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TECHNICAL AND ECONOMIC VIABILITY OF THE HYDROPOWER PLANT IMPLEMENTATION ON THE URBAN WATER SUPPLY NETWORK: CASE STUDY - WTP PACAS JOÂO MONLEVADE

Marina Júnia Vilela Caldeira
UEMG/Faenge - Avenida Brasília, nº 1.304 – Bairro Baú – CEP 35.930–314 – João Monlevade/MG
marinajvilela@gmail.com

Rieder de Oliveira Neto
Federal University of Itajubá (UNIFEI) – Mechanical Engineering Institute (IEM), Av. BPS 1303, Itajubá – MG, CEP 37500-903, Brazil
rieder.neto@gmail.com

Christian Jeremi Rodriguez Coronado
Federal University of Itajubá (UNIFEI) – Mechanical Engineering Institute (IEM), Av. BPS 1303, Itajubá – MG, CEP 37500-903, Brazil
christian@unifei.edu.br

Gilmar Rodrigues da Silva
UEMG/Faenge - Avenida Brasília, nº 1.304 – Bairro Baú – CEP 35.930–314 – João Monlevade/MG
gilmar.silva@yahoo.com.br

Geraldo Magela Obolari de Magalhães
UEMG/Faenge - Avenida Brasília, nº 1.304 – Bairro Baú – CEP 35.930–314 – João Monlevade/MG
obolari@gmail.com

Luciano da Silva Delgado
UEMG/Faenge - Avenida Brasília, nº 1.304 – Bairro Baú – CEP 35.930–314 – João Monlevade/MG
luciano766@gmail.com

Jonatas Franco Campos Mata
UEMG/Faenge - Avenida Brasília, nº 1.304 – Bairro Baú – CEP 35.930–314 – João Monlevade/MG
jonatasfmata@yahoo.com.br

Abstract. The present paper deals with the technical and economic analysis of the hydropower generation system implantation. The project case study was the Water Treatment Plant (WTP) Pacas, located in the João Monlevade city (Minas Gerais - Brazil). It was studied a system that replaces the booster, used to increase the water city supply pressure, by gravitational hydraulics forces. This solution proved to be practical, sustainable (because it does not affect the environment in an expressive way) and a good way to save energy, with the booster disuse, which represented a significant saving in the electricity accounts of the water treatment plant in the João Monlevade city.

Keywords: Hidropower; Renewable Energy; Technical Analysis; Economic Analysis.

1. INTRODUCTION

The construction of a hydroelectric system through channels or reservoirs is an effective way of producing electricity from a renewable resource, and since it is a practical option, there is no need for investments in works to capture and store water, adds numerous benefits as a cost reduction, which allows a cheaper and competitive production. Also, it is an energy that is not polluting, and saves on natural resources like oil.

This work proposes the implementation of a SHP (Small Hydropower Company) at the Water Treatment Plant - Pacas, located on João Monlevade city (Minas Gerais - Brazil). The principle of electricity generation is based on the use of

turbines, where it happens the conversion of kinetic energy obtained by the flow of the water channeled into electric energy. Already with the potential of calculated electricity production, as well as the energy losses throughout the plant, it was possible to evaluate the implantation technical feasibility of the hydroelectric plant. An advantageous practice, as it generates savings without affecting the quality of service.

According to Scherer and Pfister (2016), hydroelectric energy brings many benefits. It is renewable because it uses water energy without exhausting it and, at the same time, responds rapidly to changes in loads and meets peak demands, in order to ensure the electrical network reliability. Hydroelectric power also has one of the highest energy conversion efficiencies, equivalent to about 90%.

The investment of companies in renewable energy will without doubt, when assessing the current energy context, a significant recognition. This can boost sales and, by enhancing the brand's reputation, attract new investors to the company. Therefore, investing in sustainability becomes an intelligent strategy for the moment of economy, it is enough to treat the crisis as an opportunity to "reinvent" (Sirol, 2016).

Marchis, et al., (2014) carried out a study for the application of pumps working as turbines in a water distribution network located in Italy. The model analyzed four different scenarios involving turbine pumps aiming identify the most adequate solution in terms of energy production without compromising the service delivery performance of network, having positive and efficient results, where a satisfactory capital return was shown.

Similarly, Sitzenfrei and Von Leon (2014) shows the advantages of small hydropower systems in water distribution system. The procedure for each system design is different, having as a determining factor the available flow in the pressure head, in order to choose the appropriate turbine to ensure efficient operation.

Moura (2010) defines "Energy intensity" as the energy amount consumed per unit of water related to the processes of: pumping, transport, treatment and water distribution. Energy intensity can be defined as the number of kilowatt-hours consumed per cubic meter of water delivered to consumers (kWh/m³).

Ferreira (2015) emphasizes that the use of turbines, or pumps working as turbines, has become an alternative to be implemented in the replacement of pressure reducing valves, in order to take advantage of the energy being wasted. The combination between the existence of a sharp gap and guaranteed flow, becomes ideal for the electricity production.

For Qian, et al., (2016) the application of micro-hydropower can provide promising and economical solutions for the electricity generation, satisfying the increasing energy demands. It is of great importance that its application be expanded to any water system that has excess energy potential, which includes water supply, irrigation, sewage systems, among others.

Modern hydraulic turbines can convert up to 90% of the available energy into electricity, while the efficiency of fossil fuels is only about 50%, or less. The available power is proportional to the pressure head and water discharge product (DURSUN; GOKCOL, 2011).

2. METHODOLOGY (EXPERIMENTAL PROCEDURE)

Currently the water treatment plant in the João Monlevade city consists of 500 m of parallel pipes (ϕ350 and ϕ300) and 1,380 m of single pipe (ϕ350) that interconnects to a Booster (KSB ETANORM, 250 hp and 47.5 m of pumping height). It has 290 L/s of project flow and, the main reservoir, has a minimum water level of 840.8 m and maximum of 844.3 m.
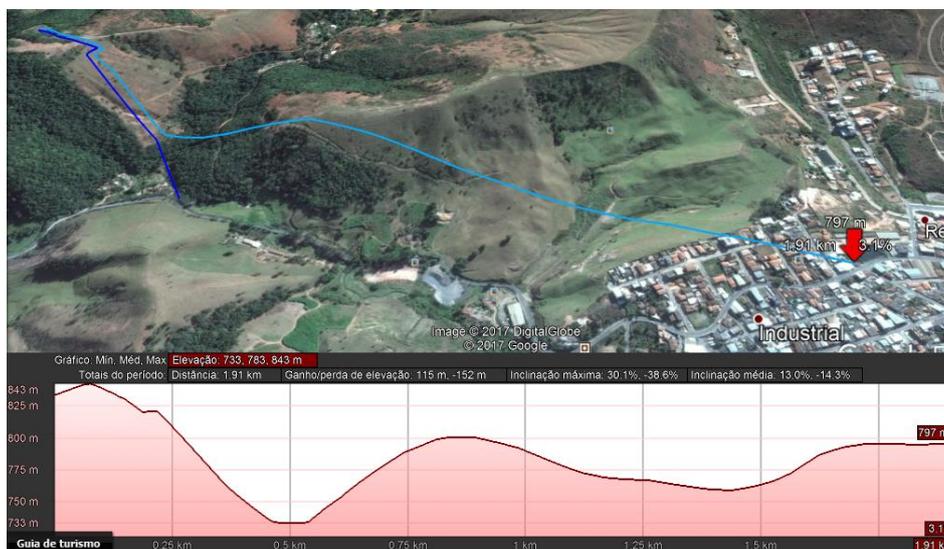

Figure 1 – City water supply system (red mark).

Through a documentary research of the provider of sanitation services (DAE), the data was surveyed, being they: the flow, powers supplied, spending on electricity, topographic dimensions, lift stations and reservoirs location, diameters, stretches lengths, arrival pressure and required pressure post booster. These initial data are necessary to determine the energy performance indicators. After the collect data, the calculations of: flow, pressure, velocity, localized pressure losses, Eq. (1) and distributed pressure losses, Eq. (2), were carried out aiming design the new pipeline, where the turbine was simulated installed.

$$h_f = \frac{k.V^2}{2g} \tag{1}$$

$$h_{dist} = f.\frac{l_{eq}}{d}.\frac{V^2}{2g} \tag{2}$$

The turbine selection was based on the calculation of the specific rotation (n_{qA}), expressed by Eq. (3) and later, through the Cordier Diagram, it was analyzed which would best suit, working with greater efficiency.

$$n_{qA} = \frac{10^3.n.\sqrt{Q}}{(H_L.g)^{\frac{3}{4}}} \tag{3}$$

Payback or "return on investment" was used to calculate the repayment time of the capital invested in the project. Equation 4 shows the calculation of the payback factor.

$$Payback = \frac{Inicial\ investment}{Gain} \tag{4}$$

In any engineering project, the technical feasibility should be verified first and then the economic feasibility. Thus, the investment price will be estimated according to the costs of electro-hydro-mechanical equipment, the pipe line and the operation and maintenance (Lopez and Martinez, 2006). The feasibility assessment was performed using the Eq. (5).

$$CRF = \frac{(1+i)^{np} * i}{(1+i)^{np} - 1} \tag{5}$$

Where:
CRF = Capital Recovery Factor (or annuity);
i = interest rate (%);
np = Period considered for plant operation.

3. RESULTS AND DISCUSSIONS
3.1 New pipeline design

The water supply system of the João Monlevade city has a steep slope as shown in Fig. 2, the highest point is at 845 m and the lowest at 722 m, which makes possible the hydroelectric plant implantation. From this point a new tubing, represented by Fig. 3, was simulated. The dimensioned tubing has a nominal diameter of 400 mm having a length of 500 m, leaving the main reservoir and connecting the ϕ350 pipe, as shown in Fig. 4.
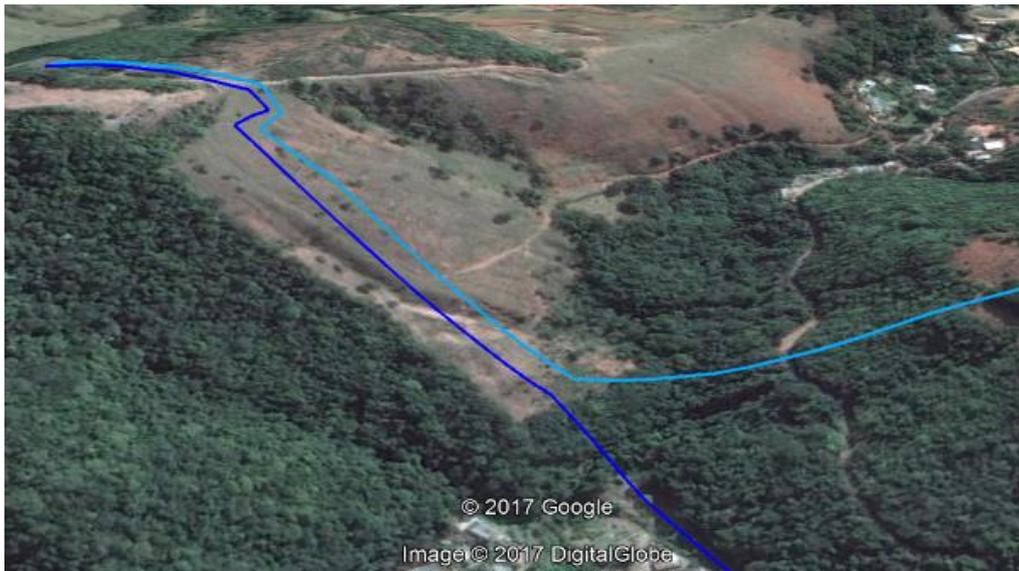
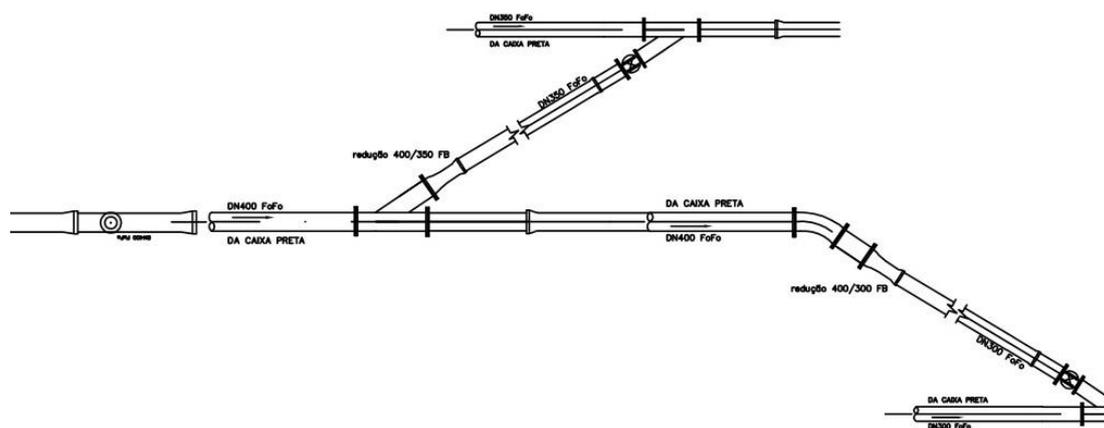Figure 2 – Existing pipes.

Figure 3 – Piping dimensioned.

Figure 4 – Pipeline ϕ400.

3.2 Pressure loss calculations

With the new piping already dimensioned, the new vessel was first calculated, followed by the velocities in the stretches of $\phi 400$, $\phi 350$ and existing piping $\phi 350$ (Table 1).

Table 1 – Inlet Values

$Q_{tube\ 400}$	0.955374 m³/s
$V_{tube\ 400}$	7.606481 m/s
$V_{tube\ 350}$	9.934996 m/s
Q_{total}	1.245374 m³/s
V_{total}	12.95072 m/s

It is known that the Booster arrival pressure is currently equal to zero in the peak hours, from this, with the goal of reaching a sufficient pressure to meet the demand in the peak times the pressure losses calculations, by universal method, that's because the pipeline is of large diameter, ending with the Bernoulli equation. Table 2 shows de parts and accessories used in new pipeline and, Table 3, presents the calculation values found.

Table 2 – Parts and Accessories.

Parts – 400mm	Quantity
DUCTILE CAST IRON PIPE WITH ELASTIC JOINT DN 400 mm	420 m
TE 400X400X400mm FLANGEED	1
REDUCTION 400-350mm FLANGE- BAG	1
CURVE 45º BOLSA-BOLSA DN 400 mm	6
CURVE 22º BOLSA-BOLSA DN 400 mm	2
FLANGEED REGISTRATION DN 400 mm	2
JUNCTION Y DN 400 mm FLANGEED	1
NOZZLE	2
Parts – 350 mm	
JUNCTION Y DN 350 mm FLANGEED	1
MECHANICAL BOARD DN 350 mm	2
CURVE 45º FLANGE-FLANGE DN 350 mm	1
CURVE 90º FLANGE-FLANGE DN 350 mm	1
FLANGEED REGISTRATION DN 400 mm	2
DUCTILE CAST IRON PIPE WITH ELASTIC JOINT DN 350 mm	60 m

Tabela 3 – New pipeline pressure losses.

400 mm		350 mm	
$h_{f\ local}$	25.361 m	$h_{f\ local}$	4.12854 m
L_{eq}	410 m	L_{eq}	60 m
$h_{f\ dist}$	60.4536 m	$h_{f\ dist}$	17.2484
$h_{f\ total}$	85.8147 m	$h_{f\ total}$	21.377 m
$h_{f\ total}$ = 107.191 m			

3.3 Turbine Selection

The turbine selection is based on the design flow (Q) and net pressure drop (H_L) parameters, which are required to obtain the specific rotation (n_{qA}), calculated in Table 4. With specific rotation already calculated, given by Eq (3), the turbine selection was done through the Cordier Diagram (Fig. 5), analyzing which one will serve better, working more efficiently.

Table 4 – Turbine Selection Parameters

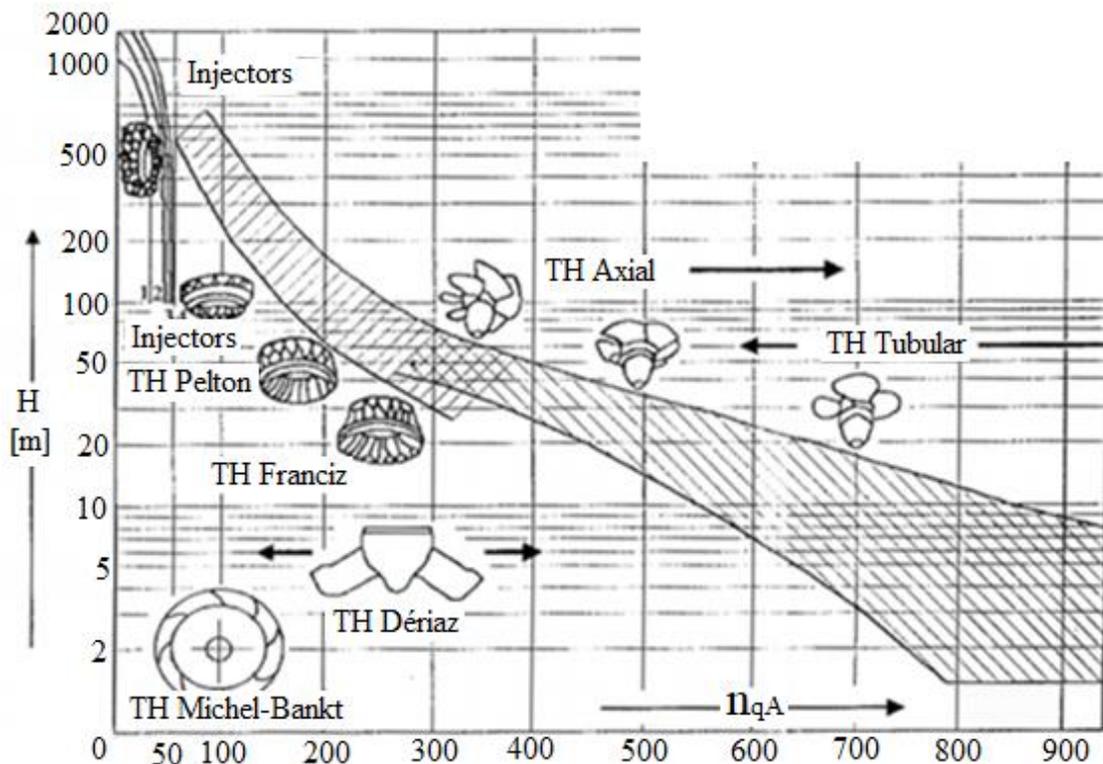| Nominal Fall Height – Hn	Nominal Effective Power – N	Rotation – n$_{qA}$
$H_n = H_b - h_{f\,total}$	$N = \dfrac{1000\,\eta_t\,Q\,H_n}{75}$	$n_{qA} = 1000\,n\,\dfrac{\sqrt{Q}}{\sqrt[4]{(H_L \cdot g)^3}}$
$H_b = 114$ m	$\eta_t = 0{,}8$	$n = 10$
$H_{f\,total} = 111{,}5806$ m	$Q = 0{,}955374$ m^3/s	$H_L \cdot g = 1{,}118.34$ J/kg
$H_n = 2{,}4193$ m	$N = 24.6543$ CV	$n_{qA} = 50.5420$

Figure 5 – Cordier Diagram.

The turbine that best serves the project is the Slow Francis hydraulic turbine, which has a **n$_{qA}$** between 50 and 120.

3.4 Economic viability

Currently, the DAE has an electric energy expenditure of, on average, 368,090.06 Reais per month only in its treatment plant, which in the last 12 months totaled an equivalent cost of 4,417,080.72 Reais. In its Booster located in the República quarter its monthly energy expenditure is on average 40,014.16 Reais, totaling the value of 480,169.93 Reais in the last year. The Fig. 6 show the values of the electricity bills for the last 12 months (treatment plant and booster). Fig. 7 contains the consumption in kWh of Booster at peak hours (HP) and after peak hours (HFP).
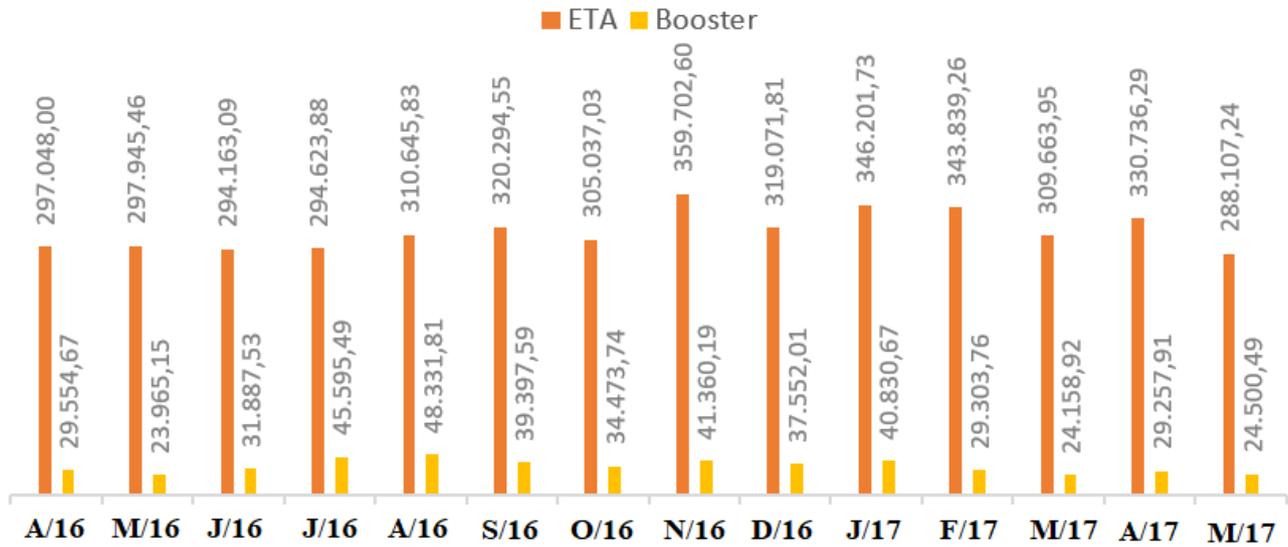
Expenditure on Electricity

■ ETA ■ Booster

Figure 6 – Expenditure on electricity in Reais.

Booster Energy Consuption [kWh]

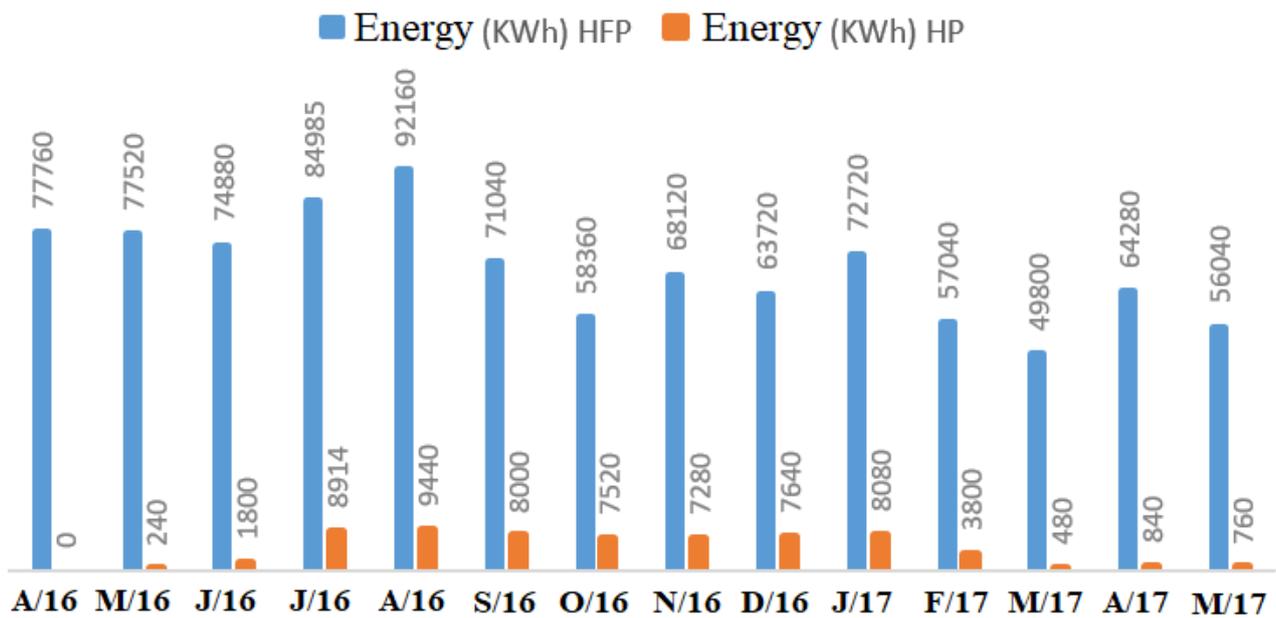**■ Energy (KWh) HFP ■ Energy (KWh) HP**

Figure 7 – Booster consumption in kWh.

In the entrepreneurial point of view, the financial evaluation is the most important parameter, the new pipeline implementation cost, including the workforce, will be about 154,445.50 Reais, the turbine cost is 1,004,387 Reais, totaling the value of 1,158,832.50 Reais. The turbine, operating with efficiency of 80%, gives 615,417.4 kWh, which represents 70% of the ETA consumption, totaling 800,000 kWh.

The Payback or "return of the investment" will be achieved in, about, 10-months period, considering the cost of the generated energy of 0.20 Reais/kWh.

4. CONCLUSION

The design of a small hydroelectric plant for the supply system of the city of João Monlevade proved to be an effective and viable alternative, allowing the company to have a return on invested capital in a short period of time, thus allowing

a cheaper production, without affecting the quality of the service besides being differentiated, for being a self-sufficient company.

5. ACKNOWLEDGEMENTS

6. REFERENCES

DAE, Departamento Municipal de Águas e Esgotos -. *Dados João Monlevade.* [personal message] Message received por: <gilmar.silva@yahoo.com.br>. em: 10 ago. 2016.

Dursun, Bahtiyar; Gokcol, Cihan. The role of hydroelectric power and contribution of small hydropower plants for sustainable development in Turkey. *Renewable Energy: A International Journal,* [s.l.], v. 36, n. 4, p.1227-1235, abr. 2011. Elsevier BV. http://dx.doi.org/10.1016/j.renene.2010.10.001. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0960148110004532>. Acesso em: 10 set. 2016.

Ferreira, Ricardo Manuel Pinheiro. *Aproveitamento de Energia em Sistemas de Abastecimento de Água.* 2015. 145 f. Dissertação (Mestrado) - Curso de Engenharia Civil, Universidade do Minho, Guimarães, 2015. Disponível em: <repositorium.sdum.uminho.pt/handle/1822/40480>. Acesso em: 03 ago. 2016.

Lopes, Rafael Emilio; Martinez, Carlos Barreira. *O uso de bombas funcionando como turbinas para sistemas de recalque de água.* 2006. Disponível em: <http://www.lenhs.ct.ufpb.br/html/downloads/serea/6serea/TRABALHOS/trabalhoO.pdf>. Acesso em: 01 set. 2016.

Marchis, M. de et al. Energy recovery in water distribution networks. Implementation of pumps as turbine in a dynamic numerical model*. Procedia Engineering,* Italy, v. 70, p.439-448, fev. 2014. Disponível em: <www.sciencedirect.com>. Acesso em: 09 set. 2016.

Moura, Gustavo Nikolaus Pinto de. *A relação entre água e energia: gestão energética nos sistemas de abastecimento de água das companhias de saneamento básico do brasil.* 2010. 222 f. Dissertação (Mestrado) - Curso de Ciências em Planejamento Energético, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2010. Disponível em: <www.ppe.ufrj.br/ppe/production/tesis/gustavo_nikolaus.pdf>. Acesso em: 04 ago. 2016.

Qian, Zhongdong et al. Performance evaluation of an axial-flow pump with adjustable guide vanes in turbine mode*. Renewable Energy: A International Journal,* [s.l], v. 99, p.1146-1152, 13 ago. 2016. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0960148116307212>. Acesso em: 06 set. 2016.

Scherer, Laura; Pfister, Stephan. Global water footprint assessment of hydropower. *Renewable Energy: A International Journal,* [s.l], v. 99, p.711-720, 27 jul. 2016. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0960148116306176>. Acesso em: 10 set. 2016.

Sirol, Rodolfo Nardez. *Sustentabilidade em tempos de crise.* 2016. Disponível em: <http://www.diariodoaco.com.br/ler_noticia.php?id=615&t=sustentabilidade-em-tempos-de-crise>. Acesso em: 5 set. 2016.

Sitzenfrei, R.; Von Leon, J.; Rauch, W. Design and Optimization of Small Hydropower Systems in Water Distribution Networks Based on 10-Years Simulation with Epanet2. *Procedia Engineering,* Austria, v. 89, p.533-539, 2014. Disponível em: <http://www.sciencedirect.com/science/article/pii/S1877705814025909>. Acesso em: 12 set. 2016.

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