LARGE-SCALE HYBRID PV-GRID IRRIGATION SYSTEM

R.H. Almeida[1,2], I.B. Carrêlo[1], 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: rita.hogan@ies.upm.es

ABSTRACT: This paper describes a 120 kWp hybrid PV-grid irrigation system at constant pressure, which has been installed in a 233 ha farm devoted to the intensive cultivation of olive trees in Tamelelt, Morocco. The description includes important information regarding system configuration, working control and implementation. In addition, monitoring data between July 18 and August 31, 2017, is analyzed and first results presented. The system has been working according to the initial expectations since July 2016 and in the 45 days currently under analysis, the number of irrigation hours were 251, being 71% the PV penetration. The PR of the system is 0,33, while the PR during irrigation hours increases to 0,69.
Keywords: Hybrid, PV Pumping, Water-Pumping

1 INTRODUCTION

Agricultural irrigation is a highly consumer of electricity and water. Accordingly, MASLOWATEN, a H2020 project [1], proposes some innovative solutions, less water and energy dependent, as well as the installation of 5 real scale systems for different irrigation applications to show its long-term viability. Therefore, four photovoltaic (PV) systems were installed in the South of Europe (2 in Spain, 1 in Portugal and 1 in Italy) and one in Morocco. This paper will be about this last system.

Morocco has an electrical consumption for water productive applications of 587 GWh, the 20,3% of the total electricity consumption for productive activities with 7% of yearly increase. The electrical consumption for irrigation in this region is estimated to yield 2500 GWh/year. This leads to a current potential market of 1,5 GW of large PV pumps, which represents a potential market volume of 2250M€, with an expected increase in the range of 7%-11% per year.

Worldwide, the high cost of electricity is encouraging the reduction or even elimination of the grid consumption [2]. This leads to the increase in the use of photovoltaic solutions [3], [4].

This paper will present the design (Section 2), implementation (Section 3) and first results (Section 4) of a 120 kWp hybrid PV-grid system for drip irrigation installed in Morocco. Finally, some conclusions (Section 5) are summarised.

2 DESIGN

2.1 System configuration

The system was installed in Tamelelt, Morocco, in a 233 ha farm devoted to the intensive cultivation of olive trees. This farm belongs to ELAIA, and the annual irrigation needs goes from March to December every year, being the months with highest consumption May and June.

A previous system was already installed and included two centrifugal surface pumps of 45 kW for irrigation at constant pressure (4.2 bar), operating at 50 Hz driven by soft starters powered from the national grid.

The farm is divided in eight sectors and the irrigation is done in 4 different shifts, each one with two sectors. The area irrigated in each shift varies from 56 to 59,8 ha and the water flow from 368,3 to 393 m^3/h.

The design of the PV system was done taking into account the characteristics of the irrigation system already installed and simulations were done using SISIFO [5], 6].

The new and current system includes a PV generator of 120 kWp, electrically divided into two equals fields of 60 kWp, each one feeding one frequency converter of 55 kW (Omron 3G3RX-A4550) - which replaces the previous soft drivers - and the 45 kW pumps (Caprari – MEC-AS4/125C+ FELM 45KW 4P) .

It is important to mention that the 120 kWp are a combination of 480 PV modules of 250 Wp, organized in 24 strings of 20 modules. These PV modules are mounted in a North-South axis tracker, occupying only 0.15% of the total available area.

Now, each frequency converter is fed both by the PV generator and the grid. Accordingly, three operating modes are available: PV mode, hybrid PV-grid mode, and grid mode.

In addition to the previous components, the system also includes a Programmable Logic Controller (PLC) – which made the communication between photovoltaic and irrigation parts of the system, a monitoring system with a touch screen, an irrigation automatism (Agronic 4000, from Progres), a filtration system with automatic cleaning, a fertirrigation system with two auxiliary pumps and a pump filling water from the fertirrigation tanks. The first two components mentioned were added to the system with the installation of the PV components. All these auxiliary loads are fed from the grid.

Figure 1 includes the main components of the system.

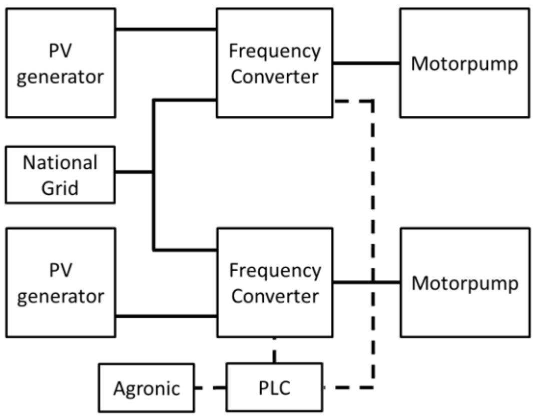

Figure 1: System configuration

2.2 System operating logic

The control of the system is done through the irrigation and photovoltaic controllers, Agronic and PLC accordingly. In normal operating conditions, the irrigation controller sends a signal to the PLC when there is a need to irrigate. At this time, the PLC sends a run signal to both frequency converters and the system starts to work.

The initial idea was that according to the end-user desire, the grid can be connected or disconnected to the frequency converters, i.e., there is a contactor in each frequency converter that can be opened and grid is not used. This can be very useful to avoid grid consumption in high price periods. In this case, if there is not enough PV power, the PLC will send a signal to the Agronic to temporally stop irrigation. Despite having this possibility, the end-user decided to be all the time connected to the grid, no matter the available PV Power.

The selection of the operating mode is done automatically according to the PV power available on each moment. This PV power is calculated in the PLC based on the measured data of irradiance and cell temperature of a calibrated solar cell installed in the PV tracker.

Accordingly, three operating modes are available:

- PV mode: if the PV power is enough to fulfill the required load, the power consumption from the grid is null;
- Hybrid PV-Grid mode: if the PV power is not enough, the grid will inject the correspondent lack of PV power to maintain the pressure in the irrigation system;
- Grid mode: if the PV power is null, the system is totally fed by the grid (like in the previous system, but now using the frequency converters instead of the soft starters).

The two frequency converters work in a master-slave mode, i.e., one of the frequency converters (the master) control the pressure in the irrigation system and sends a digital signal (representing the frequency) to the other frequency converter (the slave). It is important to note that a specific algorithm has been implemented to maximize the use of PV production.

It should also be mentioned that if there is no water on the water tank, if there is some pressure issue (pressure higher or lower than the expected one), or if one or both frequency converters have some type of mal-functioning, the PLC will send a signal to Agronic and irrigation program will be stopped.

3 IMPLEMENTATION

The PV system was installed in the field in July 2016. This means that it has been working in half of the last irrigation campaign (2016 one) and in the current one.

In order to have a better understanding of the system, the following figures include the olive tree plantation (Figure 2), the integration of the PV generator on the plantation (Figure 3), the engine room (Figure 4) and the set of pumps (Figure 5).

Figure 2: Olive tree plantation.

Figure 3: PV generator.

The engine room includes all the components that can be seen in the next figure plus the irrigation controller. The two frequency converters are in the electric boards on the ground (the master on the right and the slave on the left), while the upper board has the PLC inside and the touch screen on the door. On the left wall, the big box is the DC protection box and the small ones are related to the monitoring system.

Close to the engine room, there is the pumping room, where one can find all the additional components mentioned in Section 2. Figure 5 shows only the set of pumps.

Figure 4: Engine room.

Figure 5: Set of pumps.

4 FIRST RESULTS

The results presented in this section were obtained from data recorded between July 18 and August 31, 2017 (45 consecutive days).

During this period, the irrigation time was 251 hours, which means 92433 m^3 of pumped water and an average water flow of 368,5 m^3/h.

The PV system was able to produce 16342 kWh of DC energy, converted in 15383 kWh of AC energy. The frequency converter also registers the DC power in the DC bus, which is, in fact, the sum of the instantaneous power coming from the grid and coming from the PV generator. Since this last value is also being measured, the PV penetration, i.e., the percentage of power/energy that is coming from the PV generator is calculated. During the period under analysis this penetration is 71%, which also means that the equivalent quantity of water extracted with PV is 65609 m^3. Table I summarizes these results.

Table I: Measured data and first results

Variable	Value
Irrigation hours [h]	251
Volume of pumped water [m^3]	92433
Volume of pumped water from PV [m^3]	65609
Average flow [m^3/h]	368,5
DC energy from PV [kWh]	16342
AC energy from PV [kWh]	15383
PV penetration [%]	71

The previously mentioned measured data, plus irradiation (see Table II) and nominal peak power (120 kWp), also allows the calculation of the performance ratio (PR) of the system. In addition to the typical PR of a PV system, a specific one for irrigation applications is also presented. This last one only considered AC power and irradiance during irrigation hours. The typical PR in this time interval is 0,33, while the PR during irrigation hours (PR_{I-H}) is around the double, 0,69 (see Table III).

Table II: Irradiation

Irradiation	Value [kWh/m^2]
Total irradiation	385,4
Irradiation during irrigation hours	184,5

Table III: Performance ratios

Performance ratio	Value [ ]
PR	0,33
PR_{I-H}	0,69

Until this point, only global values were presented. To a better understanding of the system working along a specific day, two particular days are presented in Figures 6 and 7, representing the first one a clear day and the last one a cloudy day. Irradiance as well as the frequency of the master pump are plotted (it should be mentioned that the frequency of the slave pump has exactly the same behavior of the master one and for that reason it is not included in the figure).

It can be seen that, in both figures, the frequency remains constant no matter the variations in irradiance and, accordingly, in the available PV power. This is particularly noticeable in the case of the cloudy day (Figure 7).

Since drip irrigation systems have high requirements regarding both constant pressure and flow, the variability of the PV power along a day maybe a threat.

The main advantage of a hybrid PV-grid system like this one, with hybridization in the electric part, is its reliability due to its robustness to a variation in irradiance and consequently in PV power. In fact, the frequency converter will always receive their needed power, being the only difference the percentage that is coming from the PV and from the grid. Consequently, the irrigation part of the system will see no variation in pressure and flow due to clouds.

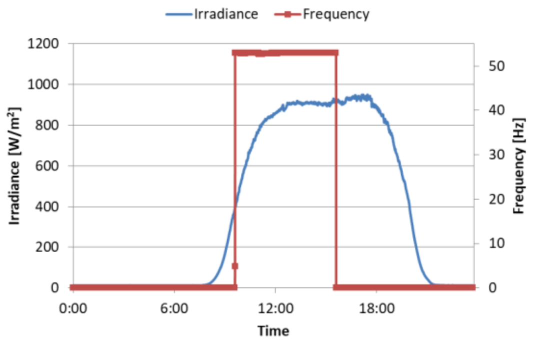

Figure 6: Irradiance and frequency of the master pump in a clear day.

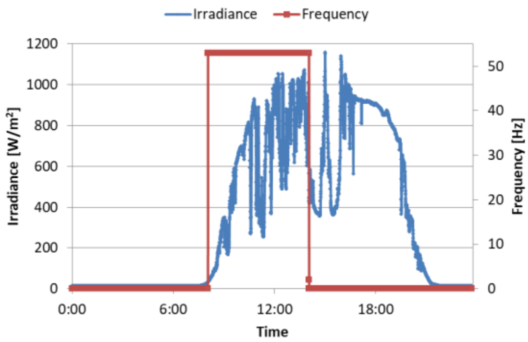

Figure 7: Irradiance and frequency of the master pump in a cloudy day.

Still keeping in mind the two particular days under analysis, it is worth mentioning that the PV penetration in the cloudy day is 62%, while in the clear day this value increases to 82%.

5 CONCLUSIONS

Considering the high requirements of pressure and flow of drip irrigation systems like the one under analysis, the PV-grid hybrid solution implemented guarantees a high system reliability.

During the 45 days under analysis, a 71% of PV penetration is achieved in the 251 hours of irrigation. This corresponds to a little more than 92000 m3 of pumped water and a PR during irrigation hours of 0,69.

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