

Energy Saving Measures in Pressurized Irrigation Networks: A New Challenge for Power Generation [†]

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Abstract: In Spain and other countries, open channel distribution networks have been replaced by on demand-pressurized networks to improve the water-use efficiency of the water distribution systems, but at the same time the energy requirements have dramatically risen. Under this scenario, methodologies to reduce the energy consumption are critical such as: irrigation network sectoring, critical hydrant detection, improving the efficiency of the pumping system and the irrigation system, or introducing solar energy for water supply. But once these measures are undertaken, the recovery of the energy inherent in excess pressure in the network should be investigated. Hydropower energy recovery in irrigation is still largely unexplored and requires further investigation and demonstration. All of these methodologies should be considered as useful tools for both, the reduction of energy consumption and the recovery of the excess energy in pressurized irrigation networks. To accomplish this, the REDAWN project (Reducing Energy Dependency in Atlantic Area Water Networks) aims to improve the energy efficiency of water networks through the installation of innovative micro-hydropower (MHP) technology. This technology will recover wasted energy in existing pipe networks across irrigation, public water supply, process industry, and waste-water network settings.

Keywords: pressurized irrigation networks; water-energy nexus; energy recovery; hydro-power; pump as turbine (PAT)

1. Introduction

In Southern Europe due to the climatic conditions, irrigated agriculture plays an essential role, using around 80% of the total water abstraction. Assuming the necessity of improving water use efficiency, measures focused on reducing water use in agriculture have been developed. As an example, in Spain, modernization projects have been promoted for the hydraulic infrastructures moving from open channel systems to pressurized networks and adopting more efficient on-farm irrigation systems. Thus around 1 million of the 3.5 million of irrigated hectares have been modernized in the last two decades in Spain. Because of this transformation, water use for irrigation per unit of irrigated area has been reduced by 21% from 1950 to 2007 [1]. However, the higher water use efficiency achieved by these projects has been linked to a large increase of 657% in energy requirements, another scarce resource. This is mainly due to the energy demanded by the pumping systems in pressurized networks and represents 40% of the total water costs.

2. Energy Saving Measures in Pressurized Irrigation Networks

Therefore, it is critical to raise strategies focused on optimizing both water and energy resources. These strategies can be sorted into:

2.1. Irrigation Network Sectoring

Network sectoring by grouping hydrants into sectors and organizing farmers irrigation time in turns according to their power requirements has shown significant energy savings in irrigation networks studied, with energy savings of around 30% [2].

2.2. Critical Points Detection

Other measures to reduce the energy consumption consist of controlling critical points. Critical points are hydrants with high energy requirements due to their elevation or distance with respect to the pumping station. Different methodologies to detect and control critical hydrants were developed. The procedure proposed by Rodríguez-Díaz et al. [3] was based on the calculation of dimensionless coordinates useful to characterize the network's topology and hydraulic design. This method carried out thousands of simulations of the irrigation network considering different water demand patterns or loading conditions. In each simulation, a critical hydrant and its power requirements were determined and actions to reduce their energy dependence were developed. Authors estimated energy savings of between 10% and 31%.

2.3. Improving the Irrigation Efficiency of the Pumping System

Fernández García et al. [4] developed a methodology to optimize the sectoring operation and pressure head, considering the pumping efficiency in an irrigation district in Córdoba (Spain). They also modeled and evaluated the benefits of installing variable speed drives. Pumps without variable speed drives provided high efficiencies for high flow demands. However, for low and medium discharges, efficiencies were frequently low. By including variable speed drives, high efficiencies were also achieved when the flow demand was medium and low. This methodology combining sectoring and variable speed drives achieved energy savings of up to 26% in the network studied.

2.4. Irrigation System at Farm Level

The incorporation of information and communication technologies (ICTs) in agriculture involves a step forward toward a more efficient use of water and energy resources. Progress in the development of different sensors to collect crop, soil, and meteorological information, among others are encouraging the adoption of precision agriculture. Different precision irrigation case studies have been raised. García Morillo et al. [5] designed a precision irrigation system to be applied to strawberries farms located in southern Spain, combining soil water sensors, smart water meters, programmers, electrovalves, and weather stations along with a more efficient on-farm irrigation system. By their methodology, water and energy use efficiency were simultaneously improved, with savings of 30%.

2.5. Renewable Energy Sources

Solar energy can provide a sustainable alternative as an energy supply source for the agricultural sector. Different authors have worked on the incorporation of solar energy in the irrigation sector. A smart solar irrigation system for olive orchards was developed and tested in an experimental field located at the University of Córdoba (southern Spain). There, water is stored in a reservoir and conveyed to the on-farm irrigation network with a 13 kW pump, supplied with a solar energy production system of 15.4 kW. The system carried out a decision-making process in real time for the activation and deactivation of the three electro-valves, taking into account the instant solar power production on the photovoltaic installation and crops irrigation needs [6]. Solar energy is a valuable energy source for irrigation, however it's viability decreases with high power demands.

3. Hydro-Power Potential for Energy Recovery in Pressurized Irrigation Networks

Irrigation water distribution networks cover large areas and in some specific areas there is excess pressure that is usually removed using pressure reducing valves. Hydropower turbines offers the option of reducing this pressure while also recovering this excess energy and making it available for other uses. An initial evaluation of the potential of this technology was carried out by García Morillo et al. [7] in a real case study during one irrigation season (2014–2015) in Southern Spain.

The methodology was divided in four different steps. In the first step, the network was simulated with all hydrants simultaneously open and the best locations to install turbines were assessed. In the second step, the maximum, minimum and mean flows and available head values per month at each turbine location were obtained using 3000 simulations of open/close hydrant patterns, applying the Clément methodology. In the third step, the flow and net head available in the turbines were transformed into energy, considering two flow design scenarios according to its probability of exceedance. In the last step a feasibility study was carried out through two indices, the payback period and the energy index.

This work highlighted that significant energy savings could be achieved by installing Hydro-Power Plants, (HPPs) using either traditional turbines or PATs, pumps working as turbines, in pressurized irrigation networks. Four different locations for HPPs (one traditional turbine and three PATs) were detected within the network. The total power generation potential by the HPPs was estimated at 261 and 198 kW for two flow scenarios (considering the probability of flow exceedance) and the total energy recovered values amounted to 270 and 205 MWh respectively. From an economic point of view, traditional turbines did not seem to be viable, with payback periods of over 10 years. On the other hand, PATs were estimated to be very competitive and economically viable, with payback period below 6 years and energy index below 0.6 €/kWh. The energy saving coming from this type of installation could translate into a significant reduction in CO₂ emissions, reducing the carbon footprint of irrigated agriculture and the agri-food industry. According to the institute for energy diversification and saving in Spain (IDAE) the conversion factor for conventional electricity in Spain is 0.399 kg eCO₂/kWh. The estimated potential carbon savings of the total installation resulted in 82 and 108 tonnes eCO₂ for both scenarios respectively.

4. Irrigation Pilot Plant Supported by the REDAWN Project

REDAWN (Reducing Energy Dependency in Atlantic Area Water Networks) aims to improve the energy efficiency of water networks through the installation of innovative micro-hydropower (MHP) technology. Three demonstration sites are going to be installed in three different water sectors such as irrigation, urban water supply and process industry.

The irrigation demonstration site will be installed in the irrigation network of the left bank of the Genil river irrigation district (GMI), in Andalusia, Spain. The irrigation district (first phase) has a surface of 6400 hectares with a predominance of citrususes, but also almond trees and walnuts are now being cultivated. The infrastructure is composed of a pressurized branched network with pipe diameters between 300 and 1200 mm, involving different materials, such as GRP or steel. The network is fed by two water reservoirs and two decanting pools. The service pressure is 35 m, and the flow design is 1.2 l s⁻¹ ha⁻¹ (see Figure 1).

The purpose of this HPP is to demonstrate the benefits and challenges of micro-hydro in irrigation networks, to shows that pumps as turbines (PATs) can be used as low-cost devices to recover energy even considering the high flow fluctuation in irrigation networks, and to examine the long-term performance of PATs in this setting. The demonstration will also help to inform and refine the design of HPPs in irrigation networks in the future, consider this will be one of the first trials of hydro power in this setting.

Three different alternatives have been studied for the location of the HPP. The third alternative has been shown to be the most convenient because the energy produced can be used directly on-site. The energy recovered would replace a diesel generator used to feed the fertigation pump and an electric panel. Thus, this HPP has two positive consequences such as the economical saving of diesel purchase, the reduction of GHG emissions, and the reduction of air pollution emission.

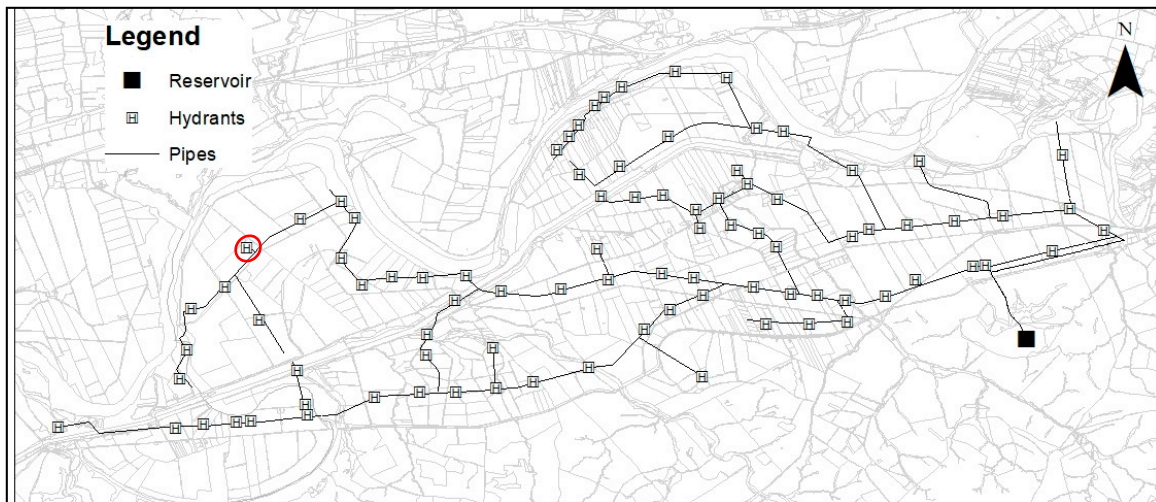


Figure 1. Hydrant and filter plant where the HPP will be installed.

There is a Pressure Reduction Valve (PRV) downstream of the hydrant, which reduces the pressure from 65–75 m to 45 m (see Figure 2). The flow oscillates between 160 and 180 l s⁻¹ during most of the irrigation season for a young walnut plantation. The optimal power calculated is 32.9 kW, with a design conditions of 165 l s⁻¹ of flow and 20 m of pressure. Since the inlet conditions are mostly constant along the irrigation season, with few variations in the flow of $\pm 6\%$, and the available pressure of more than 20 m, the PAT would always work under its best efficiency point (BEP) conditions along the irrigation season. The estimated energy recovery will be around 56,800 kWh in a full irrigation season. Considering the average Spanish energy tariff in 2017, the payback period is 5.4 years. Nevertheless, due the energy demand of the filter system is much smaller, a 10 kW plant will be installed with an estimated energy saving of 3000 €/year.



Figure 2. Hydrant and filter plant where the HPP will be installed.

5. Conclusions

Energy represents an important percentage of the total water costs in agriculture, facing that water use and energy cannot be considered independently. Under this scenario, methodologies to reduce the energy consumption are critical, but, once these measures are undertaken, the recovery of the excess energy in the irrigation network must be seriously investigated. This energy generation could contribute to reduce the exploitation costs of the systems, increasing the competitiveness of agricultural production and reducing the carbon footprint of irrigated crops.

Author Contributions: All the authors have participated in any step of this research. J.G.M. has written the document and developed the case study mentioned in item 3. J.A.R.D. has provided information about his research related to the energy saving measures and supervised the document. M.C. has designed the irrigation pilot plant in GMI. A.M. supervised the research and document.

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