JET Journal of Energy Technology

JET Volume 7 (2014) p.p. 21-32
Issue 4, November 2014

www.fe.um.si/en/jet.html

LARGE HYDRO POWER PLANTS IN SLOVENIA

VELIKE HIDROELEKTRARNE V SLOVENIJI

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Keywords: large hydro power plant, water energy, water pollution

Abstract

Electricity distribution started in Slovenia with hydro power. The first real use for electricity was street lighting, industry, and workshops. With the evolution and expansion of such usage, power lines had to be built. In Slovenia, large hydro power plants on three Slovenian rivers (Drava, Sava, Soča) account for almost one third of the electricity produced in Slovenia. Rivers have limited amounts of water, although there is a large amount of annual precipitation; the problem is that the water is not equally distributed. Slovenia has dry and rainy periods, marked by drought and flooding. With developments and investments in hydro power plants, the efficiency of turbines is being successfully improved; however, for better exploitation of water energy, building new power plants is required.

Povzetek

Slovensko elektrogospodarstvo je pričelo svoj razvoj z izkoriščanjem vodne energije. Prvi porabnik električne energije je bila javna razsvetljava mest, kasneje industrija in manjši domači porabniki, obrtniki. Vzporedno z razvojem elektrogospodarstva je potekala izgradnja daljnovodov. V Sloveniji večje hidroelektrarne katere izkoriščajo vodno energijo treh večjih slovenskih rek: Dravo, Savo in Sočo priskrbijo skoraj tretjino proizvedene elektrike v Sloveniji. Omejene so s količino vode, katere je v Sloveniji dovolj, le da je neenakomerno porazdeljena preko celega leta, tako po sušnem poletnem obdobju sledi jesensko poplavno obdobje, ki prav tako ovira konstantno delovanje hidroelektrarn. Z dogradnjo in obnovami hidroelektrarn je slovensko hidroelektro gospodarstvo uspešno

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izboljšalo izkoristke turbin in nekaterim hidroelektrarnam povečalo pretok, tako da so izboljšave na tem področju dovolj omejene, da je potrebno razmišljati dalje in iskati možnosti za izgradnjo novih hidroelektrarn.

1 INTRODUCTION

The current condition of the economics of large hydro power plants in Slovenia is the subject of this review.

Slovenian electric power distribution started its development at the end of the 19th century. During the time of Austro-Hungarian Empire, the Slovenian region was geologically and topographically explored. The first hydro power plants were planned for the Styrian region.

World War One hindered development. Although the economy was in poor shape, the development and planning of new hydro power plants continued, the electric power system grew, and new consumers were sought.

At present, the situation is reversed; the demand of consumers is greater than the amount electric energy produced. Old hydro power plants have been rebuilt, and new modern hydro power plants have been and are being build. The control and monitoring of hydro power plants are automatic and sophisticated. The system greatly depends on the amount of precipitation because Slovenia has no conventional hydro power station with large natural reservoirs, but only run-of-the-river electricity production systems. Therefore, electricity production is strongly influenced by hydrologic conditions.

The Sava River basin is a torrent type, in which large fluctuations of the river current occurs, thus influencing the electricity production, [1].

2 ENERGY STORED IN WATER

Water is the most important renewable energy source: 21.6% of electric energy produced in the world comes from exploiting energy from water, [2].

Energy stored in water is actually a gravitational force, seen as falling and flowing water. A hydro power plant is where energy conversion from potential to kinetic to mechanical work into electric energy happens. This conversion should not have an environmental impact, as the entire infrastructure of the hydro power plant brings beneficial and adverse changes to the environment in the immediate area of the hydro power plant.

Building a hydro power plant influences the environment in different ways, affecting the landscape and the surface of the river bed. It also influences the characteristics of water flow in the river and around it, [2].

Adverse influences of hydropower plants are observed via analysis of river sediment, which reveals high concentrations of toxic elements in reservoirs, such as sulphur compounds in toxic metals (lead, potassium) and eutrophication substances, such as compounds of phosphorus and nitrogen. Therefore, dropped silt is evaluated as waste, with high amounts of harmful substances [3]. Hydropower plants also endanger fauna, because the oxygen level is decreased, and fish are inevitably suffocated.

The beneficial influence of hydropower plants is in their low operational costs and long periods of operation. Hydropower plant technology is considered to be a green technology. It is reliable and stable when connected to the electrical power grid, [2].

As an environmental friendly technology, hydropower is implemented according to energy and environmental policies.

The main types of hydro power plants are, [2]:

1. Run-of-the-river HPP, with which a river flow with a relatively low drop is exploited. The river has a dam, but no large reservoir of water is created.
2. Conventional HPP of dammed water with large drop and lower river flow. Water is accumulated with dams or flooded valleys and canyons.
3. Combinations of run-of-the-river and dam hydro power plant are built in a chain, in which the first one has a reservoir.

Building a hydro power plant requires a significant intervention in the environment, as it influences farming, forestry, groundwater, the quality of the water, natural river affluent, and the economy (fishing, tourism, and infrastructure).

3 WATER IN SLOVENIA

Slovenia is water-rich country, although the water supply is not time and space consistent, [5]. An analysis data of water balance from 1971 to 2000 shows that more than half of the average precipitation (1579 mm) contributes to river flow (862 mm), [4].

Large amounts of precipitation, especially in the western and northern parts of Slovenia, classifies the country among water-rich countries on international scales. Furthermore, water is restored seasonally. According to evaluations, Slovenia has one of the largest amounts of water per capita in Europe. Water deficits are observed in the regions of Kras, Suha and Bela krajina, Obsotelj, Haloze, Slovenske Gorice and the northern part of Prekmurje. Water resources are reflections of climatic conditions, hydrology, relief and geological conditions. Inequalities of those factors determines the existence of different water regimes, [5].

Slovenia is divided into two water regions: that of the Danube River, and that the Adriatic Sea. The Soča River is part of the latter and is 95 km long. In the Danube water region there are the Sava, Drava and Mura rivers. The Sava is Slovenia's longest river; from its source at Sava Dolinka in Zelenci to the Croatian border it runs 221 km. The Drava River has 142 km in Slovenia, and the Mura 95 km, flowing directly on the border with Austria for 65 km.

Taking the river flow into account, the Drava is Slovenia's most water-rich river; after its confluence with Pesnica, the Drava's flow exceeds 320 m^3/s. Apart from the Sava and Mura, other rivers have significantly lower flow because of minor river basins and characteristics of water accumulation outskirts, [5].

4 HYDRO POWER IN SLOVENIA

4.1 Development of electricity distribution worldwide and in Slovenia

The development of electricity distribution started with the invention of the light bulb. The electric wire was first presented in Paris in 1881: a light bulb with a charcoal filament. From that year onward, electricity distribution developed into one of the strongest branches of the economy, [6].

Cities built small local power plants for electric lighting for individual facilities and factories, or for street lighting. At the beginning, there was a direct current with voltage of 65 V, then 110 V and later 220 V. In the second phase of electricity distribution, provincial lighting developed with alternating current. Power plants were placed directly by the energy source, i.e. by the water, by the coal mine.

In Slovenia, the first power plant was a hydro power plant built in Škofja Loka in 1894. The hat factory Šešir installed a water turbine in 1889 for production purposes. In 1894, a generator was implanted; it produced direct current with a voltage of 110 V and with 15 kW of power, [7]. In addition to production, the Šešir factory started to sell the electricity for street lighting in Škofja Loka, [8].

In Ljubljana, the first power plant started to operate in 1898. In 1914, there were 17 locally operated power plants in Slovenia (not counting the Primorska region), with electric power of 2500 kW.

The Završnica hydroelectric power plant was the first Slovenian public power plant. The construction of the plant occurred during World War I. And all obstacles aside, it was activated in February 1915, illuminating the streets of Radovljica and Bled.

A descriptions of that special day states: “The hydropower plant on Završnica started to operate! For our economy this is very important. Circumstances do not allow special celebration”, [9], and “We can see long desired electrical street lighting in Bled. Only now is Bled what it should have been a long time ago. The illumination is beautiful. Around the Lake of Bled crown of lights – it is magical”, [10].

The Završnica hydropower plant operated until 2005, after which it became a technical and historical monument. Its part in producing electricity was overtaken by Moste HPP.

In 1912, in Styria, preliminary planning of the Fala hydro power plant on the Drava River started. World War I caused a delay, and Fala HPP started to operate in 1918. It was intended to supply industry in upper Styria (sl: Štajerska) with electricity. When World War I ended, Yugoslavia was entitled to Fala HPP, although the investment had come from elsewhere, [11].

After World War I, electricity distribution greatly expanded, with industrial power plants being build parallel to public power plants.

World War II influenced the development of economy electric energy production. When the Primorska region joined Yugoslavia, more hydro power plants on Soča River were obtained: Doblar and Plave, [6].

After the end of the war, a systematization of electricity distribution began. A state power plant company was founded. This company joined public and industrial power plants. Six main energy regions were founded: Drava, Sava, Soča, Trbovlje, Rajhenburg, Velenje, [6].

Slovenian large hydropower plants are follows:

- SENG - Slovensko elektrogospodarstvo Nova Gorica (Hydro power plants: Doblar 1 in 2, Plave 1 in 2, Solkan, Avče)
- SEL - Savske elektrarne Ljubljana (Moste, Mavčiče, Medvode, Vrhovo)
- HESS - Hidroelektrarne na spodnji Savi (Boštanj, Blanca, Brežice, Krško)
- DEM - Dravske elektrarne Maribor (Dravograd, Vuzenica, Vuhred, Ožbolt, Fala, Mariborski Otok, Zlatoličje, Formin)

In the last quarter of 20th century, the number of small hydro power plants increased from 12 to 36. In same period, the production of electricity from hydro power plants doubled, [12].

With the expansion of economy and the erection of new power lines, the consumption of electricity increased and electricity distribution expanded. Consumption levels continue to increase (with a minor decrease following the most recent recession).

4.2 Hydro power plants of river Sava – upper course

4.2.1 HPP Moste

Hydro power plant Moste started operating in 1952. It is a hydropower plant with accumulation planned for production of electricity in peak demand. Three generators with Francis water turbines have been installed. The flow is 28.5 m³/s.

In 1977, Moste HPP built a forth generator and successfully realised affiliation with Završnica HPP. The system was planned to pump the water into the upper reservoir of Završnica and use it when demand exceeds the production of electricity. Unfortunately, this system was never realised because of water pollution. The generator was reconstructed in 1999. Between 2008 and 2010, a thorough reconstruction of the entire plant took place. The system produces 21 MW of power, [13].

4.2.2 HPP Mavčiče

Hydro power plant Mavčiče is a run-of-the-river hydroelectric power station, with a construction height of 40 m. With two Kaplan turbines and 260 m³/s of flow, the system produces 38 MW of power. Operations began in 1987. Reconstruction started in 2011 with renovation of the equipment and exterior switchyard, [14].

4.2.3 HPP Medvode

Hydro power plant Medvode lies above the confluence of the Sava and Sora Rivers. The dam is made of concrete and makes use of the reservoir from HE Mavčiče. The first two generators started to operate in 1952, the third one in 1955. When the barriers were heightened by one meter in 1964, the power of the turbine increased by 11%. Two Kaplan turbines are able to produce 25 MW of power. In 2003 and 2004, the hydro power plant was modernised; turbines and secondary equipment were replaced, [15].

4.2.4 HPP Vrhovo

Vrhovo HPP is the first hydro power plant in a series on the lower river course of the Sava. Vrhovo HPP started to operate in 1993. With a concrete dam with a construction height of 27 m, the hydro

power plant operates as run-of-the-river hydroelectric station, but also serves as reservoir for hydro power plants lying downriver. With three generators, Vrhovo HPP produces 34.2 MW of power, [16].

4.3 Hydro power plants of the Sava River - lower course

4.3.2 HPP Boštanj

Boštanj HPP is the second hydroelectric station and one of the six hydro power plants built on the lower course of the Sava River. It produces 36 MW, which represents 1% of the electricity produced in Slovenia. The plant started to operate in 2006, [17].

4.3.3 HPP Blanca

Arto-Blanca HPP is the third hydro power plant in the chain of lower course of Sava River. It produces 42 M and started to operate in 2010, [18].

4.3.4 HPP Krško

Krško HPP produces 42 MW. This hydro power plant is constructed as combination of accumulation and run-of-the-rive. It started to operate in June 2013.

4.4 Hydropower plants of the Drava River - Dravske elektrarne Maribor

The Drava River springs originates from Dobbiaco in South Tirol in Italy. Near Dravograd, it enters Slovenia and, after 133 km, it continues its flow into Croatia. Before the construction of hydro power plants, the Drava was used for transport with rafts to Danube towards the Black Sea.

4.4.1 HPP Dravograd

Dravograd HPP in the first hydro power plant in the chain of Drava on the territory of Slovenia. In 1944, it started to operate and it was one of the first pier-type power plants in Europe. Construction began in in 1941 during World War II. In April 1945, allied air raids caused considerable damage to the power plant. With the launch of the third unit in 1955, construction of the power plant was completed, [19].

With renovation of the generator, which started in 1994, the power of HPP increased by 26 MW. In 2010 and 2011, the 110 kV exterior switchyard was modernised. Construction a dam created a reservoir that spreads to Austria, [19].

4.4.2 HPP Vuzenica

Hydro power plant Vuzenica is the second in line on the Drava River. Construction started in the fall of 1947. In HE Vuzenica, the first domestically made Kaplan turbine was installed; it was produced in Litostroj. The first generator started to operate in 1953. After reconstruction in the 1990s, the power increased by 11.2 MW. It is a run-of-the river power plant with pillar construction producing 56 MW, [20].

4.4.3 HPP Vuhred

HE Vuhred operates in a region where the Radlje field closes into a narrow water channel. It is the first of two stages that share the available head of the section of the Drava between the Vuzenica

and Fala power plants. Topographical and geological surveys performed immediately after World War II showed that two power plants could be built in this section. Construction began in 1952. The Vuhred HPP was the first plant in the former Yugoslavia that had been planned and constructed on the basis of domestic experience and equipped solely with domestic Slovenian equipment. The first two units began operations in 1956 and the third in 1958. The second phase refurbishment of the Upper Drava power plants, concluded in 2005, encompassed the replacement of the turbines and the other equipment to increase the net capacity of the power plant and flow, [21].

4.4.4 HPP Ožbalt

The second power plant on the section of the Drava River between Vuzenica and Fala was built between 1957 and 1960 as the twin of the Vuhred HPP upstream. The Ožbalt HPP is the fourth power plant in the Slovene section of the Drava River; construction began in 1957 and within three years two units were operating. Since the Ožbalt HPP has the same energy specifications as the Vuhred HPP, the pier type structure was also chosen. After the refurbishment of the Upper Drava power plants in the 1990s, the net capacity increased to 73.2 MW. The plant, with its increased power, annually generates 305 million kWh of electricity. The damming of the Drava River here resulted in a 12.7 km long reservoir containing 10.5 million m^3 of water, of which 1.4 million m^3 can be used for the generation of power, [22].

4.4.5 HPP Fala

Construction of HPP Fala started in 1913 with the first five units commissioned as early as 1918. Due to increased demands for electric power, a sixth unit was built in 1925 and then a seventh was completed in 1932. When construction of all the other power plants on the Drava River was completed, the plant's turbine discharge proved low in comparison and this led to the construction of an eight unit in 1977 using a Kaplan turbine with the capacity of 17 MW. After extensive refurbishment, the three newer units make use of the 14.6 m available head, have a net capacity of 58 MW, and can generate 260 million kWh of electricity annually, [23].

Within the dam structure complex, the old power house has been preserved as an important item of technical heritage. Its units, comprising double horizontal Francis turbines and generators on the same shaft, were closed down in stages as a result of the construction of the new powerhouse. Today, the old powerhouse is an interesting vantage point for visitors allowing them to become acquainted with both the previous and current methods of operating the power plant, [23].

4.4.6 HPP Mariborski otok

This pier type power plant is located just outside of Maribor in the riverbed, exploiting the energy potential of the Drava River between the Fala HPP and the island in the Drava River.

The construction of the power plant had been planned prior to the World War II, but construction only began in 1942. The war caused the construction process to be drawn out considerably, so that in May 1945 it was still only 30% completed. Despite a number of problems after the war, construction work continued and 1948 saw the commissioning of the first unit, with the second and third units beginning operation in 1953 and 1960; its construction created a 15.5 km long reservoir. The dam structure contains three turbine piers between four spillways and a left and right bank building. Each of the turbine piers contains a vertical Kaplan turbine and a generator above it. A 10 kV switchyard and an areas for two main transformers directly connected to 110 kV transmission lines leading towards the Pekre substation are located in the right bank building. Mariborski otok HPP

uses the 14.2 m available head and, following its refurbishment, annually generates 270 million kWh of energy with a net capacity of 60 MW, [24].

4.4.7 HPP Zlatoličje

HPP Zlatoličje generates more than a fifth of all the electric power generated by Dravske Elektrarne Maribor and makes use of the energy potential of the Drava River between the cities of Maribor and Ptuj where the river turns into a flatbed. Due to its location, it has been designed as a channel-type power plant. The Zlatoličje HPP makes use of the 33 m head and, after refurbishment from 2007 to 2012, annually generates 577 GWh of electricity with a threshold capacity of 126 MW. The power plant, built between 1964 and 1969, has a supply and discharge channel separate from the riverbed, a 4.5 million m^3 reservoir and a dam structure in Melje near the city of Maribor, [25].

4.4.8 HPP Formin

As the last in the chain of power plants on the Drava River, this plant rates as the second largest in terms of electric power generated and also boasts the largest reservoir in the Slovene section of the Drava River. The power plant was completed in 1978 and, due to the natural conditions, was designed as a channel-type power plant, similar to Zlatoličje HPP. With its 29 m available head on the section between Ptuj and the national border with Croatia and with a net capacity of 116 MW, it generates 548 million kWh of electricity annually, [26].

The damming of the Drava River with a dam in Markovci resulted in the creation of the largest artificial lake in Slovenia, with a length of 7 km and a water surface of 3.46 km^2. It is called Ptuj Lake and it contains 17.1 million m^3 of water of which 4.5 million m^3 can be used for the generation of electricity, [26].

4.5 Hydropower plants of Soča River - Soške elektrarne Nova Gorica

4.5.1 HPP Doblar 1 in 2

Doblar 1 was designed during the Austro-Hungarian Empire. After World War I, research continued with an Italian company. In 1939, it started to operate. In 1979, the equipment had become obsolete and inadequate. Three vertical Francis turbines were substituted with equipment from a local manufacturer.

Dolbar 2 was constructed alongside Doblar 1 and uses the infrastructure and equipment of Doblar 1. It started to operate in 2002 with installed power of 20 MW, [27], [28].

4.5.2 HPP Plave 1 in 2

Plave 1 was planned parallel to HE Doblar and started to operate in 1940. It has a power of 15 MW. Two vertical Kaplan turbines are installed. It operates reliably and no modernization of equipment is currently needed.

Doblar 1 and Plave 1 satisfy 40% of the demands for electricity in Slovenia.

The design of Plave 2 HPP was based on research results of the available hydroelectric resources. Plave 2 essentially uses the infrastructure of Plave 1. The technology for the construction of the conducting channels was used in Slovenia for the first time. The installed power is 20 MW, and it started to operate in 2002, [29], [30].

4.5.3 HPP Solkan

HPP Solkan started to operate in 1984. Three vertical Kaplan turbines with producing 32 MW were installed. The plant is automatic and managed from the control centre of power plants on Soča in Nova Gorica, [31].

4.5.4 PHPP Avče

The concept of a pumped-storage hydropower plant is based on increased peak demand of electricity. In times of lower price of electricity (i.e. at night), the water is pumped into the upper reservoir. At times of demand the water flows through turbines to produce electricity. PHPP Avče helps alleviate deficits in electricity production in times of peak demand. The installed power is 180 MW with a vertical Francis one-stage reversible turbine. The maximum drop is 521 m. The pumps needed for pumping storage water have a power 185 MW, [32].

5 THE FUTURE OF HYDRO ENERGY IN SLOVENIA

Almost one third of electricity in Slovenia is produced by hydro power, according to Bojnec and Papler, [12]. Experts' opinion is that Slovenia could be able to exploit even more of the available hydropower. Operating possibilities could be doubled, [34].

Table 1: *Production of electricity in large hydro power plants in Slovenia from 2002 to 2010, [12]*

	Production of electricity from large hydro power plants (TWh)	Production of electricity from all power plants in Slovenia (TWh)	Share of HPP in production of electricity in Slovenia (%)
2002	3313	13319	24.87
2003	2957	12491	22.67
2004	4095	13835	29.60
2005	3461	13667	25.32
2006	3591	13643	26.32
2007	3266	13636	23.95
2008	4018	15032	26.73
2009	4713	15208	30.99
2010	4696	15260	30.77

Planned investments for large hydro power plants in the lower course of the Sava River are currently being realised, and there are also investments planned for medium-sized and small hydropower plants. The modernization of existing hydro power plants also aids in increasing the amount of produced electricity. Construction of new small hydropower plants is planned on the Soča and Idrijca Rivers. On the Drava River, the modernization of existing hydro power plants is taking place to ensure the operating conditions for the next 60 years, [34].

Construction of large hydro power plants is multidisciplinary subject, requiring radical changes in the local environment. The opinions of technicians, environmentalists, cultural heritage, sport and tourism specialists are important. Moreover, civil initiative needs to be respected, which can lead

to transnational issues. A typical example is the Mura River. There are many hydro power plants installed on river in Austria, Croatia, Hungary, but none in Slovenia [12]. Preliminary preparations for the first hydro power plants on the Mura River in Slovenia are taking place. The construction is planned to be completed in 2020; flow-of-the-river hydro power plants are planned, which have less influence to the surroundings and can be socially more acceptable, [34].

On the lower course of the Sava River, there are two hydro power plants under construction: Brežice HPP and Mokrice HPP. A survey of the area was made between the years of World War I and World War II. The idea for the hydro power plants is written in an article that was published on the 1st of June, 1925 in Technical Journal. In the article, the Authority of Yugoslavian Engineers and Architects states a report of the possibilities and advantages of water energy from the Sava River between cities Brestanica and Čatež [33].

At the beginning of 2011, a public unveiling of plans for hydro power plant Brežice took place in the city hall of Brežice. Construction should be completed in 2016.

Although Slovenia has a good water management, problems are expected in the future. The European directives for water management requires better chemical, quantity and ecological conditions of water and, minimum flows for ecological reasons. This means that there must be more natural and balanced development and better controlled water consumption. That is a new standard in planning and designing environmental politics, [5].

Worldwide, there are extensive possibilities for the future development of exploiting the water sources, especially in developing countries. However, economical, regional, environmental and social factors can substantially affect development. In recent years, the construction of new hydro power plants has significantly decreased, [34].

6 CONCLUSION

The efficiency of energy conversion in hydro power plants is generally between 85% and 95%, which is definitely more than in other types of power plants. Consequently, it can be said that the hydro power plant is the most sophisticated developed system for producing electricity.

A relatively large initial investment and long construction period make hydro power plants only slightly profitable, if taking in account only the short-term period between 10 and 20 years. If we consider a longer period of time, reliability and CO_2 emission reduction, the hydropower plant is the most suitable renewable energy source, [35].

Electricity production costs over the operating time of hydro power plant are considerably lower in comparison with other renewable sources. This fact reveals that other technologies are in a lower state of development, [35].

The development of hydro power plants in Slovenia is not final. It represents the only optimal way to a “greener” Slovenia. Although larger hydro power plants are not to be defined as entirely harmless for the environment, they can be defined as mainly harmless for the environment.

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