UPGRADING OF THE SPILJE HPP

J. Ivanova-Davidovic, V. Cingoski, V. Pavleski, V. Savevski

Abstract: Total generation capacity of the electric power system of Republic of Macedonia is 1444 [MW], out of which 1010 [MW] are installed in TPP and only 434 [MW] in HPP. The hydropower production is subordinate to the thermal one with a specific and highly defined role in the whole electricity sector. HPP Spilje usually operates so the available water storage is used rationally and the overflows are minimal. This was achieved by enlargement of the water storage useful area as a result of the decreasing the minimal operation level. This paper deals with some additional possibilities for further upgrading of the installed capacity of this power plant for achieving better operational performances.

1. Introduction

Electric power supply in Macedonia is run, controlled and managed by the sole joint stock company Electric Power Company of Macedonia (ESM) with the state ownership. ESM owns the following power generation plants:

Hydro Power:	*6 Plants, Total Generating Capacity*	*434 [MW]*
Thermal Power:	*3 Plants, Total Generating Capacity*	*1,010 [MW]*
Total Generating Capacity:		*1,444 MW]*

Accordingly, the largest part of the electricity generation in Macedonia is produced by Macedonian thermal power plants (over 75 %). The hydropower generation is subordinated to the thermal one with a specific and highly defined place and role in the whole electricity sector, mainly as a peaking capacity, rotation reserve and secondary & tertiary energy reserve for the system. The maximum peak of electric power demand of 1,320 [MW] was achieved on 2002, January 6th and the minimum peak of only 322 [MW] happened on August 4th, showing large difference between seasonal power demands in the country. In the same time, daily power demands are also strongly variable. Having in mind that the achieved peak demand of 1,320 [MW] in respect to the total installed capacity of 1,444 [MW] means only margin of 8.5 % necessity of additional power capacities becomes evident.

In the Macedonian power network, similarly as in the neighboring countries, the daily power demand changes have large influence and brings to the confrontation between existing power units towards considerable variation in demand and/or too frequent start-ups and shutdowns of the existing hydropower plants. This results with increase of the importance of maximal possible usage of all available generation capacities and their ultimate increase, flexibility of operation and reliability of the existing power plants.

On the other hand, HPPs produce electricity drawn from ecological friendly and renewable energy sources, and in the same time it is very profitable native energy resource. In case of Macedonia, although hydropower plants account for less then

20% of the total electricity produced, they are very important due to a very simple reason: beside all network regulation aspects, a lack of productivity in one of these power plants would inevitably either lead to an increase in air pollution due to increase in energy production from thermal power plants or have bad economic consequences for Macedonia as a result of its dependences on foreign energy imports paid on higher prices.
Thus, strategically speaking, it is very important for Macedonia to be able to maintain or, if possible, and/or to increase its portion of hydro energy production. Therefore, it is definitely necessary and fully justified to make any efforts in order to increase the reliability and installed capacity of the existing hydro power plants.

2. Existing HPP Spilje

HPP Spilje was put into operation in 1969. A reservoir is formed by rockfill dam with height of 100 [m]. Total volume of the reservoir is 520 millions [m^{3}] and useful volume is 223 millions [m^3]. The designed normal working level is 580 [m.a.s.l.] and designed minimal working level is 575 [m.a.s.l.] With the reservoir Spilje total Crn Drim river basin in Macedonia is regulated. The Power Plant is located at the joint spot of the two rivers Crn Drim and Radika, therefore the inflow regime to the reservoir depends on the water regime of the both rivers. The inflow from the river Crn Drim is quite steady during the year, because of the existing upstream reservoirs: Ohrid Lake and the reservoir of HPP Globochica. The river Radika is not regulated and the water regime is natural and unsteady because of the climate characteristics. Total average inflow to the Spilje profile is 1692 million [m^3].

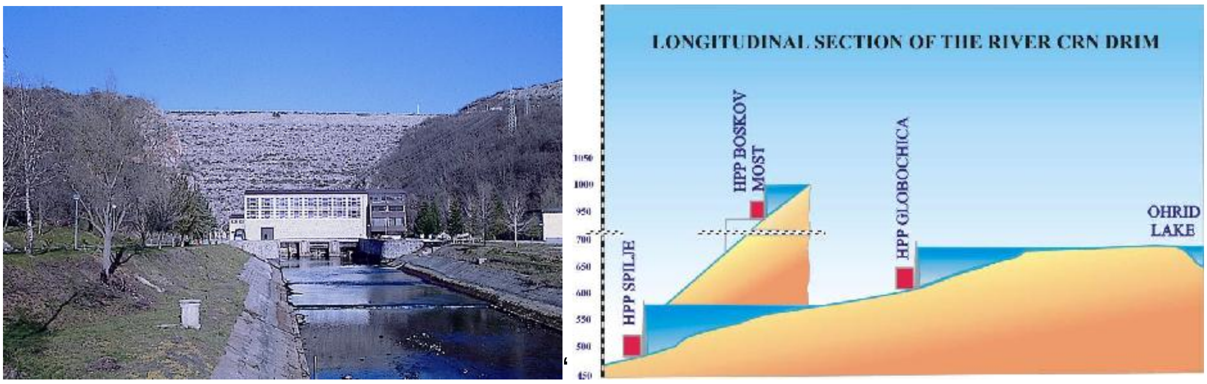


Fig 1. HPP Spilje - view from the tailrace & longitudinal section of the Crn Drim river basin.

On the left riverbank the evacuation structures such as: the diversion tunnel, overflow shaft and bottom outlet are located. The powerhouse is located approximately 70 [m] downstream the dam shear. There are three units with Francis type turbines – vertical axis and three phase synchrony generators. The turbine elevation is 485.75 [m.a.s.l.] Three step-up transformers are located outside powerhouse. The area between the dam shears and powerhouse is reserved for the 110 kV switchyard.
The length of the penstock is 321.65 [m] with diameter of 4.50 [m], and V= 5.66 [m/s]. The inlet structure sill is on elevation 546.00 [m.a.s.l.] The penstock in all length is lined with steel lining, thickness of 13 [mm]. The penstock has three branches with diameter of 2.20 [m] each. The width of the tailrace is 26.62 [m]. The tailrace elevation is 485.35 [m.a.s.l.]

HPP Spilje was designed and constructed with installed capacity of 3 x 22 [MW] and annual generation of 384 [GWh]. Between 1997 to 1999, a rehabilitation of all three existing units has been performed, increasing the installed capacity from 3 x 22 to 3 x 28 [MW], and the installed flow from 30 m^3/s per unit to 36 m^3/s.

3. Operation of HPP Spilje and problems appeared during exploitation

During plant's operation the available water was used rationally and the overflows are minimal. This was achieved by enlargement of the storage useful area by decreasing of the minimal operation level, form optimal of 575,00 [m.a.s.l.] to 562,00 [m.a.s.l.]. This has enabled better regulation of the flows and prevented the overflows, but it has decreased the net head of the power plant and also the power and the electricity generation.

Optimal way, to solve the both previously mentioned problems, is enlargement of the installed capacity at the hydro power plant. This will obtain increased electricity generation (because of the decreased overflows and increased net head of the plant) and increased power of the plant, which is of great importance in terms when 80% of the generation in the electric power system is realized by thermal power plants.

4. Possibilities For Upgrading

Enlargement of the installed capacity would cause increasing of electricity generation, which is not a basic reason for enlargement of the installed capacity, although benefits from this can not be neglected. More significant reason is increasing the power plant adaptability for larger changes to the electric power system loads. Achieved capacity during the operation of the power system in peak loads represents quality, which value is much bigger in respect to the capacity increase and power generation obtained from other run of river HPP or TPP.

Increasing of the capacity of HPP Spilje can be evaluated as a saving of the expensive fuel in some thermal power plant. In the period of high volume waters with increased generation of the plant operated as a run of river HPP, some TPPs can be switch off from the system or work with lower capacity. In the time when all energy power is necessary to be put into the system, this upgrading of installed capacity should be strongly respected and encouraged.

Taking into account all previous mentioned for importance and role of hydro power plants in the future electric power system in Republic of Macedonia, the need for upgrading of HPP Spilje becomes highly reasonable [2], [3]. Therefore, the main question to be answered is the method and the amount of upgrade.

5. Analysis Of The Variants

During initial design of HPP Spilje, possibility for change of the basic plant parameters was not considered. Therefore, any changes to these basic parameters have influence to the existing plant structures.

Existing powerhouse was designed for three units, with all necessary equipment for installation, operation and maintenance, thus for installation of new unit additional area for this unit and its auxiliary equipment is necessary to be provided. For that

purpose, extension of the existing powerhouse or construction of new one should be provided.
Regarding the head race for the new unit two variants are possible:

- **Variant A: Existing intake tunnel to be used for new unit** – in this case hydraulic losses would increase, thus electricity generation respectively would decrease. The biggest problem would appear during connection of new unit to the existing penstock. Taking into account location of the penstock, that means partial demolition of the existing110 kV switchyard and stop off of the power plant operation for some period, or
- **Variant B: New intake tunnel to be constructed** – in this case above-mentioned problems could be avoided, but there is still a problem caused by construction of new inlet structure and new intake tunnel with full water reservoir.

Upgrading of the power plant's installed capacity would also have some influence to the existing tailrace, i.e. for additional outflow, the tailrace should be reconstructed. Also, the existing 110 kV switchyard should be reconstructed and a new 110 kV bay should be added.

6. Possible Locations Of The Intake Tunnel and Powerhouse

General disposition of the structures give opportunities for several locations of the intake tunnel and powerhouse but actually following two variants are the most favorable and feasible solutions for enlargement of HPP Spilje:

<u>Variant A</u>
New powerhouse is a part of the existing powerhouse in its continuation on the right bank of the river, where existing workshop and generation units are located. The existing penstock should be used and only new bifurcation and penstock with length ~ 50 [m] is necessary. The new tailrace with 45 [m] length should be connected to the existing one at the end of quay wall.
The main advantages of Variant A are:

- Short length of the new penstock allows faster construction and putting into operation of the upgraded power plant;
- With allocation of the new powerhouse as a part of existing powerhouse in its continuation, the same erection area can be used, also the existing equipment (crane for example) can be used, which results with savings in the operation cost.

Disadvantages of Variant A are:

- Dislocation of the workshop and generating sets is necessary;
- Allocation of the surface penstock near and above downstream support dam body initiate possible danger for the dam safety, in case of penstock damages;
- Penstock, located close to the powerhouse, is entering the 110 kV switchyard, so part of the 110 kV switchyard should be demolished and rebuild. Thus, during the period of new penstock construction, the existing power plant could not operate (at least not that 110 kV bay);
- Construction of the powerhouse and tailrace is complicated because of the limited construction area. Therefore, a special organization of the site works is necessary. The construction works should be performed in the way to allow operation of the existing power plant. The additional problems are the

foundation works on the new powerhouse. During the works on the construction pit, filtration water could be expected;

- The tailrace reconstruction would make difficulties to the powerhouse access;
- Topographic conditions of this location enable upgrading with only one additional unit, thus the existing penstock could be used for 28 [MW] (36 [m^3/s]) unit output. For larger power capacity of the units, it is necessary to increase the width of the powerhouse, so existing overhead crane and erection bay could not be used.
- Connection of the new unit with the existing penstock results with no operation of the power plant during the construction period;
- Head losses will be increased and consequently the overall power plant output will be lower.

<u>Variant B</u>

Intake facility is located 60 m from the existing one and it is in the form of a reinforced-concrete tower. The sill of the intake facility is on the level 562,00 m.a.s.l. Next to the intake facility is the closing facility. The penstock is tunnel type in a length of 114,50 m, and the surface pipeline in a length of 301,20 m. The penstock diameter is 5,00 m, in a tunnel part it is concrete coated with steel sheet over it, and the other part is a surface steel pipeline. The powerhouse is located on the right bank of the river Crn Drim, 120 m downstream the existing powerhouse. A unit consisting of Francis turbine with a vertical axis and a 3 phase-synchrony generator is settled in the powerhouse. The tailrace, to the joint with the existing tailrace, is of 11,0 m length.

Concerning the increasing of the capacity of HPP Spilje for this variant studies and Primary Design for HPP Spilje 2 [2], [3], has been made. Power increase of 70 MW, that means increase of the installed flow of 90 m^3/s, has been accepted in the Primary Design [3].

Advantages of this variant are:

- Disposition of the new penstock and powerhouse allow conditions for continuous operation of the power plant during the entire construction period;
- The location of the surface pipeline, presents no danger for the dam during eventual damage of the pipeline;
- Location of the powerhouse give opportunity for applying of one or two units;
- Location of the powerhouse allows good organization of construction works especially mining works;
- Geological conditions of the penstock route and powerhouse location are favorable;
- Because of the longer distance from the reservoir, lower quantity of underground water in powerhouse construction pit should be expected;
- The length of the new tailrace is lower than in other variant.

Disadvantages of this variant are:

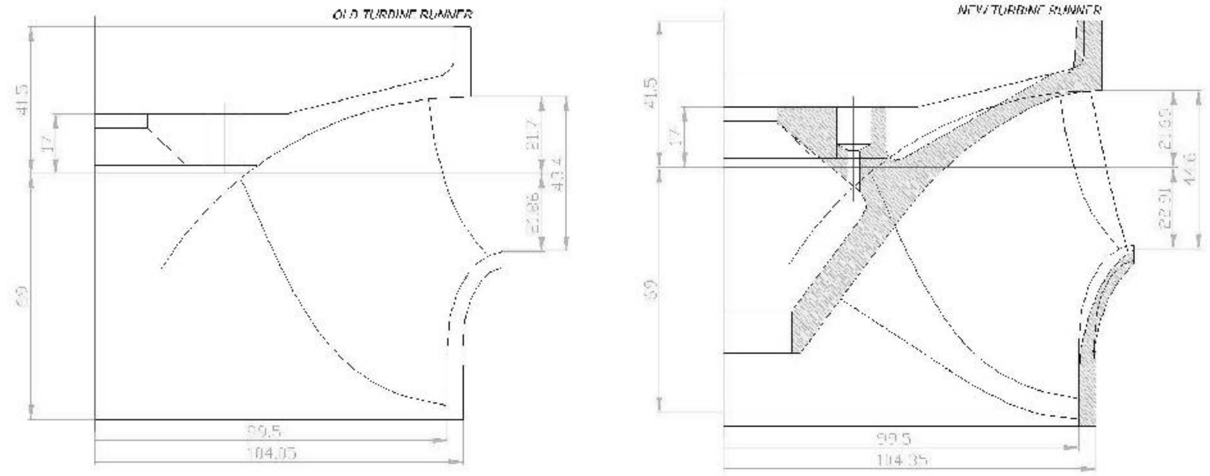
- Relatively long penstock;
- Construction of a new powerhouse with all additional equipment;
- Two powerhouses increase the maintenance and operation costs;
- Deeper embedment of the new powerhouse to allow good access is necessary.

7. Evaluation of the benefits of power plant upgrading

Having in mind that variant B involves large investment cost and longer preparation, and in the same time taking into account that with the last rehabilitation of the power plant (1996-1998), the rated water discharge was increased from 28 [m^3/s] to 36 [m^3/s], the available amount of water for the fourth unit was decreased from initial 90 [m^3/s] to 90 – (3 x 8) = 62 [m^3/s], it seems hard to financially justify a whole new powerhouse for a single unit of 62 [m^3/s]. Therefore, we concentrate our efforts mainly on the benefits that the new fourth unit could bring to the existing power plant if it is installed in the continuation of the existing powerhouse with some possible modification of the existing turbine runners.

Recently performed rehabilitation of turbine runners of the HPP Tikvesh which is identical power plant to the investigated HPP Spilje [4], show that a space for further improvement of the existing turbine runners at HPP Spilje still exist. Fig. 3 shows vertical cross-section of the existing (old) turbine runner (a) and possible new modified turbine runner for HPP Spilje that enables even better operational performances of the whole plant.

Figure 4 shows achievable increase of the installed capacity of the plant working with one to three units simultaneously and with just replacement of the existing turbine runners with new modified ones as shown in Fig. 3. The calculations show that the capacity increase is between 2 [MW] for one unit up to 4.5 [MW] for three units. In addition, Fig. 4 shows that by addition on the new fourth unit the total capacity increase for the whole plant could be as high as 25 [MW] for minimum storage level, up to 34.5 [MW] for maximum storage level.



(a) (b)

Fig. 3: Comparison of the existing with new modified turbine runner for HPP Spilje.

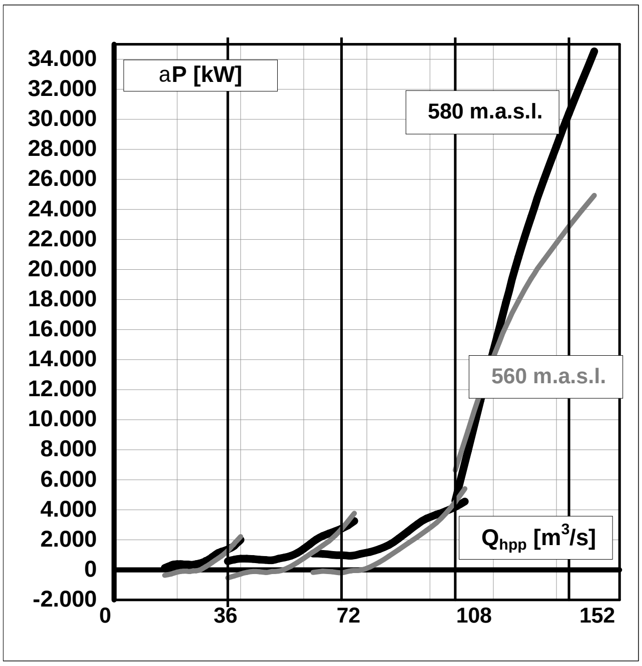


Fig. 4: Increase of installed capacity.

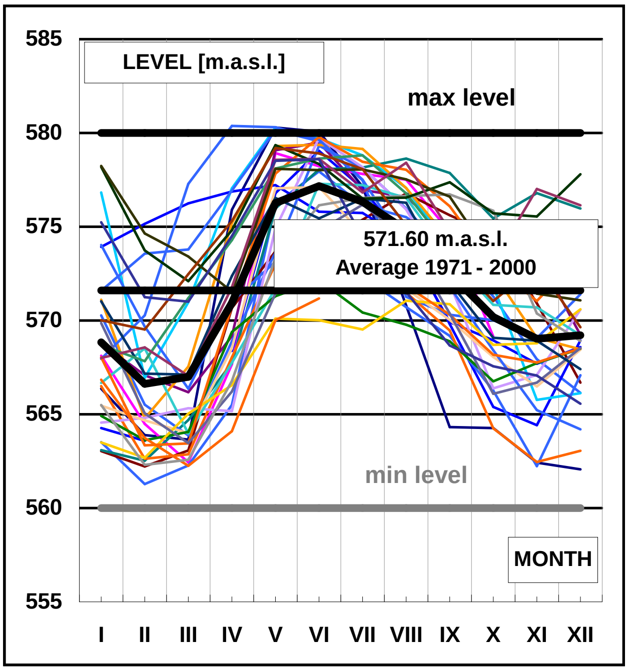


Fig. 5. Average storage level.

The achievable improvement of the performances of the power plant can be also estimated from the average monthly and yearly net head of the storage lake shown on Fig. 5. One can easily conclude that with increasing of the installed capacity the average storage level could move upper in the area of higher levels which first increases the efficiency of the whole power plant and second enables increase of the electricity production as a result of better and wider water catchments in the storage lake.

The other issue that has to be taken into account is the increase of the head losses due to increase of the water discharge through the existing intake tunnels as shown in Fig. 6. As can be seen, adding new fourth unit as expected would increase the losses from 3.3 [m] to approximately 5 [m] or for about 50 %. However, the benefits from addition of this new unit by far exceed the drawback of increasing the net head losses. This is visible from next Fig. 7, where the increase of the rated capacity of the units are shown in case of existing runners, new modified runners and upgrade of the plant with new fourth unit. With replacement of the existing runners with new improved once and with addition of the fourth unit, this power plant would have rated capacity of 116 [MW] with rated water discharge of 114 [m^3/s] at maximum storage level of 580 [m.a.s.l.]. This is the total increase of 32 [MW] from the existing rated capacity of this power plant of 84 [MW].

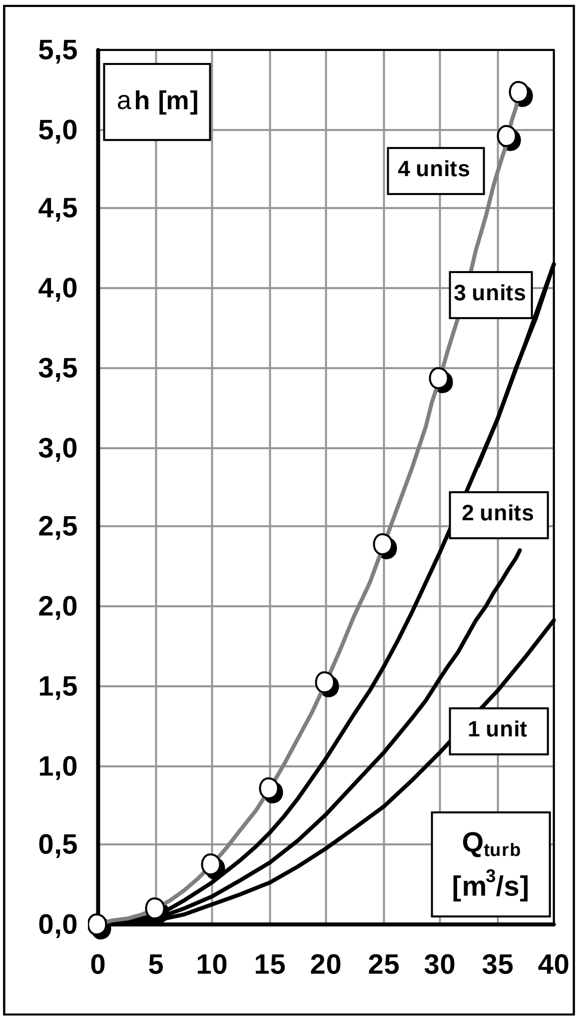


Fig. 6: Increase of net head losses.

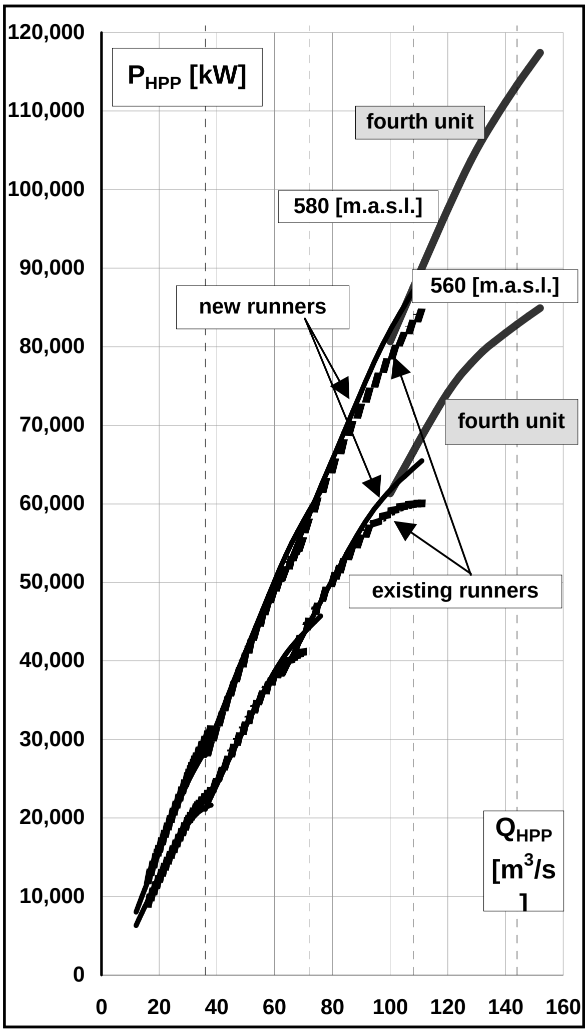


Fig. 7: Increase of the installed capacity.

Finally, and probably most important issue in the presented upgrade of HPP Spilje, is the efficiency of each unit and of the whole set of four unit, i.e. the overall efficiency of the power plant. This is shown on Fig. 8 for both storage levels, the maximum one of 580 [m.a.s.l.] and the minimum storage level of 560 [m.a.s.l.], and for the existing runners, modified runners and the fourth runner. It is visible that: (1) the efficiency of the new runners are higher than the existing once for a single unit and for each set of the units, respectively, and (2) the total plant efficiency is higher for the plant with four units (with additional forth unit) than the total plant efficiency of the existing power plant with three units and old (existing) runners. Therefore, in conclusion, this analysis shows that although at the end the net head losses increase almost for 50 % than the existing once, the final benefit of replacement of existing runner and upgrading with one more unit is strongly advisable and bring huge benefits for this power plant and for the whole energy system in the country.

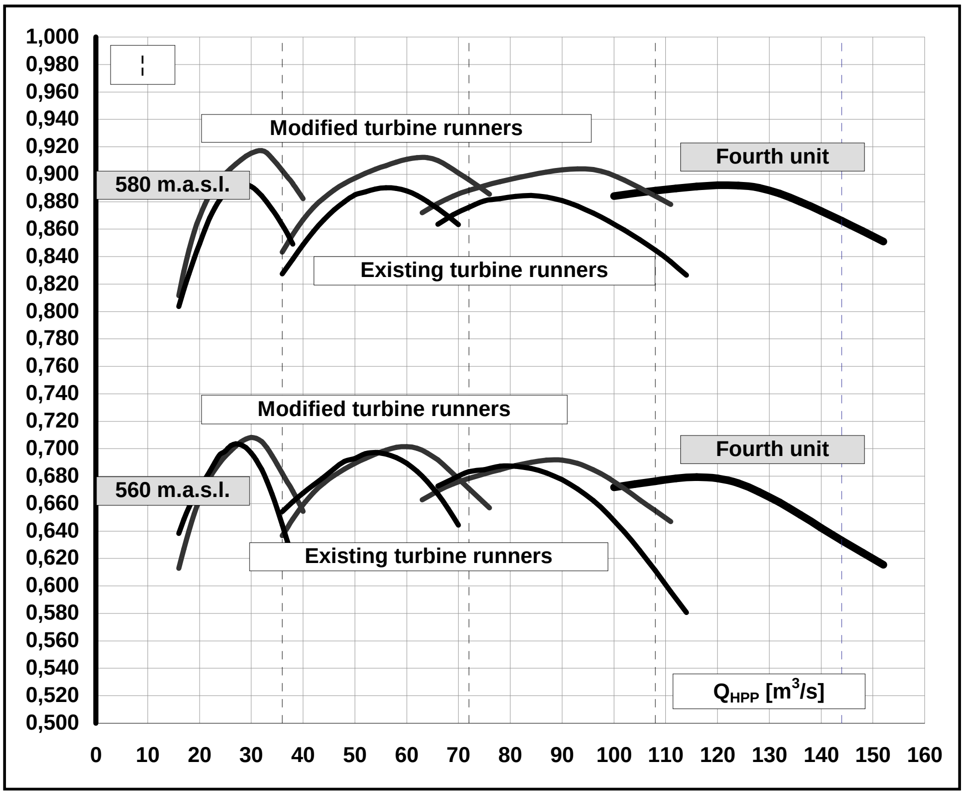


Fig. 8: Comparison of the plant efficiency for the existing and upgraded power plant.

8. CONCLUSIONS

The benefits that the rehabilitation of runners and upgrading of this HPP brings to the plant and to the electricity system in general are briefly discussed in this paper. However, for making final decision, additional mainly economical analyses and calculations should be performed. The influence of the outflow from the powerhouse in the region downstream of the power plant, and a possible flush of the part of the Crn Drim river bed in Republic of Albania, especially for variant B, where the unit discharge is envisaged at 90 [m^3/s] should be also taken into account at the final decision making process. The other crucial factors during selection should be conditions and possibilities for financing of the whole project.

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