Development of a Monitoring System for Off-Grid Wind Power Generation

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Abstract— This paper aims the development of a real-time data acquisition system for performance monitoring and evaluation of small wind turbines. The system consists of equipment capable of measuring voltage, current, power, power factor, efficiency and waveforms being produced by the wind turbine electric generator. The real-time monitoring system is connected to an off-grid wind turbine mounted on a tower and performs the data acquisition and storage continuously. Thus, from this system can determine the small wind turbine performance, is setting standards of three-phase electric generator device and the continuous monitoring of the energy generated.

Index Terms— Data Acquisition, Isolated System, Programmable Logic Controller, Monitoring, Radio, SCADA, Wind Turbine.

1 Introduction

THE use of wind power is an activity continuously exploited by man century after century. The first historical records of this use refer the civilizations that inhabited the regions of ancient Persia, Mesopotamia, Egypt and China. The vertical axis windmills were developed in order to replace the use of human or animal force in the process of grinding grains and increased water. The figure 1 shows replicas of are considered the first windmills. Although windmills have been designed centuries before, its use reached Europe only after the Crusades took place between centuries XI and XIII, where soldiers returning from the east brought about this technology. The Netherlands was the leading European country in which wind energy use was more widespread, been widely used for drainage of wetlands, promoting the economic development of the country. With the arrival of the industrial revolution, the development of electricity and the invention of steam engines and internal combustion engines, the use of wind power has fallen dramatically out due to fossil fuels take the post of main source of primary energy. The growing and continued demand for electricity over the years raised the consumption of fossil fuels, which are heading for a future breakdown. As a result, renewable energy sources, mainly wind, came to be seen as a viable alternative in the production of electricity to replace the current non-renewable fossil fuel sources. [1], [2], [3], [4]

Fig. 1. Replicas of the first eastern windmills.

As time passed and the improvement of technology, windmills have evolved to the modern wind turbines and have a wide range of constructive ways. Today, wind turbines can be differentiated according to the aerodynamic force that focuses on the blades (drag or support), orientation of the rotation axis (horizontal or vertical), gearbox (with multiplier or direct drive), number of blades (one, two, three or multiple), position of the blades in relation to the tower (upwind or downwind), power (small, medium or large), rotor speed (constant or variable), power and speed control (stall, step or active stall), local installation (on-shore or off-shore), type of electrical generator (synchronous or asynchronous) and others. [3], [4], [5]

The most used small wind turbines for power generation are the three blade Horizontal-axis wind turbines. This kind of wind turbine are driven by two aerodynamic forces called lift and drag forces. A body that blocks the wind movement suffers the action of forces acting perpendicular to the flow (lift force) and forces acting in the direction of flow (drag force). Both are proportional to the square of the relative wind speed. Lift forces also depend on the geometry of the body and the angle between the relative wind speed and the body axis. The rotors rotate predominantly by the lift forces allow release effect more potently than those turning the effect of drag forces for the same wind speed. [6]

Due to the high initial cost of these materials, its necessary to increase the life time of this equipment by the maximum. To do this, the wind turbine must operate over a wide range of temperature and speed. It is important to have a management, often remote, of the wind turbine operation. To perform the reading of the variables in sensors and subsequent interpretation of what was obtained is required an equipment to perform this work. The data acquisition boards (DAQ) are developed for this purpose. They are basically composed of electronic components, digital and analog I/Os and microcontroller. There are several types of DAQ systems, depending what want to monitoring. The board can count on devices for wireless communication, communication with Ethernet, LCD display, relays, LEDs, and others [4], [7], [8], [9]

Because wind turbines are often installed in places hard to reach, it is necessary to use equipment which allows remote management through the transmission data of the variables being monitored. There are devices that enable data transmission via wireless network. Among the technologies for wireless data transmission are radio, Bluetooth, Wi-Fi, GSM / GPRS (cellular)

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and others. [10]

2 Materials and Methods

2.1 Off-grid Wind Power Generation

Electricity is an item of extreme importance today. In urban centers the power is available with relative facility, but in places that are hard to reach or rural areas, the electricity is not present. This is often due to being too expensive or impossible to implement a traditional grid. The best solution for these cases is the use of an off-grid wind power generation. The figure 2 shows an off-grid system example.

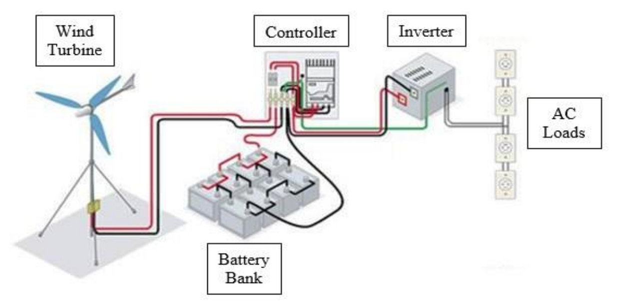

Fig. 2. Off-grid wind power generation system.

The off-grid system for electricity generation to be monitored consists basically of a small wind turbine, energy storage batteries, charge controller and inverter. The wind turbine chosen for this research was the WM2.8-1000 model. The figure 3 shows the of the wind turbine and Table 1 shows main specifications of the wind turbine.

Fig. 3. Off-grid wind power generation system.

TABLE 1
WIND TURBINE SPECIFICATIONS

Parameters	Value
Rated power (W)	1000
Output voltage (V)	24/48
Rotor diameter (m)	2.8
Swept area (m²)	6.16
Generator	Permanent magnets
Star up wind speed (m/s)	3
Operating wind speed (m/s)	9
RPM at rated output	400

The energy coming from the wind turbine feed the loads that are connected to consuming energy and perform the charging of the batteries. In order to have correct management of energy flow in the system is used a load controlling device called charge controller. The main function of a charge controller is to protect the batteries from extreme situations of operation and possible variations in seasonal consumption profile and temperature. This care helps to increase battery life. The controller that was used provides a continuous control voltage that is delivered to the batteries through a dump load system, which monitors the operation of the turbine and the batteries are charging. The controller can be used in a hybrid power generation system because has input for solar panels up to 150W.

The batteries used to store energy was the stationary type, model Freedom df4001 220Ah/240Ah made by Heliar. The wind turbine is configured to provide a 48V output voltage. As each battery has voltage of 12V were used four batteries connected in series to form a 48V battery bank.

To run AC devices and appliances with the DC power stored in the batteries its necessary an inverter. Was used a Pure Sine Wave CARSPA 2000W inverter, that is able to convert the 48V DC into 220V AC 60Hz.

2.2 Monitoring System

Develop a monitoring systems for equipment is not a simple task. The appropriate choice of technology to be used and the means of establishing communication for the integration of various equipment distributed in different locations is an important factor for the success of the data that want to monitor. The monitoring system is designed to measure voltage, current, power, power factor, efficiency and waveforms being produced by the wind turbine electric generator. From these data it is possible to analyze the wind turbine performance. Future new equipment will be added to the monitoring system, such as a weather station for collection wind data like average speed and predominant direction.

The designed monitoring system consist in sensors to measure, a programmable logic controller for read the sensors information, a communication system to sending and receiving the data, a supervisory system and a computer to show the information to the users. The figure 4 shows a simplified diagram of the monitoring system.

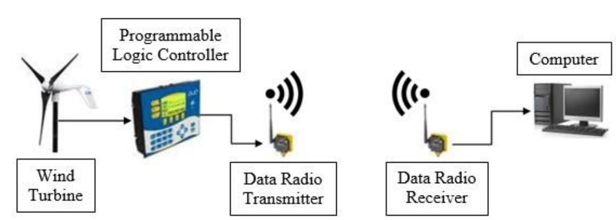

Fig. 4. Monitoring system workflow.

To monitor the power generation from the wind turbine was designed circuit with ACS712 Hall effect sensors. This sensor while under the application of a magnetic field, responds

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with a variation in its output voltage. Two cables from the wind turbine were sectioned to allow the installation of electric current sensors. A third sensor has been installed in series with the cable that connects the battery to the inverter. The figure 5 shows the electronic circuit for monitoring and conditioning the signals generated from the wind turbine.

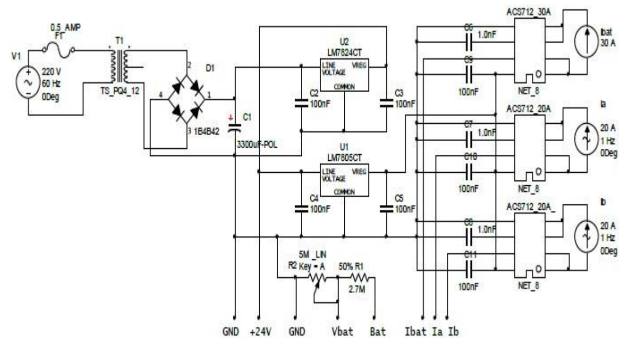

Fig. 5. Electronic circuit diagram used for measuring electrical currents.

For the acquisition of electrical values measurement on the Hall's sensor was used a programmable logic controller model DUO, manufactured by Altus. The specific programming of the programmable logic controller is performed using the MasterTool IEC software, compatible with the international IEC 61131-3 standard. This programming software is suitable both for controller programming as the human-machine interface. It offers six programming languages and the possibility to use more than one type in the same application. The main features of this controller are shown in table 2 and figure 6 shows the controller.

TABLE 2
PROGRAMMABLE LOGIC CONTROLLER GENERAL FEATURES

Parameters	Value
Digital inputs	20
Digital outputs	16
Analog inputs	4
Analog outputs	2
Display	3.2" graphic display with a 128 x 64 dot matrix – fully configurable.
Connectivity	2 communication ports (1 x RS232 and 1 x RS 485) with MODBUS master and slave
External power supply voltage	19 to 30 Vdc
24 Vdc input current	350 mA
Power consumption	8.4 W
Operation temperature	0 to 60 ºC
Panel protection	IP 54 (front) and IP 20 (back)


Fig. 6. DUO series programmable logic controller.

For remote monitoring of the generated electrical variables and measures via the analog inputs of the programmable logic controller was used chosen the radio transmission technology. Manufactured by Banner, the DX80DR2M-H radio, was chosen to satisfy the technical criteria of the project like good signal quality when used inside buildings. The main radio characteristics are listed in table 3 and the radio is shown in figure 7.

TABLE 3
DATA RADIO SPECIFICATIONS

Parameters	Value
Device type	Multihop
Housing style	Enclosed Terminals
Power supply	12 to 24 Vdc
Environmental rating	IEC IP67; NEMA 6
Radio frequency	2.4 GHz
Radio range	3.2 km with 2dB standard antenna
Interface	Indicators: two bi-color; LEDs Buttons: two; Display: six-character LCD
Operating conditions	–40°C to +85 °C (Electronics), –20 °C to +80 °C (LCD), 95% maximum relative humidity (non-condensing)
Spread spectrum technology	FHSS (Frequency Hopping Spread Spectrum)
Communication hardware	Interface: 2-wire half-duplex RS-485, Baud rates: 9.6k, 19.2k (default) or 38.4k via DIP switches; 1200 and 2400 via the Multihop, Configuration tool data format: 8 data bits, no parity, 1 stop bit


Fig. 7. Data radio DX80DR2M-H.

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3 Results and Discussion

3.1 Programmable Logic Controller

The electrical variables generated by the wind turbine and measures via the analog inputs of the programmable controller is performed through a program developed especially for this purpose. The programming of the programmable controller was performed using the MasterTool IEC ambient provided by the controller manufacturer. The developed program reading the measured current from sensors connected to their analog inputs. The measurements were set the variables of the wind turbine stages current excursion between -20 and 20A, the current of the battery in the range of -30 to 30A and the battery voltage between 0 and 48V. These are the minimum and maximum values specified in the equipment data sheets. To not generate a lot of data with identical values, the controller carries out the reading of the sensors every thirty seconds.

3.2 Supervisory Control and Data Acquisition

The process of information collected by the programmable controller was carried out using a SCADA system (Supervisory Control and Data Acquisition). Such information is collected through data acquisition equipment and manipulated, analyzed, stored and then presented to the user. Using resources from Elipse Scada Software, a screen was created on the computer to become the supervisory system of the wind turbine. The screen consists of a graph in the cartesian plane, a display of the current value, and bar graph showing the current level for each current or voltage (being the phase currents 1, phase 2, battery current and battery voltage), plus two analog displays, one for the wind speed and the other for the generated power. The figure 8 shows the developed supervisory screen. The data generated from monitoring power generation system are stored in a digital file, which can be used for further analysis.

Fig. 8. Developed SCADA screenshot.

3.3 Wind Turbine and Monitoring System Installation

The installation of the wind turbine was carried out on the roof of the building of Electronic Engineering at the Feevale University. The selection of the installation place was performed from the search for a place where there no physical obstacles close to the wind and was easily accessible for possible maintenance. The figure 9 shows the turbine installed on the roof.

Fig. 9. Wind turbine mounted on tower.

Other equipment that make up the generation and monitoring system were installed in Electrotechnical and Energy Conversion Laboratory, which is located in the building of Electronic Engineering at the Feevale University. From the turbine installation, the choice of the programmable controller, the radio transmitter system and circuit of current measurement, the next step performed was the connection of all these parts. The figure 10 shows the equipment for generating and monitoring system installed in a room of laboratory. The figure 11 shows the radio receiver and the computer with the supervisory system for remote monitoring installed in another build room from the university.

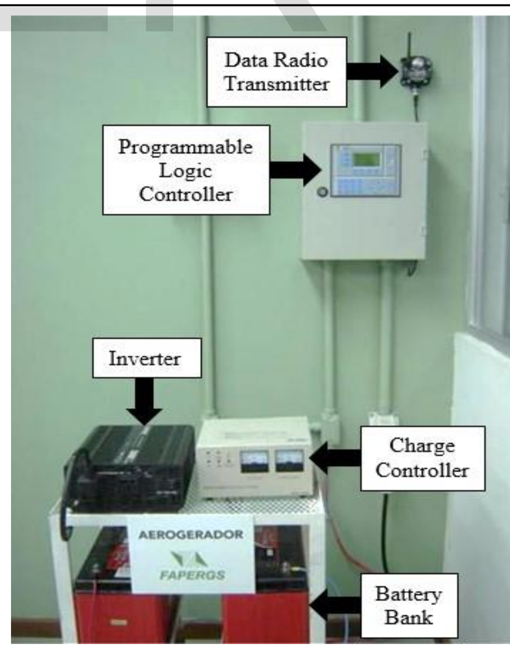

Fig. 10. Electric power generation and monitoring system equipments.

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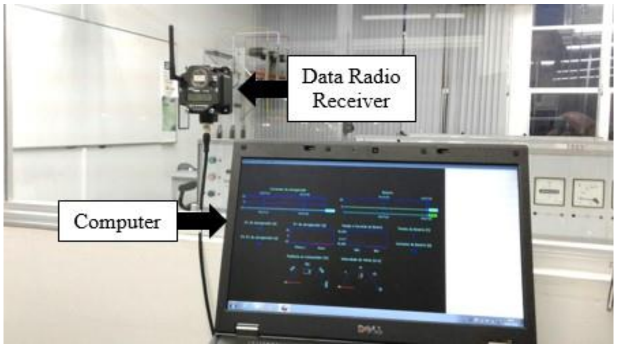

Fig. 11. Data radio receiver and computer with supervisory system.

After the installation of the monitoring system functional tests were performed. The objective of the tests was to assess the quality of data collection and transmission of information. The receiver system comprising a radio and computer was installed in three different university buildings and receives data for two hours, showing the values obtained by the supervisory screen developed.

4 Conclusions

The use of small wind turbines in off-grid systems for electricity generation has grown progressively in recent years. The off-grid systems are used in private places of electricity from the public grid. This systems work storing energy of a wind turbine in stationary batteries, which allow consuming energy when don't have windy. The batteries load management is performed by a charge controller, located between the turbine and the batteries, which has the function of controlling the input voltage in the batteries, thus avoiding overloads or excessive discharge while optimizing and extending its useful life. In order to consume the energy stored in the batteries is necessary to change the DC storage electricity into AC. For this purpose, is used a pure sine wave inverter that do the conversion. Due to the high initial cost of these off-grid systems, is desired to increase the equipment lifetime by the maximum. To do this, the wind turbine must operate as close to its limit conditions. Therefore, it is important to realize a management, often remote, from the operating information.

The study and development of a system for real-time data acquisition were performed in order to monitor the voltage produced by small turbine. The monitoring system has allowed the collection operating data from a wind turbine for further analysis in order to generate information and create fast and reliable database. The development of the monitoring system was carried out in stages involving the definitions of variables to be monitored and the selection of sensors, equipment for reading sensors, transmission technology and signal reception and processing of values.

The development of the monitoring and conditioning system of the signals generated from the wind turbine was carried out using an electronic circuit designed with magnetic Hall effect sensor, programmable controller, communication system, monitoring software and computer. The installation and configuration of all components of the system was carried out according to the research objectives. From this system it is possible determine the small wind turbine performance, setting standards of three-phase electric generator device and the continuous monitoring of the energy generated.

Communication tests were performed satisfactorily, when was possible to observe the behavior of the wind turbine for a short period of time. These results, however, cannot be taken into account for a representation of the wind turbine behavior. The wind turbine efficiency setting can only be made from the analysis of a large amount of data, which requires a long time. A database containing the values is being assembled for the operation of the wind turbine that allows to be evaluated.

The permanent monitoring of the wind turbine allows the construction of diagnostic systems and prediction that can contribute significantly in improving the performance of equipment. The monitoring of the wind turbine can be made more flexible and extended to its various components to fine-tune the mechanical parts and an optimized performance to minimize stress and avoid shortening the lifetime of monitored elements.

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