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Evaluation of Energy Contribution for Additional Installed Turbine Flow in Hydro Power Plant

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ABSTRACT
The paper presents the methodology for analysis of energy value of existing hydro power plant (HPP) comparing with the same HPP upgraded with additional power. The additional power can be added with installed turbine flows of existing unit(s) or with installing the new additional unit(s). The paper treated the energy evaluation of the storage HPP Spilje which is under installed HPP comparing the technical parameters, water reservoir, turbine discharge and water inflow. The analyses have been made based on the statistical analysis of the input parameters of hydrology through a series of hydrological inflow data for a long period of years with monthly distribution. The hydrological data (from 1970 until 2014) which covers extremely wet and extremely dry hydrological periods, which is important in order to get statistics of expected values with appropriate probabilities of occurrence – data from monthly inflow values [1]. The results from analysis can be applied in determining the expected hydro production, or appropriate expected revenue of the electricity generated from the HPP. The additional turbine flow in existing units or installing the new unit(s) can benefit with increased income coming as the result of avoiding spilling water and generating additional peak energy instead of base one.
***Keywords* -** Hydro power plant (HPP), energy, installed power, turbine discharge, water reservoir

I. INTRODUCTION

Hydroelectric power plants (HPP) are high investment projects that require serious and comprehensive analysis in terms of energy benefits and financial effects of the project. The results from HPP Spilje are presented with energy and financial benefits from additional increased turbine flow comparing with investment costs for the new unit.

The analytical approach of analyzing the possibility for additional installed turbine flow in existing hydro power plant is based on experience from operation life. First approach is to have indicators for additional installed power and discharge, and then [2] follows the energy analytical approach and economical analysis of the investment.

As study case for analyzing of additional installed turbine flow in a new unit is the hydro power plant (HPP) Spilje, which is part of the hydro system (HS) of Crn Drim.

Figure 1 shows the layout of the existing power system of Crn Drim with existing HPP Spilje (with 3 units) and additional same size unit.

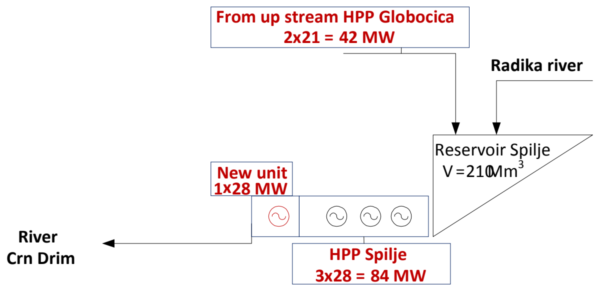

Fig.1. Layout of the HPP Spilje with new unit in a existing power house

Increasing the installed power of HPP Spilje [3], with construction of additional unit in the same power house will get more benefits, such as:

- Additional generated electricity from HPP Spilje.
- Higher operating power level of the HPP in the periods of high tariff as peak power plants in liberalized electricity market, which means higher income for the power plant and for the company as the operator of the HS Crn Drim.
- Avoiding or reducing overflows (spilling water) during periods of high inflows, and
- Ability to optimize the operating modes of the whole hydro power system of river Crn Drim.

II. TECHNICAL PARAMETERS OF HES CRN DRIM

The hydro energy system of Crn Drim consists of two cascade hydro power plants HPP Globocica and HPP Spilje and three water reservoirs Ohrid lake, Globocica Lake and Debar Lake, which operate over 50 years. The paper is focuses on hydrology data for HPP Spilje, which is on Debar Lake with 210 million m3. The installed turbine flow for each of the 3 units is 36 m3/s, or the total turbine discharge is 3x36 m3/s = 108 m3/s. The average gross head is 90 m, and the installed power of the generators are 3 x 28 MW = 84 MW [4].

Based on the hydrological data of the water inflow for the last 45 years in the Debar Lake which is the reservoir for HPP Spilje (Fig.2.), the average annual value is 47,48 m3/s.

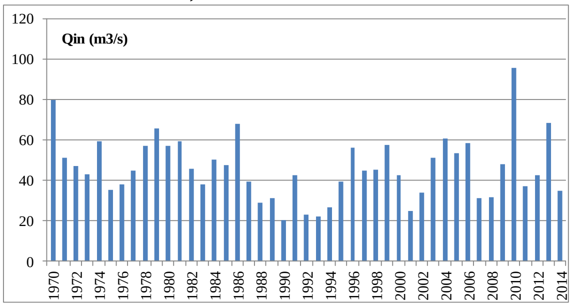

Fig. 2. Average yearly water inflow for the period 1970-2014

The basic idea comes from comparing the ratio between total turbine discharge and water inflow which is input data from hydrology and technical parameters of the HPP. This factor (K_Q) for HPP Spilje is:

$$K_Q = \frac{Q_{turbine\ flow}}{Q_{year}^{averager}} = \frac{108}{47,48} = 2,27 \qquad (1)$$

For storage HPP with reservoir, this coefficient should be in the level from 3 to 6, which depend on the volume of the reservoir. Hydrology and especially water inflows of the basin are the most important parameters in energy analyses, as well as technical parameters of HPP units. This affects of the expected production of electricity and on the benefits from electricity generated from the HPP. The other important parameter is the factor of reservoir capability (KV), which is the ratio between yearly water flow and storage capacity. For HPP Spilje it is:

$$K_V = \frac{V_{year}}{V_{reservoir}} = \frac{47.48 \cdot 3600 \cdot 8760}{210 \times 10^6} = 7,13 \qquad (2)$$

This parameter shows that, approximately more than 7 times in a year the reservoir is fully loaded and unloaded throw turbine units discharge in a year. All these analyses are made on the data for monthly water inflow for the period of 1970-2014 with computer simulations for the whole operation period. The energy contribution of the HPP Spilje is in electric power system [5], according energy market roles [6].

A. Energy value of the hydro power plant

Analysis of the electricity production for HPP Spilje are performed based on the water inflow in the reservoir taking into account the assumption of the tariffs in the liberalized electricity market shown in Tab.1. and Fig.3.

Table 1. Tariff intervals and the electricity prices during 24 hours

	Base	Medium	Peak
Duration (h)	7	10	7
Price – C (Euro/MWh)	40	60	80

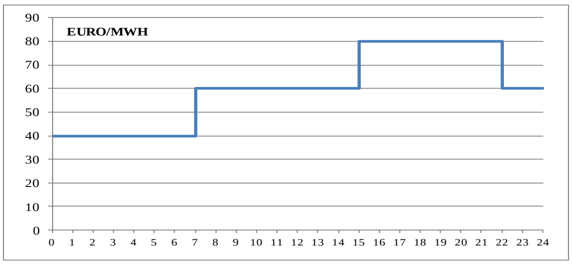

Fig. 3. Tariff prices for electricity in a period of 24 hours

The energy corresponding to the water inflow can be divided into 2 parts: the electricity production which is delivered in the grid and the lost of energy due to overflow as spilling energy, is:

$$W_{total} = W_{production} + W_{spilling} \qquad (3)$$

The electricity production ($W_{production}$) can be separated according tariff model in 3 parts: base energy (W_{base}), medium variable energy part (W_{medium}) and peak energy (W_{peak}), as the following:

$$W_{production} = W_{base} + W_{medium} + W_{peak} \qquad (4)$$

The loss of electricity due to spillway (Wspilling) is calculating with the price of 60 Euro/MWh. Tab.2 shows the annual electricity production (GWh) according to the tariff model, as well as the energy lost as spilling one.

Table 2. Electricity production and lost spilling energy in a year

W_{base}	W_{medium}	W_{peak}	$W_{product.}$	$W_{spilling}$	W_{total}
16,30	89,61	173,21	279,12	8,11	287,23

The result of the simulation for electricity production and the lost spilling energy for the period 1970-2014 is shown on Fig.4.

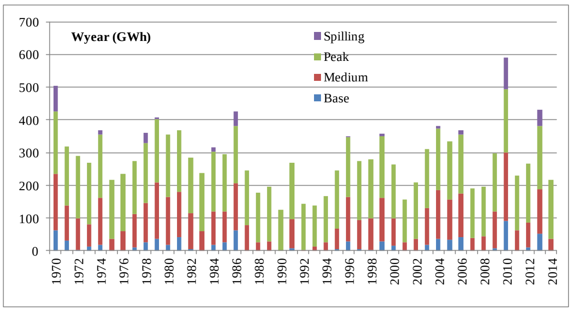

Fig.4. Electricity and lost spilling energy for period 1970-2014

B. Income from generation electricity

The main income is from electricity production (INCOME) which is calculated according tariff model.

$$INCOME_{prod} = P_{base} + P_{medium} + P_{peak} \quad (5)$$

$$INCOME_{prod} = W_{base} \cdot C_{base} + W_{medium} \cdot C_{mesium} + W_{peak} \cdot C_{peak}$$

The loss income from spilling energy (LOSS) is calculated according the price of 60 Euro/MWh.

$$LOSS_{spilling} = P_{spilling} = W_{spilling} \cdot C_{spilling} \quad (6)$$

Table 3 shows the results of calculated income and lost income per year, for the existing HPP Spilje (3 units with 108 m^3/s).

Table 3. Income and the lost from spilling in M€ (3 units)

P_{base}	P_{medium}	P_{peak}	I_{ncome}	L_{ost}	Total
0,65	5,38	13,86	19,89	0,49	20,37

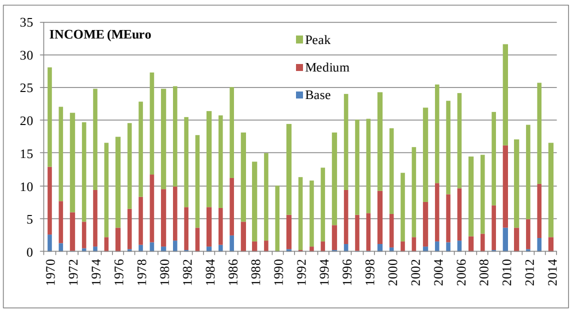

Fig. 1. Income in a year according tariff model for 1970-2014

Figure 5 gives the graphical overview for the income parts (from base, medium and peak energy) as a total income per year for the period 1970-2014.

III. EVALUATION OF ADDITIONAL INSTALLED POWER IN HPP

According to the technical performance of existing HPP Spilje and the set of hydrological data, the simulation is made for the expected production with installing additional unit in the same power house. The new unit is the same as the existing ones, with installed turbine flow of 36 m3/s and installed power of 28 MW (Fig.1.). The energy benefit and the corresponding financial impact of new additional unit in HPP Spilje can be calculated in two cases:

- Utilization of lost spilling energy into income
- Higher electricity production in periods of high tariff instead of low tariff rates

Table 4 shows the results of calculated income and lost income in a year according (5) and (6) for the existing HPP Spilje with additional unit (4 units with 144 m3/s).

Figure captions appear below the figure, are flush left, and are in lower case letters. When referring to a figure in the body of the text, the abbreviation "Fig." is used. Figures should be numbered in the order they appear in the text.

Table 4. Income and the lost from spilling in M€ (4 units)

P_{base}	P_{medium}	P_{peak}	Income	Lost	Total
0,34	4,31	17.22	21,87	0,12	21,99

The financial benefit from additional installed unit in a hydro power plant can be calculated as the difference income according following relation:

$$\Delta INCOME_{prod} = \Delta P_{base} + \Delta P_{medium} + \Delta P_{peak} + \Delta P_{spilling} \quad (7)$$

Table 5. Comparing the electricity production (in GWh) for both cases (existing HPP with 3 units and the same one with additional unit – 4 units)

	W_{base}	W_{medium}	W_{peak}	W_{prod}	W_{spill}	W_{total}
4 units	8.38	71.90	215.24	295.51	1.97	297.48
3 units	16.30	89.61	173.21	279.12	8.11	287.23
dW	-7.92	- 17.71	42.03	16.39	-6.14	10.26

Table 6. Comparision of the income for both cases (existing HPP with 3 units and the same one with additional unit – 4 units)

P(M€)	P_{base}	P_{medium}	P_{peak}	P_{prod}	$P_{spilling}$	P_{total}
4 units	0,34	4,31	17,22	21,87	0,12	21,75
3 units	0,65	5,38	13,86	19,89	0,49	19,40
dP	- 0,32	-1,06	3,36	1,98	- 0,37	2,35

The expected average annual additional financial benefit from additional installed unit in HPP Spilje is 2,35 million, of which 1,98 M€ as additional revenue generated from the higher peak power instead of the base one, and 0,37 M€ is income from the spilling energy.

A. Financial analysis for new unit

The investment to build a new unit in HPP Spilje depends on the technical design and construction works. For the case of new unit in the same power house, the main investment are for electrical and mechanical equipments, because the same existing dam and reservoir. The investment costs [3] for an additional unit in HPP Spilje with installed power of 28 MW same size as the existing ones, is estimated on 25 M€.

For the financial analyses the total amount of investment of the project is taken three values, the highest of 30 M€, an average of 25 M€ and the lowest 20 M€. The benefit is based on difference from electricity production of the HPP Spilje with additional unit and the existing HPP Spilje, which is around 2,35 M€ in a year.

The input economic parameters are: discount rate of 6%, the construction period of three years, interest rate for the loan of 4% and the repayment period of the loan is 15 years. The basic economic indicators NPV (Net Present Value), B/C (Benefit/Cost) ratio and PBP (Pay Back Period), are calculated for the 30 years of economic life of the project. The results are shown in Tab.7 for three different cases of investments.

Table 7. Economic indicators NPV, B/C, and PBP for three cases of different investment costs

Investment (M€)	**Electricity(€/MWh) Base_ Medium _Peak**	**NPV**	**B/C**	**PBP**
20	40 _ 60 _ 80	11.45	1.71	10
25	40 _ 60 _ 80	7.75	1.38	15
30	40 _ 60 _ 80	3.64	1.15	22

All variants show positive financial benefits of building new unit in HPP Spilje. The price of electricity can be change through the operation period which depends on electricity market, but there is still possibility to have positive benefit even with low prices.

IV. CONCLUSION

The new operating environment for the hydro power plants in liberated electricity market can encourage the Investors to take some investments in order to improve operation condition of the existing units. Besides the routine O&M of the plants, the additional step for increasing the installed turbine flow in new units or in existing ones can increased the power output, as well to improve the efficiency of the HPP. On the other hand, the energy analysis are very significant for improving the technical performances of the HPP in increasing the installed turbine flow in existing units, or to install additional unit(s) in the power plant.

Therefore, the contribution of the input data for water inflow, as well as the historical operation data of the hydro power plant is very important as the main indicators, to have precisely values of expected income from generation electricity of additional inflow. Economic parameters as investment costs depend on the technical solution, time of construction, the discount rate and the rate of loans, prices of generated energy and power engaged, and the operation costs. After appropriate processing of the necessary input parameters, follows the financial calculations of economic indicators, which give a certain image for the feasibility of the project.

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