Smart Water-Energy Management Using Digital Twin in Water Distribution Systems

Case Study of Santa Cruz Water Supply and Distribution System

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Abstract: One of the contributive problems to water scarcity are water losses existing in Water Supply Systems (WSS) and Water Distribution Systems (WDS), originated mainly by excess of pressures and bad network management. Due to the reduced investment made over the years by the responsible management entities, water systems don't keep pace with population growth and its consequent increased consumption.

One way of reaching better energy efficiency in the network is by replacing Control Valves (CV) by Pumps working as Turbines (PAT), allowing the conversion of excess pressure in electric power.

Digital twins appear as a virtual representation of the physical networks, integrating virtual engineering models with city-scale reality models and Geographic Information Systems (GIS) data. This technology provides accurate and reliable data that utilities can use to perform analysis throughout their water systems.

In this work, after a pressure reduction strategy implementation, the implantation of a Pumps working as Turbine (PAT) upstream of an existing reservoir was studied, achieving the same performance as the designed Flow Control Valve (FCV) complementing its functions with renewable energy production.

The study demonstrates that if these projects are implemented, a large amount of water and energy will be saved, resulting in a 3,3M m3 of water and more than 1M of kWh corresponding to 1.5M € saved every year, and also more than 530ton/year of CO_2 emissions would be avoided.

Key-Words: Excess Pressures; Digital Twins; Water Savings, Renewable Energy, Pumps working as Turbines(PAT)

1. Introduction

One of the contributive problems to water scarcity are water losses existing in Water Supply Systems (WSS) and Water Distribution Systems (WDS), originated mainly by excess of pressures and bad network management. Thus, from a perspective of sustainable management of water resources in a context of climate change, it is essential to increase the levels of efficiency in the structures through the reformulation of obsolete water systems, controlling pressure levels, so that water losses do not continue to increase. Sources of green energy production must be developed to follow the existing increasing needs. In WSS and WDS it is possible to produce renewable energy, taking advantage of the regulating devices operation conditions and, instead of dissipating energy, implementing Pump working as a Turbine (PAT) solutions, that will be responsible for energy recovering. PAT solutions are usually the chosen turbines because they appeared as a cheaper alternative to conventional turbines with reasonable efficiency levels. [1]

2. Water and Energy Losses

Due to the reduced investment made over the years by the responsible management entities, water networks operate beyond their useful life, not keeping pace with population growth and its consequent increased consumption, causing supply failures and excessive water losses in systems, shown through ruptures and leaks from pipelines and reservoir overflows. The efficiency of the systems is already beginning to be a concern of the management entities and it should be seen as opportunities to improve the management of these systems.

2.1. Water Balance and Pressure Management

The evolution of the annual water volume wasted in WDS is itself an indicator that allows to verify the evolution of the system's efficiency over the years. This value should be measured and reduced as much as possible until it reaches a minimum level, from what lower values imply an investment which is no longer economically viable [2]. According to International Water Association (IWA), water losses are defined as the difference between the volume of water entered in the system and the authorized consumption. Authorized consumption is the volume of water consumed by costumers, including domestic, commercial, and industrial purposes. Authorized consumption can be billed or unbilled by the managing entity, being some examples of this last component the following: firefighting, street cleaning and irrigation of municipal gardens. Water losses are reflected in the volume of water that does not reach any consumer, meaning that after entering the system it ends up being lost, without any associated billing. This component is divided in Apparent Losses (AL) and Real Losses (RL). The first one includes water volumes of unauthorized consumptions, ending up, consequently, unbilled by the management entity, like illicit consumption, thefts, or measurement errors associated to the existing flow meters of the distribution network. On the other hand, the second one includes the volumes of water resulting from tank's overflows, leaks or ruptures occurring along the network. The components of the Water Balance should be measured, analyzed and, in the end, considered as possible indicators [3][4].

Another indicator that should be analyzed is Unavoidable Annual Real Losses (UARL). This indicator allows the recognition of different components of Real Losses in the system as the extension of the network and connections, taking also into account the average pressure of the network in its determination.

Unavoidable Annual Real Losses (UARL) can be obtained through equation [1]:

$$UARL(l/connection/day)=(18Ld+0.80Nr+25Lr)xP \qquad [1]$$

where Ld represents water distribution system's length in km, Lr the connections' total length between property limit and the flow meter, in km, Nr the number of connections existing in the network and P the average pressure of the network.

The difference between Current Annual Real Losses (CARL) and Unavoidable Annual Real Losses (UARL) of a system represents the real losses reduction potential, being the quotient between those two variables called Infrastructure Leakage Index (ILI), a non-dimensional variable that shows the state of the network. Well-managed systems should have an ILI value close to one, meaning that the higher the result obtained the older and in worse conditions the system is. UARL represents the minimum real losses value that can be achieved in a WDS, lower values will imply costs higher than the economic value of the water saved. Of the various loss components, Real Losses have the highest expression (mainly reflected in ruptures and other small leaks existing in the distribution network), and there are several factors that are at their origin, namely the age and state of conservation of the pipelines, the characteristics and use of the surrounding land, fragile connections and excessive pressures. One of the most influential factors in water losses is the excess pressure, and, in some case-studies where volume of water was measured during periods with no consumption, it was found that there was a direct relationship between average pressure in the distribution network and the volume of water losses. Thus, the pressure in the network is one of the elements to be managed when a reduction of water losses in the system is intended, minimum and maximum values must be ensured to guarantee no absence of water or discomfort in users [5]-[7].

Pressure in a WDS can be reduced and controlled through some equipment installation as Pressure Reducing Valves (PRV) and Flow Control Valves (FCV), in strategical locations coordinating its installation with the management of existing ones and replacement of used pipes, in order to promote a good hydraulic systems' behavior and management [7][8].

Active Leakage Control (ALC) consists of a set of measures to locate and repair existing leaks and ruptures in water systems, being a prevention practice avoiding unforeseen work of damaged areas due to ruptures and reducing the volume of water losses in the systems. Because they require constant monitoring, several authors recommend that ALC measures should be considered with the creation of District Metered Areas (DMA), being easier to identify the areas with higher volume of water losses and locate the priority pipes to repair. The sectorization of the network allows better control of the system, monitoring its water losses evolution over the time and the areas with the highest volume of losses and, consequently, with the greatest need for implementation of ALC measures [7]-[10].

2.2. Energy Recovery in Water Supply Systems

Water and energy are considered to be interconnected and interdependent, requiring a constant management, in order to follow the evolution of the planet. Global population is growing, needing more fresh water and electricity resources available once its demands are expected to increase, being important to optimize this resource, optimizing its use through recycling and find new renewable energy sources. In addition, climate changes are influencing the hydrological cycle, resulting in extreme precipitation events as flooding and droughts, and consequent water storage issues [11][12].

Water Supply Systems (WSS), have potential source of energy recovery in their dissipation junctions, being the knowledge of power availability a critical factor to understand de viability of converting energy dissipation into energy production. To dissipate excessive pressures or separate areas with different energy steps in the network, Pressure reducing valves (PRVs) ore Flow Control Valves (FCV) are used. One way of reaching better energy efficiency in the network is by replacing Control Valves (CV) previously mentioned by Pumps working as Turbines (PAT), allowing the conversion of excess pressure in electric power [13].

To maximize the exploitation of a specific PAT, Variable Operation Strategy (VOS) concept was created, being achieved by establishing an optimal speed regulation. Two different procedures were established for VOS: Hydraulic Regulation (HR) and Electrical Regulation (ER). In HR, Pressure Reducing Valve (PRV) is placed in series with the PAT imposing a head drop, and a Flow Control Valve (FCV) is placed in parallel bypassing a portion of the flow, allowing the PAT to work continuously in its Best Efficient Point (BEP) but transforming only part of the total energy into electrical energy. In Electrical Regulation (ER) an inverter is attached to the PAT enabling change of its rotational speed being all flow and energy converted. In this case, PAT can work out of its BEP. The combination of both modes is called Hydraulic and Electric Regulation (HER), increasing the efficiency and energy recovery potential of the system, as sown in Fig. 1 [13][14].

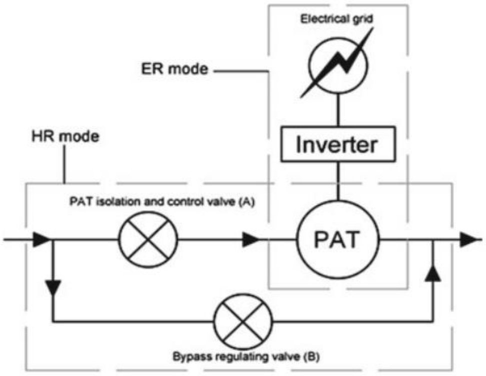

Fig. 1- Installation scheme of a PAT in Hydraulic and Electric Regulation (HER) [13]

3. Smart Systems

Smart Water Grids (SWG), as an integrated element of smart cities, are proposed as a new generation of water management considering the integration of information and communications technologies (ICT) as sensors, meters, digital controlers and analytic tools, to automate, monitor and control the water network ensuring that water is delivered with good quality only when and where it is needed. When applied to the water industry, these ICT also provide automatic remote collection of data at site and wireless transmission being easier to analyze and improve system's efficiency and quality [15]. Smart water management is responsible for reduction of water losses and leakage, contributing to sustainability and self-sufficiency in water systems and, when followed by advanced information technologies, it results in different benefits, such as: better understanding of the water system, constant monitorization of water quality and behavior, detecting leaks and controlling water losses more efficiently, reduction of financial losses, improvement of the system's efficiency and customer service reducing the water bill. Real-time data collection, variable speed pumps, dynamic control valves and smart meters are essential elements to manage water and energy demand and achieve the benefits former listed. Moreover, having an hydraulic model representing all the scenarios of the water distribution system is also indispensable, called Digital Twin (DF). This system provides a water balance with the total water resources available and the total water demand. [16]

2.3. Digital Twin for Water Distribution Systems

Digital twins appear as a virtual representation of the physical network, integrating virtual engineering models with city-scale reality models and Geographic Information Systems (GIS) data. Having the real physical data, digital twins are continuously updated with operational data from sensors, meters and other measuring devices, resulting in a model connected to digital infrastructure that supports smart water networks' management processes such as planning, design, construction and operations. Digital twins provide accurate and reliable data that utilities can use to perform analysis throughout the lifecycle of a water system reproducing disruption scenarios for resilience assessment purposes, analyzing asset prognosis and health-status to determine proactive maintenance models [17][18].

Digital twin development requires continuous adjustments and learning techniques supported by large amount of field data stored in big-data platforms. The main sources to create the platform are: (i) GIS, to provide information of spatial locations; (ii) Sensors, to receive the information from the hydraulic network; (iii) Supervisory control and data acquisition (SCADA), to supervise, monitor and control the data collected; (iv) Smart Metering, to control the network operation and customer service in independent metered areas; (v) Computerized Maintenance Management System (CMMS), to track and maintain stationary assets. As a result of the integration of the mentioned sources in the hydraulic model, using artificial intelligence algorithms and Information and Communication Technologies (ICTs), a DT model is obtained (Fig. 2) and its potential can be exploited [19].

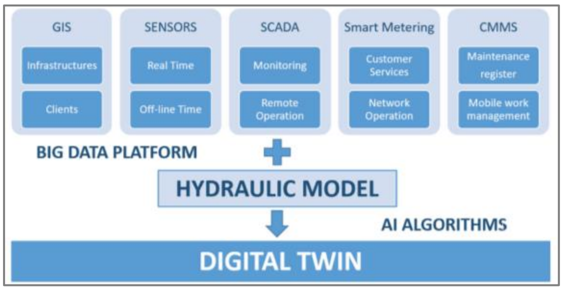

Fig. 2 - WDS Digital Twin Structure [19]

4. Case Study – Santa Cruz Water Distribution System

4.1. Santa Cruz WDS characteristics

Santa Cruz is the second municipality with more inhabitants in Madeira Island (Portugal). Located in the Atlantic Ocean, this island is characterized by its very variable altimetry, and consequent high slopes. Fig. 3 presents Santa Cruz morphology, where it is verified that in an area of 81 km2 there are elevation values varying between 0 and more than 1000 meters.

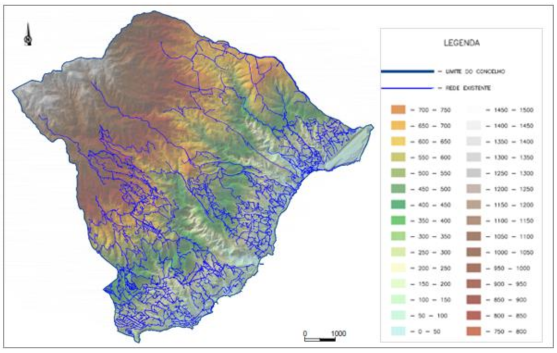

Fig. 3 - Morphology of Santa Cruz (Madeira)

According to Água e Resíduos da Madeira (ARM - *Water and Wastewater Madeira Management Entity*), that provided WSS's values, and Municipality of Santa Cruz (MSC), that provided WDS data, Table 1 indicates the annual volumes acquired by the municipality and the correspondent annual billed/unbilled volumes. A brief analysis shows that more than 7M m^3/year is not billed, representing 74% of the total acquired volume. Also, Billed Volume has remained stable over the years, which indicates that the apparent losses should not be varying substantially, which must be essentially due to errors in measure devices.

Table 1– Annual Volumes – Santa Cruz (ARM and MSC data)

Year	Acquired Annual Volume	Billed Annual Volume	Unbilled Annual Volume	Unbilled/ Acquired
(-)	(m3)	(m3)	(m3)	(%)
2010	7.211.432	2.810.567	4.400.865	61,0
2011	7.434.454	2.705.859	4.728.595	63,6
2012	7.688.409	2.656.678	5.031.731	65,4
2013	8.094.031	2.370.288	5.723.743	70,7
2014	8.011.062	2.406.423	5.604.639	70,0
2015	8.654.570	2.429.246	6.225.325	71,9
2016	8.774.399	2.481.348	6.293.051	71,7
2017	9.065.322	2.540.274	6.525.048	72,0
2018	9.233.381	2.444.474	6.788.907	73,5
2019	9.574.240	2.511.736	7.062.504	73,8

The evolution of "Unbilled Volume" shows that the total losses are increasing dangerously. Unbilled Authorized Consumption (UAC) component, corresponding to MSC expenses and water intentionally not billed, may correspond to a significant portion of the "Unbilled Volume". In conclusion, the portion that has the most weight in the increaseing volumes of Unbilled Water, which in 2019 corresponds to 73.8% of the volume entered, is Real Losses(RL).

A digital twin of Santa Cruz System was elaborated in *EPANET*, in order to study these variables in more detail and create a strategy to improve its hydraulic behavior. In the following chapter the used methodology will be presented through the example-model of Gaula, the WDS supplied by Gaula's Reservoir. The explained methodology was followed for all the other systems.

4.2. Digital Twin of Gaula WDS

Gaula tank, located in the southeast area of the Municipality, is gravitationally supplied by "*Funchal – Machico*" pipeline. In Fig. 4 is represented the morphology and location of this system, where it can be observed the highest elevation values in the Northwest region, decreasing "in parallel" to the coast.

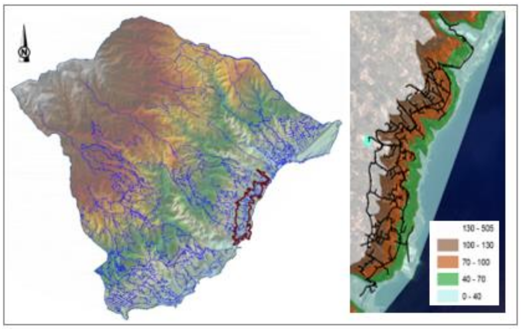

Fig. 4- Gaula – Location and Morphology

Gaula's WDS, according to MSC data, is an aged system mostly composed by high-density polyethylene (HDPE) and Galvanized Iron. For hydraulic simulation purposes, Hazen-Williams formula was adopted to calculate headlosses with a roughness coefficient "C" of 140 for new pipes in HDPE, 130 for exinting HDPE, 120 for PVC or Steel and 100 for in Fiber Cement or Galvanized Iron ducts. Since different types of solicitations occur in a distribution network, three scenarios were considered: average situation (occurrence of average consumption), peak situation (occurrence of consumption in a high-demanded situation, calculated through the application of Reglementary Instantaneous Multiplying Factor) and the static situation considering an hypothetic limit scenario in which there are no domestic flow rates or water losses, meaning the system has to carry the highest possible values of pressure. Consumption flow rates and Apparent Losses were distributed by the junctions of the hydraulic model together, being the last one mostly resulting from flow measure devices' errors. These values were introduced considering the population's distribution per node of the model, being later converted to demands applying a multiplying factor. To calculate population of each node, Thiessen polygons were created from the model's junctions, overlapped to BGRI Polygons, reaching a population value to be attributed to each node. The multiplier to be applied to all junctions was then determined to convert inhabitants into consumption, both for the medium and the peak scenario. This multiplier was calculated by dividing the average consumption flow of each scenario by the population to be supplied.

In equation [2] is presented the Reglementary Instantaneous Multiplying Factor (*f*) calculation, where *P* represents the number of system's inhabitants.

$$f = 2 + \frac{70}{\sqrt{P}} \qquad [2]$$

Applying the equation to the present case study, *f* value corresponds to 3,874, being applied only to "domestic" consumption. Of all customers in the municipality of Santa Cruz, there are several considered to have significant consumptions, being included in this group those whose annual consumption of the year 2018 was higher than 2.000m^3. Since the hydraulic model was developed individually to each subsystem, consumption parameters had to be adjusted.

The digital twin have different variables associated to each junction, being the real losses simulated with a discharge of a flow rate, independent from consumption. The flow discharged from each node is calculated according to the expressions [3] and [4], in which q represents *the* flow rate, K_f *the* discharge coefficient, *p* the pressure, g the pressure exponent that depends on the type of material of the network, *c* the discharge coefficient, L_{ij} the length of the pipe between the junctions *i* and *j* and *M* is the number of conduits connected to node j .

$$q_j = K_f\, p_j^{\gamma} \qquad [3]$$

$$K_f = c \times \sum_{J=1}^{M} 0.5 \times L_{ij} \qquad [4]$$

In order to understand the veracity of the hydraulic model, pressure results were compared with real measurements performed in 54 points of the distribution network, as shown in Fig. 5, where it can be observed that, there is an almost perfect correspondence between the measured and the calculated values, with an average 5% error into the peak hour.

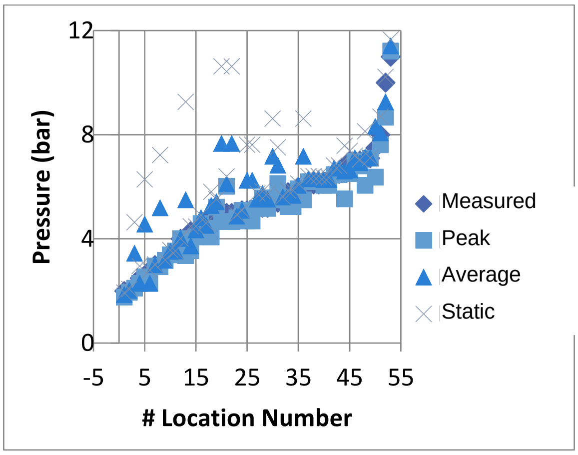

Fig. 5 – Measured and Simulated pressure values

Since most values were measured around 9 a.m., the hydraulic model corresponds to peak situation.

However, some measurements were made in the middle of the morning or in the afternoon, being closer to those average situation results. Fig. 6 shows pressure differences in Gaula hydraulic model, in the worst case-scenario, static simulation, where it was assumed that no consumptions or losses would occur. Fig. 7 shoes the pressure improved values in Gaula system due to hydraulic model changes. Comparing the average pressure observed in the average scenario of the existing and changed models, there is a reduction of 1.7 bar compared to the 5.1 bar verified in the existing situation model, where about 25% of network's junctions had pressures values above 60 mc.a. (maximum regulatory) in all scenarios analyzed (medium, peak and static).

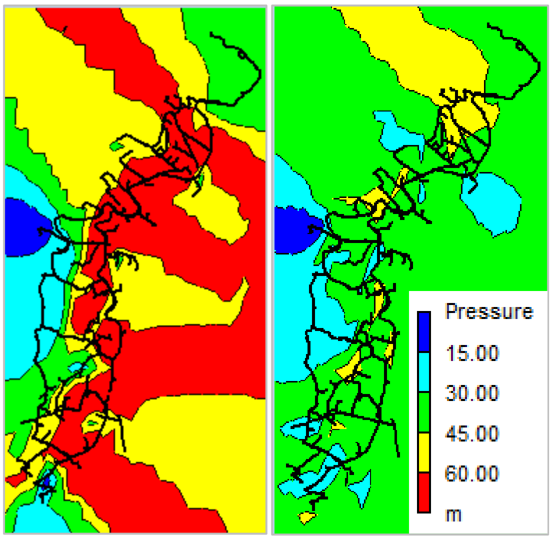

Fig. 6 – Maximum pressure scenarios Initial contention vs changed Digital Twin

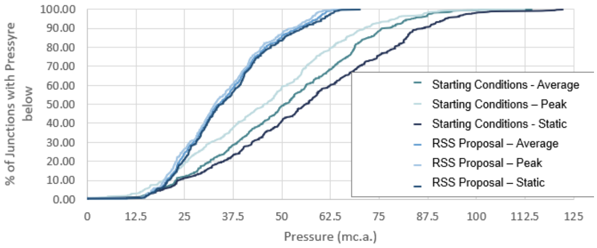

Fig. 7 - Pressure in Junctions – Epanet Results

By simulating the extreme situation (static), where consumption and losses were considered non-existent, the reduction of the mean pressure value obtained was from 56 mc.a. to 34 mc.a., being a reduction around 2 bar.

In the existing scenario, being the average pressure value 5,1 bar and considering an average extension between properties and the connection to the common conduit of 10 meters, UARL calculation results in RL potential reduction from 20 531 m3/year to 13 531 m3/year,

4.3. Water-Energy Nexus in Santa Cruz WDS

Gaula WDS's analysis and parameters previously described were applied to each one of Santa Cruz WDS sub-subsystems, totalizing 437km of pipelines. In the analysis it was considered not only the existing conditions and network characteristics, but also Influence Areas reformulation, management of existing energy levels and creation of new ones and sectorization of the network with creation of ZMAs. Difference of pressure values in static scenarios can be seen in Fig. 8.

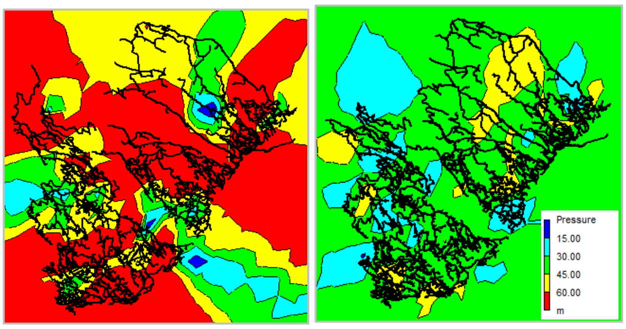

Fig. 8– Santa Cruz – Maximum Pressure Scenario (Existing Situation/RSS Proposed Situation)

The introduction of some Flow Control Valves (FCV) upstream the existing tanks was one of the proposed changes in the overall Santa Cruz reformulation plan. With the implementation of this devices, water volumes will enter the tanks through a constant flow during a certain period of time, avoiding high pressure variations and pipe breaks.

The studied FCV was the one with higher value of "QxΔH", located upstream of Quinta do Garajau Tank (QG). According to the available head and flow, the chosen PAT was Etanorm 65-250, which characteristic curve is shown in Fig. 9.

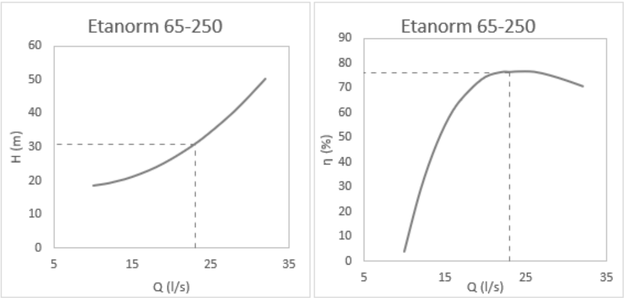

Fig. 9 – Characteristic curve of the PAT Etanorm 65-250

In the study of Quinta do Garajau behavior through the inflows and outflows, an iterative process was made to understand how many daily hours the PAT would have to work to assure that there would be no overflows or lack of water available volume, considering that the working period of the turbomachine would occur with no interruptions in which it was concluded that PAT would have to work 16 hours and 24min per day with a volume of 1.360,1 m^3 per day, corresponding to an annual volume of 496.436,5 m^3 passing through the device. In this particular case, PAT was installed in ideal conditions (Fig. 10), with the complement of a PRV, working with an almost constant flow (Q), head (H) and rotation speed (N) value, being those values: Q=23l/s; H=31m and N=1520r.p.m. The resultant power and energy production, according to the presented data are shown in Table 2.

Table 2 – Annual Energy Production

Q (l/s)	23.01
H (m)	30.99
(-)	0.74
Pu (kW)	5.2
t	16.4
E (kWh/day)	84.8
E (MWh/year)	31.1

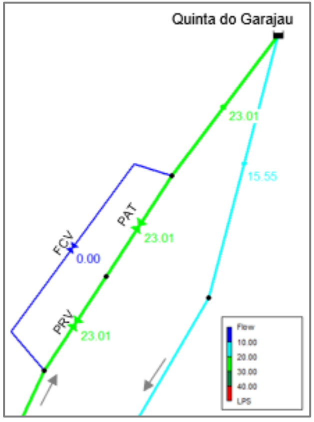

Fig. 10 – EPANET Model – PAT Installation

5. ECONOMICAL ANALYSIS

5.1. Water and Energy Savings

With a average value of buying and selling water of, respectively, 0.2954€/m^3 and 0.8502€/m^3, according to the data provided by Santa Cruz Municipality and assuming that the consumption volumes would not change and the apparent losses would represent 20% of the consumption values, the buying cost was applied to real losses volumes and the average selling price to the apparent losses. Therefore, the resulting savings for Santa Cruz Municipality are the ones presented in Table 3, where 1.204.084 kWh/year of energy representing a value of 118.000 € would be saved every year only from water that wouldn't have to be wasted in Santa Cruz WDS. Both water and energy together would lead to more than 1,5M€ annually saved, resulting mainly from pressure regulation, old pipelines replacement and adjustment to the new population data.

Table 3 – Water and Energy Savings in Santa Cruz WDS

Description	Total Values (TV)	Billed Values (BV)	Unbilled Values (UV)	UV/TV (%)
Existing situation Volume (2018) (m3)	10 123 027	2 558 487	7 564 540	74.70%
Target Volume (PEAASAR II) (m3)	3 009 821	2 558 487	451 334	0
Difference Volume (m3)	7 113 206	-	7 113 206	-
Water Savings (€)	2 536 286	435 045	2 101 241	
Energy Savings (kWh/year)	2 560 754	0	2 560 754	
Energy Savings (€)	250 953.91	0.00	250 953.91	
RSS Proposed Scenario Volume (m3)	6 778 348	2 558 487	4 219 861	62.30%
Difference Volume (m3)	3 344 679	-	3 344 679	-
Water Savings (€)	1 423 065	435 045	988 018	
Energy Savings (kWh/year)	1 204 084	0	1 204 084	
Energy Savings (€)	118 000.28	0.00	118 000.28	

5.2. Benefits of Energy Production

For this energy production economic analysis a 20 year period was considered, corresponding to the lifetime of a PAT. It was considered a 2% of installation cost as annual maintenance costs and 3 different discount rates: 6%, 8% and 10%. Energy benefits main results are presented in Table 4, showing that 7 to 9 years would be necessary to payback the investment in the hydropower technology, considering its installation independent from the remaining changes of Santa Cruz water network.

Environmental benefit resulting from the implementation of this solution should be emphasized, since this investment would lead to more than 18 tons of CO_2 emissions saved every year, due to this new green electrical consumption source.

Table 4 - Economical Analysis Main Results

Initial Investment Cost (€)	15.000,00			
Annual Maintenance Cost (€)	300,00			
Annual revenue (€/year)	3.050,74			
Discount Rate	6%	8%	10%	17,62%
NPV (€)	16.550,8	12.007,2	8.418,6	0.0
B/C (-)	7,5	9,1	11,2	26,3
Payback Period (years)	7	8	9	IRR

It was studied only one location for implementation of an hydroelectrical solution, but all the reservoirs upstream FCV and network's PRV should be studied, to create other sources of green energy produced from existing energy dissipating devices.

5.3. Overall Benefits

In an overall analysis, it would be necessary a duration of 2 years and an estimated investment of 13.800.000,00€ to apply the proposed changes to Santa Cruz network. This estimated investment, in the worst-case scenario, would be recovered after an average of 10 years when considered the cost resulting from water savings previously presented (1.423.065 €/year). The implementation of the present study coordinated with active leakage control measures could reach, in a limit situation, a period of investment return of 5,5 years, corresponding to the 2.536.268 €/year saved, and to more than 7Mm3 water every year. If to the previous limit scenario energy savings would also be considered, a value of 2.787.240€ would be saved every year, reducing the return period to less than 5 years and avoiding more than 500 tones of CO_2 emissions. Being the estimated investment costs to Quinta do Garajau WDS 42.000€, including the implantation of a flow control valve (FCV) to regulate flow entering in the reservoir and all the construction related kind of works, the turbomachine price itself would be the only additional cost to the present cost estimation in order to implement an energy-recovery source. Therefore, the cost of inputing a turbomachine in the hydraulic system, integrated in the present rehabilitation, represents less than 3% of the estimated cost, being recovered in less than a year due to its consequent annual energy saving. If several energy recovering solutions were implemented in the overall system, the return of the total investment period would reduce significantly, since as it was shown the differential cost of solutions' implementation has no relevance in the overall cost but has significant environmental and economic benefits. Finally, in this analysis it was not included the indirect saved costs, due to ruptures that needed to be fixed before the hydraulic system's restructuration, being that value much lower now due pressure regulation.

6. CONCLUSIONS

In the present work it was studied water supply and distribution systems of Santa Cruz, in the Portuguese Madeira Island, where a Pump working as Turbine (PAT) technology was implemented upstream of an existing reservoir, achieving the same performance as the designed Flow Control Valve (FCV) complementing its functions with renewable energy production. This energy study development was only possible after a pressure regulation methodology, since the saved water consequent from this approach would have more economic and environmental benefits than taking advantage of excessive pressures to produce energy. Pressure reduction study was performed in the Hydraulic Systems Company RSS, whose project was developed directly to Santa Cruz Municipality, being a real case-study to be implemented.

In terms of water balance, after the implementation of RSS proposal, there would be 3.344.679m^3 annually saved, representing 1.204.084 kW/h annual energy savings, an estimated economical saving of more than 1.5M€ and more than 530ton/year of CO_2 emissions saved. Also, if active leakage control was performed in a limit situation, it would represent an estimated annual saving value of mor than 2.7M€ and more than 7M m^3 of water saved. Finally, the studied source of renewable energy upstream the reservoir, would have an insignificant cost, when included in in the overall network reformulation, achieving a considerable amount of energy recovered, saving 3 050€/year and 18 ton/year of CO_2 emissions.

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