WiFi Monitoring Embedded System for Electrical Microgeneration using Renewable Energy Sources

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Abstract— **The present paper describes how to design and assemble a low cost online monitoring and WiFi data acquisition system using free software applied to microgeneration based on renewable energy sources worldwide. The development of online monitoring systems for microgeneration plants based on renewable energy sources is becoming more important, considering that monitoring and data acquisition systems are applicable in stages of the microgeneration process. The monitoring and data acquisition WiFi system was developed using an embedded WiFi modem (Wifly) coupled to a microcontrolled board based on the free tool SanUSB. This monitoring system was applied to a photovoltaic (PV) water pumping plant without batteries, so as the control system and the wireless communication with the online server, which is also autonomous and powered by PV panel. The free software for online monitoring and WiFi data acquisition allows the analysis of stored data and charts through mobile devices as notebooks, tablets, and smartphones.**

Keywords- WiFi monitoring; Data acquisition systems; Microgeneration; Renewable energy sources.

I.   INTRODUCTION

Based on the advent of Brasilian Electricity Regulatory Agency (ANEEL) resolution 482 [1], establishing general conditions for the connection of microgeneration plants (power up to 100 kW) in the Brazilian distribution grid, makes more relevant the development of online monitoring systems [2] of microgeneration plants based on renewable energy sources, like solar, wind, and biomass. Therefore, monitoring and data acquisition systems are applicable in various stages of the microgeneration process, for example, in the energy resource evaluation, generation failures prognosis, practical verification of project data and efficiency of generation.

As a first positive reaction, in August 2013 started working in Rio de Janeiro a PV microgeneration plant connected to the grid, able to produce 50% more than the total house electricity consumption [3].

Data acquisition and online monitoring systems are found in Brazil mainly at large power plants, with complex monitoring and relatively high costs, making impracticable the incorporation into domestic clients and in other clients

that are inside the range of microgeneration power. In this way, the present article intends to develop efficient techniques for online monitoring with open source software, sensing and WiFi data transmission to contribute with the diffusion and installation of microgeneration systems based on renewable energy sources. Until the 90s, Internet was used as a file, news and electronic messages exchange tool, used by students in academy and universities [4]. After the 90s, the World Wide Web started to draw the user attention, changing the way people interact with other people.

The Web offers a colorful and easy way to navigate in graphic interface, with a content not limited to text and hypertext, also offering icons, lines, drawing, maps and pictures. Additionally, there are also hypermedia contents, hypertext pages with sound and video. The Web content can be visualized via a browser, which verifies the files and displays the contents stored on the server, as the open source software for online monitoring developed in the present research.

This paper is organized as follows. Section II describes the hardware and software of the WiFi microcontrolled system, followed by the description of the WiFi communication protocol in Section III. Section IV provides information about the open source software and the principles of the WiFi acquisition system implemented to receive data from the photovoltaic (PV) microgeneration plant described in Section V, including sensing and conditioning. This section contains also charts obtained from the values of the microgeneration plant. Finally, conclusions are presented in Section VI.

II.   WiFi ACQUISITION SYSTEM

This section describes the developed data acquisition board with WiFi connection, shown in Figure 1. The WiFi embedded system programming is based on open source and free software, which is an advantage of the proposed system. The board sends monitored data to an online server also programmed in open source software.

This modulated hardware consists of a microcontrolled board, called as SanUSB, connected to an WiFi modem via an adapter board that was developed for this application in order to adjust the pin connections, as well as to convert the voltage from 5 V to 3.3 V.
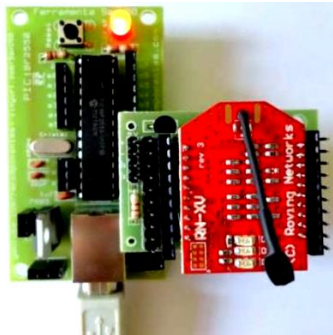
Figure 1. Acquisition data board and WiFi modem.

After coupling the embedded WiFi modem to the microcontroller pins (VCC, GND, Rx, and Tx), it is necessary to program the microcontroller with the firmware developed by Wifly configuration commands. In this way, support libraries were programmed to develop the firmware available as an Android application [5]. The users can also improve the open source firmware in order to adapt for a specific monitoring system.

A wireless system using RF signal to power a temperature sensor for on-body temperature monitoring is shown in [6]. There are also other studies on remote wireless sensing, such as those developed by [7] and [8].

Wireless sensor nodes inside buildings are used to read out sensor data and to control actuators by a reference value in [9]. The nodes need to operate for a long time with a single battery. When using a standard WiFi connection, the node battery would be depleted after a few hours due to idle currents in receive state. The use of sensor nodes with included wake-up receivers can prolong the lifetime of the sensor network to several years, because the sensor measure data and send information only when a command is received from the Internet.

The developed data acquisition board, based in a microcontroller USB programmable tool and using open source software, is patented by National Institute of Industrial Property (INPI) with register number 088503, executable in multiplatform like Linux, Mac OSX and Windows® and available in the files from the SanUSB group [10]. This tool is composed by a preprogrammed bootloader in the embedded system and a graphic interface used to program the microcontroller via USB.

SanUSB tool allows a friendly interface and also debugs directly through the virtual serial emulation via USB. This step can be implemented in a fast and efficient way when the microcontroller is connected to a computer via USB. A developed equipment for specific applications tend to be cheaper, have better cost benefit relation and make possible an easy understanding and operation. With this same data acquisition board, a monitoring system was developed for implementation of a device for high temperature control applied to thermoelectric microgenerators [11]. Figure 2 shows the program process using the designed embedded system.

Figure 2. Program process using the designed embedded system.

Also using SanUSB tool, students were champions of:

- IFCE Robotics Competition (2007, 2008, and 2009) in the Location category, Brazil;
- Brazilian Science and Engineering Fair (FEBRACE-2009) at Federal University of São Paulo (USP),Brazil, in Engineering category;
- Innovation Award for Technology Application at the *Feria Explora Medellin* in Colombia in 2009;
- International Forum of Science and Engineering 2010 in Chile in the *Supranivel* Category;
- FEMECI IFCE 2010 in labyrinth robotics category, Ceará, Brazil.

The mentioned open source software is based on contributions of Internet developers throughout the world. This software offers a better performance, encourages creativity, allows dedicated applications and stimulates finding and correcting code errors faster than private software [12]. It is important to emphasize that USB ports are used as power source by the tool microcontroller only in the code development phase. The data acquisition system is autonomous; that means, a battery or a PV panel is used as an external power source.

III. WIFI COMMUNICATION PROTOCOL

WiFi nets use radio wave technology with Institute of Electrical and Electronics Engineers (IEEE) standards, such as IEEE 802.11a, 802.11b, and 802.11g. These standards provide reliable and safe wireless connectivity. WiFi nets can be used for connection between computational devices and also to connect these devices to Internet [13]. WiFi net operates in the not licensed radio waves 2.4 GHz, in the IEEE 802.11b and IEEE 802.11g technologies and in the 5 GHz frequency of the 802.11a technology [14].

The WiFi modem (Figure 3) is based in the RN-171 module to promote connection to the wireless networks. The connection of this modem needs only four pins designated to power and WiFi communication. This device has an independent antenna to increase its reach and offers stronger signal and support for the most common communication protocols like Transmission Control Protocol (TCP), User Datagram Protocol (UDP), and File Transfer Protocol (FTP).
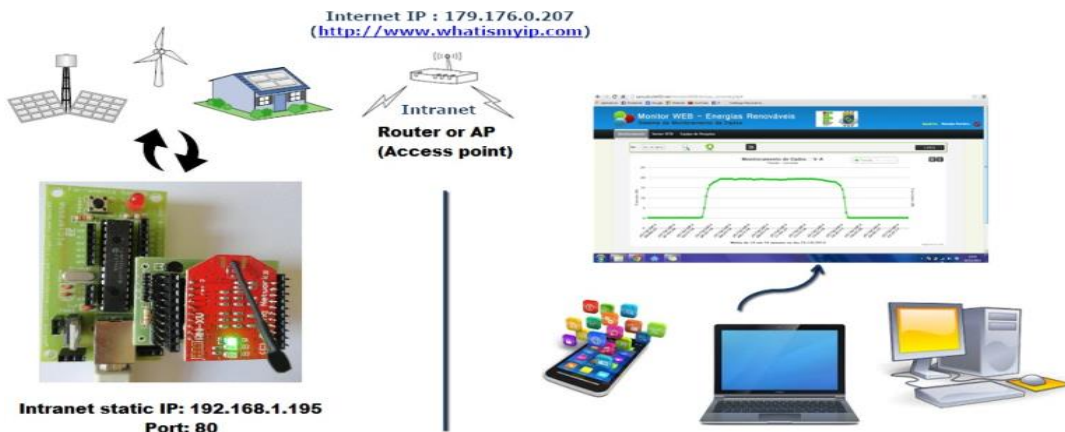
Figure 3. Online monitoring process via WiFi modem.

If more than one WiFi modem or computational device is connected on the Internet in a home network using a broadband router or a gateway, most of the time only this router will contain an Internet IP address and each device in the internal net utilizes an IP local address given by the router.

The intranet IP local address is usually created dynamically via a service called Dynamic Host Configuration Protocol (DHCP) of the gateway, or defined in a static way by the user, according to the network.

In the proposed case, the gateway is 192.168.1.1. Therefore, a fixed static IP address was defined for the WiFi embedded modem, i.e., 192.168.1.195. The proposed embedded system can be, with this firmware, server (e.g., switching a load through the instruction "192.168.1.195/YT" in address bar) or also client (e.g., a sensor value is posted to an online databank server).

IV. PROPOSED CONFIGURATION OF ONLINE MONITORING

In this item, the open source software and the principles of WiFi acquisition are described. In the present study, a PV powered pumping plant without batteries is used, in which the control and communication system with the online server is also autonomous and powered by a PV panel.

In this case, information that is sent to the online data bank is configured with remote access over WiFi without charging, different from the applications that use General Packet Radio Service (GPRS) protocol.

In this context, the development, programming and application of a WEB monitoring system and wireless data acquisition using open source software are described.

The online data bank can be queried by any computational device connected to the Internet by using a personal password. The query can be made at any time, updated every minute. Figure 4 shows the online monitoring development in two stages:

- Sensing, conditioning and data transmission;
- Data bank uploading from an online server and presentation to the user.

The first stage establishes communication between the sensors connected to the data acquisition board. The second stage, i.e., the user presentation layer, was developed in PHP with MySQL database. In this way, a free option for online monitoring applied to renewable energy sources is introduced.

The first stage of sensing, conditioning, and wireless acquisition reads the data from the sensors every minute and saves the information in an internal Electrically-Erasable Programmable Read-Only Memory (EEPROM).

Every ten minutes, the average value of the sensor measurement is calculated and sent to the stage two. It is important to mention that the actuators may be also connected to the board, allowing WiFi load control through the server. In the server, a communication interface to the acquisition system and another one working in parallel to the user communication were developed.

The first interface is responsible for data receiving, to store them in the persistent database and to send a confirmation to the board. The user interface delivers a friendly front-end that allows data visualization in the form of list or chart.

The embedded firmware was programmed using a digital filter to identify and exclude abnormal values that differ by more than 100% of the maximum and minimum values of the variable reference measured every minute.

V. PHOTOVOLTAIC (PV) MICROGENERATION PLANT DESCRIPTION

The microgeneration plant used in the present study is installed on the laboratory of alternative energy (LEA) at the Federal University of Ceará (UFC). This plant consists in a water pumping system powered by PV panels, with a maximum power (Pmax) of 87 Wp, open circuit voltage of 21.7 V (Voc) and short-circuit current of 5.34 A (Isc).

The motor-pump has a voltage of 12 Vdc, a maximal pressure of 20 psi and a pump flow of 5.9 liters per minute (2,205 rpm) and a nominal current of 4.2 A.
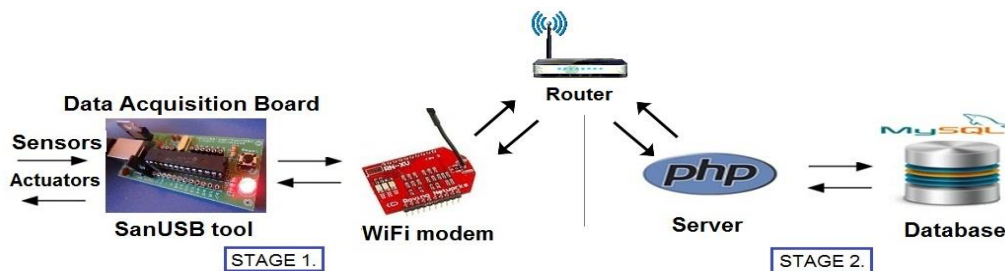
Figure 4. Steps of the open source software monitoring system.

The developed online monitoring and wireless acquisition open source software was installed to record PV panels voltage and current, motor-pump pressure and flow, ambient temperature and solar irradiance. The electronic devices were located in plastic boxes in order to avoid the influence of thermal variation.

A. Sensing, conditioning and data acquisition

To adapt the sensor signal to the analog-to-digital converter (AD) from the data acquisition system is used the principle of conditioning by voltage division, when the measured value is greater than the maximum voltage of the AD converter. There is also the principle of signal amplification with circuits that use instrumentation amplifiers to adjust the voltage or current of the sensor signal to the voltage full scale of the microcontroller AD converter.

Furthermore, the instrumentation amplifiers are also used to read sensors, with minimal or virtually no signal interference due to the high impedance input amplifiers, functioning as a signal insulator, since the amplifier output voltage is supplied by the amplifier power and not by the input voltage. For amplification of the signal from the current sensor of the PV panels, conditioning circuit for difference amplifying is used. This configuration responds to the difference between voltage signals applied to the input and ideally rejects signals that are common to both inputs. Regarding the PV panel voltage, it was necessary to deploy a board with conditioning circuit by voltage division to collect the data, because the signal exceeds the AD converter threshold voltage. In the case of voltage, the PV panel used provides maximum voltage of ca. 19 V.

B. Open source software for online monitoring

The Web Monitor is an application developed on online server with the PHP programming language, in conjunction with a structured database in Database Management System (DBMS), in order to serve as visualization of monitoring data (signals sensors) from renewable energy sources and to send them via a wireless communication (GPRS or WiFi). Figure 5 shows the initial login screen of the data monitoring system.

To access the monitoring system, it is necessary to enter the website link in PHP; after that, the system main authentication page appears, containing an authentication form (username and password). In this way, only pre-registered users can access the system. After entering the data access in the authentication step, the user is redirected to the system home page.

Figure 5. Monitor WEB login screen.

Through the WEB monitor, the user can query the stored data in the online database via smartphones or PC whereas the Ethernet standard is the solution currently used in private systems to promote network interconnectivity; the cost of monitoring systems for microgeneration in wireless network with open source software tends to be dwindling.

At the submenu *Monitoramento* (monitoring), there are two submenus: *Gráfico* (chart) and logs, as shown in Figure 6. By clicking the submenu *Gráfico* a chart of the sensor values stored in the database is generated, for example the chart showed in Figure 7, with voltage, current and electrical power data.
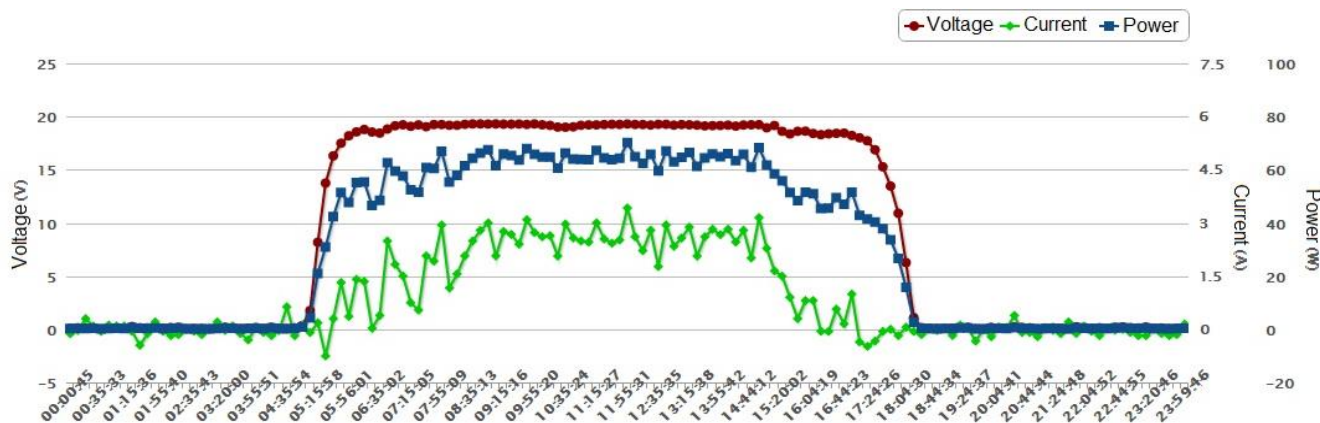

Figure 6. Menu screen expanded.

Figure. 7. PV voltage, current, and electric power.

To generate the charts, a library called Highcharts, written in Java Script, was used. The chart automatically restarts every 30 seconds. To display the sensors values involved in the chosen application in a specific day, it is necessary to inform or to select a valid date and then click the magnifying glass icon. Shortly after, the chart will be updated showing for each point a representative value averaged over the sensor values every 10 minutes.

In order to view the corresponding logs to the current values displayed in the chart, it is necessary to click the logs button. The system also provides the option to print or export (PNG, JPEG, PDF, and SVG) the entire structure of the chart view.

C. Charts of the open source software for online monitoring

In this topic, charts obtained from the open source software for online monitoring related to voltage, current and power will be presented. The PV panel voltage shape remains stable in sunny days, with a maximum of 19.3 V at noon and remaining around 19 V from 6 am to 5 pm.

The PV current chart showed in Figure 7 tends to follow the solar irradiance, reaching a maximum of 3.7 A at 12 pm, a peak of irradiance. The electrical power is obtained by multiplying the voltage and the current of the PV generator.

The power is maintained around 70 W, for a voltage of 19.29 V and a current of 3.64 A.

The flow sensor has a signal from 0 to 10 V for a range from 0 to 25 liters per minute. In order to perform the sensor reading, it is necessary that the variation is from 0 to 5 V, due to the full scale voltage of the microcontrolled data acquisition system. Thus, the l/min value for a voltage range from 0 to 5 V is 0 to 12.5 l/min (1 liter per minute corresponding to 0.06 m^3/h).

In the present study, a pressure sensor PN20 (2005) was deployed. Considering a 5 V maximum voltage of the analog-to-digital converter and a digital maximum value of 255, the sensor shows 70 psi. For a reading in kPa, the conversion factor from psi to kPa is 6.895; then the value of the actual pressure (PR) related to read digital value (Vd) is given by

$$P_R = \frac{70 \cdot Vd}{255} \cdot 6{,}895 \Rightarrow \quad P_R = 1{,}893 \cdot Vd \qquad (1)$$

Q x H product, measured in m^4/h is defined as the product of water flow (in cubic meters per hour) and pressure (in meters of water column); this product multiplied by constants indicate the hydraulic power in different units. Pressure, flow, and Q x H product of a monitoring day are shown in Figure 8.
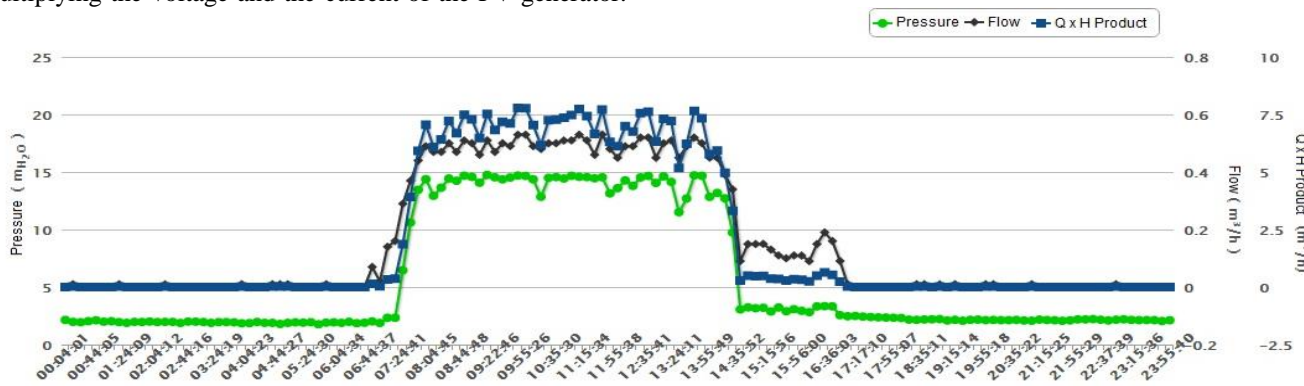

Figure 8. Pressure, flow, and Q x H product.

In the flow chart of Figure 8, the pumping system begins operation with a mean value of 0.5 m^3/h at 6 am and reducing the flow at 3 pm. This water flow reduction is due to the decrease in solar irradiance.

VI. CONCLUSIONS

As financial resources in developing countries are generally limited, solutions dedicated to monitoring and identification of local energy resources and for real-time monitoring of decentralized plants using renewable energy sources can contribute to a policy of decentralization of electric power generation in these countries. The present paper proposed a wireless data acquisition system, online monitoring applied to decentralized microgeneration of electrical power from renewable energy sources.

With the advent of ANEEL normative resolution n. 482 introducing general conditions for electrical microgeneration connected to the grid using units up to 100 kW, it becomes more important to develop online systems for monitoring processes of microgeneration based on renewable energy sources, such as solar, wind, and biomass.

The monitoring and data acquisition system proposed was developed in open source software and multiplatform (Linux, Windows®, and Mac OSX) in order to facilitate the dissemination of the computational tool developed for different user profiles. The open source monitoring software proposed enables monitoring the microgeneration plant via smartphones, tablets or other mobile devices with Internet access. As a case study for the monitoring system, a water pumping plant powered by PV panels was used.

The online database can be queried by any computing device connected to the Internet via password. Queries can be made at any time by updating the database every 10 minutes, which is usually the maximal time step for data acquisition systems of renewable energy plants. The WEB monitoring and designed data acquisition system of the microgeneration plant was efficient because of the online query possibility and real-time operation of the electrical microgeneration plant, showing a behavior according to the project. The use of tools based on open source software for online monitoring applied to microgeneration systems allows greater accessibility to general users. The online monitoring and data acquisition model proposed can be expanded to record data from other types of analog or digital sensors, as well as other types of microgeneration plants using renewable energy sources.

ACKNOWLEDGMENT

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