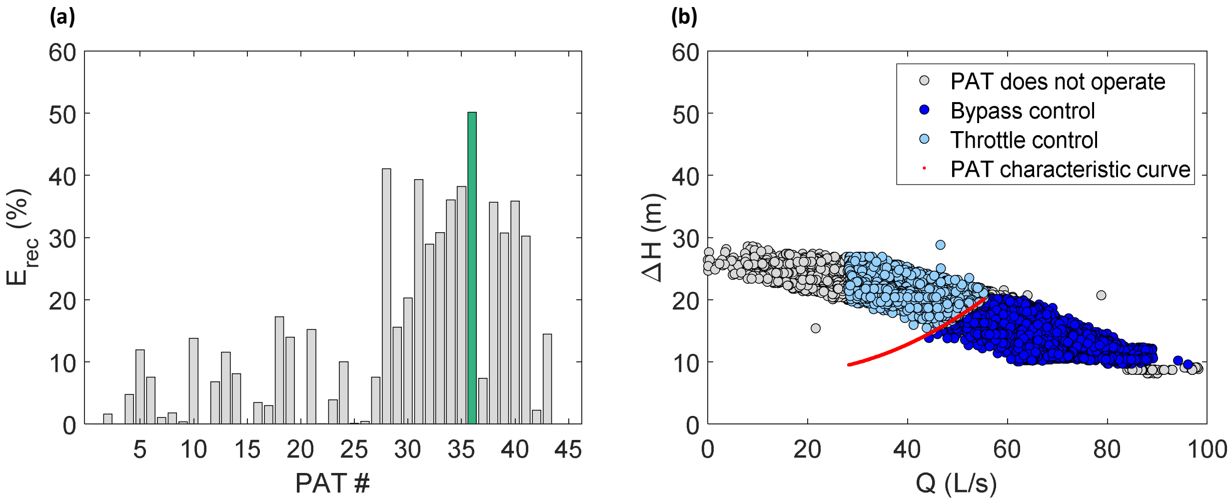

Figure 3. (**a**) Rate of energy recovery (green bar: optimal PAT; gray bars: other PATs); (**b**) operation of the optimal PAT (i.e., PAT #36).

4. Conclusions

This work focused on the estimation of the potential energy recovery in a real DMA, based on the use of PATs instead of pressure-control devices such as PRVs. To this end, the energy-recovery rate of forty-five different PATs was assessed, by assuming that PAT operation is managed based on throttle or bypass control. The optimal PAT allowed recovery of approximately 50% of the available hydraulic energy.

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