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ELECTRICAL ENGINEERING

Proposal of using sensor networks for measurements of the efficiencies of a low cost vertical wind turbine

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ABSTRACT. This work presents a vertical wind turbine with wind collector designed using low-cost materials and specific sensors for the acquisition of physical quantities relevant to obtain measures of efficiencies under different conditions of use. We describe the selection of materials; construction, assembly and mechanical tests and, mainly, sensors with applications of electrical and electronic elements; as well as some tests made to obtain the instantaneous and average efficiencies. We decided to perform experimental measurements by means of digital temperature sensors, speed of rotation, voltimeters and amperimeters, which were placed at strategic points of the wind power device. Simultaneously, using an anemometer, sought to make wind speed measurements in some experimental tests. So, it was necessary to build and refine traditional microcontroller boards whose functions were to identify and read all measurements, in addition to performing the interface between the sensors employed with the microcomputer used. The experimental parameters were identified with programs using the ScadaBR and Excel, specifically developed as necessary.

Keywords: vertical wind turbine; alternative energy; measurement sensors; energetic efficiency.

Proposta do uso de redes de sensores para medições das eficiências de uma turbina eólica vertical de baixo custo

RESUMO. Este trabalho apresenta uma turbina eólica vertical projetada com coletores de vento usando materiais de baixo custo e sensores específicos para aquisição de grandezas físicas relevantes para obtenção de medidas de eficiências em diferentes condições de uso. Descrevem-se a seleção de materiais; construção, montagens e testes mecânicos e, principalmente, aplicações de sensores com elementos elétricos e eletrônicos; além de alguns testes que para obtenção das eficiências instantânea e média. Optou-se por realizar as medições experimentais por meio de sensores digitais de temperaturas, velocidades de rotações, voltímetros e amperímetros, que foram colocados em pontos estratégicos do dispositivo eólico. Simultaneamente, com o uso de um anemômetro, procurou-se efetuar medidas da velocidade do vento em alguns ensaios experimentais. Para tanto, foi necessário construir e aperfeiçoar placas microcontroladoras cujas funções foram identificar e ler todas as medições, além de realizar a interface entre os sensores empregados com o microcomputador utilizado. Os parâmetros experimentais foram identificados com programas usando o ScadaBR e o Excel, desenvolvidos especificamente conforme as necessidades.

Palavras-chave: turbina eólica vertical; energia alternativa; sensores de medições; eficiência energética.

Introduction

Even though the importance of wind energy generation is not defined yet, it will probably be within the near future, especially considering that there is plenty of space opened by the need to reduce burning of fossil fuels for electricity generation (Bao, Jinag, & Chen, 1996). Besides this factor, there are others, such as justified or not rejection to the use of nuclear systems for electric energy, the high cost of solar photovoltaic systems and the great difficulty in building hydroelectric power stations, witch an increasing loss of land because of the reservoir created, as well as environmental impacts (Eaesl, 2016).

A big push to wind power capturing systems was performed when applied the so-called aerodynamics profiles, identical to those used in aircraft wings. However, some researchers, interested in studying the wind collectors, have focused to the development of more efficient profiles to use in wind turbines (Altan & Atilgan, 2008; Albuquerque & Pinto, 2016). These studies have made it possible to obtain a speed restriction, due to the phenomenon called ‘stall’, and also the reduce of noise caused by the high speed of tips of the propellers. Another motivation of these studies has been the use of electric alternators, for being extremely useful in terms of operations where the site´s topology is suitable to the conditions of wind speeds, allowing the construction of lighter and more powerful machines (Tang, He, Wen, & Liu, 2015).

Following the same line of reasoning, the electric coupling to the distribution networks still is an area of extensive studies, since, due to its nature permanently variable, wind offers a random power curve, forcing the electrical systems to have uncomfortable technological adjustments. In addition to being a renewable source and reducing the emission of greenhouse gases, wind energy stimulates technological and industrial development of a country in a sustainable way, which, in some years, may enlarge the offer of this energy matrix (Eaesl, 2016).

In this way, considering this optimist scenario, the study described aims to contribute with researches on generation of electricity from wind energy. In order to do that, a small vertical wind turbine was developed and its behavior analyzed concerning physical processes and parameters involved in the proposed equipment.

With the use of digital and analogic sensor of wind speed, rotation, electrical voltage and current, coupled with the use of specific computer programs, there were developed devices composed of controller modules for measuring physical values that would make possible to determinate instant and average efficiencies (Cunha & Silva, 2012). These measures of efficiencies could be obtained through analyses of the electric power generated in function of the wind speed incident, simulating different environmental conditions in laboratory.

This work provides an insight into this form of electricity generation and that can be easily understood by students of technical education, as well as graduation. The concepts discussed have direct relation with the physical content and it represents an interesting alternative to classical teaching of various topics in this discipline.

Material and methods

This research was developed in the Laboratories of Physics and Transmission Data located in the Center of Exact Science, Environmental and Technologies at PUC-Campinas, São Paulo State, Brazil. In order to implement the research, it was used as final goal the construction, testing and collection of measures within a system that uses the conversion of wind energy into electric energy. The equipment developed and studied, on the financial point of view, can be considered low-cost, besides being relatively light and easy to handle. The climatic parameters, such as temperature, atmosphere pressure, wind speed, in all processes of the studies, as well as the electric parameters, such as voltage and current generated, are considered as important sources of information and are necessary to obtain the efficiencies of the proposed device.

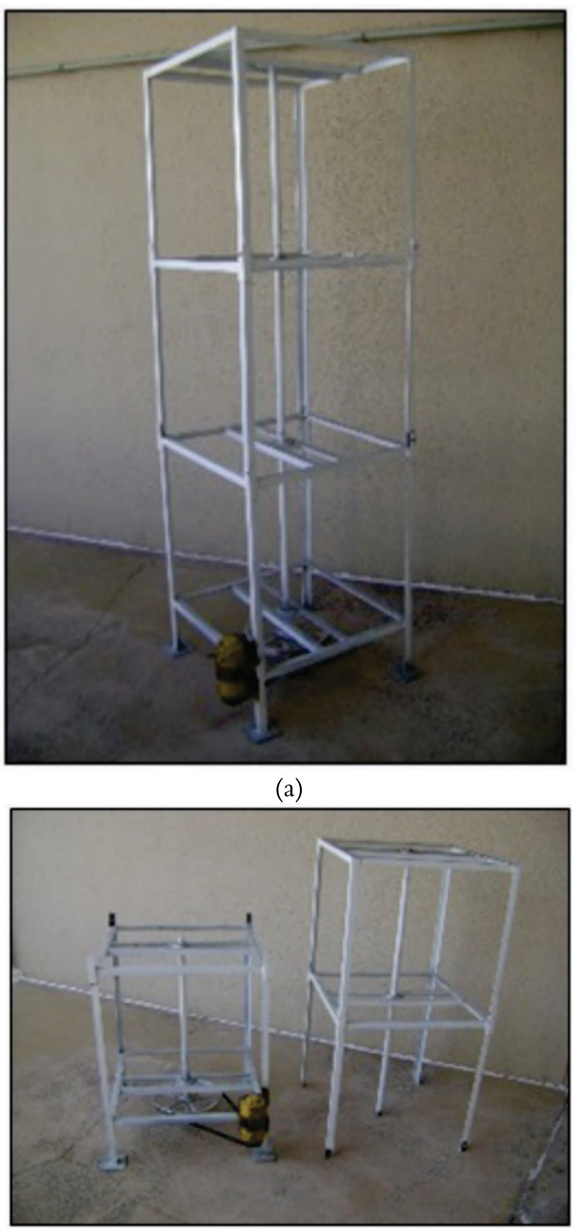
Some studies aiming measurement of energy efficiencies in wind turbines have already been developed by other authors (Saha, Thotla & Maity, 2008; Afungchui, Kamoun, Helali, & Ben Djemaa, 2010; Akwa, Vielmo & Petry, 2012; Tang et al., 2015), however, all of them approached lines of research different from the one discussed below. The aim of this project was to conduct a study on automatic measures of instantaneous and average efficiencies of a low cost wind turbine, providing a didactic and experimental material for the professor interested on the subject to use it in their teaching activities. The following topics present the main steps involved in development of this work.

Mounting the vertical wind turbine

As previously mentioned, the developed wind turbine was the vertical type, also known as 'Savonius Wind Turbine' or 'S-Rotor' (Akwa et al., 2012). We adopted this model because it differs from the other vertical and horizontal axis turbines due, mainly, to simplicity in construction and in operation. Summarily, the collectors, in specific forms, allow the efficient absorption of the kinetic energy of the wind. As they are together to an axis of rotation, it is possible to spread the wind energy into mechanic energy of rotation. Through a system of gears attached to this axis of rotation, it is possible to transfer the mechanical energy to the axis of an electric energy generator. Using voltage regulators and appropriate wires, it can load a battery or another system that requires electric energy to operate.

Before the mounting of the wind unit, some specifics information concerning the correct dimensions are required to ensure the full operation of this device. Therefore, were used the following materials: twenty meters of metal pipes of 17.5 mm in diameter; four roller bushing with 300.0 mm in outer diameter; 0.5 mm thick metal plates cut and bend; metal axis with 26.8 mm in diameter and 1890.0 mm in length; metal support to the electric energy generator; 24.0 V automotive electric alternator; frequency inverter Toshiba; regulator (with transistor) output voltage to 3.0 Volts; gears with 20 points and 80 mm in diameter; and chain (belt) to transmission.

The Figure 1a illustrates the main structure of vertical wind turbine. The first step of the assembly was to weld the metal structural pipes of wind turbine along with the roller bushing. Later, it was possible to position the rollers in bushings and the vertical axis of the rotor, as shown in Figure 1a. This structure can be separated into three modules of same dimensions, being in the lower fixed module the alternator that captures, by the adjustable belt, the rotation of the main shaft, which is fixed in rollers, and bushing. The Figure 1b illustrates a separation of the lower module (main module) with the central and superior modules.

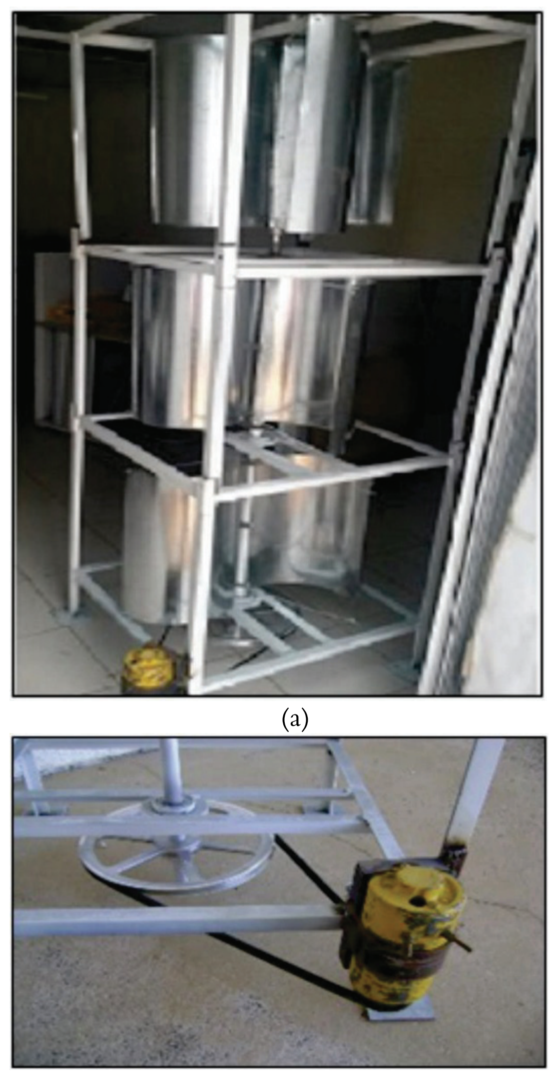


(a)

(b)

Figure 1. (a) Main structure of the vertical wind turbine. (b) Modules separated in three parts, the main that has the automotive alternator and two others.

After the mounting of these structural modules, the next step was fixing the wind collector. As mentioned before, we opted for the use of low cost materials, hence the use of the metal plates cut and bend for the greater utilization of incident wind. The Figure 2a shows the composition of these materials fixed to the rotation axis of the structure previously commented. Also aiming greater wind efficiency, it was predicted that the wind collectors should be placed with a difference of 45^0 of each module. After positioning and fixing these collectors, it was necessary to include a transmission system from the turbine rotor to the automotive electric generator, in order to perform the conversion of mechanical to electric energy, as indicated in the Figure 2b. To do this, a flexible chain connects the axis of rotation, where is fixed in a pulley, to electric alternator. After, the generated electric signal is passed on to a voltage regulator, aiming to match the output voltage.



(a)

(b)

Figure 2. (a) Illustration of vertical Wind turbine with main components for Wind collection. (b) Detail of the transmission system of mechanical energy into electric energy.

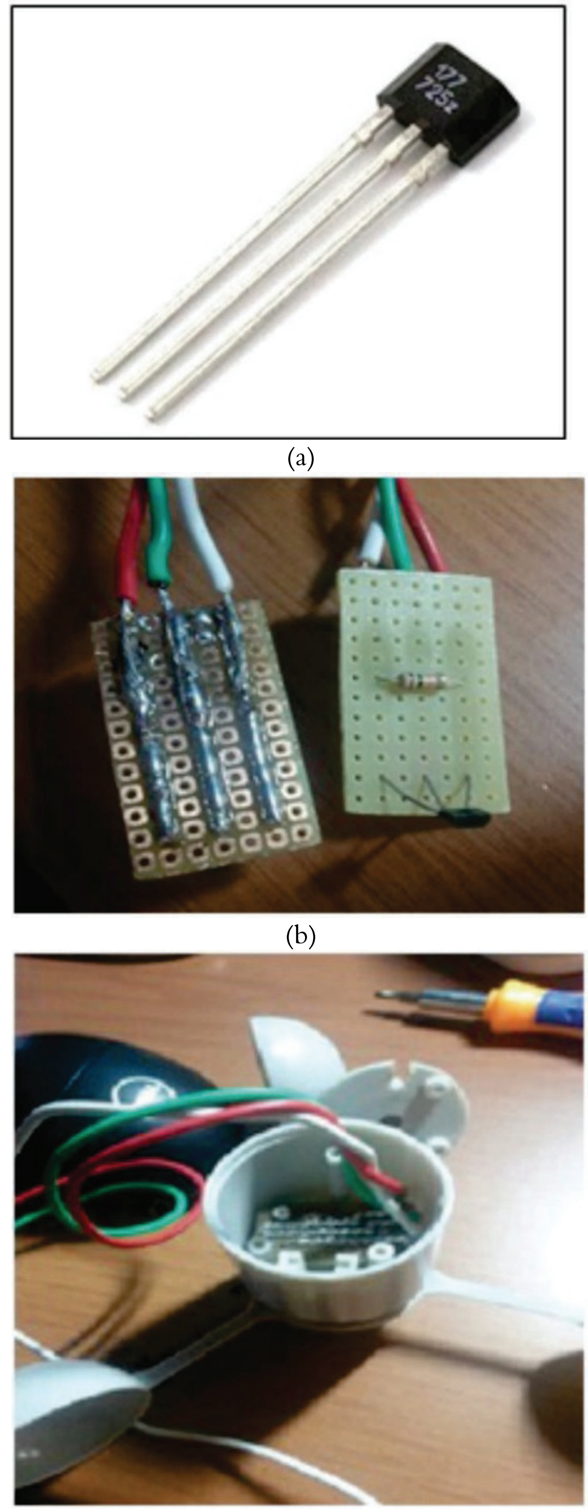
In order to perform some controlled trials, seeking experimental measures of wind turbine efficiencies, it was decided to build a prototype of 'wind tunnel', that is, a supplementary equipment that provides forced wind targeted through the use of a large electric fan (brand: Munters-Euroemme, with dimension 1.40 m versus 1.40 m). A frequency inverter was connected to the electric motor of the fan, providing control of the rotation speed and, consequently, the wind speed in wind turbine. In a closed system, where at one end is placed the fan and at the other, the vertical wind turbine, it is possible to examine the behavior of the wind turbine with the wind on it.

To assure that measurements of physical parameters could be done with satisfaction and using appropriate, fast and secure procedures, some digital and analogical sensors were used, as described below.

Measurement devices and determination of the efficiency curve

The first sensor was to be coupled to the anemometer. Thus, it was necessary to decide which component should be used so that, combined with the properties of the anemometer, could measure the amount of laps that the main axis of the device would have, in order to get the wind speed, besides determinations of rotation speeds of the main axis and, consequently, the angular and linear energies. For economical and convenience reasons, it was adopted the use of a device for measurements of rotation, with high frequency, called Hall Effect sensor (Figure 3a). As the term indicates itself, this sensor uses the principle of the phenomenon studied by the physics Edwin Herbert Hall, which consists in the appearance of a potential difference in an electric conductor, being transversal related to flow of electric current, but with the magnetic field generated by a magnet perpendicular to that current. In exchange of polarity of the magnet, the way of the current inverts, finally, there is an exchange between output pin and input pin, each time that the magnet passes through the sensor (Hall, 2016).

This component was installed inside of the anemometer. So, in order to keep a safe distance between the Hall Effect sensor and magnet used in the project, it was developed a small board to add support and functionality of the sensor, along with a resistor of 10 kΩ, used to give security between the input and output pin. The Figure 3b shows the board built, containing the Hall Effect sensor, while the Figure 3c shows that same board and the sensor placed inside of the anemometer.



(a) (b) (c)

Figure 3. (a) Image of Hall Effect sensor. (b) Board developed to use of sensor. (c) Detail of the anemometer with the board installed.

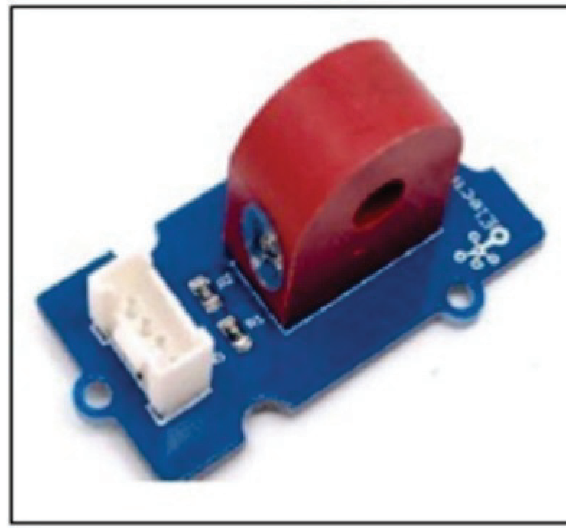
The other two sensors of rotation, in order to supply the values of angular velocities for the main shaft and the alternator, were built with the same 'layout' and methodology of board described before.

We opted for this procedure so that the same pattern would be used to the measurement of the frequency of rotation speed, of main rotor and automotive alternator.

It was also implanted sensors in order to the determination of electric power from the wind incidents in wind turbine. Therefore, it would be necessary do some measures of voltage and electric current, both of AC (alternating current) of the electric alternator installed in turbine structure. To electric current was chosen a sensor type GROVE (Figure 4a). That sensor consists in a TA12-200, that is, a current transformer that can modify an AC big signal into a signal with smaller amplitude, without losing the signal information. The maximum amplitude that this sensor can receive at the input is 5.0 A, and output 2.5 mA, that is, in the ratio of 2000:1, giving us a great safety in experimental measures (Seeedstudio, 2015).

As so the measurement of the output voltage of the alternator installed, a small voltage divider was projected (Figure 4b), that is, a small circuit to measure the potential difference in one resistor. The circuit consists of two parts, the first one would be an offset of alternating current produced, because both Arduino and Radiuino just recognize values above 0.0 Volts and, as we know, a sine wave presents positive and negative values of voltage, so, the RMS voltage and the peak voltage would be totally different from the real one and will have losses in parts of the wave. In addition, as the offset of the wave may contain noise, because there is a mitigation of the wave, we opted to install a capacitor of 10.0 μF, to filter the noises. To finish the device, we adopted a resistor of 100.0 kΩ to measure a voltage drop, followed by a 5.6 kΩ to give to system safety. Taking into consideration the comportments verified on previous tests, it was possible to notice that the automotive alternator can produce until 30.0 V before the saturation point and, therefore, the sensor was adjusted to operate at a voltage rate between 0.0 e 30.0 Volts rms. With the adoption of this strategy, it was possible to characterize and measure the sine wave on experimental trials of the wind turbine (Cunha & Silva, 2012, Arduino, 2015).

A board, shown in Figure 4c, was developed to be a controller of all data acquisition of the turbine, it receives all the information from the sensors, to make the calculus and data treatments. The board communicates with a base of type ‘UartsBee’, connected to a computer via USB, through radio communication with device BE900. The board layout is similar to some others from the market, but some modifications were done and there are some relays important to act in a system, to control something, for example, turn on some device from some value of temperature (output), and it has another part, where there are the reading of the sensors, digital or analogic (input). All of this was used altogether to the logic of Radiuino platform (Radiuino, 2015).



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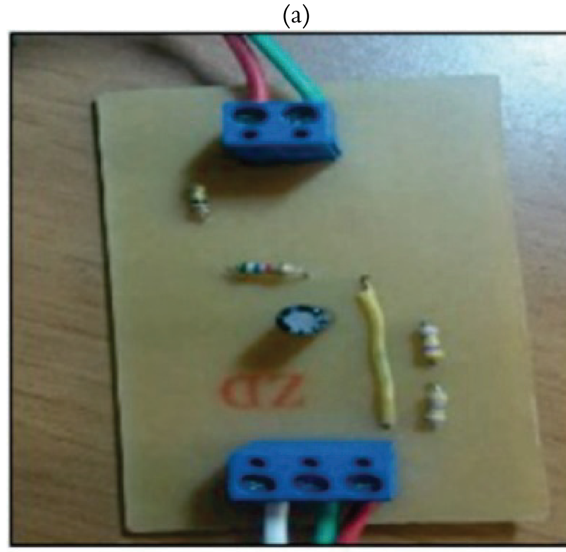

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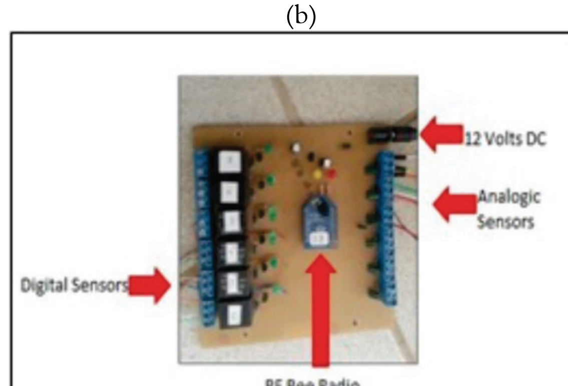


(c)

Figure 4. (a) Image of sensor GROVE to measure current and (b) of voltage sensor, to obtain the produced power. (c) Controller board developed to receive all data.

With the possibility of inferring the values of voltage and electric currents, it is possible to calculate and obtain the efficiency curve, that is, the power curve related to wind speed on wind turbine in experimental trials. At first, it is necessary to calculate the electric power by this equation:

$$P = V \cdot I \cdot \cos(\varphi) \quad (1)$$

In this expression, P represents the calculated power (in Watt = W); V is voltage (in Volt = V); I is electric current (in Ampère = A) and φ is phase angle between voltage and electric current. Additionally, the uncertain of power can be evaluate adding the uncertain due to the equipment used, that may be obtained by:

$$\frac{\delta P}{P} = \sqrt{\left(\frac{\delta V}{V}\right)^2 + \left(\frac{\delta I}{I}\right)^2} \quad (2)$$

In this equation the terms δV and δI are the uncertainties of voltage and current, respectively, determined along experimental trials.

The Figure 5 shows the position of each sensor and controller board on their places in developed turbine structure.

Figure 5. Position of the controller board and the sensor on structure of the turbine.

In all measurements performed, we opted to work with current and voltage sensors connected in alternator output terminals and a power bank, in parallel and in series, respectively. However, some procedures can be changed, depending on the problems that will appear, related to the sensors, or another equipment in a practical operation of the wind turbine.

All measurable information are sent to the management software, the *ScadaBR*, which is a 'open-source' program whose allows check and analyze data. This procedure, in addition of recognize each device in USB and RS232 ports, interprets the value in a period of time and generate graphics, as well as updates data file containing relevant information. All the calculations and graphics shown below were obtained through *Microsoft Excel*, so that could it be analyzed by any user.

Results and discussion

The electric current and voltage measurements were done in tests of 4 hours with measurements made every 5 minutes. In this aspect, it is worth to comment that the characteristics of the voltmeter are: resolution of 10 mV; range of 0 to 20 V and an uncertainty of ± (0.06% + 10 digits); While characteristics of the amperemeter are: resolution of 0.1 A; range of 0 to 1000 A and uncertainty of ± (1.5% + 5 digits).

The measured wind data used below are related to anemometer, described above and located in direction between the output of the turbine and the large fan, at a distance of 1.5 m. of each of them. The adjustment of this distance was done, after many attempts, looking for the best distribution of wind flow as uniform as possible, through the wind turbine. As said before, the variation of the wind speed was accomplished by a frequency inverter, connected to the motor of fan. The anemometer had, by isolated trials, a scale of 0 to 3600 RPM, with uncertain ± 1.2 RPM. With these information, could convert the measurements of main rotor speed (in RPM) in incident wind (in m/s). The behavior of the main rotor with the anemometer, that in case is the same of the wind speed, can be seen in Figure 6.

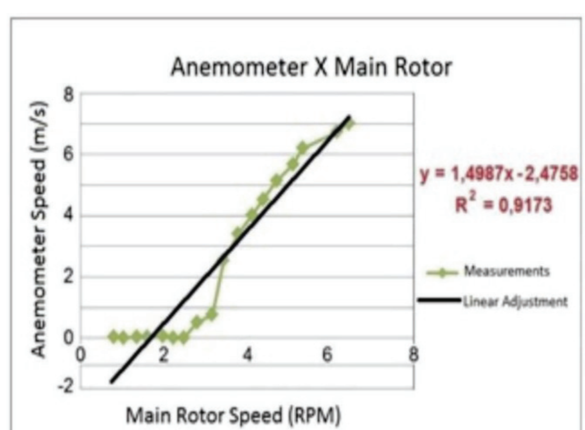
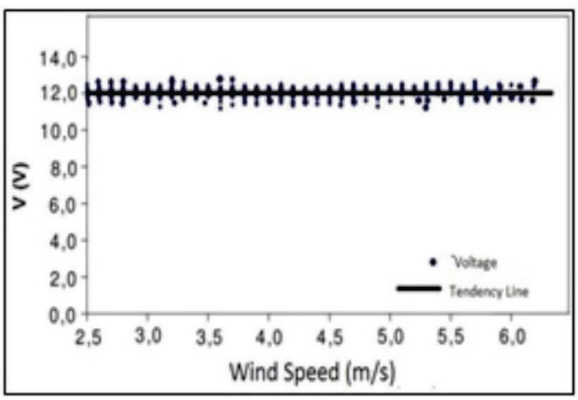


Figure 6. Behavior of incident Wind speed (in m/s) and main rotor (in RPM).

For demonstration purposes, the graph in Figure 7a shows the instantaneous voltage behavior in function of wind speed obtained by many measures in many controlled trials in lab and adjusted by a trend line using *Microsoft Excel*. Subsequently, it has been estimated average value of voltage to each wind speed, fixed in frequency inverter, obtaining the values used for the graphic in Figure 7b.

In a simple analysis of these graphics, it is noticeable that the voltage does not depend on the wind speed, directly, since the experimental curve behavior is stable during the tests, with a large difference between the maximum and minimum values being less than 1.0 V, depending on the charge of the batteries connected in electrical alternator output fixed on bottom of the wind turbine.



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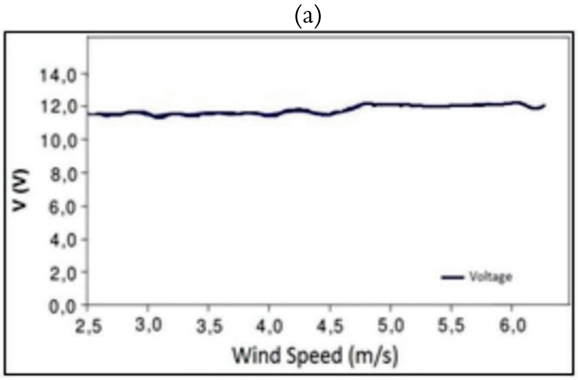

(b)

Figure 7. (a) Instantaneous and (b) Average Voltage behavior, related to the experimental trials.

The current behavior, otherwise, depends on the wind speed, as it can be verified in the graph of Figure 8. According to the figure, the average of current (*I*) increases together with the increasing of wind speed.

In the Figure 9 is shown an efficiency curve (or power curve), built from experimental results using the power calculated by multiplication of voltage and current data, obtained through measurements shown previously (Figures 7 and 8), in function of wind speed. Observing the graphic, it is possible to notice that the generated curve is similar to the current curve in Figure 8, since the voltage remains unchanged (Figure 7) throughout the tests. The uncertainty for the calculated values and their influence on the results is small, that is, 10^{-3} Watt, which ensures a good performance of the devices used in the measurements.

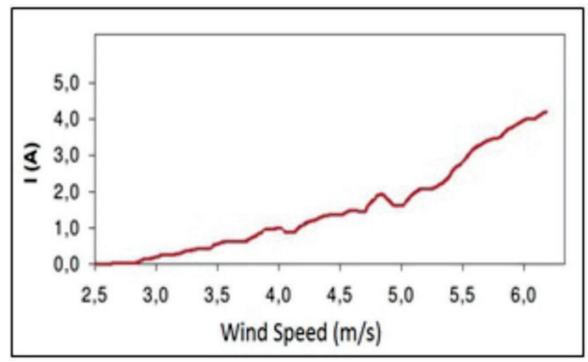

Figure 8. Current behavior.

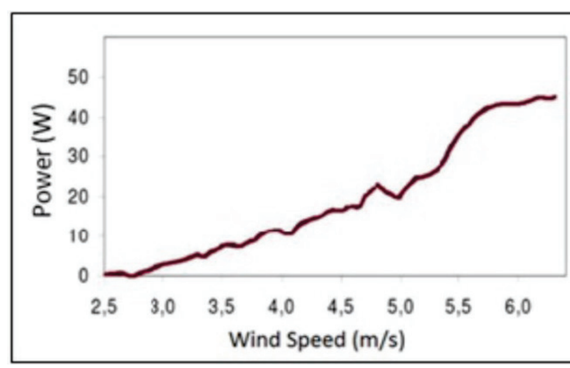

Figure 9. Efficiency curve (or Power curve) built by using data from experimental trials.

The Figure 9 presented a growth trend as the wind speed increases, but it tends to reduce with wind speed bigger than 6.0 m s^{-1}. Unfortunately, this characterization could not be verified experimentally, due security mainly related to performance of the big fan used on the wind tunnel, since it started a strong process of mechanic vibration and may have been able to break the structure. This question will be handled with greater effort in a future step of the research presented.

Conclusion

The use of wind power generation requires modification in electrical system planning, since it includes another component of uncertain that need to be properly studied and modeled. Many researches, involving wind turbines, evaluate the impact of energy generation related to reliability of the transmission system. As it was presented in this studied, it was developed a vertical wind turbine model of low cost to characterize and measure physics parameters by specific sensors in order to obtain instant and average efficiency in some experimental trials. The estimates of the measured parameters for the power in function of Wind speed showed not only the calculated capacity, but also the forced outputs of the turbine, producing a value more realistic of these measurements.

The factors of potential were between 20 and 30%, value considered reasonable by the standards of experimental trials involved until this moment. It was noticed that the kind of wind power constructed in this experiment could make it possible to convert kinetic energy into electrical power, depending, of course, on the structure of the wind turbine, as well as the behavior and strength of incident wind.

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