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ESTIMATION OF ENERGY RESOURCES POTENTIAL FOR SOLAR PHOTOVOLTAIC SYSTEMS LOCATED ON THE WATER SURFACE OF SMALL LAKES AND RESERVOIRS

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Abstract- At present, the photovoltaic (PV) systems are one of the most promising among renewable energy resources (RES), which share of power generation is growing dynamically, ahead of other types RES. The Floating PV Systems (FPV) are a new type of such systems that are located in the unused part of the water surfaces of lakes, river deltas, natural water basins, reservoirs of hydroelectric power stations. For FPV Solar Station even a small water reservoirs intended for irrigation purposes can be used, what makes it possible for additionally solving a number of problems: the appearance of a local source allows to increase electric power production, covering the water surface of the reservoir reduces water evaporation - which is important for places with a warm climate like Azerbaijan. This article presents the results of preliminary studies of all types of water bodies in order to assess the electric power generation by FPV Solar Station located on the water surface. On the example of the small lake Boyukshor, located within the boundaries of Baku city, a study and analysis of solar radiation, parameters of environment, water in the lake, as well as the selection of FPV technical parameters with 100 kW installed capacity, its operation in power Grid connection mode are considered.

Keywords: Renewable Energy Sources, Floating PV System, Solar Irradiation, Solar Energy, Grid Connected Renewables.

1. INTRODUCTION

Currently, among RES the FPV Solar Stations are considered as the most promising alternative energy sources due to the ubiquitous and sustainable nature of solar radiation. In Azerbaijan, the solar energy production is growing rapidly in accordance with the State Program for large (up to 240 MW) and small (up to 2.5 MW) solar power stations construction and commissioning.

However, a further increase in the number of these stations leads to a number of problems associated with the deterioration of landscape in places of the population residence, an increase in ambient temperature from the reflected light of solar panels, etc. Taking into account also the lack of useful arable land, the use of FPV Solar Stations will avoid some of these problems. In addition, FPV Solar Stations also use some part of sunlight reflected from the water surface and additional cooling of solar cells by water - which makes them 11% more efficient in comparison with similar stations on land [1]. FPV also reduce the evaporation of reservoir water [2] and protect algae by creating the shade [3].

Also, of course, the use of the water surface for the placement of FPV Solar Stations is an advantageous factor for countries that have a shortage of useful land. There are more than 200 lakes and water reservoirs in Azerbaijan and about half of them can be used for FPV installation placement. The most suitable for this purpose are considered 38 lakes and water reservoirs their areas and corresponding values of calculated FPV Potential [4, 11] are presented in the Table 1.

So, as we can see the Total FPV Potential of mentioned Lakes and water reservoirs is about 16 000 MW. Improving the parameters of FPV systems is an important task in the area under consideration, as well as further development of their application's technology. The applied systems of mooring, maintaining their balancing on the water [7, 8] and improving the parameters of the functioning efficiency of these systems [9, 10] were investigated as well. The report of the World Bank [1] notes that by the end of 2018, the installed capacity of solar power plants, taking into account the share of floating plants, was about 1.1 GWp. The unit of measurement Wp (Watt Peak) has traditionally been used to estimate the power output of these systems under standard test conditions. Environmental conditions can affect energy production; therefore, to assess the impact of the variability of current conditions, a standard for assessing performance is introduced: 1000 W/m2 of solar radiation, temperature 25º C and clear sky. While the Capital Costs for the construction of FPV Solar stations remain higher than those for ground based stations, but in the future, in the process of improving design and technology these costs will be significantly reduced and the advantages of floating stations will become obvious.

Table 1. Selected lakes and water reservoirs in Azerbaijan

#	Lake, w/reservoir	Square, m^2	Considered Utiliz./rate (K_U=0.33)	FPV Potential, reduced value, MW
1	Mingechevir Res.	473510000	156258300	8681
2	Semkir Reservoir	78160000	25792800	1432
3	Near Lankaran	59780000	19727400	1095
4	South of Elvend	48660000	16057800	892
5	Aras Govsaghy Res.	47010000	15513300	861
6	Yenikend Reservoir	22670000	7481100	415
7	Jeyranbatan Res.	12680000	4184400	232
8	Khoda Afarin Res.	11010000	3633300	201
9	Lake Massazyrgol	9560000	3154800	175
10	Lake Mirzaladi	9340000	3082200	171
11	Sarsang Reservoir	8930000	2946900	163
12	Varvara Reservoir	8840000	2917200	162
13	Near Tazakand	6530000	2154900	119
14	Mehmangyol	6080000	2006400	111
15	Mets Al Lakea	5110000	1686300	93
16	Jandara Reservoir	4890000	1613700	89
17	Boyukshor lake 2	4480000	1478400	82
18	Hajiqabul Lake	4100000	1353000	75
19	Lake Mirzaladi	3880000	1280400	71
20	Agstafachay res.	3750000	1237500	68
21	Arpachay Res.	3520000	1161600	64
22	Boyukshor lake 1	2560000	844800	46
23	Vilash Reservoir	2380000	785400	43
24	Near Bilasuvar	2220000	732600	40
25	Lake Ag-Gol 1	2130000	702900	39
26	Boyukshor lake 3	1930000	636900	35
27	South of Mingechevir	1920000	633600	35
28	Ayricay Su Anbari res.	1730000	570900	31
29	Yekakhana Reservoir	1630000	537900	29
30	Lake near Kurdexani	1590000	524700	29
31	Xaçin Su Anbari	1560000	514800	28
32	Near Bileh Savar	1390000	458700	25
33	Nohur Lake	1310000	432300	24
34	Qumyataq Golu Lake	1200000	396000	22
35	Mil-Mughan Res.	1160000	382800	21
36	Lovain Reservoir	1140000	376200	20
37	Khanbulaq Reservoir	1120000	369600	20
38	Zigh Lake	1000000	330000	18
Total, power production, MW				15757

The important problems of constructing PPV Solar Stations are:

- They must be cost competitive with traditional ground based Solar Stations;
- Technologies should ensure maximum investor confidence due to absolute compliance with current Standards requirements and Projects delivery;
- The presence of water operating conditions system assessing (corrosion resistance to existing water compositions, taking into account the waves presence, etc.) in the standard that determines the design requirements.

Technologically, the system consists of:

- The floating part - the task of which is to maintain the stability of the structure on the water surface;
- Component connecting the floating part with solar panels and allowing manual adjustment of their position / inclination;
- Electrical equipment (inverters, cables, etc.)
- Anchor system holding the system in a fixed position on the water surface.

Various modifications of the structure may differ in shape, weight and cost. The most common structures are of a modular type, in which 1-2 panels are placed on each module. The structure is flexible, which allows it to be modified as needed, for example, to increase the working surface area in the winter season [9], etc. Some samples of using structures are presented in Figures 1 and 2.

Figure 1. Sample of FPV solar station 1 [2, 4, 9]

Figure 2. Sample of FPV Solar station 2 [2, 4, 9]

In comparison with panels made by silicon crystal technology, panels made of semiconducting gallium and arsenic [12] demonstrates higher efficiency. Below are the average conversion efficiencies for these materials, the cost per watt, and power output per square meter of converter area [12] as Table 2.

Table 2. PV panels materials

Materials for PV panels	Effectiveness, %	Cost, USD/W	Prod. Power, W/m^2
Monocrystalline Silicone	15-25	0.4-0.6	100-190
Polycrystalline Silicone	13-21	0.38-0.56	75-150

2. INITIAL INFORMATION AND DATA OF THE RESERVOIR FOR FPV SOLAR STATION PLACEMENT

As a location for our first FPV Solar Station project the Lake Boyukshor was selected. It is a lake previously used for the discharge of industrial water, contaminated with wastes from oil production and sewage from nearby villages, is currently undergoing a cleaning process.

The large part of it (more than 30%) was already cleaned. A territory around the lake is now under remediation too. The lake is heavily saline with a pH as high as 9. According to the lake operator, it experiences waves up to 1.5 m and strong winds. The pilot project comprises a floating PV plant, a reference ground mounted PV plant and a weather ground measurement station. The lake's fragment which was already cleaned up is shown in Figure 3.

Figure 3. Location of FPV Solar station on the Boyukshor Lake, Baku, Azerbaijan

For our project, a 100 kW (121 kWp) floating solar plant of around 1100 m2 will be anchored at 37 meters from the southern portion of the Boyukshor lake. A 72-meter-long pontoon will also be installed connecting the FPV system to the shore. The pontoon and the floating solar plant will be assembled near an existing dock at the northern end of Boyukshor Lake from where it will be tugged to the installation site near the public park on the southern shore. There it will be anchored to the lake bed and connected to the inverter by a DC cable. The inverter will be connected through an underground cable to the existing grid substation.

For a water quality and buoyancy parameters [11] qualification the lake water has been analyzed and the results are presented in Table 3.

Table 3. Water parameters

Water parameter	Sample 1	Sample 2	Project area
Oil & grease, mg/l	7.2	< 5	< 5
Benzene	< 0.5	< 0.5	< 0.5
Toluene	< 0.5	< 0.5	< 0.5
Pyrene	< 0.01	< 0.02	< 0.02
pH			8.0-7.9

The water of the lake is extremely challenging and will require several measures:

- No work underwater shall be allowed;
- Work in the water will be limited to the essential and no one is allowed in the water without proper safety clothes, namely gloves;
- Access to the floating platform shall be kept to the minimum possible, namely for O&M tasks;
- All materials to be submersed must be previously tested in the same water conditions, namely cement, anchors and plastics. No electrical cables shall be allowed inside the water.

For the Bottom ground analysis [11], the soil has been decontaminated and the current analysis done by the lake operator, are shown below. No major changes are expected to the current situation in the years to come. The mixture for the cement or concrete of the dead weights construction material for anchors) should also take into consideration this data as to prevent that cement may be affected during the life time of the project (25 years).

Table 4. Lake's bottom parameters

Bottom sediment parameter	Sample 1	Sample 2	Remarks
TPH (>C10-C12), $mg.kg^{-1}$	1.6	8.3	+
Benzene	< 0.2	< 0.2	+
Toluene	< 0.2	< 0.2	+
Pyrene	12.7	< 0.5	+

3. HYDRODYNAMIC ANALYSIS

According to the lake Operator's data the currents are not strong, but the wind is strong and creates waves of 1.5 m. That creates further challenges to the floating structure tension strength and flexibility. Furthermore, modules and electrical equipment on top of the floating structure will be at increased risk as water will splash. All equipment must have proper casings and PV modules should be certified against salt mist (IEC 61701) and ammonia (IEC 62716). Any metallic surface shall be coated against corrosion by hot galvanization. Inverters will not be installed in the floating structure. The floating structure must be designed to withstand the wind load.

4. METHODOLOGY

4.1. Solar Irradiation and Weather Data

The purpose of these studies was the accumulation and primary processing of solar radiation data in a given region and related meteorological data to obtain the characteristics of the average daily solar radiation with an hourly basis. Then necessary maps of average solar radiation were completed accordingly. Assessment of the solar resource was done using available data (from PV SYST database and others). It is recommended to acquire Solar GIS satellite data including TMY files (P50 and P90). The raw solar irradiation and Meteodata from Hydromet is not free of cost and it is not clear also the level of accuracy and precision, especially regarding the global horizontal irradiation (GHI) measurement. All data were formatted consequently to align with modeling process requirements [6]. These files are considered as P50 type of TMY files. According to this source the environmental data for selected location is displayed in Table 5.

Table 5. Environment and Meteodata [6] for selected location

40.42 N 49.78 E	Temp (ºC)	Min (ºC)	Max (ºC)	GHI (kWh/ m^2)	Wind speed (m/s)	Wind direction (º)	Relative humidity (%)
Jan	5.22	-4.3	12.0	59.8	3.95	192	84.0
Feb	3.96	-7.3	13.5	81.0	3.70	181	79.9
Mar	8.25	1.1	25.2	130.0	5.49	201	78.6
Apr	13.08	5.6	24.3	170.7	2.60	186	80.0
May	19.08	10.0	30.7	210.1	3.16	187	73.2
Jun	23.78	16.0	34.8	220.9	5.18	198	67.8
Jul	26.39	19.5	36.6	219.8	4.75	205	64.5
Aug	27.56	19.0	40.8	201.0	3.31	189	60.3
Sep	22.13	13.4	33.4	150.4	4.46	196	68.6
Oct	16.33	7.3	33.0	108.1	1.20	174	81.0
Nov	12.25	2.6	19.6	67.0	3.24	186	80.4
Dec	5.91	1.3	12.4	55.8	1.48	174	82.8
Average	15.39	7.0	26.4	1674.7	3.54	189	75.1

4.2. Yield Estimates

The simulations [11] done for the FPV Solar Station (100 kW) considered several configurations:

- South 15º tilt mounting
- South 22º tilt mounting
- South 40º latitude mounting for the ground mounted PV plant. This tilt which requires completely different mounting structures for floating PV, which may not be available and will create substantial wind loads.
- PV System was used to run the simulations of the PV plant to determine the energy yields.
- The following was considered as example:
- Inverters of 45 and 50 kW were used
- PV modules of 275 Wp were used with 16.8% of efficiency
- DC/AC oversizing of 20% considered

The results are presented below in Table 6.

Table 6. FPV solar station yield estimates

	Floating 15° 95 kVA	Floating 22° 95 kVA	Ground Mounted 15° 5 kVA	Ground Mounted 22° 5 kVA	Ground Mounted 40° 5 kVA
Prod. Energy kWh/yr	169000	175000	9108	9342	9514
Specific DC prod. kWh/ kWp/yr	1470	1520	1506	1544	1573
Spec. AC prod. kWh/ kVA/yr	1783	1843	1822	1868	1903
Perfor. Ratio (PR) (%)	79.7	80.4	81.6	81.7	82.6

	Floating 15°	Floating 22°
Needed Floating Area (m^2)	979.7	1088.6

4.3. Design Parameters for FV Systems Considered in this Study

This study operates with common using types of solar panel and inverter. If in future some more effective models will be used - the benefits will only be increased.

Solar panels materials and technology improving constantly [13], and for future installations- the more innovative devices and materials will be used. The equipment cost [11] and corresponding operation costs were estimated for results in Table 7.

Table 7. Equipment costs estimates

Description	Qty.	Loc. cost	Foreign cost	Total cost
PV Modules	121 kWp		100%	0.25 $/Wp
Inverters	100 kW		100%	0.06 $/ Wp
Floating structure, (m^2)	1100		100%	
Anchors (1 ton each)	4	100%		75 $/ton
Civil works	121 kWp	20%		0,3 $/Wp
Expected total price				1.4 USD per installed Wp

For our case the cost for installation will be 1.4 USD/W and the operation and maintenance costs (OPEX) are expected to be of 2 to 2.5% of the initial investment (CAPEX).

5. CONCLUSION

The assessment of the total power generation by solar PV systems located on the water surface of all reservoirs existing in Azerbaijan has been carried out. Models for forecasting solar radiation were built, in which data on the properties of water, depth and other topographic information of the reservoir, the surface of which will be used to install the PV system, are taken into account. The results of the research carried out represent as primary data for the FPV design of each individual reservoir. As an example, the paper cites research data of a 100 kW floating water station on Lake Boyukshor, which can serve as input data for the design of real FPV systems.

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