A 140 KW HYBRID PV-DIESEL PUMPING SYSTEM FOR CONSTANT-PRESSURE IRRIGATION

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ABSTRACT: This paper describes a 140 kWp hybrid PV-diesel pumping demonstrator for constant pressure irrigation in a 200 ha olive tree plantation at Herdade de São Bernabé, Alter do Chão, Portugal. The PV system was installed in June 2016 and has been working since then. A previous system fed exclusively by a diesel generator was already implemented, and the PV part was added, maintaining unchanged all the irrigation part of the system. The new system configuration and control logic, as well as the implementation in the field, are detailed in this work. The first results obtained from monitoring data during June, July and August 2017 show that 125760 m3 were pumped (55179 m3 with photovoltaic) during 590 irrigation hours. The PR during irrigation hours is 0,42 and PV penetration 43%.
Keywords: Hybrid, PV Pumping, Water-Pumping

1 INTRODUCTION

The majority of agricultural irrigation systems are currently based on electricity from the grid of from diesel generators [1]. However, the increasing price of the energy from these sources [2], [3] boosted the development of alternative solutions using renewable energies, namely photovoltaic solar energy [4], [5].

These new solutions create new problems associated with the variability of the solar resource [1], both along the day and along the year, which leads to instability in the control and lower efficiencies, as well as problems in the hydraulic system [6] and in constant pressure irrigation plants. The system under study has robust algorithms in the standard frequency converters, programmable logic controllers and irrigation automatisms that minimized these problems.

Regarding these PV solutions, if the number of irrigation hours is higher than the number of sun hours, it is necessary to have a hybrid solution. This means that the cost of diesel or grid can decrease but cannot be eliminated. These systems can be hybridized in the electric or in the hydraulic part of the system [7]. In this particular case, a hydraulic hybridization is done.

This paper presents the design (Section 2), implementation (Section 3) and first results (Section 4) of a 140 kWp hybrid PV-diesel system for drip irrigation. Finally, some conclusions (Section 5) are summarised.

2 DESIGN

2.1 System configuration

The system was installed in a previously diesel powered drip irrigation system in Alter do Chão, Portugal. It is a 200 ha farm devoted to the super-intensive cultivation of olive trees. The annual irrigation needs of the farm goes from May to October every year.

As far as the irrigation part of the system is concerned, the farm is divided in 30 sectors, combined in 7 different shifts. The set point pressure is 5,7 bar and the working flow varies between 200 and 240 m^3/h.

The PV generator system and all its components were added to a previously installed irrigation system with a diesel generator, an irrigation automatism (Agronic 4000), a frequency converter (Diesel FC) and a soft-starter, as well as two centrifugal pumps (see Figure 1).

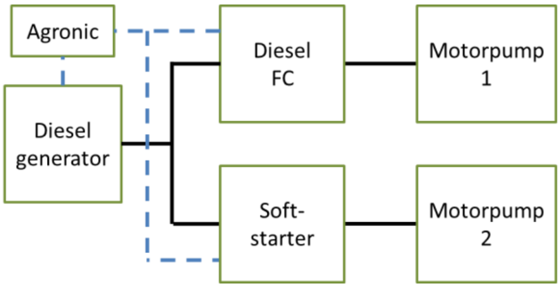

Figure 1: Previous system configuration

In order to partially substitute the diesel consumption, the current system (Figure 2) includes a 140 kWp PV generator using a North-South horizontal axis tracker. The PV generator feeds two 55 kW frequency converters (Omron 3G3RX-A4550). Each of this FC is electrically connected to a 45 kW centrifugal pump (Caprari MEC-MRS 100-2D 45 kW).

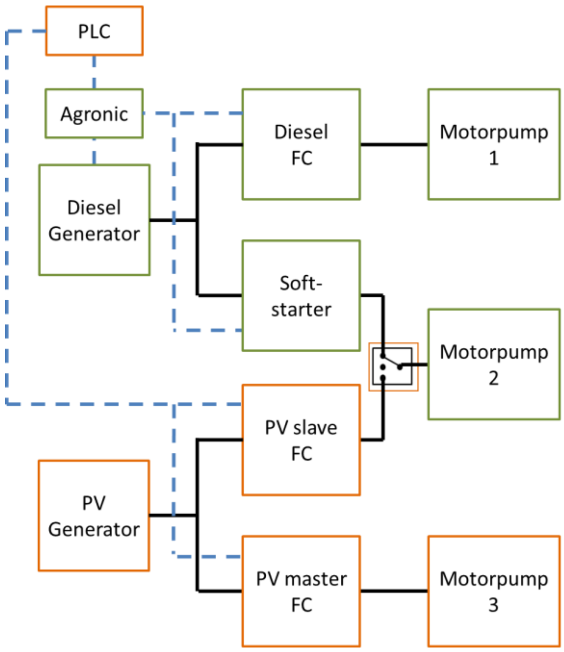

Figure 2: Current system configuration – the new components of the system are marked in orange, while the previous ones are marked in green.

As one can see, two additional FC (PV master FC and PV slave FC) were added but only one pump (motorpump 3). The pump previously fed by the soft-starter (motorpump 2) can now also be fed by the PV generator. A contactor was added before this pump to allow the change of energy source. The new components of the system are marked in orange, while the previous ones are marked in green.

Moreover, a programmable logic controller (PLC) was also added to the system, as well as a monitoring system. This PLC controls the three different operating modes that the system is currently able to work - PV, hybrid and diesel.

A 1 kWp stand-alone PV system with storage capacity is included to feed auxiliary loads, namely the PLC and the Agronic.

2.2 System operating logic

The control of the system is done by means of the PLC and the irrigation automatism. When the irrigation automatism sends a signal of irrigation to the PLC, this one calculates the instantaneous available PV power after checking the irradiance and cell temperature.

Table I includes the PV power thresholds (with hysteresis) for the three operating modes.

Table I: Power thresholds with hysteresis for the different operating modes - PV, hybrid and diesel

	Increase in PV power	Decrease in PV power
	PV	
105 kW		
	Hybrid	PV
95 kW		
	Hybrid	
55 kW		
	Diesel	Hybrid
45 kW		
	Diesel	

If the available PV power is enough to irrigate at the pressure set point, the PLC sends a run signal to both PV frequency converters. The PV master FC will regulate its output frequency according to the pressure set point value, while the PV slave FC will follow the frequency of the master through an analog signal.

Otherwise (i.e. if there is not enough power to work 100% with PV energy), the system can work in hybrid or diesel mode. In both of these last modes the diesel generator needs to be connected and for that reason the PLC sends a digital signal to the Agronic that will “inform” that it is necessary to connect the diesel generator. With the available PV power, PLC is also able to select between hybrid and diesel mode – if there is enough power for one pump to work with photovoltaics, the system will work in hybrid mode, if there is not it will work on diesel mode.

In the hybrid mode, the control of the pressure is done by the diesel frequency converter, while the PV master FC works in a maximum power point tracking (MPPT) routine.

In the diesel mode, the diesel FC controls the pressure and the soft-starter is also working.

It is important to note that the current system includes three pumps, although only two can work simultaneously (as in the previous system).

Table II allows an easy visualization of the components working and not working in each operating mode.

Table II: Status of the main components in each operating mode – PV, hybrid and diesel

Component	Mode		
	PV	Hybrid	Diesel
Diesel generator	OFF	ON	ON
Soft-starter	OFF	OFF	ON
Diesel FC	OFF	ON	ON
PV master FC	ON	ON	OFF
PV slave FC	ON	OFF	OFF

In order to increase the lifetime of the components of the system, the following protections are programmed (it is important to mention that these protections overlap the selection mode based on the available PV power):

- If the diesel generator receives 3 run signals in the same irrigation program due to, for example, passing clouds that reduce intermittently the PV power, the diesel generator will be working for at least one hour. This means that during this hour the system will work only on hybrid or diesel modes (according to the available PV power). This will protect the diesel motor against a high number of starts.
- If the soft-starter receives 3 run signals in the same irrigation program, it will be working for at least one hour. This means that the system will work on diesel mode during this time. This will protect against continuous transitions between PV and diesel modes, which can affect the irrigation system.

In both of the previous cases, once the timer finishes, the system will return to its normal operating conditions based on the available PV power.

Furthermore, an additional switch is included in the system. This switch allows the end-user to return to the previous system, i.e., if the end-user desires to use only the diesel generator, he/she only needs to activate this switch. Obviously, in this case, the available PV power will not influence the working of the system.

3 IMPLEMENTATION

This system has been working since June 2016. The following figures allow the reader to have a better visualization of the real system. Figure 3 shows part of the 140 kWp N-S axis PV generator, Figure 4 includes the set of pumps and the filter bench, while Figure 5 shows the majority of the electrically components of the system (irrigation and PV controllers, as well as frequency converters and soft-starter), as well as the stand-alone system. Finally, in Figure 6 the olive tree plantation is shown.

Figure 3: PV system generator

Figure 4: Set of pumps and filter bench

Figure 5: Engine room

Figure 6: Olive tree plantation

4 FIRST RESULTS

The first results presented are based on monitoring data recorded in the months of June, July and August 2017 (92 consecutive days).

The DC energy produced by the PV generator was 21019 kWh, which means 19866 kWh of AC energy. The water pumped with this energy was 55179 m^3, being the total pumped water 125760 m^3. The system was working during 590 hours with an average flow of 213 m^3/h. The PV penetration during this period was 43%. A summary of these values is presented in Table III.

Table III: Measured data and first results

Variable	Value
Irrigation hours [h]	590
Volume of pumped water [m^3]	125760
Volume of pumped water from PV [m^3]	55179
Average flow [m^3/h]	213
DC energy from PV [kWh]	21019
AC energy from PV [kWh]	19866
PV penetration [%]	43

Two performance ratios are calculated: the typical one and one that only considers the irrigation hours. Based on the measured irradiance presented in Table IV the typical PR is 0,16, while the PR during irrigation hours (PR_{I-H}) is 0,42 (see Table V).

Table IV: Irradiation

Irradiation	Value [kWh/m^2]
Total irradiation	895
Irradiation during irrigation hours	341

Table V: Performance ratios

Performance ratio	Value [ ]
PR	0,16
PR_{I-H}	0,42

Figure 7 includes the daily irradiance during three days in June 2017 and Table VI the number of irrigation hours in each operating mode in the same periods.

As it can be seen, June 2 and June 16 have similar irradiance profiles (typical of a non-cloudy day), while June 6 has a profile which represents a cloudy day until mid-afternoon. These profiles, if nothing else is taking into account should mean that PV penetration will be similar on June 2 and 16, being the lowest penetration on June 6. Although, seeing the values in Table VI this does not happen. June 2 is a great day regarding PV penetration (around 70%), while June 16 is not (around 20%). This happened because a hydraulic issue occurred during the day and there was the need to irrigate during nighttime. On the other side, even on June 6 (the cloudy day) the system was able to work 100% based on PV for 2 hours and in the hybrid mode during 3 hours. So, the user and the problems in the irrigation system influence dramatically the performance of the PV irrigation system independently of the quality of the PV plant.

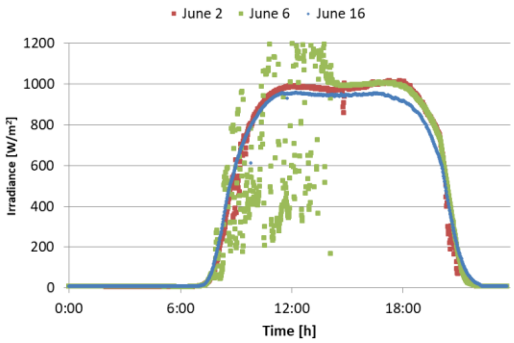

Figure 7: Irradiance daily profiles for three different days – June 2, June 6, and June 16, 2017

Table VI: Number of irrigation hours in three different days in each operating mode

Day	Mode			
	PV [h]	Hybrid [h]	Diesel [h]	Total [h]
June 2	10	1	4	15
June 6	5	1	9	16
June 16	2	3	12	17

5 CONCLUSIONS

This paper has presented the design and implementation of a 140 kWp PV-diesel pumping system installed in Alter do Chão, Portugal. The system has been working since June 2016 in accordance with the initial expectations of guaranteeing constant pressure and flow. As far as first results are concerned, 125760 m^3 were pumped during 590 irrigation hours between June and August 2017, being 55179 m^3 pumped with PV energy. The PR during irrigation hours is 0,42 and PV penetration 43%.

6 ACKNOWLEDGEMENT

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7 REFERENCES

[1] 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.
[2] R. Langarita, J. Sánchez Chóliz, C. Sarasa, R. Duarte, S. Jiménez, "Electricity costs in irrigated agriculture: A case study for an irrigation scheme in Spain," Renewable and Sustainable Energy Reviews, Vol 68 (2017), 1008-1019.
[3] M. Abu-Aligah, "Design of Photovoltaic Water Pumping Systems and Compare it with Diesel Powered Pump," Jordan Journal of Mechanical and Industrial Engineering, Vol 5 (2011) 272-280.
[4] P. E. Campana, et. al, "Suitable and optimal locations for implementing photovoltaic water pumping systems for grassland irrigation in China", Applied Energy, Vol 185 (2016) 1879-1889.
[5] L. Narvarte, E. Lorenzo, "Sustainability of PV water pumping programmes: 12-years of successful experience", Progress in Photovoltaics: Research and Applications, Vol 18 (2010) 291-298
[6] J. Fernández-Ramos, L. Narvarte Fernández, F. Poza-Saura, "Improvement of photovoltaic pumping systems based on standards frequency converters by means of programmable logic controllers", Solar Energy, Vol 84 (2010) 101-109.
[7] Technical specifications and quality control procedures for contractual frameworks, available at www.maslowaten.eu