THE ROLE OF MICRO HYDRO POWER PLANTS IN ELECTRICITY GENERATION

Matqosimov Muhammadsodiq Mahammadhoshim o‘g‘li
(PhD) Assistant, Energy Efficiency

Andijan State Technical Institute, Republic of Uzbekistan.
ORCID: 0009-0004-7849-8918

Abstract: This scientific article discusses the role of micro hydropower plants (small hydroelectric power stations) in electricity generation, their control systems, their role in voltage and frequency regulation, as well as the mechanisms of parallel connection to the grid, based on a scientific approach. The article presents control schemes developed based on semiconductor regulation elements, energy quality indicators, and the necessary calculation formulas for application in real systems. The paper concludes with scientific conclusions and practical recommendations.

Keywords: Micro HPP, renewable energy, semiconductor regulation, voltage stabilization, synchronization, grid integration, control system, electricity quality, automation, energy efficiency.

Introduction

Micro Hydropower Plants (Micro HPPs) are small power hydropower facilities with capacities ranging from 1 kW to 100 kW. These plants are typically located in remote areas near mountainous regions and water sources, with their main advantage being their ability to provide independent, stable, and environmentally clean electricity. Currently, micro HPPs are widely used in developing countries, especially in areas far from the main power grid.

In Uzbekistan, the focus on micro HPPs is also increasing. According to the Ministry of Energy, more than 30 micro HPPs are planned to be constructed by 2024, with a total installed capacity of 3-4 MW. Micro HPPs are automated to meet the needs of consumers, and their installation is relatively inexpensive, easy to maintain, and designed for long-term use. Furthermore, they play a key role in the diversification of energy supply and the development of the local economy.

The quality indicators of electricity directly affect the reliability, stability, and efficiency of the energy supply. The main parameters that determine the quality of electricity produced by micro hydropower plants are as follows:

- **Voltage Stability (U):** Micro HPPs maintain the output voltage at the required level using automatic voltage regulation (AVR) systems. This is important for both household and industrial consumers.
- **Frequency Stability (f):** The generator must maintain the frequency around 50 Hz by ensuring a stable rotation speed. Mechanical governors or electronic speed control systems are used for this purpose.
- **Power Factor (cosφ):** The cosφ value in a micro HPP should be maintained in the range of 0.9–0.98, which improves energy efficiency and reduces the load on the grid.

For micro HPPs to produce high-quality electricity, a stable operating turbine-generator pair, a voltage regulation system, and a control system that can quickly adapt to variable loads are required.

Factors ensuring parallel operation with the grid Micro hydropower plants are operated in parallel with the centralized electrical grid in accordance with technical and safety requirements. The following conditions and factors are crucial for the operation of the system:

Synchronization Equipment: The voltage and frequency produced by the micro HPP must match the parameters of the central grid. For this, automatic synchronization modules (AVR + synchronizer) are used.

- Protection Systems: In the case of short circuits, overloads, or grid failures, protection relays must automatically disconnect the micro HPP from the grid (e.g., current relays, frequency, and voltage relay settings).

- Power Flow Coordination: It is important to control the power flow depending on whether the electricity is flowing from the micro HPP to the central grid or from the grid to the micro HPP. For this, step-up transformers and contactors are used.

- Automatic Control Systems: The operational status is monitored and necessary adjustments are made using SCADA, PLC, or other remote monitoring systems.

Additionally, to ensure parallel connection with the grid, it is essential to comply with the standards specified in technical documentation (e.g., GOST R 52719 or IEEE 1547). Figure 1. The functional diagram of the micro hydropower plant is presented.

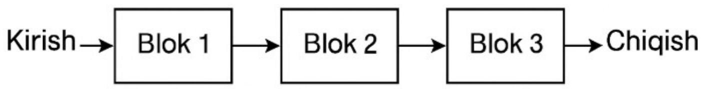


Figure 1. The functional diagram of the micro hydropower plant is presented.

Turbine Working Principle: The turbine converts the energy of the flowing water into mechanical energy. The water flow rotates the turbine blades, generating mechanical energy that drives the generator. Role in the grid it serves as the starting point for energy production in the grid. The turbine operates efficiently based on the water source and its flow rate.

Input: At this stage, the necessary data or external factors are provided to the micro HPP system. The inputs may include the following factors:

- Water flow and pressure (hydraulic energy)
- Load demand level
- Grid voltage and frequency status
- Control commands (from the operator or the automatic system)

Block 1: Energy Conversion (Converting Hydroelectric Energy to Electricity) In this block, the main function of the micro HPP — converting the mechanical energy of the water flow into electrical energy — is carried out.

Key components:

Hydroturbine: The water flow pressure generates rotational energy.

Electric Generator (synchronous/asynchronous): The rotational motion is converted into electrical energy.

Block 2: Signal Processing and Control (Automation Block)

This block operates based on a microprocessor, PLC (Programmable Logic Controller), or PID/PI regulators that control the system.

Its functions include:

- Regulating output energy (voltage, frequency, power)
- Analyzing error signals (via feedback)
- Synchronizing with the grid
- AVR (Automatic Voltage Regulator) and compensation against oscillations

Block 3: Protection and Connection System (Grid Output)

In this block, the electrical energy produced by the micro HPP is transmitted to the central grid or delivered to local consumers.

Key components:

- **Measurement Transformers** (current, voltage)
- **QF1 or other switches** (automatic disconnection)
- **Synchronization Scheme** (coordination with grid parameters)
- **Protection Relays** (overload, short circuit, frequency limits)

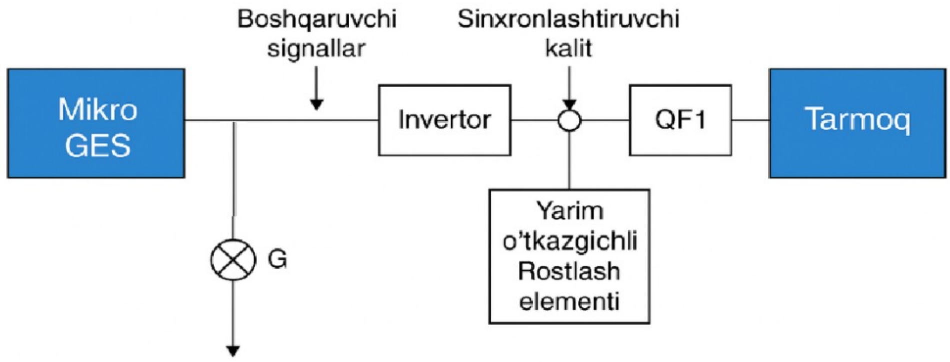
This block serves as the final control point necessary for safe and stable operation.

Output:

At the system's output, stable, high-quality electrical energy is delivered to the user or the grid. The following quality parameters are guaranteed:

- **Voltage:** 220/380 V
- **Frequency:** 50 Hz
- **Power Factor:** ≥ 0.9
- **Low Harmonic Distortion** (THD)

Figure 2: Updated control diagram with semiconductor regulation element



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Output electrical power: P=η·ρ·g·Q·H

Here:

P — Electrical power *(W)*

η — Overall efficiency *(0.6–0.9)*

ρ — Water density *(≈ 1000 kg/m³)*

g — Gravitational acceleration (*9.81 m/s²)*

Q — Water flow rate (*m³/s)*

H — Water head *(m)*

$$P_{\text{loss}} = V_{\text{on}} \cdot I + R_{\text{on}} \cdot I^2$$

here:

V_{on}— Voltage drop in the open state (masalan, 1.2 V),

R_{on} — Voltage drop in the open state (masalan, 0.01 Ω),

I — Current passing through (A)

Temperature Rise:

$$\Delta T = P_{\text{loss}} \cdot R_{\theta \text{JA}}$$

here**:**

ΔT — Temperature rise of the semiconductor element (°C),

$R_{\theta \text{JA}}$— Thermal resistance (junction-to-ambient) [°C/W]

If $\Delta T + T_{\text{ambient}} > T_{\text{max allowable}}$$\Delta T + T_{\text{ambient}} > T_{\text{max}}$ allowable, a cooling system is required.

Reactive power compensation:

If the micro HPP is connected to the grid, the power factor needs to be improved:

$$C = \frac{P}{\omega U^2} \cdot \left(\tan\varphi_1 - \tan\varphi_2\right)$$

here**:**

C — Compensation capacitor capacity (F),

$\omega = 2\pi f$ — Angular velocity (rad/s),

φ_1— Initial power factor angle,

φ_2 — Required power factor angle.

Conclusion:

Micro HPPs are an environmentally friendly and reliable energy source, and the efficiency of their automatic control systems can be further improved. The use of semiconductor elements ensures the system's speed and accuracy. In the future, the following can be recommended for micro HPPs:

- Technical support for local manufacturers
- Wide implementation of digital monitoring systems
- Standardization of protection and synchronization schemes adapted to the grid

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