Autonomous Photovoltaic-Diesel System for Microproduction of Electric Energy and with Energy Storage in Batteries

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Abstract
In some African villages located at great distances from the major cities and with few inhabitants, it is still normal that access to electricity is very precarious. This is simply because it is not economically feasible to build a connection to the conventional power grid. The need to ensure 24 hour power supply makes it possible to take into account the use of an autonomous hybrid system to make small houses self-sufficient in energy terms at a low infrastructure price.

In that context, this paper studies and tests the technical feasibility of a hybrid autonomous system with a rated power of 500W to provide electrical power to houses in rural areas that do not have access to the conventional power grid. The base system under study is composed of photovoltaic panels, a $LiFePO_4$ battery pack, a Battery Management System (BMS) and a DC/AC single-phase inverter. This base system is supported by a diesel electric generator that will be responsible for supplying power when the base system fails or can not meet the energy demand of the moment. The aim was thus to create a system capable of supplying power without any interruption. All the experimental tests were performed under real conditions and at different times of the year. And they allowed it to be concluded that the system has the capacity to supply energy to the load considered without any interruption.

Keywords: Autonomous hybrid system; Photovoltaic System; Diesel generator

1. Introduction

Angola is a country with many localities completely isolated from the world and with few available resources in health, education and electricity that are basic and essential elements to the modern Man. One way to combat this low level quality of life is to develop the energy sector of this country, since energy is one of the essential factors for improving the living conditions of the population and for the economic growth of a country [1]. By making electricity available, the health and education sectors will be positively affected. The problem is then to provide energy to these isolated communities at an affordable cost and to obtain a minimally reliable solution. The reasons for these localities not having electricity available through the conventional network are due to the fact that these are located at great distances from the major cities, the natural barriers and the lack of interest on the part of the concessionaires due to the high cost involved. Schmid e Hoomann [2], also point out that the poorest populations, without access to diesel or groups of diesel generators, are obliged to use dry batteries and automobile batteries as alternatives to have access to electricity. These alternative sources are transported over long distances, making it an expensive and inefficient option.

Thus, this paper intends to perform an analysis to a possible solution to this problem, a hybrid autonomous system formed by a set of photovoltaic panels, a bank of batteries and a diesel generator. This analysis will be made taking into account the technical factors associated with such.

2. System Componentes

The figure 1 shows the scheme of the autonomous hybrid microgeneration system that was implemented in the *Laboratório de Máquinas Elétricas* (LME) at *Instituto Superior Técnico* (IST), in order to test the technical feasibility of the same.

The solid lines of the figure 1 represent direct links, whereas the dashed lines represent the connections of the control system (BMS). The BMS has the function of monitoring certain parameters of the battery and it acts on a relay that opens or closes the circuit allowing the transit of energy or preventing it. This way, it is possible to protect

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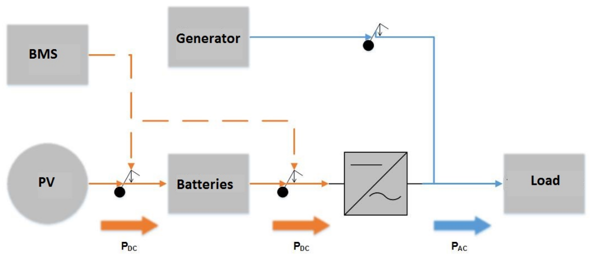

Figure 1: Block diagram of the system (source [3]).

the battery bank from overcharging or extreme discharges.

For the simulation of this system, several models were used. The sections that follow are intended to explain all the models used in the simulation.

2.1. Photovoltaic Panel

In this section it is presented the simplified mathematical model that represents the silicon photovoltaic converter, called three parameters and one diode model. As the name indicates for this model it is necessary to calculate three parameters (m, I_0, I_S). The expressions 1, 2 and 3 allow us to calculate these parameters.

$$I_{cc}^r = I_S^r \tag{1}$$

$$m = \frac{V_{MP}^r - V_{ca}^r}{V_T^r \ln\left(1 - \frac{I_{MP}^r}{I_{cc}^r}\right)} \tag{2}$$

$$I_0^r = \frac{I_{cc}^r}{e^{\frac{V_{ca}^r}{mV_T^r}} - 1} \tag{3}$$

These expressions do not take into account the irradiance and temperature factors that will affect the energy production of the panel, so it is necessary to make some changes to these expressions and based on practical results it was concluded that the diode ideality factor is always constant and that the other two parameters vary according to the expressions 4 and 5 [4].

$$I_0 = I_0^r \left(\frac{T}{T^r}\right)^3 e^{\frac{N_s \epsilon}{m}\left(\frac{1}{V_T^r} - \frac{1}{V_T}\right)} \tag{4}$$

$$I_{cc} = I_{cc}^r \frac{G}{G^r} \tag{5}$$

With all the calculated parameters it is possible to calculate the maximum voltage, V_{MP} and the maximum current I_{MP} that the panel can provide, through the expressions 6 and 7.

$$V_{MP} = mV_T \ln\left(\frac{\frac{I_{cc}}{I_0} + 1}{\frac{V_{MP}}{mV_T} + 1}\right) \tag{6}$$

$$I_{MP} = I_{cc} - \left[I_0\left(e^{\frac{V_{MP}}{mV_T}} - 1\right)\right] \tag{7}$$

Consequently, the maximum power that the panel can supply is given by the expression 8.

$$P_{MP} = V_{MP} I_{MP} \tag{8}$$

2.2. Diesel Generator

To simulate the generator, it was decided to use an uncomplicated and simple reasoning.

A switching system, created and developed in the LME, does not allow the generator and the main system (photovoltaic panels, batteries, inverter) to supply the load simultaneously. Thus, the load is connected to the main system or to the generator. But never both simultaneously. It can be said that when the generator is working it only supplies power to the system load and not to any other component of the system

From data provided by manufacturers, an estimate of the fuel consumption for 2200W generators was reached. The manufacturers claim that a 2200W generator with a 15L tank can work at maximum for 14 hours. this is equivalent to saying that the generator has a consumption of $1.0714L/h$. It would be interesting to see what fraction of this consumption corresponds to the losses of the generator. To this end, the following reasoning was followed.

A 2200W generator is capable of producing 2200Wh. By doing the conversion of Wh to Joules (9) we obtain that the generator is able to produce:

$$2200Wh * 3600 = 7920000J \tag{9}$$

Taking into account the relationship that a liter of gasoline is able to provide 32.18MJ of energy. It is possible to estimate how much fuel is consumed to produce 2200Wh. (expression 10).

$$\text{Consume [L]} = \frac{7920000J}{32.18MJ} = 0.24616L \tag{10}$$

Thus, $0.24616L/h$ is the consumption needed for the generator to be able to produce 2200W. It is easy to reach to the consumption of losses using the expression 11.

$$C_P = C_T - C_U \tag{11}$$

Where:

- C_P - Consumption due to generator losses.
- C_T - Total consumption given by the manufacturer $(1.0714L/h)$
- C_U - Consumption needed to produce 2200W $(0.2461L/h)$

Thus, using the expression 11 it was possible to calculate that the generator consumes $0.8252L/h$ due to the losses that exist in the generator.

With this known value it is possible to calculate the generator consumption through the equation 12.

$$C_{total} = C_{Perdas} + C_{carga} \tag{12}$$

C_{carga} is the fuel needed to produce the power to supply the load.

2.3. Batteries

In the simulation of the batteries, the essential thing is to be able to know what the evolution of the SOC is and how it varies over time depending on the different operating conditions of the system. For this it is necessary to know the power that flows in the batteries. Using the expression 13 it is possible to calculate that power.

$$P_B(k) = P_{PV}(k) - P_L(k) \tag{13}$$

Where:

- $P_B(k)$ - It is the instantaneous power to carry on the batteries.
- $P_{PV}(k)$ - It is the instantaneous power provided by the panels.
- $P_L(k)$ - It is the instantaneous power that the load is consuming.

Knowing the value of the power that circulates in the batteries, it is possible to calculate the capacity of the batteries through the expression 14.

$$C_B = C_B(0) + K_D(\Delta t \sum_{k=1}^{n} P_B(k)) \tag{14}$$

Where:

- $C_B(0)$ - It is the initial capacity of the battery at the beginning of its lifetime.
- $P_B(k)$ - It is the instantaneous power of the batteries.
- Δt - Time step.
- K_D - Constant associated with battery lifetime.

Thus, one already has all the necessary terms to calculate the SOC of the battery, using the expression 15 [5]:

$$SOC(k+1) = SOC(k) + \frac{P_B(k).\Delta t}{C_B(k)} \tag{15}$$

2.4. Battery Management system

As already mentioned, the BMS is the component responsible for controlling the flow of energy throughout the system. The same happens in the model created throughout this paper. Code was developed to control the system in the same way that BMS would actually do. In the figure 2 it is possible to verify a flowchart that represents the basic and simplified behavior of the code developed to simulate the BMS.

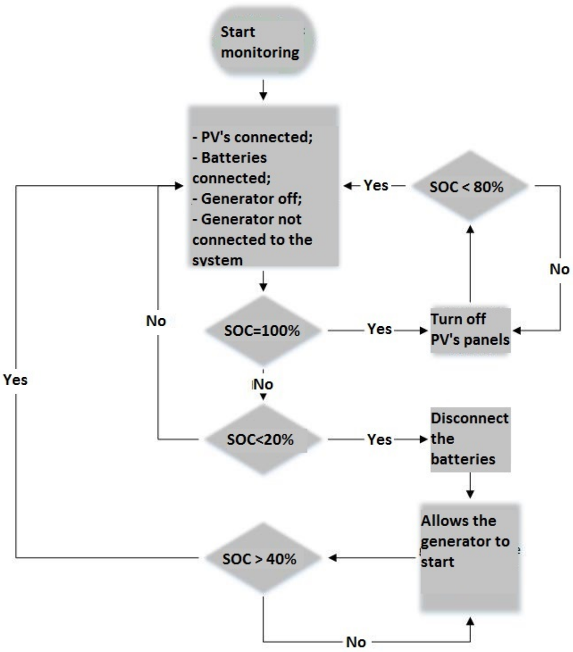

Figure 2: Flowchart of the behavior of the BMS during its operation.

It is important to note that the SOC values that cause the BMS transition from one state to another may vary because they are programmable by the user.

2.5. Electric Load

For the simulation, it was considered the values that were obtained in experimental measurements carried out at the loads. It was on the basis of these measurements that it was possible to obtain a daily load profile. To obtain this profile it was considered that:

- The refrigerator works twenty-four hours a day and consumes an average of 60.07W per hour.
- The television is only switched on at eight and stays on for two hours and consumes an average of 24.95W per hour.
- The lighting is switched on at eighteen and turned off at midnight and consumes 75W per hour.

Taking all these points into account, we obtained a daily load profile for the simulation of Angola. This profile is represented in the figure 3.

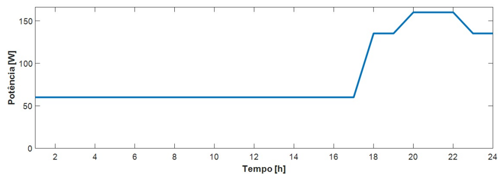

Figure 3: Daily load profile.

3. Results & discussion

In the experiments carried out, it was intended to study the power flow of the system. Thus, this section presents the practical and simulated results for the system installed in Lisbon and the results of the simulation using the meteorological data of Angola. The simulation of the system in Angola allow to study the feasibility of the system in this place.

Three different system operating situations were studied:

- **Situation A** - The SOC of the batteries reaches 100%.
- **Situation B** - The system works with a SOC that does not reach the maximum or minimum stipulated.
- **Situation C** - The System achieves the minimum SOC.

3.1. Situation A - Battery SOC reaches 100 %

As already mentioned, test A had the objective to study the behavior of the system when the SOC of the batteries reach 100%. To facilitate the performance of the assay and to allow the SOC to reach 100% faster, in this assay the system was not connected to any type of load. In other words the system was only receiving power from the solar panels.

Test A was performed on September 6, 2017, starting at 10:42 a.m. and ending at 12:52 p.m. During this period the evolution of irradiance and temperature were recorded and are represented in the figures 4 and 5 respectively.

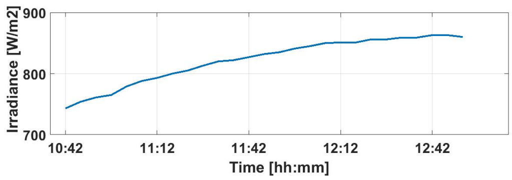

Figure 4: Solar irradiance.

Taking into account the figures 4 and 5, it is possible to estimate the power that the photovoltaic panels can produce.

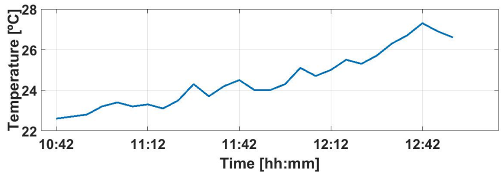

Figure 5: Temperature.

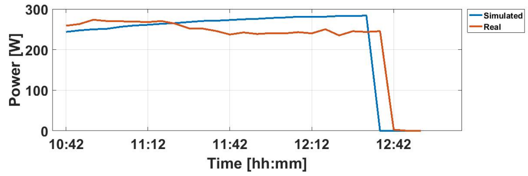

Figure 6: Real power and simulated power produced by the photovoltaic panel.

The figure 6 shows the estimation of the power produced by the photovoltaic panels and the actual power produced.

Although the system is not supplying power to any load, it must be borne in mind that the system itself has some energy-consuming elements, such as the inverter. Thus, this consumption was measured during the test and is represented in the figure 7.

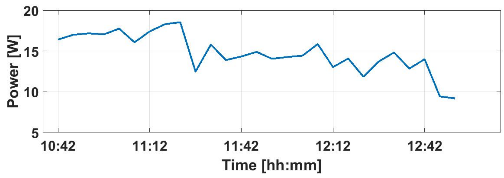

Figure 7: Power of the load.

With all these data it was possible to simulate the power flow in the batteries, the figure 8 shows the power in the batteries, both the simulated power and the real power. Do not forget that a negative power indicates that the batteries are charging and a positive power means that the batteries are discharging.

With the power flow of the batteries, (figure 8) it is possible to calculate the evolution of the SOC of the batteries. The results of the simulated SOC and the real SOC are shown in the figure 9.

As the generator did not start up or provide power to the load, the power supplied by the generator is zero. Therefore it was decided not to present the graph with the power of the generator, since this is not relevant in this situation.

3.1.1 Conclusions on the situation A

From the figures presented in section 3.1 it is possible to observe the behavior of the elements of the system, when the SOC reaches 100%. As it would be expected when the SOC reaches the maximum value (this happens around 12:35 p.m.) the photo-

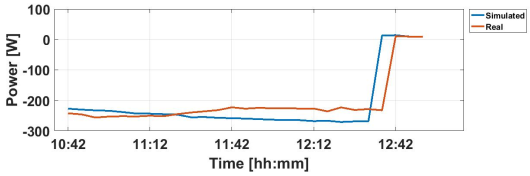

Figure 8: Power flow of the batteries.

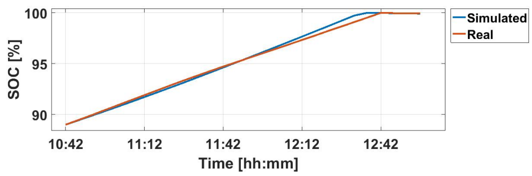

Figure 9: SOC of the batteries.

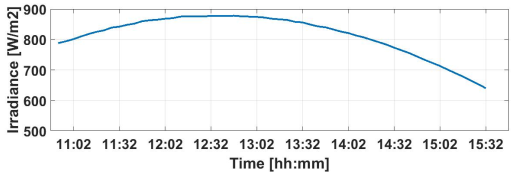

Figure 10: Solar irradiance.

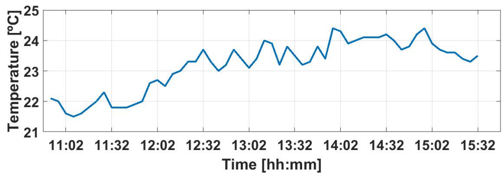

Figure 11: Temperature.

voltaic panels are switched off and do not provide more energy to the batteries.

It is possible to see that the panels have been turned off, since in the figure 6 the power reaches null values approximately at the same time that the SOC reaches its maximum value. And the batteries stop being charged, something visible in the figure 8 where the power of th batteries reaches a value almost nill.

As for the results of the simulation, these present a behavior similar to reality. It is only important to highlight that the maximum SOC was achieved slightly earlier than in reality (about 10 minutes gap). But such a result would be expected, since the simulated power that was being supplied by the photovoltaic panels presents a higher value than in the reality.

Thus, for situation A and taking into account the results presented in this section, it is possible to conclude that the real system behaves as expected and the simulation can predict and behave in a similar way to reality.

3.2. Situation B - SOC does not reach the maximum or minimum stipulated.

Assay B aimed to study the behavior of the system when the SOC of the batteries does not reach 100%, nor does it reach the user-defined minimum SOC. In this test all elements of the system are connected (photovoltaic panels, batteries, inverter and refrigerator).

Test B was performed on September 5, 2017, starting at 10:52 a.m. and finished at 3:32 p.m. The evolution of the irradiance and the temperature during the test are represented in the figures 10 and 11 respectively.

As in the previous test the evolution of the irradiance (figure 10) and the temperature (figure 11) allowed to estimate the power that the photovoltaic panels can produce. The figure 12 shows the result of the simulation of the power produced by the photovoltaic panels and the actual power produced.

The behavior of the load and the power consumed by it was controlled and recorded throughout the test. The result of this measurement can be observed in the figure 13.

With the behavior of the load (figure 13) and knowing the value of the power produced by the photovoltaic panels, it is possible to estimate the power flow of the batteries (figure 14).

From the power flow of the batteries (figure 14), it is possible to estimate how the SOC of the batteries evolves over time. In the figure 15 it is possible to observe the estimated SOC and the actual SOC for the assay of situation B.

Similarly to test A, in this test the generator was also not required. Therefore the power supplied by it is zero. For this reason, it is considered irrelevant to represent the power evolution provided by the generator in this test.

3.2.1 Conclusions on the situation B

In this test it is possible to verify that, in general, the simulation was able to reproduce the behavior of the system. There are only small differences not exceeding 50W between the simulated power of the panels and the actual power supplied by them.

Such differences gave rise to differences in SOC, a difference never greater than 2% between simulated and real SOC.

It is important to note that in the last minutes of the simulation there is a marked difference between the simulated results and the real results. This is because the weather station is not in the same place as the photovoltaic panels. So the station provided data showing that there was still sunlight (which implies that the panels provide energy), but what actually happened is that the power produced by the panels was virtually nil, since the panels were no longer receiving solar light.

This was one of the main obstacles with the system installed in Lisbon. It was not possible to take advantage of all the sunlight during the day, be-

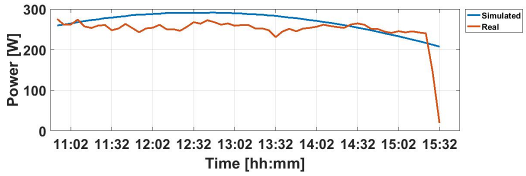

Figure 12: Real power and simulated power produced by the photovoltaic panel.

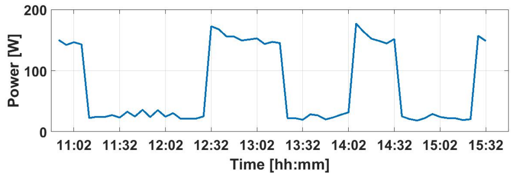

Figure 13: Power of the load.

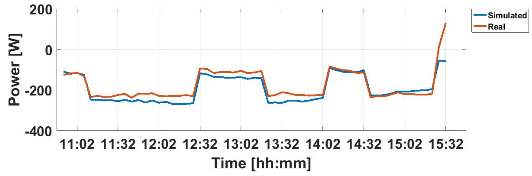

Figure 14: Power flow of the batteries.

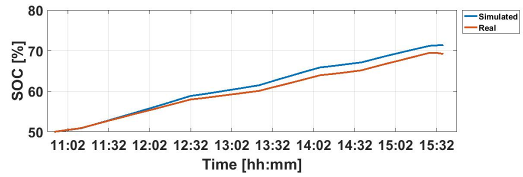

Figure 15: SOC of the batteries.

cause around 14h/15h the solar panels stopped receiving sunlight. Thus, in order to minimize this problem all the tests were performed in periods during which this situation did not occur.

From test B it is possible to conclude that the simulation can behave like the real system. Except for periods after 2 p.m.. In this case it would be necessary to obtain irradiance and temperature data at the place where the solar panels were located and the data from the IST weather station could no longer be used.

3.3. Situation C - The System reaches the stipulated minimum SOC

The test C consisted of studying the behavior of the system when the SOC of the batteries reaches the minimum stipulated by the user. In order to make it easier to carry out the test and to allow SOC to meet the minimum stipulated more easily, it was decided to switch off the panels of the system, which made it impossible to charge the batteries and consequently, the SOC reduction occurred more quickly.

Test C was performed on September 7, 2017, starting at 2:50 p.m. and ending at 6:45 p.m. For this particular test, as the photovoltaic panels were disconnected from the system, it became irrelevant to present the evolution of the power produced by them, since this was null. Also the graphs of irradiance and temperature are not presented, since this information was only relevant for the simulation of the photovoltaic panel.

The behavior of the load and the power consumed by it, was controlled and recorded throughout the test. The result of this measurement can be seen in the figure 16.

With the behavior of the characterized load (figure 16), it is possible to simulate the power flow of the batteries (figure 17).

Based on the information in figure 17, it is possible to estimate the SOC of the batteries throughout the test. The figure 18 shows the evolution of the real and the simulated SOC for test C.

In test C, the generator started and supplied power when the SOC reached the stipulated minimum. The figure 19 shows the evolution of power supplied during test C.

Using the logic of the section 2.2 it was possible to estimate that during test C the fuel consumption of the generator was $0.8292L/h$. In this small test, there was therefore a consumption of about $0.95L$ of gasoline.

3.3.1 Conclusions on the situation C

In this test it is possible to verify that the simulation behaved in the same way as the system in reality.

For this particular test and until about 05:05 p.m., the simulated results were exactly the same as the real results. This is due to the fact that the panels were disconnected from the system, which caused the inputs provided to the simulation to give rise to the same data.

As expected the batteries stopped supplying the load around 5pm. This is due to the fact that SOC has reached the stipulated minimum of 25% (figure 18).

The switching system detected the lack of power from the batteries and therefore connected the generator to the load. Thus allowing the generator to supply power to the load (figure 19). Through this graph it was possible to estimate that the amount of fuel consumed by the generator during the experiment was $0.95L$.

In figure 18 it is possible to verify that the actual SOC continues to decrease even after the batteries are disconnected, but this is due to the inverter and the sensors that continue to consume a little energy even when the batteries are turned off.

From test C it is possible to conclude that the simulation can behave in a similar way to the real system.

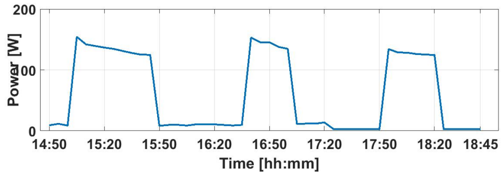

Figure 16: Power of the load.

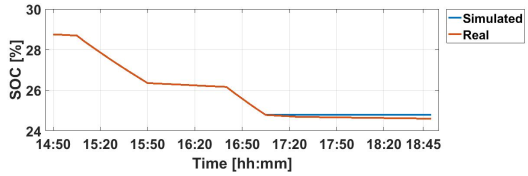

Figure 18: SOC of the batteries.

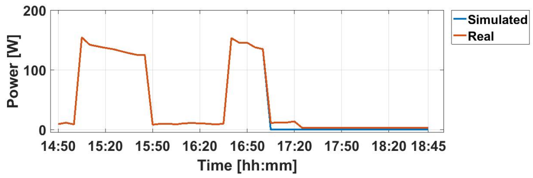

Figure 17: Power flow of the batteries.

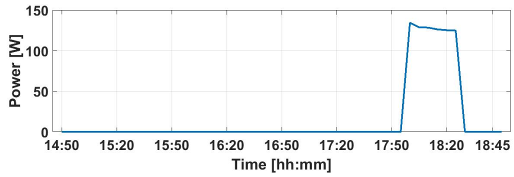

Figure 19: Power supplied by the generator.

3.4. Results of the simulation for Luanda-Angola

After the tests performed in the system installed in Lisbon and the respective analysis of the results obtained in the simulations. It was possible to conclude that the simulation can simulate the behavior of the real system. Thus, the next step was to use the program created to achieve the behavior of the system if it was installed in Angola. The objective was to test the system in the Luena region, but since it was not possible to obtain data on the temperature and irradiance of this zone, it was decided to carry out the simulation for a system located in Luanda.

For the simulation of the system in Angola, it was considered that it would be convenient to test the system in a winter month and a dry season month. Taking this into account, two simulations were carried out, one for the month of July and another for the month of January.

3.4.1 Simulation for January

In the simulation for January the following average daily data for the temperature (figure 20) and for the irradiance (figure 21) were used. In the case of irradiance and in order to make this simulation closer to reality, we opted to try to simulate the effect of clouds and good/bad weather conditions. For this, a multiplicative factor was created that evolves according to the figure 22. A multiplicative factor equal to one implies that on that day the irradiance was equal to the monthly average. A factor less than one means an irradiance below the monthly average and a factor greater than one means an irradiance above the monthly average. Using the multiplicative factor, the irradiance during the month of January used in the simulation can be observed in the figure 23.

For the load behavior, the estimated profile in the 2.5 section of this document was used, which gave rise to the graph of the figure 24.

Based on these inputs. The simulation was performed by obtaining the power supplied by the solar panels (figure 25), the power of the batteries (figure 26), the SOC of the batteries (figure 27) and the power the generator provided to the load (figure 28).

From the figure 28 and having access to the data provided by the simulation it was possible to perform the calculations explained in section 2.2.

Thus, it was estimated that for January the generator works about 157 hours and on average gave to the system $63W$. This implies that about $131L$ of fuel is consumed. What for the case of the generator used means that it had to be replenished 9 times throughout the month.

3.4.2 Simulation for July

In the simulation for July the following daily data were used for the temperature (figure 29) and for the irradiance (figure 30). As in the simulation for January, in this simulation the same multiplicative factor was applied to the irradiance (figure 22), thus obtaining the irradiance throughout the month of July (figure 31).

For the behavior of the load, the same load of the simulation performed for the month of January was used (figure 24).

Based on these inputs, the simulation was performed by obtaining the power supplied by the solar panels (figure 32), the power of the batteries (figure 33), SOC of the batteries (figure 34) and the power that the generator supplied to the load (figure 35).

Following the same procedure as in the previous simulation, from the figure 35 and having access to the data provided by the simulation it was possible to perform the calculations explained in section 2.2.

Thus, it was estimated that for July the generator works about 44 hours and on average gave the system $62W$. Which means that in this simulation were consumed about $37L$ of fuel. Which implies that the generator had to be replenished 3 times

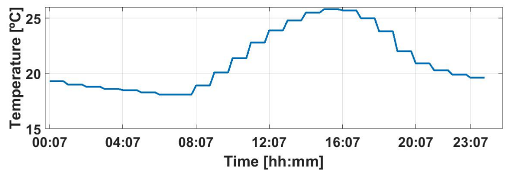

Figure 20: Daily average temperature in January.

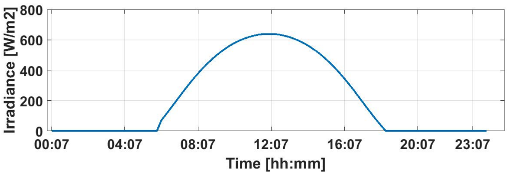

Figure 21: Daily average irradiance in January.

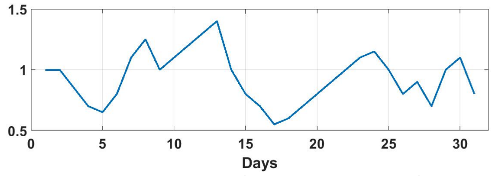

Figure 22: Evolution of the multiplicative factor.

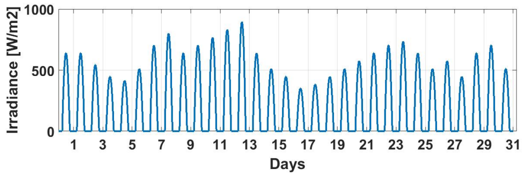

Figure 23: Irradiance throughout January.

during the month of July.

3.4.3 Conclusions on simulations

Regarding the simulation performed for the installation of the system in Luanda, there are several aspects that it is important to highlight and are now presented:

- **Power provided by photovoltaic panels** - It is possible to verify, as expected, that the panels can deliver a higher power in July (around $74W/month$ on average) than in January (about $64W/month$ on average). This is due above all to the climatic conditions. The system is exposed to a higher irradiance in July (about $240W/m^2/month$) than in January (about $200W/m^2/month$) as such panels can produce more energy during July than during the month of January.

- **SOC of the batteries** - In the SOC there are also differences, namely it is possible to see that during the month of January the SOC reaches the minimum stipulated more times than in July and never reaches the maximum SOC. In July, the maximum SOC is reached once. On average the SOC during January was about 39% and in July it was about 54% which has serious implications on the behavior of the generator.

- **Power consumed by generator** - The differences, although minimal in some cases, referred above have a great impact on the power supplied and the fuel consumption of the generator. In the simulation of the system for January it is possible to verify that the energy produced by the panels was not as high as in July. This affected the SOC of the batteries and as a consequence the generator was forced to work more often and for longer time in January than in July. This is reflected in the fuel consumed by the generator, in January the fuel consumed is on average equal to $4.2L/day$ whereas in July this value is equal to $1.2L/day$.

Taking these points into account, it is possible to verify that the system has more difficulty in supplying electric energy without resorting to the generator during the rainy season. Mainly due to the great cloudiness during this period which affects the photovoltaic generation of energy, as for the dry season the system no longer depends so much of the generator to supply energy to the load. This assertion occurs when we analyze that during the month of January the generator supplied power to the load for 21% of the simulation time while for the month of July this value dropped to 6%.

4. Conclusions

This paper addressed the supply of electricity to a rural house, typical of the Angolan region, using an autonomous hybrid photovoltaic-diesel system with energy storage in batteries. The system developed in Lisbon proved to be able to feed a typical load and showed that the MATLAB model can reproduce the behavior of the system in different situations. The same model was used to simulate the behavior of the system if it were installed in the Luanda region of Angola.

The results of the simulation showed a production of energy for the months of the dry season (that occurs between May and September), almost able to feed the load during a great part of the time of operation of the system, with the exception of a few moments, where it was necessary the generator to provide power to the load. As for the months of the rainy season (between September and May), the system has already relied more on the diesel generator when compared to the dry season months. The diesel generator during January was responsible for powering the load for 21% of the system's uptime as opposed to July where it only powered the load for 6% of the

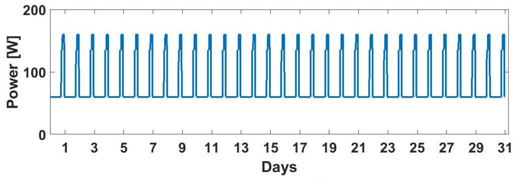

Figure 24: Power of the load.

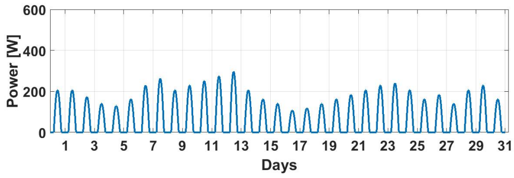

Figure 25: Power supplied by photovoltaic panels during January.

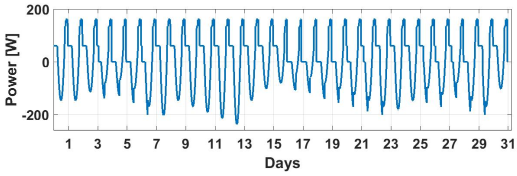

Figure 26: Power in the batteries during January.

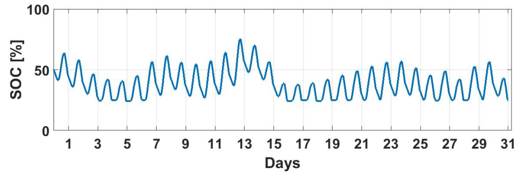

Figure 27: SOC of the batteries during January.

system's uptime. This was reflected in the fuel consumption, for January an average fuel consumption of $4.2L/day$ was obtained, a value about 4 times higher than the average consumption of July, $1.2L/day$.

For batteries, they should not be charged or discharged excessively. It should also be avoided to have unbalanced cells as this leads to a shorter battery life when compared to a system having balanced cells. Thus, a BMS was used that allowed to control the SOC of the batteries and to prevent such situations from happening. The BMS should consume as little energy as possible, as it "drains" energy continuously to power the installed sensors. In the case of this paper the consumption of the BMS is minimum, about 0.3W.

Considering the results of the simulations and practical tests obtained during this paper, it is believed that this type of system is a technically feasible solution to provide energy to the dwellings of remote regions. In the future, it is expected to see a growing investment in this type of system by developing countries, such as Angola.

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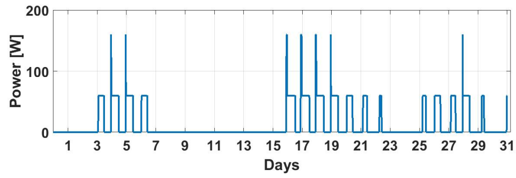

Figure 28: Power supplied by the generator during January.

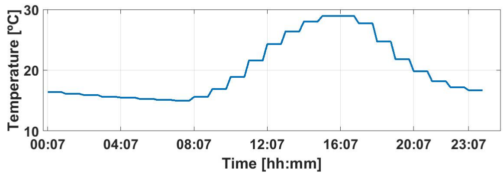

Figure 29: Daily average temperature in July.

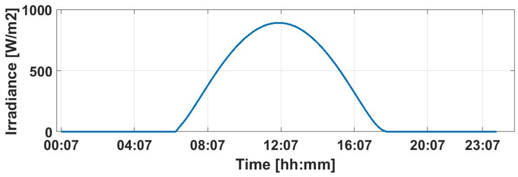

Figure 30: Daily average irradiance in July.

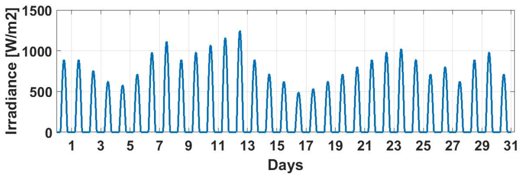

Figure 31: Irradiance throughout July.

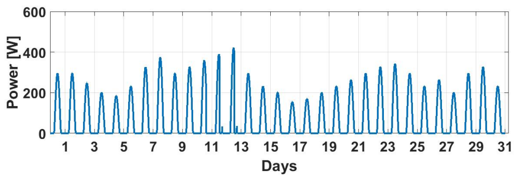

Figure 32: Power supplied by photovoltaic panels during July.

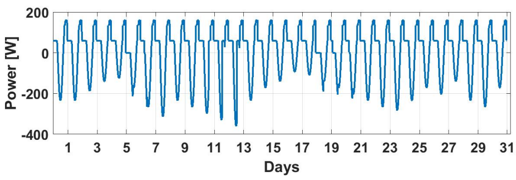

Figure 33: Power in the batteries during July.

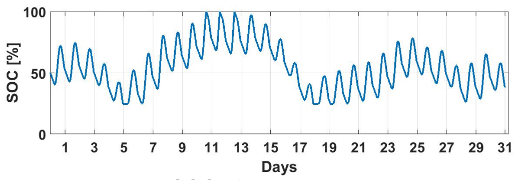

Figure 34: SOC of the batteries during July.

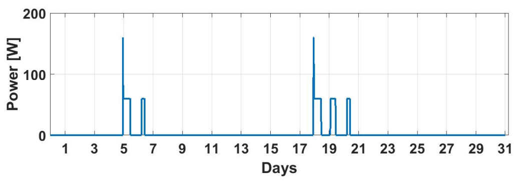

Figure 35: Power supplied by the generator during July.