Article

Turbine selection for hydraulic energy recovery in the Yuribia dam aqueduct

Selección de turbina para la recuperación de energía hidráulica en el acueducto de la presa Yuribia

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CONAHCYT classification:

Area: Engineering
Field: Engineering
Discipline: Mechanical Engineering
Subdiscipline: Hydraulics

https://doi.org/10.35429/EJB.2024.20.11.1.7

History of the article:
Received: January 10, 2024
Accepted: June 30, 2024

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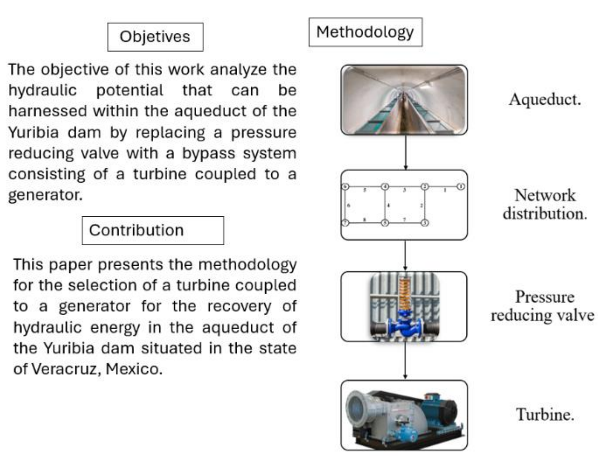
Abstract

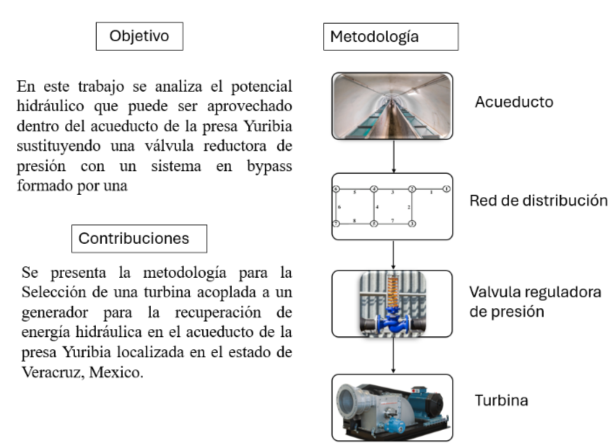
The recuperation of hydraulic energy in aqueducts is based on utilizing the energy dissipated by hydraulic devices aimed at regulating the flow or pressure within the system, in addition to fulfilling their primary purpose. This paper presents the methodology for the selection of a turbine coupled to a generator for the recovery of hydraulic energy in the aqueduct of the Yuribia dam situated in the state of Veracruz, Mexico. The results of system modeling, simulation, and calculation of the generated energy are presented.



Energy recovery, Turbine, Aqueduct

Resumen

La recuperación de energía hidráulica en los acueductos se basa en aprovechar la energía disipada por dispositivos hidráulicos buscando controlar el caudal o presión en el sistema, además de cumplir con la tarea principal por lo que fueron diseñados, en este este trabajo se presenta la metodología para la Selección de una turbina acoplada a un generador para la recuperación de energía hidráulica en el acueducto de la presa Yuribia localizada en el estado de Veracruz, Mexico. Se presentan los resultados del modelado del sistema, simulaciones y cálculos de la energía generada.



Recuperación de energía, Turbina, Acueducto

Citación: Quintanilla-Herrera, Jesús Antonio, Garrido-Meléndez, Javier, Espinosa-Arenal, Francisco and Rodríguez-García, Ernesto Raúl. Turbine selection for hydraulic energy recovery in the Yuribia dam aqueduct. ECORFAN Journal-Bolivia. 2024. 11-20:1-7.

Introduction

Hydropower is the most mature source of renewable energy, being one of the most efficient and reliable (YoosefDoost & Lubitz, 2020) and (Thyer & White, 2022). Hydroelectric plants show a higher generation efficiency than fossil fuel power plants, but they also affect the environment with the waste and gas emissions they generate. When comparing both sources, hydroelectric power is able to transform mechanical energy into electrical power with an efficiency of 90%, while in a thermoelectric plant it is around 60% (Thyer & White, 2022).

Thyler and White (2022) describe hydropower recovery as "hydropower installed in existing systems or structures where water is already being diverted from a natural watercourse". The idea is to harness the energy dissipated by hydraulic devices in different scenarios seeking to control the flow or pressure in the system, in addition to fulfilling the main task for which they were designed, e.g. pressure reducing valves (Loots et all., 2015).

Energy recovery consists of harnessing the potential and kinetic energy of water on a smaller scale than in a hydroelectric power plant, only taking advantage of the infrastructure of various types of distribution networks (Sari et all., 2018):

- Irrigation systems.
- Bridges.
- Flow measurement stations.
- Water distribution systems.
- Metering weirs.
- Wastewater treatment plants and industrial streams.

The use of energy recovery has the following advantages (The pros and cons of hydropower, 2020):

- They present the minimum affectation on ecosystems.
- They are more economical compared to hydropower plants.
- They do not disturb habitats.

This work analyses the hydraulic potential that can be harnessed within the aqueduct of the Yuribia dam by replacing a pressure reducing valve with a by-pass system consisting of a turbine coupled to a generator. The selection process of the turbine and the calculation of the electrical power generated are presented in this work.

The order in which the work is developed is as follows, in section 2 an analysis is carried out in the study area to model the hydraulic network of the aqueduct, as well as the flow reducing valve, finally, the selection of the hydraulic turbine is carried out based on the energy recovered in the system, in section 3 the results of the modelling, simulations and calculations of the energy generated are shown, finally the conclusions are presented.

Methodology

The block diagram in Figure 1 shows the steps to be followed for the selection of the turbine according to the hydraulic potential present in the hydraulic network, each of the stages is described below:

1. Collection of data from the aqueduct network to be analysed.

The data of the aqueduct under study is collected specifying its characteristics: physical and hydraulic characteristics of the potable water transport system from the Yuribia dam to the city of Coatzacoalcos.

Box 1

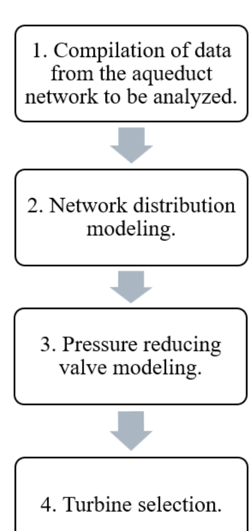


Figure 1
Block diagram of the development of the work]

Source *[Own authorship]*

ISSN-On line: 2410-4191.
RENIECYT-CONAHCYT: 1702902

Quintanilla-Herrera, Jesús Antonio, Garrido-Meléndez, Javier, Espinosa-Arenal, Francisco and Rodríguez-García, Ernesto Raúl. Turbine selection for hydraulic energy recovery in the Yuribia dam aqueduct. ECORFAN Journal-Bolivia. 2024. 11-20:1-7.
https://doi.org/10.35429/EJB.2024.20.11.1.7

1. Distribution network modelling

The next stage is the use of the US Environmental Protection Agency's Epanet software (2023) for network modelling. The Epanet software was developed as a tool for understanding fluid mechanics within distribution systems.

2. Modelling of the pressure regulator valve

With the help of the Epanet software, the analysis and modelling of a pressure reducing valve located within the aqueduct network of the Yuribia dam, which is used to regulate the water pressure reaching a group of elevated tanks responsible for the distribution of drinking water to the city of Coatzacoalcos, is carried out.

3. Turbine selection

With the modelling of the network and the valve, the hydraulic energy losses in the system are calculated, which can be used and recovered by means of a turbine. These losses will be used to determine which turbine model fits the conditions of the network.

Next, the data collection of the hydraulic network, shown in section 1, is carried out.

Collection of data from the aqueduct network to be analysed

The work carried out takes the south of the state of Veracruz as the study area, specifically the city of Coatzacoalcos with coordinates 18°09' north latitude and 94°26' east longitude, as well as the municipality of Tatahuicapan de Juárez (Puerto Coatzacoalcos, n.d.). The Yuribia aqueduct is located in the municipality of Tatahuicapan and is responsible for supplying drinking water to the city of Coatzacoalcos, coming from the Texizapan and Ocotal rivers. The data of the aqueduct of the Yuribia dam are shown in table 1.

Box 2

Driving system	By gravity
Flow rate	1.5 m^3/s.
Diameter of the pipeline	1.22 m ó 48”
Pipeline length	60 Km.
Maximum daily flow	1.2 m^3/s on average.

Table 1
Aqueduct data
Source: Pulido Javier

Water from the Yuribia aqueduct is transported through steel pipelines with a diameter of 48", having a length of 60 km from a water treatment plant with an initial height of 175m above sea level (asl), to storage tanks located in various parts of the city of Coatzacoalcos, the tank used for the analysis is located in the colony of Palma Sola with an approximate height of 29m asl.

The Yuribia aqueduct has a pressure up to the pressure breaker point of 15 kg/cm^2 and after that it decreases to 7 kg/cm^2, losing half of the energy daily.

Modelling of the distribution network

Epanet software was used to model the network, and the modelling used the following components (Lewis et al., 2017):

Connections or nodes: these are points where the pipes join which are represented with lines.

Reservoirs: External sources of energy are represented, thus representing lakes, rivers, aquifers and connections to other systems.

Tanks: Within the programme these are modelled as nodes with storage capacity.

Pipelines: A pipeline is the medium through which water circulates, it is responsible for transporting water.

Minor losses: These can be interpreted as a consequence of increased turbulence due to changes in direction, bends, fittings, etc.

Valves: Valves limit pressure and flow at specific points in the network.

Figure 3 shows the use of the aqueduct network components modelled with the data shown in the data collection section, starting on the left side of the diagram shows the tank located in the highest part of the diagram, pipes represented by the lines, nodes being the point of interconnection of the pipes and the tank located on the right being the final part of the system, the heights or elevations of these last two were provided thanks to the Google Earth programme.

ISSN-On line: 2410-4191.
RENIECYT-CONAHCYT: 1702902

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For the modelling of the network, the Google Earth programme was used to trace the route of the aqueduct, considering the elevations and changes in height that occur during the trajectory from the Yuribia dam to the location of the elevated tank, figure 2.

Box 3

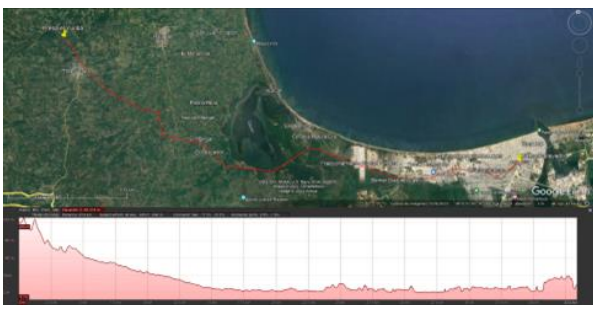


Figure 2
Water mains trajectory
Source: Google Earth

The aqueduct model was made with approximations of minor losses obtained from a first model of the network, the system already made was transferred to pipes modelled by sections, distributing the value of the losses proportionally, being connected with nodes by adding their magnitudes of elevation in each one of them, figure 3.

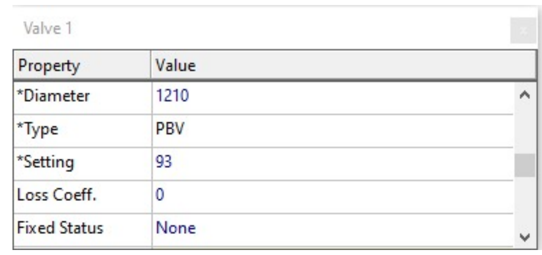
Modelling of the pressure regulating valve

The pressure regulating valve (pressure breaker) decreases the pressure inside the aqueduct. To model it in the Epanet software, the load break valve is used, using the parameters shown in figure 4.

Box 4

Figure 3
Final network modeling
Source: Own elaboration

Box 5



Valve 1

Property	Value
*Diameter	1210
*Type	PBV
*Setting	93
Loss Coeff.	0
Fixed Status	None

Figure 4
Valve modelling parameters
Source [Epanet]

The valve modlling data are specified below:

Diameter: This is the same as the diameter of the aqueduct pipe in millimetres.

Type: The load break valve was selected because it performs the same function in the program as the pressure breaker located in the aqueduct.

Fixed state: When the device is in operation, the "none" state is selected.

Loss coefficient: It is taken into account within the losses that the valve makes, presented in the setpoint section.

To obtain the setpoint parameter, a series of simulations were carried out in which, by means of the loss coefficients in the pipes, the pressure before the valve was approximated to a pressure of 16.3 kg/cm^2. Assigning to the valve setpoint a value with which an outlet pressure of 7.0 kg/cm^2 is obtained, as shown in figure 5.

Box 6

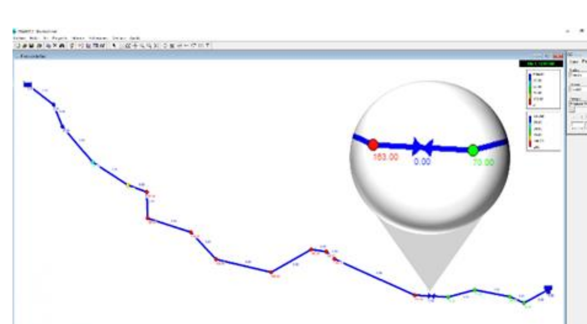


Figure 5
Static network pressure
Source: Own elaboration

Kinetically the pressure values before and after the load break valve which simulates the pressure breaker are shown in figure 6. It is important to mention that the units of pressure used by the software are water column metres.

ISSN-On line: 2410-4191.
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Box 7

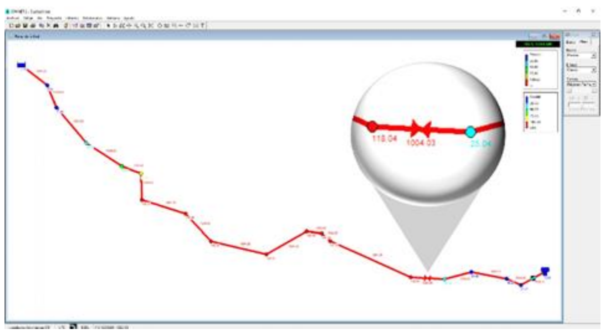

Figure 6
Pressure in the network in kinetic form
Source: Own elaboration

During the different months of the year, the value of the flow rate varies in low water seasons, so taking this into account, different set point values were proposed for the valve, obtaining different values for the flow rate.

4. Selection of the turbine.

Hydraulic turbines work under different operating ranges, these are represented by the useful head and the flow rate, as shown in figure 7. For the selection of the turbine, the energy dissipated by the load break valve is considered, considered as the head that can be recovered, the next operating parameter is the flow rate, whose magnitude depends on the setpoint value of the valve (losses, losses, etc.).

Box 8

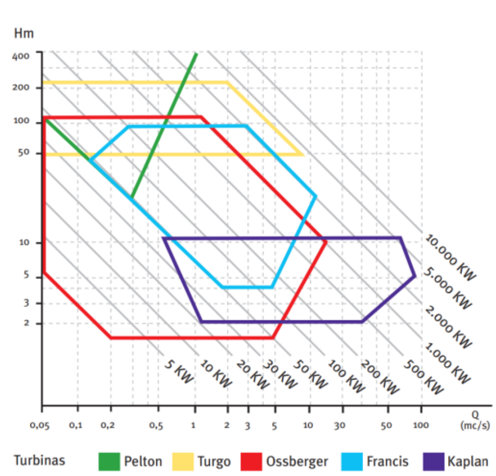

Figure 7
Operating range of turbines
Source: Castro Adriana

Results

Table 2 shows the data of the energy losses in the network, which were produced by making variations in the set point (losses) of the load break valve, showing the flow-pressure relationship in the system, obtaining a range of the same, foreseeing the different scenarios that may occur in the network at different times of the year.

Box 9

Table 2
Flow-loss ratio

Flow rate (m^3/s)	Loss (m)
1.142	78
1.097	83
1.051	88
1.004	93
0.953	98
0.901	103
0.845	108
0.785	113
0.651	123

Source: Own elaboration

Given the magnitudes presented in table 2 in the flow-head ratio, a turbine capable of covering the operating range is selected. With figure 7 presenting the operating capacities, it was observed that the Ossberger turbine is suitable to replace the pressure regulating valve.

The electrical energy that can be recovered by means of the turbine is calculated by equation 1.

$$P_T = \rho g Q H n_t \quad [1]$$

Where:

ρ: Water density (1000 kg/m^3)

g: Gravity acceleration (9.81 m/s^2)

Q: Flow rate (table 2)

H: Height (table 2)

n_t: Turbine efficiency (0.86 ó 0.85 depending on the value of the flow rate).

Applying equation 1 with the different values of flow and head, table 3 gives an approximation of the electrical energy that can be recovered by applying a turbine in the aqueduct network.

ISSN-On line: 2410-4191.
RENIECYT-CONAHCYT: 1702902

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Box 10

Table 3
Electrical power generated

Flow rate (m^3/s)	Loss (m)	Turbine power (kW).
1.142	78	751.4985
1.097	83	768.1608
1.051	88	780.2842
1.004	93	787.7422
0.953	98	787.9278
0.901	103	782.9417
0.845	108	760.9715
0.785	113	739.6666
0.651	123	667.6887

Source: Own elaboration

Conclusions

The modelling of the network was carried out to analyse the water behaviour in the load break valve and to obtain the energy losses in the system, obtaining the hydraulic potential that can be used by the turbine.

As mentioned above, there is a low water season, which affects the supply of drinking water to the city, which is taken into account in the calculation of the minimum amount of electricity generated at this time of year.

By means of the analyses carried out, it was determined that the turbine with the capacity to replace the load break valve is the Ossberger turbine, presenting an energy recovery with a maximum electrical power of 787.927 kW and a minimum of 667.688 kW.

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that might have appeared to influence the article reported in this paper.

Authors' contribution

Each of the authors contributed to and contributed to this paper.

Garrido Javier, *Quintanilla Jesús* and *Rodríguez Ernesto* carried out the first two sections of the methodology, compiling data from reliable sources on the locations of the components and carrying out a study of the area, taking into account their participation in the modelling of the network.

Espinoza Francisco and *Quintanilla Jesús* carried out the modelling of the pressure reducing valve and finally made the selection of the turbine adapted to the characteristics of the network, as well as fulfilling the function of the valve.

Availability of data and materials

The data and programs used in this article are available on request.

Funding

This article did not receive any funding.

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RENIECYT-CONAHCYT: 1702902