

TECHNICAL ANALYSYS OF A HYBRID FLOATING PHOTOVOLTAIC SYSTEM WITH HIGH FLEXIBILITY IN GENERATION

ANALIZA TEHNICĂ A UNUI SISTEM FOTOELECTRIC PLUTITOR HIBRID CU FLEXIBILITATE RIDICATĂ ÎN FUNCȚIONARE

Ing. Radu OPREANU¹, Dr. ing. Radu PLĂMĂNESCU², Dr. ing. Silvia VLĂSCLEANU³

Abstract: *Global warming and climate change is an increasingly pressing issue. Energy transition from fossil fuels to clean, greenhouse gas-free sources, is the main mechanism by which these environmental impacts can be diminished. Romania has therefore committed to 30.7% [1] of its national electricity use coming from renewable sources by 2030. This target paves the way for many investments in renewables, but the adequacy and flexibility of the power system must also be considered. Thus, these investments should take the form of units capable of responding quickly to variations in operation caused by environmental conditions, so as not to affect the functioning of the power system. In this paper, a highly flexible hybrid floating photovoltaic system has been analyzed, which has the ability to deliver electrical power to the grid according to the estimated profile without inducing imbalances caused by weather conditions. The system includes a floating photovoltaic plant, a hydropower plant with high flexibility in operation and an electricity storage system. Thus, the imbalance between estimated and actual power is compensated by the hydropower plant, which can quickly adjust its operating parameters, and by the storage system, which comes into operation for the time intervals when the power variation of the PV system is too large to be covered by the hydropower plant. Finally, a comparison between the required storage capacity of the hybrid system and the required capacity for a classical PV system is presented, to highlight the possibility to use the hydropower plant as an element of flexibility.*

Keywords: floating photovoltaic, high-reporting rate electric measurements, high flexibility hydropower plant, battery energy storage system

Rezumat: *Încălzirea globală și schimbările climatice reprezintă o problemă tot mai presantă la nivel mondial. Tranziția energetică de la combustibili fosili la*

¹ Energy Analyst, Electricity Producers Association – HENRO, e-mail: radu.opreanu@henro.ro

² Electrical Engineering Faculty, University Politehnica of Bucharest, e-mail: radu.plamanescu@upb.ro

³ Executive Director, Electricity Producers Association – HENRO, e-mail: silvia.vlasceanu@henro.ro

surse curate, fără emisii de gaze cu efect de seră, este principalul mecanism prin care aceste efecte asupra mediului pot fi ameliorate. Prin urmare, România și-a asumat ca, până în 2030, 30,7% din energia electrică utilizată la nivel național să provină din surse regenerabile. Această țintă deschide drumul către numeroase investiții în surse regenerabile, însă trebuie considerat și aspectul adecvanței și flexibilității sistemului electroenergetic. Astfel, aceste investiții ar trebui să ia forma unor sisteme capabile să răspundă rapid la variațiile în funcționare cauzate de condițiile de mediu, pentru a nu afecta funcționarea sistemului electroenergetic. În această lucrare, a fost analizat un sistem fotoelectric plutitor hibrid cu flexibilitate ridicată, care are capacitatea de a livra putere electrică în rețea conform profilului estimat, fără a induce dezechilibre cauzate de condițiile meteorologice. Sistemul cuprinde o instalație fotoelectrică plutitoare, o hidrocentrală cu flexibilitate ridicată în funcționare și un sistem de stocare a energiei electrice. Astfel, dezechilibrul dintre puterea estimată și cea reală este compensat de către hidrocentrală, care își poate regla rapid parametrii de funcționare, și de către sistemul de stocare, care intră în funcțiune pentru intervalele de timp în care variația puterii sistemului fotoelectric este prea mare pentru a putea fi suportată de hidrocentrală. În final este prezentată o comparație între capacitatea necesară acumulatorului în cazul sistemului hibrid și capacitatea necesară în cazul unui sistem fotoelectric obișnuit, pentru a evidenția necesitatea utilizării hidrocentralei ca un element de flexibilizare.

Cuvinte cheie: panouri fotoelectrice plutitoare, măsurări electrice cu rată mare de raportare, hidrocentrală cu flexibilitate ridicată, sistem de stocare a energiei electrice

1. Introduction

Currently, climate change is one of the main concerns of countries all over the world, but especially in the European Union (EU). By 2050, the EU has pledged to reach zero net greenhouse gas (GHG) emissions. To achieve this goal, a strong emphasis is placed on the transition from the use of fossil fuels for electricity generation to the predominant use of renewable sources of energy. The EU target for 2030 is for 32% of electricity use to come from renewable sources, with this target rising to 42.5% [2]. For Romania, we have committed to 30.7% of electricity use to come from renewable sources by 2030, with the target rising to 34% [1].

Renewable sources of energy, especially solar and wind, will therefore see massive growth. On the other hand, these sources are highly intermittent and can cause adequacy problems for the power system. Thus, investments in renewables will have to be developed in a way that minimises the impact on the efficient operation of the electricity grid.

In this paper, a hybrid system with high operational flexibility is proposed, consisting of a floating photovoltaic installation (FPV), a hydropower plant (HPP) and a battery energy storage system (BESS). The role of the HPP and BESS is to compensate for imbalances induced in the grid by the FPV due to deviation from the estimated generation profile. The concept is novel because, compared to other studied papers, in this work the HPP is used strictly to increase the flexibility of the system and compensate for imbalances induced by the unpredictability of the FPV. In [3] and [4], the authors propose a hybrid system consisting of a FPV and a HPP, but operating independently of each other and injecting into the grid as much energy as they can generate. In [5], the FPV and the HPP operate together to minimise costs, but the paper does not address the unpredictability of the generation profile of the FPV, which can lead to problems in the operation of the utility grid.

The paper is structured in six sections as follows: section II presents the main technical characteristics of the hybrid system; section III presents the high-reporting rate measurement infrastructure and its role in this paper; section IV describes the methodology for determining the technical solution for operating the hybrid system; section V presents the results obtained, i.e. the technical characteristics of the BESS (capacity and power) and the control band to be maintained by the HPP for imbalances compensation; finally, the conclusions are highlighted in section VI.

2. Site description

The hybrid system consists of a FPV, a HPP and a BESS. The proposed FPV has an installed capacity of 5 MW and is located in the vicinity of the Rusănești hydropower plant in Olt County, Romania. *Fig. 1* shows the location of the FPV. The electricity generated by this installation is injected into the electric substation of the Rusănești hydropower plant, located near the dam. The Rusănești hydropower plant is placed on the lower sector of the Olt River and is equipped with 4 reversible bulb hydro-aggregates, summing an installed capacity of 53 MW [6]. Due to the ability to quickly change the operating parameters, the hydropower plant operates in semi-peak and peak load mode, being a source of flexibility for the electric power system.

The signals from the two generating units are transmitted to a controller. This equipment, knowing the estimated generation profile of the FPV, determines the differences between the estimated and actual power profile and controls the HPP and the BESS to compensate for them.



Fig. 1. The location of the FPV installation

3. Information layer of the high-reporting rate measurements

The power profile of the photoelectric installation is based on the actual daily values measured by a three-phase meter using the Unbundled Smart Meter (USM) architecture [7]. The measurements have a reporting rate of 1 frame/s and correspond to a 1 kW (peak value) terrestrial photoelectric installation installed on the campus of Politehnica University of Bucharest. These values, corresponding to each day of the year, were processed to obtain the power profile of a 5 MW (peak value) installation under the climate conditions of the FPV location. The estimated profile was obtained by linear interpolation based on data obtained from the PVGIS application [8]. *Fig. 2* shows an example of the actual power profile compared to the estimated one, for one day in June.

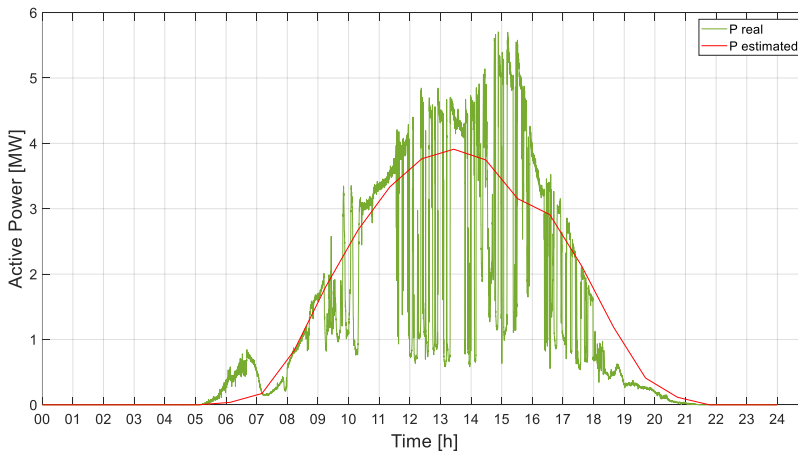


Fig. 2. Actual power daily profile for a random day in June, 1s time granularity for FPV

High-reporting rate measurements are an essential element for this study as they allow detailed analysis of the deviation of the actual power generation profile from the estimated one. This allows to determine precisely the imbalances which need to be compensated by the HPP and BESS to minimise disturbances induced in the electric grid.

4. Methodology for a flexible solution to operate the hybrid installation

The electricity to be injected or absorbed to compensate for fluctuations in the actual power profile of FPV was calculated as the difference between estimated and actual power, as shown in equation (1), where P_{comp} represents the power to be compensated, P_{est} represents the estimated power, and P_{act} the actual power.

$$P_{comp} = P_{est} - P_{act} \quad (1)$$

The high flexible HPP and the BESS work together to ensure the compensation of the power profile of the FPV in real time, according to the logic described in equation (2), where P_{hydro} represents the power mobilized by the HPP and P_{BESS} represents the power mobilized by the BESS. Thus, if the rate of change of the power to be mobilised is less than the maximum rate at which HPP can change its operating parameters (0.5 MW/s), the power compensation is provided by the HPP. On the other hand, if the rate of change of the power to be mobilised is higher than the limit of the HPP, the compensation is performed by the BESS. *Fig. 3* shows an example from June for the power mobilised by the HPP and by the BESS.

$$P_{comp} = \begin{cases} P_{hydro}, & \left| \frac{dP_{comp}}{dt} \right| \leq 0.5 \text{ MW/s} \\ P_{BESS}, & \left| \frac{dP_{comp}}{dt} \right| > 0.5 \text{ MW/s} \end{cases} \quad (2)$$

This approach aims to minimise the negative effects of the unpredictable operation of the FPV by using the combined functioning of the HPP and BESS to compensate for imbalances between the estimated and actual generation profile. The role of the HPP is to mobilise power when it is

required relatively slow compensation, and the role of BESS is to come into operation at times of fast power variation.

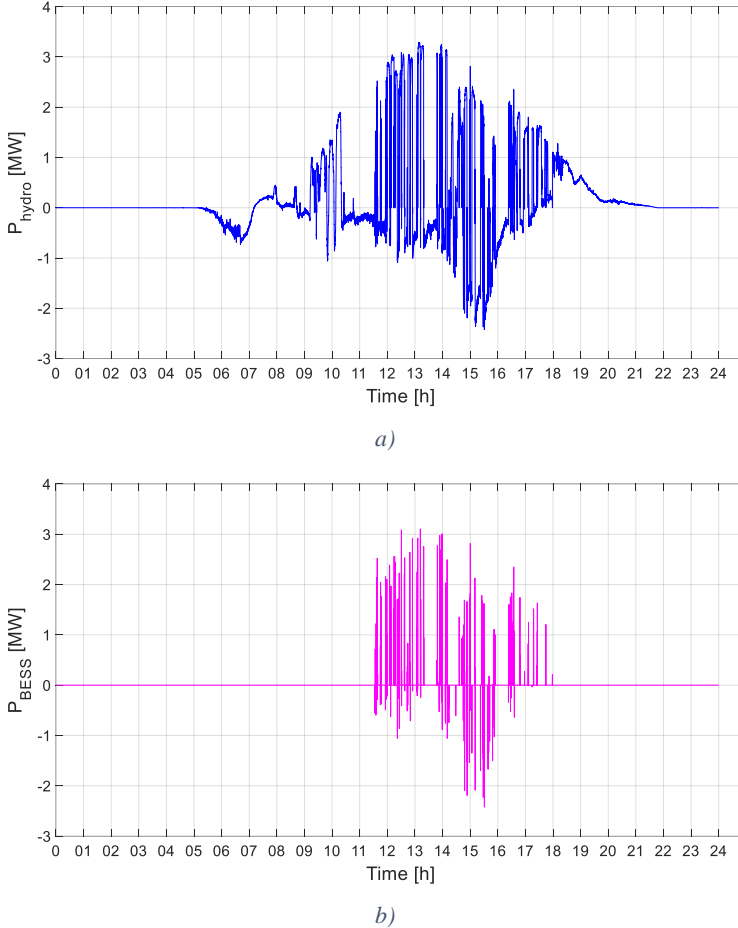


Fig. 3. Active power mobilized by:

- a) HPP and b) BESS to compensate for the fluctuations in FPV power generation profile for a random day in June, 1s granularity

5. Results

To determine the BESS capacity, both injected energy and the absorbed energy by the BESS in each day of the year were calculated, as shown in equations (3) and (4), where E_{BESS}^+ represents the energy injected by the BESS into the grid in one day and E_{BESS}^- represents the energy absorbed by the BESS in one day. The required capacity of the BESS to meet the power

transfer requirements for each day was determined by equation (5), where C_{BESS}^{day} represents the capacity of the BESS required to transfer the balancing power for a given day, DoD represents the level up to which the BESS can be discharged, and η is the efficiency of the BESS.

$$E_{BESS}^+ = \frac{\int_0^{86400} P_{BESS}^+ dt}{3600 \times 10^{-3}} [kWh] \quad (3)$$

$$E_{BESS}^- = \frac{\left| \int_0^{86400} P_{BESS}^- dt \right|}{3600 \times 10^{-3}} [kWh] \quad (4)$$

$$C_{BESS}^{day} = \frac{|E_{BESS}^+ - E_{BESS}^-|}{DoD \times \eta} [kWh] \quad (5)$$

Thus, the capacity of the BESS was chosen to meet 90% of the yearly power transfer requirements to compensate the generation profile of the FPV. This assumption has been adopted to eliminate the unreasonably high values of the storage capacity required only for a few days of the year. Therefore, assuming that the BESS can operate between the generally accepted state of charge (SOC) limits of $SOC_{min} = 20\%$ and $SOC_{max} = 80\%$ and an efficiency of 90% [9], the BESS capacity resulted 130 kWh. Also, the power of the BESS was chosen 2.5 MW.

As for the HPP control band, which must be kept available to compensate the power profile of the FPV, it was chosen a band of ± 4 MW, so as to satisfy the need for power transfer in the majority time of the year. In *Table 1* are presented the obtained results.

Table 1. Obtained results

BESS capacity	130 kWh
BESS power	2.5 MW
Control band of HPP	± 4 MW

6. Conclusions

Renewable sources of energy will account for an increasing share in the national energy mix and, because of this development trend, it is necessary to find efficient solutions for their installation, both economically and

technically. In this paper, it is analysed the operation of a FPV installation located in the vicinity of the Rusănești hydropower plant on the Olt River. The highly unpredictable variation of the power generation profile was highlighted by means of measurements with a reporting rate of 1 frame/s. Thus, to minimise the adequacy problems of the electric grid caused by the randomness of the FPV generation, the solution of a hybrid system was proposed, consisting of the FPV, the HPP of Rusănești and a BESS. The flexibility of the latter two is used to compensate for imbalances that occur between the estimated and actual generation profile of FPV.

The paper therefore address an innovative power generation solution, which, in addition to the fact that use the water surface as a site for mounting the FPV, it meets the requirements for a safe integration into the utility grid, functioning as a generating unit with predictable generation.

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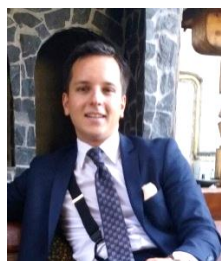
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Authors' biographies



Radu OPREANU holds an engineer diploma from University Politehnica of Bucharest, Faculty of Energy Engineering and works as Energy Analyst at Electricity Producers Association – HENRO. He is currently enrolled in the Master program “Monitoring and Control of Electric Power Systems Engineering” at the same faculty. His research topics include distributed energy sources, renewable energy sources integration in electric grid, multi-energy systems.

e-mail: radu.opreanu@henro.ro



Radu PLĂMĂNESCU holds a Ph.D from University Politehnica of Bucharest on synchronized measurements and high-reporting rate PQ equipment to develop new protection and control algorithms for microgrids. He is also an Assistant Professor at UPB and Research assistant at MicroDERLab Group at UPB. Radu also spent a leave in 2019 at Colorado State University as a Fulbright Visiting Scholar, with research focused on high-reporting rate voltage and current measurements.

e-mail: radu.plamanescu@upb.ro



Silvia VLĂSCEANU holds a Ph.D in Energy Engineering from by University Politehnica of Bucharest, Faculty of Energy Engineering. She has also graduated the Academy of Economic Studies, Faculty of Commerce. Currently, she works as Executive Director at Electricity Producers Association – HENRO. For the last few years, she has taught at Politehnica University of Bucharest and has collaborated with various authorities, organizations and research institutes in conducting studies, assessments and reports related to energy sector.

e-mail: silvia.vlasceanu@henro.ro