STUDY AND DEVELOPMENT OF A PUMPING SYSTEM USING A SMALL WIND TURBINE COUPLED TO A CENTRIFUGAL PUMP BY MEANS OF A FREQUENCY INVERTER

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1. Introduction

Water pumping in isolated communities in the Brazilian Amazon Region can be a big problem due to the lack of an electricity grid. Grid extension for those remote places can be very expensive, due to the distances and types of landscapes involved, and thus not economically feasible. Therefore, the use of diesel pumps or generators is the most commonly used solution, although the operation of diesel systems is not as simple because of the fuel cost and its local availability, transportation, handling and storage, generator maintenance, besides the environmental concern. Wind turbines can produce alternate current which can be directly connected to an ac motor for pumping water, centrifugal pumps being the most commonly used for these purposes, and a frequency inverter is used to control the pump rotation, making the process more efficient, and price competitive when compared to usual photovoltaic pumping systems, diesel or mechanical wind pumping. This work presents a study of one system which is being developed to be used under the conditions mentioned above.

With the electrical connection between the wind turbine and the centrifugal pump, there is a possibility that the turbine is placed in a location with better wind conditions, even far from the water source. This configuration eliminates the limitation of mobility imposed by pumping with mechanical systems.

Due to the simplicity and high reliability of the components used in wind pumping systems that use electricity, there is a need for less maintenance than in conventional systems. The electrical connection between the wind generator and the pump motor by means of an inverter also has the additional advantage of flexibility, and the energy generated can also be used for other purposes.

2. Wind Power

The installation of a system for the exploitation of the wind power resource at a given location must be preceded by comments on several factors. The process should start with the knowledge of the local energy demand and the purpose of application of the system. For water pumping using an electric motor, the installation may be done in an area with better wind conditions; even if this area is far from the water well. it is still economically feasible, because the energy will be transmitted to where it is needed using electric cables. Thus, there is the possibility to predict the type of equipment most suitable to be used.

With the objective already set, analyses of wind conditions in the region (speed, direction); orography (study of the topography of a region); obstacles (vegetation, buildings, etc.); land use (plantations, pasture, etc.); natural indicators (plants, dunes) must be carried out. This analysis makes it possible to define whether the sistem is viable or not.

The availability of wind power is related to various physical and geographical factors, depending on the time of day, season and other climate aspects. The power available in the wind can be calculated by eq. 1.

$$P_v = \frac{1}{2}\rho_a A v^3 \qquad \text{(eq. 1)}$$

where P_v is the power available in the wind (W), ρ_a is the specific mass of the local air (kg.m^{-3}), A is the area sweptby the rotor blades (m^2), and v is the wind speed (m.s^{-1}).

3. System Components

The components of the wind pumping system in analysis are:

3.1. Wind Turbine

The conversion of wind energy into electrical energy is performed by a machine called a wind turbine, which captures the kinetic energy of the wind through the rotor, transmits the mechanical energy by means of gears (if any) to the shaft that is coupled to the generator and, finally, the latter generates electrical energy.

The value of the nominal power of a wind turbine can set its classification as to size, presented in Table 1 (Pinho et al.,2008).

Tab. 1: Classification of wind turbines.

Classification	Nominal Power (kW)
Small wind turbine	< 100
Medium wind turbine	< 1,000
Large wind turbine	≥ 1,000

This work uses wind turbines with powers below 100 kW, which characterizes the small wind turbines, which are used in a large scale in isolated communities.

3.2. Centrifugal Pump

The pumps are machines that provide energy to the liquid through the action of centrifugal force in order to promote its elevation. They transform the mechanical work from external sources into kinetic energy and pressure, which are transferred to the liquid (Lima, 2003).

Due to the rotation of the rotor, driven by an external source of energy, which is usually an electric motor, the liquid that lies between the vanes inside the pump rotor is dragged from its center to the periphery by the effect of centrifugal force. The liquid exits the rotor through its periphery, at high speed, and is forced through the elevation pipe to the water container.

The hydraulic pumping power can be calculated by eq. 2.

$$P_h = \rho_w QgH \qquad \text{(eq. 2)}$$

where P_h is the hydraulic pumping power (W), ρ_w is the specific mass of water (kg.m^{-3}), Q is the flow rate (m^3.s^{-1}), g is the gravity acceleration (m.s^{-2}), and H the height of a static column of liquid (m).

Since the pump is driven by an electric motor, the electric power extracted from the grid is given by eq. 3.

$$P_{el} = \frac{\rho_w QgH}{\eta_p} \qquad \text{(eq. 3)}$$

where P_{el} is the electric power supplied by the grid (W) and η_p the efficiency of the centrifugal pump (%).The value of the efficiency of the centrifugal pump can be obtained with the aid of the pump curves supplied by the manufacturer.

3.3. Frequency Inverter

The frequency inverter is an electric device capable of producing a variation of frequency values in the electric motor, producing a variation of its rotation (Capelli, 2002). They are designed to work with ac motors and, as can be seen in eq. 4, when the frequency varies, the rotation speed varies accordingly, since the number of poles (p) is fixed.

$$N = 120\frac{f}{p} \qquad \text{(eq. 4)}$$

where N is the rotation (rpm) and f is the frequency (Hz).

4. Methodology and Results

This paper presents an example of a process of estimating water pumping using a small wind turbine, which starts with the analysis of wind speeds at the location where the system will be installed. For the simulation, wind data at 30 m height is considered for a particular locality, for which the percentage of occurrence of each speed for the period of one year is shown in the histogram of Fig. 1.

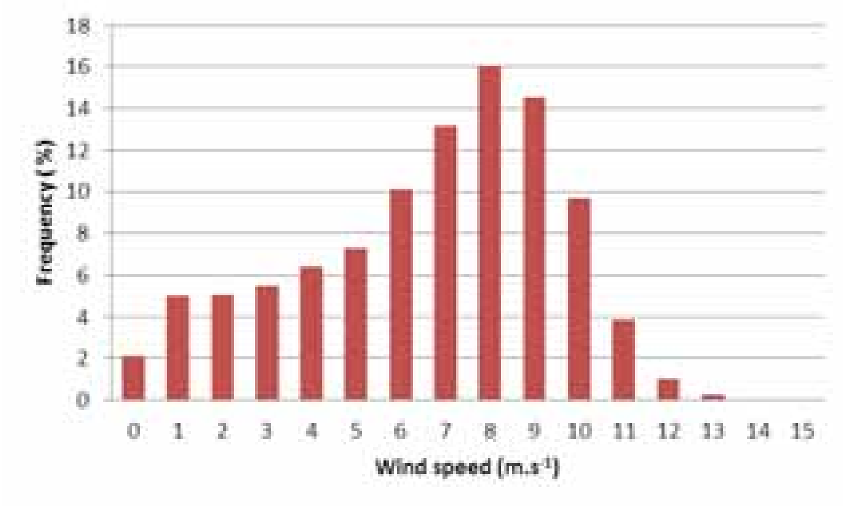

Fig. 1: Wind speed histogram for the selected location.

The average wind speed value for the considered period is *6.65* $m.s^{-1}$, which allows the installation of a small wind turbine for the purpose of water pumping.

The wind turbine chosen for the simulation has a nominal power of 1 kW. Fig. 2 shows the wind turbine power curve given by the manufacturer.

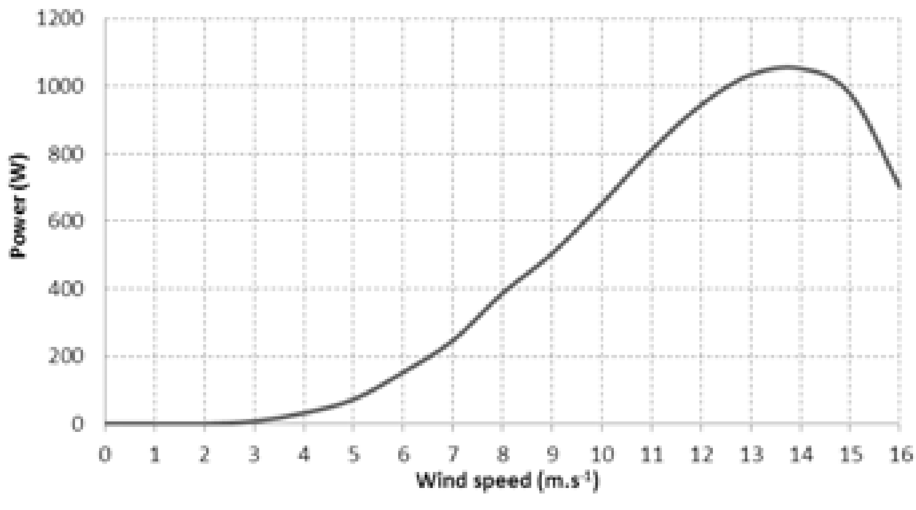

Fig. 2: Power curve of the wind turbine.

The monthly electric energy generated by the wind generator for the wind speed behavior of Fig. 1 is shown in Fig. 3.

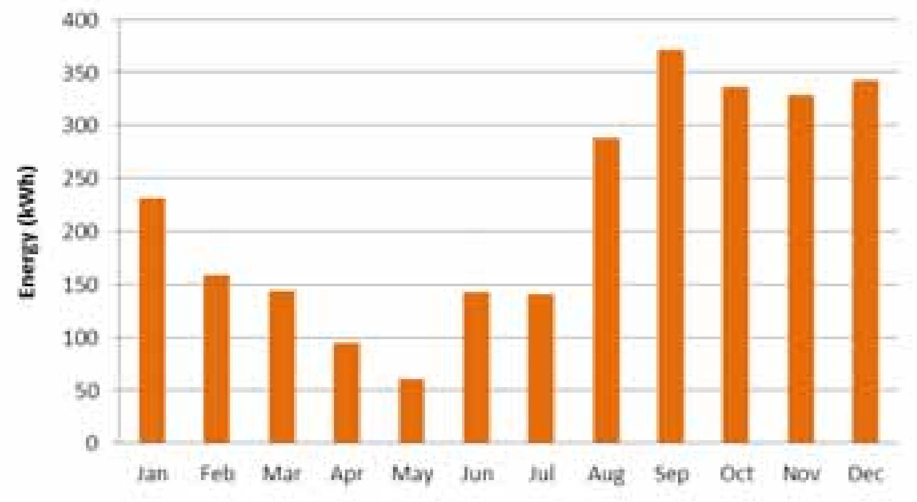

Fig. 3. Monthly electric energy generated by the wind turbine.

With the wind turbine connected to the inverter with efficiency η_{inv}, the power to be delivered to the pump can now be calculated by eq. 5.

$$P_{el} = \frac{\rho_w Q g H}{\eta_p \eta_{inv}} \qquad \text{(eq. 5)}$$

The equation for the pumping flow rate ($m^3.h^{-1}$) can be obtained by rewriting eq. 5 as eq. 6.

$$Q = 3600 \eta_p \eta_{inv} \frac{P_{el}}{\rho_w g H} \qquad \text{(eq. 6)}$$

For the simulation, the instantaneous capacity curves of a 0.5 cv pump coupled to the frequency inverter were used, where the data of flow rate versus power were obtained in a test bench for three different heads, as shown in Fig. 4.

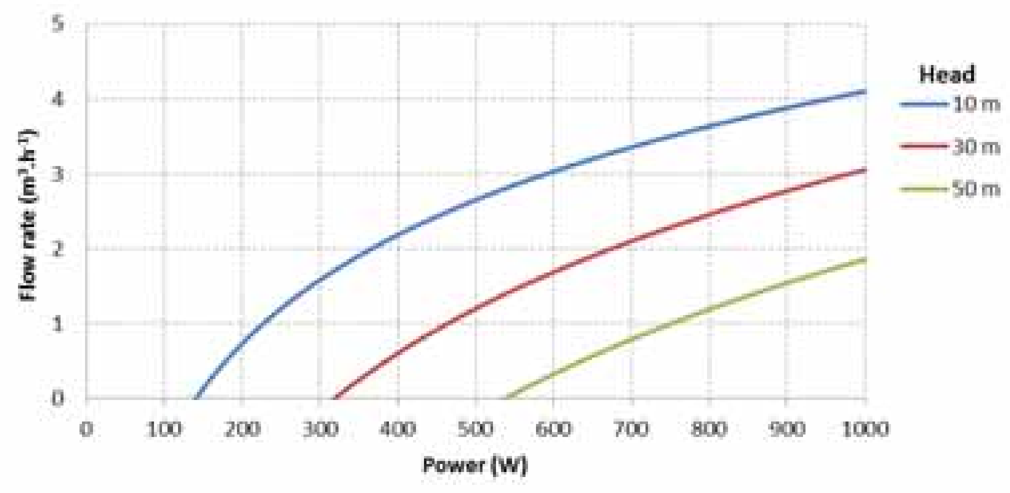

Fig. 4. Instantaneous capacity curves of the pump coupled to the inverter.

For the calculation of the average monthly flow rate of the pumping system, the values of wind speeds with the wind turbine power curve were used, and the results applied to the instantaneous capacity curves of the pump. Fig. 5 shows the result of the simulation.

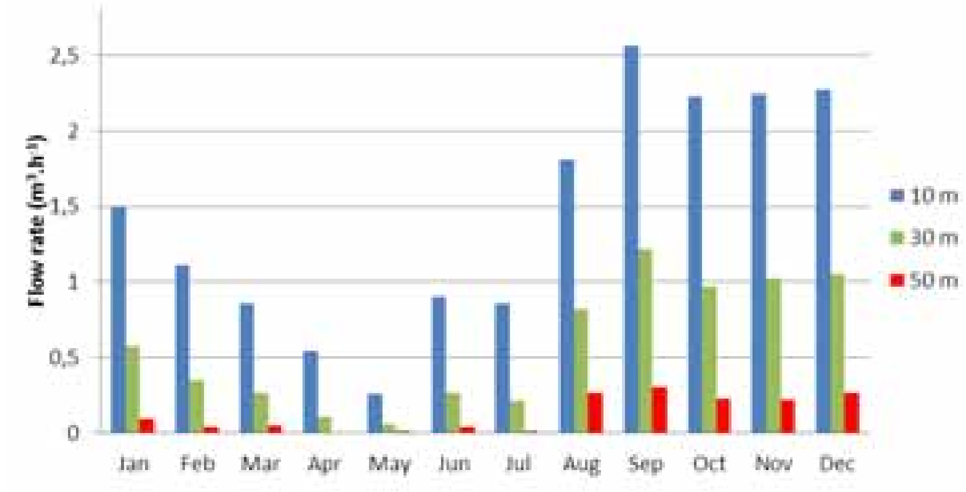

Fig. 5: Average monthly flow rate estimated for the location.

The average daily volume of water pumped for every head is shown in Fig. 6.

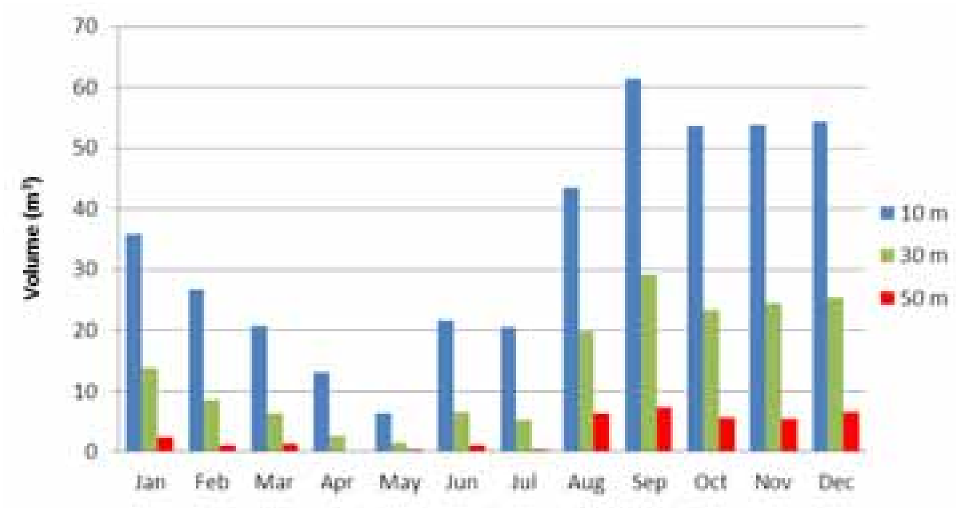

Fig. 6: Daily pumping volume estimated for the location.

As recommended by the World Health Organization (WHO), the optimal amount of water to meet the daily needs (food preparation, hydration and hygiene) of one person should be 100 liters (WHO, 2003). Considering a family with an average of 5 people, Fig. 7 shows the number of families that the system can supply.

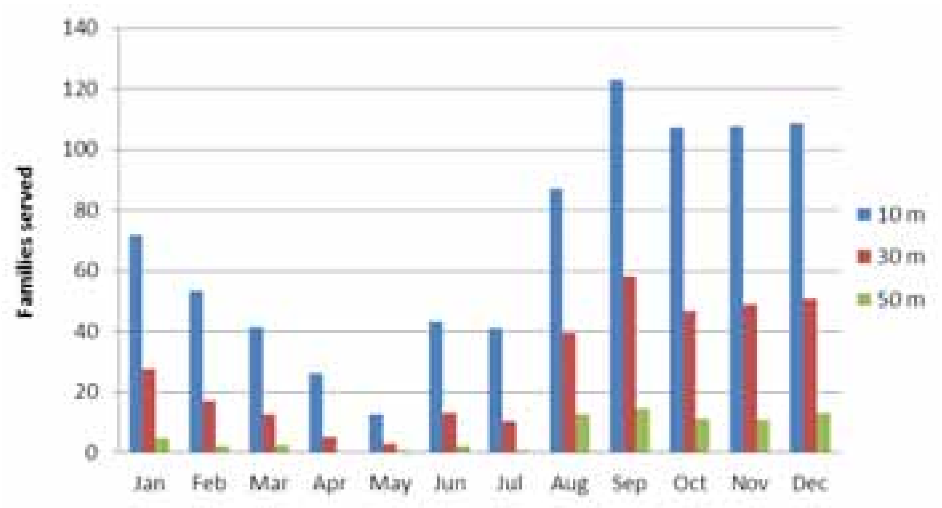

Fig. 7: Estimated number of families that can be supplied by the system.

It is noteworthy that a water storage system must be provided, to guarantee the water supply during the periods of low wind speeds or no wind at all.

5. Conclusions

As shown in the simulations, a water pumping system using wind power is perfectly able to meet the demand of an isolated community, even with low wind speeds. For this purpose, accessing the local wind data is the main factor to be considered, as well as other conditions such as water potential, location for the installation, and access to the site.

Some advantages of this system compared to using a diesel generator are related to the lifetime of the wind turbine, which is an average of 20 years, making it economically more attractive, because its higher initial cost is paid over the lifetime, also considering its low maintenance costs, and its non-polluting character.

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