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Contents

Prospects for Pump Storage HPP in Macedonia

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Abstract: The necessity of the development of new pump storage HPP in the Republic of Macedonia, mostly in the context of the liberalization of the energy market, was considered as a priority in the country's energy policy due to the following reasons:

- Macedonia has favorable topography and geology for construction of pump storage HPP,
- Favorable geographical position and sufficient regional electricity interconnections, especially with countries with dominant thermal power generation,
- Large potential for inclusion of newly developed renewable energy sources with stochastic nature of generation, in particular PV, wind, solar and small HPP.

Although, the technical feasibility for the development of pump storage HPP was proven, the past feasibility analyses questioned their economic viability and led to somehow wrong conclusions that the Macedonian Power System itself is well balanced even without any pump storage HPP. However, taking into account the above mentioned reasoning, nowadays new opportunities emerged for investigation and construction of these power projects. The aim of this paper is to give a general outlook of the several possible sites for development of pump storage HPP in Macedonia, and to briefly discuss one of them as the most promising site.

Keywords: electric power generation, pump storage, hydro power plants, energy storage, renewable energy.

1. Introduction

Pumped storage hydro power plants (PSHPP) or reversible hydropower plants are the most efficient and flexible electricity generation plants. Working in the so-called generator mode, they could generate electric power using the existing upper water storage, and alternatively working in the co-called pumping mode, pump water from the lower water storage into the upper water storage, store the energy in the form of potential energy and later, when needed again, operate in the generator mode and convert previously stored energy back into electric power. Therefore, they could permit the most efficient re-use of energy resources available during certain period of time when the energy is abundant, such as hydropower, fossil (coal, oil or gas) power or nuclear power, into electric power generation at some other periods of time when there is lack of energy on the grid. This conversion and re-use of power could result with night and day energy swaps, or energy swaps for even longer time periods such as seasonal energy swaps, if the amount of water storages permits that [1], [2].

It is common that the PSHPP provides night-day energy swaps, thus having storage capacity of about 8 hours/day with installed capacity in accordance with the energy profile of the country. Some of the existing PSHPP can even provide water storage capacity enabling stable power generation of about 8 hours/day with installed power capacity of more than 1 000 MW (Figure 1). These are the largest power swaps achievable with all alternative options, currently [3]. Therefore, the construction of new PSHPP should be considered as the first option for increasing the power system flexibility, enabling energy storage and energy re-use in accordance with the condition of the available power sources and customer needs.

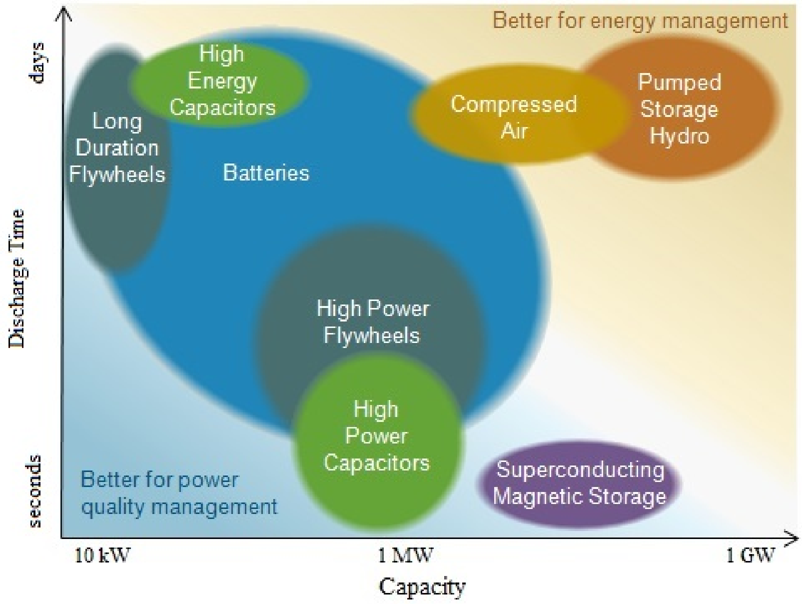

Figure 1. Comparison between various currently available power storage technologies.

Source: *U.S. Energy Information Administration, based on Energy Storage Association*

Besides for efficient power storage, the PSHPP are also important for [4]:

- Balancing thermal power,
- Balancing variable & intermittent power sources such as renewable power sources,
- Power grid stabilization,
- Providing peaking power to grid,
- Taking excess power off the grid during periods of oversupply,
- Ability to store large quantities of energy, etc.

The Republic of Macedonia due to its mostly mountainous terrain intersected with numerous small and medium rivers has favorable topological, hydrological and geological conditions for development of PSHPP with modest installed capacity, which could be advantageous for Macedonian power grid. On other hand, Macedonian power system is largely dependable on its thermal, mostly lignite-fired power plants, that are not flexible and during some periods of the year, especially spring and summer often have electricity overproduction. Finally, the Republic of Macedonia also has large potential for renewable power generation such as PV, solar and wind, which utilization could be significantly beneficial and efficient in combination with newly developed PSHPP [5], [6].

Thus, the aim of this paper is to give a general outlook of the several possible sites for future development of PSHPP in the Republic of Macedonia. Several potential sites that have already been pre-analyzed as a potential PSHPP sites are enlisted and shortly introduced. Before deriving some conclusions in respect to the discussed topics, some of the results of a pre-feasibility study done for one of the most promising PSHPP are also presented in this paper.

2. Pumping Storage HPP basics

PSHPP are very flexible power generation sources worldwide [3]. They provide efficient and cost effective way of storing energy during periods with overproduction of electricity (mostly during the night), and generation of large quantity of electricity and power over short period of time (mostly daytime hours) necessary to provide power system stability, satisfaction of customers needs and balancing i.e. flattening of the daily load curve. The operation process of PSHPP facilities is schematically given in Figure 2. It is based on a simple reversible energy cycle – *generation mode* when electricity and power are generated and supplied to the grid, and *pumping mode* when using grid energy, the power unit pumps water from the lower to the upper water reservoir.

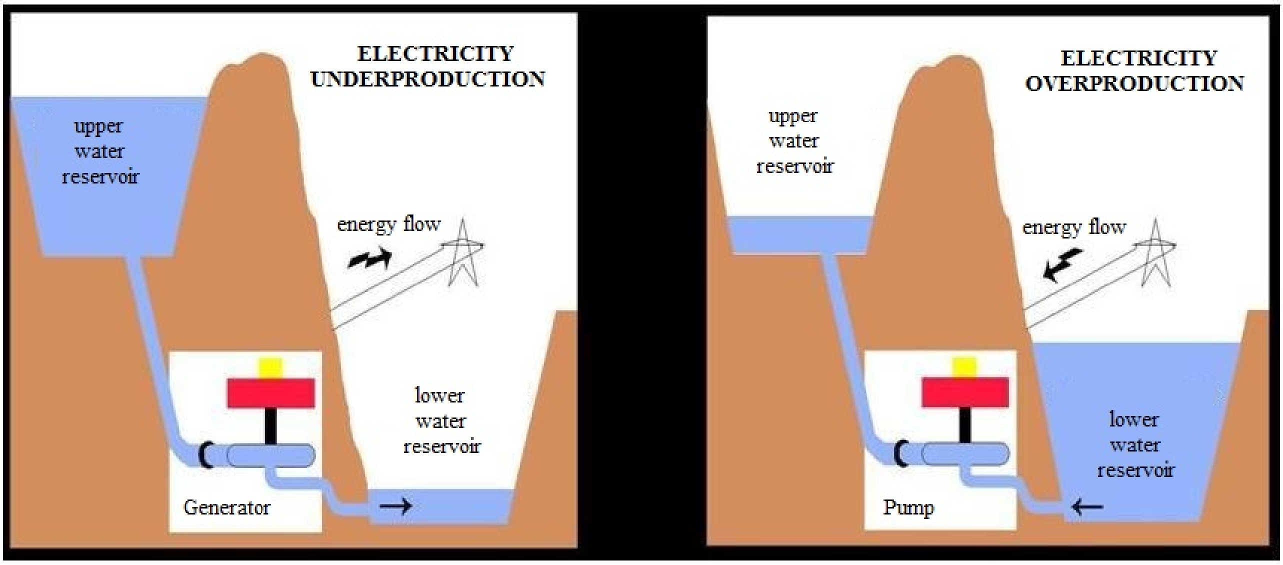

Figure 2. Simplified operation of typical PSHPP during electricity underproduction and overproduction periods.

Source: *HydroWorld.com*

Having this in mind, one could easily grasp the values that PSHPP could provide for energy management of a single electricity power grid. In Figure 3, a typical daily load diagram is presented [3]. As seen, during the night the system *"suffers"* of overproduction (green) that could be used for pumping water into upper water reservoir of a SHPP. Then, later during the day when the power system needs additional electricity and power, the SHPP generates additional energy (blue) and dispatch it to the power grid. As expected, the amount of daytime generated power is always less than the power spent for pumping during the night. However, due to the differences between daytime and nighttime electricity prices, the overall effect of the PSHPP is usually positive, not only for power grid balancing, but also from economical viewpoint. Thus, the inclusion of PSHPP into a power grid brings quantitative and not less important qualitative benefits to the power system, such as stable voltage and frequency control, need for less amount of secondary and/or tertiary power reserve for the system, less energy imports during the daytime and efficient use of the nighttime electricity overproduction, i.e. flattering the daily load curve, easy balancing of the power system between various balance-responsible entities, etc. Figure 4, gives an example of some of the benefits that could provide inclusion of PSHPP into a power grid.

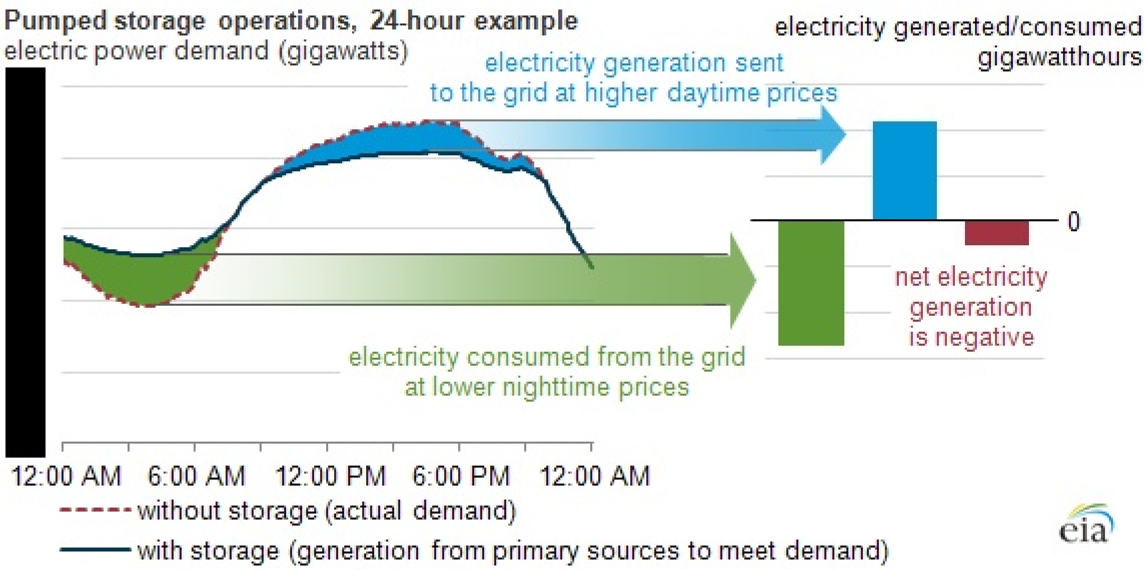

Figure 3. Energy management and benefits that PSHPP could provide based on typical daily power diagram.

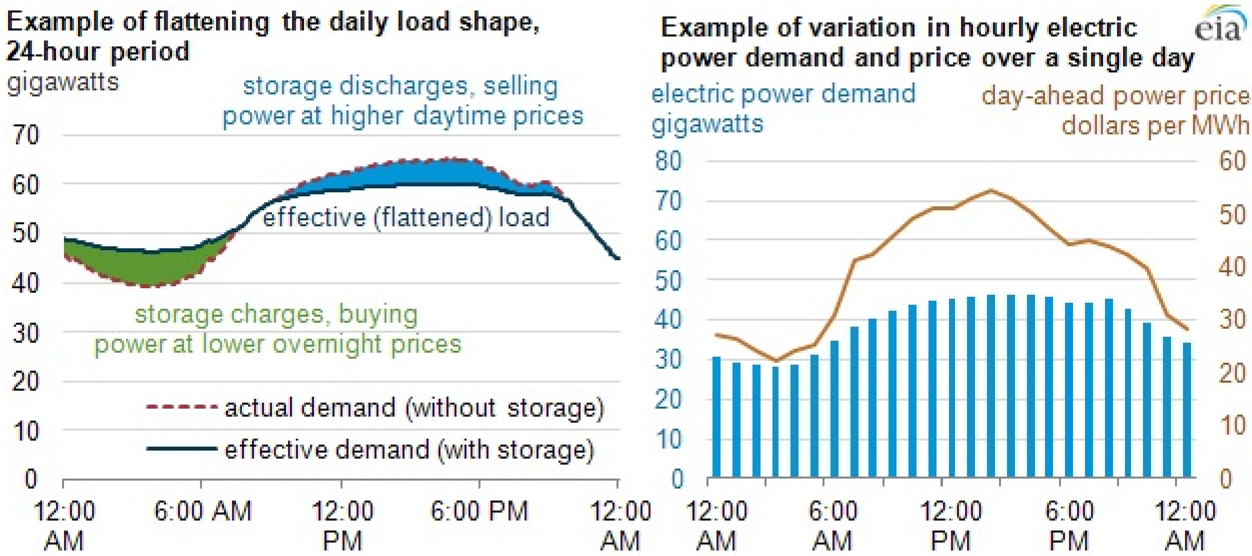

Figure 4. Effective load curve flattening and financial benefits as a result of PSHPP inclusion to a power grid.

Source: *EIA - U.S. Energy Information Administration*

When speaking about topographical, hydrological and geological conditions in Republic of Macedonia, the general outlook is that they are favorable for the development of a new PSHPP. Several studies have already been done in respect with the selection of potentially interested and suitable locations in the Republic of Macedonia for construction and utilization of PSHPP [4] – [8].

In the Study [9] the investigations were limited to seven possible and most promising locations for construction of PSHPP within the country: Sretkovo, Chebren, Galishte, Tashmarunishte, Mavrovo, Demir Kapija and Janche, as shown in Figure 5. This selection was based mostly on economic criteria and technical feasibility, however possible PSHPP between natural likes, Prespa Lake and Ohrid Like (net water level difference of approximately 157 [m]), were not taken in consideration due to environmental reasons.

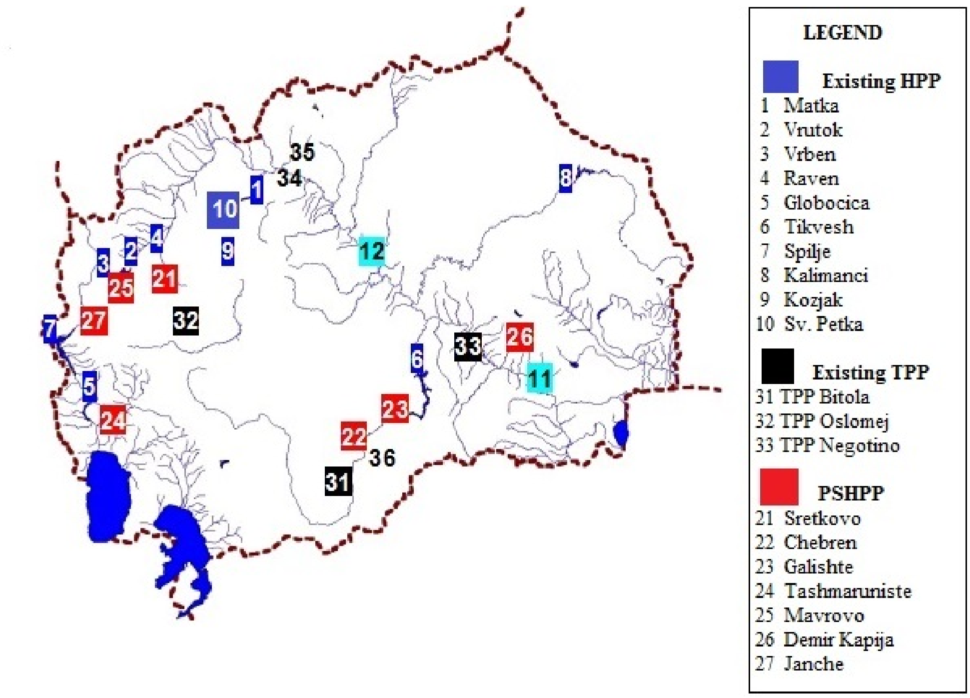

Figure 5. Location of existing HPP and TPP and potential PSHPP in the Republic of Macedonia.

3. Analysis of the potential locations for PSHPP

3.1. Locations for PSHPP with natural water inflow in the upper reservoir

From the above given list of seven most promising locations for development of PSHPP, first we present three that have natural inflow of water in their upper reservoir, PSHPP Sretkovo (number 21 in Figure 5), PSHPP Chebren (22) located on the planned large water reservoir Chebren Lake, and PSHPP Galishte (23), also on the planned water reservoir Galishte Lake downstream of the PSHPP Cebren. PSHPP Sretkovo should have own lower reservoir and use the existing Mavrovo Lake as upper reservoir, while Chebren and Galishte, both located on the Crna Riva, should use upper Chebren Lake as upper reservoir, Galishte Lake as lower reservoir for PSHPP Chebren, and Galishte Lake as upper reservoir and Tikvesh Lake as lower reservoir for PSHPP Galishte, constructing a cascade HPP system consisting of PSHPP Chebre, PSHPP Galishte and existing HPP Tikvesh.

3.1.1. PSHPP Sretkovo

With the construction of the Mavrovo Dam between 1948 and 1957, the existing Mavrovo Lake was created as a water reservoir for the HPPs Vrutok and Raven. In the previously mentioned Study [9], it was foreseen that part of the water flowing into Mavrovo Lake could be redirected towards Lakavica River, where a new irrigation reservoir named Kunovo for the Polog region could be developed. In such case, the existing HPPs Vrutok and Raven could work independently of irrigation requirements downstream for the Polog region. Therefore, near the village of Sretkovo, construction of a new reservoir, on the left tributary of Lakavica River and upper from Kunovo reservoir, becomes possible as downstream reservoir for the new PSHPP Sretkovo. It would have total volume 13 million [m^3] and useful volume of 6 million [m^3]. The headrace tunnel would be 3,500 [m] long, and the penstock 1,400 [m]. Maximum gross head between Mavrovo Lake and this new reservoir would be 398 [m], with the minimum net head of 357 [m]. Several potential variations for the installed capacity have been investigated starting with 3 x 30 = 90 [MW] up to 3 x 110 = 330 [MW].

3.1.2. PSHPP Chebren & Galishte (The Crna River Cascade)

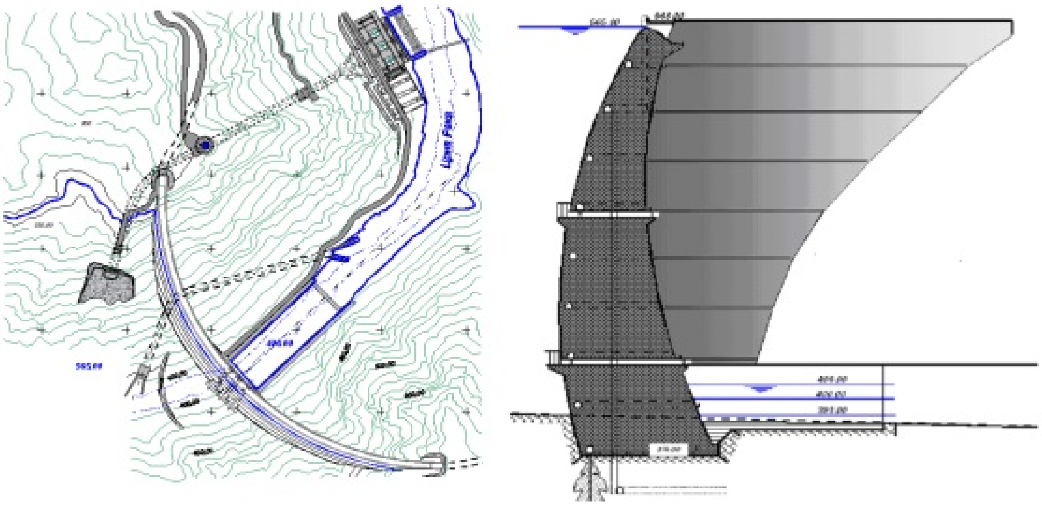

Figure 6. Layout and dam cross section of the PSHPP Chebren.

Construction of PSHPPs Chebren and Galiste, for long period of time was considered as the top priority by the Government of the Republic of Macedonia and its Energy Strategy [10]. Various investment models were already investigated such as state public investment, Joint venture, Public-Private partnership, even long-term concession models, however, until today none of them was successful.

The Crna River Cascade comprises the following hydro power plants:

- PSHPP Chebren, installed capacity of 332 [MW] / 347 [MW] (turbine/pump),
- HPP Galiste, installed capacity of 193 [MW], conventional or reversible, and

– HPP Tikves (existing) installed capacity of 116 [MW], conventional.

Thus, the total installed capacity of the Crna River Cascade could amount 641 [MW]. Having into consideration the benefits that the PSHPP could bring to Macedonian power system, lately more investors favors construction of HPP Galishte as PSHPP with several variants of installed capacity starting from 90 [MW] up to 330 [MW], mostly due to the fact that this power plant is naturally placed between two large water reservoirs Galishte Lake and Tikvesh Lake, and could use the huge Chabren Lake as basic forehead water storage.

3.2. Locations for PSHPP with existing or planned downstream (lower) reservoir

This second group of potential PSHPP consists of the following plants: PSHPP Mavrovo (25) that could use the existing reservoir of Mavrovo Lake, PSHPP Demir Kapija (26), using the planned reservoir Gradec on Vardar river, and PSHPP Tashmarunishte (24) with lower or downstream reservoir of the existing Globochica Lake.

3.2.1. PSHPP Mavrovo

For this PSHPP, the upper reservoir is planned to be created with construction of two rock fill dams: Smreka and Smrdlivi virovi, with relatively small volumes of about 195,000 [m^3] and 4,200 [m^3], respectively. With construction of these two dams the accumulation of PSHPP Mavrovo could be created with useful volume of 20.25 million [m^3]. The powerhouse will be located in the proximity to the nearby village of Mavrovo, with several potential variants for total installed capacity varying from 200 [MW] up to 800 [MW].

3.2.2. PSHPP Demir Kapija

The reservoir and low-head run-of-the-river HPP Gradec is planned on the river Vardar as part of the large multipurpose project called Vardar Valley project [11]. It should be located about 30 [km] upstream of the frontier with Greece, with a water level oscillation up to 4 [m] and useful volume 40 million [m^3]. This reservoir should be used as lower water storage for the planned PSHPP Demir Kapija. The upper reservoir for this PSHPP is planned to be set on the right side small tributary of Vardar River, the river Chelavec. The reservoir could be constructed with concrete arch dam with height of 103 [m] and volume of 160.000 [m^3]. Upper reservoir could have gross storage volume of 26.50 million [m^3] and useful volume 12.45 million [m^3]. Two variants for the installed capacity were investigated, 2 x 50 = 100 [MW] and 3 x 75 = 225 [MW].

3.3. Locations for PSHPPs that need construction of both (upper and lower) reservoirs

3.3.1. PSHPP Janche

PSHPP Janche is the only power plant from the above investigated seven which is not connected with any existing water reservoir, i.e. two new reservoirs had to be constructed for its normal operation. However, due to it extremely large gross/net head of 879/835 [m] and low nominal water flow 2 x 30 [m^3/s] in generator mode, and 2 x 21 [m^3/s] in the pumping mode, this PSHPP could be selected as a favorable one.

The upper reservoir is planned to be the Galichnik accumulation, which would be formed north-east of the village of Galichnik, while the lower reservoir could be provided using local river Radika, for which a dam should be built south-west of the village Janche. This dam should be rooted 10 [m] underground, with the height of 55 [m], crown length of 255 [m] and approximately 260,000 [m^3] of concrete. The PSHPP Janche should have four units, each with 200 [MW] installed capacity, or in total 800 [MW], with annual production of 760 [GWh/year] and could spend 1,267 [GWh/year] for pumping.

4. Pre-Feasibility Study for PSHPP Tashmarunishte

4.1. Basic Data and Location

The development of PSHPP Tashmarunishte was considered as one of the best price/performance pilot project for construction of the first PSHPP in the Republic of Macedonia. Therefore, a pre-feasibility study for this project has been done analyzing three possible variants of installed capacity, in combination of 2, 3 and 4 units, i.e installed power capacity of 100 [MW] (2 x 50), 150 [MW] (3 x 50, or 2 x 75), 200 [MW] (4 x 50 or 2 x 100) and finally 225 [MW] (3 x 75).

The study showed that the most economically viable solution is the last variant with 3 units, each with 75 [MW] installed capacity, or in total 225 [MW]. Additionally, the Study also showed that installation of the units could be done in phases, in the first phase 2 units, and in the second phase the last third unit, setting the timing of the installation of this third unit directly in correlation with the increase of the demand for peaking power and available pumping energy of the Macedonian power system.

PSHPP Tashmaruniste is forseen to use the existing reservoir of HPP Globocica, which reservoir will be downstream reservoir for this plant; the upstream reservoir should be created at the place called Cerov dol, east of the existing reservoir Globocica and south of village of Tashmaruniste, with construction of two dams as shown on Figure 7. The upstream reservoir is on altitude of 1000 m.a.s.l, or more than 310 [m] above the existing downstream reservoir Globocica Lake allocated at nominal operating level of 687.5 m.a.s.l and the minimal operating level of 682.00 m.a.s.l. The nominal operating level of the upper reservoir was set at 1022.5 m.a.s.l and the minimal operating level at 995.00 m.a.s.l. The intake of the upstream reservoir to the powerhouse is foreseen as reinforced tunnel with steel lining, length of 1280 [m] and diameter of 3.4 [m]. The powerhouse is foreseen on the right bank of reservoir Globocica, and the substation above the powerhouse.

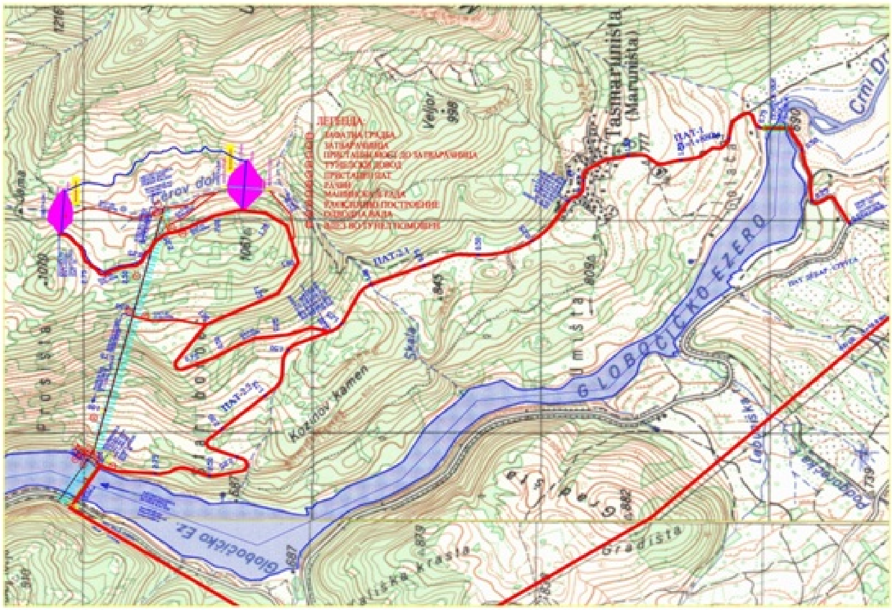

Figure 7. Layout of PSHPP Tashmarunishte with upstream (to be constructed) and downstream (existing) reservoirs.

Table 1: Basic technical parameters of the PSHPP Tashmarunishte.

Production	194 [GWh/year]
Consumption	264 [GWh/year]
Useful volume of upper reservoir	5,226,700 [m3]
Maximal denivelation of upper reservoir	27.5 [m]; (1,022.5 m.a.s.l. – 995.0 m.a.s.l.)
Maximal denivelation on weekly basis of downstream reservoir	2.3 [m]
Possibility to provide emergency power	20 [hours]

4.2. Some economic parameters for PSHPP Tashmarunishte

In the pre-feasibility study was assumed that the PSHPP Tashmarunishte could be constructed within period of three years and with relatively low investments estimated in the range of 68 – 80 million [€], or with the specific investments in the range of 355 – 450 [k€/MW]. For the purpose of economy evaluation of the project, the price of electricity for pumping in the base year is predicted to be around 40 [€/MWh] (base load price), the loan period was 25 [years] and the interest rate 2 [%] (soft loan). Then, the calculated production price was 104 [€/MWh], which is higher than today's market price, even for peak energy. With construction of the third unit, the production price decreases to 90 [€/MWh], which is still too high. Therefore, the justification of economic feasibility of this project could be seek only in the difference between peak and off-peak market price of the electricity on the regional and/or European market.

To use this opportunity which arises with the liberalization of the markets, the Macedonian energy sector should concentrate on the development of suitable 400 [kV] OHL interconnectors with its neighbors, mostly Serbia, Bulgaria, Kosovo and Albania. After putting into operation the interconnection line with Bulgaria and Serbia, the next steps should be construction of new 400 [kV] OHL to Albania. Accordingly, the general idea behind this pre-feasibility study should be that the Macedonian PSHPP imports energy on the regional electricity market during the hours of low demand, and exports electricity in the high demand hours, making positive financial balance between imports and exports by, for example, at the end of each week, month or season. For that purpose, we have to investigate the price change on daily, weekly and/or annual basis.

As can be seen from Figure 8, the base load price on average could be set at 40 [€/MWh], and the ratio between peak and off-peak prices is 40:27.5 [€/MWh], or less than 1.5 times, which hardly justifies construction of large PSHPPs. The similar pattern could be derived analyzing the annual price changes, shown in Figure 9. The price difference is dominant during the winter season in comparison with the summer seasons when prices are more stable and almost inflexible.

Additional motivation for construction of PSHPP could be large inclusion of renewable power sources, especially wind power. The wind power generated during the night could be used for pumping and could provide replacement for rather cheaper thermal energy available during that period of the day. However, countries such as the Republic of Macedonia where the amount of wind generated power is still modest and the prices are fixed, regulated and subsidized by the state, this schemes are unlikely possible.

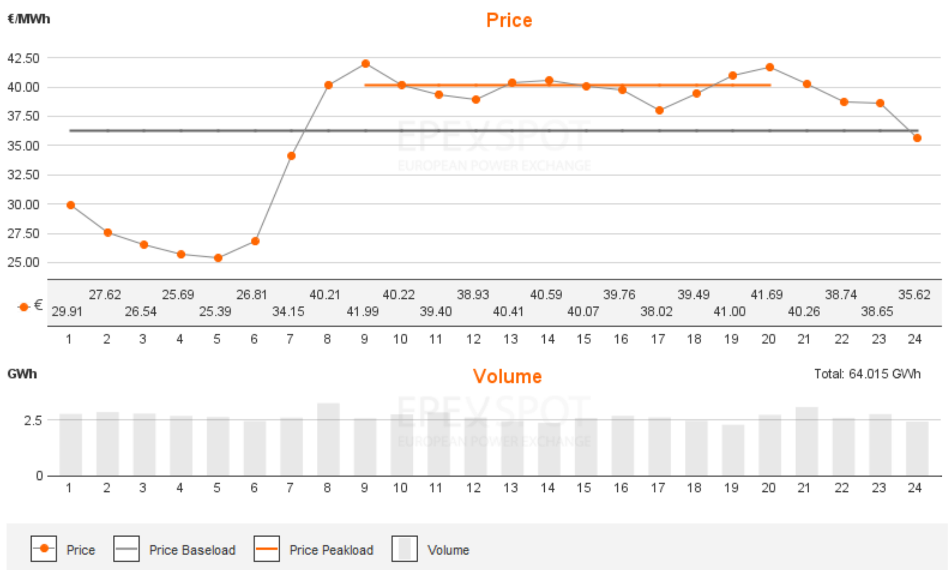

Figure 8. Daily peak and off-peak electricity prices and volumes based on SWISSIX spot market (2017).

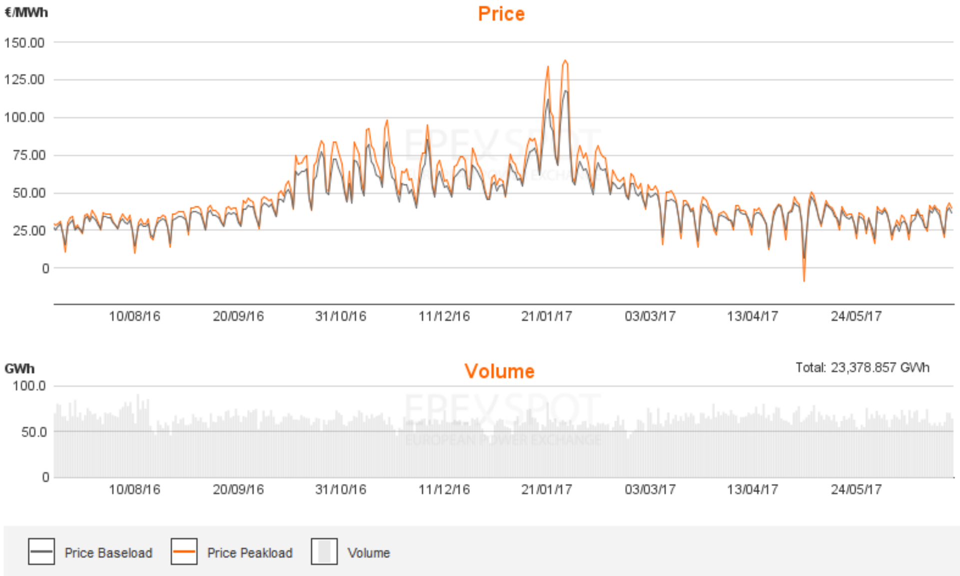

Figure 9. Annual peak and off-peak electricity prices and volumes based on SWISSIX spot market (2016/2017).

Thus, in order to set the least financially applicable utilization scheme, a sensitive analysis should be performed. In our case, by means of a sensitive analysis taking into account the market conditions under rather conservative approach, we calculate that with the selling price of the peak electricity on the spot market of 65 [€/MWh], and in the same time using the pumping electricity bought with one year ahead purchase contract agreements with prices that should not exceed 35 [€/MWh], these projects could be feasible. With these assumptions, we obtained the results given in Table 2, for both, most promising Macedonian PSHPP Chebren and PSHPP Tashmarunishte.

Table 2: Expected financial results for PSHPP Chebren and PSHPP Tashmarunishte.

	Consumption	Production	Cost of Import	Exports	Net Benefit
	[GWh]	*[MWh]*	*Million [€]*	*Million [€]*	*Million [€]*
PSHPP Chebren	785	840	2.75	5.46	2.71
PSHPP Tashmarunishte	264	194	0.92	1.26	0.38
Total	1049	1034	3.67	6.72	3.05

5. Conclusions

Macedonian geography, hydrology and topography are favorable for development of PSHPP. However, because of no sufficient surplus of pumping energy within the country, these projects should be observed very carefully and mostly from regional perspective. The fiscal deficit due to imports could be compensated with efforts in order to develop these potentials with much higher added value than the thermal generation, for which Macedonia has limited resources. Continuous tracking of the volumes and especially prices on the regional electricity markets is a must in order to achieve positive financial results.

In this paper, we presented several favorable locations within the Republic of Macedonia for potential development of PSHPP in the near future. Some of them could benefit from the existing upper water reservoirs and some other from lower water reservoirs that could significantly decrease their investment cost. Two of these power plants should lead in this process, PSHPP Chebren and PSHPP Tashmarunishte, the former due to its large installed capacity and the second due to its modest investment cost and utilization of already existing Globochica Lake as lower water reservoir. Construction of only these two PSHPPs could lead to electricity import of about 2000 [GWh/year], or net import of 950 [GWh/year] which equals annual generation of a thermal unit with installed capacity of 150 [MW] and could significantly flatten the daily load curve for the entire power system in the country.

In addition, construction of even smaller PSHPP Tashmarunishte could enable storage of electricity overproduction, in general due to operation of the existing TPP mostly in the late spring, summer and early fall seasons, and electricity generated by any renewable generators, especially significant wind power in the periods of the day when this energy, although not needed, due to feed-in mechanism must be bought.

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