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ANALYSIS AND VIABILITY OF MICROTURBINES IN HYDRAULIC NETWORKS: A CASE STUDY

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ABSTRACT

The purpose of this study is to examine the use of hydraulic microturbines to make the most of the hydraulic energy available in pressurized water distribution systems. The study was carried out on suitable points of pressurized hydraulic networks, which are managed by Giahsa, a public enterprise responsible for the management of the municipal communities of services (MAS) in the province of Huelva, southwestern Spain. The distribution system situated between the `Cabeza del Pasto´ reservoir in the Andévalo area (Huelva, Spain) and the wastewater treatment plant (WWTP) in the municipality of 'Puebla de Guzmán' (Huelva, Spain) was examined. To obtain the exact amount of energy, which reaches the microturbine, the energy conservation equation considering the loss of energy from friction was used. The results show different locations where it is possible to carry out the installation of a Francis turbine, which can generate an annual energy of approximately 280 MWh per year at the selected point, with an approximate investment cost of € 20,000 per year, which means a recovery period of this investment of 2 years.

Keywords: Water distribution system; Francis type hydraulic turbine; Renewable energy; Microgeneration.

INTRODUCTION

The 2020 European Strategy advocates a sustainable growth defined as the promotion of an economy to make greater and better use of its resources (European Commission, 2011). In addition, the electrical demand continues to grow worldwide and there is concern about supply security and about fluctuations in the price of fossil fuels, mainly in countries with high external energy dependence. The option of generating electricity from excess and unused hydraulic energy in water distribution systems could comply with the policies of priority energy efficiency and economy. This microgeneration is a good alternative for the reduction of primary energy consumption and for improves the supply security of energy systems (Fernández de Alarcón, 2010; Sunderland *et al*., 2013; Hawkes *et al*., 2014; Romero-Marrero *et al*., 2018). In specialized literature, it is possible to find some recent examples of the assessment of the installation of microturbines placed at selected points in hydraulic networks (Kim *et al*., 2015; Samora *et al*., 2016a).

In this paper, the source of the water supply is the Andévalo reservoir (Huelva, Spain), where there is a pumping station that lifts the water up to the `Cabeza del Pasto´ pond (Huelva, Spain) (at a height of 236.4 m). From this reservoir the water is channelled by gravity up to the wastewater treatment plant (WWTP) in 'Puebla de Guzmán' (at a height of 186.4 m) (Figure 1), at the entrance of which is a multistream DN300 electrical regulating valve (Multinar). This valve regulates the flow and pressure of water at the entrance of the treatment station. The average flow at the entrance is 120 l/s.

Two alternatives have been considered for the insertion of the microturbine in this water distribution network. The first one would be to place it in the space between the `Cabeza del Pasto´ reservoir and the front of the WWTP (Figure 1). The most favorable points are sought, taking into account the slope where the above-mentioned point is, in addition to the distance covered by the flow of water from the reservoir. This is due to the fact that, the longer the distance, the greater the loss of energy from friction. In the 5600 m which separate the reservoir from the WWTP, four points have been found, which have been examined. The optimal point, without taking into account the energy necessary to take the water from the point to the point to the WWTP, is situated at 1692 m from the inlet of the pond, and at a height of 157.3 m. This means that we have a slope of 79.1 m with regard to the outlet of the pond. There are two possibilities for the best location. The first option would be to place the microturbine in the same pipeline which has already been installed. The second possibility would be to insert it in a parallel position, with a by-pass through a controlling motorized valve (McNabola *et al*., 2014; Corcoran *et al*., 2016), allowing variable flow through the turbine providing greater control over the flow. This would also greatly facilitates the maintenance of the turbine, since it would not be necessary to disconnect the main line of supply.

The second alternative would be to place the microturbine in a parallel position (installation with a by-pass) to the reducing valve which is positioned at the inlet of the WWTP. In this type of installation a motorized valve would be inserted into the microturbine, which would carry out the control. The inlet of the WWTP is situated at a height of 186.9 m, which means that there is a difference in elevating of 49.5 m from the outlet of the reservoir. The main problem concerning this situation is the long distance from the point of outlet of the pond, which results in greater losses due to friction. On the other hand, it is necessary to take into account that the excessive energy with which the water reaches the WWTP is the vital energy needed to be able to use the microturbine. The net head available at any point of the installation would be the same the one at entrance of the WWTP since is the remaining energy in the installation that can be used.

Another consideration is the number of microturbines to be inserted. Samora *et al*. (2016b) contemplated the installation of four microturbines in a parallel position. This type of installation allows using the microturbines depending on the existing demand. It is also necessary to take into account the flow which goes through the microturbine when it is to be inserted. In order to achieve this, the Gibson method is frequently used (Gibson, 1923, 1959; Adamkowski, 1998; Urquiza *et al*., 2007).

The purpose of this study is to assess the possibility of generating energy from a renewable source, that is, the hydraulic energy which is derived from the regulatory valve at the inlet of the WWTP in 'Puebla de Guzmán' (Huelva, Spain). The type of microturbine has been examined as well as the average amount of usable annual energy.

AREA OF STUDY

Figure 1 shows the outline of the pipeline (ductile iron, 500 mm in diameter) from the 'Cabeza del Pasto' reservoir to the WWTP situated in the municipality of 'Puebla de Guzmán' (Huelva, south western Spain). The possibility of inserting a microturbine between the reservoir and the WWTP is being considered. For this purpose, the four most ideal points on the route (1, 2, 3 and 4) have been located taking into account only the altitude and distance that each of them has with respect to the reservoir (Rodríguez-Pérez *et al*., 2018), as can be seen in Figure 1. The WWTP would be point nº5, where the microturbine would be inserted at the inlet, in a parallel position to the regulatory valve.

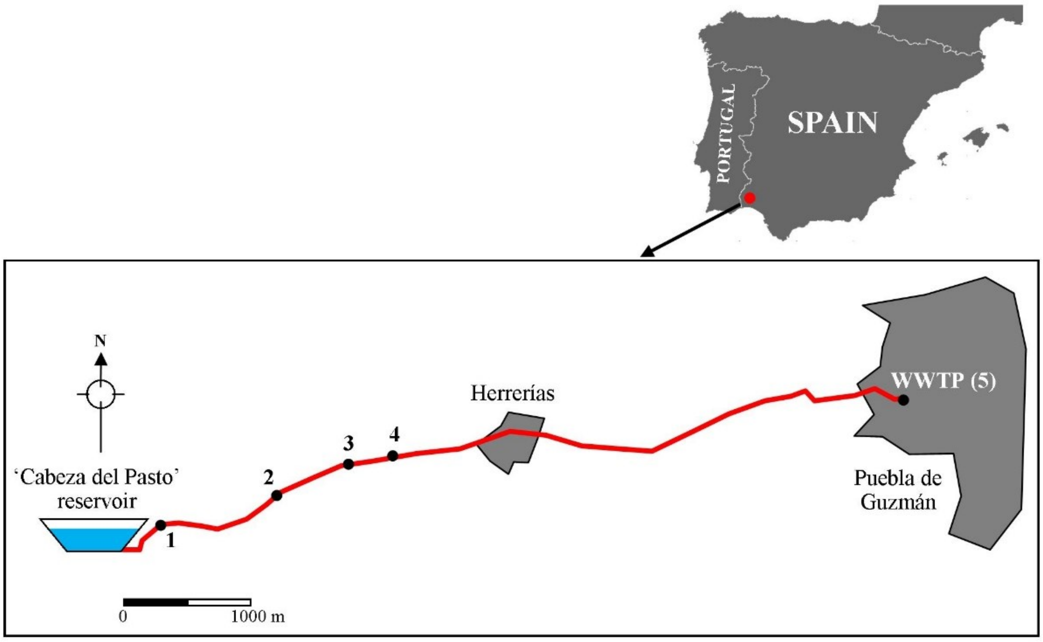

Figure 1. Scheme of the pipes line and selected points for the installation of the microturbine

In Table 1 is possible to observe the distance in m from each of the selected points to the outflow of water from the reservoir, in addition to the elevation at which each one is situated.

Point	Distance from the 'Cabeza del Pasto' reservoir (m)	Height above sea level (m)
'Cabeza del Pasto' reservoir	0	236.40
1	202.16	188.41
2	1164.30	170.35
3	1691.88	157.27
4	1997.22	156.59
5 (Inlet WWTP)	5632.58	186.90

Table 1. Points examined in the water distribution network for the microturbine installation (Rodríguez-Pérez *et al.*, 2018)

The existing installation is equipped with a multistream DN300 electrical regulating valve (Multinar) situated right at the inlet of the WWTP (Figure 2). The purpose of this valve is to reduce the flow which reaches it, and this descends from 220 l/s, when the valve is open, to 120 l/s, which is the flow normally used in the installation. In this procedure, the valve not only reduces the flow, but also limits the excessive energy which comes with the water. It is this excess energy which will be used. When the microturbine is installed, the water will reach the regulating valve with less force, which will not create a problem provided that the energy dispelled in the miroturbine is not greater than the excessive energy with which the water reaches the regulating valve. This problem would not exist if the turbine is placed in a parallel position to the regulating valve (in the WWTP).

Figure 2. Multistream DN300 electrical regulatory valve (Multinar), which controls the flow at the inlet of the WWTP in 'Puebla de Guzmán' (Huelva, Spain) (on the left) and 'Cabeza del Pasto' reservoir which channels water to the WWTP in 'Puebla de Guzmán' (Huelva, Spain) (on the right)

The `Cabeza del Pasto´ reservoir has a capacity of 140,000 m^3 of water (Figure 2), and serves as a storage and supply tank for the treatmment station of potable water (WWTP) in 'Puebla de Guzmán'. This reservoir was built only a few years ago, in the year 2013, and it was constructed at the highest possible point. This was done so that the water would reach the WWTP by gravitational force, making the use of additional pumps unnecessary.

The `Cabeza del Pasto´ reservoir is supplied by four series of pumps which obtain water from the Andévalo reservoir (Huelva). The individual capacity of each pump is

470 l/s with a height of supplied energy of 53 m. The framework of operation of this pumping station depends on the amount of water supplied by the 'Cabeza del Pasto' reservoir. When the level of water reaches the established minimum amount, the pumping station starts to operate until the maximum capacity of the reservoir is obtained.

The Andévalo reservoir has a capacity of 600 hm^3, with the possibility of this being increased to 1025 hm^3. This fact makes it the reservoir with the greatest capacity in the whole of the province of Huelva. It was built in 2003 and opened in 2004. It was constructed to satisfy the great need for the pumping of water to the whole of the Andévalo district (urban and irrigation uses).

MATERIALS AND METHODS

Alternative options for the installation of the microturbine

When we decide to carry out our installation, it is necessary to follow several steps. First of all, it is important to study where and how to install the microturbine. In other words, at which point in the pipeline under study, and whether it should be placed in a group or in a parallel position to the outline of the pipeline under study.

In order to obtain an optimum location of the microturbine, three factors need to be taken into account: (a) Height: this should be the minimum possible, so that the water pressure would be greater, in spite of gravity; (b) The distance between the selected position and the outflow reservoir -this is due to the fact that, the greater the distance, the greater the loss of pressure would be, due to friction with the pipe-; and (c) The net jump that we have at each of the points, that is, the energy that reaches the studied points less the need for water to reach the WWTP.

Therefore, the calculations that must be developed are: (a) To calculate the speed (V) with which the water reaches the microturbine at any of the points to be studied; (b) To obtain the real energy to be used at each of the points by microturbine applying the energy conservation equation considering the loss of energy from friction.

Selection of the microturbine type

When the position of the installation has been decided, it is necessary to calculate the speed with which the water fluid would reach the microturbine, in addition to its force. In order to calculate the loss of energy to friction, the Hazen-Williams equation is used because Daugherty and Franzini (1965) and Hwang and Hita (1987) suggest that this equation is applicable for the flow of water in pipes larger than 5 cm and velocities less than 3 m/s (Liou, 1998). These conditions are satisfied in the hydraulic installation under study, as shown in the results section.

Having established the flow, power and speed with which the water reaches the microturbine, the choice of type is made: turbine type (Pelton, Francis,…), the number of nozzles in the turbine (one or several nozzles), and the number of pairs of poles of the asynchronous generator (two, four, or six pairs). When these data are obtained, it is possible to obtain the energy in MWh needed to supply the microturbine each year.

Once the yearly supply has been established, depending on the surplus energy reaching the valve, a test will be made to determine whether it is necessary to install a second microturbine, which will be installed in a series or in a parallel position.

The second installation option, as has been mentioned before, would be to place the microturbine in a parallel position to the regulating valve. If this is done, the situation of the microturbine would be the inlet of the WWTP. The difficulty incurred with installing it in this position is the huge distance which exists between the outlet of the reservoir and the height at which this point is situated. This is due to the fact that there are other points at a lower level in the connection. What happens is that in the WWTP the energy with which the water arrives is the net jump, which is inside the WWTP and there is no need for an exit pressure at that point for an exit pressure at that point.

RESULTS

Optimum location of the microturbine

First of all, we calculate the speed (V) with which the water reaches the microturbine at any of the points to be studied. Then we take into account the continuous flow (Q) for the whole distance of 0.22 m^3/s, and the diameter (D) for the length of the 500 mm pipe:

$$\mathrm{Q} = V\left(\frac{\pi D^2}{4}\right) \Rightarrow \mathrm{V} = 1.12\ \mathrm{m/s} \qquad (1)$$

After this, we calculate each of the location points to be analyzed. With regard to this, it should be taken into account that the reservoir is situated at a height of 236.40 m. Considering this, we will be able to calculate the difference in height regarding all of the points. In order to calculate the losses to friction, the Hazen-Williams equation is used (Daugherty and Franzini 1965; Hwang and Hita 1987; Liou 1998). Finally, with the use of these calculations, it is possible to obtain the real energy contained at each of the points.

The Hazen-Williams equation is:

$$\mathrm{hf} = 10.67 \left(\frac{\mathrm{Q}}{\mathrm{C}}\right)^{1.852} \frac{L}{D^{4,87}} \qquad (2)$$

where Q = Flow rate (m^3/s); L = Length of the pipe (m); D = inside hydraulic diameter (m); and C = Hazen-Williams coefficient.

The pipeline is 5 years old. A life of 10 years is considered for the selection of the Hazen-Williams coefficient C for pipes line because the turbine installation and operation will begin like minimum two or three years after. For this reason the coefficient of C=110 is chosen for pipes which are between 10 and 20 years old (Giles, 1962). This value is selected due to the fact that several years may pass before the microturbine installation is made out.

This value of the Hazen-Williams C (C=110), obtained by table for ductil fundiction with 10 years of life, has been verified using the approximation suggested by Liou (1998) where C is related to the Reynolds number $\mathfrak{R}$, the relative roughness ε/D (in the friction factor f via the Colebrook-White equation), the pipe diameter (D) and the cinematic viscosity (ν) as:

$$\mathrm{C} = 14.07\ \mathrm{f}^{-0.54}\ \mathfrak{R}^{-0.08}\ \mathrm{D}^{-0.01}\ \nu^{-0.08} \qquad (3)$$

Considering a roughness of ε=1 mm, value quite common in aged pipes (Christensen, 2000), the solution of equation (3) in the study case (V = 1.12 m/s and D = 0.5 m) is approximately 110. Therefore, the value of C=110 is a good approximation.

The calculations for the location point nº 1 (Figure 1) are:

$$\Delta H1 = 236.40 - 188.42 = 47.98 \text{ m} \quad (4)$$

where ΔH1 is the difference of height between the outlet of the reservoir and point nº 1 in m.

$$\text{Losses of power} \Rightarrow hf = 10.67 \left(\frac{0.220}{110}\right)^{1.852} \left(\frac{202.16}{0.5^{4.87}}\right) = 0.63 \text{ m} \quad (5)$$

$$\Delta h1final = 47.98 - 0.63 = 47.35 \text{ m} \quad (6)$$

where Δh1 final is the final difference of height after the losses of power have been eliminated at point nº 1 in m.

The calculation of the loss of energy to friction using the Darcy-Weisbach equation, considering a roughness of ε=1 mm, gives similar results to those obtained with equation (5). In future works, it would be very interesting to estimate the Hazen-Williams coefficient C for pipe lines by measuring tracer concentrations by using the inverse method and to validate these values for a wide range of operational schemes (Al-Omari and Jamrah, 2005).

The results obtained in the other three points being studied can be observed in Table 2. These calculations were obtained in the same manner as for point nº 1.

Point	ΔH (Difference of height between the outlet of the dam and the point where it is placed in m)	Losses of power (m)	Δh final (Final difference of height after the losses of power have been eliminated in m)
1	47.98	0.63	47.35
2	66.05	3.65	62.40
3	79.13	5.30	73.83
4	79.81	6.25	73.56
5 (inlet WWTP)	49.50	17.64	31.86

Table 2. Results obtained in the points studied for the installation of the microturbine (Rodríguez-Pérez *et al.*, 2018)

The real available energy that can be consumed by the turbine is the same at all points of the installation (31.86 m at the entrance to the WWTP, Table 2), because if more energy were consumed at an alternative point of the installation the water would not have enough energy to reach the WWTP. For this reason, the only point that will be studied finally is point 5 which is located at the inlet of the WWTP.

Characteristics of the microturbine to be installed at the WWTP inlet

Due to the requirements of flow and net jump of the studied device (0.22 m^3/s and 32 m), the turbine recommended by the diagram of selection of hydraulic turbines (flow/jump net) is the Francis type (Castellano, 2008). An asynchronous generator with 6 pairs (p) of terminals is used, for which the synchronism speed (n) is calculated as:

$$n = 120 \frac{f}{p} \Rightarrow 120 \ \frac{50}{6} = 1000 \text{ rpm} \tag{7}$$

where f is the frequency of electric energy in Hz and n is 1000 rpm.

This way the calculation of the specific speed is as follows:

$$P\ WWTP = (0.87).\ 9810.\ (0.22).\ (31.86) = 59.82 \text{ kW} = 80 \text{ CV} \tag{8}$$

$$Ns = n.\ Pu^{1/2}.\ Hn^{-5/4} = 1000.\ 80^{1/2}.\ (31.86)^{-5/4} = 117 \text{ rpm} \tag{9}$$

with Pu = useful absorbed power and Hn = net height.

Therefore the energy generated by the microturbine would be:

$$P = \gamma.\ \eta.\ Q.\ Hn \tag{10}$$

where ŋ is the yield from the microturbine in this case will be 0.87 (87%); ɣ is the specific weight = water density x gravity = 1000 kg/m^3 x 9.81 m/s^2 = 9810 N/m^3.

Since the microturbine would be working an average of 14 hours a day during the whole year, the total amount of energy it would generate for the year would be:

$$\text{Energy} = \text{hours per year x P} \tag{11}$$

$$\text{Hours per year} = 14 \text{ hours x } 365 \text{ days} = 5110 \text{ hours} \tag{12}$$

$$\text{Energy per year for the WWTP} = 5110.\ 58454 = 298.70 \text{ MWh per year} \tag{13}$$

The Francis turbine type depends on Ns, in our case for Ns we have a Francis medium turbine, Ns is between 110 rpm and 200 rpm [Low speed Francis (Ns <110), medium Speed Francis (110 <Ns <200), fast speed Francis (200 <Ns)].

According to the results obtained, the ideal microturbine to be installed would be the following:

- A medium speed Francis turbine.
- Raw height (Hb) = 49.50 m
- Net height (Hn): 31.86 m
- Flow (Q): 0.22 m^3/s
- Specific speed of the turbine (Ns): 117 rpm
- Power: 59.82 kW = 80 CV
- Estimated number of hours of workload: 14 hours per day, 5110 hours per year
- Energy: 59.82 kW x 5110 h = 305.68 MWh per year
- An asynchronous generator with six pairs of terminals at 1000 rpm

Installation budget

With the corresponding data to the hydraulic installation at study, in Table 3 is shown the approached investment costs proportioned by some sector companies.

Technical Parameters			
Net Head:	Hr	32	m
Flow Rate:	Q	0.22	m^3/s
Capacity:	P	60	kW
Turbine		Generator	
Model	F246-26	Model	SF60-4/22
Rated rotating speed r	1000 rpm	Rated Efficiency of Generator ηf	91%
Efficiency of turbine ηf	87%	Efficiency of the generator f	50Hz
Rated Discharge Qr	0.22 m^3/s	Rated voltage of generator V	400 V
		Rated rotating speed r	1000 rpm
Product Price			
Name of Commodity	(pcs)	Euros	
Turbine: F246-26	1	11500	400V, 50Hz
Generator: SF60-4/224	1	3400	
Excitation Device: BKF-60kW	1	2170	
Governor: ST-100	1	1080	
Valve: Z45T-10-DN350	1	1350	
Packing fee	1	1000	
Total amount		**20500**	

Table 3. Budget the turbine + Excitation Device + Generator + Packing fee + Valve

On the other hand we have the cost of assembly and installation, which we estimate at € 19500. Which would mean a total cost of € 40000.

To calculate the annual energy generated, it is necessary to take into account the efficiency of the generator, which is 91% since we only took into account the efficiency of the turbine:

Energy: 59.82 kW x 5110 h x 0.91 = 278.17 MWh per year (14)

This equates to more than € 20,000 per year, which means that the investment has recovered in 2 years. With the requirements of flow and net height of the hydraulic network in study, a Pelton turbine was also evaluated but the total costs were higher than with the Francis turbine with a recovery period of this investment of 5 years (Rodríguez-Pérez *et al*., 2018).

DISCUSSION

This study have as main objective the evaluation of the viability of the insertion of a microturbine in a pressure network of water supply. The results show that the amount of usable energy is significant. The microturbine chosen is the Francis type, due to the fact that it is the one which possesses greater efficiency for this water flow. As has been observed, the characteristics of the microturbine vary, depending on the point chosen for its insertion. More exactly, what varies is the number of pairs and revolutions per minute at which the microturbine works.

One of the most important aspects of the study is the insertion of the microturbine, in our case, the WWTP inlet has been chosen. When the position has been decided, it was necessary to determine how to insert the microturbine, whether in a series or in a parallel position with the pressure reducing valve (Figure 3). In this regard, the latter alternative was chosen. This consists of placing the microturbine in a parallel position (with the installation of a by-pass) to the pressure reducing valve if the position chosen were the inlet of the WWTP (Figure 3a).

The final decision to place the microturbine in the WWTP inlet is that at the exit of the turbine we do not need the water to come out with a certain force and therefore we can take advantage of all the energy that reaches it. Therefore, at the input of the WWTP the water derived from 'Cabeza del Pasto' reservoir is distributed to a treatment pond with height sufficient to run the water through of the all WWTP.

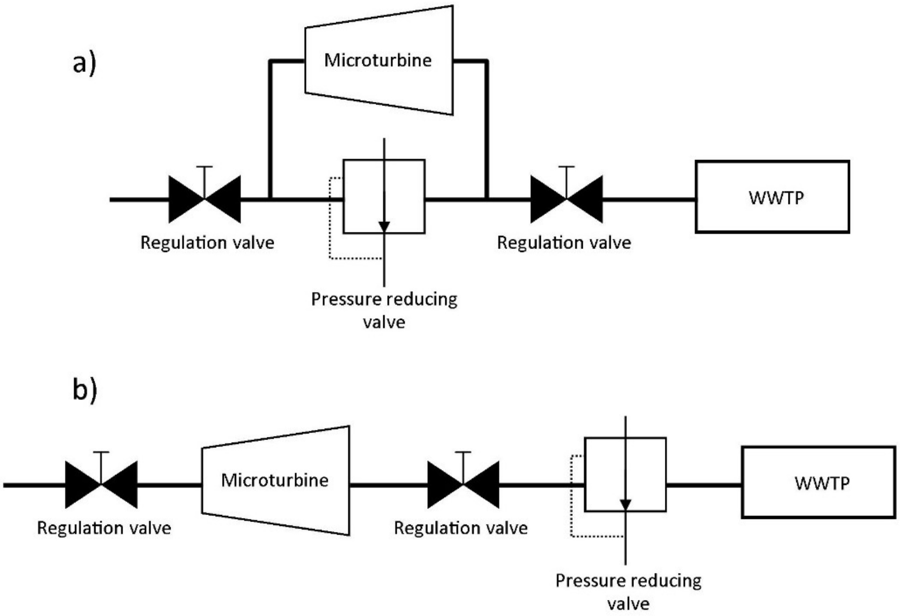

Figure 3. Diagram showing the installation of the microturbine at the inlet of the WWTP: (a) parallel position (with the installation of a by-pass) to the pressure reducing valve and (b) series position to the pressure reducing valve

This means that the most adequate position for generation is not ideal one due to inadequate pressure to reach the WWTP. The position chosen is to place it in a parallel position to the regulating valve which is situated at the inlet of the WWTP. Thus the problem is avoided but energy generated would be less. The results obtained for the annual energy generation are less than in the ideal position. However in order to calculate the installation, the most unfavorable data have been used. This guarantees that obtaining the annual energy calculated is assured and this could possibly increase.

Having made the necessary calculations for its placement, medium speed Francis turbine and an asynchronous generation with six terminals functioning at 1000 rpm has been selected for the position.

CONCLUSIONS

This paper shows how effective the insertion of a microturbine in a hydraulic network can be, and how energy can be generated by a renewable source. This type of installation has been studied with great interest in the last few years, since it could be an ideal for many urban and irrigation water distribution systems. This generated energy could be add directly to the electricity network but perhaps the best option would be to use it as self-consumption in the water distribution network (for example, for the energy requirements in control devices such as motorized valves, for the illumination of the WWTP, etc.).

In this particular case in study, the best alternative is the insertion of a microturbine in a parallel position with a regulating valve at the inlet of the WWTP. Some rather interesting results have been obtained due to the large flow available, and it has been possible to compensate losses from friction due to the long distance covered by the water between the reservoir and the WWTP. The reason for this is the huge difference in height which exists between the reservoir, from which the flow facts, and the point where the microturbine is to be placed.

This paper presents an approach for technicians and managers of water distribution systems who, with a good knowledge of the operating schemes of their hydraulic network, are aware of the significant contribution of energy that could be achieved at certain points with the installation of a microturbine. In order to quantify this energy potential in certain locations of water distribution networks, with complex operation schemes that depend on the time of day and month of the year, this work could be useful as a methodological guide for the optimum location of microturbines and for the selection of the type of microturbines to be install.

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REFERENCES

Adamkowski, A. (1998). Measurement of the flow rate with the Gibson method in the hydraulic power plant in Bielkowo. *Proc. of the 5th Scientific Technical Session 'Hydraulic Power Plant in an Electric System'*, Solina-Myczkowce, Polonia, 29-37.

Al-Omari, A.S., Jamrah, A.I. (2005). Calibration of Hazen-Williams coefficients in pipe networks using tracers. *Journal of Water Supply: Research and Technology-Aqua* 54(5), 293-311.

European Commission. (2011). *A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy*. Communication from the Commission to the European

Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Brussels (Belgium).

Castellano, J. (2008). *Centrales eléctricas microhidráulicas: Aplicación en una zona rural subdesarrollada*. Proyecto Fin de Carrera, Universidad Politécnica de Cataluña (Spain).

Christensen, B.A. (2000). Discussion of 'Limitations and proper use of the Hazen-Williams equation'. *Journal of Hydraulic Engineering* 126(2), 167-168.

Corcoran, L., McNabola, A., Coughlan, P. (2016). Optimization of water distribution networks for combined hydropower energy recovery and leakage reduction. *Journal of Water Resources Planning and Management* 142(2), 04015045.

Daugherty, R.L., Franzini, J.B. (1965). *Fluid mechanics with engineering applications*, 6th Ed., McGraw–Hill Inc., New York (USA).

Fernández de Alarcón, J. (2010). *Estudio de los sistemas de microgeneración en España*. Proyecto Fin de Carrera, Escuela Politécnica Superior, Universidad Carlos III de Madrid (Spain).

Gibson, N.R. (1923). The Gibson method and apparatus for measuring the flow of water in closed conduits. *ASME Power Division*, 343-392.

Gibson, N.R. (1959). Experience in the use of the Gibson method of water measurement for efficiency tests of hydraulic turbines. *ASME Journal of Basic Engineering*, 455-487.

Giles, R.V. (1962). *Theory and problems of fluid mechanics and hydraulics*. Schaum Publishing Co., New York (USA).

Hawkes, A., Entchev, E., Tzscheutschler, P. (2014). A comparative review of microgeneration policy instruments in OECD countries. *IEA EBC Annex 54*

Integration of Micro-Generation and Related Energy Technologies in Buildings, Technische Universität München (Germany).

Hwang, N.H.C, Hita, C.E. (1987). *Fundamentals of hydraulic engineering systems*, 2nd Ed., Prentice-Hall Inc., Englewood Cliffs, N.J. (USA).

Kim, I., James, J.A., Crittenden, J. (2015). The energy-efficient, economical, and environmental impacts of microturbines on residential customers. *2015 Seventh Anual IEEE Green Technologies Conference*, New Orleans, LA (USA).

Liou, C.P. (1998). Limitations and proper use of the Hazen-Williams equation. *Journal of Hydraulic Engineering*, ASCE, 124(9), 951-954.

McNabola, A., Coughlan, P., Corcoran, L., Power, C., Williams, A. P., Harris, I., Gallagher, J., Styles, D. (2014). Energy recovery in the water industry using microhydropower: an opportunity to improve sustainability. *Water Policy* 16(1), 168–183.

Samora, I., Manso, P., Franca, M.J., Schleiss, A.J., Ramos, H.M. (2016a). Energy recovery using micro-hydropower technology in water supply systems: The case study of the city of Fribourg. *Water* 8(8), 344.

Samora, I., Manso, P., Franca, M.J., Schleiss, A.J., Ramos, H.M. (2016b). Opportunity and economic feasibility of inline microhydropower units in water supply networks. *Journal of Water Resources Planning and Management* 142(11), 04016052.

Rodríguez-Pérez, A.M., Pulido-Calvo, I., Pereira-Villaseñor, M., Domínguez-Castro, L. (2018). Microturbina para el aprovechamiento de la energía hidráulica en el sistema de abastecimiento de agua de la ETAP del Andévalo (Huelva). *X Simposio del Agua* *en Andalucía*, SIAGA 2018, Club del Agua Subterránea, Madrid (Spain), Book II, 333-342.

Romero-Marrero, L., Pérez-Sánchez, M., López-Jiménez, P.A. 2018. Estimation of the characteristic curves of pumped systems working as turbines through their curves operating as pump. *Ingeniería del Agua* 22(1), 15-26.

Sunderland, K.M., Mills, G., Conlon, M.F. (2013). Estimating the wind resource in an urban area: A case study of micro-wind generation potential in Dublin, Ireland. *Journal of Wind Engineering and Industrial Aerodynamics*, 118, 44-53.

Urquiza, G., Adamkowski, A., Kubiak, J., Sierra, F., Janicki, W., Fernández, J.M. (2007). Medición del flujo de una turbina hidráulica de 170 MW utilizando el método Gibson. *Ingeniería hidráulica en México* XXII(3), 125-137.