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Project Of Power Generator Parasol Through Photovoltaic Panels

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Abstract: *This project aims to elaborate the construction of a prototype of parasol which captures solar energy through portable photovoltaic panels. The great motivation for this project is the creation of a product capable of providing clean energy in regions where it would not be possible, such as open fields and beaches, in addition to the possibility of using this product in open area of restaurants and bars, thus offering greater convenience to customers. This work deals with a study of how photovoltaic panels work, as well as calculating their energy intake and energy efficiency. Other factors, such as specification of materials and electronic devices, were also addressed and studied, resulting, at the end of the Project, in the idealization of a parasol with ideal solar capture.*

Keywords: *Solar energy, Portable, Clean Energy.*

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I. INTRODUCTION

Oil occupies a leading position in the energy sources scene, according to the International Energy Agency (2016). As per Soares, Y. (2018) the global energy demand is expected to grow by more than 25% by 2040 and it will require twice as much investment in oil extraction projects. However, because this is a fossil fuel, it has limited supply, in addition to its prices undergoing many fluctuations, as well as it is believed to be one of the main causes of global warming. As a result, efforts are being made to find an energy source as efficient as oil which could replace it. Observing the geographical location of Brazil, this is a privileged country when it comes to the incidence of sunlight. Much of its territory is located between the Equator and the Tropic of Capricorn and sun and heat are abundant elements in this region. In order to make the most of these elements, it is necessary to develop technologies that can use these resources, and solar energy is one of the alternative energy technologies, which has been gradually introduced in the country.

Photovoltaic panels are already being integrated into the projects of some houses and buildings, interconnecting to the electricity grid and promoting cost savings, as well as taking advantage of the incidence of lightning, and thus promoting clean energy production. However, when compared to other energy sources, it is still underused, representing only about 1.2% of the total Brazilian energy matrix (Figure 1). Aiming to increase the use of this energy source, other means of using solar energy were sought, such as the use of batteries and portable devices, and thus idealizing a project to unite the parasols placed on beaches and restaurants with the technology of photovoltaic panels , in order to promote the creation of a new portable device capable of providing energy to charge low voltage devices in places such as beaches, parks and fields, in addition to the convenience of recharging an electronic device while sitting in an open-air bar or restaurant.

Figure1. Brazilian energy framework. Source: National Electric Energy Agency (ANEEL), 2018, adapted.

Source	No. of plants	Capacity installed (kW)	Percentage (%)
Water	1341	104 472 336	60.72
Fossil	2441	25 618 887	14.89
Wind	609	14 935 293	8.68
Biomass	566	14 786 872	8.59
Solar	2469	2 074 002	1.21
Nuclear	2	1 990 000	1.16
Undi-electric	1	50	0
Import*	-	**8 170 000**	**4.75**

* Does not enter the "Installed capacity" table

II. METHODOLOGY

For this project, a bibliographic research was carried out on the topic of solar energy for the development of the prototype, obtaining greater understanding of how the operation of voltaic panels and energy conversion occurs. The basis for the construction of photovoltaic cells is silicon. The classic crystalline silicon solar cell is composed of two layers of silicon contaminated with different impurities, one being P and the other N. The sun-oriented layer is negatively contaminated with phosphorus (impurity P), and the lower layer is positively contaminated with boron (impurity N). At the junction of the two layers, an electric field is produced, which will lead to the separation of charges (electrons and gaps), which are released due to the energy provided by sunlight. For the generation of electricity, metallic contacts are printed on its front and back parts (FADIGAS, 2004). According to Carneiro, J. (2009), solar radiation is what causes the separation of electrons and the appearance of an electric current, if a consumer device is connected. During its operation, there are losses caused by recombination, by reflection, by shading between the frontal contacts, and in addition to that, a large portion of the energy emitted by the sun is not used, as the long-waves radiation which does not have enough energy, or on the short-waves part which there is a surplus of energy. At the end of the process, calculating the individual losses of each process, we can have the following energy balance of 13% to 18% efficiency, according to the production method and type of silicon used in the panels.

For this project, the construction of a system with capture and storage of solar energy was carried out. For the construction of this system, it was necessary to choose photovoltaic panels, and autonomous systems that are connected to the photovoltaic panel, which includes batteries, charge regulators and inverters, in case there is also the intention of obtain an alternating current. The objective of this work is to be able to carry out the construction of a parasol, which provides energy capable of recharging low voltage devices, such as cell phones, using direct current supplied by photovoltaic panels. Polycrystalline silicon panels were used (Figure 2), which have a lower price than monocrystalline silicon and, consequently, lower efficiency, as it has a simpler manufacturing process.

Figure2. Polycrystalline silicon panel.

The electrical properties of this panel are described in the Table 1, as provided by the supplier.

Table1. Electrical properties of polycrystalline silicon panel source: eco-worthy.com, 2019 (adapted)

Photovoltaic Panel - 18 Volts Solar Panel - 2.5 W	
Maximum Power (Pmax)	2.5W
Power Tolerance	± 3%
Voltage at Pmax (Vmp)	18.2V
Current at Pmax (Imp)	0.138A
Open circuit voltage (Voc)	22.3V
Short-circuit current (Isc)	0.15A
Temperature coefficient (Pmax)	-0.48% / ° C
Temperature coefficient (Voc)	- (0.38 +/- 0.01)% / □
Temperature coefficient (Isc)	(010 +/- 0.01)% / □
Dimensions	194 x 120 x 30 mm
Efficiency	15-17%
Net Weight	70 g

According to the NBR 16690 standard, switch-disconnector devices are not required in the circuits between the photovoltaic module and the direct current power conditioning units (UCP_{dc}) as long as the UCP_{dc} input is arranged so that:

a) it is only a photovoltaic module;

b) the cable length between the photovoltaic module and the UCP_{dc} is not longer than 1.5 m;

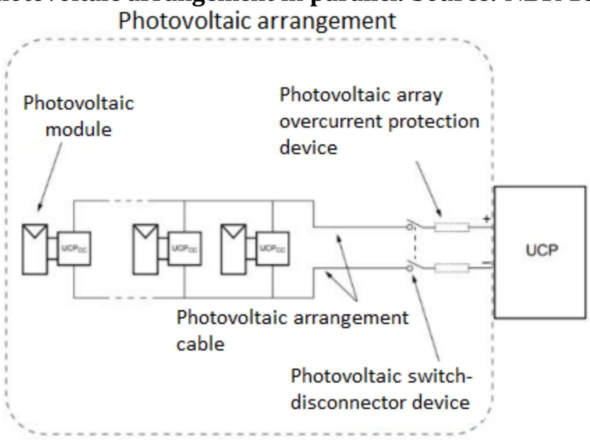
c) extension cables are not used;

d) UCP_{dc} input is limited to 350 Watts (W) (in NTP, normal temperature and pressure, irradiance equal to 1000 W/m², T = 25ºC) and, the maximum voltage, in ELV (extra low voltage - Not exceeding 50 Volts (V) in alternating current and 120 V in direct current).

e) when more than one UCP_{dc} is incorporated in a single enclosure, each input must be limited to 350 Wp (in NTP), the maximum voltage, in ELV.

The construction model of this system will be an "off-grid" system, which includes the use of batteries for storage, and its assembly will be the system of photovoltaic panels in parallel, preserving the voltage between the terminals and the current values are added (Figure 3).

Figure3. Photovoltaic arrangement in parallel. Source: NBR 16690, 2019



In this project, it was used a charge controller from brand E-WIRELESS (Figure 4), adapted for currents of up to 30 Amperes (A). The charge controller acts as a preventive measure, regulating the output voltage of the photovoltaic panel terminals, and sending it to the battery, avoiding its overload. It also blocks the reverse current, in case the battery terminals are larger than that of the panel, thus discharging them, preventing the occurrence of deep discharges, important for lead-acid batteries, which cannot be completely discharged and prevents further loss of energy, loss between 3% to 5%.

Figure4. Charge controller - E-WIRELESS.

The battery used was a lead-acid battery from Planet Battery (Figure 5), with 12 V terminals and 5 A capacity. For its charging, a lower current equal to 1.5 A and a voltage between 14.4 V and 15 V at 25°C is recommended. This type of battery has a discharge depth of 60%, which is the percentage of the nominal capacity that is used before proceeding to recharge the battery, which is a great disadvantage compared to batteries of the Nickel-Cadmium or Lithium type, whose depth is 100%. In addition, lead-acid batteries are much heavier than those of Nickel-Cadmium or Lithium. However, on the other hand, the price of lead-acid batteries is much lower, which justifies its use in this project.

Figure5. Lead-Acid Battery - Planet Battery.

The parasol was selected according to the properties of the fabric it was made of, as well as its market value. It is known that photovoltaic panels, when in operation, reach temperatures of up to 80°C, depending on their dimensions and power. The most cost-effective fabrics found on the market were polyamide and polyester. Comparing those fabrics, polyamide has a major disadvantage compared to polyester when exposed to sunlight. A study by Saly N. Thomas and C. Hridayanathan (2006), using polyamide fiber, found that these are very susceptible to degradation due to exposure to sunlight, making the polyester material the best one to this product. In addition, polyester fabric is very durable, being resistant to most chemicals, stretching and shrinking, resistant to wrinkles, mold and abrasion. It is hydrophobic in nature and quick drying, and can be used for insulation by making hollow fibers. One of the striking characteristics of polyester is to maintain its shape and, therefore, it is good for making outdoor clothing for extreme weather, and as well it is easily washed and dried (SABU & VISASH, 2011). The chosen parasol is made of polyester and with a lower silver coating, to help dissipate the heat which makes a more pleasant experience for the user that is staying under the parasol.

Finally, it is necessary to dimension the section of the direct current (DC) cables. For this, it is needed to know the respective voltage drop. According to the NBR 16690 standard, under conditions of maximum charge, it is recommended that the verified voltage drop does not exceed 3% of the voltage of the photovoltaic array at its point of maximum power. We can then calculate the section using Equation 1, being:

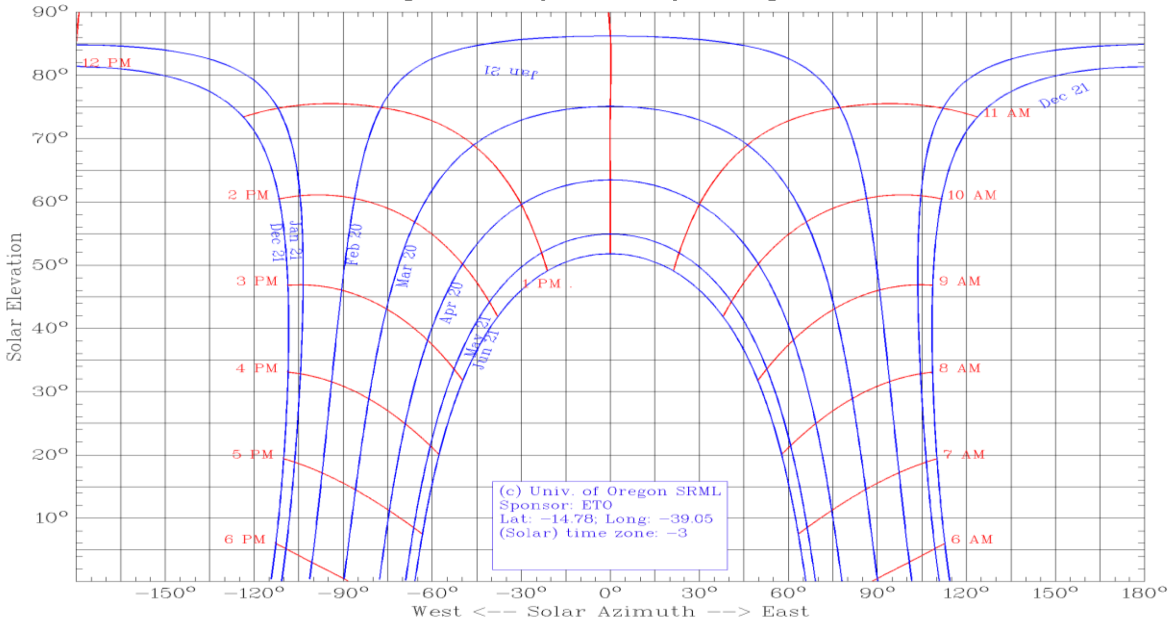
Equation 1: Section of the direct current (DC) cables.

$$S = \frac{L.P}{\sigma.e.U^2}$$

In which, S represents the cable cross-section in mm², L the cable length (positive and negative) in m, σ the electrical conductivity, in m/Ω mm², U the working voltage DC in V, P the power in W and e the voltage drop in V.

The solar energy is directly influenced by the positioning of the photovoltaic panels. In relation to positioning, it must be taken into account the azimuth angle of the Sun (α), also called solar azimuth angle. This is the angle between the projection of the sun's rays in the horizontal plane and the North-South direction, where the angular displacement is taken from the geographical north. And, should also be considered, the inclination of the absorbtion surface (β), which is the angle between the plane of the surface in question and the horizontal plane, which can vary from 0° to 90°. The relationship between these two angles changes throughout the year, depending on the geographic location and season. Through a solar radiation monitoring program carried out by the University of Oregon (Fig. 6), it is possible to extract these values, using as a reference the geographical location of the city of Ilhéus, state of Bahia in Brazil, which has a latitude of -14.78° and longitude of -39.05°.

Figure6. Azimuth and solar angulation relationship – Summer solstice. Source: Solar radiation Monitoring Laboratory, University of Oregon, 2019



For the positioning of photovoltaic panels, the slope of the optimum surface, β_{opt}, is usually considered equal to the latitude of the place (ϕ) (CARNEIRO, 2009), and the amount of irradiance received in the panels can be calculated using Equation 2:

Equation 2: Irradiance received in the panels.

$$I(\beta_{opt}) = \frac{I_o}{(1 - 4.46x10^{-4}\beta_{opt} - 1.19x10^{-4}\beta_{opt}^2)}$$

In which, *I* represents the irradiance value. For any surface, it is used Equation 3, represented below:

Equation 2: Irradiance value for any surface.

$$I(\beta_, a) = I(\beta_{opt})x[g_1(\beta - \beta_{opt})^2 + g_2(\beta - \beta_{opt}) + g_3]$$

In that, the variables g refer to losses due to the average soiling on the panel. These variables are calculated using Equation 4.

Equation 4: Average soiling on the panel.

$$g_i = g_{i1}[a]^2 + g_{i2}[a]^2 + g_{i3}$$

And their values can be consulted through the Table 2.

Table2. Coefficients for calculating solar irradiance. Source: CARNEIRO (2009).

Coefficient	i=1	i=2	i=3
g_{i1}	$8x10^{-9}$	$3.8x10^{-7}$	$-1.218x10^{-4}$
g_{i2}	$-4.7x10^{-7}$	$8.2x10^{-6}$	$2.892x10^{-4}$
g_{i3}	$-2.5x10^{-5}$	$-1.034x10^{-4}$	0.9314

So, in order to estimate the value of the energy produced by a photovoltaic panel, it is necessary to first calculate the energy ideally produced during a day, through Equation 5:

Equation 5: Energy ideally produced during a day.

$$E_{ideal} = \Delta t. P_{max}(G, T) \rightarrow day$$

Where Δt is the operating time of the photovoltaic panels, and $P_{max}(G, T)$ is the maximum power of the module as a function of the incident solar radiation and the temperature of the module, under normal temperature and pressure (NTP). The temperature influences the performance of the photovoltaic panel. η is the yield value according to the temperature. These conditions are given by the manufacturer, normally, the loss is given by $\frac{\partial \eta}{\partial T} \approx -0.5\%/ºC$. Thus, we can calculate the real efficiency from Equation 6:

Equation 6: Real efficiency.

$$\eta(T) = \eta^r[1 - 0.005(T - 25°C)]$$

In which, η^r represents the value of the yield in NTP. Then designating $K_T = [1 - 0.005(T - 25ºC)]$, we can rewrite our Equation 5 as follows, Equation 7:

Equation 7: Energy ideally produced during a day.

$$E_{ideal} = K_T \frac{\Delta t.G}{G^r} .P^r_{max} \rightarrow day$$

Where $\Delta t.G$ represents the global energy of incident radiation E (Wh/m²/day) and G^r is the incident solar radiation under the reference conditions, G^r = 1000 W/m². P^r_{max} is the maximum power of the photovoltaic panel under the reference conditions. These data are given by the manufacturer.

A more efficient way to perform these calculations is to define the concept of number of equivalent hours of Sunshine, Hs (8). This concept gives us the number of equivalent hours which the panel would generate energy under reference conditions in a given region, based on the values of the incident solar radiation present.

Equation 8: Hours which the panel would generate energy.

$$Hs = \frac{E(Wh/m^2)}{G^r(W/m^2)}$$

For example, in a region in which the incident solar radiation per m² (E) is equal to 4000 Wh/m²/day, we will have an equivalent number of hours equal to 4. Applying Equation 8 to Equation 7, we have Equation 9:

Equation 9: Energy ideally produced during a day.

$$E_{ideal} = K_T.Hs\,.P^r_{max} \rightarrow day$$

When considering a real system, it must be added to Equation 9 the losses due to electrical components, such as equipment of regulations and cables, responsible for most of the energy loss, reducing the total energy that will be delivered to the battery. If the system has an inverter, this loss is approximately 10%, thus $\eta_{inv} = 90\%$. The cabling process (F_c) has a loss of approximately 3%. Therefore, it is included the total loss amount to the Equation 7, shown in Equation 10.

Equation 10: Energy produced.

$$E_{real} = PR.K_T.Hs\,.P^r_{max} \rightarrow day$$

Where PR (Equation 11) stands for Performance Ratio, representing the system's performance index. It is calculated by multiplying all losses in the system.

Equation 11: Performance Ratio.

$$PR = \eta_{inv}\,.F_c$$

It is then possible to estimate what the annual energy produced by a photovoltaic panel will be through Equation 12.

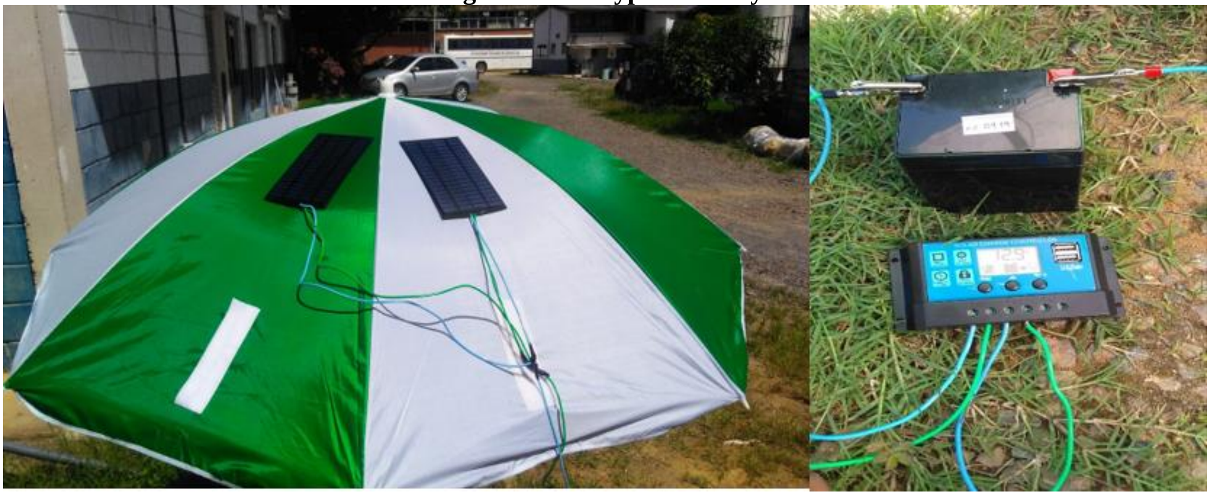
Equation 12: Annual energy produced.

$$E_{real} = PR.\left[\sum_{i=1}^{12} K_{T,i}.n_i.H_{s,i}\right].P^r_{max} \rightarrow year$$

Where i represents the month of the year, and n the number of days. For KT calculations, the average temperature value for the respective month is used.

For the elaboration of this project, two 18 V solar panels were used, as described in Table 1. Initially it is done the welding of the negative and positive poles in the photovoltaic. These panels are connected in parallel by a bypass splice and connected to a charge controller. Next to the charge controller, we also have the battery, with a 12 V differential, which will be recharged by the photovoltaic panels. These devices are attached to a parasol with the help of adhesive tapes and “Velcro” type tapes for support. Due to the rigidity of the panels, this prototype needs to be assembled and disassembled each time it is used. The test prototype can be seen in Figure 7.

Figure7. Prototype assembly.



Using this test prototype, it was measured the temperature at the lower base of the panels at different intervals, with the aid of the thermometer Instrutherm TE-400. Another point analyzed is the positioning of the panels, as it interferes directly with the performance. Two positions were selected, one ideal, with an angle of approximately 14.5° (which can be seen on Figure 7) and the other not ideal, with approximately 33.5°.

With this setup, it was measured the values of the voltage and current of the panels at different time intervals throughout the day, as well as their operating temperature. For the calculation of the generated energy values, data from solar irradiance INMET - Instituto Nacional de Meteorologia (National Institute of Metereology in Brazil) were used, which performs daily data collection in several locations of the country, with Ilhéus being one of them. With these values, it was possible to calculate and make a comparison between the theoretical and real values of the total energy generated.

III. RESULTS AND DISCUSSIONS

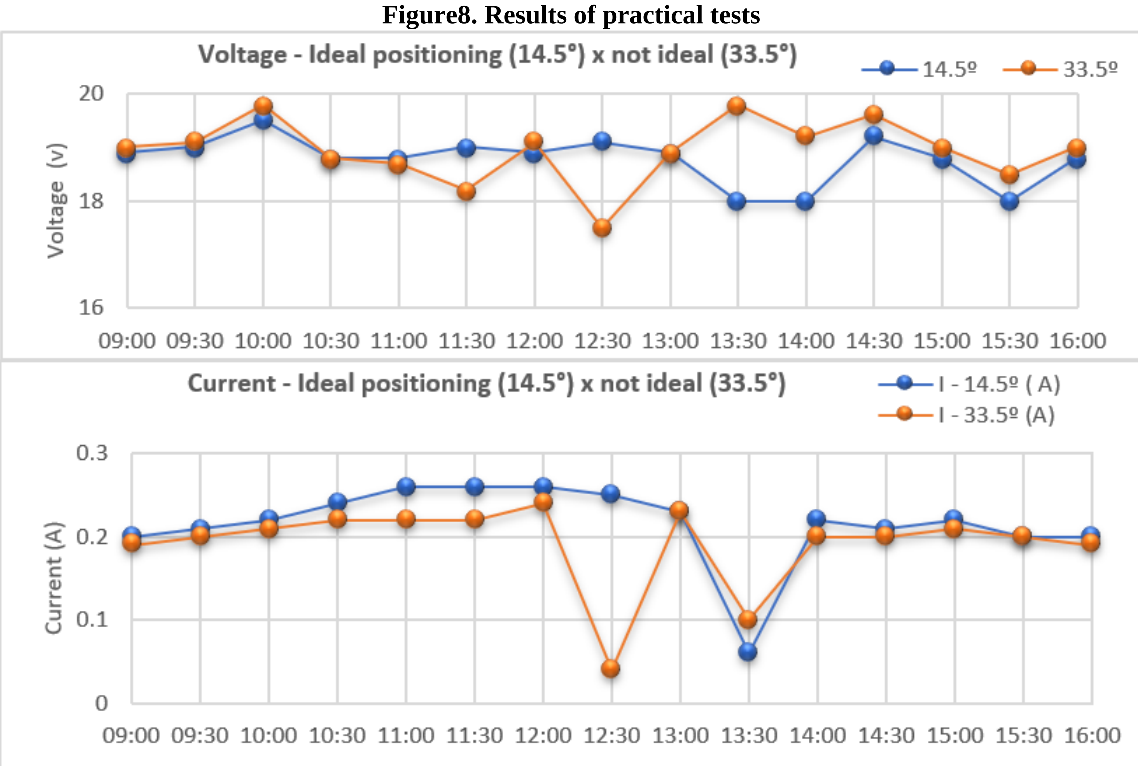
Initially, the cross section of the wire to be used for the project was calculated. Using Equation 1 and the following values of electrical conductivity values of copper equal to $61.7\frac{m}{\Omega.mm^2}$, working voltage (DC) equal to 18.2 V, working current (DC) equal to 0.276 A, power equal to 5 W, voltage drop equal to 0.546 V, estimated cable length equal to 10 m, it would tbe needed a wire with a cross section of 0.3 mm². For this project, 1.5 mm² copper cables were used. The connection was made in parallel, then it was checked the open circuit voltage (V_{oc}) of the arrangement, obtaining the value of 22.3 V, as expected and in accordance with what is described in table 1. The initial positioning of the panels is a decisive factor in the generation of energy, since it determines the amount of radiation that will be received by the panel during its operation. The panels were positioned according to the terrestrial geographic north and based on it was extracted the values of the solar azimuth angle and solar elevation from the diagram displayed in Figure 6. For simplification of the calculations, it was considered the the average positioning between the panels, so that the panels were equidistant from this initial position. It is possible to observe that at 12:00h, the solar azimuth angle is equal to 0° and the solar elevation is equal to 90° or 1.571 radians. Results can be seen at Table 3.

Table3. Azimuth angles and solar elevation.

Hour	Solar azimuth (rad)	Solar Elevation (rad)
09:00	1.073	0.688
09:30	0.969	0.812
10:00	0.873	0.935
10:30	0.698	1.059
11:00	0.506	1.183
11:30	0.247	1.307
12:00	0	1.571
12:30	-0.247	-1.307
13:00	-0.506	-1.183
13:30	-0.698	-1.059
14:00	-0.873	-0.935
14:30	-0.969	-0.812
15:00	-1.073	-0.688
15:30	-1.148	-0.564
16:00	-1.222	-0.524

Two types of positioning were considered, one ideal, whose value is 14.5°, approaching the latitude of the municipality of Ilhéus-Ba, which theoretically will guarantee a higher irradiance values received for the panel, and another of 33.5°, this being not ideal. And then, measurements of voltage and current values were performed at time intervals equal to 30 minutes on April 26th, 2019, for both setups of panels positioning, this results are shown in Figure 8.

Figure8. Results of practical tests



With the experimental data obtained, it is possible to calculate what the energy generated by this system will be and thus compares it with the theoretical values, and it is importante to highlight that the sudden peaks (see Figure 8) occurred due to the presence of clouds during the measurement, which drastically reduces the energetic potential of the photovoltaic panels due to shadowing. The local irradiance value was obtained by

INMET. Applying Equation 3 and the values in Table 3, it was possible to calculate how much irradiance was being received by each photovoltaic panel. The obtained results were the expected, which is when the panels were positioned in the ideal position it obtained higher irradiance values than when compared to panels that were in non-ideal positions. The results for the obtained irradiance values are described in the Table 4.

Table4. Solar irradiance index.

Hour	Instant irradiance (w/ m²)	Irradiance (1) (w/ m²)	Irradiance (2) (w/ m²)
09:00	1.74	1.62	1.51
09:30	53.48	49.81	46.4
10:00	105.22	98	91.28
10:30	188.4	175.47	163.43
11:00	271.58	252.93	235.56
11:30	346.35	322.55	300.38
12:00	421.11	392.13	365.15
12:30	472.08	439.64	409.43
13:00	523.06	487.13	453.68
13:30	570.56	531.39	494.91
14:00	618.06	575.65	536.15
14:30	571.81	532.59	496.06
15:00	525.56	489.53	455.96
15:30	537.36	500.53	466.22
16:00	549.17	511.53	476.47

From these irradiance values and calculating the loss factor due to the local temperature, through Equation 6 and then applied in Equation 10, and applying losses of 3% due to cabling and 3% due to the charge controller. These results can be seen in the Table 5.

Table5. Total energy production.

Hour	Local Temperature (°C)	Loss factor	Theoretical Produced Energy (W)	Real Energy Produced P1 (W)	Real Energy Produced P2 (W)
09:00	22.8	0.48	0.0042	0.0028	0.0028
09:30	22.8	0.48	0.1284	0.0964	0.0923
10:00	22.9	0.48	0.2525	0.2039	0.1976
10:30	23.2	0.48	0.4522	0.3839	0.3519
11:00	25	0.48	0.6518	0.5995	0.5046
11:30	26.1	0.47736	0.8267	0.7685	0.6229
12:00	28	0.4728	0.9955	0.9206	0.8587
12:30	29	0.4704	11.103	0.9977	0.1463
13:00	29.7	0.46872	12.258	10.028	10.028
13:30	29.8	0.46848	13.365	0.2716	0.498
14:00	30	0.468	14.463	10.777	10.451
14:30	29.5	0.4692	13.415	10.178	0.9895
15:00	29.1	0.47016	12.355	0.9616	0.9276
15:30	28.4	0.47184	12.677	0.8588	0.8827
16:00	27.5	0.474	13.015	0.9209	0.8842
Total energy produced in watts			**13.582**	**10.0844**	**9.0069**

Using this system with only two panels and considering that a Moto G4 cell phone, which has a battery with a potential equal to 3.8 V at a capacity of 2685 mA, the total energy consumption would be equal to approximately 10 W, capacity equal to that generated by the test system in 1 day. And for recharging the battery that has a difference in terminals with a potential of 12 V and a capacity of 5 A, which totals a total of 60 W, it would take 6 days to fully recharge.

IV. CONCLUSION

This project was based on the study and understanding of how photovoltaic panels work, proposing the use of two low power photovoltaic panels to create a prototype capable of recharging a cell phone. The results of this project showed that with just two panels it is possible to recharge a cell phone, although this system is not ideal because it is not very efficient. Positioning is very important to define the amount of energy to be generated by the panels. The difference when using the panels in relation to positioning 1, of 14.5° and positioning 2, of 33.5° comes to cause a difference of 11% in the total value of energy produced. If the parasol had more panels, one panel for each flap of the umbrella, totaling six panels, this value would rise to approximately 33%. The solar energy market is promising and has been gaining market share, being increasingly used in homes and some other applications as a source of electrical energy.

The prototype can still undergo numerous improvements, which would increase its efficiency, such as the use of larger, flexible and more powerful solar panels, as well as a larger parasol with greater surface area and a higher amperage battery made of lithium, having a lower weight, modifications which can be implemented in the future. However, the project proves to be promising, being an alternative for its use in open fields, clubs, restaurants that have an outdoor area, parks, thus offering the possibility of recharging portable devices, besides as well in offer a comfort condition with protection against the sun offered by the parasol.

Conflict of interest

There is no conflict to disclose.

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