

Feasibility and Environmental Sustainability of a 103.5 kWp floating Photovoltaic Electrical System with a Case Study in a Hydroelectric Power Plant, Santa Clara Hpp, Located in the South of Brazil Region

Kleber Franke Portella¹; Rodrigo Paludo¹; Gelson Luiz Carneiro¹; Júlio Werner Yoshioka Bernardo¹; Marianne Schaefer França Sieciechowicz¹; Mariana D'Orey Gaivão Portella Bragança¹; Nicole Machuca Brassac de Arruda¹; Emerson Luiz Alberti²; Augustus Caesar Franke Portella³; Magno de Oliveira³; Wendrey Mendonça Borges³

¹**Instituto de Tecnologia para o Desenvolvimento**, Departamento de Estruturas Civis, Institutos Lactec, PO Box 19.067, CEP: 81.531-980, Curitiba, Paraná, Brasil; portella@lactec.org.br; rodrigo.paludo@lactec.org.br; gelsonluiz@lactec.org.br; julio.bernardo@lactec.org.br; marianne.franca@lactec.org.br; mariana.portella@lactec.org.br.

²**Centrais Elétricas do Rio Jordão**, José de Alencar St., 2021, CEP: 80040-070, Curitiba, Paraná, Brasil, emerson@elejor.com.br

³**Universidade Federal do Tocantins**; Departamento de Ciências Exatas, Campus Universitário de Gurupi, Gurupi; Tocantins, Brazil; portella@mail.uft.edu.br; magnoempresa@gmail.com; wendrey@mail.uft.edu.br

Abstract— Typical environmental problems associated with the implementation of solar photovoltaic systems for the generation of peak electrical energy, on a larger scale, such as on the order of 1 MWp, is in the occupied area, usually more than 3 km². This can be minimized by the use of water parks or water dam's reservoir, small and large hydroelectric power plants dams. Both the terrestrial and aquatic systems can impact the site, the first one, for the need to promote earthworks, removal of extensive green areas in the surroundings, installation of new transmission line, among others; and the second, despite the fact that a flat surface is already used and that there is no need for new civil procedures for its installation and can normally take advantage of the existing power transmission line, may cause changes in the biota of the reservoir, depending on the shading areas on the surface of the lake. Due to these facts, this research was proposed to investigate, parameterize and tropicalize an electric power generation system based on floating silicon photovoltaic cell panels installed in the Santa Clara HPP reservoir, in terms of peak power, durability, aspects and environmental impacts, with the study of

possible evolutionary improvements of the project such as "tracking" or solar tracking, as well as dynamism of the structure, allowing the shadow area to be shifted over time, minimizing its effects in the local biota.

Keywords— floating photovoltaic plant, case study in hydroelectric plant reservoir, environment, durability.

I. INTRODUCTION

The generation of floating photovoltaic electricity is better utilized and with its lower costs in several countries. The main issue of its implementation is focused mainly on its clean energy and its greater sustainability, since with this technology it is possible to reuse the available surface area in lakes or even water reservoirs with large surface extensions, such as those of hydroelectric plants and, in the latter, by the joint availability of transmission lines installed therein [1-8]. However, the recent technology may cause environmental impacts that have not yet been verified in its extension, due to its recent application in the hydroelectric energy park, thus requiring, research of parameterization, environmental tropicalization and joint investigation of its generation

potential with the integrated form to the physical environment and biota.

In Brazil, the implantation of this type of enterprise is incipient [1, 9-12] and the generated environmental studies are little known and diffused, therefore, its knowledge from the multidisciplinary and environmental point of view has an innovative character. Thus, the survey of possible environmental impacts and the integrated analysis of the project are fundamental for the elaboration of the best alternative in the technical and economic aspects, mainly considering the plants with capacities of generation superior to 1 MWp, considering the necessity of a surface area of the lake or reservoir, at current power standards (of the order of 250 W, per panel), exceeding 10 km². Also, adverse climatic conditions influence the energy yield of the plant, such as the speed and direction of the winds, without even considering the other factors of a tropical country. These have direct influence on the production of an effective anchoring system in order to avoid deviations from its parallelism to the condition of the greater luminous intensity and the dynamism of the panel influenced by the waves.

II. REVISION AND STATE OF ART

From the mid-2000s onwards, interest in Brazil began for the applications of photovoltaic energy connected to the grid, in the context of research carried out by universities and research centers. With this, dozens of small photovoltaic systems, most of them smaller than 10 kWp, were installed in several regions [13].

With the promising results and in conjunction with other specific Brazilian legislation and program initiatives, in 2011, the first large photovoltaic solar power plant with an installed capacity of 1 MWp was inaugurated and in 2012, the first of a series of stadiums with the same technology, with Brazil having an installed capacity registered at Aneel at the end of 2012, of almost 2.6 MWp [13].

In 2011, there was also a strategic demand for research projects of the National Electric Energy Agency, ANEEL, Report 13, "Technical and Commercial Arrangements for the Insertion of Solar Photovoltaic Generation in the Brazilian Energy Matrix". In this, 19 research projects were registered involving solar generation with photovoltaic power plants in concessionaires of energy of practically all the Brazilian regions, with investments of the order of US\$ 110 million for an installed power of about 25 MW, that is, to a cost approximately US\$ 4.00/W. As one of the possible results of this strategic demand of ANEEL, it was the consideration that in the country, in 2013, "cleaner" energy matrixes were used, with a participation of 41% of the global amount. By 2015, according to the Information Generation Bank (BIG),

317 photovoltaic plants with installed capacity of 15.2 MW of energy were invested in the country, corresponding to 0.01% of the generation capacity, of which 95% were included in generation of up to 100 kW, and that only 6 projects, or 5%, had installed capacity greater than 1,000 kW. Among the largest investments in the area, up to 2015, are MPX's Tauá Plant (2011), installed in Ceará, with 1.0 MW (and a maximum capacity of up to 50 MW) and the Central Mineirão Plant, with an installed power of 1.42 MWp, of Companhia Energética de Minas Gerais, CEMIG. However, in none of these investments was the use of floating [14-18]. Under the call 003/2015, the companies cooperated by the Centrais Elétricas do Norte do Brasil SA, ELETRONORTE, and the Hydroelectric Company of São Francisco, CHESF [19] launched a call for a research and development project entitled "Exploration of solar energy in lakes of hydroelectric power plants", with the objective of implementing a sustainable generation system of complementary solar power of 10 MWp of power (of these: 1 MWp of a pilot system for the evaluation of the load factor and the installation of 4 MWp in each of the lakes), using photovoltaic panels mounted on floating platforms on the lakes of the hydroelectric plants of Sobradinho (BA, Northeast of Brazil) and Balbina (AM, northern region of Brazil). In this project, at a cost around US\$ 3.00 / W, the objectives were to study the behavior of this application on the surface of the reservoirs, the resulting environmental impacts, the use of ecologically correct and technically feasible materials for replication in the other reservoirs and which do not necessarily block the passage of natural light, anchorage and studies to enable the connection of the systems to the grid, as well as other electrical parameters. However, none of the data generated was previously available to the scientific community.

In 2016, the Companhia Energética de São Paulo (CESP), in the municipality of Rosana, SP, Brazil, launched the first photovoltaic plant with flexible plates and floating systems with research project with ANEEL and resources of the order of US\$6.3 million, for a rigid 250 kW ground and 25 kW floating plate system and one with 250 kW flexible solar panels and 25 kW floating systems [9], the occupied area being estimated at, approximately 500 m², and the reservoir had 2,250 km², at an approximate cost of US\$ 12.00 / W. Strangueto, 2016 [1], pointed out that the generation of floating photovoltaic solar energy installed in lakes and dams, is already used in several other countries, but in none of these has it found projects in reservoirs of hydroelectric plants. These generators are focused on the pumping of water for agriculture, for the maintenance of production or the increase in the electric grid, with additional advantages being

the reduction of the evaporation rate of the water in the reservoirs and the reduction of the algae proliferation. For Brazil, Strangueto, 2016 [1], calculated the scenario obtaining an estimate of the energy potential of the reservoirs and the total energy that could be produced, with limits for a maximum average scenario of 4,519 GWp for the Brazilian potential, with average power of 753 GW average, or up to 4,443 TWh of energy per year, and for a lower limit of 10% of these values for the lower scenario, using 80% and 8%, respectively, of the reservoirs in each scenario. As suggestions for future work related, the researcher highlighted: a) to make a parallel study of economic analysis, in which, the costs of panels, the manufacture of floats, the anchoring process in the reservoirs should be contained; b) investigate the characteristics of the environments in order to reduce the impacts caused by the losses by evaporation of water; the reduction of water oxygenation and changes in the biota of the reservoirs; c) extend knowledge about social impacts, resulting from the reduction of possible fishing and aquaculture activities, loss of leisure areas; d) to investigate and carry out the survey of field parameters, in order to obtain generation values of each system; e) to promote additional studies on the possible deflections of the systems in relation to the depth of the reservoirs and their variations of level and exclusion areas.

Projects of floating photovoltaic installations are still expanding themes and research. Its motivators are, mainly, the restriction of the use of terrestrial areas for the installation of solar plants, using as alternatives, water reservoirs. In Trapani and Santafé, 2015 [2], a review of the projects of floating photovoltaic plants installed between 2007 and 2013 was presented, being these separated in projects of conventional photovoltaic plants and conceptual projects. The common benefits presented for all the projects reviewed in this work were the reduction of evaporation of water from the reservoir and the decrease in the growth of aquatic vegetation due to the lower penetration of solar energy (when there are no environmental restrictions, as in artificial reservoirs). In most cases, it was found that the efficiency of the solar installation was improved by the cooling caused by the evaporation of the water, or by the direct contact of the panels with the water as in the conceptual design [3]. Still, in Trapani and Santafé, 2015 [2], were cited the projects implemented until 2013.

The project of the Polytechnic University of Valencia, installed in 2009 on a water reservoir for irrigation in Agost, Spain was described in Santafé et al., 2015 [4], Ferrer Gisbert et al., [5] and in Ferrer and Ferrer et al., 2010 [20], the system of support and flotation of the installation, characterized by the following elements: floating platform,

support structure, metal couplings articulated between floats, flexible joints, ropes and rigid anchorage system. The floats were designed in modular formats that allowed the fitting between them by flexible joints, to absorb the relative movement between them, also considering a possible drought situation of the reservoir. The system in general numbers was constituted of 1,458 photovoltaic panels supported on 750 floats, totalizing 4,490 m² of area on the water reservoir.

In this investigation, the parameters of tropicalization, the technical and scientific viability of the installation of a floating photovoltaic plant on the 103.5 kWp small-scale photovoltaic power plant (SFPPP-StC) reservoir were analyzed and discussed. to be installed in an area of over 1.5 km², being one of the first similar projects to be implemented in the Southern region of Brazil, in the state of Paraná. In order to do so, emphasis was placed on its influence and the environmental effects or impacts on the physical environment and biota present, since a large part of the existing energy systems are not installed in reservoirs of hydroelectric power plants.

III. MATERIALS AND METHODS

Photovoltaic panels, inverters and accessories. The acquisition of the photovoltaic panels was based on the maximum electric power available within the research budget, which was 345 Wp (watt-peak), Canadian Solar brand, type 144 Cells, poly-Si, dual cell – 1,500 V. all, were considered for the purchase, approximately, 300 panels for the service of 103.5 kWp of the plant. As inverters, 2 units of the ABB trio TM equipment, 50.0-400-power module, 3MPPT-380 V, were acquired with 98% efficiency. Other accessories made up the electrical system and corresponded to cables and fastening devices for connection to a 34.5 kV power distribution network.

Prototype float. In order to reduce the environmental impact on the physical environment and biota of the reservoir, by reducing the total area of shading by the plant, a float module constructed in metallic system of carbon steel coated by hot galvanizing was idealized. In this, the beams, the body guard, the catwalk (in perforated expanded plate) and the galvanized carbon steel fixings, with a minimum of fixing with screws were considered. For the floats, high-density polyethylene, HDPE, was added as a base material, with the addition of anti-UV material in its constitution, using 250 L cylinders from reuse material made available after the intercontinental transport of oils. These were prewashed and disinfected for reuse.

The metal fixing profile of the panels was designed to meet a static or dynamic tracking system for SFPPP-StC, following the highest daily solar incidence. Also, the design was

worked with a linear distance of 980 mm modules to obtain panel slopes up to 25° for better geometry in relation to solar radiation. In terms of safety, a body guard was designed to meet Brazilian standard requirements (NR 12 [21]) and to cause minimal shading on panels.

For the interconnection of the modules, a system was developed with the capacity to allow the angular relative displacement between them, taking into account the oscillation of the lake water. Thus, the main idea of the lateral and longitudinal junction system was to allow its movement in the most independent way possible in relation to the others. For this fixation, we chose a design with cushion systems between them.

Location of deployment of SFPPP-StC. During a technical visit to the Santa Clara HPP reservoir, three sites were economically and technically considered viable for the plant's implantation, as shown in Figure 1, A, B and C.

Hydrodynamic modeling of the reservoir for the implantation of the SFPPP-StC. In order to parameterize the reservoir for the implantation of the plant, modeling was done with respect to the water velocity, the average height of the waves, with a parametric approach that calculates the significant height of the wave as a function of wind speed, direction and "fetch" wind track in 16 directions, with delft3d software, from the company Deltares [22, 23].

The historical series of water levels, between 2006 and 2018, was raised in order to consider the linear deviation of the plant from the margin of the reservoir and to minimize its influence on the vertical displacements and water. Also, a topobathymetric profile of the region was obtained to obtain the mean depth, which will serve to launch an anchorage system.

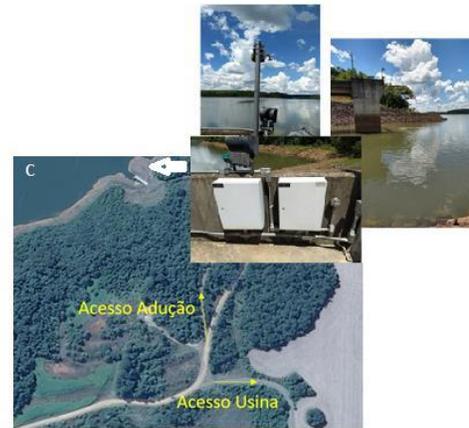


Fig.1: Illustrative images of the possible SFPPP-StC implantation sites in the Santa Clara HPP reservoir (adapted from Google Earth, 11 and 12/2017), being: A) 100 m from the left of the dam; B) 200 m from the right; and C) upstream of the adduction channel (about 150 m).

Physical-chemical analyzes of reservoir water. The characterization of the physical parameters and their chemical composition were performed considering the water quality index (IQA) of the reservoir, preliminary to the implementation of PCFF-StC, with the measurement of pH, dissolved oxygen, DO, temperature, turbidity, the total solids, suspended and dissolved and the main cations and anions.

Solarimetric index, local environmental data and their feasibility in terms of the use of a static or dynamic system of energy production. These local environmental parameters were considered for their measurement from the installation of a compact solar station with GPRS / GSM data telemetry, consisting of an HOBO RX 3003 datalogger, a S-THB-M002, with solar shelter, with wind speed sensor S-WSB-M003; with SR20-D2 secondary standard pyranometer and accessories.

IV. RESULTS AND DISCUSSIONS

SFPPP-StC installation location. The first two points with the possibility of installing the plant (Figure 1A and B) were discarded, because they are located next to the concrete dam at Santa Clara HPP and because in the rainy season, dragged by the stream of water from the reservoir flowing freely through the spillway that is located about 150 m from this site. The location of the SFPPP-StC was chosen based on the proximity of a 34.5 kV electric power distribution line, its easy access, the instrumental safety by video camera and the local sound system, the private area of the plant, being close to the adduction channel at 25°39'23 "S and 51°57'6" O, with elevation 750 m at sea level. Figure 1 C shows the idealized location of the photovoltaic plant.



The float module and features. In order to reduce the projected shading area on the surface of the reservoir, which is a function of its angular relationship with the incident radiation, this project was chosen for a higher installed power per panel. This was equivalent to 103.5 kWp, corresponding to 300 panels installed on 46 floatings modules in an area close to 1.5 km².

The total shading area projected on the surface of the reservoir, which varies with the solar zenith, was simulated to a minimum of 5.05 m², when the incident radiation is approximately 150° of this, and a maximum of 23.28 m², when the angle of the radiation is 30°, that is, in the rising sun. Between these intervals, the resulting shadow per floating module is a maximum of 13.67 m². In Figure 2, there are shown 3 schematic drawings of the float module, to reduce as much as possible the resulting shading in the reservoir and its environmental impact on the local biota. Complementing the other float modules available in the market, which mostly design a total shading on the reservoir, it was designed in order to meet different geographical positions, by changing the angle of arrangement of the solar panel in relation to the incident radiation and, also, in order to facilitate the placement of a tracking device throughout the

plant. Each module is attached to the next one by means of an articulated system, to minimize the impact of the fluvial waves on the set floating (Figure 2 C).

The prototype of the flotation module was tested for water tightness and stability over normal water and under turbulence in a controlled aquatic environment. In Figure 3, a photo of the prototype of the designed float module is shown.

Environmental considerations of the site. The depth profile of the reservoir is shown in Figure 4, and the SFPPP-StC installation region is indicated by arrow, with depths between 13 and 34 m.

Weather data. On-site historical meteorological data analyzes (number of analyzes, carried out in about 1 decade) indicated average wind speeds of up to 10 ms⁻¹, a seasonal ambient temperature ranging from 4 to 32 °C, and a solar radiation index more than 800 W.m⁻². By mathematical simulation, the maximum heights of the waves were estimated on the surface of the reservoir, which, in some way, impact on the energy yield of the plant, by altering the angle of incidence of the solar rays, having as initial variable the winds with the velocity, minimum of 1.5 m.s⁻¹, at maximum, extrapolated to 20 m.s⁻¹, reaching 0.1 to 0.40 m in height, as can be seen in Figure 5.

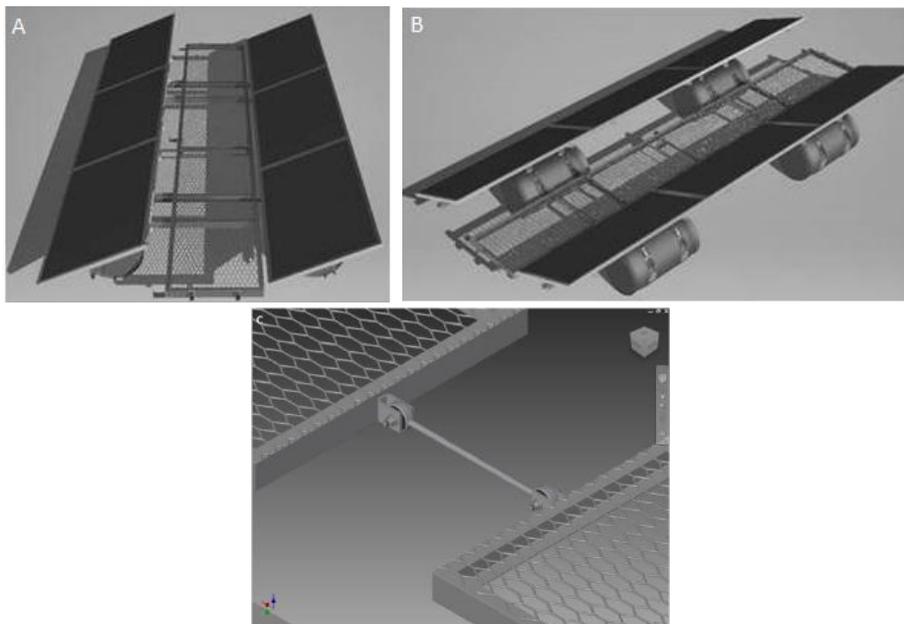


Fig.2: Illustrative schematic drawing of the SFPPP-StC float module with 6 solar cell plates with 345 Wp, each being: a) frontal view; b) cross-sectional view; and c) articulated arms for fastening between modules.



Fig.3: Illustrative picture of the prototype of the flotation module under watertight test and stability over water under conditions of greater turbulence.

By analyzing the historical data of reservoir floods, it was verified in a decade a variation of its quota in about 17 m (top / down), which makes it impossible to install the SFPPP-StC, near the reservoir margin.

Water quality Index, WQI. The analysis of the water of the reservoir, near the SFPPP-StC site, showed a WQI higher, on

average to 80%, being classified as optimal and not degraded, with annual average physical-chemical parameters, presented in Table 1. By the results of Ca^{2+} , Mg^{2+} , Na^+ and K^+ and HCO_3^- , Cl^- , SO_4^{2-} concentration, in Piper diagram showed in Figure 6, the reservoir water was classified as calcium and mixed bicarbonated.

Table.1: Analytical results of water quality in the middle portion of the Santa Clara HPP reservoir and CONAMA Standardization limit [24].

Parameters analyzed	Standardization Limit [24]	Water sample results	
Depth of sample collection (m)		0.6	16.0
Temperature (°C)		23.5	18.2
pH	6.0 to 9.0	7.5	
Electrical conductivity ($\mu S.cm^{-1}$)		25.0	
Turbidity (NTU)	100	14.0	
Total solid ($mg.L^{-1}$)		5.0	
Dissolved oxygen ($mg.L^{-1}$)	≥ 5.00	8.02	6.33
Total P ($mg.L^{-1}$)		0.03	0.03
Total N ($mg.L^{-1}$)		0.91	
Total N-NH ₃ ($mg.L^{-1}$)		< 0.1	<
			0.1
Total N-nitrite ($mg.L^{-1}$)	1.00	<	<
		0.01	0.01
Total N-nitrate ($mg.L^{-1}$)	10.00	< 0.5	0.65
Inorganic total N ($mg.L^{-1}$)		< 0.5	0.70
BOD ($mg.L^{-1}$)	< 5.00	< 2.0	
DOQ ($mg.L^{-1}$)		< 5.0	<
			5.0
Chlorofila-a ($\mu g.L^{-1}$)	30.00	0.71	
Phytoplankton ($cel.mL^{-1}$)		1,419	15
Cyanobacteria ($cel.mL^{-1}$)	50,000	611	0
Potentially toxic cyanobacteria ($cel.mL^{-1}$)		611	0
Secchi disk (m)		1.1	1.1

At the water sampling station near the SFPPP-StC site, in the deepest portion of the reservoir, a continuous stratification pattern has been observed historically, even in colder months. However, in the months of higher temperatures, as in the summer, the stratification was more pronounced in relation to the colder ones. The temperature difference

between the surface and the bottom was 7.2 °C and the DO varied 6.8 mg/L, as shown in Figure 7. With regard to its concentration in the background region, no anoxia events were observed, however, hypoxia was recorded at a depth of 29 m, where the value of 1.21 mg.L⁻¹ occurred.

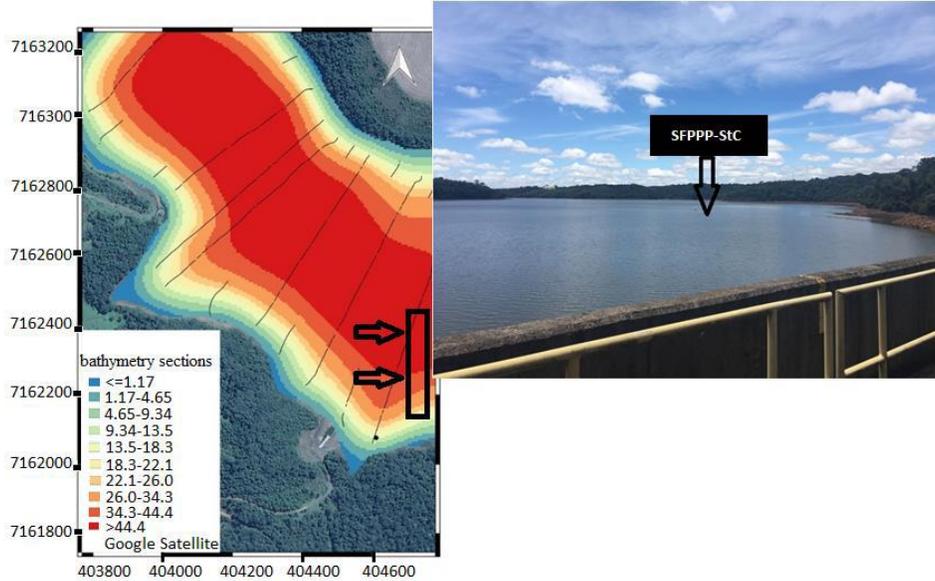


Fig.4: Graphic image of bathymetric sections, near the water outlet of the hydroelectric plant, for the installation of the SFPPP-StC.

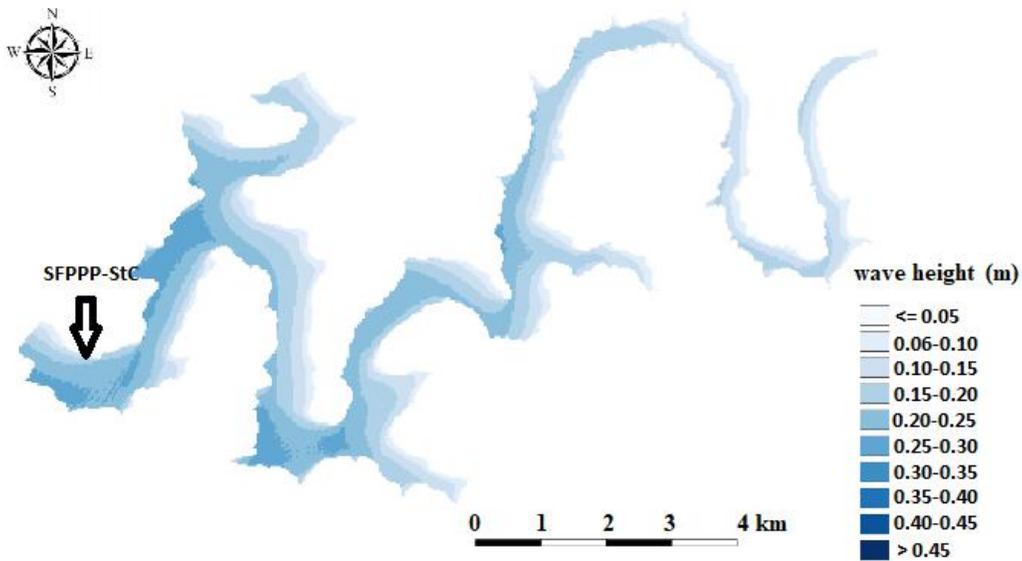


Fig.5: Georeferenced wave height map in the Santa Clara HPP reservoir, Paraná, Brazil, for a mean minimum wind of 1.5 m.s⁻¹ at 20 m.s⁻¹, in the ENE direction.

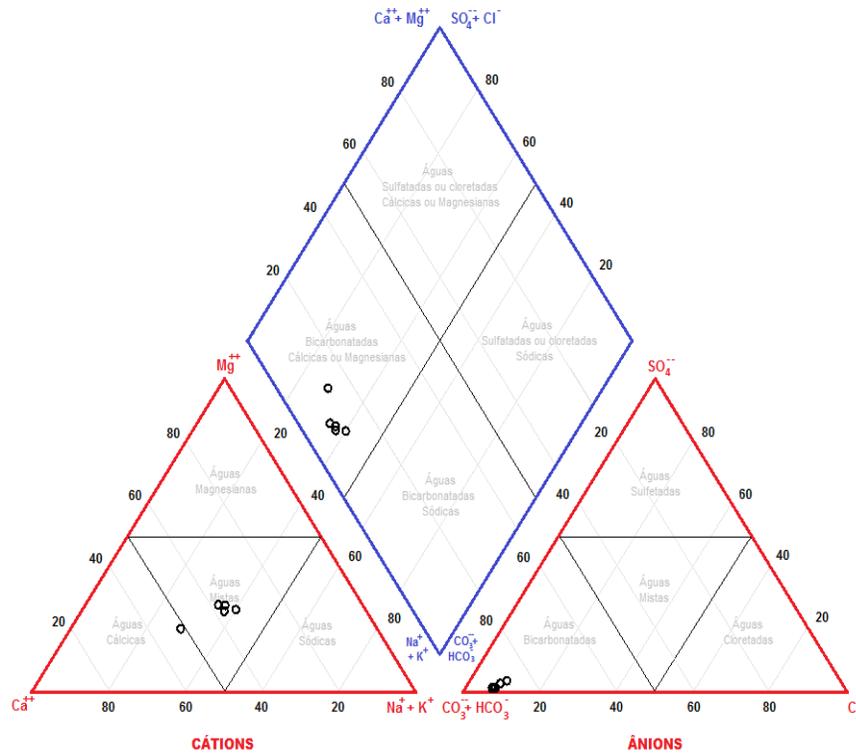


Fig.6: Piper diagram of the water samples collected in the Santa Clara HPP reservoir, at depths of 0.5 m (1); or water surface column; 3.5 m (2); 7 m (3); 14 m (4) and 28 m (5).

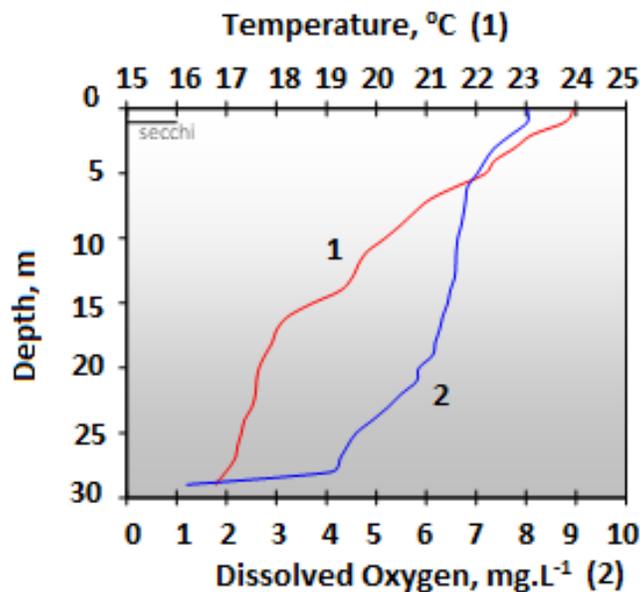


Fig.7: Graph illustrating the vertical profiles of DO and temperature, measured along the depth in the reservoir of the Santa Clara HPP, near the SFPPP-StC.

Phytoplankton. For the characterization of the phytoplankton community of the reservoir, were used data from a sample network of collection stations, one of them in the region surrounding the plant SFPPP-StC, using as indicators the cell

density, expressed in number of cells per milliliter (cells.mL^{-1}); total richness, expressed in terms of the total number of species present; the abundant species, considering those whose occurrence exceeded the average value of the total

number of individuals of the species in a sample; the dominant species, whose density exceeded 50% of the total number of individuals counted in a sample, among others [25-30].

It can be observed that the phytoplankton community was well represented by cryptophyceae, green algae and diatoms. The environment is typically oligotrophic. Potentially toxic cyanobacteria were also recorded, but at low cell densities such as *Merismopedia tenuissima*, *Aphanocapsa delicatissima*, *Aphanocapsa sp.2* and *Cuspidothrix issatschenkoi*. Another factor of the community was the presence of the dinoflagellate *Ceratium furcoides* in two seasonal moments, winter, with a density of 8 cel.mL⁻¹ and, in the spring of 2017, with a density of 4 cel.mL⁻¹. Although it does not present any toxicity, when flowering, it can alter the taste and odor of the water, as well as, cause the *DO*

decrease by the massive decomposition of the cells, compromising the quality of the water and increasing the costs of the treatment [29]. The presence of this dinoflagellate should be monitored because it is an exotic invasive species and its ecology is still little known.

The phytoplankton community present in the reservoir had been behaving in a seasonal manner, with some species, such as *Cryptomonas brasiliensis*, *Rhodomonas lacustris* and *Cryptomonas sp.*, As well as the green algae *Monoraphidium contortum*.

In the summer of 2017, in this season, the classes Bacillariophyceae and Chlorophyceae were the ones that presented a greater local abundance and the Cyanophyceae that presented a higher density of cells.mL⁻¹, as can be observed Table 2.

Table.2: Occurrence of phytoplankton species in the region surrounding the SFPPP-StC, with density in cells.mL⁻¹, in 2017.

CLASS	SPECIES	MARCH	JUNE	SEPTEMBER	DECEMBER
Bacillariophyceae	<i>Aulacoseira minuscula</i>	20	-	-	-
	<i>Aulacoseira pusilla</i>	40	-	8	3
	<i>Aulacoseira tenella</i>	-	16	-	28
	<i>Cyclotella meneghiniana</i>	-	4	-	-
	<i>Discostella stelligera</i>	147	-	4	9
	<i>Fragilaria sp. 2</i>	10	-	-	-
	<i>Nitzschia sp. 1</i>	-	25	10	-
	<i>Urosolenia obesa</i>	69	-	-	-
Chlorophyceae	<i>Closteriopsis sp.</i>	10	8	10	-
	<i>Desmodesmus sp. 42</i>	42	-	-	-
	<i>Desmodesmus sp. 25</i>	-	8	-	-
	<i>Elakatothrix gelatinosa</i>	10	-	-	-
	<i>Eutetramorus sp.</i>	39	-	-	-
	<i>Eutetramorus sp.</i>	10	-	-	-
	<i>Monoraphidium contortum</i>	20	4	27	54
	<i>Monoraphidium minutum</i>	-	8	48	32
	<i>Monoraphidium sp.1</i>	1	-	-	-
	<i>Tetranephris brasiliensis</i>	118	-	-	-
Chrysophyceae	<i>Chrysamoeba sp.</i>	-	-	76	13
	<i>Mallomonas akrokomos</i>	30	-	10	51
	<i>Mallomonas tonsurata</i>	39	8	-	-
Cryptophyceae	<i>Cryptomonas brasiliensis</i>	88	25	10	19
	<i>Cryptomonas sp.2</i>	284	90	2	2
	<i>Rhodomonas lacustris</i>	1549	385	133	318
	<i>Rhodomonas sp.1</i>	59	-	-	-
Cyanophyceae	<i>Aphanocapsa delicatissima</i>	1088	25	-	-

CLASS	SPECIES	MARCH	JUNE	SEPTEMBER	DECEMBER
	<i>Aphanocapsa sp.2</i>	1078	-	-	-
	<i>Cuspidothrix issatschenkoi</i>	392	-	-	-
	<i>Merismopedia tenuissima</i>	-	4	-	25
Dinophyceae	<i>Ceratium furcoides</i>	-	8	4	-
	<i>Peridiniopsis penardiforme</i>	10	-	-	-
Prasinophyceae	<i>Nephroselmis sp.</i>	186	16	48	13
	<i>Pedinomonas sp.</i>	412	-	48	274
	<i>Tetraselmis sp.1</i>	109	8	1	-
Zygnemaphyceae	<i>Teilingia granulata</i>	-	4	-	-

V. CONCLUSION

The float module designed for the fixation of 6 photovoltaic panels of 345 Wp each was tested in a monitored aquatic environment, passing the tests of stability and watertightness, as well as its design showed to cause a maximum shading, in the waters of the reservoir, in zenith solar at 30° of 23.28 m², with the rising sun, and of minimum, 5.05 m² when it is at 150° in relation to the panels in the floats. At the highest daily interval, the maximum projected shade was simulated at 13.67 m², at 60° solar incidence.

The calculated WQI showed that the waters in the Santa Clara reservoir presented excellent quality, being classified between calcium and mixed bicarbonated, and its results based on about a decade of the collected samples showed to be a poorly degraded environment.

As for the chemical and thermal stratification of the reservoir, in the region of plant implantation, the reservoir showed strong stratification, reaching the bottom hypoxia at depth of 29 m with an average value of 1.21 mg.L⁻¹. No anoxia was recorded by the evaluation of the dissolved oxygen profile.

The general analysis of the phytoplankton showed the possibility of having them as indicators of any occurrences of a possible environmental degradation of the water of the reservoir due to the installation of the floating photovoltaic plant.

VI. ACKNOWLEDGMENTS

The authors are grateful for the support provided by Instituto de Tecnologia para o Desenvolvimento, LACTEC; Agência Nacional de Energia Elétrica, ANEEL; Centrais Elétricas do rio Jordão S. A., ELEJOR; Universidade Federal do Paraná, UFPR; Universidade Federal do Tocantins, Campus Gurupi; and the Conselho Nacional de Desenvolvimento Científico e Tecnológico, CNPq/PIBITI/

Scholarship DT 1D, process 302672/2016-8; CNPq Law 8010/90, entities that enabled the development of this work.

REFERENCES

- [1] STRANGUETO KM (2016). Estimativa do Potencial Brasileiro de Produção de Energia Elétrica através de Sistemas Fotovoltaicos Flutuantes em Reservatórios de Hidroelétricas. Tese de Doutorado. UNICAMP. Brasil.
- [2] TRAPANI K, SANTAFÉ MR (2015). A review of floating photovoltaic installations: 2007-2013. Prog. Photovolt: Res. Appl. 23:524-532.
- [3] BAHADARAH H, SUBHAN A, GANDHIDASAN P, REHMAN S (2013). Performance evaluation of a PV (photovoltaic) module by back surface water cooling for hot climatic conditions. Energy. 59:445-453.
- [4] SANTAFÉ MR, FERRER GISBERT PS, ROMERO JS, SOLER JBT, GOZÁLVEZ JJF, FERRER GISBERT CM (2015). Implementation of a photovoltaic floating cover for irrigation reservoirs. Journal of Cleaner Production. 66:568-570.
- [5] FERRER GISBERT C, FERRÁN-GOZÁLVEZ JJ, SANTAFÉ MR, FERRER GISBERT P, ROMERO FJS, SOLER JBT (2013). A new photovoltaic floating cover system for water reservoirs. Renewable Energy. 60:63-70.
- [6] ELETROBRÁS. In: http://webserver.eln.gov.br/pdnet/pd/arquivos/Edital%2003_2015.pdf, acessado em 30 de setembro de 2016.
- [7] CESP. In: <http://www.investmentosenoticias.com.br/noticias/negocios/sao-paulo-tera-a-primeira-usina-solar-flutuante-do-brasil-a-partir-de-maio>, acessado em 30 de setembro de 2016.
- [8] AMERICA DO SOL. In: <http://americadosol.org/pesquisa-e-desenvolvimento-no-brasil/>, acessado em 30 de setembro de 2016.

- [9] CESP, 2016. Disponível em, <http://www.investimentosenoticias.com.br/noticias/negocios/sao-paulo-tera-a-primeira-usina-solar-flutuante-do-brasil-a-partir-de-maio>, acessado em setembro de 2016.
- [10] Brasil inaugura primeira usina solar flutuante do mundo em lago de hidrelétrica. In: <http://agenciabrasil.ebc.com.br/pesquisa-e-inovacao/noticia/2016-03/brasil-inaugura-primeira-usina-solar-flutuante-do-mundo-em-lago>. Acessado em janeiro de 2018.
- [11] Presidente da Irrigo implanta projeto pioneiro de energia fotovoltaica em Cristalina e é destaque na imprensa. In: <https://www.irrigoiias.com.br/single-post/Presidente-da-Irrigo-implanta-projeto-pioneiro-de-energia-fotovoltaica-em-Cristalina-e-%C3%A9-destaque-na-imprensa>. Acessado em janeiro de 2018.
- [12] PRIMEIRA USINA SOLAR FLUTUANTE É PAULISTA. In: <http://www.ambientelegal.com.br/primeira-usina-solar-flutuante-e-paulista/>. Acessado em janeiro de 2018.
- [13] CEPEL - CRESESB, 2014. Manual de Engenharia para Sistemas Fotovoltaicos. Rio de Janeiro. 2014. 530 p
- [14] AMERICA DO SOL, 2016. Disponível em, <http://americadosol.org/pesquisa-e-desenvolvimento-no-brasil/>. Acessado em janeiro de 2018.
- [15] EPE, 2014. Empresa de Pesquisa Energética (Brasil). Balanço Energético Nacional 2014: Ano base 2013 / Empresa de Pesquisa Energética. – Rio de Janeiro: EPE, 2014. 288 p.
- [16] ANEEL - AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA, 2015. BIG - Banco de Informações de Geração. Disponível em www.aneel.gov.br/aplicacoes/capacidadebrasil/capacidadebrasil.cfm, acessado em maio de 2015.
- [17] MPX conecta usina solar de Tauá (CE) à rede elétrica nacional, 2016. Disponível em [http://www.eneva.com.br/pt/sala-de-imprensa/noticias/Paginas/MPX-conecta-usina-solar-de-Taua-\(CE\)-a-rede-eletrica-nacional.aspx](http://www.eneva.com.br/pt/sala-de-imprensa/noticias/Paginas/MPX-conecta-usina-solar-de-Taua-(CE)-a-rede-eletrica-nacional.aspx), acessado em novembro de 2016.
- [18] CEMIG, 2016. In: https://www.cemig.com.br/pt-br/A_Cemig_e_o_Futuro/inovacao/Paginas/Dashboard-Mineirao.aspx, acessado em novembro de 2016.
- [19] CHESF, 2016. CHAMADA PÚBLICA 003/2015, Exploração de Energia Solar em Lagos de Usinas Hidrelétricas Eletronorte / CHESF. In: <https://www.chesf.gov.br/pdi/Pages/Como%20participar/ChamadaPublica003-2015-Eletronorte.aspx>, acessado em novembro de 2016.
- [20] FERRER FERRER C, FERRER GISBERT C, SANTAFÉ MR, FERRÁN-GOZÁLVEZ JJ, ROMERO FJS, SOLER JBT, PUIG EP (2010). Technical performance of a photovoltaic floating cover system. In: International Conference on Agricultural Engineering-AgEng. France.
- [21] ABNT NR-12, Norma Regulamentadora 12 – Segurança no Trabalho em Máquinas e Equipamentos e estabelece nova redação, 2017.
- [22] LAING AK (1998). An Introduction to Ocean Waves In: Guide to Wave Analysis and Forecasting. Geneva: Suíça. 1:1-14.
- [23] MARQUES M (2013). Modelagem paramétrica bidimensional para simulação de ondas em águas continentais. Tese de doutorado pelo Programa de Pós-Graduação Engenharia de Recursos Hídricos e Ambiental. Curitiba: Universidade Federal do Paraná. Curitiba. Brasil.
- [24] BRASIL. Resolução CONAMA nº 357, de 17 de março de 2005. Classifica as águas doces, salobras e salinas.
- [25] ROUND FE (1983). Biologia das algas. Editora Guanabara Dois, Rio de Janeiro. do Território Nacional, segundo os usos preponderantes, revogando a Resolução CONAMA nº 20. Diário Oficial da União, Brasília, DF. 18 de março de 2005.
- [26] BICUDO CEM, RAMÍREZ JJR, TUCCI A, BICUDO DC (1999). Dinâmica de populações fitoplanctônicas em ambiente eutrofizado: o Lago das Garças, São Paulo. In: R. HENRY (ed.). Ecologia de reservatórios: estrutura, funções e aspectos sociais. Fundibio, Botucatu, pp. 449-508.
- [27] HODOKI Y, OHBAYASHI K, KOBAYASHI Y, OKUDA N, NAKANO S (2012). Detection and identification of potentially toxic cyanobacteria: Ubiquitous distribution of *Microcystis aeruginosa* and *Cuspidothrix issatschenkoi* in Japanese lakes. Harmful Algae. 16: 49-57.
- [28] CARDOSO LS (2013). First record of expansive *Ceratium Schrank*, 1793 species (Dinophyceae) in Southern Brazil, with notes on their dispersive patterns in Brazilian environments. CheckList. 9(4): 862–866.
- [29] MATSUMURA-TUNDISI T, TUNDISI JG, LUZIA AP, DEGANI RM (2010). Occurrence of *Ceratium furcoides* (Levander) Langhans 1925 bloom at the Billings Reservoir, São Paulo State, Brazil. Brazilian Journal of Biology. 70(3): 825–829.
- [30] OLRİK K (1993). Phytoplankton ecology. Denmark: DEPA. 183p.