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# THE IMPORTANCE OF MAINTENANCE IN HYDRAULIC DRIVE SYSTEMS FOR MICRO HYDROPOWER PLANTS: A COMPARATIVE ANALYSIS

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***Abstract:*** *This comparative study aims to thoroughly explore the impact of maintenance on the energy efficiency of micro hydropower plants and to analyse maintenance techniques and practices that contribute to the optimal operation of hydraulic drive systems. To achieve this goal, three specific cases were examined. By collecting and analysing empirical data, this study provides a comprehensive overview of how proper maintenance can influence the performance and durability of micro hydropower plants.*

***Keywords:*** *Small hydropower plant, maintenance, fluid power actuation*

## 1. Introduction

Micro hydropower plants are an integral part of the renewable energy landscape. They play a pivotal role in providing clean and sustainable electricity to communities, especially in regions with access to flowing water sources such as rivers, streams, or even small waterfalls. Unlike large-scale hydropower plants that require massive dams and reservoirs, micro hydropower plants are characterized by their compact size and minimal environmental impact. They offer an environmentally friendly solution for harnessing hydropower without causing significant disruption to local ecosystems.
For water diversion, the river water level has to be raised by a barrier, the weir (1). The water is diverted at the intake (2) and conveyed by the channel (3) along the landscape´s contour lines. The spillways (4) protect against damage from excessive water flow.

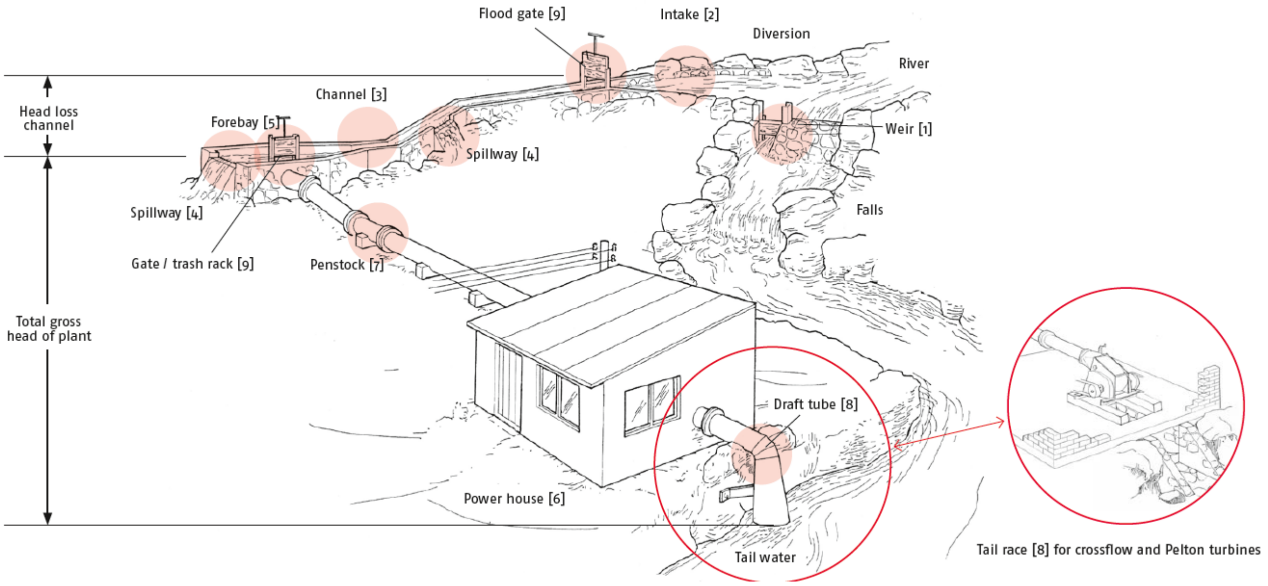


**Fig. 1.** Components of a small-scale hydropower plant [1]

Water is slowed down and collected in the forebay (5), from where it enters into the penstock (7), the pressure pipe conveys the water to the power house (6) where, the turbine, responsible for converting the energy of flowing water into mechanical energy, the generator that transforms the

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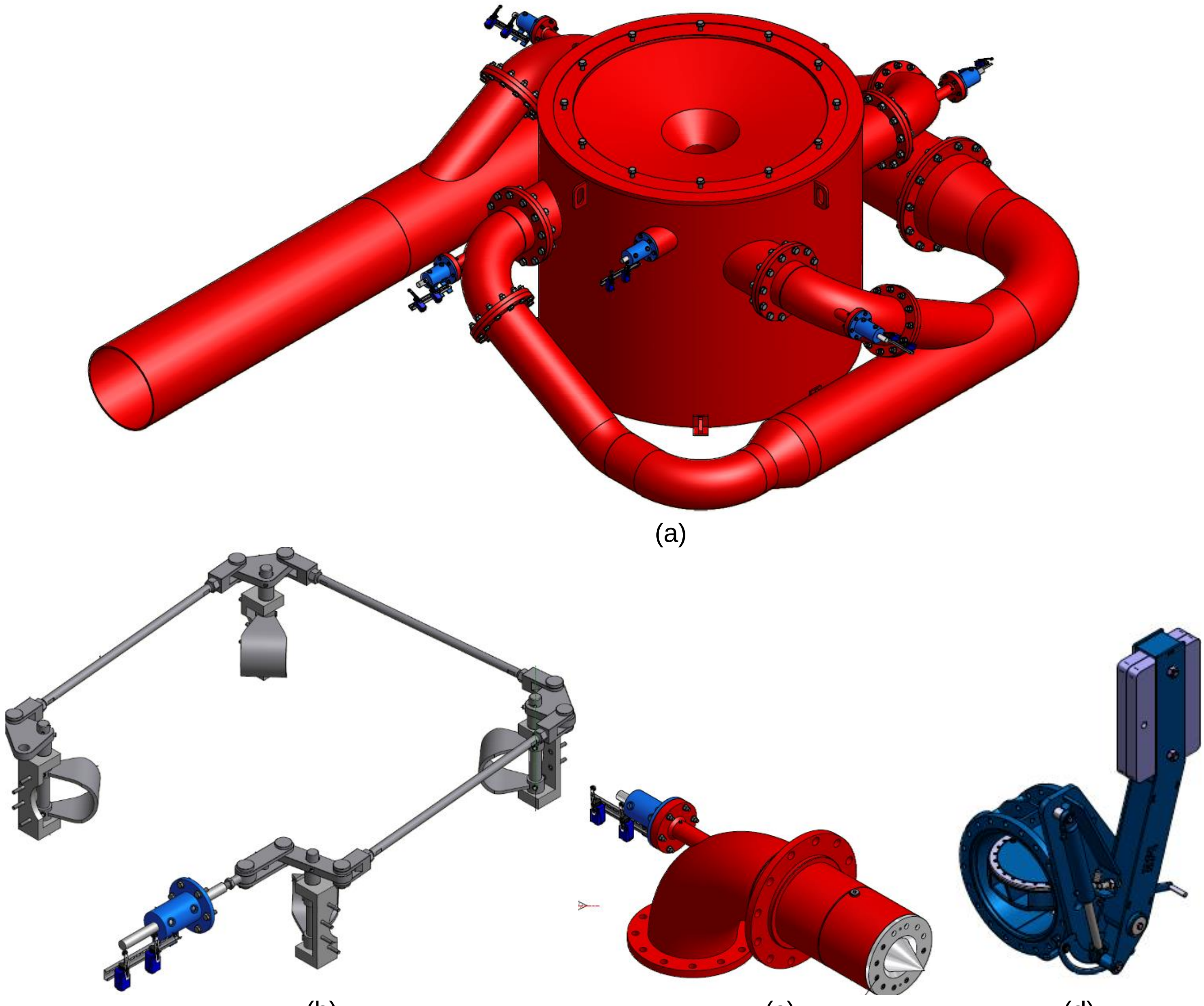
mechanical energy into electrical energy and the control system, used to regulate the flow of water and adjust the turbine's speed, are installed. The water is discharged via the draft tube (8) or a tail race channel in case of crossflow or Pelton turbines. [1]
Typically, these systems employ hydraulic turbines, such as Pelton, Francis, or Banki turbines, to efficiently harness the energy of the flowing water. These turbines are equipped with control mechanisms and hydraulic actuators that adjust the flow of water based on the electricity demand or other external factors. Usually, a Pelton turbine with a power below 2 MW is equipped with four or six injectors, for speed regulation, a deflector mechanism, for breaking the turbine, and a butterfly valve for completely shutting off the turbine supply.



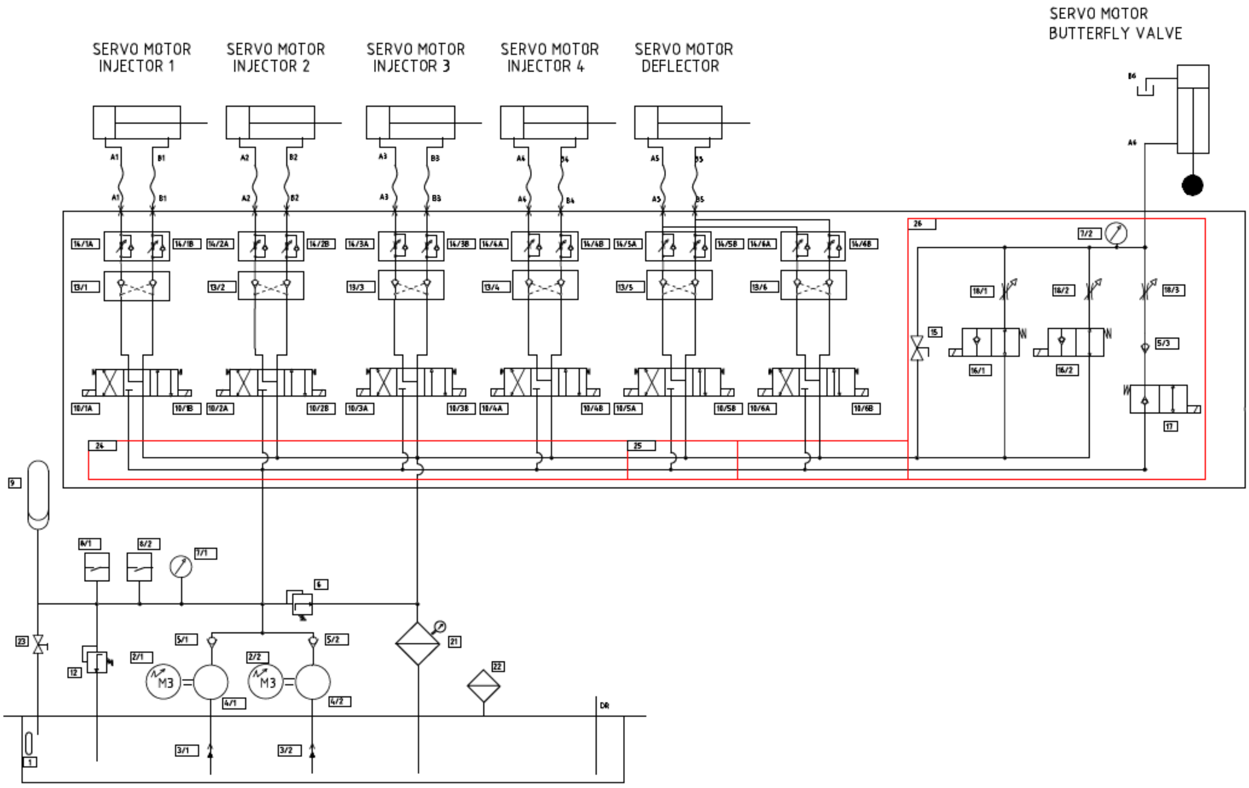
(a)

(b) (c) (d)

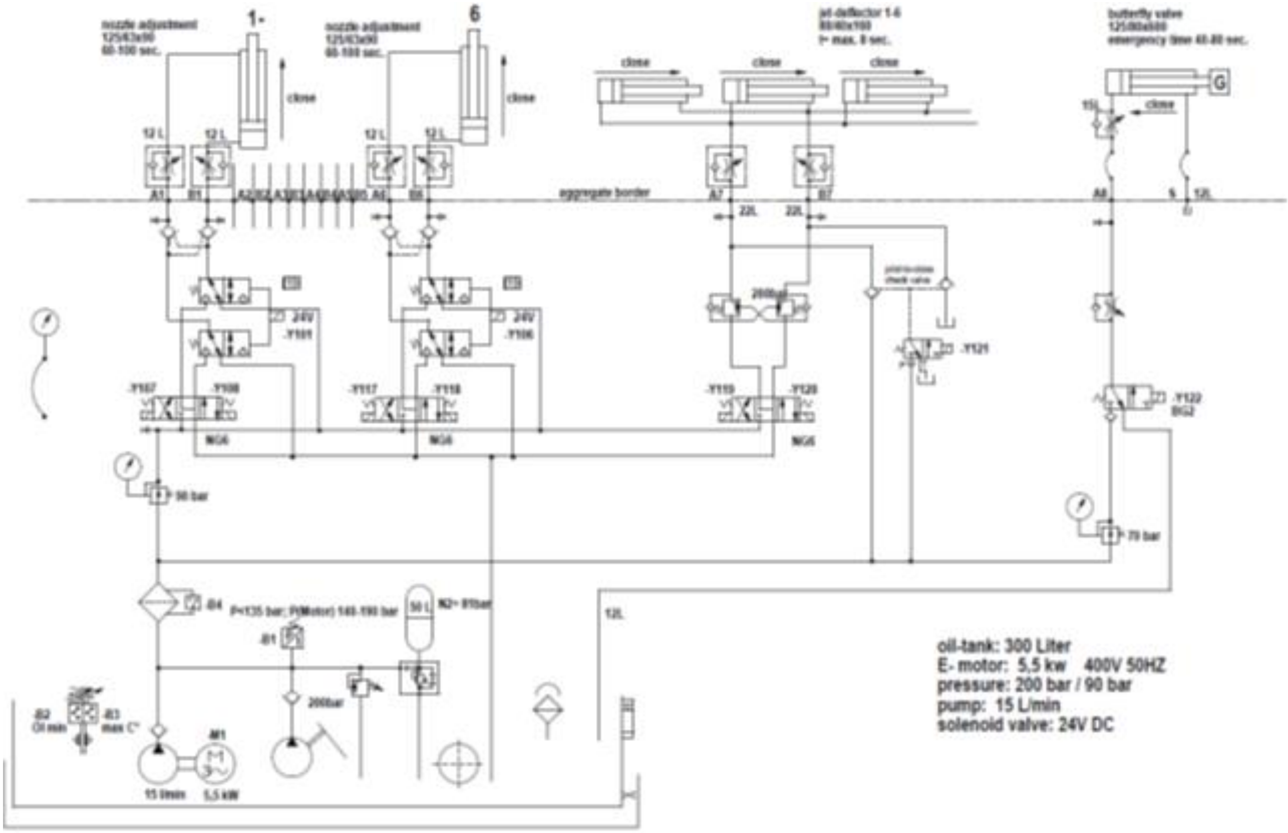
**Fig. 2.** Low power Pelton turbine < 2 MW
(a) the turbine casing connected to the supply pipe (in blue the hydraulic cylinders). (b) deflector mechanism with hydraulic cylinder. (c) injector for adjusting the turbine speed. (d) butterfly valve with hydraulic cylinder and counterweight.

The hydraulic drive system is a critical component of micro hydropower plants, as it ensures the efficient and precise regulation of turbine performance, which ideally should work without interruptions. In these systems, fluid power is used to control the flow of water to the turbine, thereby managing its rotational speed and, consequently, the electrical output.
The fluid power drive system comprises various key components, an accompanying schematic representation is show in figure 3.

Gear pumps are responsible for drawing in and pressurizing hydraulic fluid.
The pressure relief valve ensures that the hydraulic system maintains safe pressure levels by diverting excess fluid back into the reservoir.
The bladder accumulator, filled with nitrogen, acts as a storage and pressure maintenance device for the hydraulic fluid.
The manifold block with distributors is responsible for directing hydraulic fluid to various components.
Hoses serve as conduits for hydraulic fluid to flow between different parts of the system.
Non-Return Valves prevent backflow of hydraulic fluid, ensuring the system functions as intended.
Hydraulic cylinders are used to convert hydraulic energy into mechanical motion, used for control and actuation purposes of the butterfly valve, turbine injectors and deflector mechanism.
Filters are critical components that remove contaminants and particles from the hydraulic fluid, ensuring the system remains clean and free from debris that can cause damage or reduce efficiency.
The ability to finely tune the hydraulic drive system plays a crucial role in the overall efficiency and productivity of the microhydropower plant. By maintaining and optimizing this system through proper maintenance practices, operators can ensure a consistent and reliable energy supply, ultimately contributing to the sustainable generation of clean electricity. [2]
Understanding these components and their interactions, is crucial to grasp the intricate role that the hydraulic drive system plays in the overall efficiency and operation of microhydropower plants.




a)




b)

**Fig. 3.** Fluid power system layout for Pelton turbine control
a) simple version (6 hydraulic cylinders); b) more complex version (13 hydraulic cylinders)

## 2. Basic information of the surveyed power plants

In this chapter, the essential information is provided, about the three surveyed micro hydropower plants, each equipped with Pelton turbines. This information serves as the foundation for the subsequent comparative analysis of maintenance impact on their performance.

**Case A:**

- Location: Cluj County
- Turbine Type: Pelton turbine with 6 injectors.
- Installed Capacity: 1,6 MW.
- Year of Commissioning: 2013.
- Fluid power system for turbine control: Figure 3 a).
- Water Intake Features: The water intake is equipped with hydraulically operated metal sluice gates, racks, and an automatic rack cleaner for the inclined grate at the water inlet into the conduit.
- Maintenance Information: The project designer provided general information on maintenance and a periodic maintenance plan.

**Case B:**

- Location: Alba County
- Turbine Type: Pelton turbine with 4 injectors.
- Installed Capacity: 0.729 MW.

- Year of Commissioning: 2012.
- Fluid power system for turbine control: Figure 3 b).
- Water Intake Features: The water intake lacks hydraulic actuators and relies on grates and an automatic cleaner for the grate.
- Maintenance Information: The project designer did not provide general maintenance information or a periodic maintenance plan.

**Case C:**

- Location: Bistrița-Năsăud County
- Turbine Type: Pelton turbine with 4 injectors.
- Installed Capacity: 0.402 MW.
- Year of Commissioning: 2014.
- Fluid power system for turbine control: Figure 3 b).
- Water Intake Features: The water intake lacks hydraulic actuators and relies on grates and an automatic cleaner for the grate.
- Maintenance Information: The project designer did not provide general maintenance information or a periodic maintenance plan.

This foundational information sets the stage for the comparative analysis, allowing us to understand the variations in equipment, maintenance practices, and their impact on the performance of these micro hydropower plants.

## 3. Comparative Analysis

In this section, a comparative analysis is conducted to assess the influence of maintenance practices on the technical condition and performance of the surveyed micro hydropower plants, specifically Case A, Case B, and Case C. Efficiency decline graphs are employed to depict the decrease of efficiency over time, with maintenance scores serving as the basis of categorization: 1 (comprehensive recommended practices), 2 (infrequent maintenance), and 3 (minimal intervention limited to component replacements essential for functionality).

**Case A**

Maintenance Score:

Years 1-5: 1 (Proactive Maintenance)
Subsequent Years: 2 (Reactive Maintenance)
Total in 10 years: 1,5

The graph below visualizes the decline in efficiency:

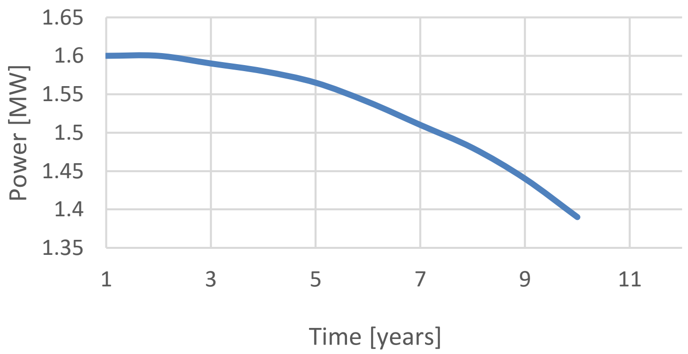



**Fig. 4**. Variation of global efficiency over time - Case A

Observations: The graph reveals a gradual but notable decline in efficiency. The reduction in power output, with 17%, is attributed to the transition from proactive to reactive maintenance practices.

**Case B**

Maintenance Score:

Regular Periodic Maintenance: 2 (Infrequent Maintenance)
Component Replacements: 3 (Minimal Reactive Maintenance)
Total in 11 years: 2,5

The graph below illustrates the efficiency decline:

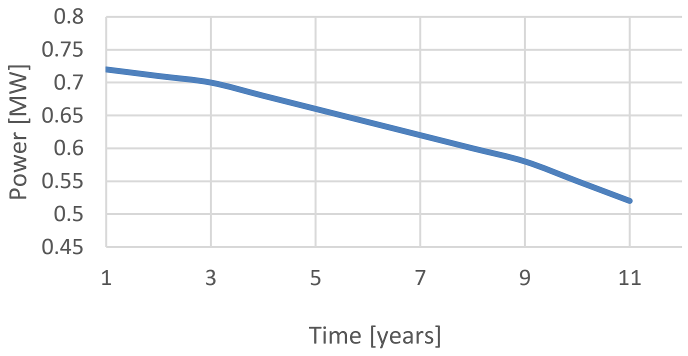



**Fig. 5.** Variation of global efficiency over time - Case B

Observations: The graph demonstrates a more substantial reduction in efficiency, with power output diminishing by 37%. The sporadic nature of maintenance activities contributes to this decline.

**Case C**

Maintenance Score: 3 (Minimal Reactive Maintenance with Limited Protective Measures), for whole period of 9 years.

The graph highlights the drastic efficiency decline:

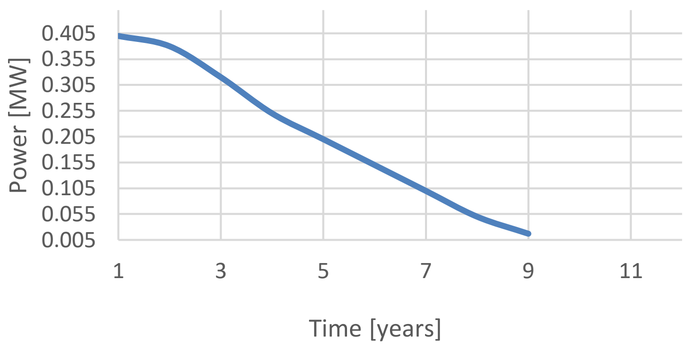



**Fig. 6.** Variation of global efficiency over time - Case C

Observations: The graph portrays a remarkable 96.6% reduction in efficiency, with power output almost negligible. The complete absence of proactive and periodic maintenance practices, alongside the lack of protective measures at the water intake area, is the primary driver of this severe efficiency drop.

All three cases were periodically technically inspected, the last check being in 2023, and the status was recorded as shown in the following table:

**Table 1:** Technical inspection report of the fluid power unit (August-September 2023)

| No. | Designation | Inspection/Measurements | Case A | Case B | Case C |
|---|---|---|---|---|---|
| 1 | Oil | Fluid level | O | O | O |
| | | Contaminants, Colour | R | R | X |
| | | Temperature | R | R | R |
| 2 | Oil Tank | Air breather; Ball valve; Cleaning cover | O | R | R |
| | | Oil level indicator | O | O | O |
| | | Thermostat | O | - | - |
| | | Oil level gauge | O | - | - |
| 3 | Pipes; Hoses; Fittings | Check leakages | R | R | R |
| | | Tensions from fixation, bendings, strangulation | R | R | R |
| 4 | Gear pumps | Check alignment with drive mechanism | O | O | O |
| | | Couplings | O | O | R |
| | | Noise | O | O | O |
| | | Increasing pressure | R | R | R |
| | | Wear or damaged internal parts | R | R | R |
| 5 | Suction Filter | Warping | X | X | X |
| | Filter with indicator/ | Indicator | X | X | X |
| 6 | Pressure valves | Temperature | O | O | O |
| | | Noise | O | O | O |
| | | Adjustments | O | O | R |
| 7 | Pressure sensor | Compared with gauge | O | R | R |
| 8 | Check valve (pumps) | Temperature, Noise, , Leaks | R | R | R |
| 9 | Hydraulic accumulator | Gas Pressure | R | R | R |
| | | Temperature | O | O | R |
| 10 | Accumulator block | Temperature, Noise, Leaks | R | R | X |
| 11 | Solenoid valves | Voltage | O | O | O |
| | | Temperature, Noise, Leaks | O | R | R |
| 12 | NC & NO valves | Temperature, Noise, Leaks | O | R | R |
| 13 | Pilot non-return valves | Temperature, Noise, Leaks | O | R | R |
| 14 | Check valve | Temperature, Noise, Leaks | O | R | R |
| 15 | Throttle valves | Temperature, Noise, Leaks | O | O | R |
| | | Adjustments | O | O | R |
| 16 | Cylinders | Leaks | R | X | X |

where:
O = Good operating parameters;
R = Operational but Needs in-depth Tests and Work;
X = Out of normal operating parameters;

### 3.1. Implications and Recommendations

The maintenance scores assigned to each case were determined based on a comprehensive evaluation of their maintenance practices:

- Maintenance Score 1 (Proactive Maintenance): This score was assigned to Case A for the initial five years, reflecting their proactive approach to maintenance by following recommended practices, including regular inspections, preventive maintenance, and adherence to maintenance schedules.
- Maintenance Score 2 (Infrequent Maintenance): This score was attributed to Case A beyond the initial five years. Case B received this score as they conducted periodic maintenance at intervals of 1-2 years, signifying a somewhat structured approach. However, their maintenance practices were infrequent and inconsistent, impacting efficiency.
- Maintenance Score 3 (Minimal Reactive Maintenance): Case B for rare maintenance interventions, and Case C for minimal reactive maintenance. It signifies minimal proactive or periodic maintenance, with a focus on component replacement only when essential for functionality.

These maintenance scores reflect the evolving nature of maintenance practices within each case, highlighting their varying degrees of proactive and reactive approaches.
The efficiency decline graphs provide vital insights into the profound impact of maintenance practices on micro hydropower plant performance. To address these findings:

- Proactive Maintenance (Case A): The graph showcases a discernible decline in efficiency when maintenance transitions from proactive to reactive. To mitigate this reduction, Case A should reinstate proactive maintenance measures and adhere to recommended practices.
- Periodic Maintenance (Case B): The graph exemplifies a more substantial reduction in efficiency due to intermittent maintenance practices. To maintain power output and efficiency, Case B should implement a more frequent and consistent maintenance schedule.
- Limited Maintenance (Case C): The graph underlines a severe decline in efficiency resulting from the absence of maintenance practices. Case C must prioritize comprehensive maintenance, including protective measures in the water intake area, to rectify this dramatic decline.

The graphical findings underscore the pivotal role of maintenance in sustaining efficiency and the longevity of micro hydropower plants. In the subsequent sections, best practices for hydraulic drive system maintenance will be explored, and recommendations provided to enhance the technical condition and performance of the equipment, ultimately contributing to the sustainable generation of clean electricity.

## 4. Best Practices for Hydraulic Drive System Maintenance

This section delves into the crucial aspects of maintaining hydraulic drive systems in microhydropower plants, focusing on key practices and recommendations that can enhance the technical condition and performance of these systems.

### 4.1. Proactive Maintenance

Proactive maintenance is a fundamental approach to ensure the reliability and efficiency of hydraulic drive systems. It involves a structured framework of activities that include:
Regular Inspections: Implementing periodic checks of all system components, including pumps, valves, filters, and hydraulic cylinders, to identify wear, leaks, or other issues. [3]

Preventive Maintenance: Adhering to a scheduled maintenance plan that includes tasks such as oil changes, lubrication, and cleaning of critical components. These tasks help prevent wear and ensure optimal operation. [3]
Maintenance Scheduling: Establishing a calendar of maintenance activities and adhering to it consistently. This includes regular maintenance intervals that ensure components are serviced before issues arise. [3]

### 4.2. Component Specific Maintenance

Maintenance is a combination of all the technical actions, administrative and managerial taken during the lifecycle of the equipment in order to maintain or restore the ability to perform the desired function (acc. To European Standard EN 13306). From this definition it shows that maintenance activities that include the identification, measurement, control operation, testing, detecting faults, repair, adjustment or replacement of parts items and service. [4]
Each component of a hydraulic drive system requires particular attention:
Pumps with Gear Wheels: Regularly inspecting gear pumps to ensure they operate efficiently and replacing worn-out gears promptly to maintain performance.
Valves and Relief Valves: Checking and calibrating pressure relief valves to avoid over-pressurization, which can cause damage to the system.
Filters: Replacing filters at recommended intervals to maintain oil cleanliness, preventing contamination and wear on system components.
Hydraulic Cylinders: Regularly monitoring the condition of hydraulic cylinders, including seals and rods, and promptly addressing any leaks or wear.
Check Valves: Ensuring that check valves are operational to prevent reverse flow in the system, which can lead to damage.

### 4.3. Protection and Monitoring

Water Intake Protection: Implementing protective measures at the water intake area to prevent debris, sediments, or foreign objects from entering the system. Grates, screens, and automatic cleaners can be used to maintain water quality.
Continuous Monitoring: Employing monitoring systems to track system parameters such as pressure, flow, and temperature. These systems can provide early warnings of potential issues. [5]

### 4.4. Training and Documentation

Staff Training: Ensuring that maintenance staff are adequately trained to perform maintenance tasks effectively and safely. Training programs can enhance their understanding of hydraulic systems and maintenance procedures.
Documentation: Creating and maintaining comprehensive maintenance records, including equipment manuals, maintenance schedules, and records of all maintenance activities performed.

## 5. Conclusion

This article has explored the comparative analysis of maintenance practices in micro hydropower plants, emphasizing the profound impact of maintenance on performance and efficiency. The implementation of proactive maintenance strategies, comprehensive component-specific maintenance, protection measures, monitoring systems, and well-documented practices are vital for maintaining optimal performance.
Micro hydropower plants play a significant role in sustainable energy generation. Through effective and proactive maintenance practices, they can continue to provide clean and reliable electricity for years to come. The knowledge and recommendations provided in this article serve as a foundation for enhancing maintenance practices in these critical energy systems.
By adhering to best practices and continuous improvement in maintenance, micro hydropower plants can fulfil their potential in contributing to a cleaner and more sustainable energy future.

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