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About the availability of hydro-energy units from the Iad–Drăgan Hydropower Subsystem

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Abstract. *The paper presents possibilities to determine the factors that influence the availability of hydro aggregates. The case study presented in the paper is focused on the hydro–energy units from the Remeți and Munteni hydroelectric power plants belonging to Bihor Power System. The analyzed performance indicators refer to the specific activities of electricity production, respectively the management and exploitation of hydro aggregates at the maximum allowed capacity, as well as the specific activities of the system service, respectively the coordination of operation to meet the demand of National Power System. The purpose is to determine, respectively analyze, the availability coefficient (POF) respectively unavailability (UOF) and the cost of maintenance over a certain period of time.*

Keywords: *hydro-energy units, availability, cost-maintenance*

1. Introduction

The method of obtaining hydroelectric energy is due to the operation of hydro aggregates (hydro-energy units). Hydro aggregates are the most robust, reliable and durable structures that facilitate lifetime repairs, without major modernizations for optimal operation [6]. Due to the robustness, all energy generation equipment suffers irreversibly by reducing performance, reliability and availability, which lead over time to total unavailability, re-engineering, withdrawal from operation for a certain period of time and modernization. The availability of any technical system, including hydro aggregates, can be quantified by three specific indicators [3]: availability, average availability and the availability coefficient. Each of these indicators has a particular practical importance, as they characterize locally or on an interval the state of the system. The results recorded over a period of time indicate the cost for planned and accidental works.

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The share of unavailability of hydro aggregates increased from year to year, both for planned and accidental works. Efficiency in operation by reducing the time of unavailability and maintenance costs is the basis of a refurbishment program, a catalog that is applied according to Romanian Government Decision no. 2139 of November 30, 2004 and also includes the classification and normal operating durations of fixed assets [8]. Following a re-engineering, the downtime is reduced, after the expiration of the guarantees for the works, the application of preventive maintenance is considered [1][2].

The hydroelectric plants (HPP) on which the study was carried out in the paper are Remeți HPPand CHE Munteni I HPP. They are located on the Crisuri hydropower development in the upper basin of the River of Crișul Repede. They are under the management of the Cluj branch of Hidroelectrica SA, being managed through the Oradea Hidroelectric Plan t[9]. They have the installed power of 100 MW (Remeți) and 50 MW (Munteni I). They are equipped with Francis-type turbines, respectively vertically arranged synchronous electric generators, with a power of 50 MW per unit in the case of the Remeți HPP and 25 MW/unit for the Munteni HPP.

2. Iad-Drăgan Hydropower Subsystem

The Iad - Drăgan hydropower subsystem is part of the Romanian National Power System (NPS) and is included in the Crișuri hydrographic basin. It is distributed on the territory of Cluj and Bihor counties. The location of the subsystem with its territorial delimitation is shown in figure 1.

Figure 1. Location of Iad-Drăgan hydropower subsystem

As a hydraulic development, it consists of two reservoirs Drăgan and Leșu and for electricity production it includes two hydropower plants (HPP), Remeți and Munteni I and two microhydropower plants (μHPP), Leșu and Munteni 2. Two of these hydropower projects are presented in figure 2.

Located on the course of the Drăgan River, with a height of 120 meters and a canopy opening of 424 meters, with a double-arch concrete construction, the Drăgan Dam is the largest of its kind in the country. The reservoir formed behind the dam has a total volume of 112 million m^3 of water, allowing the annual regulation of a flow of 8,7 m/s, the production of electricity, the water supply of complex uses as well as the mitigation of torrents and floods.

The Remeţi Hydroelectric Power Plant, located on "Valea Bisericii", is the largest power station within the Oradea branch, being a semi-buried station, the average energy supplied is 200 GWh/year, the nominal flow rate Q = 40 m^3/s, the drop height H = 335 m.

a. **b**

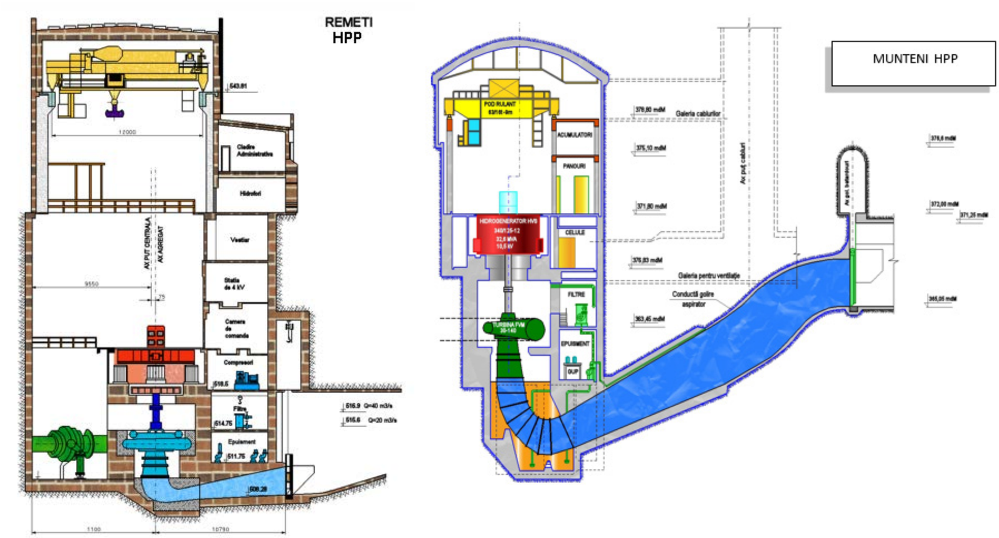
Figure 2. Dam&lake of Drăgan(a) and Munteni I HPP(b)

The Leşu microhydropower plant is located at the foot of the Leşu dam (a dam belonging to the Crişuri – Oradea Water Directorate) and discharges the water, after processing, into the main intake Munteni I, through an 8.1 km long secondary intake gallery Energy produced is E = 10 GWh/ year, nominal flow rate Q = 9,3 m^3/s at a drop height H of 53,5 m.

The Munteni I Hydroelectric Power Plant, located on the right bank of the Iad Valley, is an underground plant on the derivation, being equipped with two vertical turbines of the Francis type, it processes the turbine water at the Remeţi HPP and the Leşu μHPP. The average electrical energy produced is E = 120 GWh/year, flow rate Q. = 49 m^3/s, height H = 146m. A Munteni II microhydropower plant was commissioned in 1992 in the Munteni I HHP premises, which is equipped with a

0,63 MW Francis type horizontal turbine, processing the water from the difference in the basin of the river Iad, between the Leşu µHPP and the Munteni I HHP. The energy produced by the Munteni II microhydropower plant is about 2 GWh/year at a flow rate Q of 2 m^3/s and the drop height H = 45 m.

The functional schemes with the location of the hydropower units (HA) for the Remeți and Munteni I hydropower plants are presented in figure 3.



a. **b.**

Figure 3. Functional diagrams with location of HAs into Remeti HPP(a) and Munteni I HPP(b)

3. A few calculating models for the availability of hydro aggregates

To determine the availability of hydropower aggregates, specific coefficients are determined [3], [4], [5], the applied mathematical model indicating their degree of reliability.

Availability(D), represents the ability of a system (equipment) to fulfill its specified function under the combined aspects of reliability, maintainability and management of maintenance actions, at a given moment, or in a specified time interval[3]:

$$D(t) = R(t) + F(t) \cdot M(t) \tag{1}$$

Along with the term that specifies the maintainability or degree of maintenance of the hydroaggregate M(t), in relation (1) appear the terms R(t) and F(t) which will be defined as follows:

- The probability of good operation R(t) is itself the "quantitative concept of reliability", it represents the probability that a product (device, system, etc.) will fulfill its specified function, under given conditions and over a given duration, namely [4] :

$$R(t) = Prob(t \geq T) \tag{2}$$

whete : t – time variable(time of mission);

- The failure probability F(t) is complementary to the function R(t) and it has the relation [3]:

$$F(t) = Prob(t < T) \tag{3}$$

If the equipment can only be in one of two states (operational, malfunctioning), then write:

$$R(t) + F(t) = 1 \tag{4}$$

The occurrence of defects can be characterized by the frequency function or the distribution density f(t) which expresses the relative frequency of falls (Δn_i) in a period of time Δt_i, namely [3]:

$$\begin{cases} \Delta n_i = N(t_i) - N(t_i + \Delta t_i) \\ \hat{f}(t_i) = \dfrac{\Delta n_i}{\Delta t_i \cdot N_0} \end{cases} \tag{5}$$

In which: $N = N_0 - n$ = the number of hydro units in operation at the time (t_i),
$\Delta n_i = f_i$ – the absolute frequency; $\Delta t_i \cdot No = T_i$ - the total number of test hours in the considered interval.

Between indicators R(t), F(t) şi f(t) exist the following relations:

$$F(t) = \int_0^t f(t)dt, \quad R(t) = 1 - F(t) = \int_t^\infty f(t)dt \tag{6}$$

For the failure record can be considered the indicator called Rate (intensity) of falls (defects) Z(t) which is defined by the relationship [3]:

$$Z(t) = \frac{f(t)}{R(t)} \tag{7}$$

If we accept the exponential distribution for the operation and recovery times, the indicator called "availability coefficient" can be expressed as follows:

$$K_D = \frac{MTBF}{MTBF + MTR} = \frac{\mu}{\lambda + \mu} \tag{8}$$

Similarly, the following coefficients are defined:

- the unavailability coefficient (the proportion of inactive time):

$$K_I = \frac{MTR}{MTBF + MTR} = \frac{\lambda}{\lambda + \mu} \tag{9}$$

- the coefficient (proportion) of use:

$$K_U = \frac{MTBF}{T_A} \tag{10}$$

Where MTR is the mean time to repair and MTBF is the mean time to good operation. The term T_A represents the duration of the analysis, including actual use times, maintenance times, stagnation times.

In this paper for the calculation of the two specific indicators, the following relationships were applied[3]:

a. POF (Planned Outage Factor) - which represents a component of the time unavailability coefficient corresponding to the planned shutdowns:

$$POF = \frac{100\ xTP}{T}\ [\%] \tag{11}$$

Where TP: the total duration of planned stops in the reference period T[hours] and respectively:

b. UOF(Unplanned Outage Factor) – which represents a component of the unavailability coefficient over time (UF) corresponding to unplanned stops:

$$UOF = \frac{100\ xTN}{T}\ [\%] \tag{12}$$

Where, TN : the total duration of unplanned shutdown states in the reference period T [hours].

4. Evaluation of the availability indicators for the considered hydro-energy units

From the power plants analyzed, the evaluation of the coefficients of interest was carried out for the two hydro aggregates from Remeti HPP and the respective two from Munteni HPP. These hydro aggregates are marked HA_1 and HA_2 and the results obtained are presented graphically in color code. The analysis period was 9 years, respectively from 2013 to 2021. The reduced availability requires thorough technical analyzes to determine the factors that contributed to it. Depending on their nature, measures for maintenance, modernization or replacement of a hydro unit can be established. Thus the technical aspects are linked with the economic and financial ones. The allocation of expenses for increasing the availability of hydro aggregates can be done on the basis of the cost-benefit analysis that includes several economic criteria [7]. For example, this method of analysis and evaluation of expenses may represent an attempt to measure the costs and gains from the operation of a hydropower plant as a result of the development of the programs established on the hydro-energy units.

The results of the financial analysis according to the cost-maintenance criterion, in order to make production more efficient and to reduce major expenses in the case of the UOF and POF indicators, of the unavailability time are mentioned in figures 4 and 5.

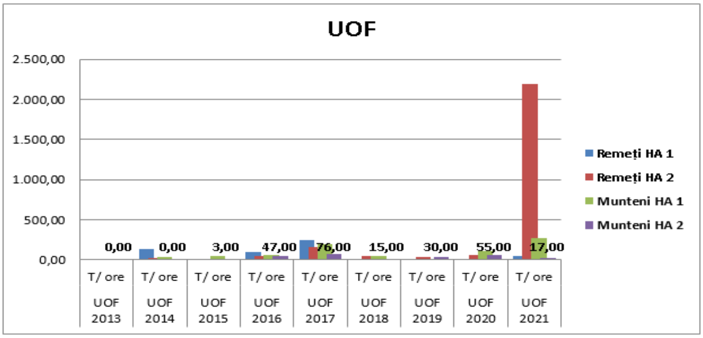


Figure 4. Values of UOF

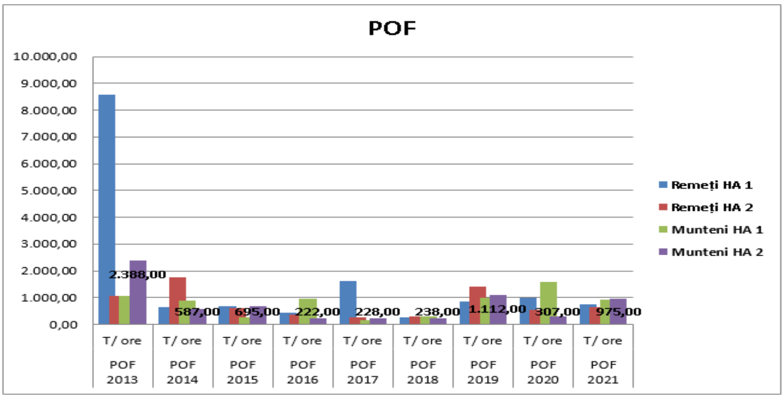


Figure 5. Values of POF

From the comparison of the continuity indicators recorded in the mentioned period, it can be seen that for planned interruptions (POF) they recorded degradations, and for unplanned interruptions (UOF) they recorded decreases. Also, it can be seen from the recording of the values for the case of the accidental unavailability index, an average of 5% over the analyzed time interval, the causes that can explain this situation can be taken into account, namely, the state of all assemblies and installations that complete the operation process of the hydro unit (planning and carrying out preventive maintenance, to reduce long-term unavailability).

The results obtained for the calculation of the energy availability coefficient are presented in figure 6.

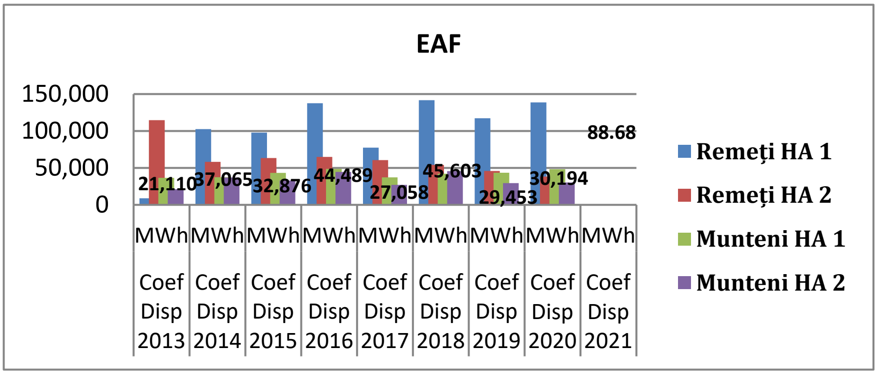


Figure 6. Values of Energy Availability Factor (EAF)

4.1. Availability of Remeți HPP

The calculation results obtained for the availability coefficient of Remeți HPP, for the analysis period, are graphically highlighted in figure 7.

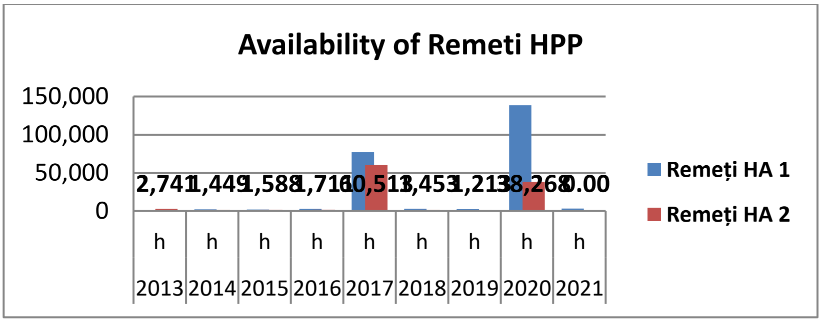


Figure 7. Availanility coefficient of Remeți HPP, from 2013 to 2021

4.2.Availability of Munteni HPP

The calculation results obtained for the availability coefficient of Remeți HPP, for the analysis period, are highlighted graphically in figure 8. For comparison, the availability coefficients for a Munteni II µHPP and Leșu µHPP were also evaluated. The latter was stopped in 2012. The results obtained in this case are presented in figure 9.

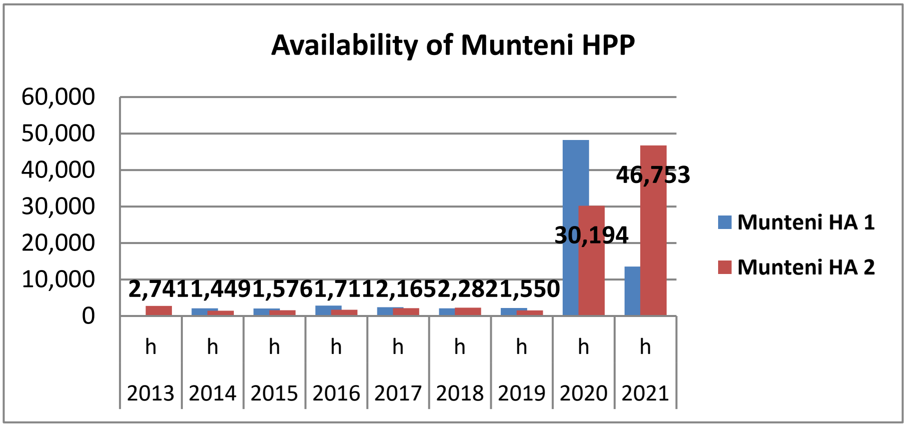


Figure 8. Availability coefficient of Munteni HPP, from 2013 to 2021

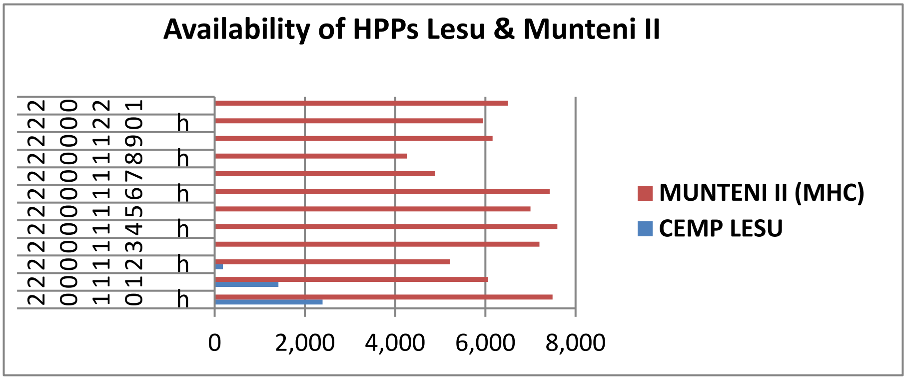


Figure 9. Availability coefficients of Leșu - Munteni II µHPP from2010 to 2021

5. Conclusions

In the elaboration of the paper, two directions were followed as an approach: a theoretical one in which the studied theme and mathematical modeling are presented, issues included in chapters 1,2 and 3, and an applied one, in chapter 4, in which based on experimental measurements and records of given in the centrals, the indicators of interest were calculated. At the end of the paper, are presented the conclusions resulting from the study.

The maximum powers at which the hydro-energy units can operate are 47,86 MW for HA_1 and respectively 37,43 MW for HA_2 due to the operating restrictions resulting from the operation of the generators, the maximum powers given by the producer for each hydro-energy unit, being 50 MW. With reference to HA_1 and HA_2 of Munteni I HPP is to conclude following the monitoring that the maximum achieved powers at which the hydro-energy units operate are 20,34 MW for HA_1 and respectively 19,83 MW for HA_2. These are lower than the maximum powers given by the manufacturer, which have a value of 29 MW for each hydro aggregate. Based on the measurements and analysis performed, the minimum operating power for both hydro aggregates can be P = 5 MW.

Following the results obtained and represented graphically in chapter 4 of the paper, the following specific conclusions can be formulated:

- the factor of energy availability has the highest values in the years 2018 and 2019 respectively for the hydro unit HA1 of the Remeți HPP;
- the availability coefficient of Munteni II μHPP is much higher than that of Lesu μHPP. The availability of MHC Munteni II was the highest in 2014 when the availability coefficient reached the maximum value of 7245 hours/year;
- the availability coefficient for Munteni HPP was the highest in 2020 for HA_1. For HA_2, this coefficient reached its maximum value in 2021;
- for CHE Remeti, the highest values of availability were recorded in the case of HA1, the first maximum being equivalent to 2017 and the second for 2020.

Finally, we can highlight the observation that the hydro aggregates cannot be exploited at the maximum capacity given by the manufacturer, due to wear and tear in operation.

The original contributions of the authors were focused in particular on: experimental measurements and investigations of databases from the archives of hydropower plants, the calculation of availability indicators, the selection, processing and statistical analysis of the data of interest or the synthesis of the results with their presentation in a logical form.

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