Technical and Economical Analysis of Photovoltaic Pumping Systems with V Type Concentrators in Irrigation System to Productive Chains

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ABSTRACT

This paper presents the dimensioning of a photovoltaic pumping system (PVPS) with concentrator type V for irrigation of a culture in the semi-arid area of the Northeast of Brazil. The elaboration, and analysis of the overhead irrigation was accomplished by drops of water, where data of water, soil, climate, labor availability and energy were verified. The grape is a perennial culture, with a deep radicular system, that is able be adjusted, to certain point, to a limited supply of water. For determining the hydric need of the culture, we adopted the model proposed by FAO, that uses the equation of Penman-Monteith to define the evapotranspiration. We also considered, a layer of water for washing the soil, to avoid salinization. With the purpose of attending the hydric demand of the plant the following factors were considered: pumped volume, pluviometric precipitation, storage of water in the soil and area to be irrigated, interrelated by the equation of mass conservation. The pumped volume is estimated by utilizability method, starting from the characteristic curve of the pump and the average monthly collected solar radiation. Finally the equipment used in the irrigation project is dimensioned and an economic analysis is carried out.

Keywords: photovoltaic pumping system, concentrator type V, irrigation systems.

1 INTRODUCTION

Irrigation cannot and should not be understood as a unique and exclusive artificial procedure for dealing with soil humidity conditions when aiming to improve agricultural production, as much for quantity as for quality. In fact, it is made up of a group of operation that are intended for attending the necessity of water for the plants that surpass, purely and simply, the soil-water plant relationship, that should come together with the soil, the geology, man, the vegetation, the culture and the economy of the locality in which the irrigation project is meant to be implanted.

The art of irrigation, as defined, is very far reaching and interdisciplinary, and goes through exact fields of agrarian science (hydraulic, civil, electric), and social (economic, sociological, political) fields. As the most recent there is solar engineering, whose knowledge is being used in association with irrigation technology. Non of them is more important than the other, because, when the final decision regarding the water is given, all these factors jointly have to be taken into consideration.

Thus, the choice of varieties that are adaptable to a region, as well as adequate planting space, manuring that satisfies high production conditions, phytosanitary control, combating erosion, water collection, the source of energy to be used, correct application of water during irrigation and finally the harvesting and commercialization, should be part of a unique system of production and not be considered isolated activities.

The great source of concern is the question of when and how much water to use in the irrigation. Knowing the correct moment to start irrigations and how much water must be applied is the objective of rational irrigation management. Nowadays it has been verified that there is not only an increase in energy costs but also in the scarcity of water resources. Therefore, the rational management of irrigation associated with the technical resource of photovoltaic pumping necessarily passes through an analysis of the technical aspects involved in the process.

In this work the grape was defined as a culture to be irrigated by presenting: A high tax of profitability, market adaptation and employment generation, this activity presents a prosperous experience in the semi-arid region near to the São Francisco river region [1].

2 SCHEDULE FOR IRRIGATION PROJECT ATTENDED BY PVP

The elaboration of a complete irrigation project includes data on water, soil, climate, availability of labour and energy. Besides this, an annual program of cultivation, hydric balance, water sheets, frequency and annual calendar of irrigation should be contemplated. Therefore, the first step to be carried out is to define and collect data on the local where one intends to implant the irrigated agriculture. The next activity would be the project and an economical analysis. Next, follow a schedule for elaborating the irrigation project that is assisted by a photovoltaic pumping system.

1. Definition of the blade to be applied in the area: this blade varies in function, mainly, of the culture (each culture presents an evapotranspiration and therefore, water consumption) and the geographic region in which the area is situated (climatic conditions from region to region, such as, the rains, evaporation and winds, which can vary significantly;
2. The selection of more adequate equipment or alternative equipment for the area: this selection, takes into account the culture, the topography of the area, the size of the area and the availability of water;
3. Calculation of periods of watering and functioning time by position: to do these calculations, the following must be taken in to consideration: the daily water consumption that the culture needs, the depth of the root system, the resistance that the plant presents in the "deficit" of water and the physical characteristics of the soil, principally, regarding its capacity to retain water;
4. Calculation of volume: This calculation refers to the total flow rate of the equipment and is based on the area to be irrigated, on the defined precipitation and the number of daily working hours;
5. Hydraulic dimensioning: dimensioning of piping and the accessories, such as: valves, hydrants, derivation elbows and others. It is based on the total flow rate, on the manometric height needed and water velocity inside the tubes. Once selected the piping and accessories proceed to their location in the area;
6. Dimensioning of the motor-pump group: the dimensioning of this group is also based on the flow rate, on the manometric height and the power needed. In the choice of the pump besides the items cited previously, attention must be taken that the chosen pump works at maximum productivity level or as near to it as possible and with maximum suction height;
7. Definition of the photovoltaic generator;
8. Elaboration of plan or sketch: the calculations carried out should be elaborated on a plan or sketch, where the collection point, the master line and the lateral lines, the accessories and positioning of the equipment are located in the area;
9. The schedule continues with an economical analysis of the project and other items, such as, costs, revenue, cash flow, commercialization, in accordance with the demand of the analyzed case.

3 METHODOLOGY OF PV SYSTEM DIMENSIONING FOR IRRIGATION

In this way, the chosen area is characterized and it is defined the kind of culture to be employed.

3.1 Data of the Culture

The data regarding the culture, that are necessary to sizing the photovoltaic system, this information was obtained through researches carried out with specialized enterprises in irrigation systems, as well as, consultants in the area of irrigation and grape cultivation. All the sources of information are located in the city of Petrolina in the state of Pernambuco.

3.2 Elaboration of a Plan of Use, Production and Commercialization, Association to Photovoltaic System Dimensioning

A defined area of 2 ha located in the Valley of the São Francisco River, which permits all year round use, depending on the adopted commercial plan, according to [4], the principal production complexes and grape commercialization centers in Brazil, are described in Table 1. Supply with their products local, regional and national markets, being that some of them, as in the lower reaches of the São Francisco region, also commercialize their products on the international market. The level of the irrigated area will be 100 % all year round

State	Month of the year											
	11	12	1	2	3	4	5	6	7	8	9	10
RS		x	x	x	x							
SC		x	x	x	x							
PR		x	x	x			x	x	x			
SP										x	x	x
SP		x	x	x	x	x						
PE e BA	x	x	X	x	x	x	x	x	x	x	x	x

Source: CD- Management of grapes without seed, author César Mashima, Publish by SEBRAE in 2004.

Table 1: Grape harverting periods in different regions of brazil

It can be seen that the main advantage of viniculture of the state Pernambuco-PE and Bahia-BA in the region of the Lower São Francisco, reaches in relation to other productive states of the country is that they value the coming possibility of obtaining successive cycles of production, which makes harvesting possible at any period of the year. This also allows taking advantage of better price opportunities in the internal and external markets. The external market for Brazilian table grapes is an in – season market ready to put "winter fruit" consumption on the tables of the countries that import fruit in the Northern Hemisphere, where two important markets are emphasized: the European Union and the United States. During the year there are two distinct periods for exporting grapes, one is from April to June, when a third of the exportation is commercialized, and the other begins in October and finishes in December, when the rest of the two thirds are shipped. From what is shown above, a production and commercialization plan is defined according to Table 2.

Culture	Month of the year											
	1	2	3	4	5	6	7	8	9	10	11	12
Grape	P	P	P	C	C	P	P	P	P	C	C	P

P – Production C – Commercialization

Table 2: Production and commercialization plan

3.3 Necessity of Irrigation Water for a One Month Period

Table 3 shows the values that determine the monthly quantity of water for grape culture in a one hectare area. These values are calculated from the procedures utilized in [3] using the following equations:

$$NIL = ET_c - PE \quad (1)$$

$$NIB = \frac{NIL}{\eta_{irrig}} \cdot 100 \quad (2)$$

$$Dm = NIB \cdot 10 \quad (3)$$

where:

ET_c evapotranspiration of culture (mm/month)
NIL necessity of liquid irrigation (mm/month)
PE effective preciptation (mm/month)
NIB brute irrigation necessity (mm/month)
η_{irrig} efficiency of adopted irrigation system (%)
Dm monthly water demand for one hectare (m^3/ha.month)

The culture coefficient represents a percentage of water consumption in relation to the evaporation reference which varies with the phonological state of the culture, the value of 0.65 was adopted for the project, as in accordance with [5], corresponding with the state of growth of the fruit, the phase in which the plant requires a greater volume of water.

Month	Eto (mm/month)	Kc	ETc (mm/month)	PE (mm/month)
JAN	189.11	0.65	122.92	83.21
FEB	163.65	0.65	106.37	77.13
MAR	169.55	0.65	110.21	129.20
APR	156.37	0.65	101.64	65.41
MAY	150.16	0.65	97.60	22.13
JUN	151.57	0.65	98.52	11.58
JULY	161.14	0.65	104.74	8.65
AUG	182.79	0.65	118.81	3.82
SEPT	207.92	0.65	135.15	5.26
OCT	227.86	0.65	148.11	9.74
NOV	209.77	0.65	136.35	49.33
DEC	194.86	0.65	126.66	66.72

Month	NIL (mm/month)	NIB (mm/month)	Dm (m^3/ha.month)
JAN	39.71	41.80	418.01
FEB	29.24	30.78	307.84
MAR	-18.99	-19.99	-199.88
APR	36.23	38.14	381.37
MAY	75.47	79.44	794.42
JUN	86.94	91.52	915.21
JULY	96.09	101.15	1011.52
AUG	115.00	121.05	1210.48
SEPT	129.88	136.72	1367.20
OCT	138.37	145.65	1456.49
NOV	87.03	91.61	916.06
DEC	59.94	63.09	630.91

Table 3: Monthly water demand for grape culture in 1ha

According to Table 3, the month of October presents the higher indices for the Necessities of Brute Irrigation (NIB) parameters, making it a critical month for grape culture, or be it, the month which the culture most needs water. But, following the production and commercialization plan, October will be a commercialization month of the culture, or in other words, the land should be inactive; then the month that presents the higher consumption of water and which is found in the period of production is the month of September, with this, making it's maximum NIB value the one that is used in dimensioning the irrigation system.

3.4 Parameters for management of daily irrigation

The values of parameters calculated for irrigation management, was elaborated using the results obtained in Table 3, with the following equations:

$$NIL_{daily} = \frac{NIL}{D} \quad (4)$$

$$Ll = NIL \cdot TR \quad (5)$$

$$Lb = \frac{Ll + Lv}{E} \cdot 100 \quad (6)$$

$$Dm_{p/ha} = Lb \cdot C \cdot 10 \quad (7)$$

$$Dm_{Total} = Dm_{p/ha} \cdot A \quad (8)$$

$$T = \frac{k \cdot Lb \cdot D}{n \cdot q} \quad (9)$$

where:

Ll Liquid layer of irrigation (mm)
NIL_{daily} Daily necessity of liquid irrigation (mm/day)
$Dm_{p/ha}$ Total daily water demand for irrigation per hectare (m^3/day/ha)
Dm_{Total} Total daily water demand for irrigation for irrigated area (m^3/day)
TR Period of watering (day)
Lb Brute blade of irrigation with mineral washing (mm)
Lv Blade of mineral washing (mm)
C Coefficient of covering for grape with irrigation by drops, equal to 0.5
A Irrigated area (ha)

T	Watering unit/hour of functioning
N	Number of emitters / ha
Q	Flow rate emitter (l/h)
K	Equal to 333, constant for 30 working days per month
$\dot{V}_B$	Pumping flow rate (m^3/h)
D	Number of days worked
E	Efficiency of irrigation system (95 %)

3.5 Dimensioning of Photovoltaic Pumping System with V Type Concentrator

Next, expression is presented for calculating a photovoltaic pumping system with V type concentrator. The hydraulic power produced by the pump can be written in function of the collected solar irradiation (Equation 10), through this approximate procedure, information can be obtained on the order of sizing equipment dimensions.

$$P_h = A_G \cdot I_{col} \cdot \eta_{FV} \cdot \eta_{mb} = \rho \cdot g \cdot H_m \cdot \dot{V}_b \quad (10)$$

where:

P_h	Produced hydraulic power (W)
A_G	Area of photovoltaic module (m^2)
I_{col}	Collected hourly solar radiation (W/m^2)
η_{PV}	Mean efficiency of photovoltaic generator (12 %)
η_{mb}	Mean efficiency of motor pump group (25 %)
ρ	Water density (1000 kg/m^3)
G	Acceleration of gravity (9,8 m/s^2)
Hm	Total manometric height (m)
$\dot{V}_B$	Flow rate of pumped water (m^3/s)

Considering a photovoltaic generator of nominal power ($P_{PV,nom}$) corresponding to solar radiation (I_{col}) equal to 1600 W/m^2, radiation incident on absorber considering the radiation incident on plate gap equal to 1000 W/m^2, for a system with V type concentrator [2], we can write:

$$A_G \cdot \eta_{FV} = \frac{P_{FV,nom}}{1600} \quad (11)$$

Substituting equation 11 in Equation 10 and integrating the resulting equation along all the day, gives equation 12 which relates collected solar energy H_{col} (Joule/m^2) with the hydraulic energy.

$$\frac{H_{col} \cdot P_{FV,nom} \cdot \eta_{mb}}{1600} = \rho \cdot g \cdot H_m \cdot V_B \quad (12)$$

where V_B is the volume of pumped water or hydric demand of the culture to be irrigated. Using the Collares-Pereira method the collected solar radiation value (H_{col}) was determined on the absorber plate for the case of V type concentrators, using the mean monthly value of 9.297 kWh/m^2 in the calculations carried out. The critical level of the pumping system was considered, and applied in Equation 12, which reduces the value of collected radiation (H_{col}). Based on experimental results that were obtained for the configured system, then, the value of 100 W/m^2 was adopted for the critical level. After determining the photovoltaic generation system, it should be divided by a factor of 1.6 which represents the proportional benefit of the V type concentrator use, as determined in [2]. Table 4 shows the parameters of photovoltaic generation systems.

Hcol (kWh/m2)	Hcol (MJ/m2)	Hydraulic Energy (MJ)
9.297	33.469	24.740
$P_{PV,nom}$ (kW)	$P_{PV,nom}$ concentrator type V (kW)	Nº of modules (Power - 53 Wp)
5.046	3.154	59.507

Table 4: Parameters of photovoltaic generation system.

4. FINAL COMMENTS

The analysis carried out shows that microcultures, such as fruit culture, in a 2 ha order can be irrigated with type V concentrator PVPS, which provide a 37.5% power reduction in the PV generating system when compared with a fixed system. In this work an approximate calculation methodology was used for definition of PV arrangement. However, more rigorous procedures, were taken into account in the monthly significant parameter variations (insolation, precipitation, evapotranspiration), being presented as important advantages from the point of view of optimization of the photovoltaic panels and motor pump group. The simplicity of installation, availability of in energy in high insulation regions, such as, the semi-arid Northeast of Brazil, is adequacy between scarce precipitation and elevated demand for energy, indicates the excellent potential of the analyzed system.

5. REFERENCES

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