# Hybridization with Floating Solar, Offshore Wind Farm and Batteries in Hydroelectric Power Plant Reservoirs

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Hybridization, Floating Solar, Offshore Wind Farm, Hydroelectric Power Plant, PS Simul

Abstract - *This paper aims to conduct studies of integration of floating photovoltaic sources in reservoirs of Hydroelectric Power Plants (HPP). The hybridization possibilities in these power plants will also be discussed through the integration of Offshore Wind Farms and Batteries. In July 2019, Brazil was pioneered the launch of this type of energy by creating floating photovoltaic plant at the Sobradinho Hydroelectric reservoir. The objective was to integrate the solar plant with the operation of hydroelectric plants and to evaluate the influence of this integration on the reservoir and the ecosystem.*

## 1 INTRODUCTION

The technological developments and the reduction in costs of photovoltaic modules over the past few years allow an exponential growth of the photovoltaic source in the world. At the same time, this initiative has been an excellent alternative to assist the production of electricity and, consequently, studies have been carried out to integrate this type of generation with hydroelectric power plants, being positioned in the dams with the technology of floating photovoltaic panels.

The recent national pilot projects, shown in Fig.1, with the use of floating photovoltaic technology associated with hydroelectric plants achieve visibility and their important results highlight the benefits of this technology, still little studied.

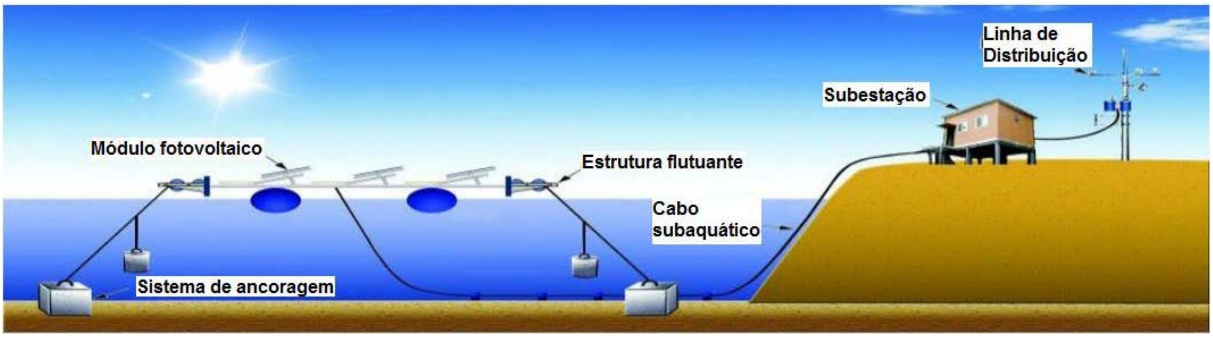


**Figure 1: Pilot project with the use of floating photovoltaic technology.**

## 2 STUDY OF THE SOLAR PLANT IN AN AUXILIARY SERVICE SUBSTATION

A portion of the power system presented in Fig. 2 where the integration of solar generation was carried out was modeled by using PS SIMUL [1] software, which allows the detailed modeling of the solar plant. Such modeling, allows the short-circuit behavior of the solar plant to be adequately represented and studied. The system modeled in the PS Simul software is shown in Fig. 3.

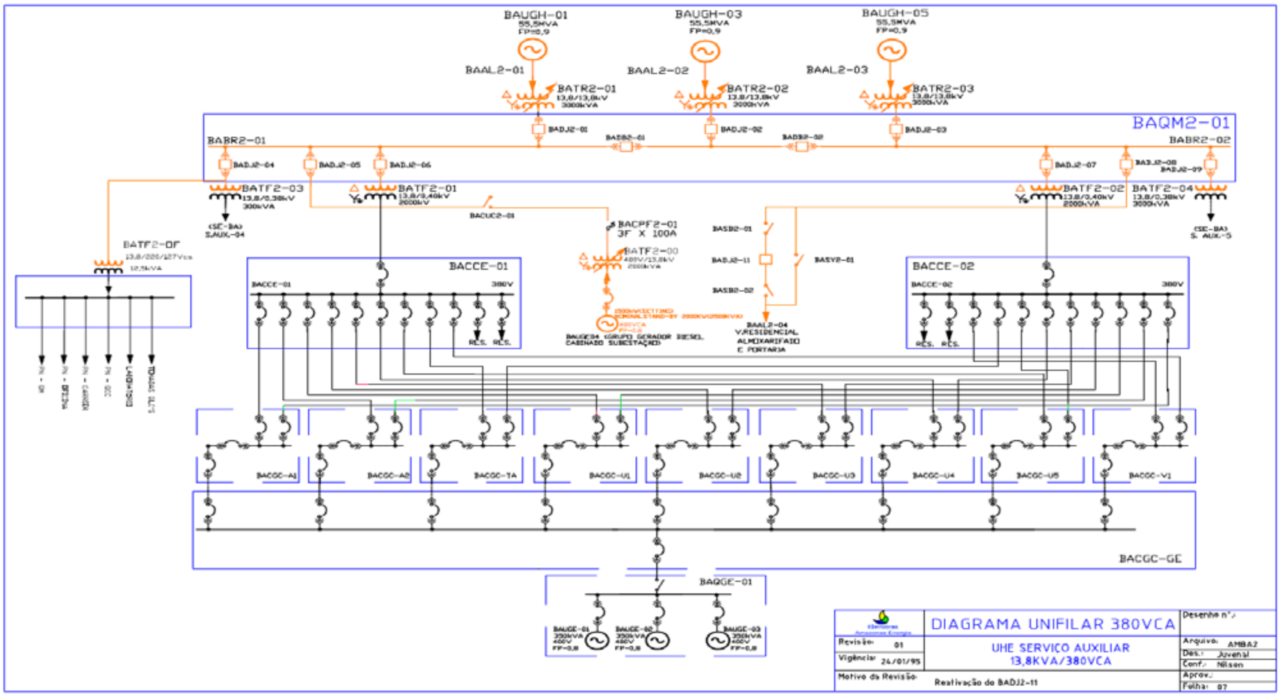


**Figure 2: Solar Plant Evaluated.**

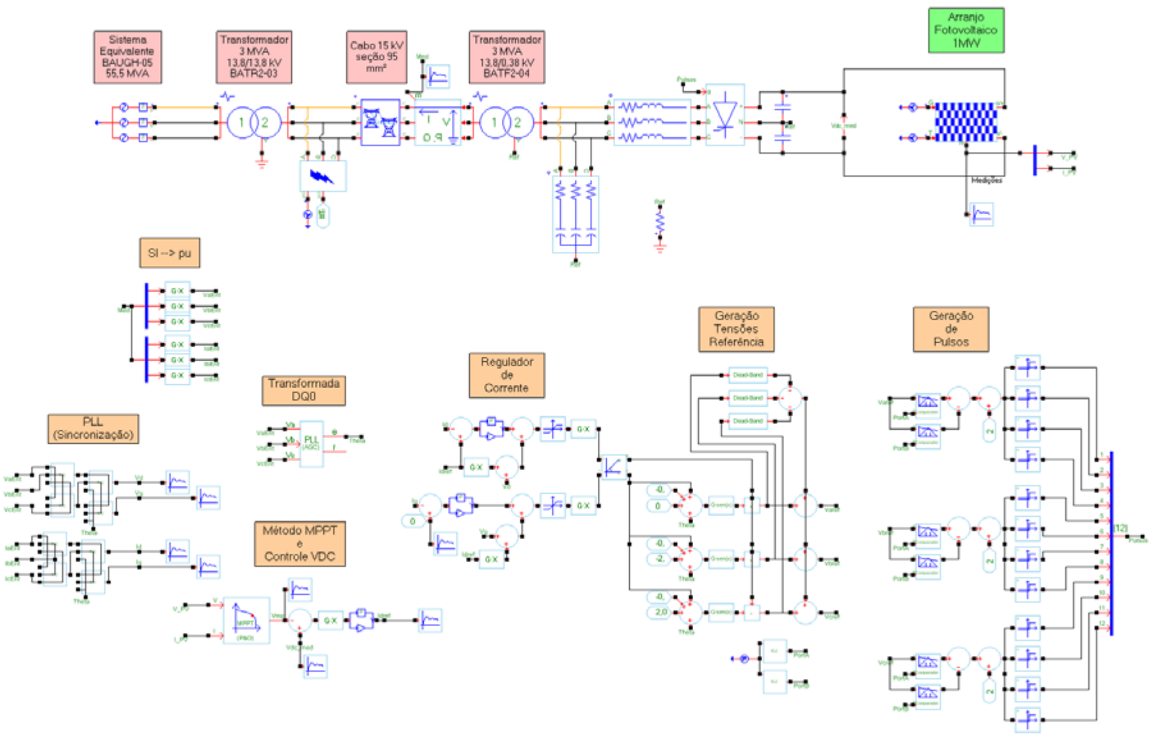


**Figure 3: System modeled in the PS Simul software.**

The initial deployment of pilot plants in the reservoir started with a generation of 1 MWp of each unit connected in the Eletrocenter with a capacity of 2.5 MWp. Because they are clean and cheap forms of energy, solar, wind and by batteries, compared to non-renewable forms of energy, bring several benefits that include significant cost savings. Even requiring an initial investment, the savings made possible by renewable sources quickly outweigh the amount paid.

It is worth noting that renewable technologies can be applied both in residential units and in industrial units. In both cases, replacing non-renewable forms of energy with renewable alternatives brings benefits and such generation alternatives can even be connected to the substation auxiliary service buses, as was done in the pilot project highlighted in this work.

In this context, one of the objectives of the work is to simulate and analyze the contribution of the solar plant during the occurrence of short circuits in the system, focusing on the influence of this contribution on the operation of the protection systems. Initially, the first stage of generating 1 MWp will be carried out by the solar plant. In the future, the second stage with generation of 2.5 MWp also by the solar plant will be involved together with a 1 MW generation by an offshore wind farm and another 1 MW generation with the use of battery banks.

### *2.1 Analysis of Results*

In order to verify the shorting levels in the face of contingencies in the system, we simulate occurrences of faults on the 13.8 kV side of the coupling transformer. Some of the simulated scenarios, together with the current and voltage waveforms obtained and the harmonic decomposition of currents in the three phases, are illustrated below in Figures 4 and 5.

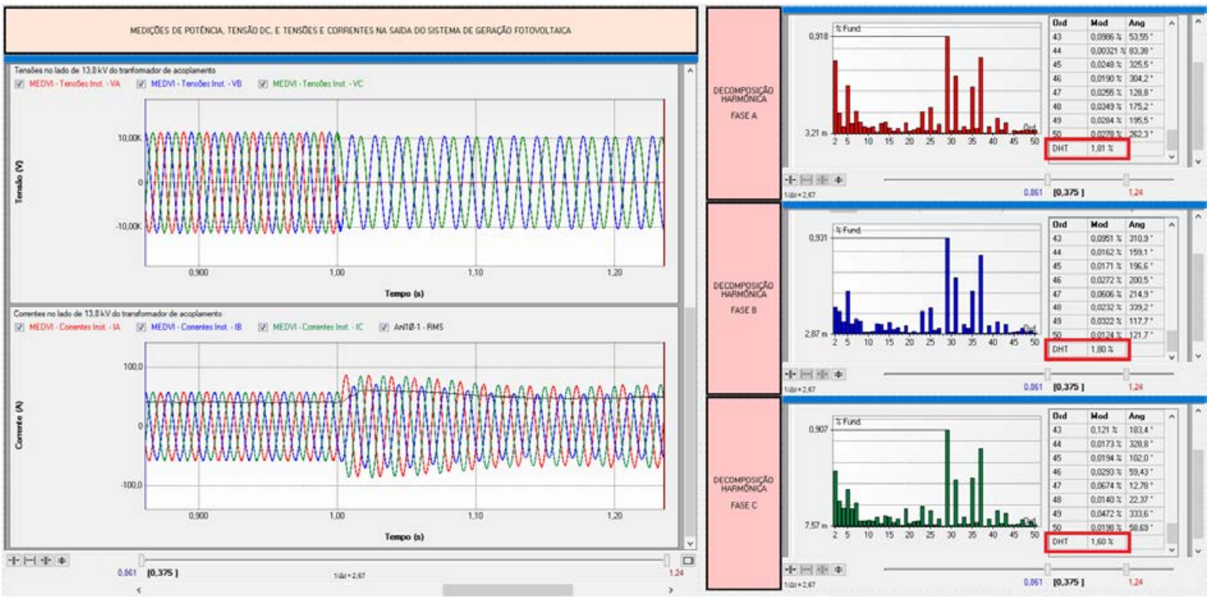


**Figure 4: Solar Plant Evaluated - Scenario 01 (AT FAULT).**

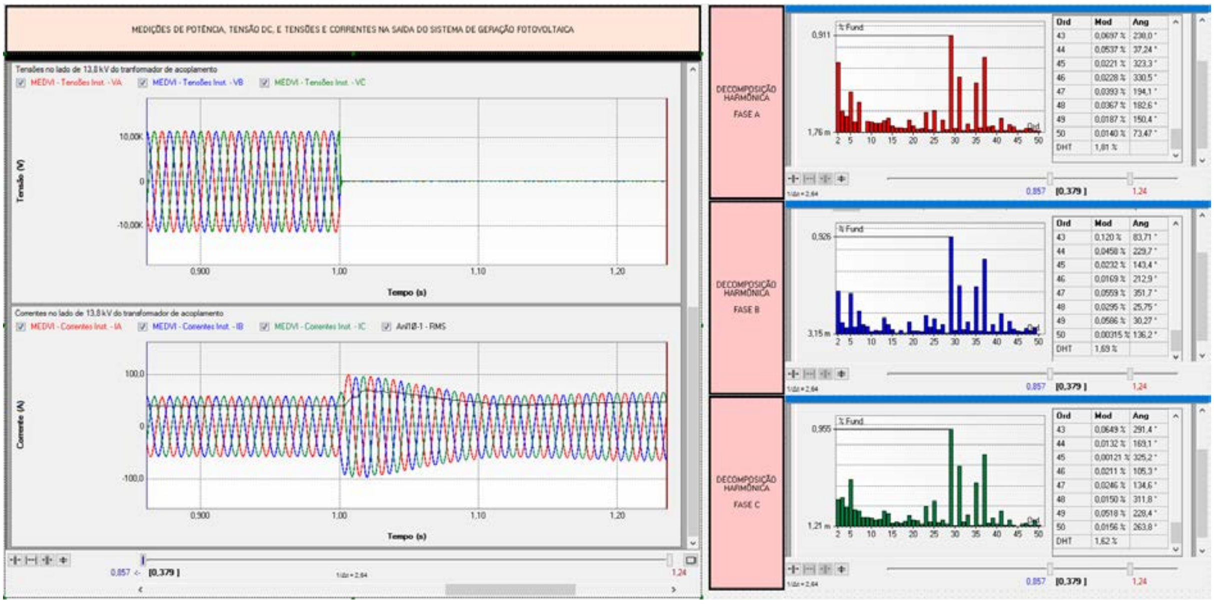


**Figure 5: Solar Plant Evaluated - Scenario 02 (ABCT FAULT).**

### *2.2 Modeled control functions of the AC / DC converter*

The modeling of the inverter system was done based on previous modeling experiences that we had already carried out [2], and we were concerned about keeping the current DHT <3% and its operating DC voltage in the range of 540 - 850 V (as specified in the inverter's technical datasheet).

### *2.3 Analysis of Waveforms*

From the results obtained, we can infer a maximum fault current with a value of 1.28 times greater than the rated current (which in this case is approximately 40 Arms). In addition, a DHT of approximately 1.8% was measured. It is worth noting that the fault current obtained depends on the limits set in the current regulator (if the limits are increased, it is possible that the fault currents also increase depending of the contingency experienced by the system).

## 3 ANALYSIS OFFSHORE WIND FARM

According to the wind turbine types described in IEEE PES Wind Plant Collector System Design Working Group, “Characteristics of wind turbine generators for wind power plants”, there is a number of different possible configurations that may be used to assemble the generation units. The wind power unit mentioned in this paper is defined as Type 4, whose mathematical details of the models can be found in PS SIMUL. It is composed by a mechanical turbine, a synchronous generator (SG), and a full-converter with its associated controls, as depicted in Fig. 6.

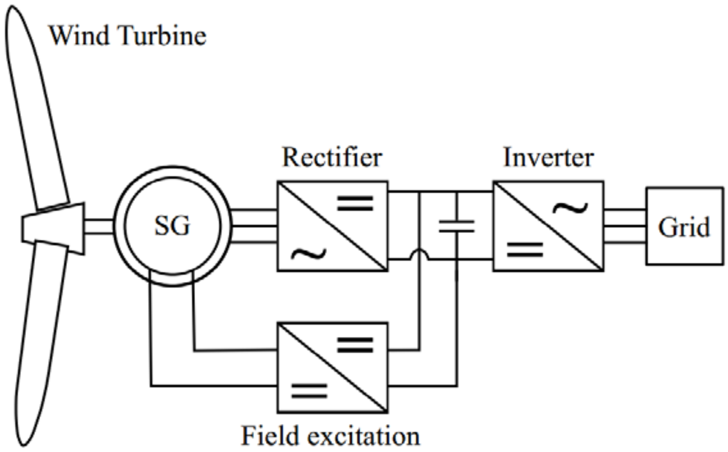


**Figure 6: Full Converter Wind Turbine Generator (Type 4).**

PS SIMUL simulations were carried out using 1.0 us time step, emulating real analog signals. A third order low-pass anti-aliasing Butterworth filter with cutoff frequency at 480 Hz was applied and then the filtered signals were resampled to 32 samples per cycle of 60 Hz in order to proceed with the phasor-estimation process. The results and discussions related to this type of generation can be consulted in the paper referenced in [3].

As the amount of integration of inverter-based resources increases and displaces synchronous generation, the amount of short circuit capability available on the circuit decreases. Also, in many part of circuit where the wind and solar resource are electrically remote from load and generation, there is a reduction of fault currents and short circuit strength, as depicted in Fig. 7.

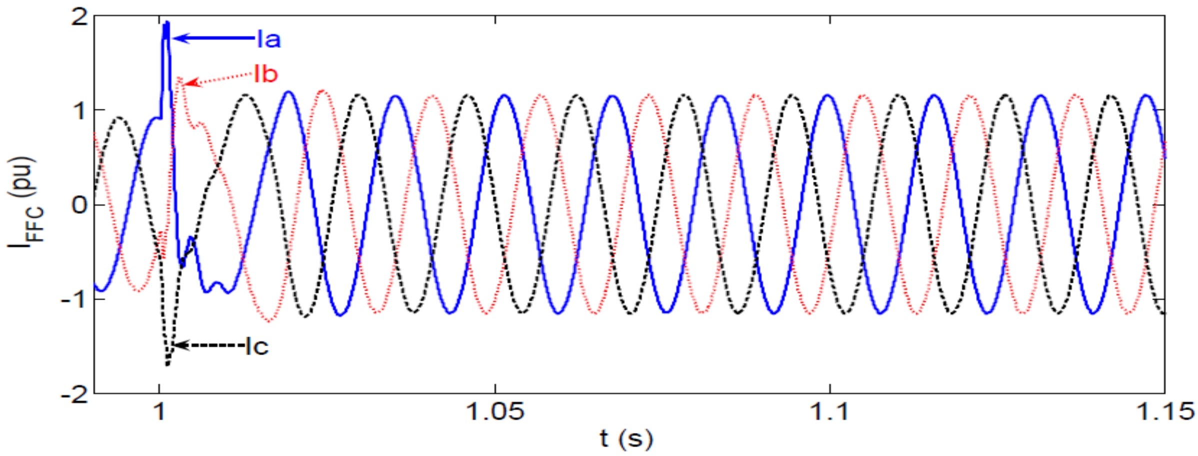


**Figure 7: Inverter Based Resources Fault Response Characteristics.**

From the database of field research related to equipment, devices and interconnection cables, it is possible to establish maximum and minimum values of short-circuit in the busbars, which allows the definition of ranges to adjust the respective protection relays. In addition to relay parameterization, actuation curves are presented to demonstrate the selectivity between cascade protections [4].

## 4 OTHER ISSUES

From an operational and economic standpoint many factors need to be considered for the purpose of operation planning studies and system operations. This is a complex area of technical details, outside of the scope of this document. However, a brief mention will be made here of some of the salient points. These may include: predicting hour ahead and day ahead availability of the inverter based renewable resources (Wind/PV), managing resource variability, reserve allocation, system flexibility (e.g. fast startup units etc.) to manage the maximum expected ramp rates from the variable resources, preparedness and managing extreme weather events and other natural events (e.g.) severe weather patterns that might cause sudden shutting down and ramping up of large portions of wind generation, storms resulting in rapid cloud movement that affects PV generation, solar eclipse effects on PV generation, etc. For all this intemperate an Energy Management System (GEMS) need to be developed, as depicted in Fig. 8.

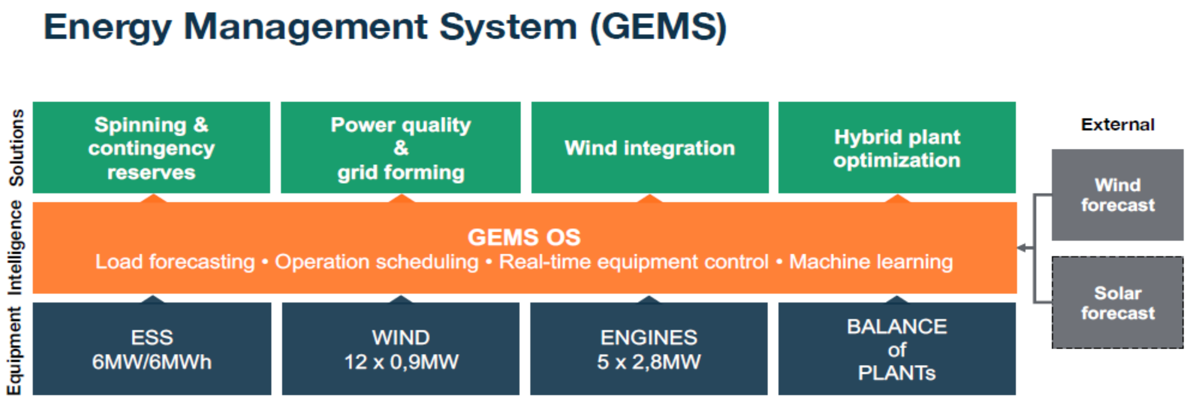


**Figure 8: Energy Management System (GEMS) Characteristics.**

## 5 HYBRID GENERATION WITH HYDROELECTRIC POWER PLANTS

The floating photovoltaic installation in the reservoir of a hydroelectric plant can optimize the use of the transmission / distribution network. Another advantage would be the possibility of storing more water if the photovoltaic generation moves the hydroelectric plant, acting as a “virtual battery”. However, such an operation scheme would only be possible in plants with a reservoir. In run-of-the-mill plants, with the most limited regularization capacity, there would be no such versatility in the operation, both of which behave more closely to a non-dispatch able set. In the case of reversible hydroelectric plants, the floating photovoltaic solar technology could also contribute with the energy needed to pump water or to increase the energy injected into the network.

In Brazil, the largest floating photovoltaic plant in operation is in the reservoir of Sobradinho HPP, in Bahia. The first stage of the project has 1 MWp, inaugurated in July 2019, and will have a capacity of 2.5 MWp by 2020. In the project phase, there is the floating photovoltaic solar technology that will be installed in the UHE Balbina reservoir, also with an expected capacity of 2.5 MWp, as depicted Fig. 9.

**Figure 9 - Floating Photovoltaic Solar Plant in the Sobradinho, Balbina and Porto Primavera HPP reservoirs.**

## 6 CONCLUSIONS

This paper highlights the importance of studies that involve the modeling and simulation of energy systems are needed to survey short levels and protection parameters. In this context, renewable generation systems (solar and wind) that interface with the grid through inverters, have been widely discussed today. To carry out these studies involving renewable energy, a Brazilian software called PS Simul has been used by the working group of Cigre Brazilian members and the results have been quite satisfactory.

Under fault conditions these new sources do not behave in the same way as large synchronous generators. The unique response of these sources to fault conditions considerably challenges traditional protection principles developed decades ago for grids with synchronous generators driving fault currents. With the increased penetration of these new sources, traditional grid protection principles will be stressed to the point of potentially losing reliability.

The relay manufacturers do not have any fixed source characteristics to work with. A possible solution to this challenge is to explore possibilities for identifying characteristics of non-synchronous sources, primarily inverter-based sources, that can be standardized and thus give the relay manufacturers and application engineers a fixed reference to work with. It is given that such common characteristics. An inverter-based source will not replicate a synchronous machine, but it can still respond in a consistent predicable way to fault conditions allowing properly re-designed relays to work dependably even if the network consist of only these sources.

The floating photovoltaic solar energy market tends to grow with the maturation of technologies, opening a new front for the global expansion of renewable energy and bringing growth opportunities to several countries and markets, especially in land-restricted locations. In fact, regions where there is a scarcity of land, other land uses and the cost of acquiring or renting land are higher, from the perspective of economic viability, may be more appropriate places for floating photovoltaics. As an example, there is the case of installations in weirs on rural properties, using the land for agriculture, at the same time that electricity is generated for productive activity. With an increasing number of parks in operation in the world, including some R&D projects in Brazil, it will be possible to obtain more robust and accurate data, especially on the efficiency of the modules, minimizing uncertainties related to costs, technological complexities and socio-environmental impacts.

From the point of view of energy planning, the fact that photovoltaic installations take place on land or in water mirrors is indifferent, and it is up to the entrepreneurs to prospect the most competitive projects, including assessing synergistic gains in the case of hybrid plants. Among the benefits of floating photovoltaic solar technology, it is expected that the efficiency gains due to the reduction of the temperature of the modules will lead to a higher production than in ground installations in fixed structures. However, there is still no clarity about the production gains with the installation of a floating solar instead of a conventional solar plant, with less expressive gains being pointed out in recent experiments in Brazil, especially in more humid locations.

The adoption of floating facilities in other countries was, in many cases, due to space limitations or to avoid land acquisition costs. In China, there was also a strong movement of installation in deactivated coal mine lakes. Given the high availability of land in Brazil, at low costs in the regions with the best irradiation, this type of land advantage is not so relevant [5].

Considering the higher installation cost, the cost of generating floating photovoltaic solar technology does not seem competitive at this time. It is necessary to monitor whether, with the growth in the number of installations in the world, the structural costs will be reduced to a level where there is competitiveness. Still, no positive externalities or benefits were identified in relation to conventional photovoltaic systems that cannot be captured with the current regulation, nor particularities of the floating photovoltaic solar technology that require different treatment. For the aforementioned reasons, one must follow the evolution of technology, allowing it to compete with others, without the need to introduce subsidies or dedicated contracts

With the development of the market in Brazil, even though participation in auctions is already allowed, one must seek to eliminate barriers to the development of floating plants, by means of clear rules, especially those related to environmental licensing and use of the area, in order to promote fair competition between different solutions, leading to lower generation costs. I this way the floating solar technology could naturally find its place in the Brazilian market [6].

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