Energy Recovery in Irrigation Networks Using Pump as Turbine (PAT)

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***Abstract*—** Energy recovery in irrigation networks using pumps as turbines (PAT) is a promising approach to address the challenges of water scarcity and energy efficiency in agriculture. This article provides a comprehensive overview of the concept, design considerations, operational characteristics, and integration of PAT systems in irrigation networks. By utilizing pumps in reverse as turbines, the excess pressure in the network is converted into mechanical energy, which is then transformed into electricity. The article discusses the potential benefits of PAT systems, including optimized water management, reduced energy waste, and enhanced the sustainability. It explores the economic feasibility, environmental advantages, and potential challenges associated with implementing PAT systems in diverse agricultural contexts. Furthermore, the article highlights the resilience and adaptability of PAT systems, offering decentralized and reliable energy generation solutions in areas with unreliable power supply. Through knowledge dissemination and insights, this article aims to inspire further research, development, and practical applications of energy recovery using pumps as turbines in irrigation networks, ultimately fostering a more sustainable and efficient future for agricultural practices.

***Keywords*—**PAT, Irrigation systems, Energy recovery, Experimental set-up, Hydraulic simulator.

I. Introduction

It is impossible to overestimate the significance of sustainable energy options in the modern world. Investigating novel approaches to capture renewable energy sources becomes crucial as we work to lessen our reliance on fossil fuels and lessen the consequences of climate change. One such exciting strategy is the energy recovery in irrigation networks utilizing pumps as turbines (PAT), which is the focus of this paper.

Pumps have historically been used to move water from a source to fields for agricultural irrigation. However, once the extra pressure is released by pressure relief valves or other mechanisms, this process frequently results in a large quantity of lost energy. In recent years, the idea of using pumps as turbines to collect this energy has drawn a lot of interest. PATs can be utilized in standalone systems or in hybrid power systems that combine them with other renewable energy sources as solar, wind, or diesel generators. Overall, the usage of PATs can offer an affordable and long-lasting solution for rural electrification, as well as help the world's shift to renewable energy [1-2].

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By harnessing the untapped potential of pumps as turbines, we can effectively convert the excess pressure into valuable electricity. This approach offers a dual benefit: it not only optimizes the energy usage in irrigation networks but also provides an additional renewable energy source that can be integrated into the grid or used for on-site power generation. One of the most important sources for micro-hydropower generation with PAT is the irrigation system. Various upgrades have been made to the overall irrigation system. One of those methods involves switching the flow of water from an open channel to a pressurized conduit. As a result, energy usage has increased dramatically.

Reference [3] shows, the improved irrigation system uses more than twice as much energy as the older system did. Using PAT is a successful strategy to disperse the inescapable surplus pressure caused by elevation difference and demand variation on the irrigation network as well as to recover the extra energy as a result of the modernization of irrigation. Actually, the variance in energy required to run a pump as a turbine is decreased by the variation in water requirements based on the season and the type of crops planted.

II. Methodology

The current study demonstrates the methods created utilizing an experimental irrigation network model that was duplicated in the Instituto Superior Técnico's hydraulic lab at the University of Lisbon. Using the program EPANET, simulate hydraulic properties through modeling.

A. Experimental Analysis

The Instituto Superior Técnico's hydraulic lab is where the experimental analysis is held. The irrigation network setup with Pump as turbine is shown below in the Figure.1

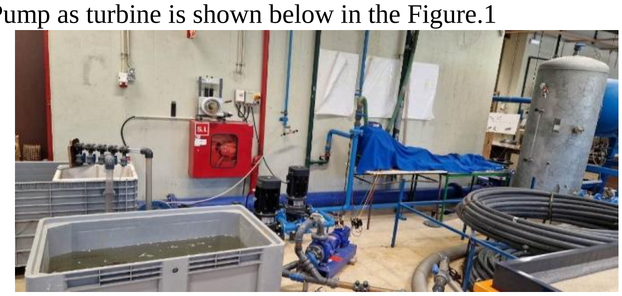
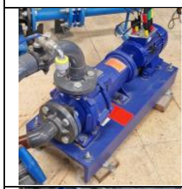


Fig. 1 Irrigation network setup in Hydraulic lab of IST, university of Lisbon.

Major hydroelectric components of the network system and their specification is illustrated in the Table.1

TABLE I:
MAJOR HYDROELECTRIC COMPONENTS AND SPECIFICATION IN THE NETWORK

Components	Specification
	Two Grundfos pumps, with a Power of 4KW are deployed in the irrigation network with a parallel connection.
	Two KSB product of Eta-32-125 model, Pump as Turbine (PAT) are installed in the network.
	The air tank is in charge of maintaining the network's constant pressure about 3 bar. It has a 1m3 capacity and reaches a maximum pressure of 4bar.
	A metal Pipe line is the primary section that delivers water to the air vessel tank from the reservoir. Two different length HDPE pipes with a length of 100M and 1.4M follow the metal pipe line connection. The flow of water in the PAT section inflow and outflow by the hydrants is through the PVC pipe lines. In between the flow is control under a number of FCV.
	There are five hydrants and one separate outflow line. The emitting of water through each hydrant is controlled by the valve independently one to the other.

For the experimental set-up, one of the pumps and one of the PAT's has deployed. Tests performed firstly with all hydrants open

To obtain the maximum flow then the generator was connected to the capacitor bank using the switch to begin the excitation process. The electric load was applied, the generator was stimulated, and the electrical output characteristics were recorded. The result from the network will be discussed in Results and Discussion session.

B. Hydraulic Simulation using EPANET

The software program EPANET is used to simulate water distribution networks all over the world. It was created as a tool for analyzing how water elements flow through distribution networks and what happens to them after that. However, it may be used to a wide range of distribution systems analysis [4-7]. The PAT pilot station model creation by EPANET followed by assigning the required parameters. In the Fig. 2 the model of the PAT pilot station is shown.

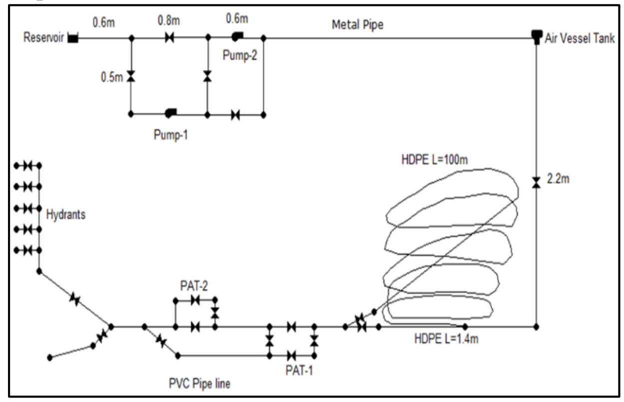


Fig. 2 Scheme of the experimental set-up in EPANET

A single-point pump curve is defined by a single head-flow combination that represents a pump's desired operating point. For the Grundfos Pump Model: 96087179P203230004 the curve is defined as shown in Fig.3.

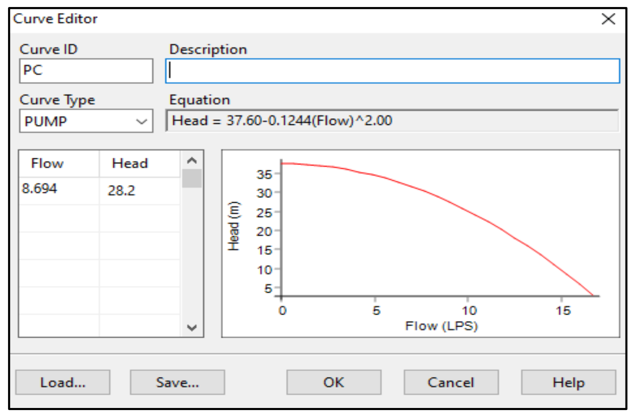


Fig. 3 Pump curve

In EPANET it is not Possible to define Pump as turbine directly. But the PAT is inserted as a Valve but its type must be General Purpose valve. Beside the valve type for the PAT type installed the characteristic curve should be defined and linked to the PAT which is defined by the General-purpose valve. The Fig.4 below shows the characteristic curve for Eta-32-125 PAT.

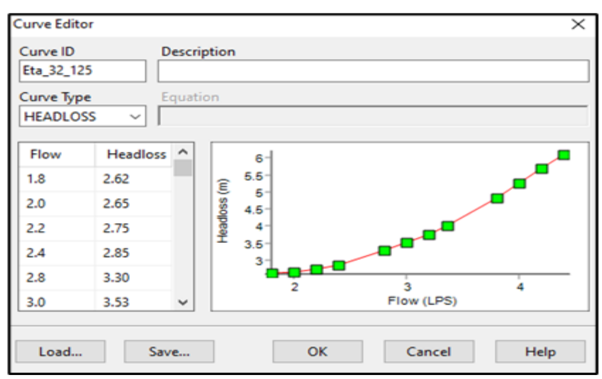


Fig. 4 Characteristics Head loss curve for Eta_32_125

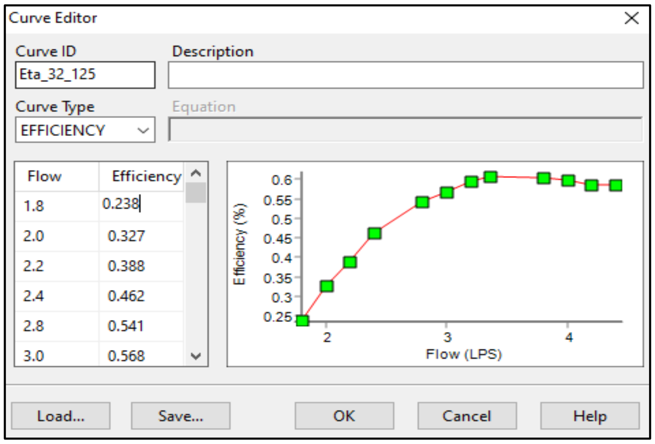


Fig. 5 Characteristics Efficiency curve for Eta_32_125

III. Results and Discussion

A. Experimental Results

The flow in the simulated experimental system is maintained by opening all the hydrants. The head and efficiency of the PAT is determined on the base of the flow. According to the Manufactures curve the best efficiency curve is described in the Table 2.

TABLE II

BEST EFFICIENCY POINT BY MANUFACTURER'S CURVE FOR ETA_32_125

Q [l/s]	H_0 [m]	P_H [kW]	P_E [kW]	η [-]	N [rpm]	η_s [m,kW]
3.36	4.00	0.13	0.08	0.607	1020	51

The maximum flow recorded during the experiment is 4.65 l/s. On the basis of the flow the head and efficiency of the PAT can be obtained from Fig. 4 & 5. And further energy recovery calculation can be made.

From experimental data as the flow increases the rotational speed also increases. Here the graph below in Fig.6 is shown.

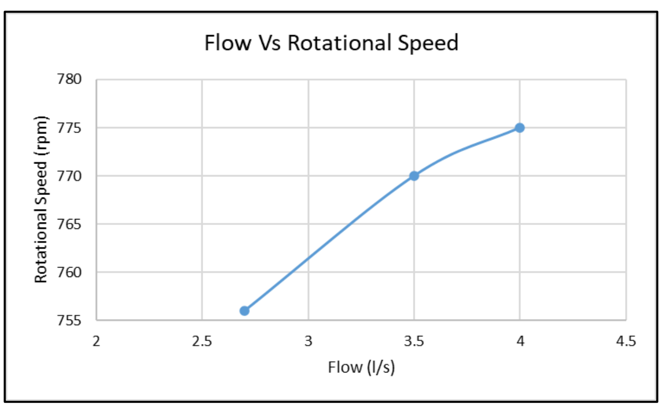


Fig. 6 Characteristics Efficiency curve for Eta_32_125

In the same manner as the load or the consumption of the energy increases the rotational speed also increases in order to satisfy the required demand by the load. In the experimental tests the load considered is a simulation of the electricity demand in house appliances, Industries so on.

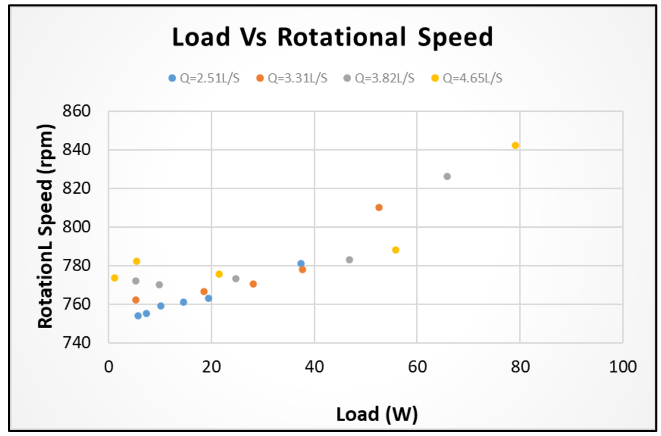


Fig. 7 Load Vs Rotational Speed

Four distinct situations are taken into consideration for the experimental study built around the active hydrant. the control of valves that manage network flow to open, close, and partially open the hydrants. Direct correlation exists between the flow and rotating speed. The relationship between rotational speed and active power is seen in Figure 8.

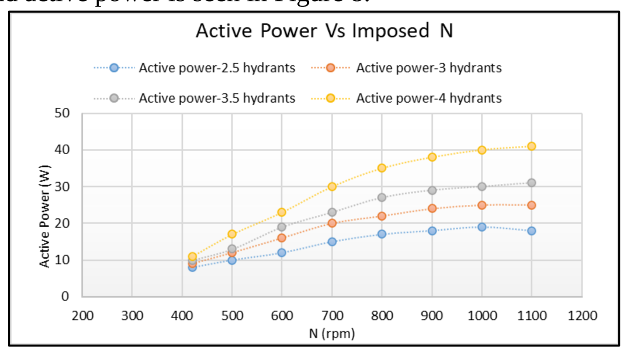


Fig. 8 Active Power Vs Imposed N

From Experimental data analysis and the graphs shown in the figure 6,7 & 8 indicates in the off-grid system as the energy demand increases the rotational speed of the PAT also increases. In turn it requires the rise of flow in the network system. Fig.8 also proves this, the active power increases as the rotational speed increases for the larger number of active hydrants.

Finally, from experimental analysis the PAT efficiency is analyzed in relation with the rotational speed. The largest the active hydrant number has a highest rotational speed which increases the efficiency of the PAT.

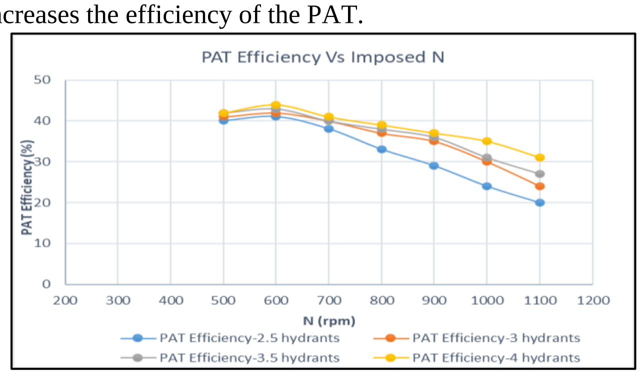


Fig. 9 PAT Efficiency Vs Imposed N

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B. EPANET Simulation

The simulation of the network model (Fig. 10) is analyzed for a 5hr total duration. The demand pattern defined with a 15-minute interval.

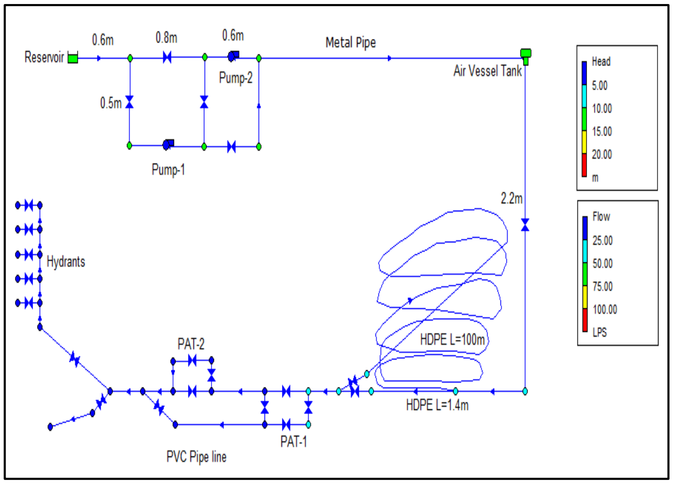

Fig. 10 Network Simulation

The main reason for the installation of Pump as Turbine is to reduce the excess pressure in the water distribution network and produce energy. In this simulation the application of PAT in the network reduced the pressure without affecting the base demand for the distribution.

On some specific nodes the pressure before and after the adaption of Pump as Turbine is assessed (Fig. 11).

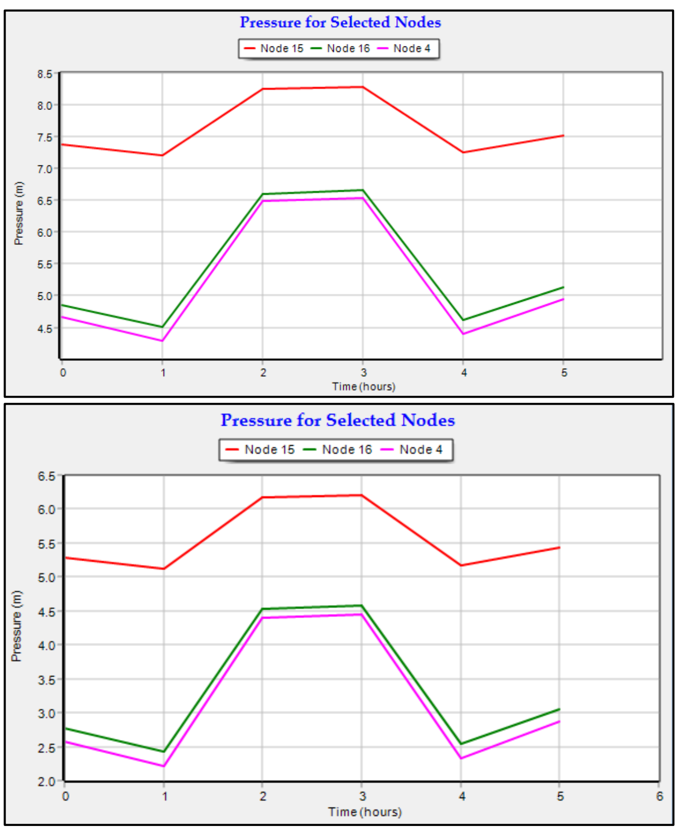

Fig. 11 Pressure Vs time series graph before (top) and after PAT (bottom).

For the purpose of producing energy, it is advantageous to use a pump as a turbine rather than a valve that lowers the pressure and controls network flow. The PAT will utilise the increased pressure for energy generation, while the valves will dissipate the extra pressure inside the network to control the flow. The energy production considering different flow rate in the network is obtained through the following equations.

$$P = Q * H * \gamma * \text{n} \quad (1)$$

$$E = P * \Delta t \quad (2)$$

TABLE III
SUMMARY OF ENERGY PRODUCTION

ID	Q(L/S)	H(M)	g	h(%)	P(W)	T(hr.)	E(W/hr.)
1	2.51	3.0	9.81	0.49	36.2	5	180.98
2	3.31	3.7	9.81	0.58	69.68	5	348.41
3	3.82	4.5	9.81	0.59	99.5	5	497.47
4	4.4	2.65	9.81	0.57	65.2	5	326.00

The energy production for 5 hr. simulation of the network with a pump as turbine is illustrated in the Table-3 with the results of experimental analyses and hydraulic simulation using EPANET integrated model.

C. Economic feasibility and cost-benefit analysis

The economic feasibility of PAT systems considers factors such as energy generation potential, cost savings, among others. Whereas cost-benefit analysis controlling factors are Capital Investment cost, Maintenance and Operational costs, Lifespan and Payback period and Environmental Benefits.

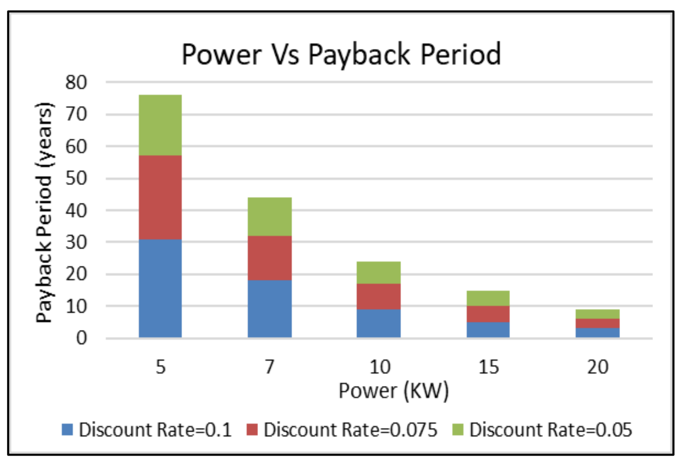

Fig. 12 Power Vs payback period.

As the power output from PAT increases the Payback period decreases (Fig. 12). For small scale projects the payback period will be long and the efficiency and the feasibility of the project will decrease. Increasing the power output gives a linear and almost similar payback period for different discount rate. The shorter payback period there a lower chance of dramatical change in discount rate is.

In addition to cost savings, PAT systems offer substantial environmental benefits. By utilizing renewable energy and reducing greenhouse gas emissions, they contribute to sustainability and align with global efforts to combat climate change. While these benefits might not have direct monetary value, they should be considered in a comprehensive cost-benefit analysis. The energy produced by PAT is a green energy without environmental pollution. The energy recovery will avoid fossil fuel use in the Irrigation network.

IV. Conclusion

The implementation of energy recovery systems in irrigation networks using Pump as Turbine (PAT) technology presents a promising and sustainable solution for optimizing energy consumption. Through the recovery of excess pressure and flow, PAT systems efficiently convert hydraulic energy into valuable electrical energy, benefiting both the environment and the economy.

The economic feasibility of energy recovery in irrigation networks using PAT systems is supported by multiple factors. Firstly, the potential for energy generation from untapped hydraulic energy sources within the network offers a renewable and reliable power supply. By harnessing this energy, irrigation networks can reduce their dependence on external electricity sources and significantly lower energy costs.

Analyzing costs and benefits is essential for determining if PAT systems are viable. The upfront costs of building PAT systems, which include the turbines and related infrastructure, must be taken into account, although the long-term cost reductions surpass them. The project's economic feasibility is aided by lower energy costs and the opportunity for cash generating from excess energy output.

Furthermore, it is impossible to ignore the environmental advantages of energy recovery in irrigation networks. By using renewable energy, lowering greenhouse gas emissions, and encouraging a better future, PAT systems support sustainability initiatives. Irrigation networks may support global objectives of reducing climate change and protecting natural resources by putting these systems in place.

Careful planning, precise cost calculation, and thorough feasibility studies are necessary to guarantee effective implementation. During a project development, variables including flow rates, pressure levels, site conditions, and regulatory requirements must be properly taken into account. The general effectiveness and acceptance of PAT systems in irrigation networks are influenced by integrating stakeholders throughout the process, consulting experts, and conducting thorough site inspections.

Finally, energy recovery in irrigation networks employing Pump as Turbine systems offers a win-win situation for the sustainability of both the economy and the environment. PAT systems have the ability to lower costs, use less energy, and provide a cleaner source of electricity by using the unused hydraulic energy found in irrigation networks. A crucial step toward attaining energy efficiency, resource optimization, and a more sustainable future is the integration of these technologies into irrigation networks.

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