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Monitoring efikasnosti hidroelektrana kroz parametre SKADA sistema

Monitoring of the Hydropower Plants Efficiency through SCADA Parameters

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Rezime **-** Savremeni pristup modernizaciji energetskih kapaciteta u hidroenergetskom sektoru JP Elektroprivreda Srbije (EPS) je viđen kroz intenzivne revitalizacije i izgradnju novih hidroelektrana (HE). Iako su navedeni prioriteti definisani kao dugoročni planovi, i dalje postoji mogućnost optimizacije radnih režima postojećih HE. Stručni tim EPS-a je nakon nekoliko meseci rada i istraživanja pripremio mesečne izveštaje koji sadrži operativne parametre hidroelektrane. U ovom radu, kao primer, istraživani parametri i rezultati za jedan agregat HE Đerdap 1 (eng. Iron Gate I/rom. Portile de Fier I) su prikazani. Generalno, u trenutnoj fazi istraživanja, mesečni izveštaj je pripremljen i sadrži arhivirane podatke (kote gornje i donje vode, snage i protoke agregata) i zajedno sa podacima o topografskim dijagramima turbina, gubicima u dovodno-odvodnim organima, generatoru i sl. definisani su izlazni parametri. Izlazni parametri koji se razmatraju i prikazuju u ovom radu su stepen korisnosti turbine i generatora, odnosno agregata, i gubici u radu sa kotom gornje vode nižom od maksimalne radne kote. Osnovni parametri agregata i cele hidroelektrane su preuzeti iz SKADA sistema, osrednjeni na minutnom nivou i prikazani za period od jednog meseca.

Ključne reči - optimizacija, SKADA, efikasnost, hidroelektrane, radni režimi

Abstract **-** Modern approach to the modernization of the power generation capacities in the hydropower sector of PE Electric Power Industry of Serbia (EPS) is seen through intensive rehabilitations and building new hydropower plants (HPPs). Although these priorities are defined by long-term investment plan, there are also improvements that are seen through the optimization of the operational regimes of HPPs. EPS technical expert team, after several months of adjustment and investigation has prepared monthly reports with the operational parameters of the HPP. In this paper, as an example, investigated parameters and results for one particular aggregate of the HPP Iron Gate 1 (ser. Đerdap 1/ rom. Portile de Fier I) are presented. Generally, in the current phase of investigation, monthly report is prepared which includes selected parameters that are archived (such as headrace and tailrace water level, the aggregates' power and discharge) and based on data from the hill charts, losses in pipeline, generator etc. output parameters are defined. Output parameters which are considered as important for the presentation are efficiency of the turbine, generator, hence aggregate, and losses in the operational regimes with the elevation lower than the maximum headrace level. Basic parameters of the aggregates, and generally HPPs' operational regimes, are retrieved through SCADA system, averaged on minute time intervals, and presented for the one month period.

Index Terms - Optimization, SCADA, Efficiency, Hydropower plants, Operational regimes

I INTRODUCTION

According to the contracts and regulations in the Republic of Serbia, EPS is responsible for the balancing of electro energetic system and guaranteed supply of electricity in Serbia. EPS recognized renewable energy sector as a priority for the investments and optimization. Capital projects regarding rehabilitation and building of HPPs are already in the progress. Currently, roughly 30% of electricity generation is from the renewable energy sources (RES), mainly HPPs, representing approximately 3 GW of installed power capacity. EPS recognized three main directions in the process of improving energy production from RES: (1) building of the wind and solar power plants, (2) rehabilitation and building of the HPPs and pumped storage hydropower plants (PS-HPPs), and (3) optimization of the existing plants. For the optimization of the existing plants, EPS technical expert team has analysed and proposed various solutions taking into consideration the low-cost constructive and operative measures for the improvement of the energy efficiency. Monthly report is formed with a defined parameters of the HPPs, and in this paper, general parameters are presented for the HPP Iron Gate 1, and adequately for the one of its aggregates. Methodology and equations that are used are also presented.

Iron Gate 1 is the largest HPP in the Republic of Serbia and one of the largest in Europe, with the 12 (twelve) aggregates that are divided between Romania (six aggregates) and Serbia (six aggregates of 200 MW each). Rehabilitation of the HPP Iron Gate 1 is in the final stage. Rehabilitation of the last aggregate

A3 on the Serbian side is planned for the year of 2022. HPP Iron Gate 1 is working as a first in the cascade with the HPP Iron Gate 2 which is considered a tailrace compensator.

In previous works of importance, related to the optimization of the operational regimes in the HPP Iron Gate 1, were the development of the Hydro-Information System Iron Gate 1 (HIS Iron Gate 1) with the general goal to conduct better understanding of historical and future hydrological events. That work was performed by the Institute for the development of water resources “Jaroslav Černi“ [1]. Index Tests to optimize CAM relation of the Kaplan turbines was done by the University of Belgrade, Faculty of Mechanical Engineering [2].

Previous works of importance, related to the optimization of operational regimes of other HPPs in EPS, were HIS Drina [3], HIS Vlasina [4], Intra-stationary Optimization of Vlasinske HPPs [5] and Index Tests to Optimize CAM Relation of the Bulb Turbines in HPP Iron Gate 2 [6]. Further on, regarding the intra-stationary optimization of the cascade Vlasinske HPPs, software for the joint regulator is in a development phase [7].

II METHODOLOGY FOR THE CALCULATION OF THE AGGREGATES’ EFFICIENCY

In previous years EPS developed central SCADA system PROTIS which integrated all HPPs’ and thermal power plants’ SCADA systems and enabled to retrieve all available data through special application. Parameters and data retrieved from SCADA system are stored on a server, archived and afterward used for the analyses. The use of PROTIS made manipulation and analyses much easier with no need to retrieve data from the HPP and lose time in the process, which led to the smoother research for the purpose of optimization. Parameters of importance that are retrieved from the archive are headrace and tailrace water level, and aggregates’ active power and discharge. Detailed design, and numerous investigations on the mechanical and electrical equipment during exploitation, allowed for reliable information on the losses in the trash rack, pipeline, draft tube, and on the efficiency of the generator. Specified data along with the hill chart of the turbines is used for calculations.

Operating points of the aggregate are averaged for every minute of the exploitation, and the net head is calculated by the equation (1) [8, 9].

$$H_n = H_{br} - h_{los,A-I} - h_{los,II-B} = Z_{HR} - Z_{TR} - h_{TRR} - h_{B-C} \quad (1)$$

where: H_{br} is the gross head, $h_{los,A-I}$ is summary of losses from the headrace to the turbine inlet, $h_{los,II-B}$ is summary of losses from the turbine outlet to the tailrace, Z_{HR} and Z_{TR} are headrace and tailrace water levels, respectively, h_{TRR} is loss in the trash rack, and h_{B-C} is Borda-Carnot loss.

Friction losses may be neglected for the run-of-river HPPs with short pipeline so the dominated loss from the headrace to the turbine inlet is in the trash rack, whereas, dominated loss from the turbine outlet to the tailrace is Borda-Carnot. The losses in the trash rack are defined in a detailed design as a function of the discharge (Q) for the clean trash rack, (eq. 2). Borda-Carnot losses are defined by the equation (3),

$$h_{TRR} = f(Q) \quad (2)$$

$$h_{B-C} = \frac{1}{2gA_{II}^2}Q^2 \quad (3)$$

where: A_{II} is outlet section area, and g is the gravity acceleration. Calculation of the net head for the specific operating regime, with the information on the discharge, gives possibility to unambiguously determine the efficiency of the turbine from the hill chart [10,11]. Depending on the availability of the documentation, it is possible to acquire model or prototype turbine hill chart. For the model hill chart, it is necessary to conduct scale-up of the characteristics for which up-to-date IEC 60193 standard is recommended [12]. In this case, prototype hill chart defined by the net head and discharge is considered, meaning the previous step is avoided. Turbine power can be calculated by the equation (4),

$$P_{TURB} = \rho Q g H_n \eta_{TURB} \quad (4)$$

where: ρ is the density of the water, and η_{TURB} is the efficiency of the turbine. With the known efficiency curve of the generator depending on the turbine power and the power factor, $\cos(\varphi)$, the efficiency of the generator can be determined, and hence the efficiency of the aggregate by the equation (5),

$$\eta_{AGR} = \eta_{TURB}\eta_{Gen} \quad (5)$$

where: η_{Gen} is the efficiency of the generator. Aggregates’ power can be determined by the equation (6).

$$P_{AGR} = P_{TURB}\eta_{Gen} = \rho Q g H_n \eta_{AGR} \quad (6)$$

With the possibility to acquire data of the aggregates’ active power from the SCADA system, it is convenient to compare it with the calculated power and to determine deviations.

III RESULTS

In this section results on the conducted analyses are presented. Figure (1) presents retrieved results from the SCADA on the headrace, including maximum and minimum values, and the tailrace water level, along with the gross head oscillations of the HPP Iron Gate 1 for the one month period.

In figure (2), daily production of the HPP is presented with the partial production of each aggregate. Moreover, energy losses for the operating regimes with a headrace water level that is lower than the maximum, herein defined as headrace losses, are also presented for every day in the one month period.

In figure (3), for the aggregate A2 of the HPP Iron Gate 1, archived, calculated and optimum power are presented along with the time of the operation in the secondary regulation regime, and the HUPX price of the electricity for the one month period [13].

Daily electricity generation of the aggregate A2 for the defined one month period, with the headrace losses is presented in figure (4).

Figure (5) presents efficiency of the turbine, generator and aggregate, along with the values in the optimum operational regime for the aggregate A2 of the HPP Iron Gate 1.

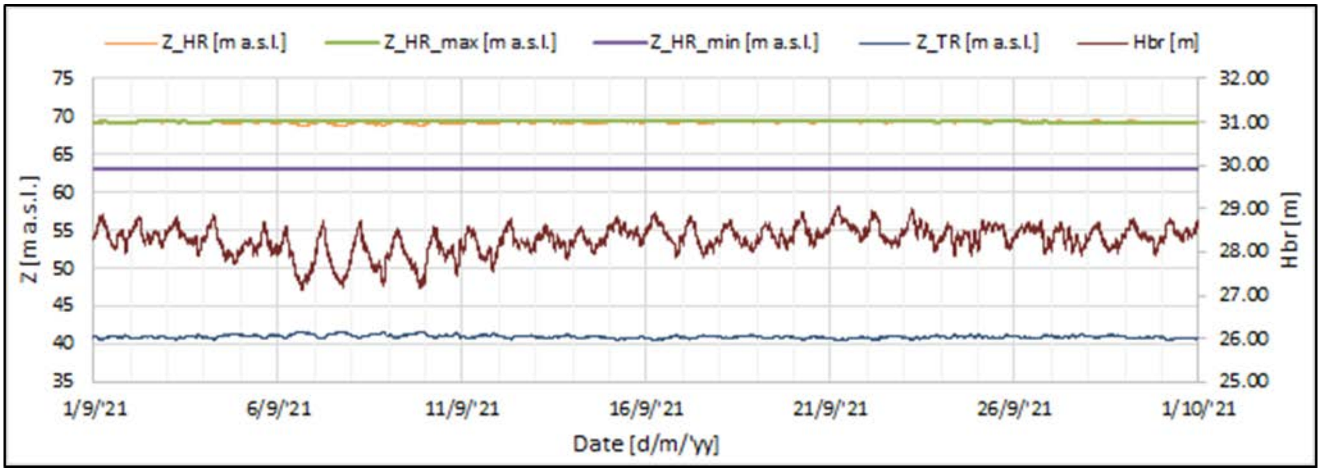

Figure 1. HPP Iron Gate 1 - headrace (archived, maximum and minimum values) and tailrace water level, and gross head

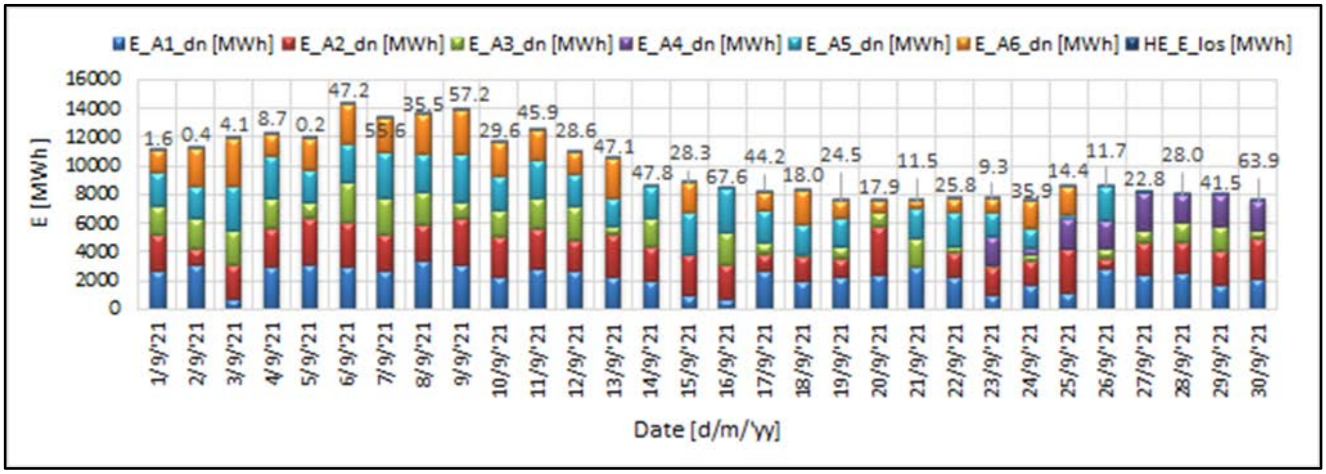

Figure 2. HPP Iron Gate 1 - daily production and participation of all six aggregates, and the headrace losses

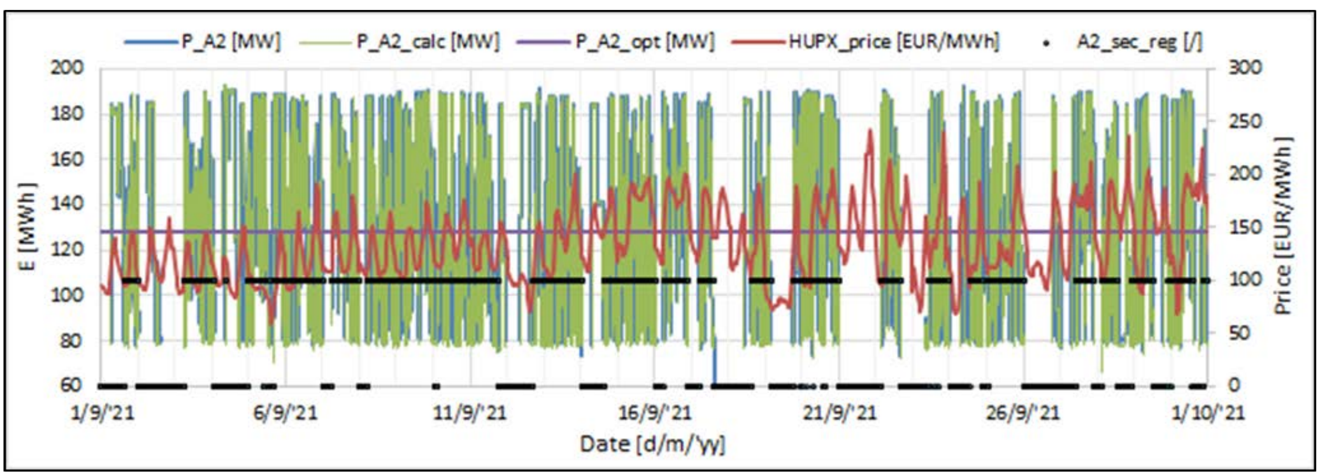

Figure 3. HPP Iron Gate 1 - Aggregate 2 - Archived, calculated and optimum power, HUPX price for MWh and secondary regulation regime

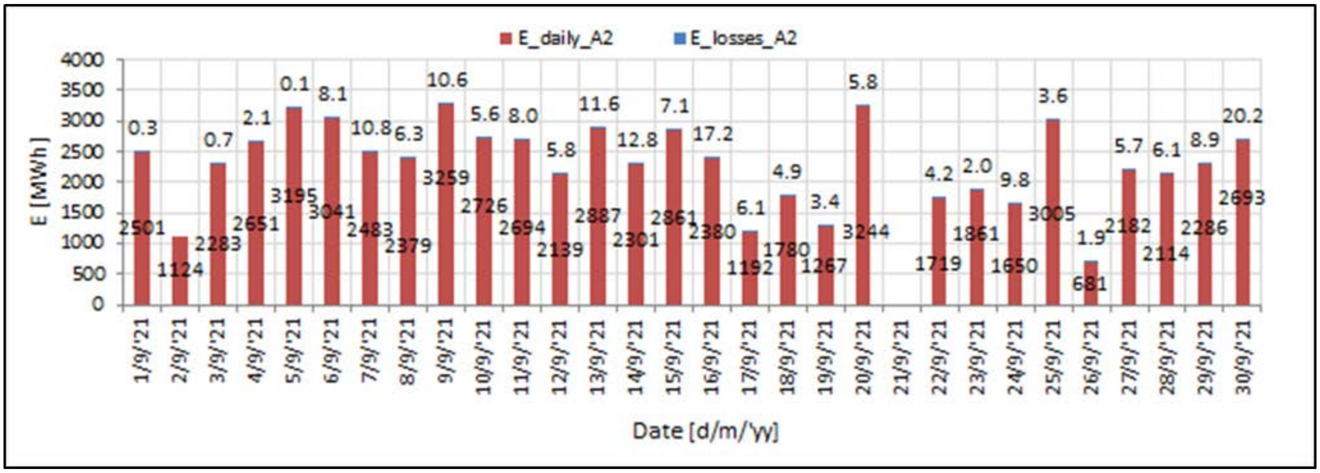

Figure 4. HPP Iron Gate 1 - Aggregate 2 - Daily production and the headrace losses

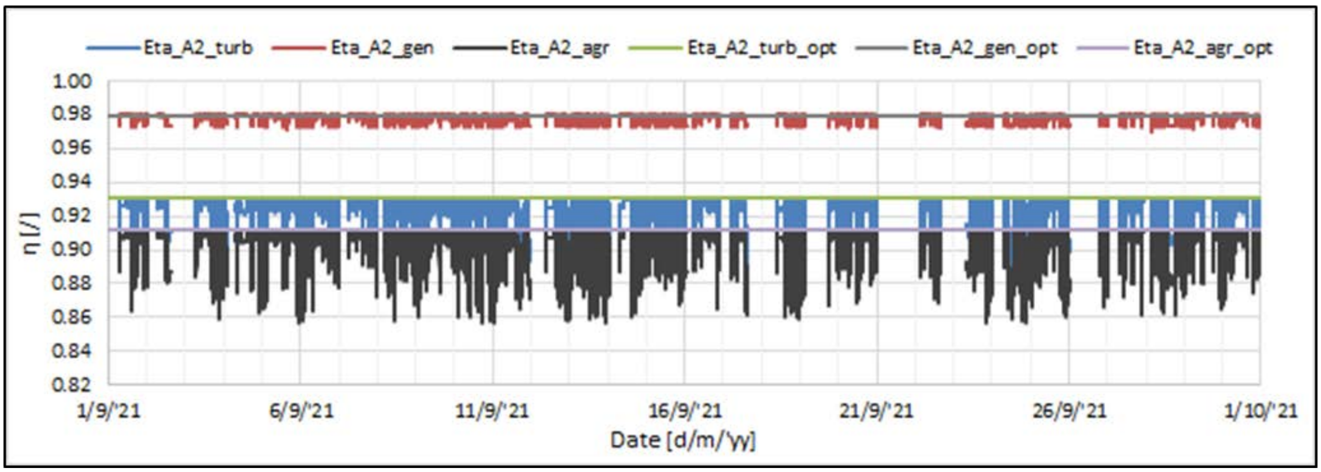

Figure 5. HPP Iron Gate 1 - Aggregate 2 - Efficiency of the turbine, generator and aggregate with their optimum values

Table 1. HPP Iron Gate 1 - Summary results for the period of one month

Aggregate	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**
Monthly production, E_{agr} [GWh]	68.51	**66.58**	39.56	15.44	58.16	45.65
Average efficiency, $\eta_{agr, average}$ [%]	90.27	**90.34**	90.36	90.26	90.35	90.17
Headrace losses, E_{los} [GWh]	0.21	**0.19**	0.14	0.05	0.15	0.13
Time operating in secondary regulation, $t_{SR, rel}$ [%]	/*	**82.30**	0.00	87.15	86.60	26.84
Summary production, E_{HPP} [GWh]	**293.91** (± 4.09)					
Summary headrace losses, $E_{HPP, los}$ [GWh]	**0.87** (± 0.01)					

*Not calculated because of the signal loss

Summary of the results for the calculated and archived production on monthly period show that the relative difference for the aggregate A2 of the HPP Iron Gate 1 is 0.83 % which is considered satisfactory. Summary of the results is presented in Table 1. In Table 1, production of the aggregates, average efficiency, headrace losses, time of the operation in the secondary regulation, and summary of the energy production and headrace losses, for the one month period is presented. Efficiency of the aggregates in the optimum operating point is 91.20 %.

IV DISCUSSION

Lower electricity generation in the presented one month period resulted from the inflow reduction of the Danube River in September 2021. Oscillations of the headrace water level are approximately 0.7 m and infrequent (fig. 1) which implies that the gross head mostly depends on the tailrace water level respecting to the number of the engaged aggregates and to the overspill in flood period.

Simulations of the HPPs' exploitation with the maximum headrace water level is conducted with the methodology defined in this paper, for the real discharge and tailrace values. The difference between simulations with the maximum headrace water level and real-time data is defined as a headrace losses. It can be seen, with the review on the headrace losses and percentage share (fig. 2), that HPPs' headrace is on nearly maximum value most of the time, and that better performance cannot be expected. Maximum values of the headrace water level are not fixed, and they depend on the water level of the Nera River (left tributary of the Danube) on its mouth.

Review on the average efficiency shows that the operational regimes of the aggregates are nearly optimal considering that the optimum efficiency of the aggregates is 91.20 %, and that lowest average efficiency is 90.17 % for the aggregate A6.

Average efficiency analyses shows that the aggregate A3 has the maximum efficiency in the defined one month period. Aggregate A3 is planned last for the rehabilitation, but in the defined simulations hill chart that is used is of the rehabilitated aggregate, because of the simplicity and long-term methodology. There is a slight difference in calculated and real results which directly implies lower efficiency of the aggregate A3 than the presented. Aggregate A3 does not participate in the secondary regulation regime so this may also improve the behaviour and the efficiency.

Comparison of the electricity generation data and simulations for the one month period shows good matching with the difference of 0.83 %. The mentioned difference justifies the trustworthiness of the methodology for the calculations of the headrace losses, and for the further investigation.

V CONCLUSION

As a leading company for the electricity generation and supply in Serbia, EPS permanently invests in the development of the energy resources. EPS participates in the global priority for the renewable energy sources, and realizes investments through the rehabilitation, building and optimization of the HPPs, and further on, wind and solar plants. Technical team for the optimization of the HPPs has been established in January 2020, with the main goal to conduct researches on the low-cost constructive and operational measures for the improvement of the energy efficiency in HPPs. Currently, basic parameters of interest have been determined and the methodology for their calculation created and applied. Monthly reports are made for the HPP Iron Gate 1, HPP Iron Gate 2, HPP Bajina Bašta and HPP Bistrica. In this paper, part of the one monthly report is presented, with the main focus on the HPP Iron Gate 1 as the largest HPP in the Republic of Serbia.

In the further research, all HPPs in EPS will be analysed through defined, or extended methodology, depending on the type of the HPP. Afterwards, each HPP will be analysed in details with the recommendations of the possible improvements.

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