A 360 KWP PV IRRIGATION SYSTEM TO A WATER POOL IN SPAIN

I.B. Carrêlo[1], R.H. Almeida[1,2], L.M. Carrasco[1], F. Martinez-Moreno[1], L. Narvarte[1]
[1] Instituto de Energía Solar - Universidad Politécnica de Madrid, 28031 Madrid, Spain
[2] Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal
*Phone: +34 913365531; E-mail: isaac.barata@ies.upm.es

ABSTRACT: This paper describes a 360 kWp PV water pumping system to an elevated water pool in a borehole named San Cristóbal of the Irrigator's Community of Alto Vinalopó, Villena, Spain. This system is able to work along the year, being the maximum need to satisfy in July. The goal of this paper is to show the design, the implementation of the system and some first results by analysing the monitoring done since 1st of June until the end of August. During this period, 173780 m3 of water were pumped and it was working more than 800 hours thanks to its north-south horizontal axis tracker.

Keywords: Design, Monitoring, Stand-alone PV Systems, Water-Pumping

1 INTRODUCTION

The use of photovoltaic (PV) generators for water pumping is not new [1], but with regard to irrigation at large-scale, it is innovative. Nowadays, the state of the art relating to irrigation in agriculture is based on power supply by the national electrical grid or by using diesel generators [2].

However, the rise of the electricity price (in Spain, for example, around 1250%, since 2008) [3], as well as the disappearance of the fossil fuels has forced the irrigators' communities to seek for alternatives.

As a result of this, photovoltaic water pumping systems appeared as a different way for supplying the irrigators needs.

Hence, some regional agriculture associations are intrigue by the opportunity of integrating large stand-alone PV pumping systems in their systems [4].

This paper illustrates the design (Section 2), the implementation (Section 3) and first results (Section 4) of a stand-alone PV water pumping system installed in a borehole named San Cristóbal of the Irrigator's Community of Alto Vinalopó, Villena, Spain.

2 DESIGN

2.1 System configuration

The PV irrigation system consists of a submersible pump of 250 kW (Caprari - E12S55FUS/10A+ MAC 12340 /1C/DF/V-8) in a 400m-deep borehole that provides a daily peak water flow of 226 m^3/h powered by a 360 kW_p PV generator. .The water pumped during the day is accumulated in a water pool of 173000 m^3, elevated 12 meters from the ground. As the pump is installed at 300 m, and the dynamic level of water in the well at maximum water flow, Q_{max}, is 257 m. The total manometric head is 269 m.

To be able to irrigate more hours a day, the PV generator has a north-south horizontal axis tracker divided in 18 rows with 80 panels each one (2x40). This system includes a frequency converter of 355 kW (OMRON A1000 CIMR-AC4A0675AAA), able to transform the direct current (DC) generated by the PV modules to alternating current (AC) at a variable frequency, allowing the pump to work at different frequencies according to the available power. This system also includes an external Programmable Logic Controller (PLC) which plays an important role for the proper functioning of the system (See figure 1).

It is also installed a datalogger system, that not only saves and send by internet the status of each variable from the PLC and frequency converter (by Modbus - serial) but also allows the Irrigator's Community to know the real status of the system by seeing its touch screen.

Since there is no electrical grid connection, in order to fed all the auxiliary charges (monitoring and control systems), it was installed a stand-alone PV system with batteries. This system has a nominal power of 1.5 kW and a total capacity of 32.9 Wh (up to 6 days of autonomy).

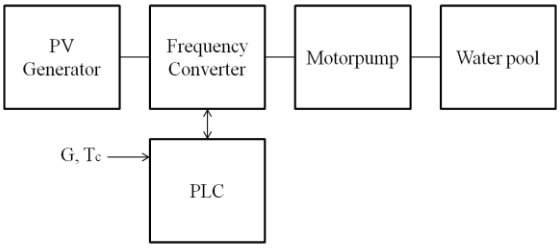

Figure 1: System configuration

2.2 System operating logic

Regarding the control of the system it is important to make a difference between normal and deviant working conditions.

Normally, the PLC is always estimating the available PV power, through the measurement of the irradiance and cell temperature that is possible to get from a reference module which is installed in the tracker, side by side to the rest of modules. Once this estimated PV power is equal or higher than a threshold that allows the pump to work, the PLC gives the run signal to the frequency converter and the system starts pumping water to the water pool.

From this moment, the PLC will execute a Maximum Power Point Tracking (MPPT) routine (which maximizes and improves the efficiency of the PV production), by estimating the set point voltage and sending it to the frequency converter in order to work in this condition.

However there are some deviant conditions that can occur and are expected in the logic of the system.

The first is the instability that occurs due to passing clouds. When the clouds pass over the PV generator, the irradiance reduces and for this reason the current

provided by the panels also decreases ($G \sim I_{DC}$). Hence, the V_{DC} falls down and the frequency converter may have an error [5] [6]. In this installation this does not occurs because there were developed algorithms to avoid this problem decreasing the effect of power intermittences due to clouds in the overall system performance.
There are four more abnormal conditions that are predicted in this system: the motor overheating, empty engine, leakage current and the measure of the isolation of the PV generator. In all of these situations there are installed sensors that give information by analog or digital signals to the PLC. Once the PLC receives these information and "knows" what is happening, sends a stop signal to the frequency converter and does not reset until the problem is solved. Through the screen the user may know what the problem is.

3 IMPLEMENTATION

In order to have a better visualization of the overall system under analysis, the following figures illustrate its main parts. In the figure 2, it is possible to see half of the PV generator oriented to East, in the morning.

Figure 2: PV Generator

The following figure is the reservoir to where the water is pumped. From this waterpool, the water falls by gravity to others reservoirs that the irrigator's community has. Our system has no control of the water that is in the waterpool, pumping all the water possible, since the frequency of the pump is variable (from 38 to 45.5 Hz).

Figure 3: Waterpool

The next figure presents the building where are all the electronic, control and monitoring devices. It is possible to see the stand-alone system installed in the roof.

Figure 4: Building with electronic, control and monitoring system.

Inside this building it is the frequency converter (figure 5). On the right side of the frequency converter, there is another frequency converter in charge of connecting an external fan in case of the temperature inside the box surpasses a specified level.

Figure 5: Frequency Converter

Also inside of the building, in a box, it is installed all the control system (marked in blue) and the monitoring system (marked in orange), that can be seen in the next figure.

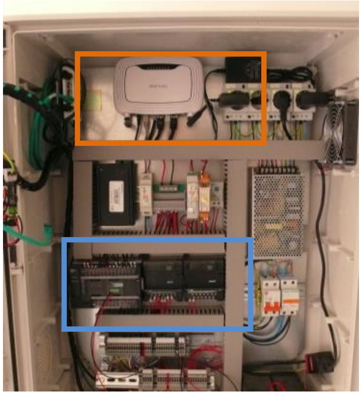

Figure 6: Control (in blue) and monitoring system (in orange)

4 FIRST RESULTS

Regarding the results presented in this paper, an analysis for 92 days (from 1st June to 31st August) is performed. Due to a monitoring problem in one of the days (the file was corrupted), only 91 days are taking into account.
In the next figure it is possible to verify the behavior of the pumping system for a clear sky day.

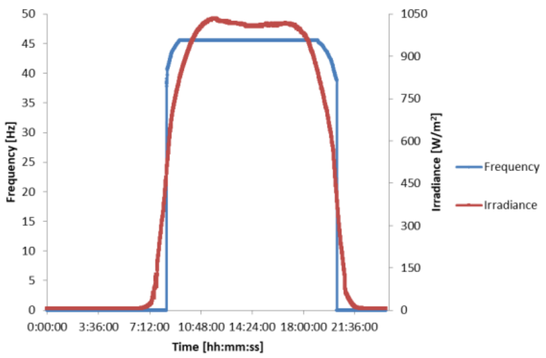

Figure 7: Pump Frequency related with the irradiance received by the PV generator (2nd June 2017).

As it was referred before, when the estimated power surpass a certain threshold, the PLC gives the run order to the frequency converter. This estimated power was adjusted *in situ* in order not only to verify that no error occurs when the system starts to pump but also to optimize the operation of the system, guaranteeing more pumping time. Regarding the maximum frequency, 45.5 Hz were applied in this system due to the dynamics of the well.
According to these 91 days, the volume of pumped water was 173780 m^3 during 823 hours. It is important to refer that if for any reason the pump stop, it will be in that condition for more 8 minutes, in order to empty the tubing. Taking into account the water pumped and the working hours, the average water flow rate is 211.2 m^3/h.
The energy consumed in DC (before the frequency converter) is 203370 kWh and the AC energy is 199690 kWh.
Table I summarizes these monitoring results.

Table I: Monitoring results

Variable	Unit	Value
Pumped Water	[m^3]	173780
Irrigation Hours	[h]	823
Q_{avg}	[m^3/h]	211
AC Energy	[kWh]	199690
DC Energy	[kWh]	203370

From these values it is possible to get the frequency converter efficiency, 0.98 (Table II).
Besides the frequency converter efficiency, having the hydraulic energy, it is also possible to calculate the motorpump efficiency, 0.62 (Table II).
The performance ratio (PR) is one of the most important variables to do an evaluation of a PV system. It is expressed by the ratio between the AC energy yield and the theoretical energy production by the PV generator. In this paper, it is made a distinction between two electrical PR. The difference is in the denominator of the equation. While PR considers all the theoretical energy PV production, the PR_{I-H} only considers the PV energy production when the system is pumping. For that reason PR_{I-H} is greater than PR (0.75 and 0.64, respectively).

Table II: Values resulting from the monitoring system

Variable	Value
PR	0.64
PR_{I-H}	0.75
η_{MP}	0.62
η_{FC}	0.98

5 CONCLUSIONS

The results show that the demonstrator has been working in accordance to the initial expectations. More working time is needed to fully demonstrate the long-term viability of the solution but the first results have been showing a high reliability and performance – it can be mentioned that, on average in the 91 days, the system was able to pump nearly 2000 m^3 per day.

6 ACKNOWLEDGEMENT

This work has been possible thanks to the funding from the European Union's Horizon 2020 research and innovation programme in the project MArket uptake of an innovative irrigation Solution based on LOW WATer-ENergy consumption (MASLOWATEN), under grant agreement nº640771, as well as the financial support by MIT Portugal Program on Sustainable Energy Systems and the Portuguese Science and Technology Foundation (FCT), grant PD/BD/105851/2014 to Rita Hogan Almeida.

7 REFERENCES

[1] R. Enochian, "Solar-and Wind-Powered Irrigation Systems", United States Department of Agriculture, Economic Research Service, Agriculture Economic Report Number 482, 1982.
[2] J. Carroquino, R. Dufo-López, J. L. Barnal-Augustin, "Sizing of off-grid renewable energy systems for drip irrigation in Mediterranean crops," Renewable Energy, Vol 76 (2015) 566-574.
[3] Grant Agreement number 640771 – MASLOWATEN, European Commission
[4] J. Munoz, J. Carrillo, F. Martínez-Moreno, L. Carrasco and L. Narvarte, "Modeling and simulation of large PV pumping systems," in Proceedings of the 31th European Photovoltaic Solar Energy Conference and Exhibition, Hamburg, 2015.
[5] L. Narvarte, E. Lorenzo, M. Aandam, "Lessons from a PV pumping programme in south Morocco" in Progress in Photovoltaics Research and Applications 13, 261–270, 2005.
[6] J. Fernández-Ramos, L. Narvarte, F. Poza-Saura, "Improvement of photovoltaic pumping systems based on standard frequency converters by means of programmable logic controllers" in Solar Energy 84, 261–270, 2010.