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CHARACTERIZATION OF AN INNOVATIVE OFF-GRID HYDRAULIC DEVICE FOR IRRIGATION SUSTAINABILITY

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ABSTRACT

Pressurized irrigation systems are increasingly relevant as climate change accelerates the shift from traditional, less efficient distribution methods, such as canal-based systems, to the more efficient pressurized solutions. This study contributes to a research project dedicated to the development of the Off-grid Automatic System (OAS), an innovative patented technology designed at the Politecnico di Milano. The research evaluates the benefits of OAS and defines operational strategies for its integration into irrigation networks. The adoption of OAS devices in a water distribution network creates a digital ecosystem by communicating data within the network and enabling advanced control strategies to enhance water distribution efficiency. A key achievement of this work is the detailed characterization of the device in terms of hydraulic capacity and operational efficiency under various hydraulic conditions. This research addresses a crucial technological gap in modern agriculture, where water distribution often suffers from resource wastage and the absence of real-time monitoring and control. By enabling smarter water management, the proposed solution not only reduces inefficiencies but also represents a significant step forward in the digitalization of irrigation systems, offering economic and environmental benefits for the agricultural sector.

Keywords: Pressurized Irrigation; Pressure control; Digitalization; IoT; residual energy.

1. Introduction

The agricultural sector is at a critical juncture, facing the convergence of divergent and often opposing needs. On one hand, projections indicate a looming necessity for agriculture to increase production to meet the demands of a growing population. On the other hand, the sector must significantly reduce its environmental impact in order to adapt and contain climate change effects, conforming to European policies aligned with the Green Deal. Indeed, in 2022, agriculture accounted for 11% of greenhouse gas emissions in Europe (European Environment Agency, 2023) and 70% of global water usage was allocated to irrigation and agricultural purposes (Gruère et al., 2020). The environmental toll is substantial, exacerbated by the observable effects of climate change, such as droughts and shifting environmental conditions that are likely to render many agricultural areas impractical and unusable.

In response to these challenges, digital technologies have emerged as pivotal tools for transforming and optimizing agricultural practices. These technologies promise to enhance resource efficiency, reduce environmental impact, and promote agricultural sustainability and adaptability (Trendov et al., 2019). For instance, integrating digital technologies into water distribution networks can improve decision-making processes in network management, allowing for better evaluation of irrigation system efficiency and equitable distribution of water resources.

Pressurized Irrigation Distribution Systems (PIDS) offer superior performance and distribution efficiency compared to open channels. However, their adoption presents challenges, including constraints on maximum

discharge (Fouial et al., 2020) and increased energy consumption (Rodriguez Díaz et al., 2012). This paper introduces the OAS solution, which stands for Off-grid Automated System for Irrigation Sustainability. OAS proposes an innovative approach by integrating an electrically actuated smart valve, designed to recover energy from the throttling process. Harnessing energy from water flow, OAS sustains measurement instruments and logical components for remote control and network management. OAS addresses key challenges in the agricultural sector, enhancing irrigation management strategies to improve resource efficiency, flexibility, and equity. Additionally, the integration of IoT and digital technologies necessitates significant energy distribution throughout irrigation networks, a challenge that the OAS technology aims to overcome, providing a valuable asset for both end-users and irrigation network managers in advancing digital and precision agriculture.

2. The OAS

The Off-grid Automatic System is an hydraulic gate valve that recovers part of the energy dissipated during the throttling process and reuses it to power the actuator, the integrated sensor system, the electronics, and the data transmission system composing a stand-alone, self-sustainable remote terminal system. Although batteries can sometimes provide a viable solution, they cannot ensure continuous operation for high-demand tasks such as valve actuation or high-frequency (1 Hz) monitoring and data transmission. OASIS overcomes this problem by recovering energy directly from the excess pressure available in the fluid flow while the system is active. The remote control of the device enables the implementation of control logic throughout the network, optimizing the management of the irrigation system with a focus on reducing energy and water waste.

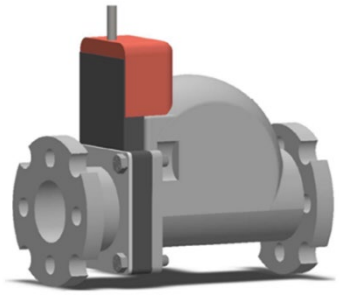

Fig. 1. Scheme of the first concept of the OAS laboratory prototype.

3. The OAS hydraulic and energetic characterization

The prototype was tested on the Control Valve Test Rig at the Fantoli Hydraulic Laboratory, Politecnico di Milano. The test rig is fed by a gravity-driven system powered by a reservoir positioned 10 meters above the testing point. All tests were conducted in compliance where possible with the International Standards IEC60534 about valve capacity assessment.

The experimental campaign focused on characterizing the device's flow regulation and energy harvesting capabilities. Key parameters of interest included the Flow Coefficient (CV) and the turbine efficiency (η), which were systematically measured to assess the prototype's performance under various operating conditions. The flow coefficient is defined as:

$$CV = \frac{Q}{N_1 \sqrt{\frac{\Delta P}{\rho / \rho_0}}} \quad (1)$$

Where ρ [Kg m^{-3}] is the current density of the fluid flowing according to atmospheric pressure and temperature at test time, ρ_0 is the reference density in standard condition (water at 15° and 1atm) and N_1 represents a transformation parameter depending on the unit used for Q, ΔP and ρ (with flowrate expressed in m^3h^{-1}, pressure drop ΔP in bar and density ρ in Kg m^{-3} , N_1=0.865).

The energetic efficiency was evaluated as the ration between the power recoverable through the turbine and the total power dissipated by the device, yielding to:

$$\eta = \frac{\omega\, T}{\rho g\, Q\, \Delta P} \quad (2)$$

Where T is the measured torque, in this case obtained through a torquemeter connected to the shaft, and ω is the rotational velocity of the shaft in rotations per minutes, measured through a digital tachometer, and g is the gravity acceleration [m s^{-2}]. The resulting value for each of the investigated parameter has been obtained through the cumulated mean value acquiring measurements for 30 seconds

4. Results

Several datasets were collected under varying pressure and flow conditions. Figure 1 presents the final results, highlighting two key aspects: the OAS device's ability to recover energy from the flow and the valve's performance in terms of flow capacity. The data illustrated in the figure provide a basis for assessing the feasibility of installing the device under real-world operational conditions.

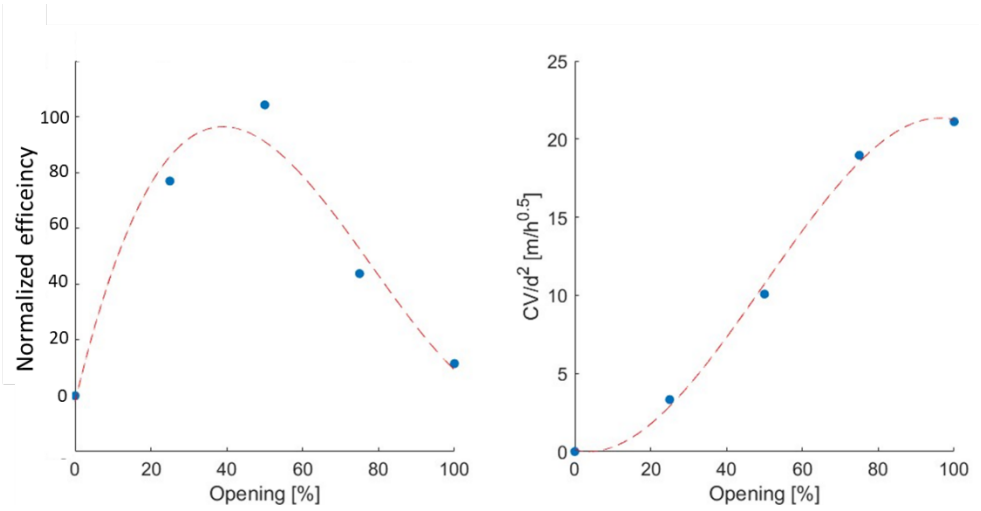

Fig. 2. Efficiency on the left plot and flow coefficient of the OAS prototype on the right plot.

5. Conclusions

The agricultural sector is at a critical juncture where the need to increase production to meet growing population demands must be balanced with the imperative to minimize environmental impact. The OASIS system presents a promising innovation in addressing these challenges, combining energy efficiency and sustainability in water resource management. The results of this study provide valuable insights into the practical implementation and effectiveness of the proposed OAS technology in pressurized irrigation networks. The detailed characterization of the device's hydraulic performance and its ability to operate as part of a digital ecosystem confirm its potential to address critical inefficiencies in water distribution.

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