PERFORMANCE OF A 40 KWP PV IRRIGATION DEMONSTRATOR COMBINING VARIABLE AND CONSTANT PRESSURE PUMPING

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ABSTRACT: This paper describes a 40 kWp PV irrigation system combining variable frequency and constant pressure pumping installed in Sardinia, Italy. The objective of this paper is to present the design, as well as the implementation of the system. Moreover, monitoring data from 2017 irrigation season, from June to the end of October is analyzed and some first results are presented. During this period, the PV irrigation system pumped a total of 20574 m^3.
Keywords: Design, Monitoring, Stand-alone PV Systems, Water-Pumping

1 INTRODUCTION

Nowadays a huge part of the irrigation systems are fed by the national grid or from diesel generators [1]. However, the rise of the conventional energy price [2] increased the need for an alternative by using renewable energies [3], such as the solar energy. A H2020 project named MASLOWATEN [4] recommends solutions, and includes the installation of 5 real scale photovoltaic irrigation systems (PVIS) as a way to answer the irrigators' needs [5], [6], [7], [8]. There are 4 criteria that we consider as crucial in order to be considered as a PVIS. First, the system should be able to surpass passing clouds without destabilize. Second, the PVIS should be designed regarding the preexistent irrigation system. Third, the PV production should be similar to the irrigation demand. And finally, its reliability must be assured in order to work for at least 25 years.

This paper is about one of these PV Irrigation Systems that is installed in Sardinia, Italy.

The aim of this paper is to present the design (Section 2), the installation (Section 3) and first results (Section 4) of the last irrigation season (2017) from June to October.

2 DESIGN

2.1 System configuration

The system is located in the farm Sarciofo, Uri, 15 km Southwest from Sassari, Italy. It is a 5.4 hectares dedicated to the ecological cultivation of artichoke. In this case, a previous system was already installed. This was composed by two wells with 4 and 3 kW submersible pumps (from now on, well nº1 and well nº2) elevating water to the same 2000 m^3 water pool. The irrigation can be done by gravity or by using a third horizontal surface centrifugal pump of 4 kW to irrigate through low-pressure sprinklers.

The new system was designed to feed the three pumps on the farm with a 40 kWp PV generator, organized in 8 strings of 20 modules (160 PV modules). These modules are mounted in a North-South horizontal axis tracker - 2 STI-H160 (single row).

The pump of well nº1 – P1 (originally 4 kW) was replaced by a new 18.5 kW submersible pump (Caprari E6SX50/14A+MACX625B-8V). In order to allow the installation of a larger pump, the owner widened and protected the borehole walls with a new tube, achieving an increase in capacity. In order to get the confidence of the user, the system is allowed to feed the pump both from the PV system and from the previous system (electrical grid), switching manually according to the user decision. In both cases the power is supplied by a 22 kW frequency converter (OMRON 3G3RX A4220-E1F).

In the well nº2, the original pump 2 – P2 (Caprari E4XP35 / 27 + MCH44-8V) has been kept. This pump can be supplied from both the solar system with a 5.5 kW frequency converter (OMRON 3G3RX A4220-E1F) or directly from the grid.

The original irrigation pump – P3 (4 kW) was replaced by a 7.5 kW pump (Caprari MEC-MR65-3 / 2C+ FELM 7.5 kW) able to provide 50 m^3/h at 25 m. This pump can be powered from the solar system by an 11 kW frequency converter (OMRON 3G3RX A4110-E1F) or from the grid with a soft starter.

Figure 1 includes the main components of the system (in green the new system, in orange the previous system).

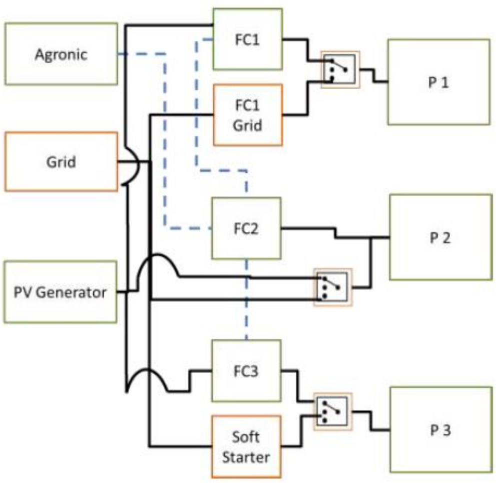

Figure 1: Current irrigation system

2.2 System operation logic

Regarding to the control and operation logic of the system, this system is considered a standalone PV irrigation system. So, it was necessary to create an operating logic control based on the available PV power and the end-user irrigation needs. If there is no irrigation, only P1 and P2 will work. Otherwise, three pumps can work simultaneously according to the available PV power. Table 1 shows the system operation logic according to the user's need to irrigate based on the available PV power.

Table I: Operation of the system when there is an irrigation program

	Increase in PV power	Decrease in PV power
	P1, P2, P3	P1, P2, P3
14.5 kW		
	P2, P3	P1, P2, P3
13.5 kW		
	P2, P3	P2, P3
9.0 kW		
	P2, P3	P2, P3
8.8 kW		
	P2, P3	P2, P3
8.7 kW		
	P3	P2, P3
8.0 kW		
	P3	P3
7.5 kW		
	P2	P3
7.0 kW		
	OFF	P2
2.8 kW		
	OFF	OFF

As it can be seen, hysteresis logic was programed to avoid the continuous stop and start of the pumps due to small variations of the PV power.

For the borehole pumps (P1 and P2) a master-slave configuration has been implemented. FC2 (master) does a Maximum Power Point Tracking routine and FC1 (slave), when is pumping, follows the frequency of the master. FC3 does a pressure control routine, being able to work in three different pressure set-points (2.5, 3 and 3.5 bar) according to the irrigation sector. All frequency converters have passing cloud routines.

3 IMPLEMENTATION

In order to have a better picture of the overall system under analysis, the next figures show the real system. Figure 2 shows the PV generator and its integration on the field.

Figure 3 shows an inside view of the building with the 4 frequency converters (marked in green) and the monitoring (marked in orange).

Figure 4 shows the 2000 m^3 intermediate water tank, between the borehole pumps and the irrigation system, and Figure 5 the low-pressure sprinklers installed in order to save energy.

Figure 2: PV Generator

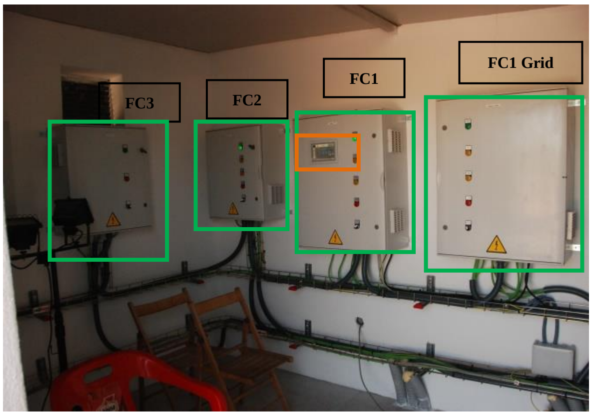

Figure 3: Inside view from the building with electronic, control and monitoring system

Figure 4: Water tank

Figure 5: Low pressure sprinklers

4 FIRST RESULTS

The first results presented are based on monitoring data recorded in the months of June, July, August, September and October 2017 (the last irrigation season). The irrigation period was from June to October, being the highest irrigation needs in July and August (around 6 hours a day). The annual irrigation hours of P3 with PV, were 519, while the boreholes pumps worked for 1902 h. This year was really dry and the nearest lake which feeds most wells in the area was almost without water. This has led local authorities to limit the use of water. Even so, in August, P1 worked, on average, 14.56 hours a day and P2 worked 10.76 hours. These almost 15 hours of use of the P1 cannot be all provided by the PV generator and mainly because of that the PV penetration in this month was 69%.

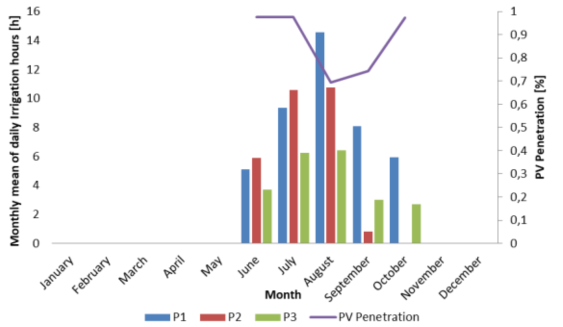

Figure 6: Pumps working hours per day in each month and PV penetration

Figure 6 also shows the PV penetration along the year. In 2017 irrigation period the PV penetration was 87%.

The irrigation pump worked for 683 hours and the borehole pumps for 1323 and 830 hours (P1 and P2), which means a total volume of water of 25695 m^3, 3849 m^3 and 20574 m^3, respectively for P1, P2 and P3.

In table II, it is possible to verify a summary of the measured data.

Based on the measured irradiance presented in Table III, two performance ratios are calculated: the typical one and one that only considers the irrigation hours. The typical PR is 0,16, while the PR during irrigation hours (PR_{I-H}) is 0,37 (see Table IV). These values are low but can be justified by conditioned by the low utilization ratio caused by the lack of water.

Table II: Measured data and first results

Variable	Unit	Value
Total volume of irrigation water	[m^3]	20574
Total volume of pumped water	[m^3]	29545
PV water flow penetration	[%]	87

Table III: Irradiation

Irradiation	Value [kWh/m^2]
Total irradiation	2181
Irradiation during irrigation hours	956

Table IV: Performance ratios

Performance ratio	Value [ ]
PR	0,16
PR_{I-H}	0,37

Until here, only global values were presented. To better know the way the PV system works, the following figure represents a typical daily profile of irradiance and frequency of both pumps.

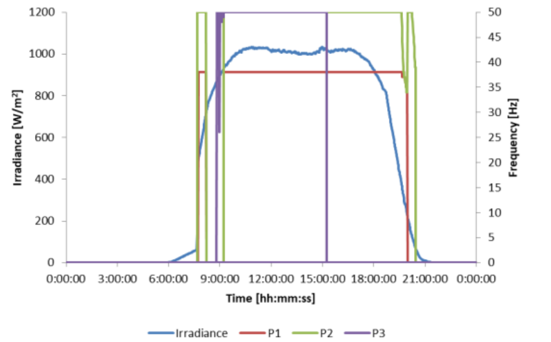

Figure 7: Pumps frequency related with the incident irradiance (3rd June 2017)

As it can be seen both pumps, P1 and P2, started to work at 7h41. They stopped 20 minutes later because they filled the water tank. At 8h49, according to the farmer desire, it starts to irrigate (P3 starts to work) until 15h14. In the meantime the others two pumps worked as well. In fact, P1 works until 19h58 and P2, 30 minutes more. It is interesting to see that at the end of the day P2 starts to regulate the frequency until 34 Hz until P1 stops. After that, having more available PV power, the frequency of P2 returns to 50 Hz.

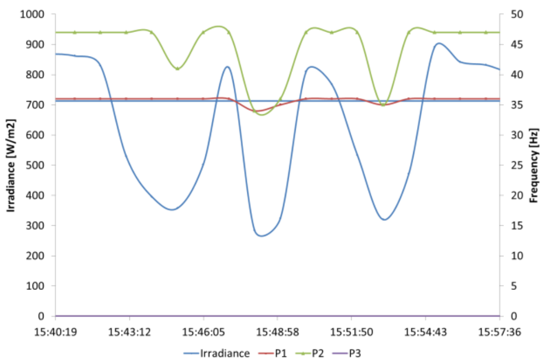

Figure 8: Passing clouds during 17 minutes (22nd September 2017)

In this demonstrator was implemented the algorithm that allows the system to surpass the passing clouds without destabilizing. In figure 8, it can be seen this occurrence. During the 17 minutes the irradiance is varying however the frequency converters do not stop. They are able to surpass these variations.

5 CONCLUSIONS

2017 was a very dry year and, accordingly, the user does not have all the water the user wants to irrigate. For example, July and August were the months in which the irrigation needs were higher.

Regarding the performance of the PV irrigation system, the electric PR during irrigation hours in the highest water-demanding months reached 0.39The PV Irrigation System has shown a good performance - PRs values were conditioned by the low utilization ratio caused by the lack of water.

The control made between the three pumps worked as expected. This allowed a total annual volume of water pumped of 50119 m^3 by the three pumps.

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