SOLAR PHOTOVOLTAIC SYSTEMS FOR HIGH POWER PUMPING: A USE CASE

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ABSTRACT: Solar water pumping combines solar photovoltaic (PV) technologies, hydraulic engineering, and high-efficiency technology to provide water management techniques and optimise irrigated farming. Within the context of the SolaQua project, a solar photovoltaic system design for water pumping was developed and implemented in Montes Velhos Pumping Station, located in Aljustrel, Portugal. This pumping station has 2.813 MW of total installed pumping power and a maximum flow rate of 3.08 m^3/s. The designed PV system has 320 kW_p installed on 1-axis North-South horizontal sun-trackers in a hybridised configuration with the electricity grid. This work aims to analyse the real operation data from that hydro-agricultural system from 2019 to May 2022. It is intended to analyse data regarding the electrical conversion efficiency of the pumping station, to calculate the annual performance ratio (PR) and other equally relevant variables for the pumping station and solar photovoltaic plants, such as self-consumption rates and annual savings. The designed system allowed the cost reduction of the pressurised pumped water and increased the share of renewable energy (RE), presenting a cost-effective alternative to the previous energy sources, diesel generators or electric grid for water pumping.

Keywords: Solar Water Pumping, Water Pumping, Pumping Station, PV System, Pressurised Pumped Water.

1 INTRODUCTION

Agricultural irrigation in Southern Europe is a high consuming activity: of electricity (24,000 GWh/year) and of water (70,000 Hm^3/year). In the last years, the electricity price has increased across the region (in Spain 1250% from 2008 to 2013 for the Irrigators Communities, in Portugal 226% and in Italy 32%), reducing the competitiveness of agriculture business models [1]. Futhermore, with the recent european crisi context, eletricity gross market prices have been increasing at faster rates.

Most of the current agricultural pumping systems are powered from the national electric grid or diesel generators. However, both the increase in the price of this conventional electricity and the trend to phase-out fossil fuels, has boosted the look for alternatives to power these systems. Solar photovoltaic irrigation/pumping systems appear as a sustainable solution due to the decrease of the PV modules prices in international market, as well as the removal of technological barriers that limited the power of PV pumping systems [4].

This work aims to analyse real data obtained from the hydro-agricultural system of Roxo (Portugal) over the period of 2019 to 2022, mainly from a high-power photovoltaic pumping setup. Solar pumping is based on a combination of photovoltaic (PV) technology, hydraulic engineering, and high-efficiency water management techniques to optimize irrigated farming. The designed system allowed the cost reduction of the pressurized pumped water as well as an increase of the share of renewable energy (RE), presenting a cost-effective alternative to the previous energy sources.

2 CONTEXT OF THE ROXO HYDROAGRICULTURAL DEVELOPMENT

The Roxo Beneficiaries Association (AB Roxo) is the entity responsible for managing the Roxo hydro-agricultural operation since 1968. This system was designed around 80 years ago, in the first half of the 1930's, and has allowed the conversion of thousands of hectares from rain-fed to irrigated land in an area around the Roxo stream and between the city of Beja and the towns of Ferreira do Alentejo and Aljustrel, in Portugal. The main infrastructures of this system, managed by this association are:

- The Roxo Dam;
- A gravity and a pressure water distribution network;
- The Montes Velhos pumping station, associated to the irrigation blocks with pressurized water distribution (Montes Velhos and Aljustrel);
- A drainage network, with a total length of 71.91 km [2].

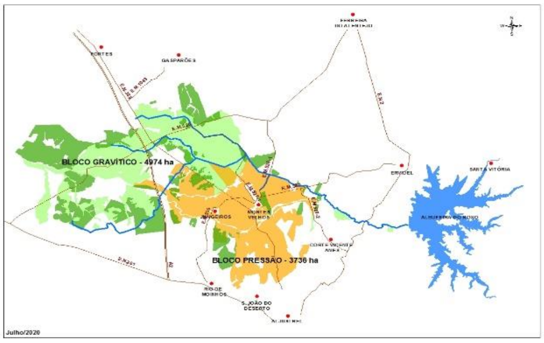

Figure 1: Water distribution network from the Roxo dam

3 PV GENERATION SYSTEM FOR SELF-CONSUMPTION AT THE MONTES VELHOS PUMPING STATION

In order to develop sustainable strategies and policies, the AB Roxo decided to invest in renewable energy sources with the construction of a photovoltaic power plant to generate the electricity needed to operate the pumps at the Montes Velhos pumping station, in order to reduce the total operational costs [3]. Thus, the Roxo photovoltaic power plant was designed with a total installed power of 320 kWp, on a setup with solar tracking on a horizontal north-south axis, allowing it to properly meet the seasonal and daily electrical needs of the pumping station, improving the key performance indicators, that would not be achieved with a standard south facing fixed tilt PV system [2]. This pumping station has 2.813 MW of total installed pumping power and a maximum flow rate of 3.08 m^3/s.

Figure 2: Montes Velhos Pumping Station and its PV plant, Portugal

3.1 Operation of the Pumping Station and Photovoltaic Plant

The next figure shows the simplified scheme for power flows of the hybrid configuration: pumping station, the photovoltaic plant and the public electric grid as well.

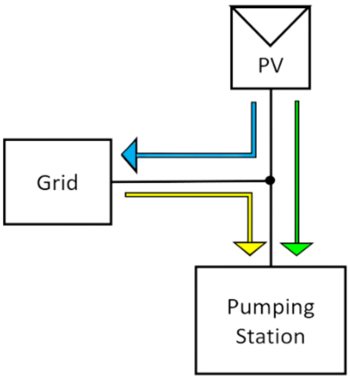

Figure 3: Simplifed scheme of power flow for the current setup at the Roxo Pumping Station

Part of the photovoltaic generation is self-consumed by the pumping station to meet its energy needs, represented in the scheme by a green arrow. The remaining PV electricity generated is injected into the grid and sold to EDP (market electricity trader), represented with the blue arrow. When the PV generation is not enough (or not available) to supply the pumping station demand, AB Roxo buys the necessary power from ENDESA (market electricity trader), injecting from the grid, represented by the yellow arrow.

This purchase/sale of electricity to ENDESA and EDP, respectively, is made possible under the decree-law no. 15/2022 [4], currently in force in Portugal.

4 RESULTS ANALYSIS

4.1 Irradiation in the Plane of the PV Modules

With the TMY available on the PVGIS website [5], a preliminary data quality check was done regarding the values collected by the pyranometer installed in this photovoltaic plant, concluding that are closely aligned in accordance with the typical seasonality values and monthly irradiation values.

The real data collected showed that July 2020 presented the highest monthly solar irradiation total so far. The higher difference of irradiation values summer-Winter is due to the horizontal tilt of the PV system and is an part of the goals for the customized design.

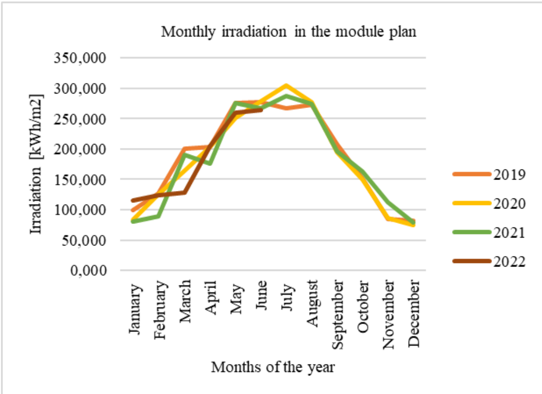

Figure 4: Monthly total Irradiation in the PV Modules plan

4.2 Annual PR

The concept of PR, *performance Ratio*, is used as a quality index with regard to the connection of photovoltaic systems to the grid and is also used to monitor the operating quality of the installation in the long term. This quality index is directly related to the efficiency of converting solar irradiation into electrical energy, and for this situation it was obtained using the following expression:

$$PR_{monthly} = \frac{E_{AC,monthly}}{E_{DC,monthly\ module\ output}}$$

Where, monthly AC Energy corresponds to the energy measured at the output of the photovoltaic installation's electricity meter and monthly DC energy corresponds to the power measured at the output of the photovoltaic modules.

The monthly DC energy at the output of the photovoltaic modules was obtained using the following expressions [5]:

$$\sum E_{DC\ (med,PV),monthly} = G_{monthly}{}^{*} \times A_{active,total} \times \eta_{module}$$

Where, the first term corresponds to the monthly irradiation and the following terms correspond to the total

active area of the installation and the efficiency of the modules installed, respectively.
To calculate the total active area of this photovoltaic installation, it was necessary to consider the specification sheet of the modules installed [6], from which the following was calculated:

$$A_{active,total} = n^{o}\ cells\ \times length \times width \times n^{o}\ modules\ \leftrightarrow$$

$$A_{active,total} = 72 \times (0{,}156) \times (0{,}156) \times 1000$$

$$\eta_{module} = 16{,}5\ \%$$

When this photovoltaic plant was installed, a minimum annual PR was defined in its specifications (Technical Specifications, part of the installers contract documents) and it was required to be above 85%. All the calculated PR values, monthly and annual, should be higher than that figure, otherwise specific correctives measures have to take place by the installer in order to achieve the defined minimum annual PR.

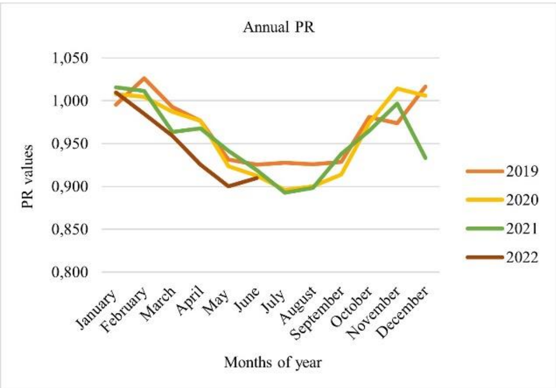

Figure 5: Annual PR – calculated from real data (2019 to May 2022)

The previous figure shows a clear seasonality regarding monthly PR values, with the majority of the months being above 90%. The PR seasonality is often related to the operating temperature and humidity for all equipments, cabling, soiling, etc. The precision of this PR values is clearly affected by the lack of proper O&M and periodic cleaning of pyranometers and PV modules, presenting several values above 100%. Recommendations were issued to the plant owner in order to avoid these issues in future operation. Missing O&M records also do not allow to perform an in depth analysis of these outliers.

4.3 Self-Consumption-Rate

The self-consumption rate is related to the ratio of electricity that is self-consumed according to the pumping station's energy needs. The self-consumption rate depends on the energy that is produced and that is consumed locally. In general, due to the characteristics of the irrigation profile in Mediterranean countries, in summer months the self-consumption rate achieved is lower, increasing the grid energy consumption. In particular, in years with less rainfall or during drought periods, the irrigation needs become higher and, in consequence, the pumping station electricity needs increases.

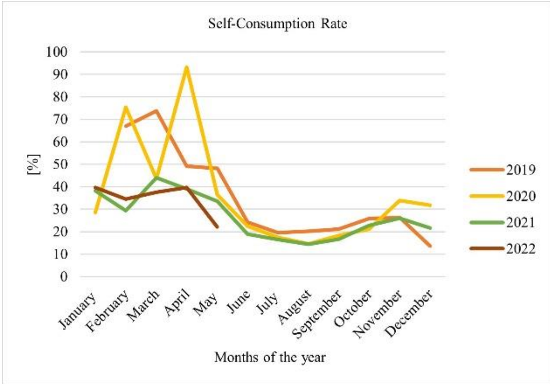

Figure 6: Self-Consumption Rate

4.4 Generation *Vs.* Consumption

Although the design of the PV system (horizontal tilt) produces the largest difference between summer and winter energy generation values, when compared with standard PV systems design, the seasonality effect of this application is critical for the improvement of technical-economic indicators. While the production is higher in summer, it is not enough to meet the energy needs of the pumping station, as can be seen (Figure 7) by the large difference between solar generation and consumption in summer. An carefully designed expansion of the existing PV plant is needed to further reduce the existing gap during summer energy needs and solar generation, without creating a large solar energy surplus in the winter period (economically less interesting due to lower tariffs).

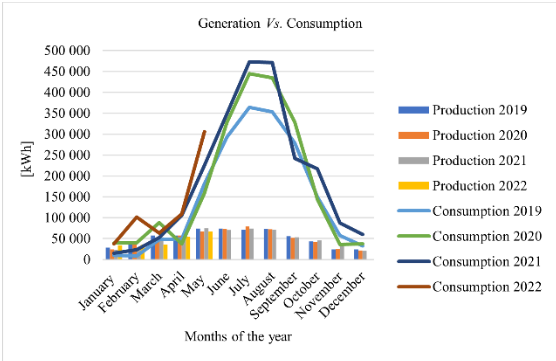

Figure 7: Generation Vs. Consumption

The generated solar energy in this period has enabled to avoid the emmissions of 809.8 tons of CO_2, considering a total production of 2.030 GWh and a average specific emmissions factor (ENDESA) of 398.88 g/kWh of CO_2.

4.5 Savings

Given that AB Roxo must meet their business model goals, this renewable energy project must accomplish important savings regarding the pumping energy cost, and, in consequence, pressurized water cost to be sold to the end-users (farmers, irrigators). Savings in the pressurized water cost (€/m^3) are reflected directly in the increased sustainability of the farmers business model. The current trend of improvement of hydraulic and irrigation efficiency often causes an increase of energy consumption (from gravity irrigation systems to pressurized precision irrigation systems), turning the electricity cost a major driver in the modern farming model.

Due to the night period (or cloudy periods) pumping needs, a alternative energy source will always be needed (or energy storage). This hybrid configuration enables important savings and guarantees energy supply safety.

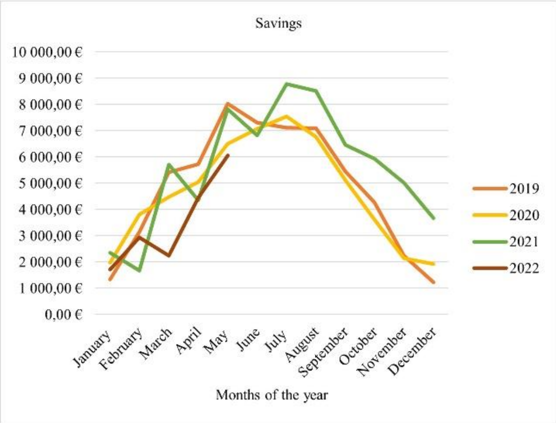

Figure 8: Monthly savings (self-consumed eletricity)

Total savings for the analysed period (2019 to May 2022) are 198 365€ (59.5% of CAPEX), an average of 56 675€ saved per year.

4.6 Surplus electricity injected into the grid

Energy generation surplus can be injected into grid and provides an additional cashflow for AB Roxo, when sold to an electricity trader. Furthermore, the project economic indicators can be improved trough selling the winter surplus energy at a higher tariff, and made possible by the current decree-law in force, e.g., with the creation of an self-consumption energy community with existing neighbors (peer-to-peer energy trading).

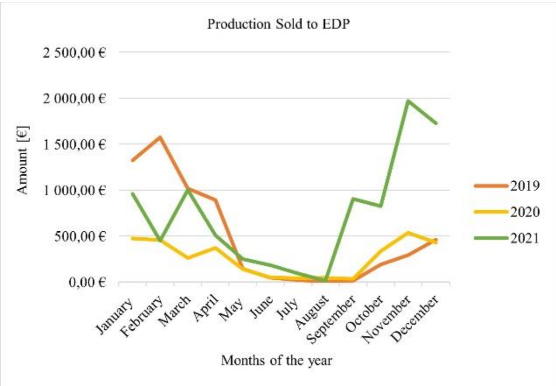

Figure 9: Monthly cashflow from surplus eletricity sold to the grid

Due to the absence of 2022 data, Figure 9 does not depict this values.

5 CONCLUSIONS

High power PV pumping provides a sustainable solution for irrigators and farmers. As shown in this work, investments in this technology should increase, providing a lower cost to pressurized water and contributing to the overall CO_2 emissions reduction. The use case presented is the first large scale system in Portugal, in a hybrid configuration with the pre-existing electricity grid. The results presented showed that depict existing some challenges regarding performing proper O&M tasks, the operation data points to good PR results, and significative savings in OPEX.

Regarding the self-consumption of this pumping station, presents a seasonal variation, as expected. The summer months gap between solar generation-consumption can be addressed in the future, with a upscale of the total installed solar power, reaching higher self-consumption rates. On winter months the existing surplus is injected into the grid and sold to an electricity trader. The existing Portuguese Decree-Law allows the creation of energy communities, which could further improve the project key performance indicators, trough peer-to-peer energy trading with existing neighbors.

The economic indicators point to favorable achieving of the AB Roxo business model goals and reached so far total savings of 198 365€.

ACKNOWLEDGMENTS

The authors would like to thank the support of this work, partly funded by European Union's H2020 Programme as part of the SolaQua project (Accessible, reliable, and affordable solar irrigation for Europe and beyond), Grant agreement ID 952789.

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