

Improvement of photovoltaic pumping systems based on standard frequency converters by means of programmable logic controllers

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Abstract

Photovoltaic pumping systems (PVPS) based on standard frequency converters (SFCs) are currently experiencing a growing interest in pumping programmes implemented in remote areas because of their high performance in terms of component reliability, low cost, high power range and good availability of components virtually anywhere in the world. However, in practical applications there have appeared a number of problems related to the adaptation of the SFCs to the requirements of the photovoltaic pumping systems (PVPS). Another disadvantage of dedicated PVPS is the difficulty in implementing maximum power point tracking (MPPT). This paper shows that these problems can be solved through the addition of a basic industrial programmable logic controller (PLC) to the system. This PLC does not increase the cost and complexity of the system, but improves the adaptation of the SFC to the photovoltaic pumping system, and increases the overall performance of the system.

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1. Introduction

The use of photovoltaic energy sources for water pumping in remote areas has been progressively implanted in several countries around the world (McNelis et al., 1988; Posorski, 1996). Photovoltaic pumping systems (PVPS) based on standard frequency converters (SFCs) and standard centrifugal pumps have been proposed in recent years (Alonso Abella et al., 2003) and there have been prototypes and commercial applications since 1995 (Liebard, 1999). The advantages of this new approach to dedicated systems can be summarized as:

- Lower cost because their components are manufactured in large quantities.

- Increased reliability because they are designed to work in industrial environments and conform to very stringent regulations.
- Increased range of power, so they can be applied in different projects with very different requirements for pumping head, flow rate, etc.
- Technological independence and better component availability in those countries where these systems are often installed (Posorski, 1996).

PVPS based on SFCs carry out a PID (proportional integral derivative) control algorithm whose process variable to be controlled is the voltage of PV array (V_{DC}) and output variable is the output frequency of the SFC (F_{OUT}) (Alonso Abella et al., 2003; Brito and Zilles, 2006).

F_{OUT} is adjusted to match the V_{DC} with a set-point voltage (V_{SP}). If the V_{DC} is greater than the V_{SP} , then the PID controller increases F_{OUT} , so that the V_{DC} decreases. When the V_{DC} falls below the V_{SP} , the PID controller decreases

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F_{OUT} . In order for the PID operate in this way, its control action is selected for the reverse option.

To match to the pump characteristics, the SFCs require the configuration of a large number of parameters, such as the v/f pattern, acceleration and deceleration times, functions of analogue and digital input and output terminals, etc. However, the critical parameters for the optimal operation of the SFC are the V_{SP} and the PID parameters: Proportional Gain (K_p), integral time (T_i) and derivative time (T_d). Brito and Zilles (2006) proposed a systematic method for obtaining the optimal values of these parameters.

PVPS have been tested in several international projects, such as those presented in Narvarte et al. (2006), Poza (2008), Narvarte et al. (2005) showing quite good levels of quality. In spite of this, it is worth noting that some unsolved problems derived from the incorrect adaptation of the SFCs to PVPS. The most relevant ones are as follows:

1.1. Instability due to a sudden fall of irradiance

Some experiences with this kind of system (Narvarte et al., 2005) have shown that the system stops when the irradiance received by the panels is reduced sharply for some reason, such as shade from that passing of a cloud. In this situation, the current provided by the panels (I_{DC}) is also reduced sharply, so the pump cannot keep the power that was delivering. However, F_{OUT} cannot change so abruptly, so that the SFC is trying to provide the current necessary to sustain this frequency. As a consequence, the V_{DC} quickly falls below the V_{SP} . To increase the V_{DC} , the PID controller should decrease F_{OUT} , but it cannot respond as quickly as is necessary thus the V_{DC} falls below the minimum supply voltage of the SFC (V_{DCmin}), causing a low-voltage error which stops the pump. Fig. 1 shows the V_{DC} and I_{DC} curves of this process.

The dynamic behaviour could improve by changing the value of the parameters, such as increasing K_p , but this worsens the steady state operation, with large oscillations of around V_{SP} , which makes this solution unfeasible.

This instability brings about operating problems in PVPSs such as oscillations, the “water hammer” phenomena or even lower water pumping capacity (Poza, 2008).

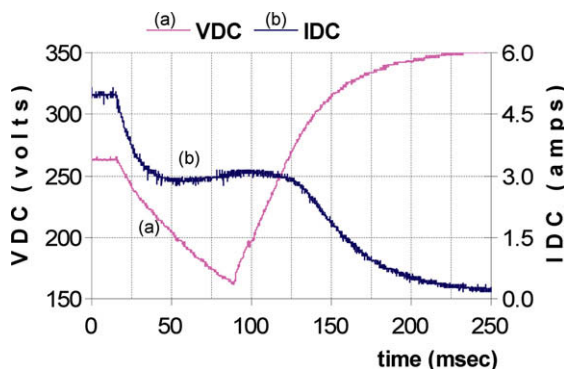


Fig. 1. V_{DC} and I_{DC} curves for a sudden fall of irradiance.

1.2. Lack of maximum power point tracking

PVPS based on SFCs operate with constant a V_{SP} , for reasons of simplicity. The losses occasioned by this practice are less than 4% with respect to a system with MPP tracking when the deviation of the V_{SP} related to the V_{MPP} is within $\pm 5\%$ (Alonso Abella et al., 2003).

The problem is how to set V_{SP} so that it always stays within these margins. This is a difficult problem to solve in places where the temperature difference between summer and winter is very high, such as in mountainous areas. Under these conditions, there is a risk that if the V_{SP} is set to a value that provides good operation in the winter, it is possible that this point is very different from the MPP in the summer or, in extreme cases, it even falls outside the power curve of the PV array.

Fig. 2 shows the I – V curves for several cell-temperatures of 10 PV series-wired panels. If the set-point is fixed at 360 V, which is the approximate value of the V_{MPP} at 15 °C (typical value in winter), the set-point is placed at (1) and the power delivered by the PV array will be around 1575 W. But in the summer, the temperature can easily reach 55 °C. In this situation the set-point would be located at (2), and the power delivered by the panels is around 650 W, less than half that in winter.

To avoid this problem, the typical solution implemented in systems with a constant V_{SP} is to set it to a V_{MPP} at maximum work temperature of the PV array. For the PV array in Fig. 2, the set-point could be set at 290 V (3), so the maximum power that could be obtained is 1270 W, 20% lower than the maximum that could be obtained in winter if an MPPT algorithm is used.

Another negative consequence of this set-point selection is that the PV array will work almost always at lower voltages than V_{MPP} and therefore closer to the V_{DCmin} . In this situation, the sensitivity of the system to a sudden fall of irradiance is much greater than when the V_{DC} is greater than or equal to the V_{MPP} .

1.3. Protections against the special states of empty well and full tank

Normal operation of the system requires that there be water in the well and that the storage tank has sufficient capacity to store the pumped water. If any of these conditions are not met, the system must be able to detect it and stop the operation of the pump.

The most serious problem is the empty well. This can occur during drought seasons or when the power of the pump is excessive in relation to the capacity of the well. When this happens, the pump runs dry and serious damage could be done if the pump relies on the water for cooling.

Moreover, most of the systems evaluated did not have the infrastructure to use excess water when the tank is full. Although this problem is not dangerous to the integrity of the system, it represents a huge waste in countries where water is a scarce resource.

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