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Guidelines for hydraulic and energetic assessment in urban landscapes.

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***Abstract*— The study is focused on providing solutions for the management of water and energetic resources in parkland irrigation networks with the aim of minimizing consumptions originated by their use. An evaluation methodology based on indicators is proposed to assess energetic performance of the system. In the case the system is not managed properly from the energy point of view, an optimization irrigation scheduling by means of genetic algorithms is proposed to improve energy uses. The assessment protocol has been used in the irrigation network of the Universistat Politècnica de València gardens. Results showed that applying this methodology up to a potential saving of 26.8% in energy consumption could be achieved.**

Keywords—Urban landscapes, irrigation efficiency, assessment, optimization, decision-making

I. Introduction

In urban landscapes usually predominates the combination of turf and tree species from temperate climates. These associations have high water requirements in the semiarid conditions of the Mediterranean ecosystem.

Some figures highlight this important use of the water. The Spanish Association of Parks and Gardens [1] quantifies irrigation water irrigating urban landscapes in 6.6 mm/day in the period of high water needs. Besides most of water supply systems require energy to operate due to they do not have enough elevation for supplying water by gravity.

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As a consequence double consumption of limited resources is produced, representing environmental and economic impacts. Then assessment should focus to reduce water and energy consumption. In the case of urban landscapes, it should be achieved by maximizing irrigation efficiency. This concept was defined [2] as the balance between the water used by the plant and water applied on plot. The energy efficiency will be achieved supplying water with the minimum energy consumption

Management and maintenance of green areas is not always the desired. At the project level or in the early stages of garden management, facilities are built according to the theoretical conditions but with time, deficiencies often arise and it is essential to detect and to correct them for achieving irrigation efficiency. The aim of the present work is to provide users a tool to assess the quality of irrigation system and to show management solutions regarding with energy consumption.

II. Materials and methods

A. *Pilot site*

The methodology developed in this document was conducted in the gardens of the Universitat Politècnica de València (UPV), Spain (39° 28’ 54’’ N, 0° 20’ 37’’ W, 7 m about sea level). The campus has 106000 m2 of landscaped area with more than 2300 trees. The garden has an irrigation system that supplies water by means of 22 km of pipes. The system is divided in two networks operated by two pumping units. The study is focused in the subnet called well two (w2) where there are 160 intakes and approximately 1400 emitters (sprinklers and diffusers). The irrigation network is operated by a centralized remote system that enables to establish irrigation scheduling by means of opening or shutting electrovalves than run groups of emitters.

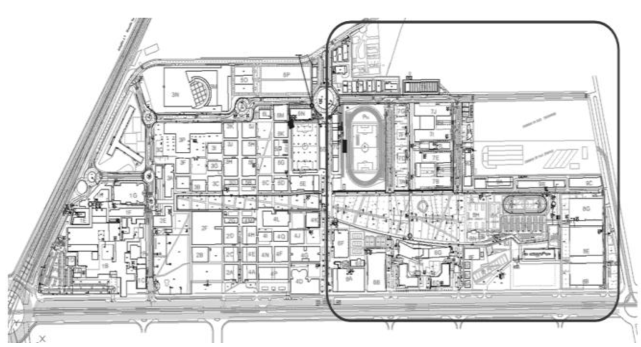

Figure 1. Pilot site. Subarea w2 highlighted.

B. *Hydraulic model of network*

In order to assess hydraulic performance of the system, the irrigation network should be modeled using a simulator. The target is to obtain a model that simulates hydraulic process involved in pressurized irrigation, to detect anomalies and optimize irrigation scheduling.

In this work, the hydraulic simulation was carried out using EPANET [3]. This software performs extended period simulations of hydraulic behavior in pressurize networks. The model has been developed from the data previously obtained from an inventory of the hydraulic system. In addition, the model must be calibrated to ensure the correlation between the simulation and the real system. The adjustment proposed has two steps that can be performed simultaneously.

First, simulated pressure values should be compared with the registered by means of pressure sensors installed in the network. Any difference greater than 0.05 MPa between the measure values and EPANET simulation should be rectified with a correction factor. Second, it is essential to obtain every emitter coefficient (k) that determines the relation flow (Q) – pressure (P) for each intake. This calibration is fundamental due to if there is any discrepancy in k, application dose in plot, scope and droplet size of emitters will be altered. In this work two methodologies are proposed.

- Option 1: Measuring k

This option is the best way to obtain k, especially if, in the case study there are many emitters from several typologies and brands. The measurement is divided into two steps. Firstly, using a pressure sensor and a flow meter with two data-loggers, pressure (P_r) and flow (Q_r) should be measured for each intake. Using the following equations real emitter coefficients for an intake (k_r) are calculated,

$$Q_r = k_r\, P_r^{\alpha} \quad \text{where} \quad k_r = Q_r / P_r^{\alpha} \qquad (1)$$

where α is the emitter exponent (0.5).

Secondly, if there are some technical or economic problems and it is impossible measure each intake, a general emitter constant (k_g) can be obtained for other intakes following these equations.

$$k_{g1}=k_{r1}/n_{1}, \quad k_{g2}=k_{r2}/n_{2}, \quad k_{g3}=k_{r3}/n_{3}, \ldots, \quad k_{gn}=k_{rn}/n_{n}$$

$$k_g = (k_{g1}+ k_{g2}+ k_{g3+\ldots+}\, k_{gn})/n \qquad (2)$$

where n is the number of emitters for intake.

This last step involves an approximation in the method that let evaluators solve derived problems in the measure and save evaluation time.

- Option 2: Deducing k

This option has a theoretical approach and is recommended only if it is impossible to measure emitter coefficients in the hydraulic network. Besides, this alternative will be viable only in urban landscapes with high homogeneity in emitter types and brands. It basically consists in obtaining an equivalent emitter constant for an intake (k_s) by means of the emitter constant for a representative emitter (k_i) multiplied by the number of emitters working for an intake.

$$\text{1 emitter:} \quad Q_i = k_i P_i^{\alpha} \qquad (3)$$

$$\text{n emitters:} \quad Q_s = \Sigma(k_i P_i^{\alpha}) \approx \Sigma(k_i) P_i^{\alpha} = k_s P_s^{\alpha} \rightarrow k_s \approx n k_i \qquad (4)$$

where the subindex "i" represents the emitter and the subindex "s" represents a group of emitter for an intake. This simplification can be done if head losses are not considered in the modeling. And this procedure reduces the assessment time.

C. *Energy efficiency characterization*

Another important issue of the assessment is quantifying the pumping energy. The first phase consists in defining the behaviour of pumping groups by means of their characteristic curves. The essential information is the flow-head curve (Q-H) and the flow-performance curve (Q-η). The best way of obtaining this information is measuring directly in the system with pressure sensors, flow meters and electric analyzers. But in the case that these data were impossible to acquire the information provided by manufacturers could be used.

This theoretical option can be used with some considerations in the case that pump units work with variable frequency drives (VFD). In that case, when a VFD modifies rotational speed of the pump (N), performance is lower than if the pump is working with the nominal rotational speed. This fact can be taken into account with the equations defined by Sârbu and Borza [4]. Thus, the following information is indispensable for defining the pump's behaviour.

$$H_1 = f(Q_1) \rightarrow H_1 = A - BQ^2 \qquad (5)$$

$$\eta_1 = f(Q_1) \rightarrow \eta_1 = EQ - FQ^2 \qquad (6)$$

Following affinity laws and Sârbu and Borza:

$$H_2 = f(Q_2) \rightarrow H_2 = A\alpha^2 - BQ^2 \qquad (7)$$

$$\eta_2 = f(Q_2) \rightarrow \eta_2 = EQ/\alpha - FQ^2/\alpha \qquad (8)$$

$$\eta_{def} = 1 - (1 - \eta_2) \cdot (N_1/N_2)^{0.1} \qquad (9)$$

Where subindex "1" corresponds at nominal rotation speed conditions for Q, H, η; "2" corresponds at rotation speed conditions other than nominal for Q, H, η; and η_{def} is the final performance.

Moreover, the VFD rules will be necessary to be detailed, i.e., from which setpoint pressures starts to operate VFD; and in case of having a system with associated pumps, define their conditions for on and off.

Once all this previous information is collected, coefficients should be used to assess performance system. In this study, the proposed indicators are adapted from the official indicators of the Instituto para la Diversificación y Ahorro de Energía (IDAE) [5,6] and they are very commons in auditing process from agriculture irrigation networks. Three coefficients are defined:

- General energy efficiency (EEG)

This coefficient assesses the global efficiency of the irrigation network including the pump unit. EEG is given by

$$EEG = EEB \times ESE \qquad (10)$$

where EEB in the pumping energy efficiency and ESE is the energetic supply efficiency.

- Pumping energy efficiency (EEB)

This first factor that compounds the EEG represents the balance between the supplied energy by pumps (E_{su}) and the absorbed energy (E_{abs}). EEB is given by

$$EEB\ (\%) = (E_{su}/E_{abs}) \cdot 100 \qquad (11)$$

Both factors can be obtained by means of direct measurements in the system during a representative period of time. In particular, E_{su} for each period in which different intakes work simultaneously (shift) into the operating time is given by the following equation, where Q_i and H_i are flow and pressure measured with a flow meter and pressure sensor.

$$E_{su} = \Sigma\, \gamma\, Q_i\, H_i\, t_i \qquad (12)$$

The other component of EEB is E_{abs}. In this case, for each shift, the factor should be obtained measuring with a network analyzer. E_{abs} -is defined as follows includes an energy value that considers a global efficiency of the pump. The equivalent equation is given by

$$E_{abs} = \Sigma\, \gamma\, Q_i\, H_i\, t_i\, /\, \eta_b\, \eta_{me}\, \eta_{vdf} \qquad (13)$$

where η_b is the global efficiency of the pump, η_{me} is the electric motor efficiency and η_{vdf} is the VDF efficiency.

- Energetic supply efficiency (ESE)

ESE represents the ratio between required supply energy at the system and real energy provided by the pumping. ESE is given by

$$ESE\ (\%) = (|\Delta E|/ICE) \cdot 100 \qquad (14)$$

where ΔE is the energy balance of supply and ICE is rate of energy charge and if there is an only pumping source, this indicator is equivalent at head supplied by the pump, i.e., is the specific supplied energy by pumps (E'_{su}).

Particularly, ΔE quantifies the energy needed to satisfy, for each shift of the sequence, the head required by the most pressure demanding intake (H_{min}). The equation is the following,

$$|\Delta E| = \Sigma V_i H_{min\ j}/V_T \qquad (15)$$

where V_j is the demander volume water for each shift and V_T is the total irrigation volume.

D. *Optimizing irrigation scheduling*

This last step of the assessment protocol can be considered as a tool of searching solutions in the case the system is not being managed properly. The target is to improve energy efficiency by scheduling the irrigation intakes in such a way the required head is lower and pump efficiencies is higher.

The methodology chosen to optimise intakes scheduling is genetic algorithms (GAs). This mathematical tool is a heuristic method based in the mechanisms of evolution and natural selection [7]. The optimization has three components: i) decision variables that corresponds with operating starting intervals for each intake; ii) restrictions that are conditions to solve the problem, like minimum pressure required at any intake, water elevation and minimum performance of the pumping; iii) and the optimization function that is minimize energetic consumption of the irrigation sequence and it is given by the following equation.

$$E\ (kWh) = \Sigma\, \gamma\, Q_i\, H_i\, t_i\, /\, \eta_i \qquad (16)$$

where *i* is the time frequency analyzed.

To start the optimization, the algorithm needs a random group of solutions to assess. This is the initial population of chromosomes composed of a string of genes, i.e., a defined sequence of slots where the intakes can start to operate and stop when their scheduled time is fulfilled. Irrigation times are rounded to the slot length. Thus, the process of optimization starts evaluating for each generation the fitness of each chromosome. Chromosomes that have better fitness are selected to produce offspring for the next generation, which inherited the best traits of both parents. Besides, to avoid reaching a local optimum, a random mutation changes the order of some shifts inside chromosome. After many generations, where the fittest chromosomes are selected, it is expected that the result shows better. [8]. For the case study, the parameters used in the GAs are the following: i) initial population: 100; ii) generation number: 1000; iii) mutation percentage: 10%; iiii) termination mode: maximum number of generations.

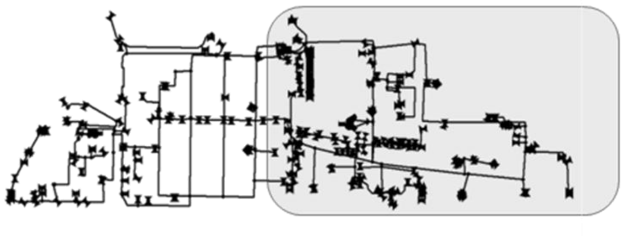

Figure 2. Hydraulic simulation. Subarea w2 highlighted.

In the case study, the optimization of scheduling sequence of intake's operation has been done under four different scenarios. Firstly, two irrigation sequence durations were defined. One option was 14.5 hours that is the current period used by the UPV, and the other option was a reduced schedule of 12 hours. Moreover, the time slot for opening an intake was of 10 minutes. So, there were 87 and 72 slots where intakes could start to operate. Secondly, two approaches were defined to solve the problem considering the head pressure at pumps (H_c). On the one hand, the opening sequence was defined considering a constant H_c for the entire schedule, thus the maximum value registered in the sequence was the chosen. On the other hand, the optimal order of opening was calculated with an H_c variable for each slot. In addition, the restrictions were defined. The minimum pressure required at any intake was 0.4 MPa, the water elevation was -5.1 m and the minimum performance of the pumping was 10%.

III. Results and discussion

A. *Hydraulic model of network*

The UPV network was simulated with EPANET and then, coefficient emitters were adjusted using the option 1 explained before. In the impulsion pipe, a flow meter and a pressure sensor was installed to measure flows and pressures. An additional assessment was done with k_r and emitter coefficients from a previous inventory of the hydraulic system (k_{proy}) done at 2010.

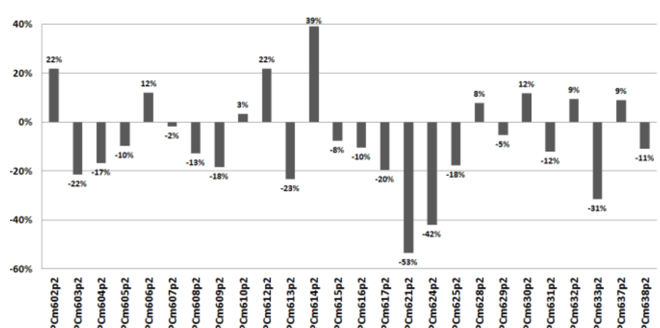

Figure 3. Percentage variations between k_r and k_{proy}.

Differences are shown in Fig. 3. In particular, the average difference between k_r and k_{proy} was 17% and the maximum difference was 53%. These results show an evolution of the system, because there are not the same elements that were when the network was built. Therefore, it is justified the need to periodically calibrate models and to assess systems. Once the model was calibrated, a typical day schedule was simulated with two goals. Firstly, to build the basis tool for comparing optimization results; and secondly, to assess pressure evolution in each intake during a complete irrigation sequence. This showed that there were some intakes with lower pressure than the required.

B. *Energy efficiency characterization*

The studied subnet w2 has a pump unit in a well with a flow of 1100 l/min and a dynamic level of -5.1 m. There are two pumps in parallel of 11kW (Grundfos, SP 46/7). They work in a staggered way with two VDF (Schneider Electric, Microdrive ME 22.5) and two pressure sensors. One pump supplies water maintaining the pressure over 0.5 MPa, and when demanding increases and pressure decrease below 0.4 MPa, the other pump starts operating to support the main one. Theoretical Q-H and Q-η curves are:

$$H = -0.00005Q^2 - 0.0024Q + 91.636 \quad (17)$$

$$\eta = -0.00014Q^2 + 0.2059Q + 2.924 \quad (18)$$

Energy assessment results are shown in Fig. 4 and Fig.5. Two consecutive days in a high necessity period have been studied. During these days, flow, pressure and power were registered. The unitary energy consumption obtained was 0.59 kWh/m^3.

In addition, adapted indicators from IDAE were used to assess the efficiency system. For the 5^{th} of June the EEB was 47.9% and the EEG was 23.9%. For the 6^{th} of June the EEB was 42.6% and the EGG was 21.0%. The limit value considered acceptable for EEB is 45.0% and for EEG is 25% [5].

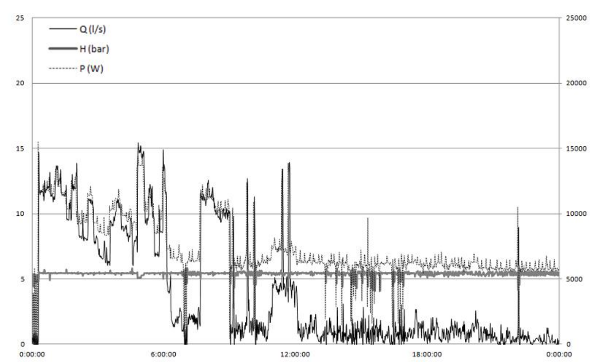

Figure 4. Flow, pressure and power registed at 06/06/2013.

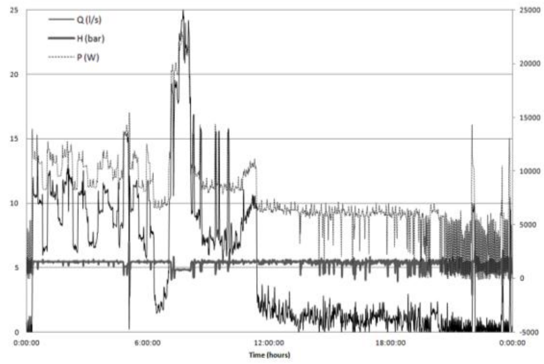

Figure 5. Flow, pressure and power registed at 05/06/2013

Thus, EEB in average is acceptable and EGG in both days is not acceptable. Therefore results show that the system is not operated properly under current conditions.

C. *Optimizing irrigation scheduling*

Scenario results using GAs are shown in Table 1. Only one scenario is feasible to be applied in the UPV system: 14.5 h and constant H_c. The other three have been refused for two reasons. For the option 12 hours, pumps have not enough power in some moments. And variable H_c cannot be implemented because the pumping group have not an adequate level of automation.

The selected option consumes 0.39 kWh/m^3. The consumption in a real schedule simulate using EPANET is 0.50 kWh/m^3. The saving reaches the 26.8%. The improvement is evident and the grouping of irrigation intakes is an efficient strategy to decrease energy consumption.

D. *Conclusions*

This work presents a methodology for assessing urban landscapes from the hydraulic and energetic point of view.

First a group of recommendations is suggested to build the mathematical network model. After the model was built big differences were found in the average difference between k_r and k_{proy} that meant are not the same elements that when the network was built. Then a serial of energy performance indicators has been applied to assess the network operation. These results showed that EGG was not acceptable. Finally a methodology to optimize irrigation scheduling was applied. Results for a feasible scenario showed a potential saving of 26.8% in terms of energy.

These results show the necessity to manage efficiently energy in irrigation systems due to current energy prices and environmental problems.

TABLE I. ESCENARIO RESULTS USING GAS

Scenario	*kWh*	*kWh/m³*
12 h -H_c constant	150.2	0.42
14.5 h - H_c constant	121.5	0.39
12 h -H_c variable	104.9	0.29
14.5 h - H_c variable	114.3	0.32

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