21th International Conference on Renewable Energies and Power Quality (ICREPQ'23)
Madrid (Spain), 24th to 26th May 2023
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.21, July 2023

Sizing of on-grid photovoltaic systems for water pumping in irrigation communities

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Abstract. This paper describes a technical-economical analysis to achieve the most appropriate sizing of grid-connected photovoltaic systems for water pumping in irrigation communities. The profitability of different tracking systems are analysed based on the price of the electrical energy consumed from the network. The case study of a real pumping system of an irrigation community located in Zaragoza (Spain) is presented, which supplies a geographical area of 2000 Ha, with six 630kW pumps and eight 110kW units.

Key words. Photovoltaics, Self-consumption, Demand side management.

1. Introduction

Irrigation water is defined as that which is applied through different irrigation systems for the correct development of crops. Its origin can be very diverse since it can come from rivers, lakes or continuous currents of natural waters, from wells, etc.
Agriculture is by far the largest consumer of water globally. 70% of the world's water consumption is for crop irrigation. In several developing countries, water used to irrigate crops represents 95% of the water consumed, and plays a key role in food and food production. In most of these countries, the development of future agricultural strategies involves maintaining and improving the expansion of this irrigated agriculture.
Within the European Union (EU) agriculture represents about 30% of water abstraction. The intensity of irrigation varies with the countries obviously depending on the climate, the crop and the methods used. For example, the type of irrigation in southern European countries where irrigation is basically for production agriculture is completely different from that in Central and Western Europe. Most of the irrigated land in Europe is found in the South, specifically in Spain, Italy, France, Greece and Portugal, which account for 85% of the total land dedicated to irrigation in the EU. For example, in Spain, irrigated agriculture accounts for 56% of its total agricultural production and occupies only 18% of the land devoted to agriculture.

Irrigation communities are public law corporations attached to the Basin Agency (public entity in charge of managing water in hydrographic demarcations) that must compulsorily create users of water and other assets of the public hydraulic domain of the same intake or concession.
The main functions of an Irrigation Community are: Organize the collective use of public, surface and groundwater that are common to it. Distribution and administration of the granted waters, subject to regulations sanctioned by the Administration and elaborated by the users themselves.

Energy is of paramount importance for the management and development of water resources. Water infrastructures are completely dependent on energy throughout their value chain, from groundwater pumping, transport, water purification, desalination, distribution of water to economic uses and population to the collection, management and treatment of wastewater.

Current pumping systems often use fossil fuels or electricity. The development of renewable energies opens a door to achieve more economical and sustainable pumping. In particular, the use of photovoltaic solar energy to supply an important part of the electrical consumption of pumping systems is receiving great attention for various reasons. One of them is the use of a clean and native resource. Another, which has gained special importance in the last two years given the increase in the cost of the electric kWh, is economic savings. The necessary investment required for the construction of the photovoltaic plant and the necessary electrical infrastructure can be recovered in a not very long period of time. But the initial cost is not the only consideration. The energy study cannot be based on net balance analysis, but it is important to analyze the energy balance at least on an hourly basis. Given the variability and intermittency of the resource, it is also necessary to consider irrigation strategies different from those used up to now.
If possible (due to having reservoirs available both for water extraction and for high-level storage) it will have to

be pumped at those times when there is solar resource. This is radically different from the strategy used until now, which consisted of pumping in those periods in which electricity is cheap. Therefore, it is necessary to adapt consumption to generations, in a system that we could consider as Demand Side Management. In addition, in the planning phase of the required plant, an optimized economic technical design must be carried out. From the study of the solar resource, the implementation of photovoltaic systems with or without monitoring, types of monitoring, etc. should be considered.

2 Case study

This paper presents a case study of a pumping system of an irrigation community located in the province of Zaragoza (Spain) that supplies water for agricultural uses of 2000Ha. It consists of two systems in series. The first system is called “Catchment” (which obtains water from a river reservoir). The second system is called “Re-pumping system”, located a few kilometers away from the previous one, and which pumps the water again (without the existence of an intermediate reservoir).) in order to achieve the necessary height. The current load curves, amount of energy consumed and current economic cost collected in bills from the electricity supplier in recent years are known. Figure 1 shows the energy consumption of both systems in the years 2020, 2021 and 9 months of 2022.

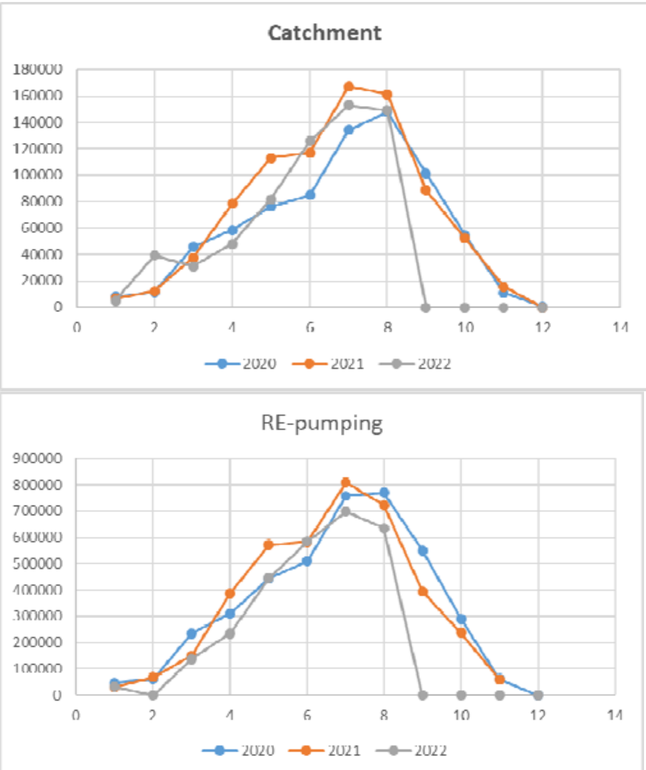

Fig. 1: Monthly comsumption (kWh) a) in catchment system, b) in repumping system

Figure 2 shows the annual energy consumption and the annual energy cost. Note that with similar amounts of energy consumption in Catchement system, the total cost is much higher in 2022 due to the increase in electricity prices that occurred that year. Something similar occurs in the re-pumping system. The annual cost of both systems in 2022 is estimated to be 1.4 MEuros

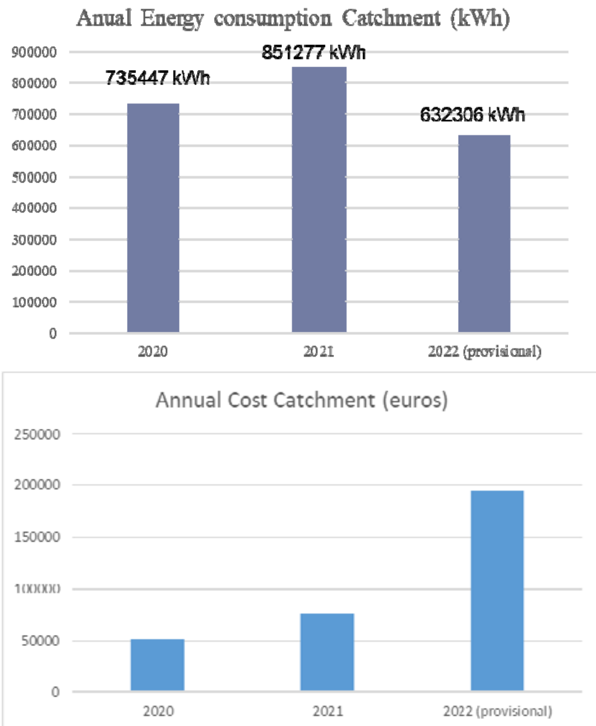

Fig. 2: Annual energy consumption and energy cost in Catchment system

Several scenarios resulting from different photovoltaic technologies and demand management are designed, finally providing recommendations on the size of the most appropriate photovoltaic plant, as well as the associated economic profitability.
Below are several figures related to the load curves and profitability depending on the installed photovoltaic power.

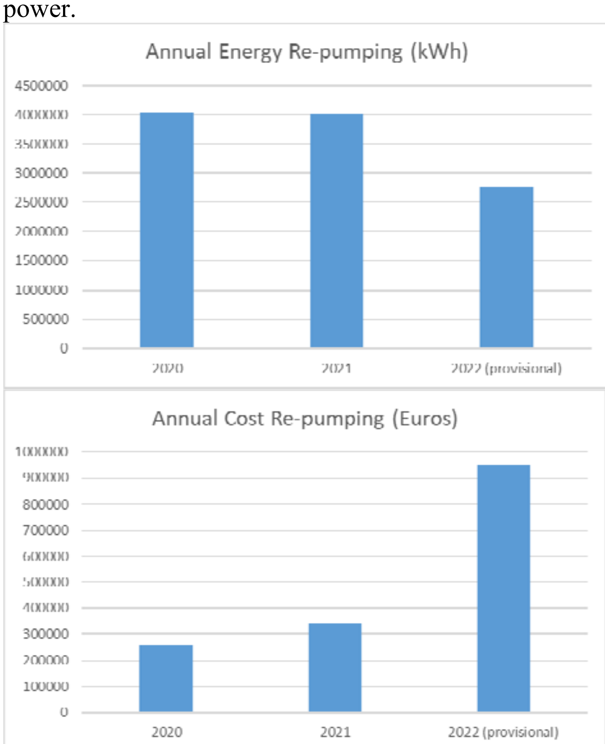

Fig. 3: Annual energy consumption and energy cost in Repumping system

The hourly consumption data were analyzed, drawing the load curve and the load duration curve of both systems. In the following, only the Repumping systems analysis is presented.

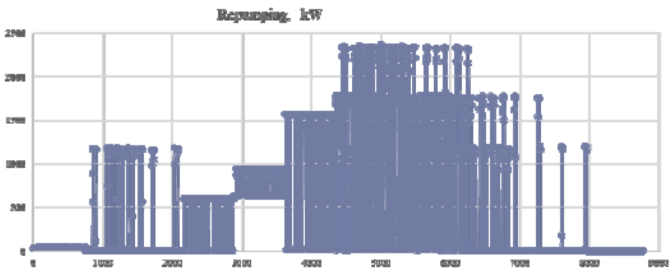

Fig. 4. Initial Load Curve of Re-puming system

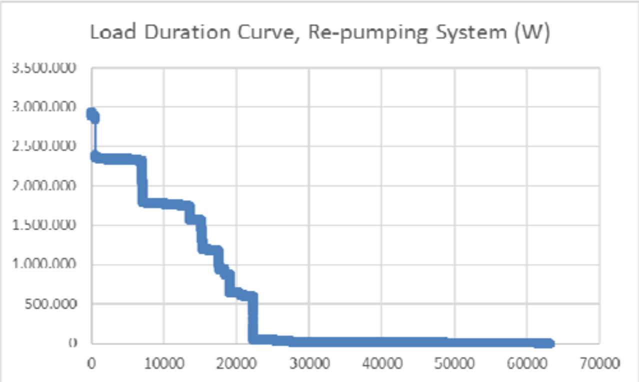

Fig. 5. Load Duration Curve of Re-pumping system

3. Selection of the type of photovoltaic generation systems Energy for Water

The convenience of a fixed panel system or systems with solar tracking will be assessed.

The convenience of a system of fixed panels or systems with solar tracking will be assessed. In particular, inclinations of 5 degrees and 38 degrees (the optimum for the chosen location), systems with horizontal axis tracking, polar axis tracking and two-axis tracking will be considered.

Figure 6 shows the annual production of 1kWp at the site, according to inclination or tracking system, and figure 7 show the monthly production. In figure 8 a more detail view of the summer months is presented.

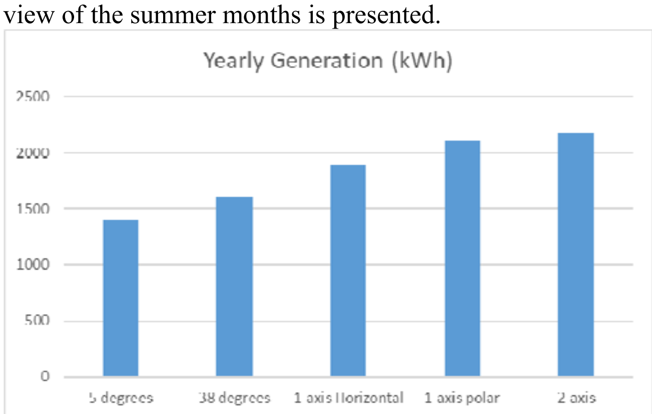

Fig. 6. Yearly production of 1 kWp for different slopes and tracking systems in Caspe (Zaragoza)

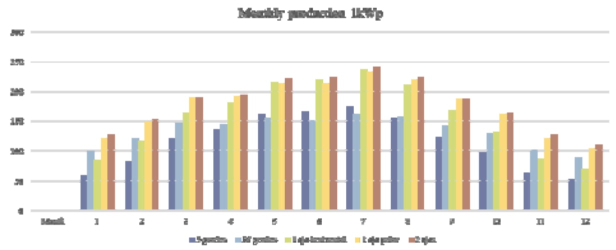

Fig. 7. Monthly production of 1 kWp for different slopes and tracking systems in Caspe (Zaragoza)

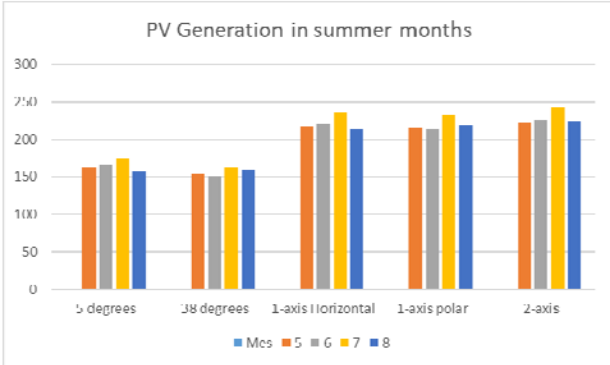

Fig. 8. PV generation in summer months for different slopes and tracking systems.

Figure 9 shows the production of 1kWp in the summer months. In the figure you can see the generation profile on a typical day in July. It can be seen that a tracking system is more convenient since the generalization profile is flatter than in fixed systems.

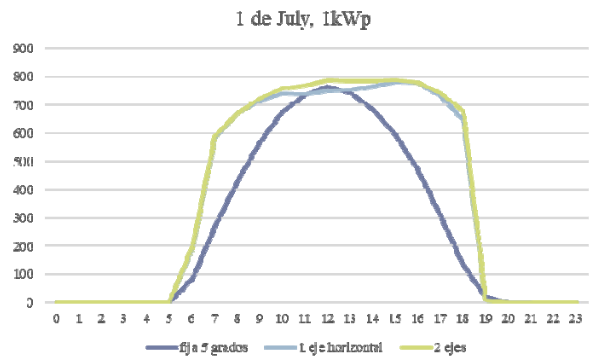

Fig. 9. PV generation de 1st of July of 1kWp for 5 degrees fixed slope, 1-axis tracking system and 2-axis tracking system.

From the previous figures it can be concluded that obviously with tracking systems we obtain more generation than with fixed systems, so less PV power (and space) will be required.

The shape of the hourly generation with tracking systems is much more convenient for the pumping installation than the fixed systems (wider and flatter curve).

In fixed systems, although a slope of 38 degree has higher annual production, in the summer months a 5 degree inclination is more convenient.

In tracked systems, in the summer months the horizontal axis system is more convenient than the polar axis and not much different than the two axis generation, but with much simpler technology.

To optimize self-consumption it is necessary to change consumption pattern. Until now, prices were cheaper at

night, but this has now changed. In particular, in this system it was possible to pump at times when the cost of electricity is cheaper (P6 period hours)
With self-consumption, we must try to consume when we have production, as much as possible. The figure 10 shows the new consumption curve in the re-pumping system, so that we ensure the same amount of water pumped but in a similar way to the photovoltaic production pattern.

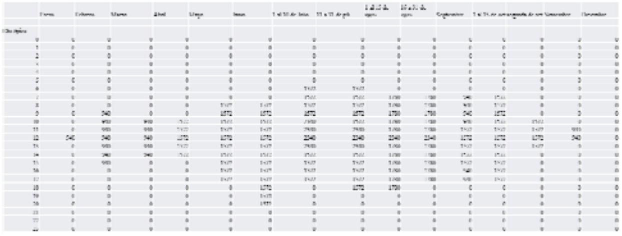

Fig. 10. Load curve of Repuming system adjusted to resource

In figure 11 the rescheduled load curve in the re-pumping system and energy generation of a single axis tracking system of 3MWp the 1st July is shown.

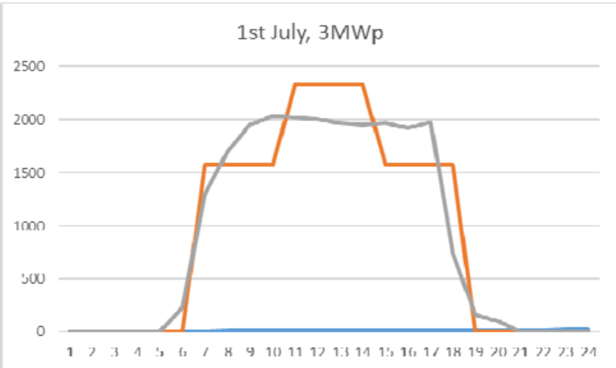

Fig. 11. Rescheduled Load curve in Re-pumping system and energy generation of a single axis tracking system of 3MWp the 1st July

With the rescheduled load curve, and the simulation of the hourly generation, an annual analysis of generation, grid purchase and surplus (kWh) is carried out for different nominal powers of the photovoltaic plant.
For the economic analysis, the following hypotheses are established:
Investment cost:
-0.85 euros/Wp in 1-axe horizontal solar tracking
-0.75 in fixed system with an inclination of 5 degrees
Electricity price, 0.1-0.3 euros/kWh
Production depreciation: 0.7% per year.
Maintenance costs: 15 Euros/kW and year
The most unfavorable case will be considered, which is that no income is obtained from the surplus energy that may be produced.
In what follows, the case of solar tracking to a horizontal axis is shown.

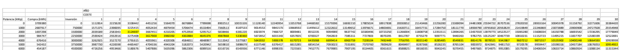

Fig. 12. Profitability based on size, single axis tracking system

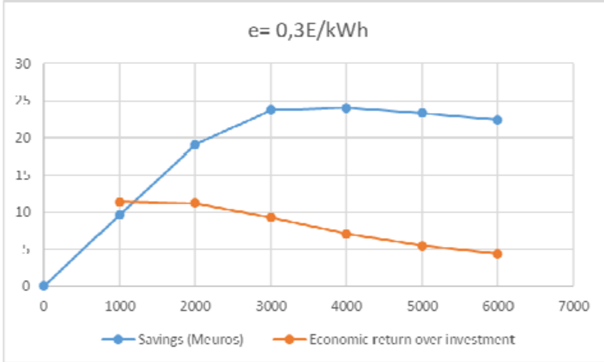

Fig. 13. Monetary savings (MEur) and Return over investment for several sizes of PV (kWp), single axis tracking system

From the figure 13 it can be deduced that if the cost of electricity is 30 Euros/MWh, the most convenient size of photovoltaic power to install is 3MWp, recovering the investment in just over two years and with a profit of 9 times the investment at the end of 30 years. About 5,5 hectares of land are required
Similarly, the study can be carried out for an electricity cost of only 10 Euros/MWh, although this case is considered unlikely. Again, the size that optimizes savings is 3MWp. In this case, the investment takes longer to recover (7 years), with a profit of the order of 2.
With a photovoltaic system with fixed panels inclined by 5 degrees, the power that maximizes savings is 4MWp, higher than in the previous case (with monitoring). The economic investment is recovered 7 times over the 30 years considered.

4. Conclusion

Several scenarios resulting from different photovoltaic technologies and demand management are designed, finally providing recommendations on the size of the most appropriate photovoltaic plant, as well as the associated economic profitability. The best option is the installation of PV system with one-axis solar tracking.

Acknowledgements

Grant TED2021-129801B-I00 funded by MCIN/AEI/ 10.13039/501100011033 and by European Union NextGenerationEU/PRTR.

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