OPTIMIZATION OF WATER DISTRIBUTION ENERGY COSTS WITH SMART DIGITAL TWINS: A CASE STUDY IN UTILITIES.

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Highlights:

- Relocation of pumping operation moments to times when the energy cost is shown to be more favorable.
- Reprogramming frequencies and operation mode of the motors of the electro pump sets for the moments of greater energy efficiency.
- Better operational safety for the Operational Control Center (OCC), in the control of pressures of the distribution network and consequent reduction of the volumes of treated water losses.
- Reduction of carbon emissions, motivated by the efficiency in programming the frequencies of lifting stations.

Keywords: Energy Efficiency; Artificial Intelligence; Water Supply System.

INTRODUCTION

Understanding the water-energy nexus can directly contribute to achieving the universalization of sanitation services. Generally, electricity consumption for water supply averages around 7% of global consumption, and from a common perspective, production and distribution costs for water amount to approximately 80% due to electricity consumption (TRIPATHI, 2007). The use of systems equipped with digital tools employing artificial intelligence for behavior learning and prediction is a global trend in the water sector. However, the application of this approach in Brazil is still in its infancy. This article presents the results of applying an artificial intelligence platform capable of optimizing consumption, the percentage of peak-hour consumption, and electricity costs in a section of a water supply system in the municipality of Curitiba and its metropolitan area, equipped with an operational monitoring and control system. The use of the platform resulted in a decrease in motor activations, as well as operation within the most suitable frequency range in the pump stations equipped with inverters. By using computational algorithms, historical and real-time data were processed to obtain, among other things, future water supply predictions. Thus, the platform established operational orders with which the pump stations were operated, generating energy efficiency. The study suggests that the artificial intelligence platform can be replicated in other sections of the water supply system and highlights the importance of developing protocols and interfaces for process automation.

METHODOLOGY

The artificial intelligence platform was used to optimize the operation of the water transfer pumping stations between the reservoirs of the Passaúna Water Supply System, north section, in the city of Curitiba and the metropolitan region. The evaluated section is composed of six reservoirs in cascade flow, with a storage capacity of 42,470 m³ and five pumping stations with an installed power of around 5,000 kW, of which four pumping stations have a frequency inverter and only one does not. This system serves a population of 560 thousand inhabitants, about 28% of the total population of Curitiba and neighboring regions. The artificial intelligence platform integrates different databases into a single dashboard (intuitive and customized control panel), replicating data from the company's SCADA/iFix system and adding, among others: (i) the functionality of predicting energy, flow, and water consumption at different points in the network in real time through machine learning techniques structured by Artificial Neural Networks (ANNs); with the Extreme Gradient Boosting XGBoost, and also the GMDH (Group Method of Data Handling), but also statistical models such as ARIMA; (ii) the hydraulic model of the network calibrated with real data in order to simulate its real behavior (digital twin); (iii) algorithms composed of Artificial Neural Networks (ANNs) for optimization by the gradient descent method, specifically SLSQP (Sequential Least Squares Programming) which, based on the price of electricity and its availability, minimize costs and optimize the operating period of the pumps, as well as the frequency of the variable speed drives, reduce the number of starts of each pump, ensuring water demand and respecting the operating limits of the reservoirs. (iv) visualization of the real and future levels of the reservoirs, as well as all the rules of operation of pumps and valves; (v) calculation, in real time, of metric (KPIs) of the cost per cubic meter (R$/m³), the cost per kilowatt-hour (R$/kWh) and the ratio between energy consumed and water distributed (kWh/m³), for all sections of the supply system where it was applied and for each motor pump set inserted in it. In this study, the platform was used to evaluate two different conditions: (a) Ex-ante evaluation, with historical data values, in the implementation phase, when the hydraulic map and water balance based on field analyses, SCADA system data, real-time operation data and engineering calculations were developed; (b) Ex-post evaluation, with measured values, considering the electricity savings (in kWh), the reduction in the percentage of electricity consumption at peak hours (in %) and the costs actually spent (in R$), based on consolidated invoices from the electricity concessionaire and with reference to data from the same months of the previous year (2021). The digital artificial intelligence platform is composed of three major modules: (a) Simulation: creates a virtual simulation module (intelligent digital twins), which allows the analysis of different operating parameters. (b) Forecasting: based on historical operation and meteorological data and based on machine learning techniques, it forecasts water and energy consumption, as well as the behavior of complex systems. (c) Optimization: this module makes it possible to find the best control parameters for each phase of the process, seeking to maximize its efficiency and reduce process costs. To do so, they extracted historical data from SCADA to feed the artificial intelligence platform over a period of 180 days. This data was processed and modeled. Subsequently, the platform was prepared to read the real-time data from SCADA, make predictions and self-adjust according to the operation carried out by the company. Comparisons were made for the parameters measured between May and November of 2021 (without using the artificial intelligence platform) and in May 2022 (using the platform).

RESULTS AND CONCLUSIONS

The application of the artificial intelligence platform allowed the optimized operation of the section of the water supply system under investigation, enabling the reduction of consumption, the percentage of consumption at peak hours and electricity costs. The platform promoted the reduction of the number of motor drives, as well as the operation within the most appropriate frequency range in elevators equipped with a frequency inverter. With the use of computer algorithms, historical and real-time data were processed to have future forecasts of the water supply. The dynamic algorithms form the platform's artificial intelligence, which make it possible to predict, among others, the daily water consumption and the level of the reservoirs, as illustrated in Figure 1 (a) and (b) of the Dashboard screen for WTP Passaúna.

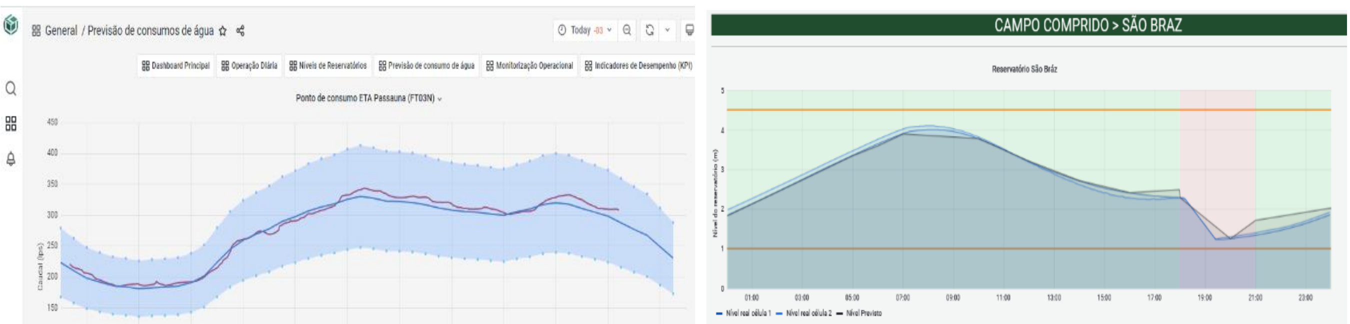

Figure 1: (a) Actual and predicted water flow curves. (b) Reservoir level, actual data and prediction.

(a) The blue line represents the data predicted daily by the algorithms and based on the system's historical data, while the red line represents the data received in real-time. As you can see, both lines are very close together demonstrating the accuracy of the models. Thus, the platform provides operational orders as a return for the analyses it performs, calculated on an hourly basis. (b) The predicted and realized level behavior in the operating reservoir. The black line is the predicted level, and the blue line is the levels realized for the two chambers of the reservoir. The behavior of the level is due to the pumping orders determined by the artificial intelligence platform and executed by the operator at the upstream pumping station. Finally, the optimization stage includes the generation of operational orders for the activation of the motor pumps, the optimal frequency of the variable speed drives (Hz) and compliance with the minimum and maximum operating levels of the reservoirs. In the Figure below, the dashboard screen for Operation Orders.

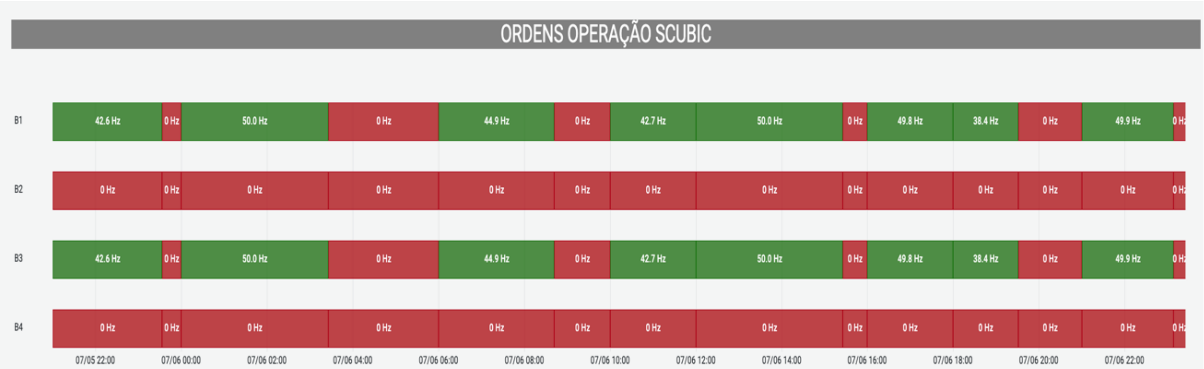

Figure 2: Issuance of operation orders: on/off and frequency (Hz) of the motor pumps.

In this way, the platform established operational orders with which the lifts were operated, generating energy efficiency, thus achieving a reduction in the average specific consumption of electricity of 20.61% in kWh/m³ (Table 1), as well as a decrease in the percentage of electricity consumption at peak hours of about 28% (Table 1). In addition to the specific objective proposed by the artificial intelligence platform, direct benefits of its ability to save resources that have been successfully achieved stand out: (i) reallocation of pumping operation times to times when the energy cost is more favorable; (ii) reprogramming of frequencies and mode of operation of the motors of the electric pump sets for the moments of greater energy efficiency with consequent reduction of energy consumption for the same pumping work; (iii) better operational safety, in the control of pressures in the distribution network and reduction of the volumes of real losses of treated water; (iv) reduction of labor costs with the automation of on-and-off operations, pumping and operational planning of supply; (v) reduction of carbon emissions.

Table 1: Electricity consumption and monthly water production data without and with the use of the artificial intelligence platform.

Period	**Electric power consumption**(kWh)			**Water production**	
May/2022 to October/2022	Peak	Off-peak	% P/OP	Volume (m³)	Specific consumption (kWh/m³)
TOTAL	**406.577**	**4.401.174**	**8,46%**	**13.538.031**	**0,3551**
Period	**Electric power consumption** (kWh)			**Water production**	
May/2023 to October/2023	Peak	Off-peak	% P/OP	Volume (m³)	Specific consumption (kWh/m³)
TOTAL	**291.789**	**4.498.758**	**6,09%**	**16.994.467**	**0,2819**

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