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Thermal and electrical performance prediction of an FSPV system: a case study in the Douro/Portugal climatic conditions

Paulo Vargas[1], Salviano Pinto Soares[1,2] and Sérgio Silva[1,3]

[1] School of Sciences and Technology, Engineering Department UTAD, Vila Real Portugal

[2] IEETA UA, Aveiro, Portugal

[3] INESC TEC Porto, Portugal
al70216@alunos.utad.pt;salblues@utad.pt;

al52620@utad.eu

Abstract. The use of traditional renewable energies such as hydro, wind and solar has been the solution to the world's energy demands in order to make the final energy consumption more sustainable. In the last decades new technical solutions are beginning to emerge like the Floating Solar Photovoltaic systems, which are normally deployed in lakes, and dams. Since it is known that the percentage increase in energy efficiency depends on the location, microclimatic conditions, this work uses the knowledge obtained from data weather stations in Portugal and tries to assess the possibility of installing a system FSPV in the climatic conditions of the Douro/Portugal wine region as a function of the thermal and electrical performance.

Key words. Renewable energy, FSPV systems, forecasting.

1. Introduction

Floating Solar Photovoltaic (FSPV) systems represent an opportunity in which Photovoltaic (PV) systems are sited directly on water bodies like dams, lakes, or reservoirs. In Portugal there are about 250 large dams with a height of over 15 meters and storage of over 2 hm^3 [1] leading to a strong opportunity for the country to achieve the goals defined in PNEC2030 [2]. Nevertheless, it is necessary to increase the efficiency of the energy sources, reducing the consumption of primary energy and increasing renewable resources [2]. Despite some engineering constraints and challenges, there are some reasons to use floating solar power over other solar installations such as:

- Floating solar structures are more efficient than equivalent structures over land due to the water surface winds that lower the temperature of the structure;
- Floating solar structures are composed from Solar panels that are fixed and attached to a floating platform than is anchored to the bottom of the dam, lake or reservoir;
- The systems can either use a floating inverter, or, in the case of smaller installations, a land inverter can be used to deliver the energy to the grid.

2. Theorical concepts

The sun fuses about 620 million metric tonnes of hydrogen per second and some of this energy can be collected on earth, although the intensity with latitude, the amount of cloud or the time of year (seasons). The photovoltaic effect was discovered in 1839 by a 19-year-old French physicist Edmund Becquerel. Edmund, verify that metal platinum or silver dipped in an electrolyte potential produce an electric difference, when exposed to light. In 1964 Gerald Pearson, Calvin Fuller and Daryl Chapin from the Bell Labs discovered that the silicon semiconductor doped with impurities are light sensitive, originating first investment in Photovoltaic Energy production and the first financing program that aims to use the photovoltaics cells as an alternative to fossil fuels in electricity production [3].As the ambient temperature near a waterbody is lower than the ambient temperature at land with the additional fact that the wind speed, in water, tend to be higher when compared to on land, thus resulting in a cooling effect that results in lower operating temperatures of the systems.

A-Floating solar panels technology

In the late years many technical solutions contribute to the development of a regional and national cluster of the solar energy sector.In EU nowadays we see a vision from manufacturers, research and innovation institutions such as Fraunhofer ISE [4] which has joined forces with Solar Power, the Association of European of Research Institute Centers (EUREC) [5], the National Association and ten other major EU research institutes to define an industrial strategy for European solar energy: indeed the solar industry is an opportunity for the economy.
Normally constructed of plastic, tested and rugged to withstand demanding conditions such as ripple, wind or corrosion. There are same configurations for supporting structures. And usually has four modules:

- Photovoltaic modules;
- Floating structure that allows the installation of the PV panels;

- Mooring/anchoring that adjust to water level see Fig. 1;
- Electrical connection to the electrical grid.

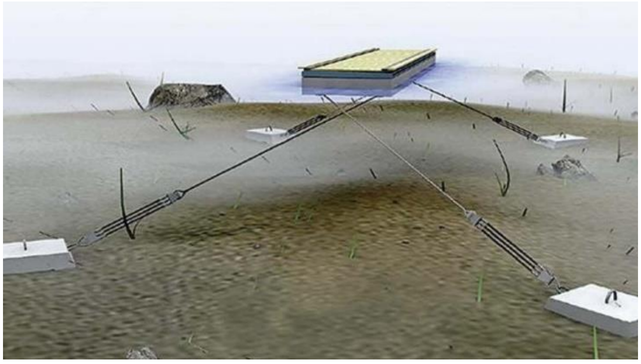

Fig. 1.Anchoring scheme under the water surface

B-Anchoring systems

Anchoring systems technology are well developed and with good examples in Europe and in Portugal.
Normally the system choose the anchor point under the water, but also can choose the anchor point on the waterfront. The procedure of installing anchoring system will be designed in accordance with the condition of water area.

3. The Portuguese case

Portugal has favorable conditions for the installation of solar systems due to the good average annual solar exposure that increase from North to South: particularly the South has high exposure to radiation [6]. There are a few FSPV projects that were deployed in Portugal: one of these projects is a pilot installed in Alto Rabagão dam, it consists of 840 PV panels, providing an installed capacity of 220kWp, with an annual production around 300 MWh[7].Another FSPV project, was deployed in the South of the country, in Alqueva dam, it consists in the installation of 10 FSPV stations , and are used to provide the energy to several pumping station installed in the Alqueva complex. Currently the energy production is 100% for self-consume, nevertheless, the government awarded the rights to develop 263 MW of floating PV capacity, with 7 lots being auctioned. EDP renewables, secured the highest lot with 70 MW capacity. The existing structure is composed by an approximately 3000 PV panels, occupying an area of 1 hectare.The Portuguese government, to achieve the solar energy generation capacity goals has implemented solar auctions for the 7 pre-identified water reservoirs, located in major dams. All the reservoirs are public waterbodies, with the beds and banks being private. Under the defined mechanism, the selected developers will be allowed by the government to have the right to use the water for 30 years .The EU is presented in several R&I programs engaging both public and private sector, the Horizon Europe Framework Programme is focused on tackling climate change, fostering the UN´s sustainability goals and increasing overall EU´s competitiveness. The global cumulative installed floating PV capacity topped 3GW in the end 2021 with more than 600 completed projects around the world according to the Solar Energy Research Institute of Singapore (SERIS) annual report see Fig 2.

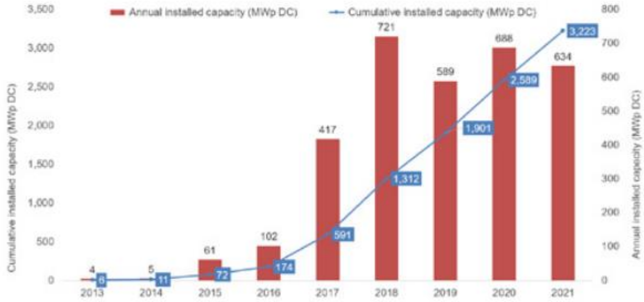

Fig.2- Globally installed FPV capacity

An interested analyses can be done if we compared the FSPV prices with traditional PV, Fig 3 displays the breakdown of FSPV installation cost. We can see that the cost breakdown is comparable to traditional PV systems, but has some added costs for the floating platform, anchoring and mooring charges [8].

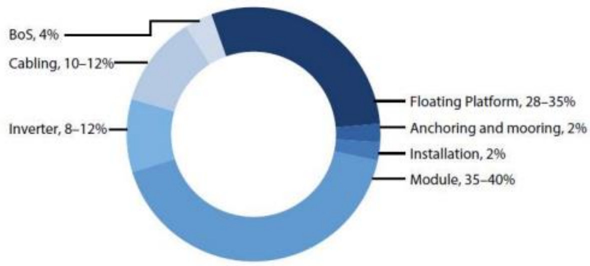

Fig. 3 -FSPV Major costs breakdown according SERIS [18]

4. Case Study

Since it's known that energy efficiency depends on the location, microclimate conditions, and technology of modules (Lee et al., 2014) this paper bases it's findings in the compilation of weather data (temperature, wind, speed direction, humidity) from several weather stations located in Portugal (data was provided by IPMA [2]) and the data provided by the ADVID - Vine and Wine Cluster and CoLAB [18](https://www.advid.pt/pt/meteorologia) at the Douro/Portugal region trying to understand the potential of the FPV systems at Douro/Portugal wine region climatic conditions. The data, provided by IPMA [9], are related to temperature, humidity, precipitation, average wind speed and direction from weather stations in various locations in mainland Portugal. The data analyses make possible to have good indications of the climate variability over the last years [2006-2020], at national dimension.

A-Analysing the data

In this section will use the data from all the weather stations and with the help of the software Rapidminer [10] we intend to analyse the possibilities to install a FPV according to the best climate condition focus on the thermal and electrical performance. For that we have conducted various experiments to develop models for forecasting energy generation. The IPMA weather station more closed to the Douro region, are at Porto/Pedras Rubras and Vila Real/ Aerodrome. In this case study the focus of the work is the Douro region and for more accurate data was chose the data from ADVID [18], collected in Douro region.

The energy data was collected from February 2022 to February 2023 (12 months period), and the dataset comprises daily temperature observations collected in a FPV installation on the Douro River region. The dataset comprises three different variables which are selected due to their direct effect on energy generation, those include, air temperature (ºC), the hour of the day (0–23), and air humidity. An additional variable CO_2 was also captured and included to understand if it directly affects the energy generation. The next table describes and presents some statistics of the collected dataset.

B-Table Statics

To evaluate the Model forecasting capabilities the following metrics were used: The (1) Root-Mean-Square Error (RMSE): was used to measure the accuracy of model prediction performance since it is commonly used to calculate standard deviation of the residuals or prediction errors; The (2) Mean Square Error (MSE): was also used since it provides an indication on how well the regression model is by computing the distance between the data point and the regression line; and finally the (3) Mean Absolute Error (MAE): it was also used since it gives the mean of the absolute differences between forecasted and actual values.
These metrics are usually defined by the following formulas [11]:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(F_i - O_i)^2} \quad (1)$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(F_i - O_i)^2 \quad (2)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|F_i - O_i| \quad (3)$$

Where F_i was the forecasted value, O_i was the actual value, and n was number of data samples. There was some dataset pre-processing, normalization and reshaping to convert the dataset into a supervised learning problem where we learn from the previous data points in the series to forecast the next value in the future. Therefore, the sequence of observations inferred from the series was transformed as feature variables from which the models could learned. The following technics were used in *Rapidminer*: Generalised Linear Model (GLM), Deep Learning (DL), Random Forest Tree (RF), Gradient Boosted Tree (GBT), Decision Tree (DT), and Support Vector Machine (SVM).The following main stages were used during processing of the variables, the pre-processing, the Model Training and Testing and the Model Evaluation.
The following images illustrates these stages in *Rapidminer* blocks:

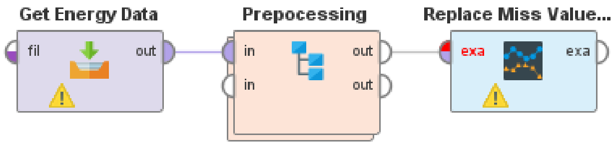

Fig. 4-RapidMiner blocks for pre-processing.

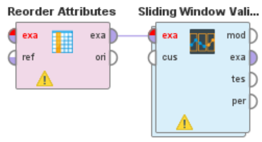

Fig. 5 - RapidMiner blocks for Training and Testing

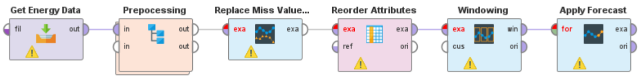

Fig. 6- RapidMiner blocks for Model evaluation.

The training was done in 80% of the dataset while the testing was done in 20%, the following image shows the blocks for the testing phase:

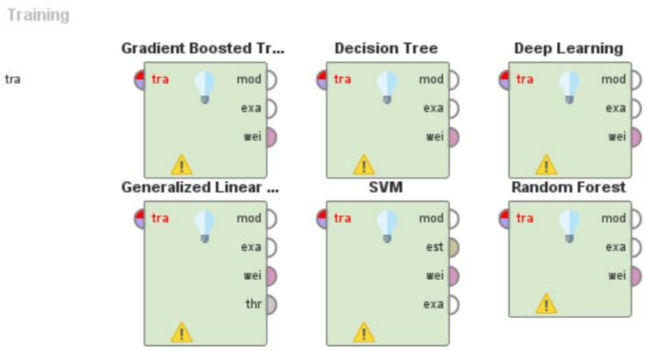

Fig. 7 - RapidMiner blocks for each of the Models.

For the testing we used the following blocks:

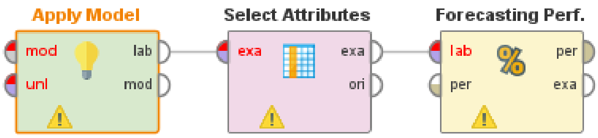

Fig. 8- RapidMiner testing blocks.

RapidMiner computes the performance based as explain in 20% of the unseen dataset. This dataset was embedded for a multi-hold-out-set validation where the average performance was automatically computed for seven different subsets. The following table shows the correlations between the different variables:

Table 1- Variable correlations

Attributes	air_humidity	air_temperature	barometric_pressure	battery	co2
air_humidity	1	-0.893	0.276	0.072	-0.552
air_temperature	-0.893	1	-0.456	-0.179	0.267
barometric_pressure	0.276	-0.456	1	0.059	-0.015
battery	0.072	-0.179	0.059	1	0.175
co2	-0.552	0.267	-0.015	0.175	1

The results obtain for the RMSE are summarized in the following Fig. 9 and Table 2:

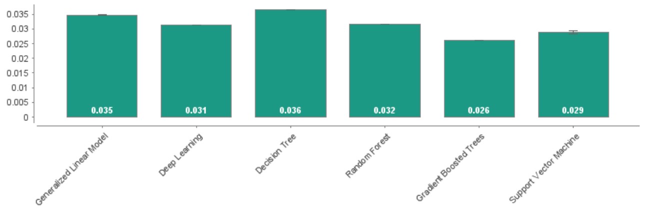

Fig. 9- MSE results for the Models.

Table 2 - MSE results for the Models

Model	Root Mean Squared Error
Generalized Linear Model	0.035
Deep Learning	0.031
Decision Tree	0.036
Random Forest	0.032
Gradient Boosted Trees	0.026
Support Vector Machine	0.029

According to our best results, we can see that the Gradient Boosted Trees is the model with lower error.
For the MSE the results obtain are displayed in the following Table 3:

Table 3 - MSE results for the Models

Model	Squared Error
Generalized Linear Model	0.001
Deep Learning	0.001
Decision Tree	0.001
Random Forest	0.001
Gradient Boosted Trees	0.001
Support Vector Machine	0.001

Finally, the MAE results obtain are displayed in the following Fig. 10:

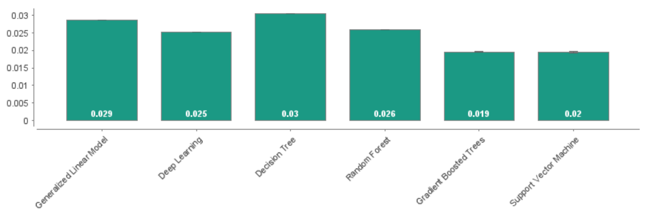

Fig. 10- MAE results for the Models.

And in the following Table 4:

Table 4 - MAE results for the Models

Model	Absolute Error
Generalized Linear Model	0.029
Deep Learning	0.025
Decision Tree	0.03
Random Forest	0.026
Gradient Boosted Trees	0.019
Support Vector Machine	0.02

The following Fig. 10 show the relation between the predictions and the real values for each model:

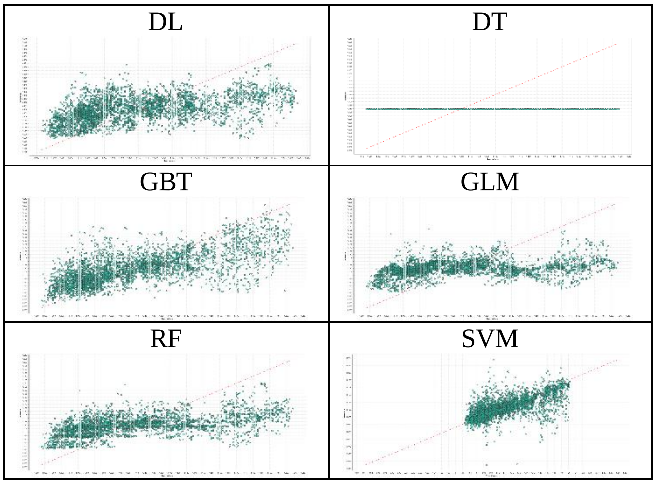

Fig. 10- MSE results for the Models.

As depicted in Table 2 and Table 4, Gradient Boosted Tree obtains the best performance in both evaluation metrics amongst all techniques to forecast power generation. This is commonly due to the strong scalability and regularization quality of the GLM amongst other techniques [14].It is also, evident that Decision Trees performance was poor, this is since DT commonly forecasts an average of unseen training samples since it is not able to extrapolate the normal increasing and decreasing trends in the dataset, thereby does not scale well for this time series data. This work uses the knowledge obtained from data weather stations in Portugal and tries to assess the possibility of installing a system FSPV in the climatic conditions of the Douro/Portugal wine region as a function of the thermal and electrical performance.
In Portugal, in the North, Alto Rabagão [15], is one example of these type of installations. This System, is a power plant, located in Dam reservoirs, with an area of 250 m^2 and an installed capacity of 220 kWh that currently is capable of make annual production around 300 MWh [16].
The Douro River is a good example where we can install these systems. In future works we will explorer the comparison between the energy produced in a farm in the

Douro River over the water surface and in the similar system in the Land.
The following equation (4) will be used to calculate the energy produced in these system [17]

$$E = \eta_{inv} \sum_{i=1}^{n} P_{max}(G,T)\Delta t_i \quad (4)$$

E- Energy (Wh)
$\boldsymbol{\eta_{inv}}$ – Perfomance (%)
$\boldsymbol{P_{max}(G,T)}$- Maximum power depending on the incident radiation and temperature (W)
$\boldsymbol{\Delta t_i}$ – Time interval considered (s)

5. Conclusion

Our country has ideal conditions for the exploration of PV and FSPV systems [6]. For that reason and to achieving carbon neutrality by 2050, the Portuguese government developed a 2030 National Plan for Climate and Energy – PNEC to reach the goal of 80% of electricity consumption to be provided by renewable energies. With that in mind several solar auctions are being deployed to allocate 30 years licences for solar power generation in public water reservoirs. The goals are set to carry out at least two 500MW tenders per year, awarding a total capacity of 1GW per year trying to achieve the 9GW before 2030.

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