

UTILIZATION OF INDUSTRIAL WATER FLOWS FOR MINI HYDROPOWER GENERATION

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Abstract

The increasing demand for energy and the need to reduce greenhouse gas emissions have stimulated interest in recovering energy from existing industrial processes. Industrial water systems, cooling circuits, process water networks, and wastewater treatment facilities represent significant sources of unused hydraulic energy. This paper analyses the potential of utilizing industrial water flows for electricity generation through mini hydropower plants. Technical aspects, application possibilities, advantages, limitations, and practical examples are discussed. The results indicate that mini hydropower systems can improve energy efficiency, reduce operating costs, and contribute to sustainable industrial development.

Keywords: mini hydropower plants, industrial water, energy recovery, renewable energy, energy efficiency

1. INTRODUCTION

The industrial sector is one of the largest consumers of electrical energy worldwide. At the same time, many industrial processes utilize significant quantities of water under pressure or with considerable elevation differences, resulting in losses of hydraulic energy. In recent years, the concept of hidden hydropower has emerged, referring to the utilization of existing water flows within industrial and municipal systems for electricity generation using mini and micro hydropower plants [1]. Unlike conventional hydropower plants, mini hydropower systems utilize existing infrastructure and do not require large reservoirs. Consequently, they have a significantly lower environmental impact, shorter implementation periods, and lower investment costs. A particularly important potential exists in industrial facilities where water is transported under pressure or where substantial differences in elevation occur between inlet and outlet points [2]. The objective of this paper is to analyse the possibilities of utilizing industrial water resources for electricity generation through mini hydropower plants, with particular emphasis on technical solutions, energy benefits, and implementation challenges.

2. INDUSTRIAL WATER AS A SOURCE OF HYDROPOWER

The operating principle of a mini hydropower plant is based on converting the potential and kinetic energy of water into mechanical energy through a turbine and subsequently into electrical energy using a generator. The power output can be determined by:

$$P = \rho * g * Q * H * \eta \quad (1)$$

where:

P – generated power [W]

ρ – water density [kg/m³]

g – gravitational acceleration [9.81 m/s²]

Q – water flow rate [m³/s]

H – available head [m]

η – overall system efficiency.

Industrial systems often provide continuous water flow and stable hydraulic conditions, making them suitable for mini hydropower applications. The greatest potential can be found in cooling systems, technological water transport pipelines, wastewater treatment plants, industrial water supply networks, and facilities within the food and chemical industries [3]. Research has shown that substantial amounts of energy can be recovered from industrial and municipal water systems without negatively affecting their primary functions [4,5].

2.1. Energy Recovery Concept

The application of mini hydropower plants in industry is mainly based on the concept of energy recovery. Instead of conventional pressure-reducing valves, turbines can be installed to convert part of the hydraulic energy into electricity while simultaneously regulating pressure levels [6]. This approach increases overall energy efficiency and contributes to reducing electricity consumption from external sources. Furthermore, the generated electricity can be consumed on-site or supplied to the local power grid, depending on national regulations and technical conditions.

2.2. Example of Power Calculation

To illustrate the energy recovery potential, consider an industrial water pipeline with a flow rate of 0.50 m³/s and an available head of 20 m. Assuming an overall efficiency of 80%, the generated power can be calculated as:

$$P = 1000 * 9.81 * 0.50 * 20 * 0.80 \quad (2)$$

$$P = 78480 \text{ W} \sim 78.5 \text{ KW} \quad (3)$$

Assuming continuous operation for 8000 hours annually, the yearly electricity production would be approximately:

$$E = 78.5 * 8000 = 62800 \text{ KWh/year} \quad (4)$$

This amount of electricity can significantly reduce the operating costs of industrial facilities and decrease dependence on external energy suppliers [1,6].

3. RESULTS AND DISCUSSION

Wastewater treatment plants offer particularly attractive opportunities for mini hydropower implementation. Treated water streams frequently possess sufficient flow rates and hydraulic heads for the installation of micro and mini hydropower units. Studies conducted in Spain demonstrated that industrial and municipal wastewater networks represent a significant untapped energy resource capable of reducing both electricity costs and carbon dioxide emissions [3]. Positive results have also been reported from the application of pico-hydropower systems with capacities below 5 kW. Case studies indicate that a portion of the energy required for pumping operations can be recovered, thereby increasing the overall energy efficiency of industrial facilities [7].

An interesting example comes from Japan, where electricity generation systems utilizing industrial process water have been successfully developed. Small turbines adapted to existing industrial water flows demonstrated both technical feasibility and economic viability [8].

3.1. Comparison of Potential Industrial Applications

The hydropower potential of industrial water systems depends primarily on flow rate and available hydraulic head. Different industrial sectors exhibit varying characteristics, resulting in different levels of electricity generation potential. Typical values reported in the literature are presented in Table 1. [3,6,8]

Table 1. *Typical characteristics of industrial water systems suitable for mini hydropower applications*

Industrial system	Flow rate [m ³ /s]	Head [m]	Potential power [kW]
Cooling water systems	0.10–2.00	5–30	5–400
Industrial water pipelines	0.05–1.50	10–100	5–800
Wastewater treatment plants	0.05–1.00	3–25	2–200
Food processing industry	0.02–0.50	5–40	1–100
Chemical industry	0.05–1.00	10–50	5–300

As shown in Table 1., the highest hydropower potential is generally associated with industrial water pipelines and large cooling-water systems due to their relatively high flow rates and pressure levels. Wastewater treatment plants also represent attractive locations because they operate continuously throughout the year, ensuring stable electricity production [3,6].

3.2. Proposed Mini Hydropower Configuration

A typical energy recovery system for industrial water applications consists of a turbine-generator unit installed within an existing pipeline, together with a control

system and electrical connection. The general configuration of such a system is presented in Figure 1.

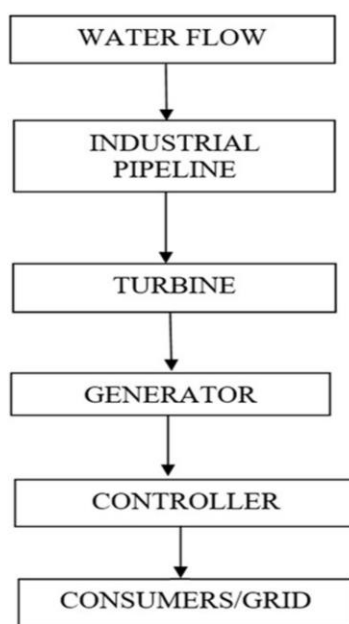


Figure 1. Schematic representation of a mini hydropower system integrated into an industrial water pipeline

The turbine converts the hydraulic energy of flowing water into mechanical energy, which is subsequently transformed into electricity by the generator. The generated power may be supplied directly to industrial consumers or exported to the electrical grid, depending on local operating conditions and regulatory requirements [6]. The implementation of mini hydropower units in existing industrial infrastructure usually requires minimal modifications. In many cases, turbines can directly replace pressure-reducing valves, allowing simultaneous pressure control and electricity generation. This approach minimizes installation costs and shortens the payback period of the investment [6]. Economic analyses reported in the literature indicate that the payback period typically ranges from 3 to 8 years depending on flow conditions, electricity prices, and equipment costs [1,9]. Consequently, mini hydropower systems are increasingly recognized as a viable technology for improving industrial sustainability and reducing operational expenses. The main advantages of utilizing industrial water for mini hydropower generation include increased energy efficiency, reduction of electricity costs, reduction of greenhouse gas emissions, utilization of existing infrastructure, reliable operation, and minimal environmental impact [1]. Despite numerous advantages, several limitations remain. Water flow rates and available hydraulic heads must be sufficient to ensure economic feasibility. Variations in industrial processes may also

result in fluctuations in electricity generation. Additional challenges include turbine selection, system maintenance, and integration with existing electrical networks [4,5]. Recent studies suggest that the potential for implementing mini hydropower systems in industrial water networks remains significantly underutilized worldwide [9].

4. CONCLUSION

Industrial water systems represent an important and largely untapped source of renewable energy. Through the implementation of mini hydropower plants, a portion of the energy that would otherwise be lost during water transport and treatment processes can be recovered. The reviewed literature confirms considerable opportunities for installing mini hydropower plants in industrial water supply systems, cooling circuits, and wastewater treatment facilities [3,4,6]. Such systems contribute to increased energy efficiency, reduced operating costs, and lower environmental impacts. Future development of this technology will depend on improvements in turbine performance for low-head and low-flow conditions, as well as on economic incentives promoting energy recovery solutions [9].

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