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Research Paper

Semi-arranged demand as an energy saving measure for pressurized irrigation networks

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ABSTRACT

In many regions, water resource scarcity has required adapting irrigated agriculture towards more efficient water distribution networks and irrigation systems. These systems, however, have higher energy requirements. To overcome this problem, a new semi-arranged demand model combining network sectoring and critical points have been developed. The model computes a new indicator known as the optimal number of disabled hydrants (ONDHY) to determine the number of critical hydrants in the sector that are only allowed to irrigate at off-peak hours, while the rest of non-critical hydrants can irrigate at any time. The proposed model has been applied to each of the 11 irrigation networks in the Bembezar MD irrigation district located in southern Spain. The results showed potential energy savings of 5.6%–25.8% with 14.5% and 7.8% of critical hydrants that could only operate during off-peak hours, respectively, thus satisfying crop irrigation requirements. The proposed methodology is a useful and easy tool to optimize energy consumption in pressurized irrigation networks.

1. Introduction

To achieve increased water use efficiency, water distribution networks have undergone a thorough transformation from open channels to pressurized networks. In many cases, however, this transformation has led to high energy requirements, making measures to optimize the use of this resource also necessary (Giustolisi et al., 2015). In pressurized irrigation networks, which are usually organized on-demand and in some cases are designed for 100% water demand simultaneity, energy requirements are much higher now than in the previous gravity-fed systems. As a result, operation and system maintenance costs have risen dramatically by as much as 400% (Rodríguez-Díaz et al., 2011).

Different measures to improve energy efficiency in this field have been developed. McNabola et al. (2014), for example, proposed the use of hydropower turbines to recover the energy wasted in break pressure tanks. Creaco and Franchini (2014) aimed to achieve the optimal design and operation of water distribution networks through the simultaneous analysis of installation and operational costs, as well as the costs of pressure reducing valves.

Several authors have proposed other management strategies to reduce the energy consumption in these networks (Abadia et al., 2012). One of these measures consisted in network sectoring, where farmers are organized in irrigation turns according to their energy requirements. In a similar line, methodologies for optimum sectoring have been developed for networks with a single water source (Carrillo Cobo et al., 2011; Jiménez-Bello et al., 2010) and multiple water supply points (Fernández García et al., 2013). However, sectoring has operational limitations, such as the organization of farmers in irrigation turns, who frequently prefer on-demand organization where water is continuously available. Moreover, the pumping station has to work under a wider range of pressure heads, which usually results in low pumping efficiency; a problem that is frequently solved by installing variable speed drives (Córcoles et al., 2016; Fernández García et al., 2014; Khadra et al., 2016; Lamaddalena and Khila, 2012).

Critical points are hydrants with special energy requirements which are usually caused by their distance from the pumping station and/or their elevation. These hydrants set the pressure head requirements at the pumping station. Rodríguez-Díaz et al. (2012a) reported that only a few points may be responsible for large fractions of the total pressure head at the pumping station (up to 30%

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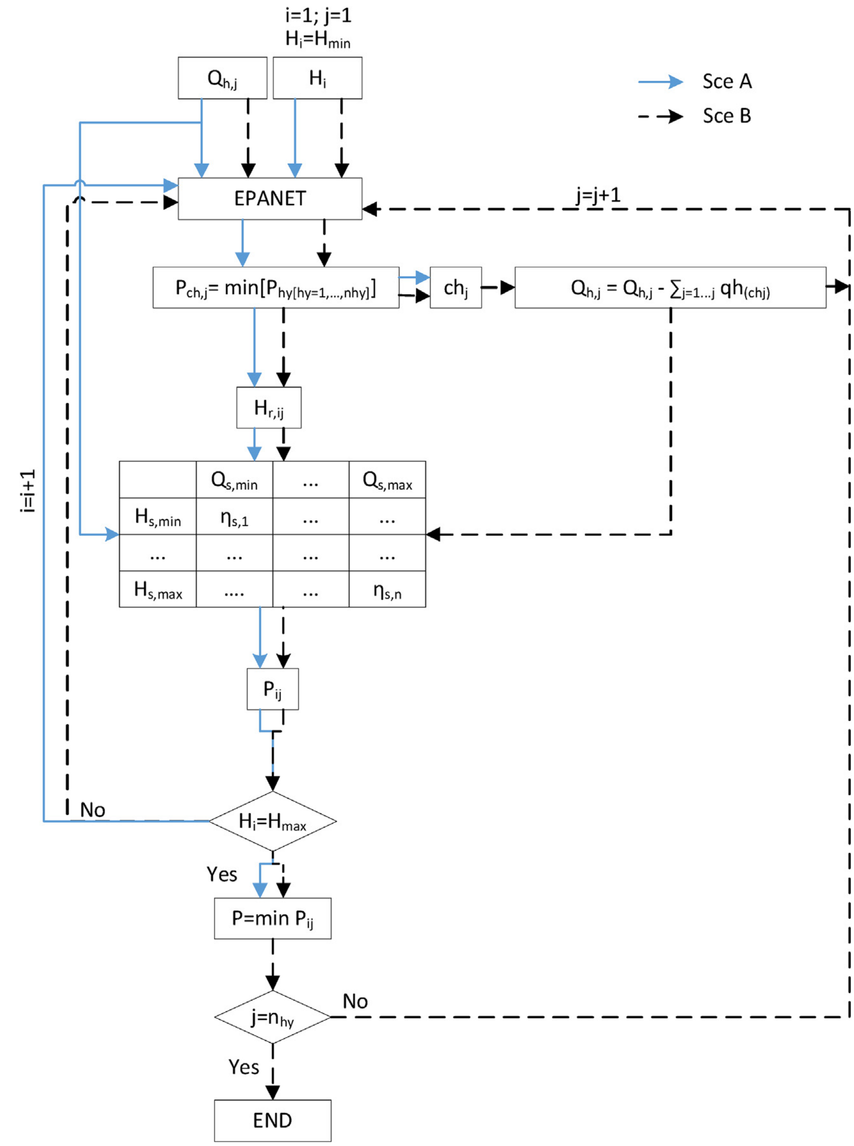

Fig. 1. Flow chart of the optimization algorithm.

in typical irrigation supply networks in southern Spain). However, these authors also showed that pressure demand could be reduced in these hydrants by installing booster pumps or replacing undersized pipes. Moreover, the significant energy savings achieved do not involve a high investment and still allow on-demand management (Rodríguez-Díaz et al., 2012b).

All these measures should be implemented taking into account energy tariffs, which have increased dramatically in recent years. Although the proper selection of the electricity tariff leads to significant savings, it does not reduce energy demand (Córcoles et al., 2015; Fernández García et al., 2016). Because electricity tariffs are usually structured according to time-of-use rates, concentrating irrigation in off-peak hours may lead to a significant reduction in operational costs. For this reason, in modernized systems, farmers tend to irrigate at night to avoid the peak hours when energy is more costly.

Sectoring and critical points control have both advantages and drawbacks. On the one hand, sectoring requires the organization of farmers in turns, while critical points control allows on-demand irrigation. On the other hand, critical points control requires improvements in the hydraulic infrastructures, which are unnecessary in sectoring. In many cases, however, a mixed strategy would be a better solution.

In this work, sectoring and critical points control are merged into a new semi-arranged demand model in which critical hydrants, determined by a new indicator known as the optimal number of disabled hydrants (ONDHY), are organized to irrigate at off-peak hours, while non-critical hydrants can irrigate at any time. The potential energy savings are assessed in a real case study in Southern Spain.

2. Methodology

2.1. Study area

The Bembézar Margen Derecha (BMD) irrigation district (southern Spain) was created in 1967 and covers over 11,900 ha, providing water to 1300 farmers with an average farm size of 7 ha. The climate in the region is Mediterranean, with rainfall occurring mainly in autumn and spring and dry spells in summer. The average annual rainfall in the area is 540 mm and the average temperature is 17.9 °C.