SHORT-TERM ENERGY OPTIMIZATION OF A MIXED THERMO-HYDRO POWER SYSTEM WITH EMPHASIS ON HYDROELECTRIC PLANT EXPLOITATION

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The paper focuses on the optimization of a mixed thermo-hydro power system production, with a particular emphasis on A comprehensive overview of mathematical models and optimization methods, addresses the challenges and opportunities in enhancing energy efficiency and reliability. The delves into optimizing hydropower systems across various time horizons: long-term, mid-term, and short-term planning. A detailed analysis is provided on the division of power outputs for individual generating units during plant operation, ensuring optimal performance across different scenarios.

A low-head hydropower plant case study explores short-term optimization, crucial for meeting daily load demands. This section highlights the operational strategies and decision-making processes necessary for maintaining a balance between energy production and system reliability. In addition, the paper investigates energy optimization strategies for a reconstructed hydropower plant, incorporating ecological requirements to align with modern sustainability standards.

Keywords*: Hydroelectric, Plant, Energy, Ecology, Optimization*

1. Introduction

Due to the constant increase in global electricity consumption and its associated costs, there is a pressing need for more economical production and optimal utilization of existing capacities. The power system must ensure safety and reliability, providing continuous supply to consumers while acknowledging the fact that direct storage of electrical energy is practically negligible due to small and expensive accumulator stations. Consequently, production units must always ensure stable voltage and frequency, aligning power output with consumption and continuously adapting to variations in grid demand [1,8].

The meet these requirements, the power system relies on automatic regulation, the creation of backup primary energy reserves, long-term planning for the construction of new facilities, and the maintenance and revitalization of existing infrastructure. The power system encompasses various types of power plants: reservoir and run-of-river hydroelectric plants, gas and steam thermal power plants that use gas, coal, and nuclear fuel, and as well as pumped storage hydroelectric plants, which play a crucial role in grid stability. Additionally, some thermal power plants or heating plants are utilized to cogenerate electricity and thermal energy which together with intermittent renewables, make optimization more complex. [2, 8, 9, 10, 11, 12, 13,14].

However, all power generation units can't operate under optimal conditions simultaneously. The overall optimum of the system is not and cannot be achieved through the superposition of the individual optimums of all its parts. Instead, the system's optimum is determined according to clearly defined criteria while considering various constraints, which are often contradictory. Recent advancements in power system optimization models have considered parameters of economy, safety, and reliability.

Recently, ecological parameters have gained increasing importance, reflecting the growing emphasis on environmental protection and sustainability. These include efforts to mitigate climate change impacts, minimize pollution (e.g., carbon dioxide and nitrogen oxide emissions), and reduce waste generation, particularly waste that affects public health. Incorporating these ecological considerations into operational optimization is essential for modern power systems [4].

Finally, while optimizing energy generation, electricity consumption in industries and households is equally critical, but this aspect lies beyond the scope of the present paper. Nevertheless, addressing consumption efficiency is essential in achieving broader sustainability goals [5].

2. Methods for Determining Optimal Conditions

2.1 General Method of Operational Optimization Power Plants

Determining optimal operating conditions of a thermo-hydro power system is solved by establishing an objective function, the extreme value of this function corresponds to the optimal parameters of the system. In general, the objective function is defined by the expression:

$$F = F\left(t, x_1, x_2, \dots, x_i, \dots x_k, u_1, u_2, \dots, u_j, \dots, u_n\right) \quad (2.1)$$

where the symbol t represents time as the independent variable, and the $(x_1, x_2, \dots, x_i, \dots x_k)$ are dependent variables representing a set of parameters, while the values $\left(u_1, u_2, \dots, u_j, \dots u_n\right)$ are control variables determined during the resolution of the task [1,5,6,7,8]. These are used to select the variables x_i that influence the state of the system and the optimality criteria.

The variables $(x_1, x_2, \dots, x_i, \dots x_k)$ can be viewed as phase coordinates of the vector $\boldsymbol{x}$ in a k-dimensional space, and the set of quantities $\left(u_1, u_2, \dots, u_j, \dots u_n\right)$ can be represented as the vector $\boldsymbol{u}$. This leads to the transformation of the previous equation into the form:

$$\boldsymbol{F} = F(t, \boldsymbol{x}, \boldsymbol{u}) \quad (2.2)$$

In the process of determining the optimum, along with the objective function (maximum possible energy production or minimum water consumption in the case of hydropower plants), there may be constraints on the variables x_i and their controlled variables (u_{ji}), as well as additional relationships involving the quantities x_i and their derivatives with the amounts u_j, based on the data regarding initial and boundary conditions.

When these types of tasks are applied to the hydropower system, the independent variables are the elevations of the upper and lower water levels, flows and drops in hydroelectric power plants or fuel consumption, thermal power for steam production and its parameters in thermal power plants. The dependent variables are the power of the units or entire power plants. The limitations are

$$x_i \in x_{g,i}, i = 1,2, \dots, k, \quad (2.3)$$

and

$$u_j \in u_{g,j}, j = 1,2, \dots, s \quad (2.4).$$

The relationships between variables and their derivatives are given by equations of the form

$$L(t, x, \boldsymbol{x}', \boldsymbol{x}'', \boldsymbol{x}''', \dots, \boldsymbol{x}(m), \boldsymbol{u}) = 0 \quad (2.5).$$

Initial and final conditions are defined by expressions

$$f_o(t_0, \boldsymbol{x_0}, \boldsymbol{x_o'}, \boldsymbol{x_0''}, \dots, \boldsymbol{x_0}(m), \boldsymbol{u_0}) = 0 \quad (2.6)$$

and

$$f_k(t_k, \boldsymbol{x_k}, \boldsymbol{x_k'}, \boldsymbol{x_k''}, \dots, \boldsymbol{x_k}(m), \boldsymbol{u_k}) = 0 \quad (2.7).$$

The optimization task consists of finding a set of functions $\boldsymbol{u}$ such that the objective function, determined by the equation (2.2), achieves extreme values while satisfying the conditions (2.3) through (2.7), all that for a given time t (as the only independent variable) and for all other variables.

Solutions to this task can be performed using analytical methods [1, 5, 6] and, more recently, numerical methods [4, 7]. The former includes differential and variational calculus, Pontryagin's maximum principle, and discrete maximum principle, while the latter encompasses gradient methods, coordinate or random search methods, linear and nonlinear programming, as well as dynamic programming. All this implies that practical optimization solutions need not to be determined for a long time interval during which all time dependant variables are considered quasy stationary instead.

2.2 Optimization of Operating Conditions of Hydropower Plants

In the following text, only optimization of the hydroelectric and water management systems are considered. The usual approach is to optimize the utilization of potential with maximum efficiency, meaning that from a given volume of water (m^3), one aims to produce the maximum possible energy (kWh), particularly during periods when the demands of the electric power system are the highest. Otherwise, the electricity generated is either be used to save fosil fuels burnt in thermal power plants or is accumulated in reservoirs for a later use.

The hydroelectric potential for a given time interval (0, T) is expressed as:

$$\Pi = \int_0^T \rho Q g H dt \tag{2.8}$$

where: ρ is the density of water, Q is the inflow into the reservoir, g is the acceleration due to gravity and H is the available head.

The energy produced during the time interval (0, T) is given by:

$$E = \sum_{i=1}^{N} \int_0^T \rho Q_t g H_t dt \tag{2.9}$$

or

$$E = \sum_{ht=1}^{N} \int_0^T \rho Q_{ht} g H_{ht} dt \tag{2.9a}$$

In this equation, the index *ht* refers to the hydro turbine, and *N* is the total number of turbines considered. The relationship between these two equations represents the efficiency of utilizing the potential.

Optimization of the operation of a hydropower system is performed in the long term, for several months, medium-term, usually every week, and short-term, up to one day. For the first, a forecast of water regime - inflows into the reservoir is required: accumulated water in the catchment area, soil saturation with moisture, the thickness of snow cover and frozen soil layer, weather forecasts, etc. Based on statistical data and the forecasts mentioned above, hydrographs are determined chronological diagrams of average flows for the selected river profile, for one year, but also daily, weekly, or monthly flows.

Data about reservoirs are usually presented through diagrams that show the relationship between the surface area and volume of water at different levels in the reservoir. The dynamic behavior of the reservoir is modeled as a relationship between water level, inflow, and volume. Consumption curves depict the relationship between lower water levels, flow rates, and tailwater elevations.

The operational characteristics of the facilities include topographic diagrams of the turbines and generator characteristics to establish the power curves of the aggregates, as well as the dependence of power on flow and head. Based on this data, the operational curves of the coupled aggregates are defined. The parameters of the economic efficiency of the facility are defined either by specific energy production:

$$e = \frac{Pg}{Q} \left[\frac{\mathrm{J}}{\mathrm{m}^3}\right] \tag{2.10}$$

or by its reciprocal value:

$$Q = \frac{1}{e} = 3600 \frac{Q}{Pg} \left[\frac{\mathrm{m}^3}{\mathrm{kWh}}\right] \tag{2.10a}$$

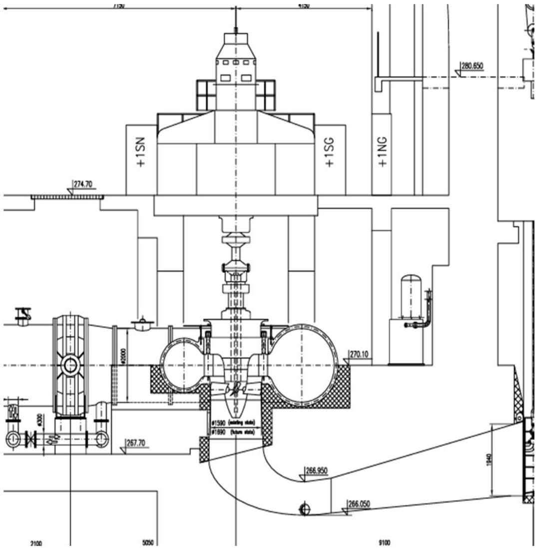
These formulations help assess the efficiency and economic viability of the hydroelectric system's operations. Optimal working conditions are characterized by maximizing the first parameter *e* and minimizing the second parameter *Q,* during the selected time interval (time from *t*=0 to *t* =*T*).

Regarding the goal function, optimization parameters, and periods, of time there are long-term, quarterly, or multi-month optimizations, mid-term optimizations every week, and short-term optimizations on a daily or multi-hour period. As previously mentioned, long-term optimization requires forecasts related to reservoir conditions, inflow and water consumption, and the operational state of machinery and equipment in power plants. For mid-term optimizations, data on the state of accumulation, water and energy consumption forecasts, and the condition of machinery and equipment in the power plant(s) must be available. Short-term optimization relies on the daily diagram of electricity production in the power system and the distribution of power among the power plants to determine the correct power distribution among the units in each power plant. Of course, there are constraints on the water levels in the accumulations and water management requirements at the dam, the dynamic state of the units and equipment, hydroelectric and cavitation characteristics of turbines, losses in the supply and drainage systems, efficiency of generator characteristics, and more.

3. Short-Term Optimization and Power Allocation by Aggregates

Short-term optimization focuses on meeting the requirements of the daily load curve (electricity production), which entails selecting the number of aggregates (generating units)of a hydropower plant. and determining their power output. This task must be achieved while assessing the condition of the aggregates, including stress, vibrations, cavitation damage to the turbines, and other constraints such as environmental protection, water quality, air quality, soil quality, and biodiversity. By ensuring that all these factors are taken into account, short-term optimization aims to efficiently allocate resources while minimizing potential negative impacts on the environment and maintaining the operational integrity of the hydroelectric system. In a text that follows the modernization of the hydropower plant HPP "Medjuvršje" was considered, which included the reconstruction of both of its old units to extend their service life and increase the power output and total electricity production, as well as the installation of a smaller unit whose main purpose was to ensure the guaranteed flow of the river downstream of the dam at low inflows.

The "Medjuvršje" HPP was built on the Zapadna Morava River near the town Čačak, Serbia, and connected to the grid in 1957. The HPP is an accumulation-storage facility, with an accumulation volume capacity at the beginning of operation of 18 million cubic meters. The dam of HPP "Medjuvršje" is one of the high dams of the concrete-gravity type. The length of the dam in the crown (elevation of the crown 275.50) is 189 m, and the total structural height is 32.00 m. In 1965, the dam withstood a catastrophic water level (flood), during which the height (thickness) of the overflow jet above the crown of the dam (275.50) was 1.30 m of water column, and the overflow was the entire length of the dam. The fullness of the reservoir, according to measurements from 1987 to 1991., is 68.90%, and according to data from 2018, it is 78.00%. In the machine room of the power plant, there were 2, and after reconstruction, there are 3 operating units. The units U-1 and U-2 consist of two vertical Kaplan turbines directly connected to a vertical, synchronous generator (shown in Fig. 1a. and Fig. 1.b.).



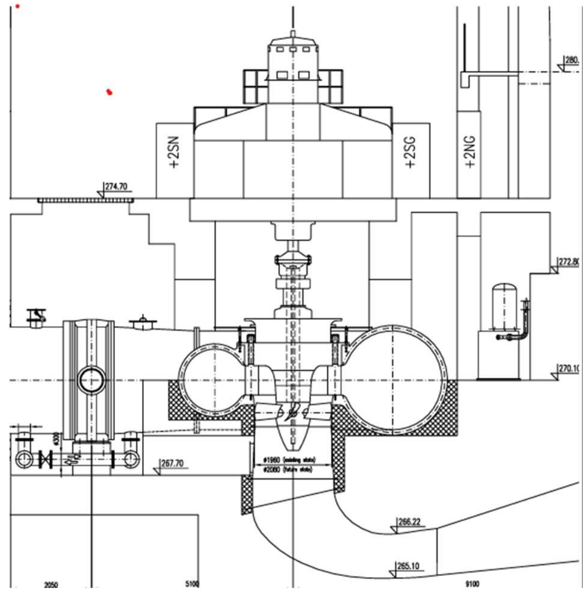
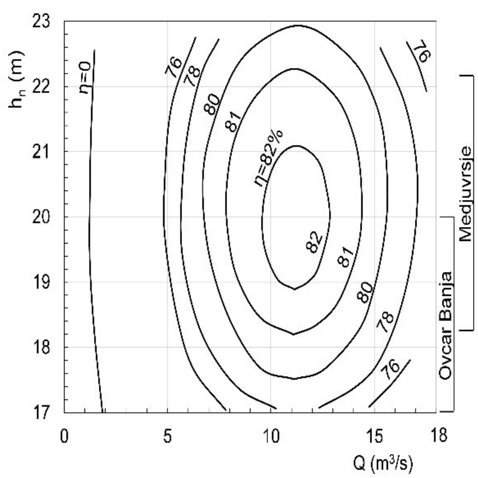


Fig. 1.a. Unit A (U-1) original

Fig. 1.b. Unit B (U-2) original

Fig.1. Kaplan turbines

After 40 (forty) years of operation complex on-site measurements were conducted, including energy characteristics, maximum loads and stresses during transients, vibrations, and finally optimization of power outputs was computed [2]. Hill charts of units A (U-1) and B (U-2) are presented in Figs.2.



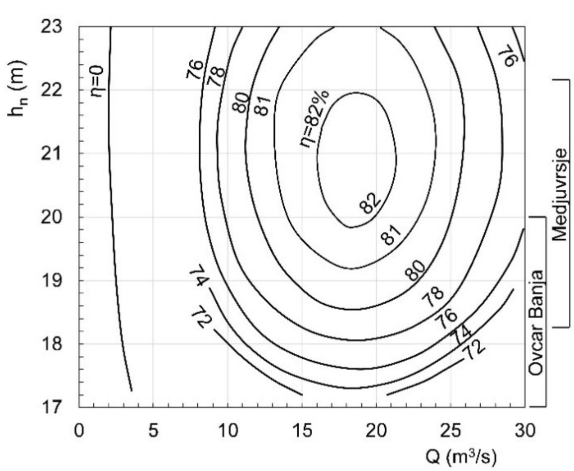
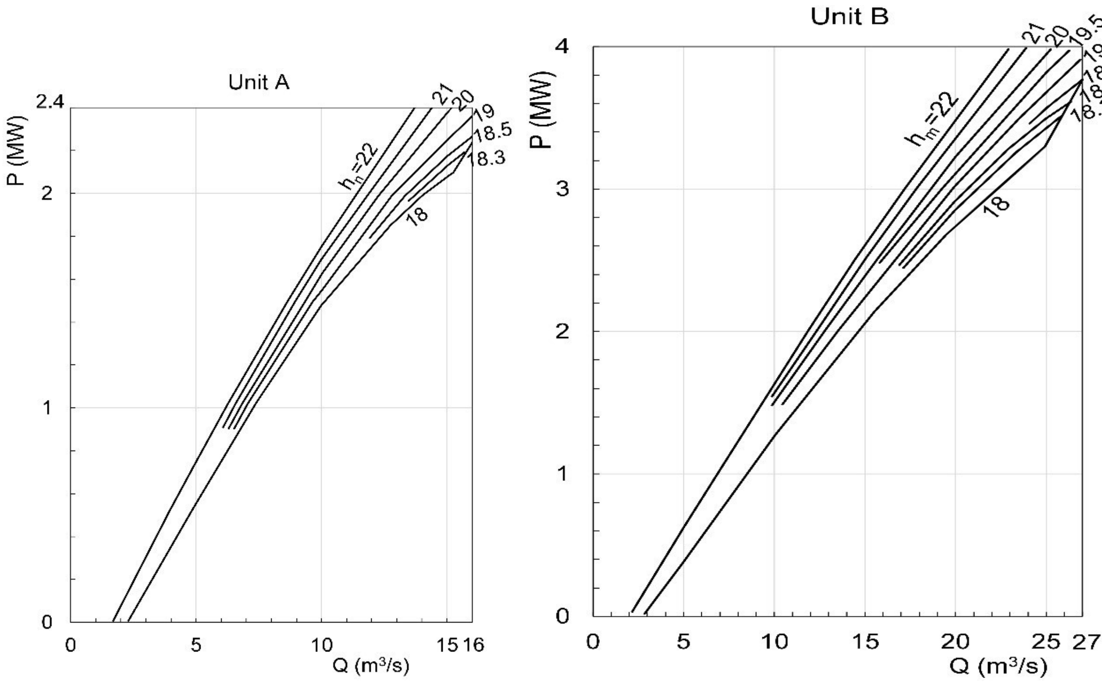


Fig. 2.a. Hill charts of the unit A in HPP

Fig. 2.b. Hill charts of the unit B in HPP

Fig.2. Hill charts

The dependence of power outputs on h_n net head and Q discharge are shown in Figs. 3 for each of the two old units.



a) Unit A (U-1) b) Unit B (U-2)

Fig. 3. Power outputs versus discharge and net head

Figs. 4 and 5 show head losses in the penstocks and draft tubes of both units.

According to the hydraulic characteristics shown above, the division of power outputs per unit in operation is shown in Fig. 6.

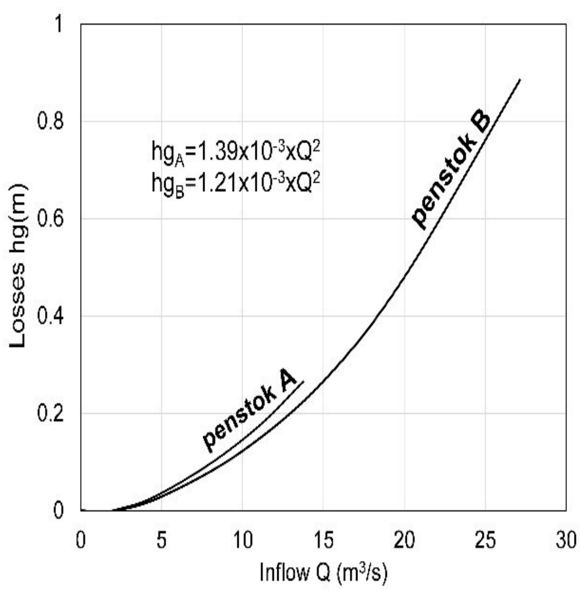


Fig. 4. Head losses in the penstocks

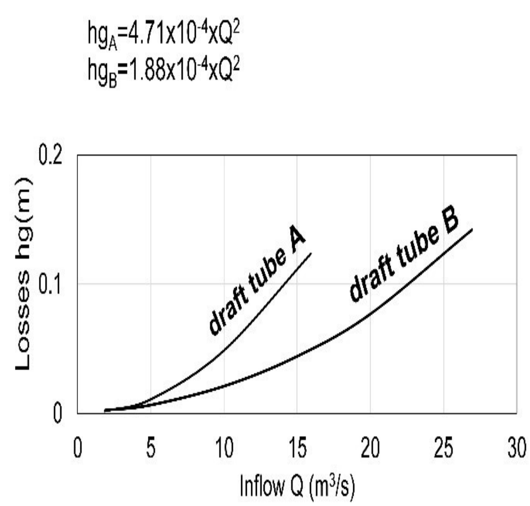


Fig. 5. Head losses in the draft tubes

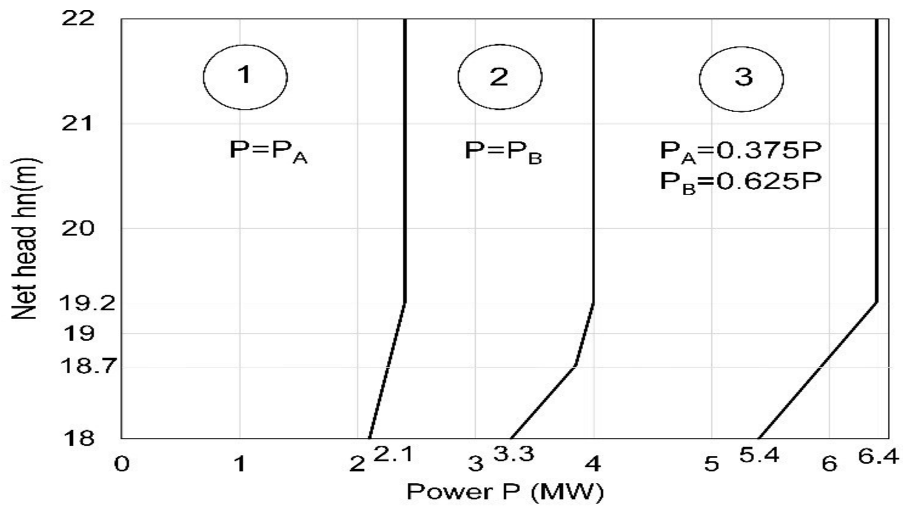


Fig. 6. Power output of units A and B

After more than 50 years of operation, in 2009 and 2010, modernization was conducted, which included the reconstruction of both units with an increase in power output and total production and extended the service life of the equipment. The installed turbine flow after revitalization is 19.50 m^3/s for the smaller B (U-2) and 30 m^3/s for the larger A (U-1) unit.

The third power unit in the "Medjuvrsje" HPP was installed in 2014., and its main purpose was to ensure the guaranteed flow of the Zapadna Morava River downstream of the dam at low inflows, which according to the Water Management Permit is Q_{gar}=3.75 m^3/s. The third unit consists of a horizontal Francis turbine and a horizontal synchronous generator with an installed power of 650kW. The average annual production of HPP "Medjuvršje" is 33.00 GWh. Optimization of the new and two revitalized units will have to take into account constrains posed by the specific environmental conditions in the upstream water These are presented in detail in Section 4..

4. Optimization of the reconstructed plant to meet the environmental goals

Hydropower plants have varying environmental impacts depending on the complexity of physical and socio-geographical settings. These impacts are measurable both upstream and downstream of the catchment areas, affecting diverse environmental features. Notable changes include the modification of hydrological and hydrogeological regimes, riverbed sediment build-up and slope destabilization beside the riverbanks, microclimate modification, soil alteration and degradation, and biodiversity changes in riparian habitats and animal communities [15]. Upstream, reduced river flow velocity often results in elevated groundwater levels. Higher groundwater levels can change the soil properties, waterlogging in flat areas, and an increased risk of soil degradation, pollutant accumulation, or salinization. In the downstream part, frequent and abrupt fluctuations in water levels destabilize slopes, potentially triggering landslides and endangering the structural integrity of riverbanks and dams [16]

Current water quality monitoring at HPP Međuvršje relies on physical, chemical, and microbiological tests conducted quarterly. However, this system is insufficient for addressing dynamic environmental changes. The development of a real-time, sensor-based monitoring system, capable of tracking parameters such as water temperature, pH, dissolved oxygen, and pollutant concentrations, is necessary. Advanced sensors can detect key contaminants like phytoplankton and cyanobacteria, ammonia, and nitrates, enabling early-warning systems to mitigate ecological and operational risks (IEEE, 2023).

Such innovations will provide detailed insights into water quality dynamics, support decision-making processes, and enhance the socio-economic sustainability of the region by balancing environmental protection with efficient energy production.

Besides the operational challenges described above in section 4, the "Medjuvrsje" power plant faces numerous environmental challenges, including:

- Excessive sediment deposition of unknown composition.
- Proliferation of aquatic vegetation (algae blooms, reeds, and invasive species).
- soil erosion in surrounding areas
- ammonia and nitrate pollution in water,
- High levels of bacterial contamination.

To address these issues, it is essential to consider the entire Zapadna Morava river basin (>15,000 km²) during monitoring and modeling to address these issues. Regional analyses can be conducted for indicators like water temperature erosion, precipitation, evaporation, and pollutants. At the same time, local factors such as biodiversity, groundwater dynamics, and slope stability require focused assessments near the power plant [17]. Current water quality monitoring at the "Medjuvršje" power plant relies on physical, chemical, and microbiological tests conducted quarterly. However, this system is insufficient for addressing dynamic environmental changes. The development of a real-time, sensor-based monitoring system, capable of tracking parameters such as water temperature, pH, dissolved oxygen, and pollutant concentrations, is necessary. Advanced sensors can detect key contaminants like phytoplankton and cyanobacteria, ammonia, and nitrates, enabling early-warning systems to mitigate ecological and operational risks (IEEE, 2023). Such innovations will provide detailed insights into water quality dynamics, support decision-making processes, and enhance the socio-economic sustainability of the region by balancing environmental protection with efficient energy production.

The irregular inflow into the reservoir of the upstream "Ovčar Banja" hydropower plant, and subsequently into the reservoir of the "Međuvršje" power plant, causes water level fluctuations and unbalanced currents. If we add to this the irregularities in exploitation and the variable flow through the power plant turbines, the water currents in the lakes become even more unstable. These variations exacerbate soil erosion, silt deposition, and microorganism migration into the downstream reservoir. of the "Međuvršje". According to the original plan, the lower water from the plant was intended to be used for supplying the town of Čačak with drinking water, for irrigating agricultural land in the district of the Western Zapadna Morava, and a bathing area for the citizens of Čačak. None of these plans were systematically realized, so, for example, Čačak's water supply was ensured through an expensive state project involving the construction of the "Arilje-Rzav" water management system, which was extended to Čačak and beyond. During periods of reduced inflow in the "Arilje-Rzav" system, it was planned to mix water from the lower reservoir with the first one to achieve an adequate capacity.

High sedimentation has reduced the effective storage capacities of both reservoirs, significantly impacting operational efficiency and environmental stability [18]. It should be noted that both reservoirs—the upstream "Ovčar Banja" reservoir, which is filled with rockfalls, and the downstream "Međuvršje" reservoir, which has significant silt deposits—have seen a considerable reduction in their effective storage capacity. This also impacts the efficiency of the exploitation of the mentioned hydroelectric power plants.

The high silt levels and elevated water levels in the lower reservoir have led to the proliferation of reed beds, particularly along the left bank near the monasteries of the Ovčar-Kablar Gorge, which are of exceptional cultural significance. These reed beds have occupied a large part of the lake's surface area and slowed down the water flow, resulting in the frequent accumulation of wooden debris in the lake. During periods of sudden inflow increases caused by floods, this debris reaches the intake structure of the hydroelectric power plant, often clogging the intake grilles, which in turn increases energy losses and reduces the flow through the hydroelectric plant.

Naturally, in such situations, the inflow of microbiological contaminants is also intensified, due to the increased and uneven water currents across the cross-section. The transformation of the river into low-flowing lake ecosystems (accumulations) led to drastic changes in the ambient conditions for fish and other aquatic organisms, to which they have adapted differently. Quarterly measurements of physical and chemical parameters of water quality as well as the annual sampling of biological material (fish, macro zoobenthos, and macrophytes) reveal that the water in the Međuvršje accumulation reservoir is among the most polluted in Serbia. Key pollutants include ammonia, nitrites, and microbiological contaminants like *Escherichia coli*, which often exceed permissible limits for water quality classes III and IV [5]. In summary, these occurrences lead to morphological changes, have negative impacts on water quality and soil erosion, and adversely affect the environment as well as the economic viability of the hydroelectric plants on the Morava River. Therefore, it is necessary to develop and integrate solutions with robust sensors that can, by automated monitoring of certain biochemical or physical water properties, combined with appropriate understanding and modeling of the collected measured quantities, provide reliable and timely information on HPP's impact on the environment as well as on the socio-economic sustainability of the region.

Data currently collected at the location of "Međuvršje" HPP on a quarterly basis comprise a Report on the analysis of water and watercourses (physical and chemical tests - water temperature, pH value, suspended matter, turbidity, electrical conductivity, dissolved oxygen, dry residue, sedimentation of matter after 10 months, COD, BOD5, total inorganic nitrogen, total nitrogen, total phosphorus, ammonium ion, nitrates, nitrites, sulfates, chlorides, Fe, Mn, As, Ba, Zn, Cd, Co, Cr, Pb, Sn, Cu, Ni, Mo) and Microbiological tests (total number of coliform bacteria). The historical data is available, but it has not been digitized, thus significantly reducing its usefulness.

Developing and implementing a digital sensor-based real-time water quality monitoring system (with early warning) will enable far more detailed insight into the water quality dynamics than the prescribed procedures. Together with the existing monitoring data, this system will support the power plant decision-making processes and enable more efficient and expedient management and maintenance procedures.

The novel state-of-the-art sensing device will, apart from typical water-related parameters (Water Temperature, Electrical Conductivity, pH, Dissolved Oxygen, Oxidation Reduction Potential), enable real-time monitoring of most relevant pollutants, namely, Cyanobacteria (blue-green algae), Ammonia, and *Escherichia coli*.

Namely, Cyanobacteria (blue-green algae) produce hazardous and quite persistent toxins (cyanotoxins), which can contaminate the respective water bodies. *Cyanobacteria* (blue-green algae) blooms further exacerbate water quality issues by producing cyanotoxins, potent neurotoxins, and hepatotoxins harmful to both aquatic life and human health. Chronic exposure to these toxins has been linked to neurodegenerative diseases, such as Alzheimer's and Parkinson's disease [17]. Cyanotoxins can also accumulate in other animals such as fish and shellfish, and cause poisonings such as shellfish poisoning. In addition, exposure to the cyanobacteria neurotoxin BMAA may be an environmental cause of neurodegenerative diseases such as amyotrophic lateral sclerosis, Parkinson's disease, and Alzheimer's disease.

Ammonia and nitrites, critical indicators of water quality, pose significant ecological and health risks. Elevated ammonia levels can be toxic to aquatic life, causing oxidative stress, immune suppression, and mortality, while nitrites interfere with oxygen transport in aquatic organisms, leading to severe ecological disruptions [16]. The presence of ammonia at higher than geogenic levels is an important indicator of fecal pollution of water. In an aquatic environment, ammonia exists in two main forms such as unionized ammonia (NH_3) and ionized ammonia (NH_4 +). The toxicity of ammonia is significantly affected by the levels of pH; the increase in pH induces the concentration of NH_3 to increase. The toxic effects of ammonia exposure to aquatic animals strongly occur by the high concentration of unionized ammonium (NH3) because it can readily diffuse through the gill membranes. Excessive ammonia can cause a growth performance decrease, tissue erosion and degeneration, immune suppression, and high mortality in aquatic animals, which acts as toxicity by increasing ammonia levels in blood and tissues. In addition, ammonia exposure also induces neurotoxicity, oxidative stress, and oxygen delivery impairment as well as hyperactivity, convulsions, and coma.

Escherichia coli (E.coli) is not only a member of the most relevant foodborne and waterborne pathogens but also a major reservoir of antimicrobial resistance genes. E. coli is a faecal indicator bacterium in environmental water quality testing. E. coli strains are predominantly harmless commensals in the gastrointestinal tract of mammals and birds and can reside, independent of a host, in water, soil and sediments. When adapted to extra-intestinal niches in humans, E. coli can cause diseases with a significant burden on health systems globally, such as urinary tract infections, pyelonephritis, sepsis, and meningitis. They can arise as a result of uncontrolled discharge of faecal water into the river, due to the presence of a large number of cottages in the upstream course of the river and can significantly affect water quality.

Taking into account all the above problems, a complex and intricate biodiversity monitoring system is of exceptional importance in order to better model all impacts on both environmental parameters and the operation of the hydroelectric power plant itself (Figs. 7a and 7b for upper storage in summer and winter conditions).

Fig. 7.a. Upper Storage, 12.16.2022

Fig. 7.b. Upper storage, 09.09.2024

Fig.7. Storage of the hydroelectric power plant

5. Conclusions

Energy optimization of power systems is very important and will see a rise in demand in the future. The energy and economic benefits of such efforts are expected not only when new power plants are designed and constructed, but also when operating and maintenance of the existing ones, as well as these their operating life is being extended and particular systems modernized thanks to continued advancements in equipment manufacturing and digitalization of control processes. The above refers to both thermal power plants fired by coal ao natural gas and hydroelectric power plants, as demonstrated here on a particular case of "Medjuvršje" hydropower plant on Zapadna Morava river.

A particular section of the paper considers environmental issues of hydropower plants., like hydrological and hydrogeological regimes, riverbed sediment build-up and slope destabilization beside the riverbanks, microclimate modification, soil alteration, and degradation, biodiversity changes in the riparian habitats and animal communities. A monitoring system will be installed for supervision of the upper storage of "Medjuvršje" hydropower plant The development and installation of the proposed sensor device will provide real-time insights into the dynamics of the most relevant water parameters. Together with the digitized historical data, the proposed monitoring system will, for the first time, enable the development of the corresponding environmental and socio-economic models. In addition, it will enable the development of the early warning water quality system, as well as provide an important feedback and evidence to policy roadmaps for the digital transition. The numerical program will include desilting the lake, water pollution and water regime disruptions due to extreme meteorological events.

Acknowledgments

Authors appreciate for inclusion in project HORIZON-CL5-2022-D3-03-08. "Development of digital solutions for existing hydropower operation and maintenance". Data presented in this paper is mainly obtained from this project.

Nomenclature

E- energy production [MWh]	*Π*- hydroelectric potential [MWh]
e- specific energy production [Jm-3]	*Q*- turbine inflow [m3s-1]
g- acceleration due to gravity [ms-2]	*ρ*- density of water [kgm-1]
h- head [m]	*t*- time [s]
h_n – net head [m]	*T*- time interval [s]
h_g – head losses [m]	η- efficiency [-]
N- number of turbines	Index
P- power output [MW]	*ht*- *t*urbine No

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Submitted: 28.12.2024.
Revised: 20.02.2025.
Accepted: 27.02.2025.