

FLOATING PHOTOVOLTAIC POWER PLANT AND ESTIMATION OF POTENTIAL IN BOSNIA AND HERZEGOVINA

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Abstract: Generation of photovoltaic power plants is growing rapidly in the last ten years in the world. One of the key factors for the construction of floating photovoltaic power plants is to provide space for their construction. This paper presents statistical indicators of installed capacities of floating photovoltaic power plants, as well as a detailed description of the components of these power plants. Approaches to construction and maintenance recommendations are described in more detail. The basic results of simulations are presented on a concrete example of a floating photovoltaic 1 MW power plant on Lake Modrac. The available areas of artificial lakes in Bosnia and Herzegovina were analysed, and it was shown that the installation of floating photovoltaic power plants on 5% of the surface of artificial lakes would provide around 10% of the total electricity consumption in Bosnia and Herzegovina.

Keywords: floating photovoltaic power plants, construction, maintenance, potential, generation, consumption

INTRODUCTION

The production of electricity from photovoltaic (PV) power plants has been growing intensively in the last ten years. According to [1], the capacities of PV power plants in 2020 were around 710 GW. It is estimated that these capacities will reach around 3,000 GW in 2030 and around 8,500 GW [2] in 2050 (Figure 1).

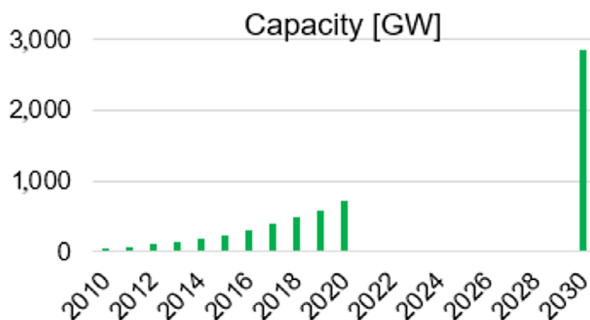


Figure 1: Capacities of PV power plants in the world and expected values in 2030 [2]

PV power plants of greater power require large areas of land, which is in collision or conflict with other branches of science, such as agriculture. In recent years, large available areas of water have been used for the construction of large power plants. There was an increase in recent years regarding the construction of large power plants whose total installed capacity in 2019 amounted to 2,400 MW and the forecasted production of floating PV plants in 2030 is 710 TWh [3]. The first floating PV power plant was built in 2007 in Aichi, Japan for research

purposes, and the concept of the floating PV power plant is described in [4]. So far, the largest floating PV power plant was built by the Huaneng Power International in China with an installed capacity of 300 MW [4]. The authors in [3] analysed the current contributions of floating PV power plants in electricity production with estimated production trends and values of installed power plants until 2030. Various options for designing floating PV power plants with the aim of increasing efficiency and cost-effectiveness, including cooling and monitoring changes in power plant components, are described in [5] – [9]. In [10] the advantages and disadvantages of floating compared to ordinary PV power plants are considered, with a detailed overview of the technologies, the current status as well as different ways of performing/designing them. The potential of floating PV power plants in Spain is presented in the article [11]. It was concluded that using 10% of the available water surface would cover 31% of electricity consumption. By developing the full potential of floating PV power plants, Spain would reduce the use of conventional energy sources up to 81% of current production, and direct most of its production to renewable sources and obtain long-term benefits. Article [12] deals with experimentally obtained results in weather conditions characteristic of Jordan. It was concluded that the construction of floating PV power plants is more suitable in these areas due to easier maintenance, preservation of water quality and reduction of evaporation. These studies have shown that using floating PV power plants can reduce the problems of limited energy resources, which is a general feature of the countries of the Middle East. In [13] it was discussed whether does the floating

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or conventional PV power plant produce more electrical energy. As it is known, in PV systems electrical efficiency increases as the temperature decreases. The paper concluded that floating PV power plants have higher electrical efficiency by 0.79%. Article [14] analysed impact of floating PV systems on aquaculture. The authors came to conclusion that ecosystem has benefits from building floating PVs such as resolving food, energy and water problems. Also, in article [15], the authors came to a conclusion related to the advantages of floating photovoltaic power plants, such as better water quality, reduction of the growth of bacteria and algae due to reduced conditions for photosynthesis, less dust and a better albedo effect compared to photovoltaic power plants located on earth surface. In article [16], research is focusing on comparing the improvement of efficiency in PV modules by using the floating method and the passive cooling method. The results showed that the increase in power is 30.54% by using the first method. In [17] data was taken from Chah-Nimeh Lake in Iran, and was proven that floating PV power plant saved approximately 724 m³ during a year. Article [18] is about efficiency of the tracking-type floating PV systems that are designed to use solar sensor to determine the location of the sun, even when it is cloudy or rainy, and then using separate mechanical devices, PV models are rotated to the most optimal position at that moment. The results of mathematical models in [19] that were used to evaluate the performance of floating photovoltaic modules with passive or active cooling showed that passive cooling increases energy by 3% (maximum possible 6.4%), while in the second case, by adding active systems for additional water cooling, energy increases by 9.7% (maximum possible 13.5%). The research was made on floating photovoltaic systems installed in Catania, Italy. The impact of the thermosiphon cooling method on floating PV systems is presented in article [20]. The results showed that the output energy increased by 3.34% using this method. Authors in article [21] proved that mere presence of water is not the only factor in the temperature of floating PV system. Their research showed that the main factors for module temperature are ambient temperature, insolation and wind speed. Various techniques for cleaning floating PV power plants are described in article [22]. To choose the appropriate technique, it is important to know the purpose of floating PV system, as well as the conditions in which it is installed in order to achieve correct and economical maintenance.

The key research contributions of the paper are to define advantages of the floating over the conventional PV power plants, to show how much potential Bosnia and Herzegovina has for building floating PV plant and how much electrical energy can floating PV power plant produce covering small area of water. In this paper, the basic data on the components of floating PV power plants, as well as on their construction, operation and maintenance, are processed. In order to better present

the utilization of the lakes of Bosnia and Herzegovina as potential areas for the construction of these power plants, an illustrative example of the power plant on Lake Modrac is presented. In this work, other aspects related to floating PV power plants, such as the connection and impact on the power system, the impact of the selection of individual components on production, etc., were not analysed.

The paper is written in 4 sections. In first two sections, theoretical foundations for floating PV power plants are described. In the third is given the example of one floating PV power plant installed on lake Modrac, on the basis of which calculations were made that were used in further research and analysis of the profitability of floating PV power plants. In the last section the results are summarized and the main conclusions of the work are given.

1. COMPONENTS OF FLOATING PHOTOVOLTAIC POWER PLANTS

A floating PV power plant generally consists of the following components [4] and [5]:

- pontoon,
- plastic structure,
- anchoring systems,
- PV modules,
- cables and connectors,
- inverters,
- protection.

A pontoon is a structure that can withstand high water pressure. The amount of these parts depends on the number of PV modules, but also on the requirement of the surface area of the platform and on the available space on which the floating power plant is built on. Several connected pontoons later form the platform of the floating PV power plant. In order to form one pontoon, it is necessary to connect several parts. They are made of HDPE (high-density polythene), i.e., solid polyethylene. HDPE material is suitable for use due to its resistance to UV rays and corrosion. GRP (glass fibre reinforced plastic) can also be used to make a floating platform. The anchoring system for the floating PV power plant is a system that adapts to changes in the water level and stabilizes the floating structure. The type of anchoring system depends on several parameters that correspond to the configuration of the site and local conditions, such as soil composition, available space, wind load or water level variations.

The anchoring system consists of piers, anchor buoys and mooring buoys. Installing a deep-water mooring system can be demanding and expensive. Wire rope and nylon webbing can be used to complete the exit platform anchoring system. The rope can be attached to the edge terminal and adjusted to any angle. According to

the available researches, the usual PV modules available on the market have been used so far. Special attention during exploitation should be focused on metal parts that are subject to corrosion.

The energy produced by the PV modules is transmitted via DC cables to the inverter, and after conversion via AC cables to the switchgear. On this way, electricity is generated in the grid. It is also possible to create a system that stores energy in batteries, which depends on the very purpose of the PV power plant. Direct laying of cables through the water is generally not practiced, but the cables are connected to facilities on the shore with a suitable floating structure. Devices such as inverters and batteries are only installed in dry places. Centralized or string inverters can be used. The method of execution and configuration of floating PV power plants mainly depends on the power and the price of the equipment, a basis on which designers decide which types of inverters and plants to use. The environmental impact assessment is an important part of the construction preparation process, where it is necessary to respect all norms from the regulations that define the environment.

2. CONSTRUCTION, OPERATION AND MAINTENANCE

2.1. Construction and operation

One of the key requirements that a design for the floating PV system should fulfil is that it should be cost-effective, lightweight and that the installation, as well as the commissioning of the entire system, should be efficient [6]. Before the construction of the floating PV power plant itself, it is required to investigate the potential location in order to identify possible limitations or disadvantages for construction, if they are present [7]. It is necessary to carry out a precise measurement of the depth of the water on that location, a process called bathymetry. On the basis of previously collected data on soil characteristics, appropriate types and sizes of anchors, suitable for the examined area, are selected. One of the key things during construction is to precisely place the anchors and have accurate information about their positions, in order to avoid damage and large economic losses. The plan is made depending on the characteristics of the water surface, i.e., the year of expected use, smaller or larger water surface, depth, changing water level, wind speed, wave height, type of water bottom, climate and many other parameters. Assembling the structure requires precise project drawings, as well as hierarchical partitions of the structure, i.e., a precise assembly plan. Cables, which are previously protected against water and UV radiation, are carried out and connected upon completion of construction. For floating PV power plants, grounding is performed in accordance with regulations and technical recommendations. Most often, these cables are led to the coast and there they are connected to the grounding

device. Designers look for alternative solutions, if this is not an efficient grounding solution [4]. The purpose of protection against atmospheric overvoltages is to protect the floating system from possible direct atmospheric discharges. This is why this type of protection is installed directly at the power plant, and consists of an external and an internal part. The external system includes the following components: grab bars, down conductors and grounding device. An SPD (Surge Protective Device) device belongs to the internal system, and type II SPD devices are recommended for this type of system [5]. After all the steps have been taken, the floating PV power plant is ready for commissioning.

2.2. Maintenance

Given that floating PV power plants are systems belonging to relatively recent technologies, the experience for maintenance and supervision is quite poor. As their application grows, this segment will develop along with them. The protocol for monitoring and maintenance of any part of the power system is also applied to the floating PV power plant, which is defined by current regulations. Competent services dealing with supervision, management and maintenance of the PV power plant implement maintenance processes in three segments: preventive, corrective and predictive maintenance [4].

Preventive maintenance implies routine inspection and service at predetermined intervals. It is planned with the aim of preventing damage and failure. Preventive maintenance should be planned regularly. Preventive maintenance includes: general space maintenance, cleaning of PV modules, cleaning of floating pontoons (mainly from bird droppings), fly abatement, inspection of cables, connectors, system balance, and periodic re-commissioning checks and maintenance of data collection and monitoring systems.

Corrective maintenance mitigates possible downtime when components fail. It is performed as needed and should be minimized by proper monitoring and preventive maintenance. Although power plant owners strive to reduce the initial costs of preventive maintenance, equipment will still break down from time to time. Speed of response time and speed of repair time are important items in the maintenance category. Corrective maintenance of PV systems usually includes: resetting tripped inverters (mainly caused by insulation failures), replacing blown fuses, tightening cables or loose connectors (due to system movement), repairing broken equipotential conductors (also caused by system movement) as well as repairing communication breaks. The term communication refers to the collection and transmission of data.

Predictive maintenance uses current data to monitor the plant and predict possible failures. It has a higher initial investment and supports the quality of system monitoring.

It reduces maintenance costs over time because it manages to predict failure and therefore manages to prevent it. Predictive maintenance is the most effective method that supports the multi-year efficiency of PV power plants. This type of maintenance usually serves as a warning system because it provides information about potential failures based on seasonal influences on power plants, system failures or unplanned downtime, etc.

3. ILLUSTRATIVE EXAMPLE AND ESTIMATION OF THE POTENTIAL IN BOSNIA AND HERZEGOVINA

3.1. Illustrative example

The PV power plant on Lake Modrac was chosen as an illustrative example. In Figure 2, the area that would be occupied by this floating PV power plant (1,140 kWp) is visualized. This structure was built in east-west orientation and occupies an area of 0.0081 km² (90m x 90m). For this locality, according to the available data, the annual production of this floating PV power plant is 1,261 MWh (1,103 kWh/kWp). Such structures are modular in nature and enable the construction of floating PV power plants of higher power.

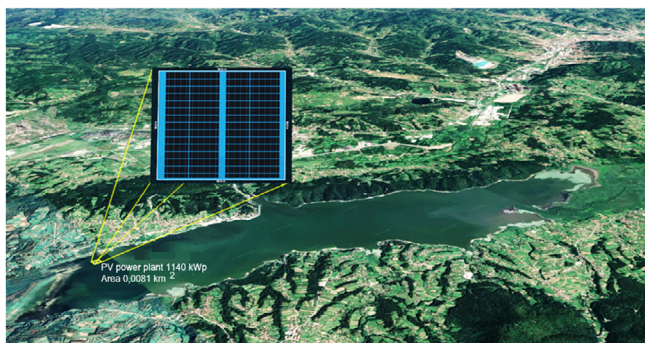


Figure 2: Visualization of the floating PV Modrac power plant

Figure 3 shows the production of a floating PV power plant from an illustrative example with a power of 1,140 kWp. Calculations on electricity production are made in available online software tool Sunny Design, [23]. From the results of the calculations, it can be concluded that the highest production can be expected in the month of July, about 190,000 kWh. Lowest estimated production is in the month of December and it amounts to about 30,500 kWh.

Today, floating PV power plants of higher power are made with central inverters and transformer stations, which are usually in the central part of the floating structure.

For floating PV power plants of higher power, which are connected to the transmission network, the investment price is around €1 million/MW [24]. In other words, for a power plant of, for example, 20 MW and with 20% more installed panels on the DC side, the value of the

investment would be around €24 million (this cost is calculated roughly without any detailed calculations).

The annual production of this power plant at this location would be 27,360 MWh per year [23]. If we briefly analyse the selling prices of, for example, €75/MWh, €100/MWh and €125/MWh [25], the profitability of the investment ranges from 11.7 to 7 years, respectively. Of course, these results should be taken with caution given the constant changes in electricity prices on the market, as well as significant differences in the price of equipment, and thus the initial investment.

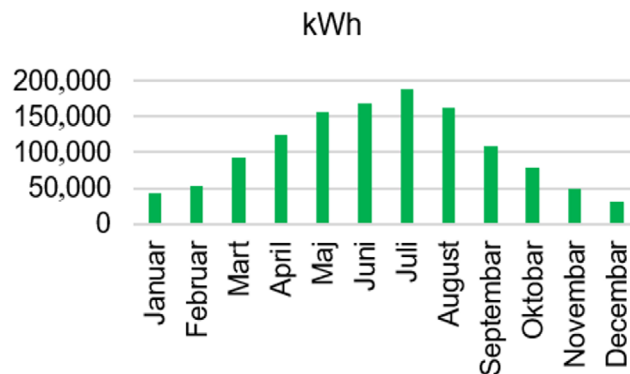


Figure 3: Electricity production of the floating PV power plant from Figure 2

3.2. Estimation of potential in Bosnia and Herzegovina

Electricity consumption in the period from 1946 to 2021 is shown in Figure 4 [26]. In the last few years, the COVID-19 pandemic had a significant impact on electricity consumption in Bosnia and Herzegovina, whereby consumption stagnates or is in decline. According to [26], the share of production from renewable sources is about 35%. A significant increase in renewable sources in total production would imply significant investments and the gradual abandonment of existing thermal power plants.

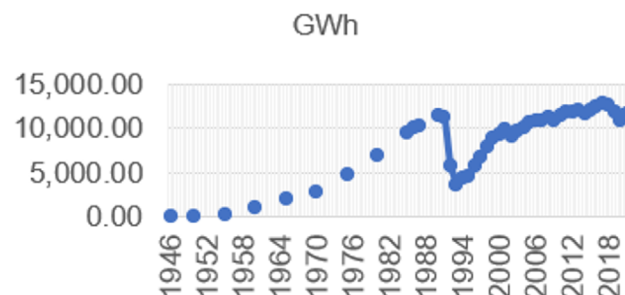


Figure 4: Electricity consumption in Bosnia and Herzegovina

Renewable sources imply investment, primarily in wind power plants and PV power plants. One of the problems with the construction of PV power plants of higher power is the available surface. To overcome this problem, available water surfaces and the construction of floating PV power plants can be used. When researching the potential for

the construction of floating PV power plants in Bosnia and Herzegovina, lakes of larger areas were considered. Basic data are presented in Table I. The insolation listed in Table I varies depending on the geographical position of the lake and ranges from 1,480 to 1,750 kWh/m². The area of the seven largest lakes in Bosnia and Herzegovina is 149.6 km², which represents a serious potential and available area for the possible construction of floating PV power plants. Based on the data and an illustrative example, it was concluded that on only 5% of the total surface of the considered lakes (7.48 km²), about 1,066 MWp could be installed, which would give an annual electricity production of 1,215 GWh (1,140 h). This annual production would cover 10.13% of the average total electricity consumption in Bosnia and Herzegovina for year 2021, as shown in Table II.

Table I: Areas of larger lakes in Bosnia and Herzegovina

Lake	Area (km ²)	* (kWh/kWp)	** (kWh/m ²)
Buško Blato	55.8	1,362.27	1,723.45
Bilećko Lake	33	1,524.8	1,754.6
Modrac Lake	17.1	1,165.3	1,497.86
Ramsko Lake	15.3	1,280.6	1,546.3
Jablanica Lake	13.3	1,285.1	1,558.3
Zvornik Lake	8.1	1,121.7	1,483.4
Vidara Lake	7	1,209.9	1,527

*Yearly PV energy production for optimal angle (PVGIS V5.1.)

**Yearly in-plane irradiation for optimal angle (PVGIS V5.1.)

Table II: Data on the potential utilization of the lake

Total area of lakes (km ²)	5% of total area of lakes (km ²)	Generation (GWh/year)	Percentage of total consumption (%)
149.6	7.48	1,215	10.13

4. CONCLUSION

This paper describes the basic components of floating PV power plants, which represent a relatively new technology of production facilities based on the production of electricity from the PV system. Although they still represent relatively expensive technological solutions, their main advantage compared to PV power plants on land is the construction space, which does not destroy arable land. Other advantages compared to land-based PV power plants include: construction, management and decommissioning are simpler, reduction of water evaporation, cooling of the floating structure is simple, the platform can be easily rotated, which facilitates tracking of the Sun. It is known that the efficiency increases as the temperature of PV module

decreases. This gives the biggest advantage to floating PV power plants over other conventional PV systems. There are also disadvantages in the design phase, such as: the elements must have greater resistance to corrosion, the system must withstand wind blows and heavy waves, operational activities are more difficult to perform on water than on land. The construction of these power plants requires detailed preparations and research of the future construction area, as well as adequate definition of the connection to the electric power system. In the illustrative example for which the Modrac lake was chosen, a floating PV power plant with a power of approx. 1 MW whose annual production would be 1,261 MWh. Considering the surface of this lake, the surface that would be covered by a floating power plant of 1 MW is negligible. On the other hand, the total consumption of electricity in Bosnia and Herzegovina is about 12,000 GWh today, and the share of renewable sources in electricity production is about 35%. In other words, production from thermal power plants is still dominant, which will have to change over time. The area of the seven largest lakes in Bosnia and Herzegovina is 149.6 km² and represents a significant potential for the construction of new power generation facilities. If 5% of the total area of the observed lakes were to be used, the installed power would amount to 1,066 MWp, which would give an annual electricity production of 1,215 GWh (1,140 h). According to current prices, the realization of these forces would be over one billion euros, which represents large investment funds and requires long-term planning for the realization of these projects. In further research, the focus will be mostly on the components of the floating PV power plants and the systems for grounding and protection.

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