INTEREST OF PHOTOVOLTAIC SYSTEMS FOR AGRICULTURE IN HUAMBO MUNICIPALITY - PRE-SIZING AN IRRIGATION FACILITY

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ABSTRACT

The socio-economic development of isolated regions is dependent on two main factors, which are access to electricity and water for domestic purposes and irrigation. In the absence of access to the mains electricity, solar energy can be used to advantage, in particular for pumping water for irrigation. This natural resource, scarce in some places, but which is abundant in Huambo (Angola) allows us to admit that its use by small and medium farmers, if well managed, may increase production levels and, consequently, the income of local producers. Refer to the advantages and disadvantages, from the environmental and economic point of view of solar energy compared to conventional energy sources, and some photovoltaic systems for pumping water for irrigation (SFVR) are described. A case study involving the creation of a model installation of an SFVR located in the municipality of Chipipa, in the municipality of Huambo, is presented, having been pre-dimensional analytically and using computer software (PVsyst 6.0. 1) and the results obtained by the two methods mentioned are compared.

Keywords: irrigation; photovoltaic pumping systems; solar energy; sizing; Water.

1. INTRODUCTION

Due to climate change, which has had its most dramatic manifestation in global warming, over the past few years, there has been a substantial investment in the production of electricity from renewable energies, namely in obtaining photovoltaic solar energy for injection into the distribution network. However, this alternative does not seem to be the most effective way to use the referred technology. Thus, for example, in rural areas far from the electricity grid, the use of photovoltaic technology will be the most efficient and cost-effective way to obtain energy. In fact, and according to Burney (2010), the use of solar energy for pumping water in areas far from the electricity network presents itself as an economically advantageous and straightforward option to implement. However, to date, this possibility has been little exploited due to the emphasis and subsidies given to large-scale electricity production.

In turn, and according to Silva (2000) and Michels (2007), supplying water to rural populations through renewable energies of autonomous generation is very important, since this contributes to the socio-economic development of many isolated regions that do not have access to the conventional electricity network, allowing to increase rural productivity and reduce the incidence of diseases associated with the use of water with inadequate quality for the different uses. The use of renewable energy from autonomous generation is even cheaper than resorting to a water pumping system powered by an internal combustion engine, usually diesel.

The interest in using photovoltaic energy in a given location is dependent on the level of solar radiation available there, an availability that in Huambo reaches an average value of 5.65 $kWh.m^{-2}.day^{-1}$.

Due to its specific characteristics in agricultural and agro-climatic terms, the central plateau of Angola appears, at the outset, as a region potentially devoted to the use of photovoltaic energy in agriculture. In this context, the study on which this article is based was carried out, in which the interest in the use of solar photovoltaic systems in irrigation in rural areas of Angola, in particular in the province of Huambo, is evaluated and the importance of correct dimensioning is shown. respective facilities.

Thus, and after the description and characterization of some projects of photovoltaic irrigation systems implemented in the world, a pre-dimensioning of a photovoltaic system for pumping water for irrigation is carried out, using a fictitious study case capable of representing a specific situation of the Huambo region.

2. ADVANTAGES AND INCONVENIENCE OF SFVR

Photovoltaic water pumping systems for irrigation of crops are particularly suitable for small and medium-sized irrigation installations and can be used in installations with any type of irrigation, namely in the sprinkler or drip irrigation systems,

The advantages of using an SFVR in an irrigation facility are manifold.

Thus, in a system like the one used in this work as a case study and pre-dimensioned below, it is possible to maintain constant pressure in the network without having to use batteries, nor does it necessarily have to resort to the accumulation of water in large deposits/reservoirs to compensate for the variations in the adduced flow throughout the day due to the variations in the received solar radiation.

This is because conventional pumps are used in SFVR, so if they are used in an installation where the depth of water in the holes has increased over time or where water needs are greater than those considered in the project, it is possible to solve the problem by acting at the level of the installation's components, namely increasing the number of solar panels that supply the installation and modifying the system's load controller.

Another of the significant advantages of SFVRs is the fact that, contrary to what happens with systems that use liquid fuels, they avoid the emission of large amounts of CO_2 into the atmosphere. In addition, it should be noted that irrigation with solar pumping guarantees the farmer energy autonomy in relation to the supplier of the energy needed for the installation (in this case reduced to the energy necessary to guarantee the functioning of the emergency equipment). This protects the SFVR owner from the profitability problems of operating the installation resulting from future increases in the cost of energy imposed by the electricity or hydrocarbon suppliers.

The advantages mentioned above were confirmed by Monteiro et al. (2014), at full scale, in an irrigation system with high power solar pumping, with constant pressure and flow, installed on a farm where sugar beet was produced in a total area of 56 hectares.

According to the authors cited, it was possible, in this case, to reduce the cost of irrigation by 80% and CO2 emissions into the atmosphere by 100%. In turn, studies carried out by Morales (2011) show that photovoltaic water pumping systems have numerous advantages over diesel systems, namely the fact that diesel is an expensive fuel and requires reliable transport at a high price. , contrary to what happens with photovoltaic systems, which do not need external fuel supply.

However, Sousa et al. (2004), referring to the use of solar energy in irrigation, point out several problems that have contributed to hindering this practice. Namely the fact that many small and medium farmers, to ensure the pumping of water, are obliged to invest in expensive electrical installations, involving the installation of transforming stations (PT`s) of electricity distribution networks, when their problem could easily be solved using photovoltaic energy. According to the aforementioned authors, such problems are most often related to the lack of information and experience of companies operating in this field, since even accredited companies often do not have the information that allows them to choose the most beneficial solution for the farmer.

3. MATERIAL AND METHODS

The methodology followed in the present work resulted in the following steps:

- – Collection of information, through bibliographic consultation and visits to facilities using solar energy, including SFVR, existing and/or under construction in Angola and Portugal.
- – Creation of a case study that would serve as a basis for the pre-dimensioning of a photovoltaic system for pumping water for irrigation that would allow evaluating the advantages and disadvantages of using solar energy in an irrigation installation about the methods commonly used by peasants for irrigation. capture and transport the water necessary to irrigate the crops (use of diesel engines and/or human effort and/or animal traction).
- – Pre-dimensioning, in hydraulic and energetic terms, analytically but also using specialized software, of the model installation of SFVR (the calculation of head, pump power, power of the photovoltaic generator and energy produced and consumed by the system. The software used was PVsyst 6.0.1, a program that allows the dimensioning of photovoltaic solar systems, based on the location and characteristics of the installation to be created, having carried out several simulations that led to obtaining data such as the energy obtained throughout the year (from available radiation), the power of the solar panels and the model of the pump and photovoltaic generator to be installed.
- – Comparison of the results of the pre-dimensioning of the irrigation installation used as a case study obtained by the two previously mentioned routes (analytical route and using specialized software).

4. RELEVANT STUDIES AND PROJECTS INVOLVING THE USE OF SRFV

This section refers to some irrigation installation projects with photovoltaic irrigation systems implemented in different countries. A more detailed description of the SFVR history can be found in Fedrizzi (2002), Poza (2008) and Morales (2011).

According to the aforementioned authors, the use of solar energy for pumping water had been tested since the second half of the 20th century. However, the technological conditions necessary to allow photovoltaic pumping only occurred much later.

However, it is difficult to know precisely when this technology started to be used for irrigation.

Nevertheless, it is known that in the 60s of the last century a photovoltaic irrigation system was successfully implemented in a remote semi-arid area in the southeast of the former Soviet Union. In Japan, some of the photovoltaic systems installed between 1963 and 1973 were used for irrigation or to drive fans to dry grain and other equipment.

In 1998, in an area of California characterized by long periods of drought, an irrigation project with photovoltaic pumping was carried out to irrigate forage crops for cattle (Rochin, 1998). Between 1998 and 2002, the German Cooperation Agency Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) started the Irrigation Pilot Project (PVP) program, under which ten SFVRs were installed in Chile, Egypt and Jordan (GTZ, 2003). According to the agency, the experience showed the acceptance of the technology by the users and the viability of the SFVR in relation to the internal combustion systems under certain conditions (high degree of use of the system, cultivation fields smaller than four hectares and crop production with high market value).

Furthermore, the Regional Solar Program (PRS), which aims to supply water using photovoltaic energy to eight countries in the Sahelian region, installed 1,040 pumping photovoltaic systems. In addition to domestic use, watering of vegetables and fruit trees was promoted. This program was a pioneer in the evaluation and quality control of equipment before being installed (Fedrizzi, 2002).

In turn, the Water Pumping Program (WPP), implemented in Morocco with support from the European Union, allowed 12 years of promising experience. During this period, 49 systems, totalling 173 kWp, supplied five million cubic meters of water to a population of around 40,000 people (Morales, 2011).

5. CHARACTERIZATION OF THE STUDIED SFVR

5.1. Location

As a working hypothesis, it was established that the system in question would be located in the municipality of Chipipa, 19 km north of the municipality of Huambo, and can be used to irrigate small properties of peasants in the region.

Figure 1 shows the location of the photovoltaic water pumping system for irrigation used as a case study.

Figure1- Location of the pre-dimensional system.

Source: http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php?map=africa&lang=en#

5.2. Climatic characteristics

The plateau area of Huambo, the region chosen for the location of the virtual installation to be used as a case study, has two well-defined climatic seasons: the dry season, commonly known as "cacimbo", and the rainy season (Dinis, 1979).

During the cacimbo season, there is greater availability in terms of solar resources, observing the highest monthly average value in the months of August (6.34 kWh.m-2 .day-1). and September (6.14 kWh.m-2.day-1). (Retscreen, 2014). A careful observation of the available data shows that it is during this time that peasant families seek to diversify and increase production levels, especially of vegetables, since the demand for these products by consumers in formal and informal markets assumes a relevant dimension, but whose satisfaction is limited by the lack of water.

5.3. Characterization of the model installation considered

The photovoltaic system considered as a case study, which was considered to have the objective of irrigating a 900 m2 plot, is represented schematically in figure 2.

It indicates the main data characterizing the situation that was considered to exist at the site of the model installation to be studied, namely the indispensable data for the pre-dimensioning of the SFVR organs object of the present work (in the circumstance the pump motor group and the panels listed below in a more exhaustive way.

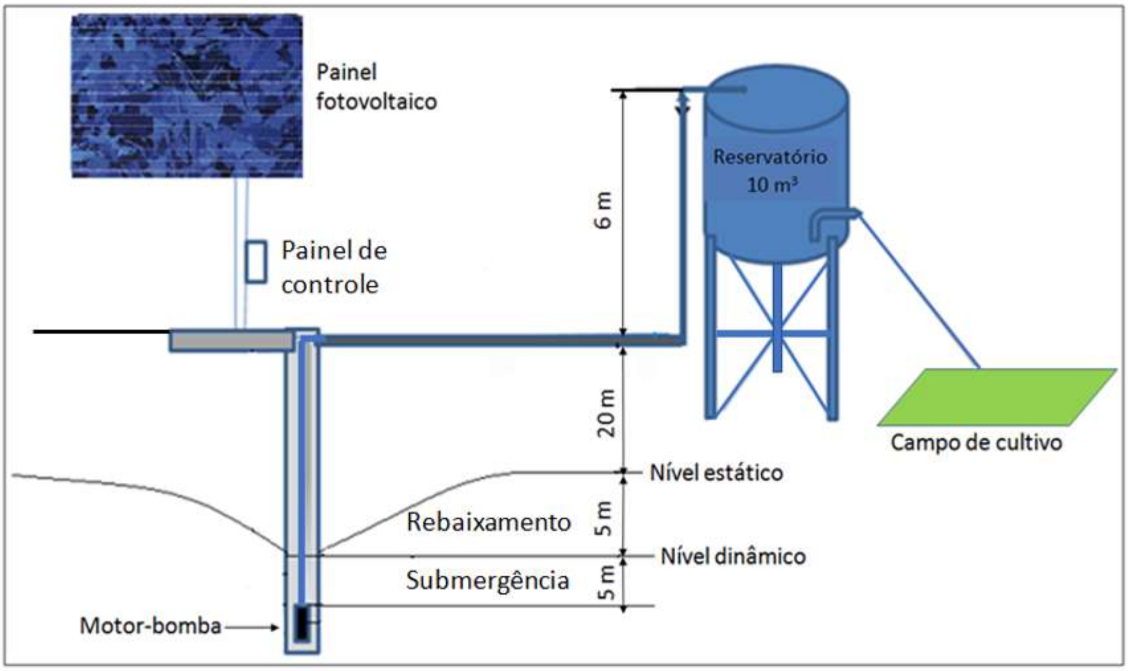

Figure 2 - Model installation to consider for the purpose of pre-dimensioning an SFVR.

Table 1 - Elements characterizing the irrigation installation to be pre-dimensioned

Irrigated area	900 m^2
Hole water level (static level)	20 m
Lowering the water level in the hole	5 m
Desired daily flow	5 m^3/day
Maximum water temperature in the hole	25 ºC
pH of water	6,0
Hole depth	32 m
Inside hole diameter	0,30 m
Pump depth in the hole	30 m
The diameter of the pickup tube (PVC)	*3/4”*
Tank/reservoir capacity	10 m^3

6. PRE-SIZING THE INSTALLATION

6.1. Data used

Taking into account the agro-climatic conditions characteristic of the area chosen for the installation of the SFVR to be studied and the crops to be watered, chosen in terms of their suitability for irrigation production among the most representative of the region, and the characteristics of the aforementioned installation proceeded pre-dimensioning a photovoltaic system that would guarantee the necessary energy to pump water captured in a hole to the reservoir destined to store water to irrigate an area of 900 m2.

Regarding the parameters characterizing the pump and the photovoltaic equipment to be installed (solar panels), the data related to the level (static and dynamic) of the water in the borehole (shown in figure 2) as well as the other elements characterizing the installation in the figure referred and previously listed.

In calculating the energy required for the installation, it was considered possible to have a minimum pressure of 10 m.c.a[1] on all drippers installed in the distribution network without having to resort to pumping water from the reservoir or downstream. Pumping which, due to the reduced height accepted for the reservoir, would not be necessary only if the distance to the plot to be irrigated and the elevation of the land in this location would ensure a load availability at the exit of the reservoir compatible with the desired pressure value for the distribution network.

6.1.1. Irrigation water requirements

The photovoltaic water pumping system was designed considering that it would serve to water two crops: corn (Zea mays) and beans (Phaseolus vulgaris).

The water requirements for irrigating a given crop depend on the type and stage of development of the crop, the climatic conditions of the site (in particular the temperature, humidity, and wind speed, conditioning factors for evapotranspiration), the season and irrigation method used. However, it is also essential to take into account local practice and experience.

For the two crops considered, corn and beans, the critical periods related to the water deficit, that is, the moments when, according to Nogueira (2009), the lack of water causes great losses in productivity, are shown in table 1.

Table 2 - Critical crop periods in terms of water deficit

Crops	Critical periods
Corn	Flowering formation and filling of the shank.
Bean	Flowering, the appearance of pods and the beginning of grain development.

Source: Nogueira, 2009

Table 2 shows the water consumption values for corn and beans reported by the mentioned author.

[1] m.c.a: meters of water column

Table 3 - Water consumption of corn and beans during their development cycle.

Crop	**Daily consumption**		
		Average values	
	Characteristic values (mm)	**(mm)**	**(m^3 ha^{-1} day^{-1})**
Corn	4 – 7	5,50	55
Bean	3 – 5	4,00	40

The daily water requirements of the crops to be irrigated (corn and beans) considered were the average of the respective characteristic values previously mentioned (5.5 mm for corn and 4.0 mm for beans). Under these conditions, the volume of water that allows irrigating the entire cultivated area (900m2) when consumption is higher is 4.95 m3. What will happen when the land is fully occupied by the crop with the greatest needs (in this case, corn).

In view of this value, it was decided to accept the existence of a reservoir with the capacity to ensure a reserve volume of 10 m3, that is, twice the daily requirement considered.

6.2 - Pre-dimensional of the equipment.

The pre-dimensioning of the equipment involved the calculation of the lifting head, the energy consumed and produced by the system, the maximum power of the photovoltaic generator (peak power) and the power of the pump.

Taking into account the level of the water to be pumped (static level at 20 m below the ground and a drop of 5 m, which corresponds to a minimum submergence of the pump of 5 m) and the geometric difference between the motor-pump group and the section from the duct to the entrance to the elevated reservoir (6 m), the geometric elevation height found was 31.0 m.

Accepting that the pressure drop in the elevating duct and its accessories correspond to 15% of the geometric lifting height, it will be assumed that the lifting head (HMT) will be equal to 35.7 m.

7. PHOTOVOLTAIC SYSTEM

7.1. Energy consumed

The energy consumed daily by the pump (Ec) was calculated based on the expression below, contained in the elements of study made available within the scope of the master's course - referred to in this text (Patrício, 2013).

$$Ec = \frac{\rho \times g \times Q \times HMT}{\eta_b \times \eta_e}$$

In this expression ρ is the density of the water (kg / m3); g the acceleration of gravity (m/s2); Q the daily flow (m3 / day); HMT the total manometric height and $\eta_b \times \eta_e$ the efficiency of the pump and the electric motor, respectively.

7.2. Energy produced

The energy that the photovoltaic system under analysis is required to produce for 24 hours (Ep) to guarantee the energy consumed in that period (Ec) is related to the latter through the expression

$$E_p = \frac{E_C}{K}$$

- Where K is a correction coefficient that takes into account the following factors:
  - meteorological uncertainties;
  - no correction of the inclination of the modules throughout the year;
  - point of operation of the modules that is rarely ideal, which can be aggravated by the loss of quality in the performance of the modules over time due to ageing and the accumulation of dust;
  - performance of the regulator;
  - inverter performance.
- For pumping systems, this coefficient generally varies between 0.7 and 0.9, with a value of 0.8 being adopted.

7. 3. Peak power photovoltaic generator

The peak power of the generator (Pp) was calculated based on the expression below,

$$P_P = \frac{E_p}{HSP}$$

Where (HSP) represents the number of hours of full sun per day.

8. RESULTS and DISCUSSION

8.1. Results obtained analytically

Based on the scheme shown in figure 2, the energy required to raise 5m3 of water daily to a total head of 35.7 m was analytically estimated, with the peak power of the photovoltaic generator of 230 W.

This value was calculated considering, as mentioned, that the head loss that occurred along the ducts and accessories until entering the reservoir was 15% of the geometric elevation height. In these conditions, considering the average pump (ηb) and motor (ηb) yields 55 and 85% respectively, the mechanical energy Ec required to raise the desired daily flow to the reservoir is given by the expression.

$$Ec = \frac{\rho \times g \times Q \times HMT}{\eta_b \times \eta_e}$$

Under these conditions the value found for *Ec* will be:

$$Ec == 3{,}74 \text{ x } 10^6 \text{ J.day}^{-1} = 1039 \text{ W.h.day}^{-1}$$

The energy to be produced per day (Ep), calculated using 0.8 as the correction coefficient (K) led to the value of Ep = 1300 W.h.

The calculation of the peak power of the photovoltaic generator (Pp) carried out analytically based on the average number of hours of full sun (HSP) led to a maximum value of this power of 230 W.

This value was obtained using an HSP value corresponding to 5.65 kWh.m-2.day-1, which corresponds to the average daily value of hours of full sun equals to 5.65.

An important aspect to take into account in this dimensioning is that the radiation received varies throughout the day, so there is an increase in the energy produced until solar noon, which then decreases until sunset. This has important implications for pumping irrigation water, as it means that there will be a variable flow throughout the day.

This flow variability can be considered as a problem that may lead to the need to implement solutions to standardize the flow. The simplest solution could be the construction of an elevated reservoir to receive the collected water with a capacity that allows regulating the flow distributed daily through the distribution network. However, this solution implies the construction of a reservoir with some dimension, possibly equipped with a secondary pumping system, with the costs inherent to it. Pumping which, as already mentioned, will be necessary in case the unevenness between the distribution duct at the outlet of the reservoir and the land to be watered does not guarantee the minimum desired pressure in the drippers.

8.2. Results of system sizing using PVsyst 6.0.1 software

8.2.1 System power

The values of the required energy per day and the peak power of the photovoltaic generator previously calculated analytically were also calculated using appropriate software (PV syst 6.0.1).

As can be seen in table 3, the power values of the solar panels to be installed obtained by the two mentioned routes are very approximate,

Table 3 - Values obtained for the power of the solar panels

cia dos painéis solares	
Cálculo analítico	**Software PVsyst 6.0.1**
230 W	240 W

Although the referred power values obtained through the analytical calculation and using the software used are approximate, the procedure adopted allowed to relate the different variables and better understand the energy balance of the system.

Thus, the results, shown in Table 4, which indicate the requirements to be met by the main components of the system under study, as defined by the software used, show that to pump 5 m3. day-1 for a total head of 35.7 m, the system needs an approximate power of 240 Wp, a requirement that is satisfied with four 60 Wp modules.

In turn, and taking into account the value of the total manometric height shown, the software used led to the use of a pump with a power of 196 W.

Table 4 - Installation requirements for the solar pumping system obtained with the PVsyst 6.0.1 software.

Power of solar panels	240 W
Pump power	196 W
Pump model	9300 SERIES // SURFLO
Generator Model	AP-6106/ASTRO POWER
Number of modules	- Four modules of the si-monocrystalline type of 60 Wp each; - Two groups of 2 modules in series and two groups connected in parallel.
Configuration	Direct connection to the booster

9. Conclusions and recommendations

The research work carried out, which involved the analysis of some of the projects involving photovoltaic systems in irrigation installations and technical visits to installations that in Angola and Portugal use solar energy for different purposes, allowed us to reach the following conclusions demonstrating the interest in using these systems in irrigation facilities, particularly in the region under study:

a) An SFVR can ensure the availability of water in places and at times when this availability is reduced, which from an economic point of view is extremely important, since it is possible to reduce the risks of harvest losses, increase production and to diversify cultures, opting for those that have a higher market value, thus enabling job creation and the existence of a diversified economy that guarantees balanced development.

b) In comparison with irrigation systems with other energy sources, an SFVR has low operating costs and substantially increases the autonomy of the farmer in relation to the fuel suppliers essential to the operation of systems dependent on conventional energy sources, thus contributing to development more economically sustainable.

c) Not depending on the use of fossil fuels, producing no noise or generating any other type of environmental pollution, namely air pollution, the use of SFVR presents itself as an environmentally friendly alternative.

d) The Huambo plateau area presents excellent conditions for the use of solar photovoltaic systems for irrigation due to the high availability of solar radiation, which, at the time of the cacimbo, coincides with the greatest need for water by the plants.

e) The advantages inherent to SFVR can only be obtained in installations correctly designed and dimensioned and operated in suitable moulds.

f) The methodology used in the sizing of the irrigation water pumping system used in the present work made it possible to determine with certainty the type and characteristics of the pump and the number of solar panels to be used, as well as to know the amount of electrical energy that panels to be installed must produce so that the pump to be used is capable of raising to a reservoir the volume that satisfies the water needs of the plants to be irrigated.

As a corollary of these piecemeal conclusions, it can be said that the use of the software used can contribute effectively to ensure the necessarily correct pre-dimensioning of photovoltaic systems, particularly in the municipality of Huambo, where this hypothesis is promising.

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