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Photovoltaic powered irrigation system applied to familiar agriculture

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Abstract: This paper aims to analyze the technical and financial feasibility of a stand-alone photovoltaic powered irrigation system applied to a familiar production unit. The agricultural unit was installed in the Center for Teaching and Research in Urban Agriculture (NEPAU), which operates in partnership with the Alternative Energy Laboratory (LEA), both located at the PICI campus of the Federal University of Ceará. The unit occupies a floor area of 134 m^2, with a water reservoir that simulates a pond, lake or well with capacity of 3534 liters, a 12 VDC pump motor and a photovoltaic module of 135 Wp. The efficiencies of photovoltaic module, pump and global set were 8.4%, 42% and 3.5%, respectively. The assumed service life is 25 years and the capital returns after 9,3 years.

Key words

Photovoltaic pumping, irrigation, familiar agriculture

1. Introduction

In a world facing environmental questions like the climate change, renewable alternative sources of energy are a key tool for developed and developing countries.
In most of the developing countries a significant part of the population has no access to conventional electricity grid and no reliable drinking water supply for human consumption [1]. Additionally, the cost of the electricity needed for irrigation is high, a crucial element to the continuous and stable food and raw materials production [2].
In this context, this paper aims to experimentally analyze the technical and financial feasibility of a photovoltaic (PV) powered irrigation system as a component of a Center of Sustainable Food Production. The center aims to disseminate knowledge in the areas of technological innovations to eradicate poverty and hunger, familiar agriculture, generation of employment and income and environmental preservation.

2. Energy and agriculture

The productive use of energy consists in the exploitation of energy for activities that improve the economic income and the well-being of people [3]; in this way, the success of the agricultural practice is strictly dependent on energy availability.
The agricultural activity is centered in energy transformation processes, as a fundamental variable to provide integrity to the agronomic growth. The energy is used for irrigation, machinery drive, processing and conservation of agricultural products and other forms of exploitation of energy resources in agricultural production [4].
In the 19th century, Japan and the United States have adopted practical policies to support the features and technologies involved in agricultural production. This strategy has boosted the rapid development of cultivated and irrigated areas in these countries, taking agricultural activities to high levels [5].

2.1 Subsistence agriculture

Agriculture is the set of human actions that serve to transform the natural environment in a way suited for the development of crops [6]. The activity is basically classified into two principal groups:

- subsistence agriculture and
- market agriculture.

The subsistence agriculture is practiced in areas smaller than 2 hectares and the most applied irrigation techniques are: surface, aspersion or sprinkler and localized [7]. According to data from the Brazilian Institute of Geography and Statistics (IBGE) [8], 82.9% of the field hand labor of the Brazilian Northeast region is represented by family farmers.

2.2 Photovoltaic pumping system

Water pumping systems are classified according to the energy source that powers the system and the technical characteristics of the system; there are basically five types of pumping systems used in irrigation of crops [5]:
a) photovoltaic (PV) pumping systems;
b) wind pumping systems;
c) pumping systems connected to the conventional power grid;
d) pumping systems powered by internal combustion engines;
e) manual pumping systems.
PV pumping systems generally consist of an area of PV modules, motor – pump unity, power conditioning system (drive, pump controller) and storage system (optional). These systems are specially designed for pumping water from wells, ponds, rivers and reservoirs and are similar to conventional systems, with the basic difference that the pump motor drive is made by PV modules.

Sizing parameters of PV pumping systems

For Fedrizzi [9], regardless of the tool used for the PV pumping sizing, at least the following parameters must be defined, even if only for estimates:

- Water and energy demand;
- Solar irradiation data;
- Characteristics of water resources;
- Hydrological cycle seasonality;
- Pumping regime.

Hydraulic power depends on the daily water flow and total head [10]:

$$P_h = 2.725 * Q_d * H_{MT} \qquad (1)$$

- Qd – daily flow designed (m^3)
- H_{MT} – total manometric height (m)
- P_h – hydraulic power [W]

Electric motor power

$$P = \frac{P_h}{\eta_{MP}} \qquad (2)$$

- P – Electric motor power [W]
- ηMP – Pump efficiency [%]

Solar power over the area of the PV module

$$H = G * A_M [W] \qquad (3)$$

- H – Solar power [W]
- G – Global solar irradiance [W/m^2]
- A_M – Useful area of the PV module [m^2]

Efficiencies

The overall efficiency of the PV pumping system was calculated in 3 steps, according to Equations 4, 5 and 6:

1) PV Module Efficiency

$$\eta_{FV} = \frac{P}{G * A_M} = \frac{V * I}{G * A_M} * 100 \qquad (4)$$

- V – Voltage [V]
- I – Current [A]
- η_{FV} – PV module efficiency [%]

2) Motor pump Efficiency

$$\eta_{MB} = \frac{P_h}{P} * 100 \qquad (5)$$

3) Overall efficiency

$$\eta_G = \frac{P_h}{G * A_M} * 100 \qquad (6)$$

- η_G – Overall efficiency [%]

To meet the water demand of the production unit, a minimum irradiance is required for the used 135 Wp PV module [11]. In this way, the minimum irradiance (G_{min}) was calculated using:

$$G_{\min} = \frac{P_{\min} * G_{padr\tilde{a}o}}{P_M} \qquad (7)$$

P_{min} is the minimum power required for the system to operate in the desired conditions, $G_{padrão}$ the standard global solar irradiance (1000 W/m^2) and P_M the maximum PV power output.

3. Materials and methods

For the analysis of the unit were used the analytical method of calculation and the experimental method. The financial analysis was performed by the method of internal rate of return (IRR) and the analysis of the cash flow. The analysis of cash flow was performed to assess the investment time of return using the computational tool RETScreen [12].
The production unit occupies a floor area of 134 m^2, with a reservoir of water that simulates a pond, lake or well with capacity of 3534 liters, a 12 VDC motor - pump and a 135 Wp PV module. According to Fig. 1, the measurements include: water flow, pressure, voltage, current and solar irradiance. The nominal motor power is 55 W and pump output pressure is 14 psi.

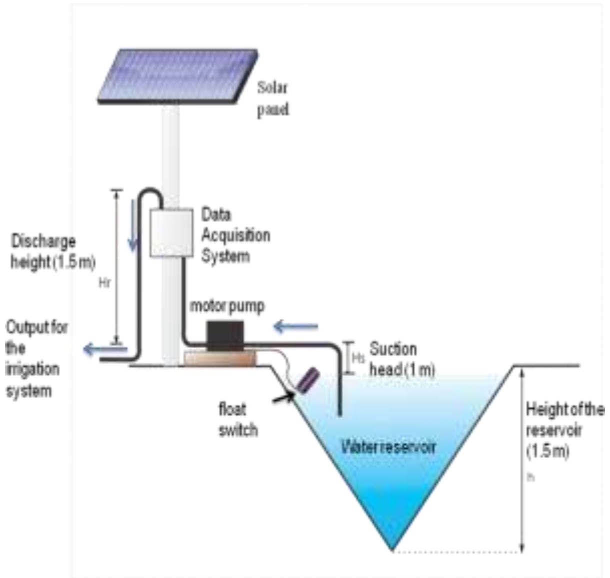

Fig.1. Diagram of the PV powered pumping system

For data acquisition, a RTF pyranometer / 82 -05, a SU7000 flow sensor, a pressure sensor PN2024, current and voltage sensors were used. The control and data acquisition is made by the SanUSB system and data transmission by the Wi-Fi system [13]. SanUSB is a computational tool for data acquisition using microcontrollers; the tool has low-cost components found in the Brazilian market and has free access (Fig. 2).

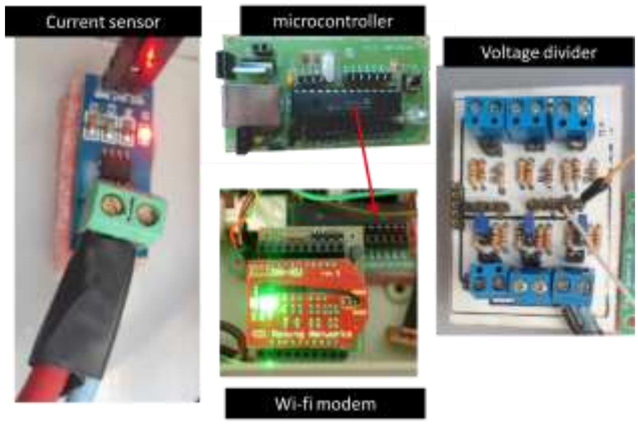

Fig.2. SanUSB system and data transmission

The irrigation system consists of 24 micro-sprinklers with a working pressure between 10 to 20 feet of water column, distributed uniformly along the circular beds (Fig. 3). Twelve micro-sprinklers installed along the sidelines are operated simultaneously, each at a pressure of 14 psi, with an average flow of 0.9 l/minute for sunny days; for cloudy days three micro-sprinklers are operated simultaneously with a pressure of 15.3 psi and flow of 1.1 l/minute. The choice of circular beds was due to some advantages such as a better cultivation area use, water efficiency for irrigation and creation of green and harmonious environments in rural and urban areas.

Fig.3. PV powered irrigation system applied to familiar agriculture

4. Results and discussion

The PV plant has the capacity to pump water during the hours of sunshine throughout the day. Figures 3 and 4 show irradiance, flow and pressure values in a cloudy and in a sunny day, respectively.

Irradiance, flow and pressure data were collected during the coriander production cycle in August and September 2014; in a second phase, the days were classified in sunny and cloudy days.

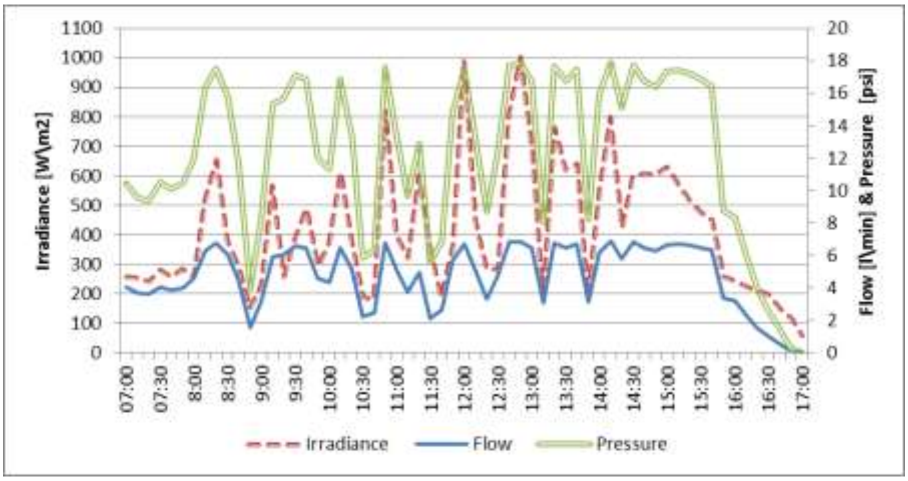

Figure 3: Irradiance, flow and pressure values in a cloudy day

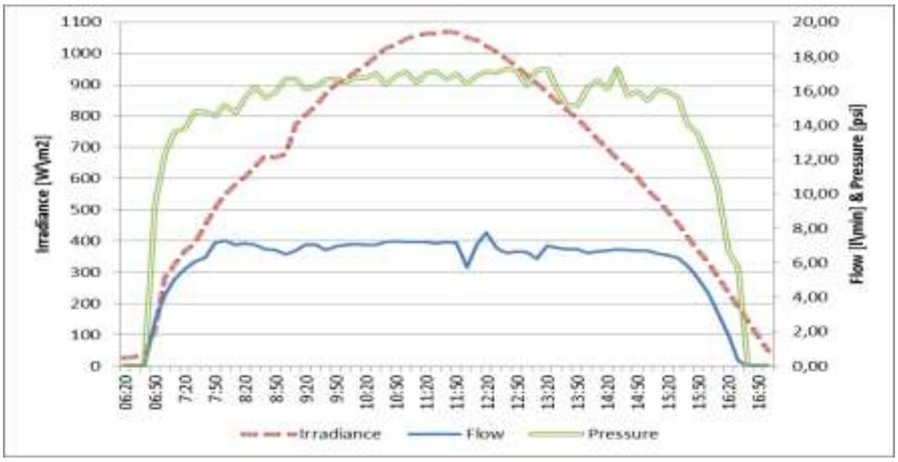

Figure 4: Irradiance, flow and pressure values in a sunny day

On September 9, 2014 (cloudy day), the flow and pressure curves followed the irradiance; solar irradiation was 4.3 kW/m^2/day, a volume of 2850 liters was pumped and the average flow was 4.75 l/min with an average output pressure of 12.2 psi.
On September 15, 2014 (sunny day), solar irradiation was 7.04 kWh/m^2/day, a volume of 3973 liters was pumped and the average flow was 6.5 l/min with an average pressure of 15.4 psi.
For irrigation of coriander, the unity daily water demand was 1600 liters in the area of 134 m^2.

PV pumping system efficiency

The obtained efficiencies are summarized in table 1.

Table 1: Obtained efficiencies

	Efficiency (%)
PV module	8.4
Motor pump	42
Overall	3.5

Financial analysis and cash flow

The cost of the PV modules and accessories and the lack of benefits provided by the PV generation in a country like Brazil, with high level of solar irradiation, are still barriers to the mass use of the technology. Advances are recorded in incentives for microgeneration and distributed minigeneration and power compensation systems (Normative Resolution 482, April 17, 2012, of the National Electric Energy Agency - ANEEL).
In the present analysis, the input variables were the monthly mean irradiation values over a year in Fortaleza, PV module tilt angle, electricity price [R$/MWh] for Ceará and defined by ANEEL and motor pump and PV generator initial costs.
Figure 5 illustrates that the cash flow becomes positive after 9,3 years of plant operation, considering a lifetime of 25 years and an internal rate of return of 12.5%.

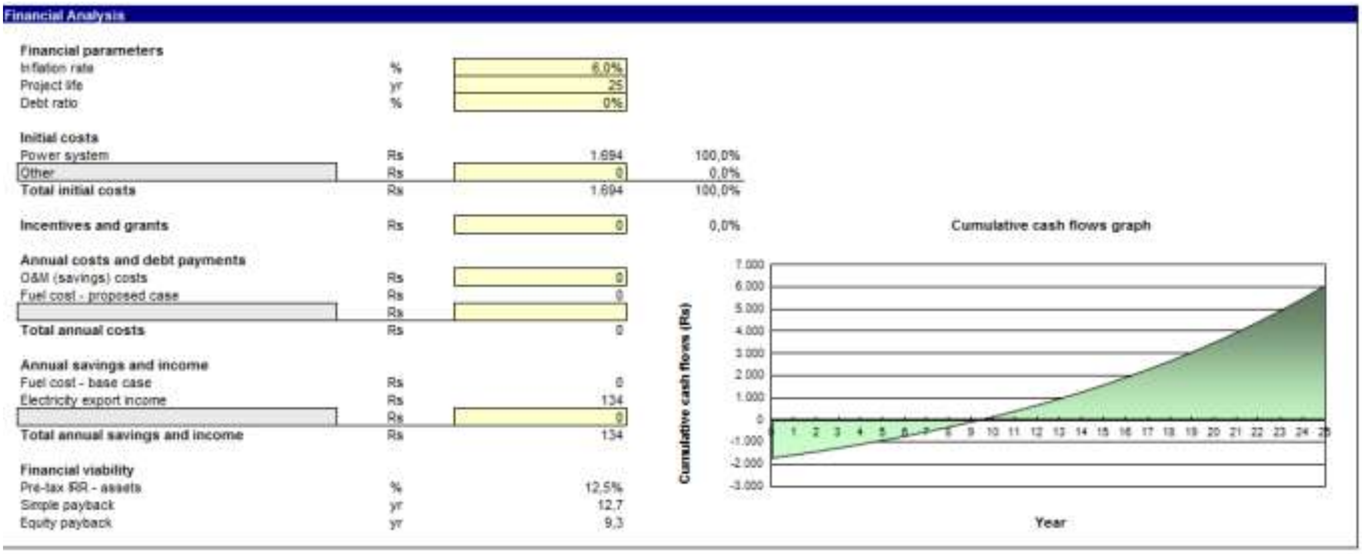

Figure 5: Cash flow

5. Conclusions

Considering technical issues, some operational conditions of the pumping and irrigation systems need to be guaranteed to adequately meet the unit demand, such as electric power and pump pressure. The results show that, using a 135 Wp PV module, a solar irradiance of 407 W/m^2 is necessary to ensure an electric power of 55 W and a pressure of 14 psi. In this way, a measured mean solar irradiance of 645 W/m^2 is enough to supply the load.

The use of circular beds allowed to save 3608 liters of water during cultivation of 69 kg of coriander, which was equivalent to the economy of 1.6 kWh of electrical energy compared to a cultivation system with conventional beds.

In the present study, the invested capital returns after 10 years, considering and internal rate of return of 10.2%.

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