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DEVELOPMENT OF A HYBRID ALTERNATIVE GENERATOR FOR COMPLEMENTATION OF SMALL CONSUMER POWER UNITS

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Abstract. *The extensive access to solar and wind resources make them excellent members of the energy matrix for small consumer units. In order to decentralize the power generation, wind turbines and photovoltaic panels are being gradually incorporated into homes. Given this scenario, this work aimed to create a hybrid electric generator (wind and solar) to complement small power grids. Soon, a prototype was constructed, composed by a Savonius turbine with photovoltaic cells inserted on top of the propellers. The connection of the energy produced by the wind and solar systems was made with the use of diodes, to avoid a return of the electric current. After the construction, the prototype was submitted to tests to evaluate its performance. The temperature drop of the photovoltaic cells occurred as expected due to the rotation of the propellers. The wind generator produced little energy at low speed, identifying the need for a speed multiplier. Finally, interference occurred between the waves emitted by the wind turbine and the photovoltaic system, resulting in power loss of the dynamo.*

Keywords: *Renewable energy, hybrid generator, wind generator, photovoltaic cells.*

1. INTRODUCTION

Fossil fuels are present in society from the ancient use of kerosene in oil lamps to modern natural gas plants. Although they are massively used, the emission of gaseous pollutants caused by the combustion of these resources has become a worldwide problem. Along with this, the demand for electricity is growing fast (de Carvalho, 2008).

The global average temperature may increase from 2 °C to 6 °C by 2100 if carbon dioxide emissions into the atmosphere do not reduce. The momentum of economic growth in developing countries, especially China and India, increases the demand for energy year by year. The result of these two factors make problematic to determine the longevity that oil banks possess before reaching critical levels. In this scenario, one possible strategy is to decentralize the energy matrix through the integration of other sources (Singh and Singh, 2012).

The free energy available on solar and wind resources make them great members to complement the electricity grid. Photovoltaic panels and mini wind turbines are being gradually incorporated into urban environments as micro generators. This is due to the rapid deployment and generation near the consumption center, which reduces losses due to transmission (Freire and Almeida, 2008).

In this context, this work presents the development of a Hybrid Solar-Wind Electric Generator (HSWEG). It is a concept that allows the simultaneous capture of these two resources in a single equipment. Therefore, a prototype was built with the goal of enhance the energy supply of small consumers.

2. DEVELOPMENT OF THE GENERATOR

Electric generators using renewable sources face a major challenge: to maintain constant energy output amidst climatic variations (Verbruggen, et al., 2010). Regarding solar and wind power, this phenomenon occurs more frequently and are shorter. The unpredictability occurrence of winds, change of direction and speed instability hinder the operation of wind turbines. While cloudiness and geographic location interfere the levels of solar radiation incident on photovoltaic panels. Faced with such facts, the motivation of this project is to minimize fluctuations in the performance of wind and solar systems, by integrating these two technologies into a single equipment (Bermann, 2008).

HSWEG uses the best features of each resource to provide reliable energy by adapting itself to the instantaneous condition of the environment (Huang, et al., 2015). The main point of this concept is the complementary natural pattern that winds and solar radiation present throughout the day. Ensuring that the hybrid generator will probably not idle for long periods of time (Nema, Nema and Rangnekar, 2009).

The designed prototype is composed by a Savonius generator with photovoltaic cells installed at the top of the propellers. After the construction, the generator was evaluated by: the capacity to integrate the wind and solar systems; adaptation to different weather conditions; and if there was an increase of the photovoltaic cells efficiency caused by temperature drop due to the intensification of the heat exchange with the wind generated by the rotation of the propellers.

2.1 Savonius Turbine

Savonius wind turbines, patented by S.J. Savonius in 1922, are composed of two blades with semi cylinder shape arranged side by side in opposite positions and connected by a vertical axis. They present low generation under slow winds, but may exhibit considerable efficiency at high speed as they use wind drag forces (Paraschivoiu, 2002). To convert wind energy into electricity, the airflow pressure must drop as it crosses the propellers, explained by Betz's Law.

Equation (1) determines the energy extracted from the wind by a propeller. It considers that the mass flow before, inside and after the rotor must be the same:

$$W = \frac{1}{2} C_p \rho U^3 A_d \tag{1}$$

Where: *W* is the amount of kinetic energy of the wind converted into mechanical energy in the rotor in Watts. *Cp* is the Betz's Limit, ρ is the air density in kg/m³, *U* is the wind speed in m/s and *Ad* is the cross sectional area of the rotor in m² (Burton, et al., 2001).

The Betz's limit, also known as power coefficient, was conceptualized by Albert Betz. German physicist who in 1919 concluded that no wind turbine can reach *Cp* = 0.593. This limit is not caused by any deficiency in the design, but because the airflow must expand after the rotor at the expense of the kinetic energy of the wind, hence it cannot be converted into electricity (Burton, et al., 2001). However, even the maximum limit of the power coefficient has been established theoretically, the current wind turbines do not reach this value. It decreases due to engineering requirements, especially durability, reaching values between 0.35 and 0.45. Adding all the inefficiencies of a turbine system (transmission, inverter and others) only about 10% to 30% of wind power is converted into electricity (Devinant, Laverne and Hureau, 2002).

The wind turbine was designed using Eq.1. Therefore, the variable *Ad* was isolated to size propellers capable to produce 12 W.

$$A_d = \frac{2W}{C_p \rho U^3} \tag{2}$$

The speed and density of the air were 5.0 m/s and 1.225 kg/m³, respectively, according to Amarante, et al. (2001) for the region of Belo Horizonte, Minas Gerais. The power coefficient was *Cp* = 0.35 as vertical wind generators have low efficiency. The result found by Eq.2 determined propellers with cross sectional area of 440 mm². Soon, to obtain considerable area to install the photovoltaic cells, it was decided to build two propellers with 440 mm in height and 500 mm in diameter.

2.2 Photovoltaic Cells

Photovoltaic Systems (PS) are components that convert part of the solar radiation directly into electricity. They are able to harvest the photons, energy units contained in solar radiation, and use them to release electrons from their surfaces. The atomic rearrangement that should normally occur, in this case induces an electric current due to the way the photovoltaic cells are assembled. A PS sheet manufacturing begins with silicon doping in small amounts using boron, forming the P-type silicon. While another piece is doped with phosphor, forming the N-type silicon. An insulating barrier separating these sheets results in deficiency of electrons (Duffie and Beckman, 2013).

Thus, the only path for the particles that are released from the atom is to travel the conductive wire connecting the P-type and N-type silicon sheets. Although this configuration generates electricity directly, there are some setbacks. There is a minimum required number of photons that triggers the electrical effect, however the excess is only converted to heat. As the temperature increases, the efficiency of the photovoltaic modules decreases (Duffie and Beckman, 2013).

The environment insolation level dominantly influences the cells temperature. However, this relationship is detrimental to the photovoltaic array because the voltage decreases significantly while the current undergoes a small rise at high temperatures. Therefore, the power generated by the module drops, this phenomenon is best observed through the Fig. 1 (GTES, 2008).

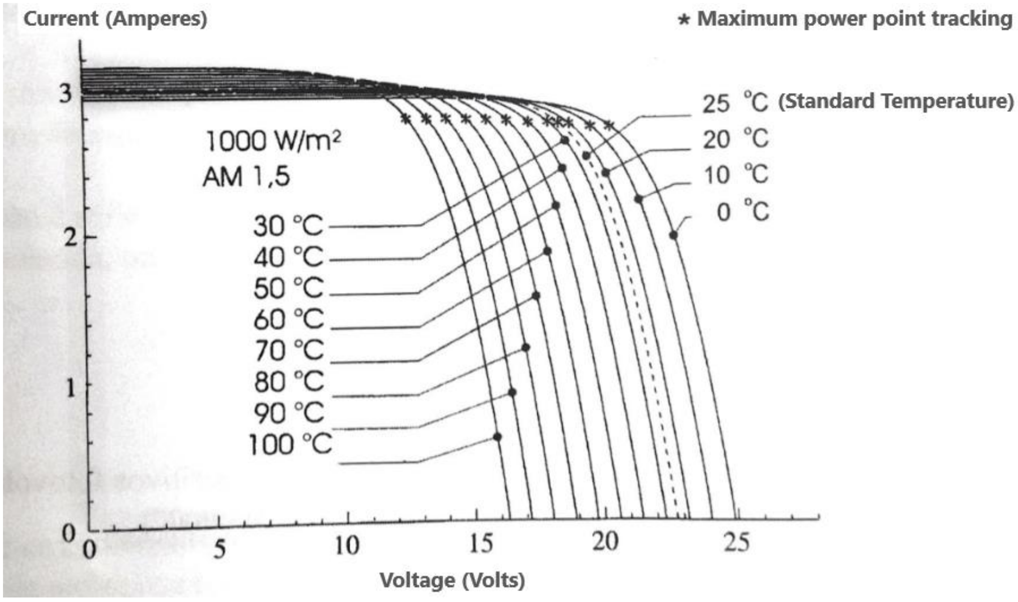

Figure 1. Effect of temperature on photovoltaic cells taken from GTES (2008).

The diagram presents several IxV curves for a same cell submitted to different work temperatures under an environment with 25 °C and irradiance of 1000 W/m². It can be observed that the maximum power point shifts to the left as the temperature increases, evidencing the drop in efficiency (GTES, 2008).

3. CONSTRUCTION OF THE GENERATOR

Figure 2 shows the outline of the prototype: the photovoltaic cells are in green and the Savonius generator in black.

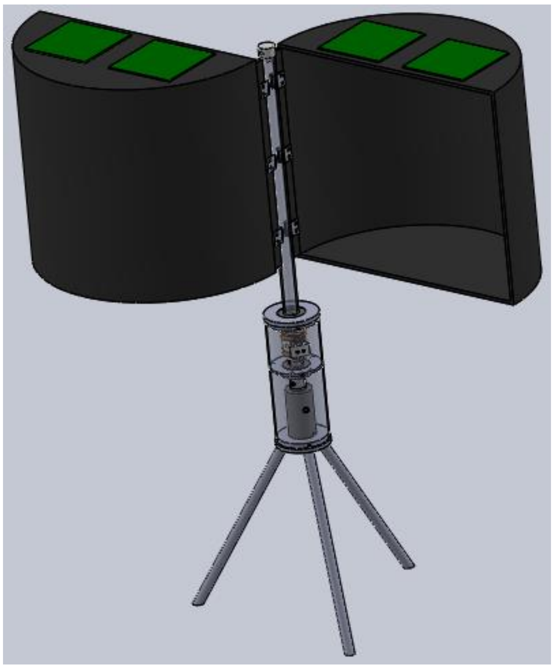

Figure 2. Outline of the HSWEG.

The propellers were constructed of carbon fiber, as this material is light and resistant. For this purpose, a 500 mm diameter PVC tube cut in half with a height of 440 mm was used as the mold. Depron Styrofoam was used as the matrix for lamination because it is a lightweight material and is easily molded when heated. Two sheets of fiber grammage 130 were used as reinforcement, one external and other internal. Semicircles cut into wood with a diameter of 500 mm were used to laminate the end plate. As can be seen in Fig. 3, the results were propellers that offered support for the PS and that do not deform easily with the wind.

Figure 3. Propellers in carbon fiber.

An aluminum shaft with inner diameter of 1 1/8", wall of 1/8" and 700 mm in height was chosen for fixing the propellers, as it is a lightweight material. A ball bearing with the following dimensions: 2 1/8"x 1 1/8" x 1/2" was installed on a 106 mm diameter housing bearing to support the propeller shaft. A 350 mm tripod supports the entire assembly. The connection of the generator to the aluminum tube is made by means of an aluminum coupling with a diameter of 1 1/8" and 12 internal splined teeth. Figure 4 shows all the components mentioned.

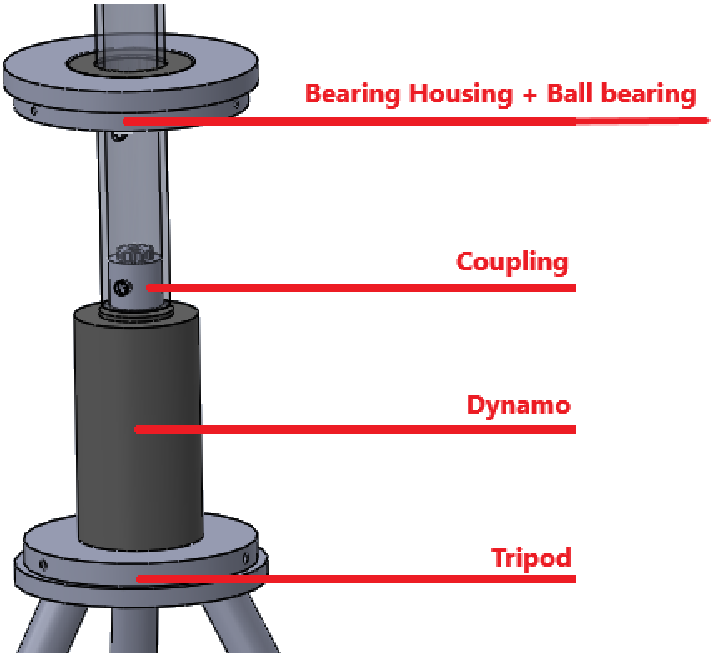

Figure 4. Mechanical assembly.

The electric design of the hybrid generator was developed to meet low voltage systems with 24 V, 1 A and 24 W. Therefore, was used a dynamo capable of generating 12 V at 175 RPM. One collector ring and two brush holders were fabricated to transmit the energy generated by the spinning cells at the top of the propellers to the static part of the generator. The collector ring was designed for maximum voltage of 24 V and with internal diameter of 1 1/8". In addition, it has two copper rings, so each phase of the photovoltaic panels was soldered in a lane. Two carbon brushes obtained from an old drill were used, they have 10 x 10 mm and maximum current of 1 A. The support for them was made of nylon in order to insulate them. Figure 5 shows the cited components.

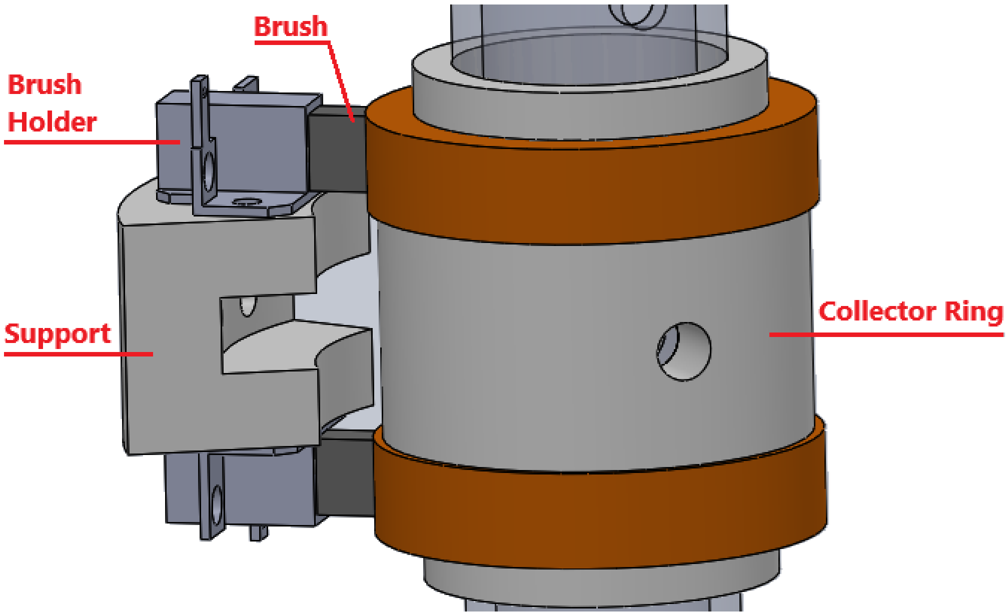

Figure 5. Electrical assembly.

The available space for the photovoltaic panel is that of a circle with 500 mm in diameter, so four cells with 145 x 145 mm were chosen, each has 6 V, 500 mA and produces 3 W. Due to the assembly, two cells on top of each helix are connected in series and the pairs in parallel. Another 4 cells were connected in the same way to be used as reference in the tests, so the results of these static cells could be compared with those installed in the HSWEG. The last item are the diodes, model 1n4007, with the function of preventing the return of wind energy to the solar system (GTES, 2008). Figure 6 shows the electrical diagram of the generator.

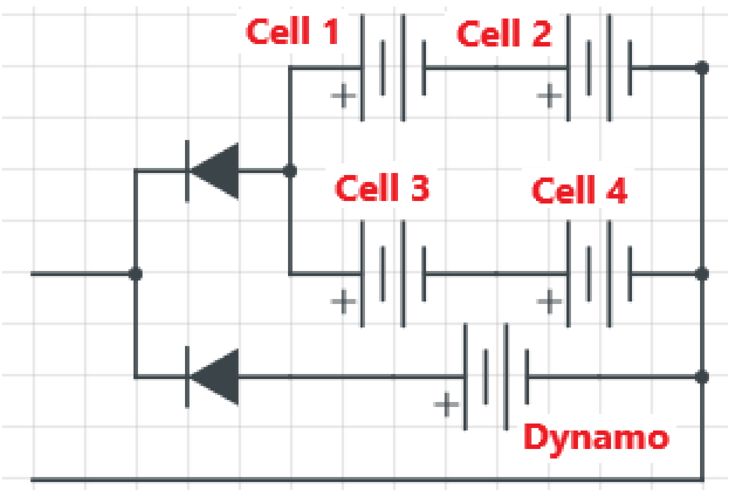

Figure 6. Electric diagram.

Figure 7 shows the HSWEG ready. The propellers were fixed through welded splines on the shaft and a PVC pipe with 102 mm in diameter and 260 mm in height protects all electrical items. The last component added to the prototype was a nylon cap at the end of the aluminum shaft. Its function is to protect the cables of the photovoltaic cells and to prevent the entrance of dust in the generator.

Figure 7. HSWEG.

4. EVALUATION OF THE GENERATOR

The tests were carried out on August 22nd and 23rd because this month has strong winds and on those days, in particular, the sun's rays were more intense. On day 22, the tests started at 3:00 p.m. and last until 3:28 p.m. While on the 23rd, they started at 1:30 p.m. and closed at 1:58 p.m. Minor intervals were chosen because as the experiments were performed outdoors, both the wind speed and the irradiation changed rapidly. Otherwise, it would be more difficult to assess the individual performance of the wind or solar part if the intervals were large.

The data were acquired through instruments connected to the dynamo and to the photovoltaic panel. The voltage and current were measured through a multimeter model HM-2090 manufactured by Hikari with resolution of 1 V and 100 mA. The irradiance information was provided by the GREEN laboratory of PUC-MG. Sector of the University that concentrates research related to renewable energies. Rotation of the propellers was measured using a TC34 digital tachometer manufactured by Simpla, with measurement range of 2.5 to 100000 RPM and resolution of 0.1 RPM. The temperature of the cells was measured by a thermal camera model TH7102MX manufactured by NEC. It has measuring range of -20 °C to 250 °C and resolution of 0.08 °C. Fig. 8 is a photograph taken with this latter equipment to demonstrate how the temperature of the cells was measured.

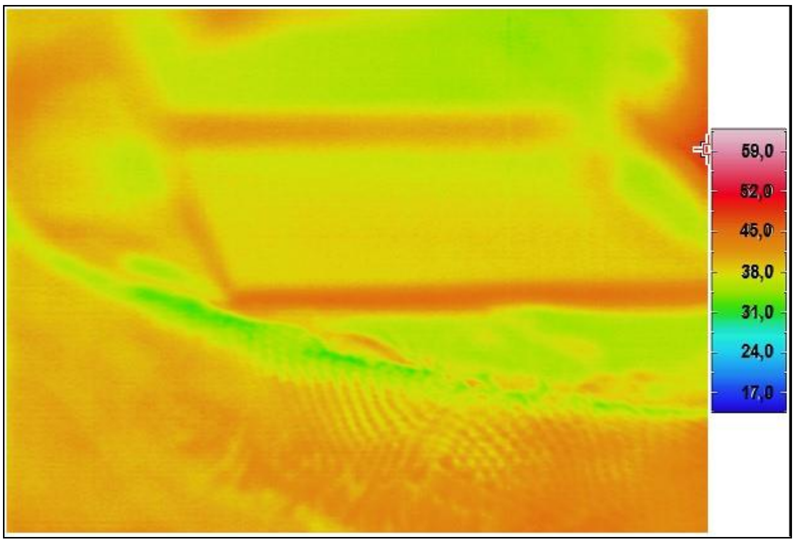

Figure 8. Thermal camera register.

Graphs are presented in the following figures to evaluate the prototype's ability to generate electricity in different climatic conditions. They relate the power generated by GESEH with the irradiance under the cells and the angular velocity of the helices. Fig. 9 presents the data for day 22 and Fig. 10 for day 23.

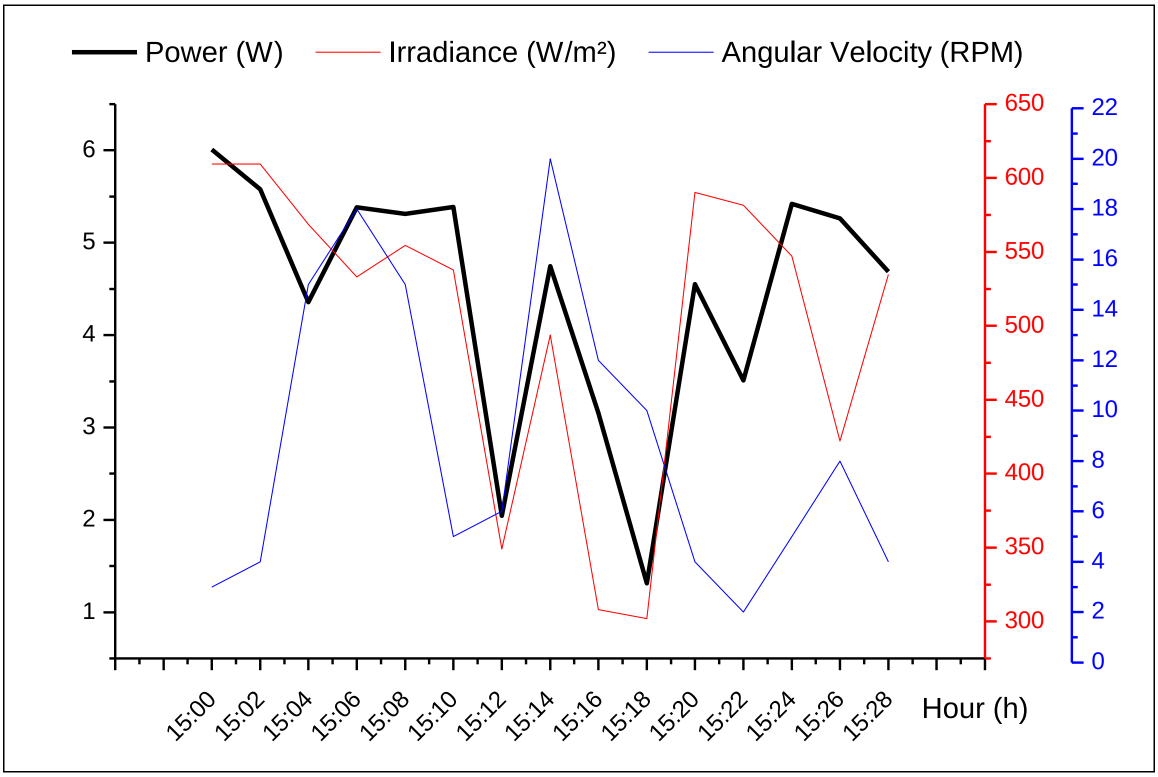

Figure 9. Power generation graphic for 8/22/2017.

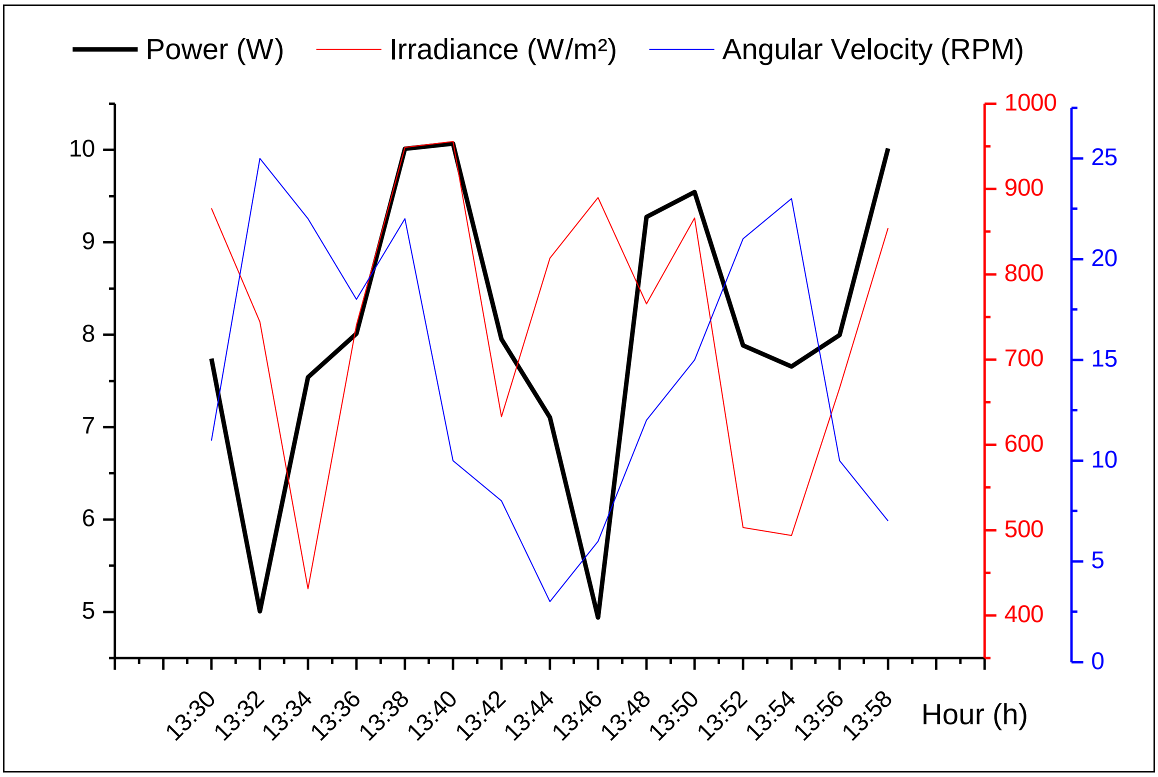

Figure 10. Power generation graphic for 8/23/2017.

As can be seen in the graphs, GESEH is always generating energy even with the variation of irradiation or angular velocity caused by the wind. The black line (power) follows the same path as the red (irradiation) most of the time in both graphs. Even if the duration of the tests has been short, this behavior might be predominant over an entire day. However, it was observed that the action of wind system causes some influence on the solar panel and does little to contribute to the hybrid generation.

Observing the graph of day 22 between 15:00 hours and 15:04 hours, it can be seen that the energy production maintains the same pattern as the irradiation. Evidencing that the prototype is inefficient in its wind potential even with the increase of the propellers rotation. This is confirmed by observing Fig. 10, which in the period between 13:30 and 13:34 shows a drop in the availability of solar energy while the propellers are accelerating. Again, the dynamo does not contribute to the generator's output. It is concluded that the total power generated is not sensitive to the increase of the generator rotation and follows the profile of the irradiation in most of the time. GESEH is little effective in converting the available wind energy into the environment to electricity.

Another phenomenon observed is the interference between the two forms of energy. For example, on day 23 between 1:42 p.m. and 1:46 p.m., total power dropped following the reduction in angular velocity, while irradiation was increasing. This indicates interference between the signals from the two energy sources. Most likely, the wave oscillation emitted by the wind generator interferes with the more stable signal of the photovoltaic cells. Thus, producing a decrease in the total power when the dynamo starts to run in the hybrid electric system, even with the use of diodes.

The graphs below were designed to evaluate whether the rotation of the GESEH helices was able to cool the cells at the top of the helices. Therefore, they make a simultaneous comparison between the power and temperature of the hybrid generator with the reference static photovoltaic cells. Fig. 11 refers to day 22, at ambient temperature of 25 °C; and Fig. 12 at day 23, at an ambient temperature of 28 °C.

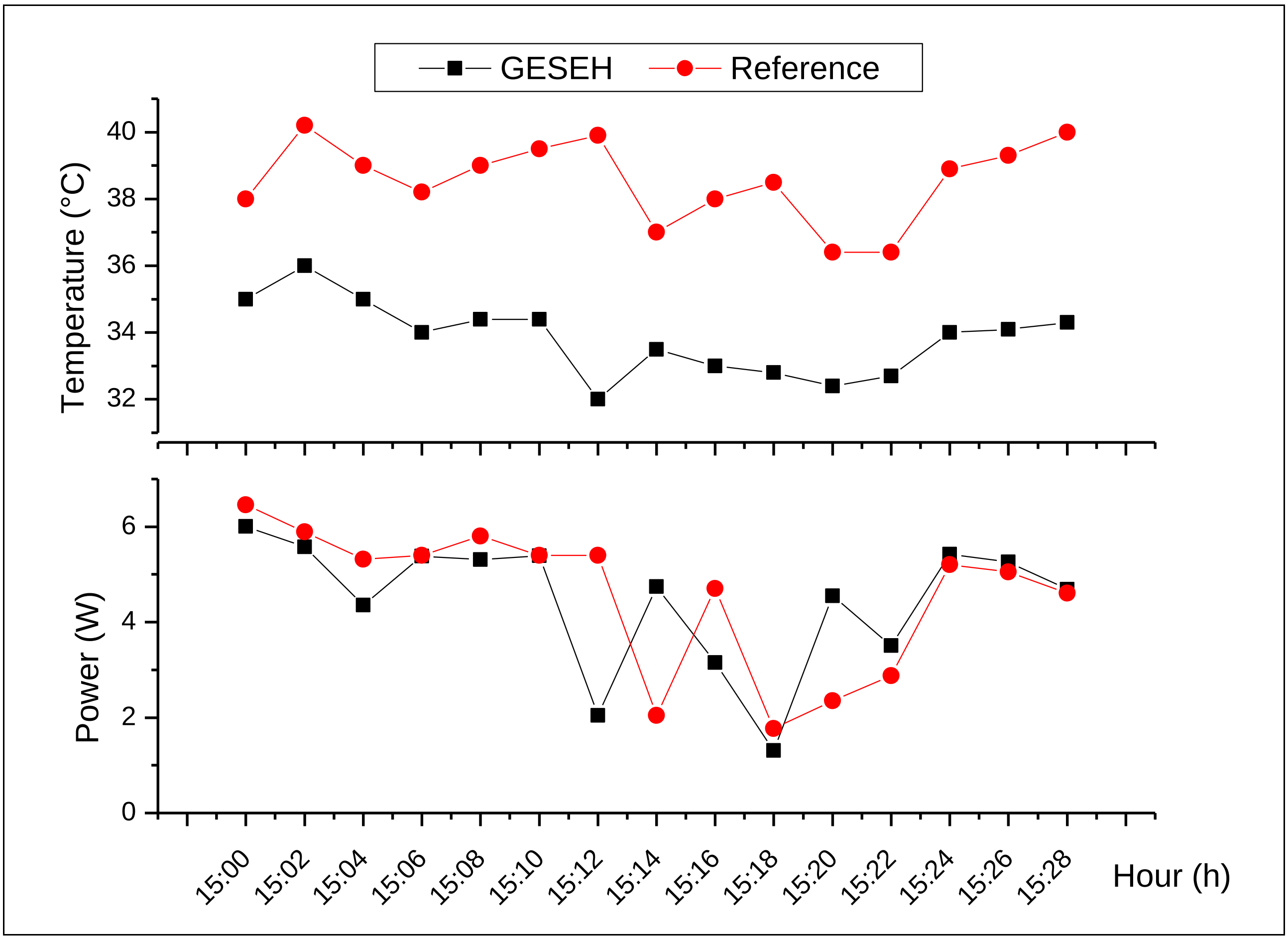

Figure 11. Cool down effect graphic 8/22/2017.

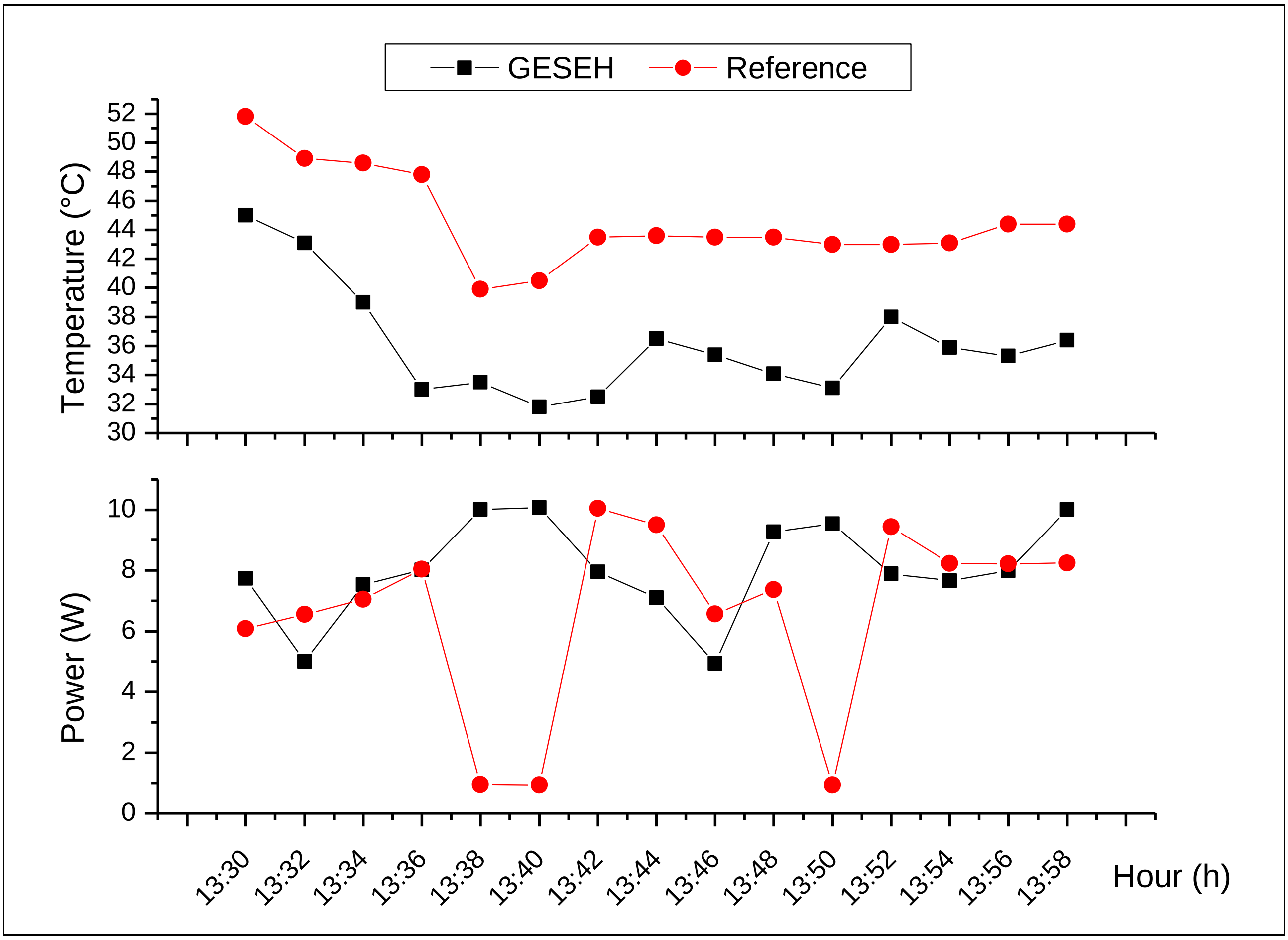

Figure 12. Cool down effect graphic 8/23/2017.

As can be seen in the graphs, reference cells were at a higher temperature than those installed in GESEH. At day 22, the reference cell temperature was on average 4.71 °C higher than in the prototype. While on the 23rd, it was around 8.5 °C, because it was a warmer day and with more winds. Soon, the prototype was shown to be able to cool the cells with the movement of the propellers.

However, no improvement in performance is noticed when comparing the energy generated by GESEH and the reference cells. On day 22, the average difference between the energy generated by the prototype and the static panel was (-0.11) W, that is, the single cells produced more energy. On the 23rd, doing the same analysis, we obtain 1.5 W, that is, the GESEH was more efficient than the reference photovoltaic system. Based on the results, it was concluded that even with cooling, there was no significant improvement in solar efficiency. This phenomenon can also be a consequence of wave interference, considering that the wind generator negatively affected the power of the GESEH.

5. DISCUSSION AND FINAL COMMENTS

This project met the main goals initially proposed. It was possible to improve the concept of hybrid generation through further research on each technology used. Moreover, with the construction of the suggested models, it was possible to identify the challenges of each stage of development of the prototype: design, construction and testing.

The results indicated that the mechanical integration between the aerogenerator and the photovoltaic panel occurred satisfactorily. However, the same did not occur from the electrical point of view. It was identified that the wind generator does not contribute significantly to the total energy production. Moreover, there are indications of interference in the wind wave signal on the solar. That is, the use of the diodes did not guarantee that the sum of wind and solar generation occurred effectively. On the other hand, GESEH proved to be efficient in generating energy in different climatic conditions at short intervals of time.

The project needs more research, as it is an early prototype, and improvements to bypass all the flaws encountered during the tests. It is believed that installing a mechanical reducer in the wind generator will increase the rotation and, consequently, the power produced. In the case of wave interference, the most appropriate is to separate the wind from solar systems. This can be done by connecting a battery to each power source and then connecting them to a load manager, for example. As for the cooling of the cells through the rotation of the propellers of the GESEH, it is believed that another method must be used to generate real gains in the production of electric energy.

6. ACKNOWLEDGEMENTS

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