Feasibility analysis for the implementation of floating solar panels in reservoirs of hydroelectric dams. Case study Mazar in Ecuador

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Abstract— This article analyzes the feasibility for the implementation of floating solar panels in reservoirs. For this, the Mazar hydroelectric dam in Ecuador will be taken as a case study. It is intended to contribute to the growing demand of the country and the transition processes that Ecuador and the world are experiencing towards renewable energies that are more friendly to the environment. Ecuador has a large contribution of hydroelectricity in its energy matrix, which represents an opportunity to take advantage of reservoirs, which are areas that can be better used to implement floating solar panels, as is done in other countries of the world. It is of special interest to be able to increase the power generation capacity with floating solar energy and, on the other hand, reduce the levels of use of fossil fuels. This case study can be an important basis to replicate in other hydroelectric power plants in Ecuador and be a reference at the international level.

Keywords— Renewable Energy, floating solar panels, reservoirs, hydroelectric dams, Mazar in Ecuador.

I. INTRODUCTION

We live on a planet where energy plays an essential role in our lives. The presence and evolution of technology means that energy generation has become a human need. Currently, this sector is experiencing an urgent need for change due to the presence of major global problems such as climate change [1]–[4]. That is why we constantly seek to reduce CO2 emissions and other greenhouse gases to reduce pollution and limit the increase in the average global temperature on the planet [5].

For them, the use of energy from renewable sources or also considered clean energy is proposed worldwide. Within renewable energies, photovoltaic is one of the most incidental sources today [6]. Solar energy is the rich energy source for power production by taking advantage of radiation properly [7].

Installations of solar photovoltaic (PV) plants are expanding remarkably around the world with the aim of generating electricity from clean and renewable sources [8]. However, large-scale photovoltaic plants are not sustainable, since they require large areas of land to be mounted, which conflicts with other land uses such as agriculture or livestock [9].

In recent years the country has been making a strong commitment to renewable energies with an emphasis on hydroelectric, wind and solar energy [10]. From now on, there is a need for foreign investments to go to other emerging areas, such as wind energy and solar energy, since the country has excellent conditions to grow in these two areas [11]. In this way, as an alternative, the use of solar energy from floating systems is sought, since there are large bodies of water available that could be used as a base for floating panels [12]–[14]. This is another interesting option that deserves to be explored.

Floating photovoltaic solar power plants are currently an emerging form of photovoltaic technologies that use the surface of water bodies such as irrigation, lakes, water treatment plants, reservoirs, etc. It does not require the use of any land property, therefore the land is conserved [15]. But if it requires a floating and support structure, floating photovoltaic plants in reservoirs can help reduce water evaporation, increase efficiency in power generation. They can also make the photovoltaic module somewhat more effective by extending its useful life, due to the cooling process, it limits the growth of algae by blocking the penetration of sunlight [16].

Compared to conventional ground-mounted PV modules, an average increase in conversion efficiency of 12.5% was measured for the floating PV modules [17]–[19]. In addition, the integration of a floating photovoltaic solar plant with a hydroelectric plant by installing it in the dam reservoir for the utilization of an optimal energy mix is an excellent opportunity that could reduce additional transmission and distribution costs [20].

The case studies in the Brazilian [21] and Australian [22] semi-arid consider two scenarios: high level of reliability (90%, scenario 1) and low level of reliability (70%, scenario 2). The level of reliability is linked to the production of electricity; the reduction in evaporation is proportional to the area of the FPV plant [23].

II. METHODOLOGY

In the present investigation, a model for the use of floating photovoltaic energy is proposed to be injected into the Ecuadorian interconnected ring. This study is focused so that in the near future it can be carried out with sufficient resources in the reservoir of the Mazar dam in Ecuador. Next, in Fig. 1, the scheme of the proposed system under study that combines the existing hydroelectric plant is presented.

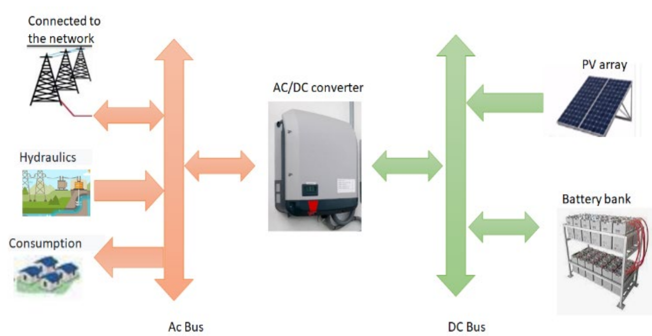

Fig 1. Scheme proposal for the supply of electricity in Mazar-Ecuador.

III. LOCATION OF RESEARCH

The Mazar Dudas Hydroelectric Project of 21 MW of power is located in the province of Cañar, Azogues Canton.

The Mazar Dudas Hydroelectric Project takes advantage of the potential of the Pindilig and Mazar Rivers. The project is made up of 3 uses for hydroelectric generation, which are: Alazán (6.23 MW), San Antonio (7.19 MW) and Dudas (7.40 MW), with average annual flows of: 3.69 m3/s, 4.66 m3/s and 2.90 m3/s respectively, usable for generation, providing an average energy of 125.4 GWh/year.

Fig 2. Location of Mazar in Ecuador

IV. MODELING AND SIMULATION

A. *Solar Photovoltaic Floating*

The solar panel that will be used in the energy supply request must have sufficient structures to remain floating on the reservoirs, in addition to sufficient supports and anchors to keep them in one place and not drag to the front or sides. The mathematical model is expressed after a review of the literature as references [24]–[29] and Figure 6 corresponding to the equivalent circuit of the photovoltaic solar panel is presented.

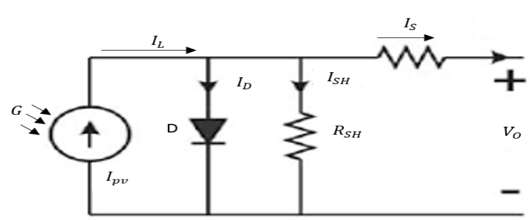

Fig. 3. Equivalent circuit of the PV.

Next, in Fig 4, the proposed design of the location of the solar panels on the reservoir of the Mazar dam is presented.

Fig 4. Proposal for the inclusion of floating solar panels in Mazar-Ecuador

The normalized working temperature T_W has been obtained using.

$$T_W = 273 + 25 \qquad (1)$$

Equation (2), which is indicated below, has been used to calculate the working temperature (T_P) of the solar panel. The operation of the panel at different temperatures [30]–[33] have been obtained as expressed:

$$T_P = 273 + T_C \qquad (2)$$

The effect of radiation on the panel area (I_{P0}) has been calculated using (3) and divided into 1000 to obtain the current. The greatest solar radiation to produce a considerable current is 1000 W/m^2 [34], [35]

$$I_{PO} = I_{SC_{PO}} \frac{Irr}{1000} \qquad (3)$$

The relationship between photocurrent (I_L) and temperature is obtained by using (4). *Ko* represents the current temperature coefficient of the panel.

$$I_L = I_{PO} + Ko\,(T_W - T_O) \qquad (4)$$

The saturation current (Io) is calculated using (5). Where, *q* is the electron charge (C), *Vo* is the output voltage of the panel (V), *n* is the quality factor of the diode, k is the Boltzmann constant (J/K) [36]

$$I_O = \left(\frac{I_{SC_{TO}}}{\frac{qV_{OC}(T_O)}{e^{nkT_{O-1}}}}\right)\left(\frac{T_K}{TO}\right)^{\frac{3}{n}}\left(\frac{qV_g(T_O)}{e^{nk\left(\frac{1}{T}-\frac{1}{T_0}\right)}}\right) \qquad (5)$$

The open circuit voltage of the module would be *Vo*, where I_{SC} and V_{OC} are short circuit current and open circuit voltage of the individual cell, respectively.

$$Vo = I_{O_{TO}} \frac{q}{nkT_O}\, e^{\frac{qV_{OC}(T_O)}{nkT_O}} \qquad (6)$$

The resistance effects of the panel series (R_S) are calculated with (7)

$$R_S = -\frac{dV}{dI_{V_{OC}}} - \frac{1}{Vo} \qquad (7)$$

The value of the derivation resistance (R_{sh}) was not taken into account in terms of ease of operation in the calculations carried out [27] - [35]. Equation (8) is used to calculate the output (I_a). V_a represents open circuit voltage, V_t means panel thermal voltage in (8) [37].

$$I_a = I_a - \frac{I_L - I_a - I_O\left(e^{\frac{V_a + I_a R_S}{V_t}} - 1\right)}{\left(-1\left(I_O\left(e^{\frac{V_a + I_a R_S}{V_t}} - 1\right)\frac{R_S}{V_t}\right)\right)} \qquad (8)$$

Next, in Fig 5, the meteorological data obtained in Homer are presented.

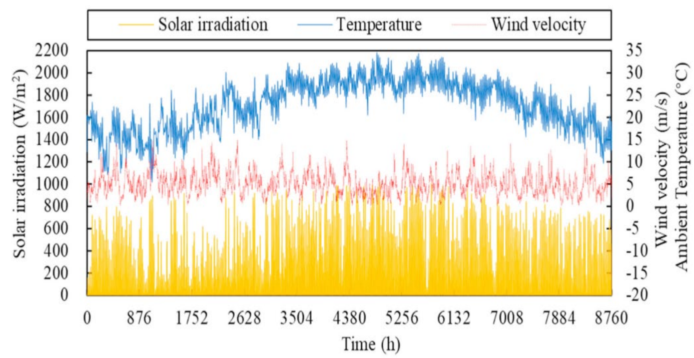

Fig. 5. Time series meteorological data for Mazar-Ecuador

For the case under study, an average speed similar to that of the Pindilig and Mazar Rivers, which allows the conversion of energy from the kinetics of the river to electricity, See Fig 6.

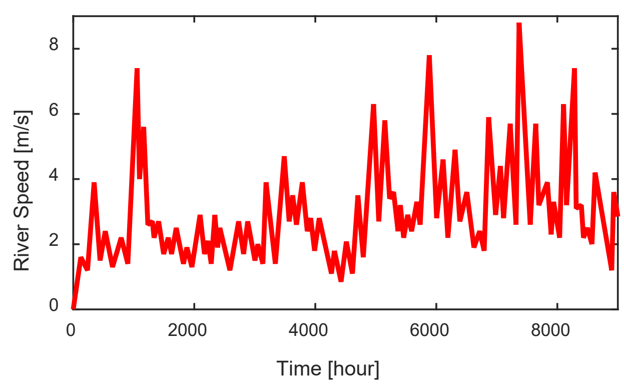

Fig. 6. River velocity profile assumed for the analysis.

Next, in Fig 7, the flow diagram of the electrical energy conversion process is presented.

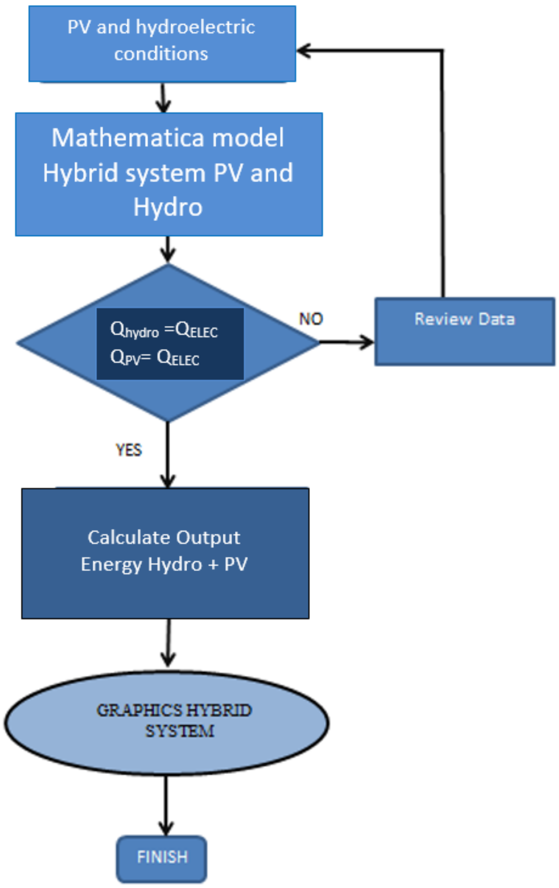

Fig 7.- Flow diagram of hybrid system calculation

V. RESULTS

Equations (1) to (8) previously presented in the previous section that govern the use and conversion of photovoltaic solar energy into electrical energy and form the energy mix with the existing hydraulic system are solved. It is taken into account that the total power may not be simultaneous as it is presented in Fig 8, and for validation purposes, this aforementioned simulation model was coded before being presented as the final result. Note that the hydraulic system will always be above the photovoltaic system at all times. Hydropower will go up to 12MW and will have a minimum of 4.5MW. The floating photovoltaic solar power will not exceed 2MW in an area of 7Km^2.

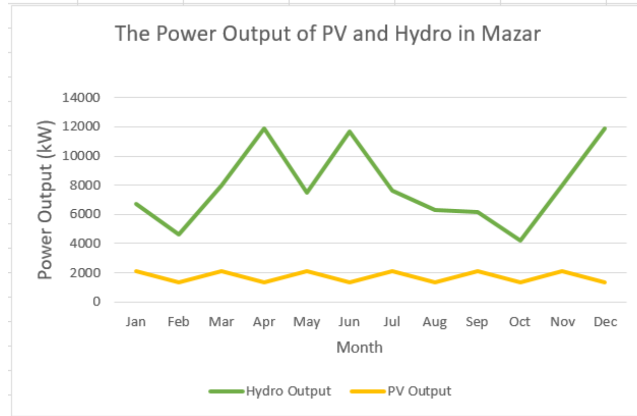

Fig 8.- Electrical power curves obtained from the hybrid photovoltaic-hydraulic system

VI. CONCLUSIONS

In Ecuador it is possible to carry out this type of implementation at the level of reservoirs including floating solar panels, in fact it is not new that in other parts of the world these systems are planned that include solar panels not only in reservoirs but also in natural water channels of low flow. In Ecuador, these possibilities of expansion of the electrical system are opened, taking advantage of renewable energy sources with a view to leaving aside fossil fuels that have historically had a great presence and that on several occasions have been the cause of conflicts in the streets. This research allows opening this line of development for other researchers to deepen the study for the inclusion of panels in hydroelectric dams, which are extensive spaces that can be very well used to inject energy into the national interconnected system.

Ecuador is in a permanent search for options that allow it to transform its energy matrix with a high participation of renewable energies. It will be possible when initiatives of this nature that come from the private and public sectors are planned and put into practice for the greater benefit of the communities and citizens in general.

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