International Conference on Renewable Energies and Power Quality (ICREPQ'15)
La Coruña (Spain), 25th to 27th March, 2015
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.13, April 2015

Solar and Wind powered Stand Alone Water Pumping system

Arruda. M. F. D.[1], Carvalho. P. C. M.[1], Albiero, D. J.[2], Canafistula, F.J.F. [2], Teixeira, A. S.[2]

[1] Department of Electrical Engineering
Federal University of Ceará - UFC
Campus of Pici – Humberto Monte, Fortaleza/CE (Brazil)
Phone/Fax number:+0055 85 3366 9585, e-mail: **marcelo.arruda@plc.ifmt.edu.br**, **carvalho@dee.ufc.br**

[2] Department of Agriculture Engineering
Federal University of Ceará - UFC
Campus of Pici – Humberto Monte, Fortaleza (Brazil)
Phone/Fax number:+0055 85 3366 9585, e-mail: **daniel.albiero@gmail.com**, **firmino@ufc.br**, **adunias@ufc.br**

Abstract. The purpose of the article is to verify the performance of a wind and photovoltaic (PV) hybrid plant with battery bank for water pumping. The system can be used in isolated areas without access to electricity grid.
The plant is installed at the Federal University of Ceará, in Fortaleza, Brazil. The plant consists of a wind turbine (1 kW - permanent magnet) and 4 polycrystalline PV modules (87 Wp each), 5 batteries (150 Ah each) and 1 power electronic converter (1 kW). A datalloger is used for acquisition and storage of data (wind speed, global irradiance, water flow and electrical data). The present study uses data from four non-consecutive days in November/2014 and December/2014; in the first day only PV and the battery bank supply the load.
The recorded mean flow was 25.26 L/min, showing little variation, even with intermittence of the resources, condition minimized by the energy storage. As a consequence of the energy storage, the hybrid system shows low operation request, enhancing the life cycle and consequently reducing the plant replacement costs.
.

Key words

Hybrid plant, energy storage, water pumping.

1. Introduction

The International Energy Agency (IEA) published in 2010 that 1.5 billion people worldwide have no access to conventional power grid [1]. In Brazil, the percentage of the population with no access to conventional power grid is 2.2%, mainly in the Northern region of the country [2-3]. In these cases, the electricity generation is generally done via diesel generators, which has limitations due to fossil fuel transport and CO_2 emission [4].
Additionally, according to RIO + 20, 1.6 billion people live in regions with absolute drinking water scarcity; by 2025, 2/3 of the world population may be affected by critical conditions of water supply [5]. Brazil has about 13% of the world fresh water, but this distribution is not uniform, according to the Ministry of Environment. Example of this non-uniformity is the semi-arid region, also called drought polygon, covering 9 Brazilian states and defined by Federal Law 175/1936. This Brazilian region is characterized by a high wind and solar potential. In this way, renewable sources can give a contribution to diversify the energy matrix and to supply electricity for water pumping in Brazil.

2. Materials and Methods

A wind and PV hybrid plant with battery bank for water pumping was installed in the Laboratory of Renewable Energies - LEA at the Federal University of Ceará, Brazil, downstream from a dam (Fig 7). The choice of the site was due to the local wind conditions and low roughness (Fig.7).
Due to the intermittent characteristics of the two sources (wind and solar), the hybrid plant makes use of energy storage with the function of supplying electricity when generation is lower than the load demand [6]. Fig. 1- 6 show the configuration and components of the used hybrid plant. Water pumping is done by a 1 phase 0.5 HP centrifugal pump, water being pumped into a tank 5 meters high.

A. Materials

The hybrid plant consists of:
- 1 kW permanent magnet wind turbine, stall control, installed on a 10 meters high tower;
- 4 series connected polycrystalline PV modules (87 Wp each), with an inclination of 10° N.
- 5 series connected 150 Ah electrolytic batteries;
- 1 kW converter/controller unity concatenating the generation components with the load and the battery bank;
- Datalloger;

- Cup anemometer, pyranometer, sensors for battery bank and PV panels voltage and current.
- 0.5 HP monophasic motor - pump;

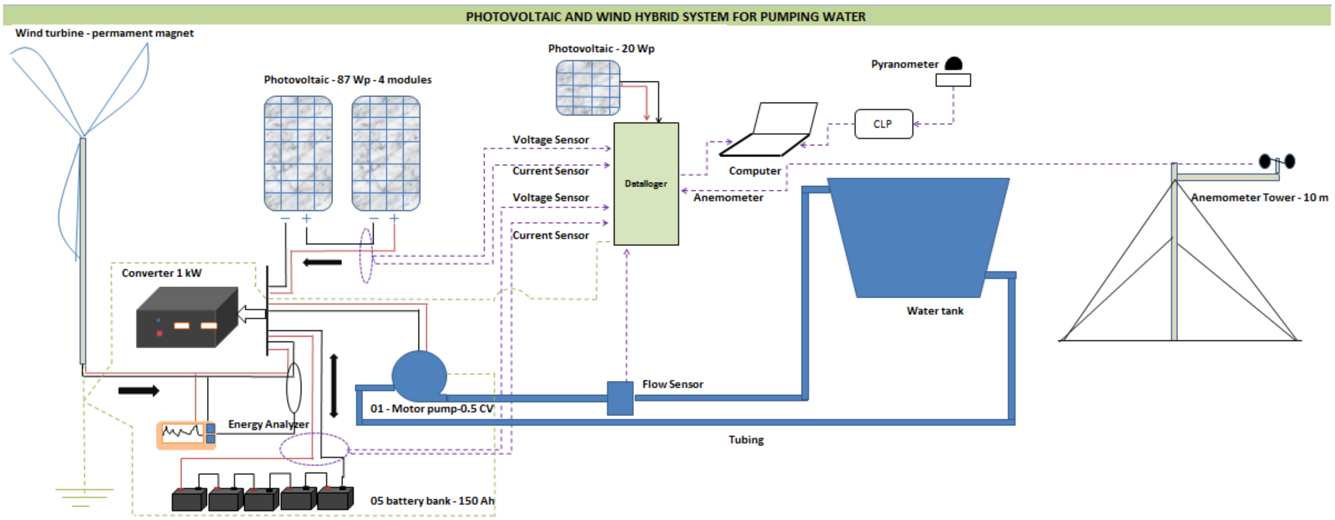

Figure 01: Hybrid plant configuration

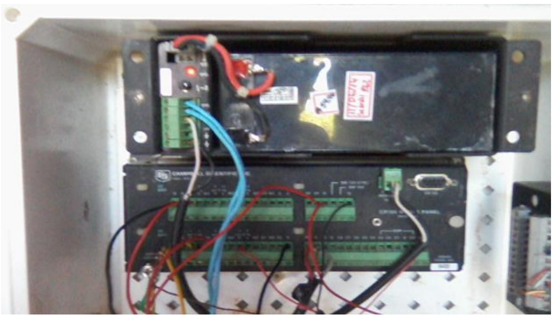
Figure 02: Dataloger


Figure 03: Wind turbine


Figure 04: Photovoltaic Modules

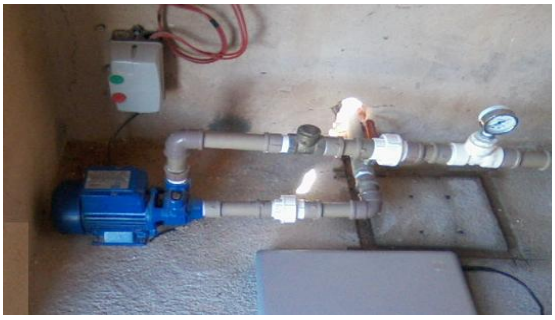
Figure 05: 0.5 HP monophasic motor - pump


Figure 06: Battery Bank

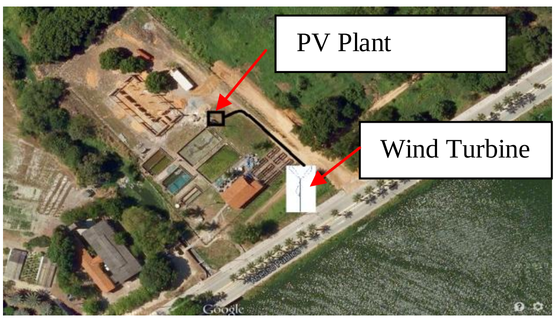

Figure 07: Hybrid plant site

B. Methods

The methodology consists of the use of statistical techniques for characterizing the wind speed (m/s) and the irradiance (W/m²) data in order to assess the potential for harnessing wind and solar resource. The electricity to be delivered by a wind converter can be calculated using [6]:

$$E_w = \sum f_i P_i T \quad (1)$$

f_i is the wind speed frequency, T the period under investigation and P_i the power data obtained from the turbine power curve [7]. For the histogram adjustment, a Weibull distribution was used [6]:

$$F_w = \frac{k}{c}\left(\frac{v}{c}\right)^{(k-1)} e^{-\left(\frac{v}{c}\right)^k} \quad (2)$$

v is the wind speed, C and k the scale and shape parameters, respectively. C and k are found by application of the empirical method [8]:

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \quad (3)$$

$$\bar{v} = C\Gamma\left(1 + \frac{1}{k}\right) \quad (4)$$

$\boldsymbol{\sigma}$ represents the wind speed standard deviation.

PV electricity production can be calculated using [9]:

$$E_{pv} = P_{pv} H_{sf} \eta_g \quad (5)$$

P_{pv} is the nominal PV power, H_{sf} the number of hours of full sun, η_g efficiency generality the system. The capacity factor is defined by the measured electricity production E_G divided by the electricity generation in rated power E_{GR} [6]:

$$C_f = E_G / E_{GR} \quad (6)$$

C. Data collection and storage

Measurements were collected and stored in a datalloger (Fig. 02). The measured electrical parameters are:

- Battery bank voltage and charge and discharge current;
- Photovoltaic panels voltage and current;
- Wind turbine current, voltage and power (apparent, active and reactive).

Other measurements include:

- Wind speed - (*m/s*) using a anemometer;
- Irradiance - (*W/m²)* using a pyranometer;
- Water flow – using a flow sensor.

The datalloger is parameterized to record an average value every 1 minute.

3. Results and Analysis

A. Site Characterization

For the characterization of the wind and solar resources the following variables were determined for the months of September, October and November, 2014 (Tab.1).

Table 1: Wind and solar resources characterization

Description	September	October	November
Shape parameter	2.84	3.02	2.44
Scale parameter (m/s)	5.01	5.33	4.08
Mean wind speed (m/s)	4.54	4,76	3,62
Mean global irradiation (kWh/m²/day)	6.39	6.94	5.79
Capacity factor – Wind	24.1 %	26.9%	13.2%
Capacity factor – PV	23,9%	25,5%	21,6%

According to the Weibull distribution, wind speed values concentrate between 4 and 6 m/s in September and October; in November and December the values concentrate between 3 and 5 m/s (Figs. 09-12). The capacity factor is calculated using the power curve of the wind turbine (Fig. 8); in the manufacturer's manual indicates that the turbine power coefficient is 0.45 [7]. Notes that the reduction in the capacity factor for the month of November in low average of the function of wind speed.

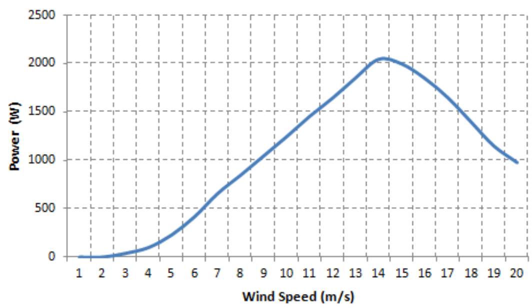

Figure 8: Power Curve of the 1 kW wind turbine

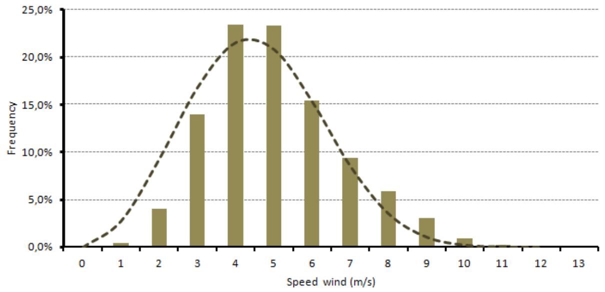

Figure 09: Weibull Distribution – September/14

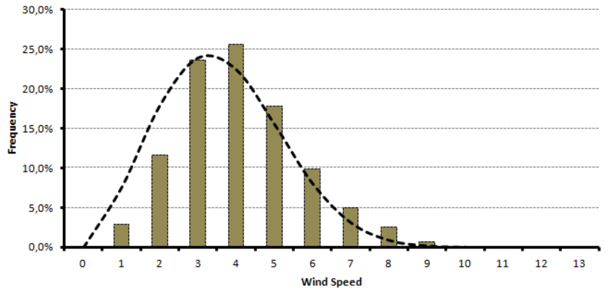

Figure 11: Weibull Distribution – November/14

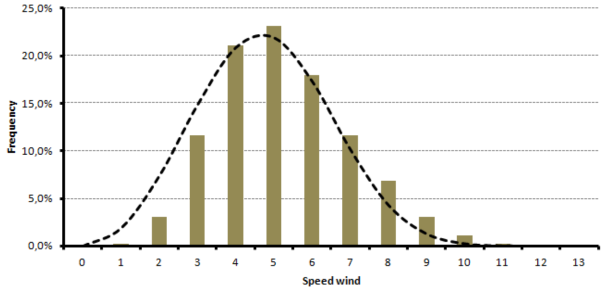

Figure 10: Weibull Distribution – October/14

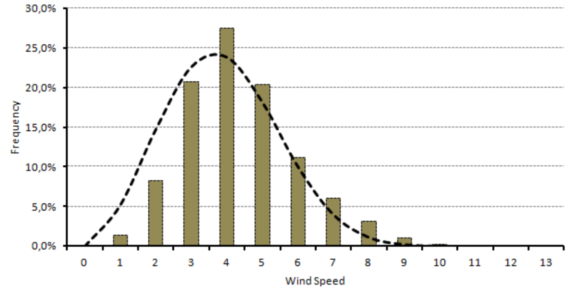

Figure 12: Weibull Distribution – December/14

Fig.13 show global irradiation values in September/14 at the plant site

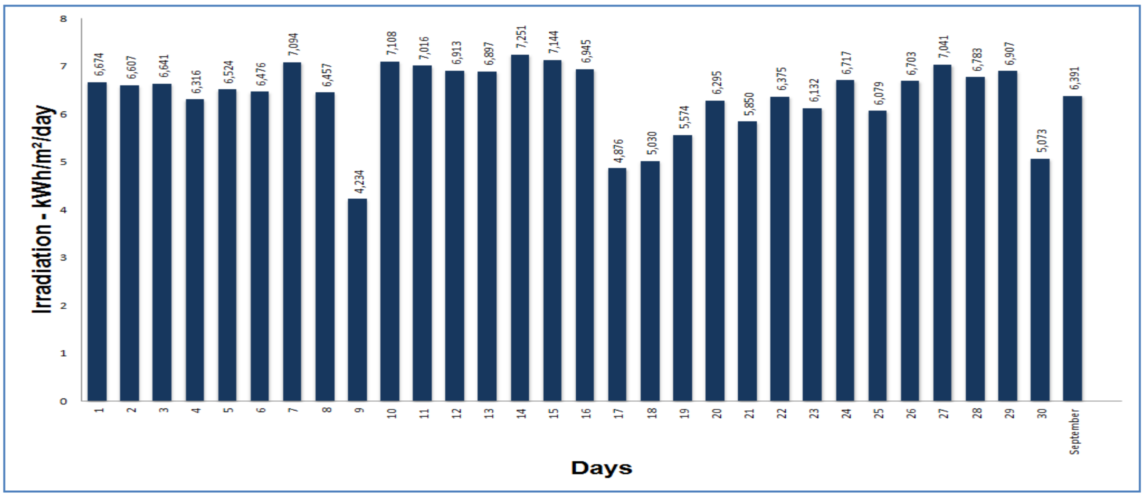

Figure 13: Mean Global Irradiation – kWh/m²/day (September/14)

B. Hybrid system

The proposed application of a hybrid plant has the advantage of the complementarity between the primary sources (wind and solar). As consequence, this strategy mitigates the dependence of the battery bank, increasing the life time of this component.

Tab. 02 and Fig. 14 show measured data for four non-consecutive operation days (November 17th and 24th, December 10th and 20th); in the first day, only a PV - battery bank configuration is used. The period of analysis is between 8:30 am and 5 pm.

For the other three days, fig. 14 shows the wind turbine, PV modules and battery bank power output and water flow (L/min). The battery bank power shows negative (discharge) and positive (charge) values. The battery participation occurs in the case of an unbalance between electricity generation and load consumption.

In the mentioned days, water flow variation was 0.56 L/min, maintained due to the balancing between electricity generation and storage. The average water flow was 25.26 L/min for the four days.

Fig.15 shows the energy balance of the components for the four mentioned days**.** November 17th shows the highest discharge rate of the period, due to the used PV - battery configuration. As expected, the use of two sources considerably reduces the battery bank participation when compared to the configuration using a single source.

According to the curves, the electricity generation using wind and solar resources was less than the required demand, characterizing an energy deficit (negative values in Fig. 15).

Table 02: Measured data for four non-consecutive operation days

Variable	November 17th	November 24 th	December 10th	December 22th
Mean Wind Speed (m/s)	3,83	5.75	5.13	4.55
Mean Irradiation (kWh/m²/day)	5.81	5.84	5.21	-
Wind Speed Standard Deviation	1.19	1.44	1.31	1.37
Mean Water Flow (l/min)	25.45	25.34	25.34	24.89

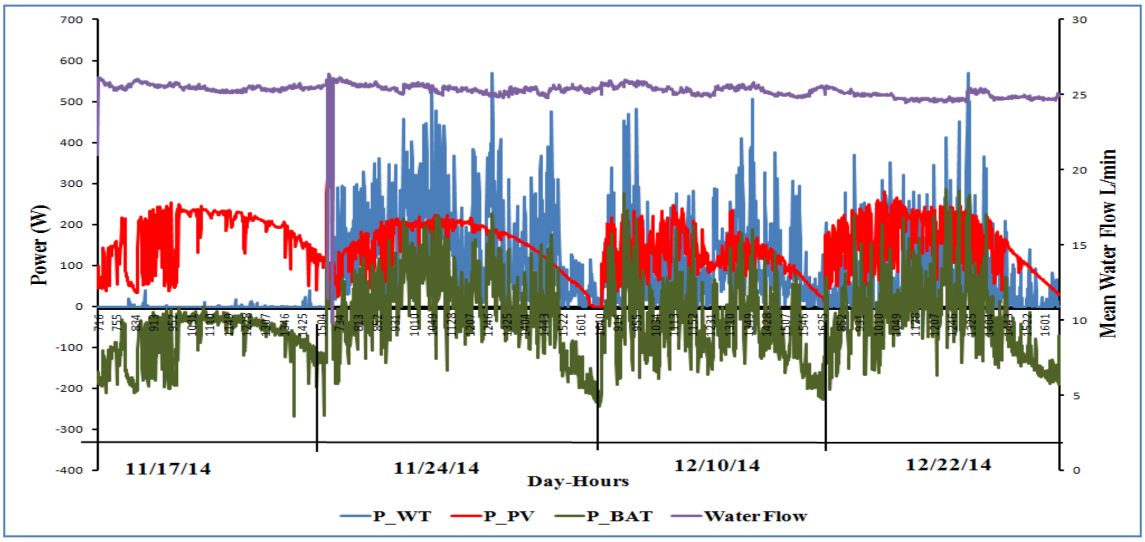

Figure 14: Wind turbine, PV and battery bank power curves

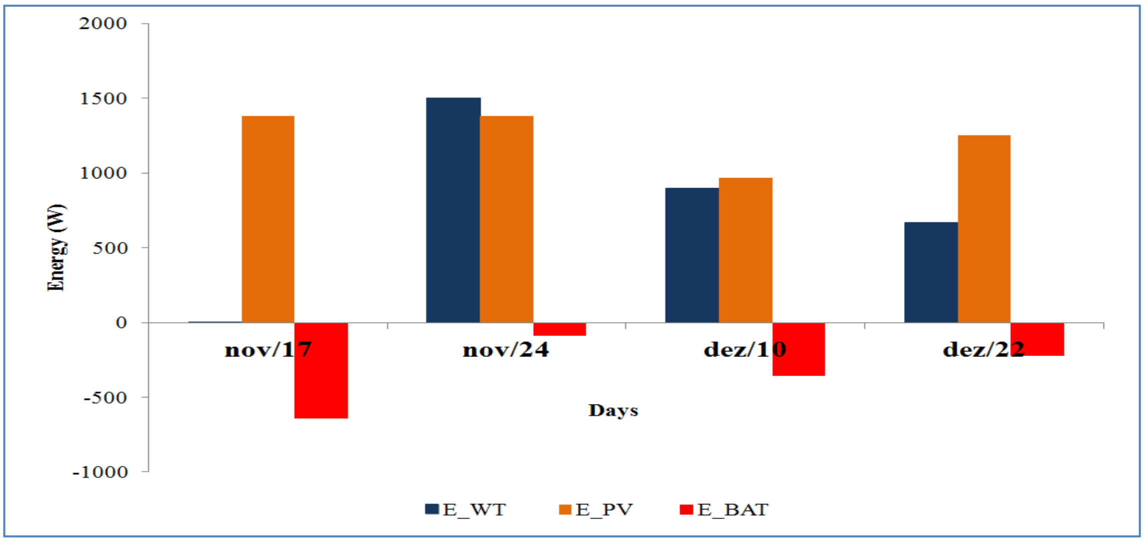

Figure 15: Energy Balance

4. Conclusions

For the period under analysis, both the wind – PV - battery bank and the PV - battery configurations are in conditions to supply the motor - pump demand. The mean water flow shows small variation even with the intermittent characteristics of the wind and solar resources; this variation is mitigated due to use of the storage unity. However, considering the balance between electricity generation and load, the wind – PV – battery bank configuration needs less energy storage than the PV - battery configuration. As a consequence of the energy storage, the hybrid configuration shows low operation request, enhancing the life cycle and consequently reducing the plant replacement costs.

Some actions can be proposed:

1) To ensure compatibility between the motor – pump operation period and the availability of the solar – wind resources.
2) To evaluate the possibility of increasing the PV participation in the hybrid configuration, considering the relative low local mean wind speed value. This increase should be based on a

financial technical analysis to determine the optimal size of the PV plant and storage system.

3) To verify the possibility of using a higher wind turbine tower (installed in this project at 10 meters); a financial technical analysis is also necessary.

4) To validate the wind turbine power curve due to the difference between manufacturer and measured data.

Acknowledgements

Electrical Engineering Department – Federal University of Ceará;
Federal Institute of Mato Grosso (IFMT);
LEA (Alternative Energy Laboratory) for the support and availability of resources and equipments;
LEMA (Mechanical and Agriculture Engineering Laboratory) for support in equipments;
CEBIAQUA for the site of the hybrid plant.

References

[1] Tao Ma, Hongxing Yang, Lin Lu, Jinqing Peng, Technical feasibility study on a standalone hybrid solar-wind system with pumped hydro storage for a remote island in Hong Kong, Renewable Energy (2014), pp 7-15.
[2] ATLAS DE ENERGIA ELÉTRICA DO BRASIL. AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA – ANEEL: http://www.aneel.gov.br. Accessed 15th October/2014.
[3] CENSO DEMOGRÁFICO 2010 CARACTERÍSTICAS DA POPULAÇÃO E DOS DOMICÍLIOS – RESULTADO UNIVERSAL. INSTITUTO BRASILEIRO GEOGRÁFIA ESTATÍSTICA - IBGE: http://www.ibge.gov.br. Accessed 14th October/2014.
[4] BORGES NETO, M. R; CARVALHO, P. C. M. Introdução à geração de energia elétrica, IF Sertão Pernambucano, Petrolina (2011), pp 216-240.
[5] FATOS SOBRE ÁGUA E SANEAMENTO. UN – UNITED NATIONS. http://www.onu.org.br/rio20/temas-agua/. Accessed 15th October/2014.
[6] CARVALHO, P. C. M., Geração Eólica, Imprensa Universitária, Fortaleza (2003), pp 11-38.
[7] MANUFACTURER´S MANUAL - WIND TURBINE SYSTEM HUMMER 1kW; http://www.brasilwindservice.com/downloads/power_output_1kw.pdf. Accessed 10th June/2014.
[8] CARNEIRO, T. C., CARVALHO, P. C. M. Caracterização de Potencial Eólico: Estudo de Caso para |Maracanaú (CE), Petrolina (PE) e Parnaíba (PI). V Congresso Brasileiro de Energia Solar, Recife, 2014.
[9] Pinho, J. T.; Barbosa, C. F. O.; Pereira, E. J. S.; Souza, H. M. S.; Blasques, L. C. M.; Galhardo, M. A. B.; Macêdo, W. N. Sistemas Híbridos: Soluções energéticas para a Amazônia. 1. Ed. Brasília: Ministério de Minas e Energia, 2008. 394p.