Hybridization with Floating Solar Plants in Reservoirs of Hydroelectric Power Plants

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***Abstract*—This study aims to integrate the Floating Solar Power Plants in the reservoirs of Hydroelectric Power Plants HPP. Sunlight does not emit polluting gases or other types of waste. Brazil was pioneered the launch of this type of energy by creating solar power plants on floats at hydroelectric Power Plant, in Brazil´s regions North and Northeast, South and Southeast. The objective was to integrate the photovoltaic solar plant with the operation of hydroelectric power plants and evaluate the influence of this integration on the ecosystem of the reservoirs.**

Keywords; hybridization, photovoltaic solar, hydroelectric power plant HPP

I. Introduction

Brazil has just surpassed the 14 gigawatts (GW) mark of operational power of the photovoltaic solar source, adding large power plants and its own electricity generation systems on roofs, facades and small land, but only 10% of these 14GW in hydroelectric power plant reservoirs. With this, the solar source exceeds the installed biggest Brazilians hydroelectric power the Itaipu hydroelectric power plant, according to the mapping of the Brazilian Association of Photovoltaic Solar Energy. According to the entity, the solar source has already brought to Brazil more than R$ 74.6 billion in new investments, R$ 20.9 billion in revenue from public coffers and generated more than 420,000 jobs accumulated since 2012. The emission of 18.0 million tons of CO2 in electricity generation was also avoided. Large floating photovoltaic solar power plants generate electricity at prices up to ten times lower than emergency fossil thermal power plants or electricity imported from neighboring countries today, two of the main ones responsible for the tariff increase on consumers. This is the best time to invest in floating photovoltaic solar power plant, precisely because of the new increase already foreseen in the electricity bill of Brazilians and the transition period provided for in the law, which guarantees until 2045 the maintenance of current rules to consumers who install a solar system on the roof by January 2023. Currently, large solar plants are the sixth largest source of generation in Brazil and are present in all regions of the country, with projects in operation in nineteen Brazilian states and a portfolio of 31.6 GW granted for development. Why not invest in photovoltaic solar plants in reservoirs of hydroelectric plants? In search of alternatives to expand HPP's energy generation during the low-level period of the reservoirs. There is already a project still under study, but the plan is to have a photovoltaic solar plant in the largest HPP reservoir of 137.48 MWp

II. What are, how are, how many are, where are and pros /cons the floating solar plants in reservoirs in Brazil

A. What are floating photovoltaic solar power plant in reservoir? In solar floating, the plates are installed on types of buoys that float in large reservoirs, normally the same ones used in ports and marinas.

B. How this iniciative has been done in Brasil? The project started in March 2016 at hydroelectric power plants, which is located in the Brazilian Northeast and now in the Soutwest and North respectively, as a way of taking advantage of the large space provided by the lake's water mirror, such as the substations and transmission lines that were underused in the regions. In this study, the feasibility of integrating the renewable source of hydroelectricity with solar sources is being verified, these sources are to be used in large proportions, in Brazil, there is still a reduction in the costs of energy produced by solar plants. At the same time, this initiative has been seen as an excellent alternative to assist in the production of electricity from other sources and, consequently, the use of production capacity is already being expanded to the Northeast dam, which is located in the São Francisco River.

C. What are the Pros of this iniciative?

The floating photovoltaic installation in the reservoir of a hydroelectric plant can optimize the use of the transmission and 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. Reduction of evaporation losses and increased efficiency of PV modules due temperature, no need lands. Synergy with the electrical infrastruture, when combined with auxiliary services. Possible reduction of algae level and water available for cleanning modules.

D. What are the Cons of this iniciatives ?

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. Complex mooring and anchoring, Possible environmental impact due to reduced light. Specialized maintenance with boats and divers.

E. Where are the Photovoltaic Power Plants?

In Brazil, the largest floating photovoltaic plant in operation is in the reservoir of Sobradinho HPP reservoir, in Bahia. The first stage of the project has 1 MWp, inaugurated in July 2019, and will have a capacity of 5 MWp by 2023. In the project phase, there is the floating photovoltaic solar technology that will be installed in other reservoirs, also with an expected capacity of 16.5 MWp, as depicted Fig.1

Fig. 1 - Floating Photovoltaic Solar Plant in HPP reservoirs.

III. PS SIMUL

The PS Simul software, developed in Brazil since 2009, had its first version released in 2014, and is available on the company's website in a FREE [1] version. This software, created with the main purpose of allowing the user to model complex power, control systems and to simulate electromagnetic and electromechanical transients, works with a very friendly interface, with a series of resources that facilitate the obtaining and evaluation of results, data entry, visualization, among others. In order to enable the creation of any power and/or control system, library with more than 400 components are available, including several not covered by any other transient simulation software. In addition to carrying out the simulations, the software allows the reproduction / acquisition of the signals by the test set.

The software can be used to perform any type of electromagnetic studies such as insulation coordination, lightning strikes, transient recovery voltages, energizations, saturations of current transformers, motor starting, overvoltages, power quality, control logics, etc. PS Simul also allows run complex simulations, such as involving HVDC and renewable energy.

Among the various software features, we can highlight:

- *Hybrid solution method*: solves the differential equations applying trapezoidal + interpolation + Euler to avoid the occurrence of numerical oscillations during switching;
- *Global variables (constants)*: allows adjustments common to several blocks at a single point;
- *Automated multiple tests*: possibility to change of one or more system constants;
- *Transmission line faults*: application of faults without the need to divide the transmission line manually;
- *Transformers*: short circuit between turns of the transformer through access to its windings;
- *Reports:* creates complete reports;

As mentioned before, it is possible to reproduce and acquire signals by PS Simul. To do that are available in the software library inputs and outputs blocks for binary/GOOSE and analog/*Sampled Values*. The output components are used so that the results obtained in the simulation environment can be reproduced on real devices. The input components will be used to enable the signals acquired by the test sets channels to be used in the software.

The digital input signals are used by a repetitive process, running recursively and this procedure is identified for any changes in logic levels or just for the rising or falling edges. In this methodology, the signal is applied, for example, to modify the simulation in order to command the opening and closing of the circuit breakers or at any other circuit points that involves boolean digital logic. This process of signal generation and acquisition occurs by automatic overlapping of stages with the circuit feedback, thus configuring a closed loop system in stages with excellent results. It is worth highlighting that this methodology is only possible due to the IED's trip repeatability, which have great accuracy in the acquisition and processing of signals.

In addition, the effectiveness of the repetitive method for conducting closed-loop tests has already been compared with the methodology used by real-time simulation systems, where it has been proven that the results for testing applications in protection devices are the same.

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IV. 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 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.

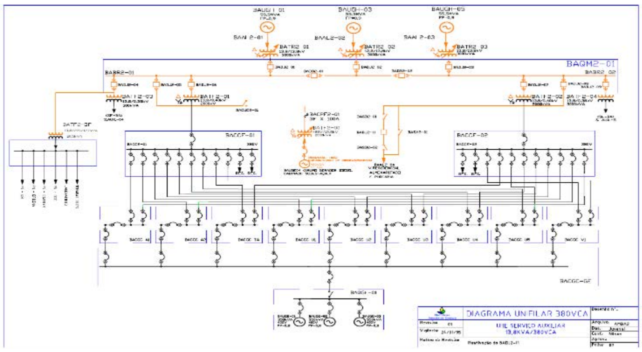

Fig. 2: Solar Plant Evaluated.

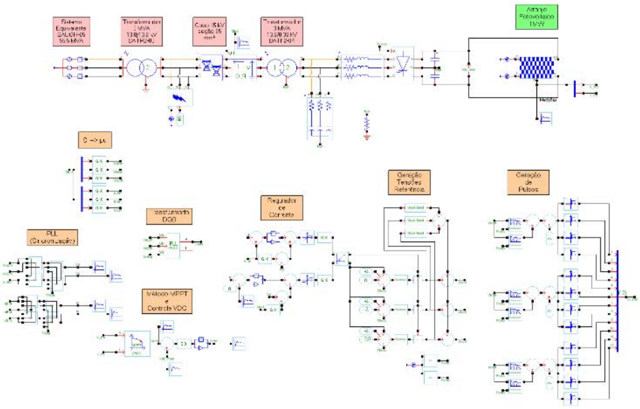

Fig. 3: System modeled in the PS Simul software.

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.

A. *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.

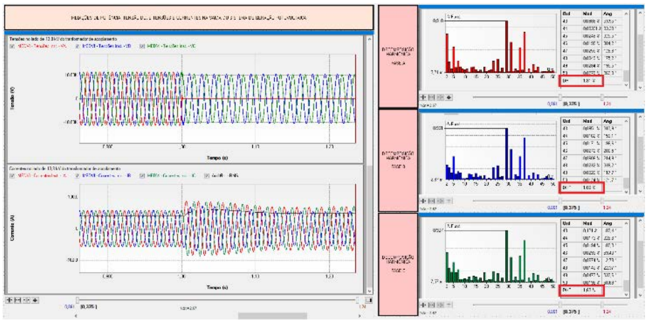

Fig. 4: Solar Plant Evaluated - Scenario 01 (AT FAULT).

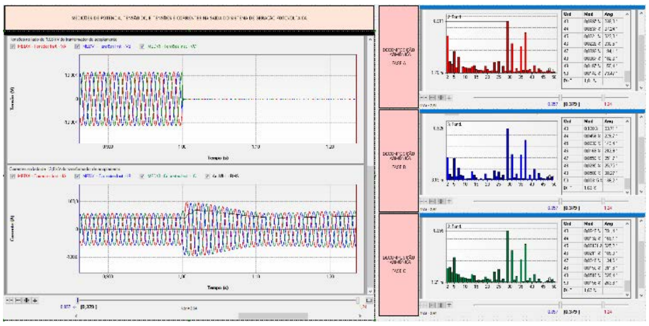

Fig. 5: Solar Plant Evaluated - Scenario 02 (ABCT FAULT).

B *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).

C 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).

D Some 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.

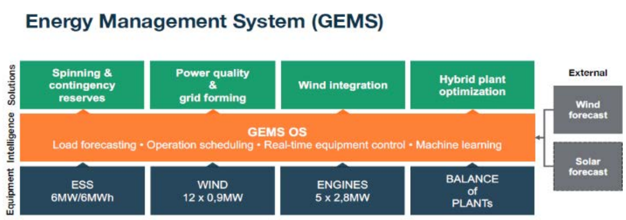

Fig. 8: Energy Management System (GEMS) Characteristics.

V. : INVERTER BASED RESOURCES FAULT RESPONSE CHARACTERISTICS

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.

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 parts 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. There is a lack of technical expertise in companies to detail EMT models and analyze vast number of models for interconnection requests as depicted in Fig. 9

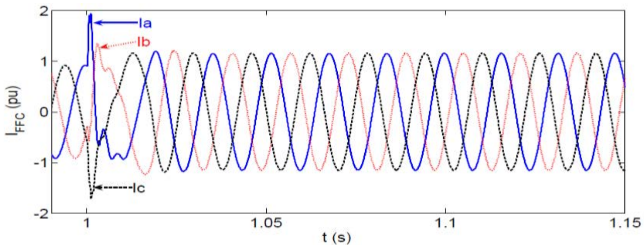

Fig. 9: Inverter Based Resources Fault Response Characteristics.

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].

VI. TO HYBRIDIZE OR NOT TO HYBRIDIZE?

Brazil is the 8th largest consumer of electricity globally with over 212 million inhabitants. The country currently relies on hydroelectricity for almost two thirds of its total consumption and Solar Power is seen as a highly complementary technology. This is due to the countries exceptional Solar Resources, notably during the dry season, when reservoir levels are low

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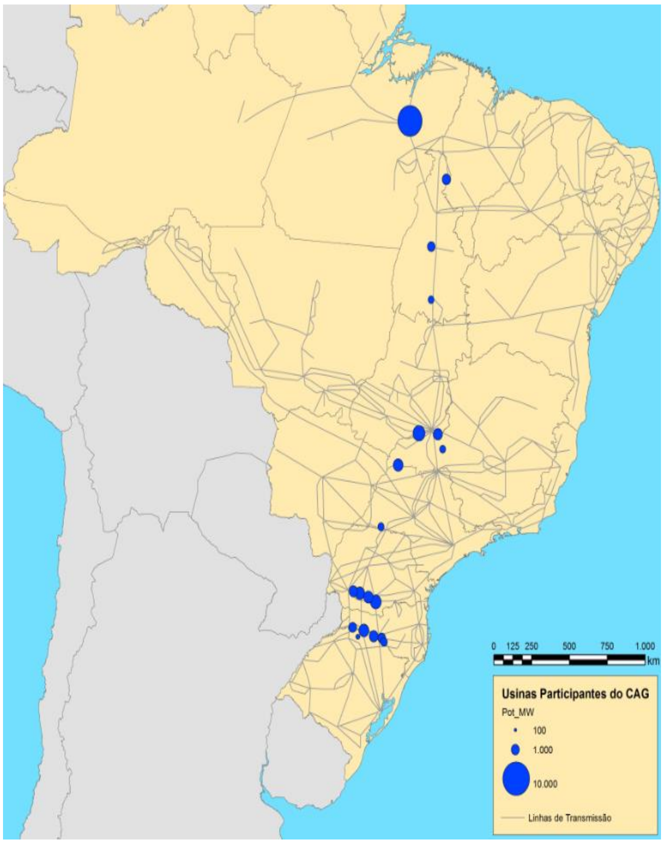

HPP Água Vermelha
HPP Barra Grande
HPP Emborcação
HPP Nova Ponte
HPP Estreito
HPP Lajeado
HPP Itá
HPP Machadinho
HPP Foz do Areia
HPP Segredo
HPP Capivara
HPP Tucuruí
HPP Itumbiara
HPP Campos Novos
HPP Peixe Angical
HPP Foz do Chapecó
HPP Passo Fundo
HPP Salto Osório
HPP Salto Santiago
HPP Belo Monte

Fig. 10: Main HPP in Brazil.

VII. 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 photovoltaic) 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.

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.

VIII. Acknowledgment

We acknowledgment in Brazil ANNEL and EPE is without them it was supported by funds from Brazilian's people and thanks to CONPROVE ENGENHARIA footnote on the second page.

IX. References

[1] PS SIMUL - Software for modeling Power Systems and Simulations of Electromagnetic and Electromechanical Transients developed by CONPROVE Acess 23th March 2022, in: https://conprove.com/en/products/08-ps-simul-software-for-power-systems-modeling-and-electromagnetic-transients-simulation

[2] Operational Studies of Wind and Solar Generations Plants through of an innovative computational plataform. P. S. P. Junior - XVIII ERIAC Foz do Iguaçu, Brasil – May of 2019. Acess 21th January 2020, in: https://conprove.com/artigos/utilizacao-de-uma-plataforma-sul-americana-de-simulacao-para-estudos-envolvendo-sistemas-de-transmissao-ca-e-cc/

[3] Investigation on Full-Converter-Based Wind Power Plant Behavior During Short-Circuits. Costa, S. J., 4th Workshop on Communication Networks and Power Systems (WCNPS 2019). Acess 26th February of 2020, in https://ieeexplore.ieee.org/abstract/document/8896241.

[4] AVIZ, C Data taken from the work "Solar Floating Plants in Reservoirs of Balbina and Sobradinho Hydroelectric Power Plants – Aviz Consulting – Acess 21th January de 2020, in: www.aviz.com.

.

[5] FARFAN, J.; BREYER, C. Combining floating solar photovoltaic power plants and hydropower reservoirs: a virtual battery of great global potential. **Energy Procedia**, 2018. 403-411. 12th International Renewable Energy Storage Conference, IRES 2018.

.

[6] Solar Fotovoltaica Flutuante - Aspectos Tecnológicos e Ambientais relevantes ao Planejamento No. EPE-DEE-NT-016/2020-r0 Acess 21th February 2020 in http://www.epe.gov.br