Solar Manager: Acquisition, Treatment and Isolated Photovoltaic System Information Visualization Cloud Platform

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Abstract- This article describes a platform of acquisition, processing and visualization of the behavior for isolated solar systems called SOLAR MANAGER. The recording of measurements was conducted in an isolated photovoltaic installation *of the Faculty of Engineering Electronics Systems and Industrial, Ambato Technical University*. The acquisition system will provide the information necessary for performing maintenance monitoring, operation and supervision through variables such as voltage, current, temperature and humidity system to generate renewable *energy remotely from a CLOUD COMPUTING platform. It is intended that the implemented system is economically viable, because the system is developed in open source allowing compete with commercial monitoring systems.* The control and monitoring of photovoltaic installations isolated platform - SOLAR MANAGER, in the future one will become a central monitoring and control of all isolated PV plants installed all over the country

1. Introduction

The electricity supplied by photovoltaic systems is currently very competitive economically due primarily to recent advancements in technology, as well as, a reduction in the investment cost. A considerable amount of these isolated systems have been installed in rural zones with difficult access in Ecuador. The main difficulty with isolated photovoltaic systems lies in the absence of a remote monitoring system which would permit *a* follow up of their operation [1]. The absence of a monitoring system can lead to a break in the electric current supplying isolated areas. Isolated photovoltaic systems require the use of wireless measuring devices and virtual platforms which allow the monitoring the systems to follow their activity in real time. Monitoring systems speed up the operation and maintenance of the components that make up photovoltaic generator systems [1].

Presently, the large variety of commercial monitoring systems used for photovoltaic systems *exhibit* many disadvantages, such as:

• Require software from the same manufacturer.

• Limited autonomous control.

• Consume large amounts of electricity.

• Limited storage capacity.

• High maintenance cost.

These disadvantages encourage the development of monitoring systems that are based on open-source software and free hardware. Taking advantage of this, the Solar Manager Platform – Acquisition, Treatment and Isolated Photovoltaic System Information Visualization Cloud Platform – was installed using open-source software and hardware. This way, an easily adaptable modular system was obtained which has a great capacity for integrating new technological trends. Currently, the existence of online services and computer applications, such as, remote wireless monitoring systems allow for a large amount of registered data to be transmitted and stored. Cloud computing platforms are the best way to manage large volumes of information and web services while guaranteeing adequate levels of reliability, scalability and accessibility as well. The use of open-source systems *provides* excellent benefits:

• Reduced energy consumption and equipment costs.

• Remote access.

• Automatic updates and reduced cost.

• Many options for scalable storage.

• System improvement through open-source programming.

• The capacity for personalized configuration of platform features.

2. Description of Existing Experiences with Remote Monitoring

In the past few years, innovative proposals related to remote wireless monitoring have been developed; the most notable of which are described below.

In [2], the use of Arduino platform microcontrollers consisting of free hardware and software designed to control, supervise and monitor the state and operation of different electronic devices is proposed. The use of the Arduino platform presents big advantages due to its quick and simple programming, as well as, being easily learned. The design of the Arduino platform is simple, low cost and has low electricity consumption in comparison to the BeagleBone microcontrollers and the Raspberry Pi cards. Likewise, the Arduino platform has its own programming language which is compatible with various versions of operating systems and also provides a simple means to interact with other devices. On the other hand, the BeagleBone and Raspberry Pi cards have a GNU/Linux operating system. The acquisition of high intensity analog

signals could damage the device's memory wherever it is located within the operating system.

Table 1 presents a comparative analysis of the technologies described above.

Table 1: Comparison between Arduino, BeagleBone and Raspberry Pi -

	ARDUINO UNO	*BEAGLEBONE*	*RASPBERRY PI*
MODEL	*R3*	*REV A5*	*MODEL B*
PROCESSOR	*ATmega 328*	*ARMCortex-A8*	*ARM11*
CLOK SPEED	*16 MHz*	*700MHz*	*700MHz*
RAM	*2KB*	*256MB*	*256MB*
FLASH	*32KB*	*4GB*	*SD*
MIN POWER	*42mA*	*170mA*	*700Ma*
DIGITAL INPUT	*14*	*66*	*8*
ANOLOG INPUT	*6*	*7*	*8*
ETHERNET	*N/A*	*10/1000*	*10/1000*
DEV. IDE	*Arduino tool*	*Python Scratch. Cloud9/Linux*	*IDLE. Scratch. Squeak/Linux*
COST	*$29.95*	*$199.95*	*$35.00*

 In [3] a home automation control based on the Arduino platform is presented as a low cost alternative to commercial control systems. The cost of implementing a home automation control may be reduced by using Arduino microcontrollers and it integrates low consumption devices, such as, sensors, regulators, actuators and communicators. The procurement of information about the state of the rooms in a dwelling, by use of sensors, is anticipated. The sensors and actuators will send information through wireless communication, applying Bluetooth and Xbee protocols. The required actions of the user will be managed through a server which will allow for control and visualization of the information outside of the dwelling through mobile applications or from an Internet browser. In addition, a central microprocessor ARM1176JZF-S with an operating

frequency of 700 MHz is included in the server's design. This way, the server will establish communication between measuring devices and control devices from individual or general environments. An Ethernet module for Arduino will be used to connect to the server through a physical means to a router. That way, all the devices located inside the local network will be able to access the server.

A functionality test of the home automation control server based on an Arduino microcontroller is represented in figure 1. The server indicates the location of the dwelling used for data acquisition and also provides a measurement variable required by the user, in this case the temperature.

Figure 1. Web server based on Arduino [3].

The design for an electric variable registration system based on an Ethernet communication system which allows the procurement of information about the electric consumption in a single-family dwelling is presented in [4]. The recorder's design is based on Arduino technology. Furthermore, the acquired information is processed by the microcontrollers and transmitted through Ethernet protocol to a graphic interface. An Arduino Micro connected to voltage and current sensors was used during the acquisition process and registration. Arduino One, incorporated with its Ethernet module, transmits the data to by means of the Internet, figure 2.
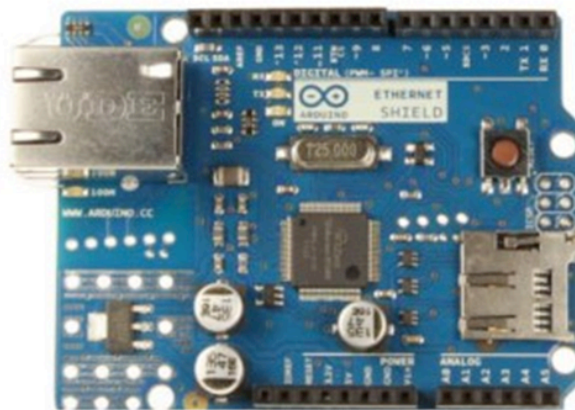

Figure 2. Ethernet module compatible with Arduino One and Mega [4]

In [5] a low-budget monitoring system with flexible control and monitoring characteristics for working from mobile devices is presented. The system integrates a web server, which establishes an IP – Internet- Protocol connection to access and control electronic devices and appliances. The access and control is done from applications developed for Android smartphones. The architecture of the control and monitor system consists of 3 layers:

- home environment.

- linkage gateway.

- remote environment.

The remote environment includes all of the users who access the system through an application on a mobile device which operate on Android. The use of a mobile device allows the user to connect by Wi-Fi or through a 3G/4G network. Moreover, the gateway establishes a connection between a hardware interface module and a web server. The main device which integrates the web server is an Arduino microcontroller with its corresponding Ethernet module. The use of this microcontroller permits the server to manage, control and monitor the components of the hardware interface module. The server notifies the user regarding the status of said hardware interface module through periodical reports. The information presented in the reports is acquired from the sensors and actuators that are interconnected with the Arduino microcontroller, figure 3.
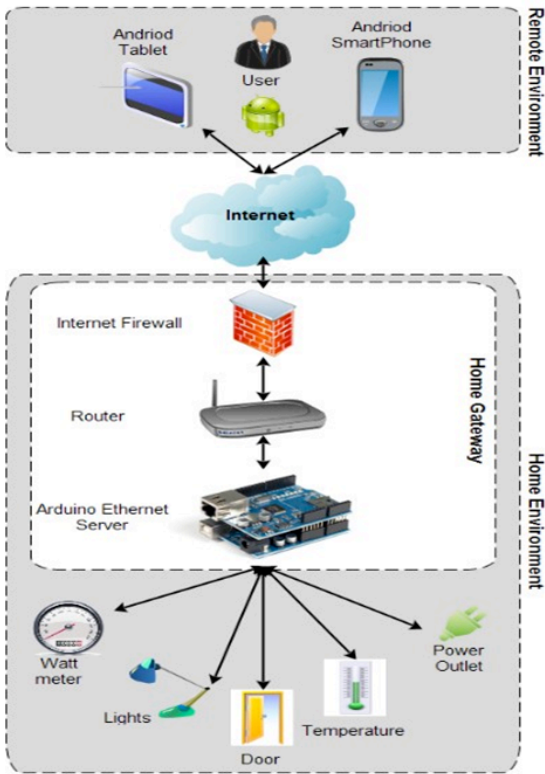
Figure 3. Architecture of the Arduino Control and Monitor System [5].

In 2014, the Chennai Technological Institute of Engineering in India proposed an illumination system supervised by means of a monitoring platform with a cloud server. The data acquisition system is based on Arduino technology which transmits information about the status of each component in the illumination system with the help of wireless Zigbee sensors based on the standard 802.15.4. The implementation of a wireless network of sensors requires proper and secure placing of the equipment that connects to a Web server. The status information of the illumination system updates automatically through the Internet [6]. Furthermore, the information reports are presented in periods established by the user. *In Figure 4,* a block diagram of the implemented system can be seen.
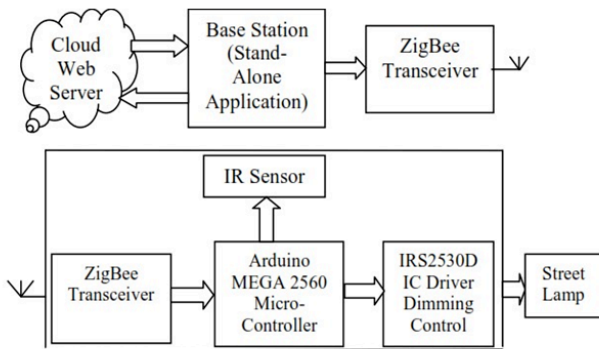

Figure 4. Block diagram of the cloud monitoring system.

The Internet of things, IoT, allows physical devices to link to the Internet with the help of sensors and actuators [7]. The afore mentioned interconnection facilitates the development of monitoring systems, smart measuring platforms, home automation, smart public lighting systems, and tele managing systems from Internet accessing devices. The information acquired from the sensors is managed through a web server with a fast connection from fixed and mobile devices. Moreover, the use of a server permits the user to control processes and supervise them from the Internet, figure 5.
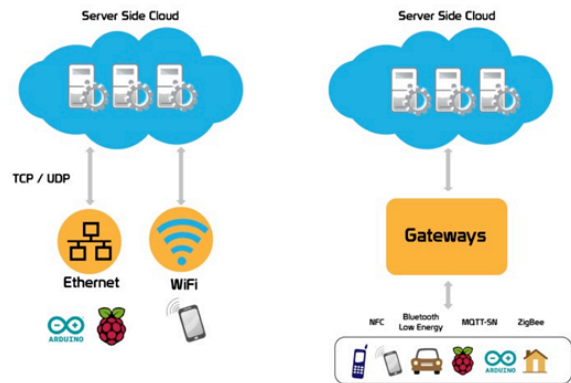

Figure 5. Internet of things – IoT – and access devices [7].

The analysis of existing experiences *indicates* a series of deficiencies and disadvantages in the commercial and experimental systems of the remote wireless monitoring systems. The implementation of the Solar Manager monitoring platform allows the adaptation and integration of the advantages of the innovative wireless remote monitoring systems acquiring information on the isolated photovoltaic systems and overcome the previously described disadvantages. The advantages of the Solar Manager platform are:

• A scalable solution based on open hardware and software.

• Use of a Cloud platform with web services in the "SaaS" modality for managing and publishing registered information.

• A proposal for the creation of a low cost innovative monitoring center of the isolated renewable installations in Ecuador.

3. Solar Manager Platform Structure

The development of the Solar Manager Platform, Acquisition, Treatment and Isolated Photovoltaic System Information Visualization *Could* Platform, consisted of four important phases during the implementation process:

• Cloud platform implementation.

- •   Information acquisition.

- •   Information treatment.

- •   Information visualization.

3.1 Cloud Platform Implementation

Cloud computing technology allows equally distributed services. Information is presented to the user in a centralized manner with high performance. Generally, a Cloud platform is divided into three layers: acquisition, storage and connectivity [7]. Figure 6 shows the connection between various information storage devices with information visualization and acquisition devices which will later be published on a remote data base.

Figure 6. Access diagram to the cloud platform [7].

Cloud computing presents diverse service architectures (IaaS, SaaS, PaaS and XaaS). To adequately select the appropriate Cloud platform, it is necessary to do a comparative analysis of current platform architectures like Open Stack, Open Nebula and Eucalyptus. In the comparative analysis, the following technical characteristics were considered: scalability and security and data storage redundancy in case of an emergency. The comparative analysis indicated that The Open Stack architecture offered the most benefits. Open Stack is a Cloud Computing platform developed by NASA which has a scalable, compatible, flexible and open architecture [8].

The Cloud Computing platform guarantees:

- •   Reliability, scalability and availability of services and application offered.

- •   The capacity to adjust fixed economic costs.

The Open Stack platform's architecture is shown in figure 7. Open Stack architecture integrates a controller node, a compute node, an image storage service node, Open Stack storage objects and other applications, such as, the Dashboard, Keystone and Quantum that for faster implementation of remote managing systems.
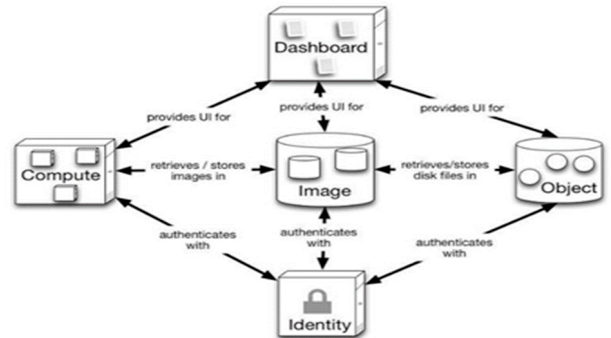

Figure 7. Block diagram of the Open Stack architecture [8].

The controller known as Nova allows administration of the platform through clouds in IaaS configurations. Likewise, it manages networks by use of several virtual machines. On the other hand, the Open Stack image service stores information and distributes the images to the virtual machine discs. The Open Stack storage objects offer more storage space, scalability and redundancy [8]. Open Stack allows information storage in petabyte order taking into account available hardware.

Table 2 shows comparison of the principal architectural solutions of Cloud Computing based on the IaaS service. In the comparative analysis the security, information storage, codes and licensing each cloud solution possesses were considered.

Table 2: Comparison of cloud platforms' IaaS service.

	Solutions cloud computing IAAS		
	Eucalyptus	*OpenNebula*	*OpenStack*
Storage Network Security	+ + + + + + + + + + + + +	+ + + + + + + + + +	+ + + + + + + + + + + + + + +
Hyper Scalable	+ + + + + + +	+ + + + + + +	+ + + + + + + + + +
Installation Documentation Code and License	+ + + + + + + +	+ + + + + + + + + + +	+ + + + + + + + + + + + + + +

In table 2 it can be seen that the software of Open Stack cloud architecture offers more benefits than the Eucalyptus and Open Nebula architectures. Open Stack facilitates the installation, configuration, administration and scalability of the cloud platform.

3.2 Information Acquisition

The second phase of the Solar Manager consists of low energy consumption electronic sensors. These sensors measure properties associated with photovoltaic system performance registering tension, intensity, temperature and humidity values. The information gathered in real time, is necessary for knowledge of the behavior of photovoltaic installations in different situations, *guaranteeing* the continuity of electric service for users. The Solar Manager platform is implemented in an isolated photovoltaic installation within the Technical University of Ambato. Figure 8 shows the system's components which were evaluated:

• 3 100 Wp photovoltaic panels.

• 4 105 Ah batteries.

• 1 40 A charge regulator.

• 1 2500 W inverter.

Figure 8. FISEI renewable generation system.

It's important to indicate that the monitoring of the system allows evaluation of the photovoltaic solar system's energy performance. The Cloud Computing platform permits visualization of the registered information by means of periodic reports according to the user's needs [10]. The implemented acquisition system shows the operation status of the photovoltaic system in real time. The monitored variables are taken from the subsystems that make up the photovoltaic installation. This way, the photovoltaic panels, regulator, batteries and inverter are monitored. The monitored properties in each subsystem are: tension and intensity.

The information acquisition system consists of:

• Xbee Modules.

• Arduino Mega.

• Arduino Ethernet Shield.

• Resistances.

• ACS 712 Sensor.

• DHT 22 Sensor.

• SCT-013 Sensor.

The values of the afore mentioned properties taken from photovoltaic modules are acquired by sensors compatible with Arduino technology. These properties are transmitted through an Xbee wireless communication module.

A DHT22 sensor was used to measure the temperature and humidity of the photovoltaic modules. The Arduino microcontroller acquires the read values directly from the sensor's own library.

The inverter's tension and intensity are measured with the help of *sensors*. A noninvasive, pincher- type SCT-013 sensor is used to acquire current intensity information. The photovoltaic modules present an ideal maximum tension rate of 17.20 V in direct current.

A tension divider was used to measure voltage which links the voltage signal to Arduino card operation levels. The intensity is measured by an ACS712 sensor with a range of intensities of up to 30 A, figure 9.
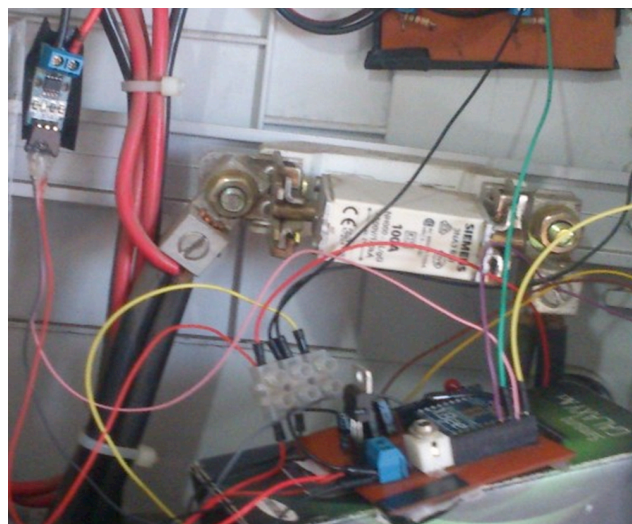

Figure 9. Information transmission through an Arduino Ethernet module.

The Arduino Mega processes acquired data and transmits it through physical communication established by means

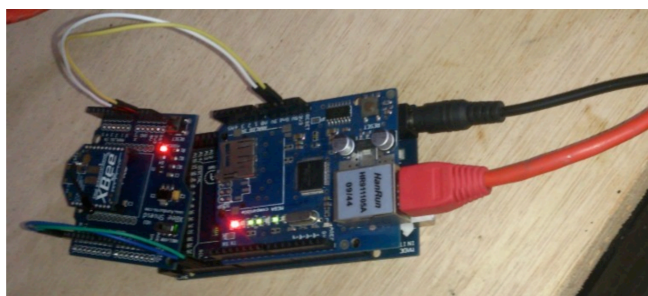of an Ethernet module to a cloud-based web server, figure 10.

Figure 10. Information transmission through an Arduino Ethernet module.

Electric properties require a signal-conditioning circuit to be monitored. Figure 11 shows the regular configuration of a tension divider. The tension divider guarantees a maximum voltage of 5V DC permitting the correct functioning of the Arduino microcontroller.
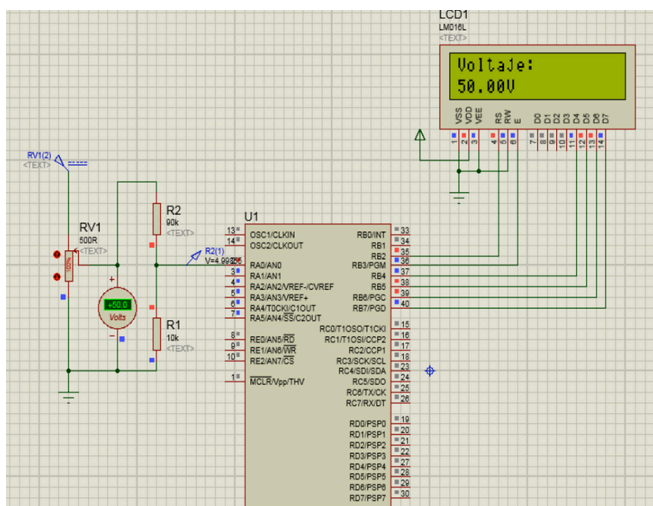

Figure 11: Tension divider simulation.

Figure 12 presents the linking circuit, compatible between the SCT-013 sensor and the Arduino card. The use of resistors connected in series fulfill the same function as the tension divider. Additionally, an AC/AC energy transformer and a wave rectifier must be used to limit the voltage received by the microcontroller.

The SCT-013 sensor provides a sine wave current signal. To this end, a charge resistance and tension divider are used to limit the signal between 0 – 5V DC, a voltage admissible by the Arduino card's microcontroller.
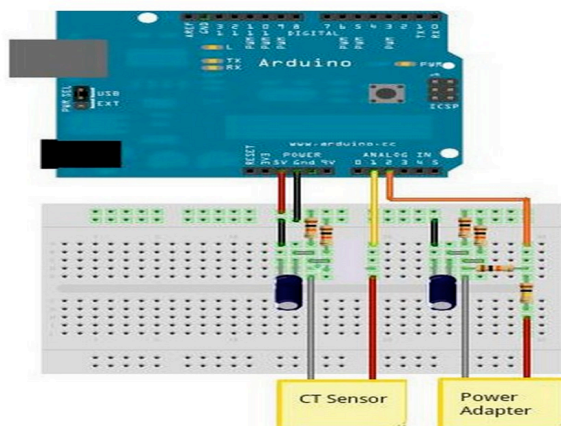

Figure 12. Linking circuit for the SCT-013 sensor.

3.3 Information Treatment

The treatment of the registered information is based on a wireless communication system implemented by using various XBee modules. These XBee modules establish communication of up to a distance of 100 meters in a direct line of sight and 30 meters without a direct line of sight. Moreover, the XBee modules can be configured as if they were a network's end devices. In the mentioned configuration, the modules can connect with several sensors and actuators. The information is sent through a communication framework. For this, the XBee modules must be programmed in API mode. Figure 13 shows and example of a data framework configured in API mode [10]. The XBee modules' origin and destination addresses may be seen in the framework. Likewise, the ID of the network established by the communication modules can be seen. The 0XF5 registry provided by the 19 bit is called Checksum and allows the length of the data in bits' tube seen as the information is being processed.

	Byte	Example	Description
API format for Remote AT Command Request	0	0x7e	Start byte – Indicates beginning of data frame
	1	0x00	Length – Number of bytes (ChecksumByte# – 1 – 2)
	2	0x10	
	3	0x17	Frame type - 0x17 means this is a AT command Request
	4	0x52	Frame ID – Command sequence number
	5	0x00	64-bit Destination Address (Serial Number)
	6	0x13	MSB is byte 5, LSB is byte 12
	7	0xA2	
	8	0x00	0x0000000000000000 = Coordinator
	9	0x40	0x000000000000FFFF = Broadcast
	10	0x77	
	11	0x9C	
	12	0x49	
	13	0xFF	Destination Network Address
	14	0xFE	(Set to 0xFFFE to send a broadcast)
	15	0x02	Remote command options (set to 0x02 to apply changes)
	16	0x44 (D)	AT Command Name (Two ASCII characters)
	17	0x02 (2)	
	18	0x04	Command Parameter (queries if not present)
	19	0XF5	Checksum

Figure 13. Xbee data framework in API mode [10].

The properties obtained in the measuring phase are processed in an Arduino Mega. An Arduino Mega was

used due to the number of serial ports available for communication between the Xbee and Ethernet modules.

The Arduino Mega captures the information network sent from the Xbee in end device mode with the help of the Xbee Shield. The Xbee processes the property information acquired by the sensors connected to the analog inputs. Once the information is processed, the Arduino Mega transmits the acquired data through the Ethernet module. Internet service exists in the isolated communities in Ecuador thanks to the EUROSOLAR program. The V-SAT technology installed at the Technical University of Ambato permits the cloud server to connect through the Internet.

The GET method assists the cloud platform in the acquisition of data. This method permits information to be transmitted from the Arduino to a file (.php) stored in the cloud. In case of not having an Internet connection, the information will be transmitted through mobile technology: GSM, GPRS, HSDPA and 4G.

3.4 Information Visualization

The IP address is a public address which allows access to information on the Internet from any geographic location with an Internet connection. An identification system was established in the file (.php).that has one user with one access key. In this way a security system for the monitored information is created. [11]. Figure 14 shows the interface access to the Solar Manager platform.
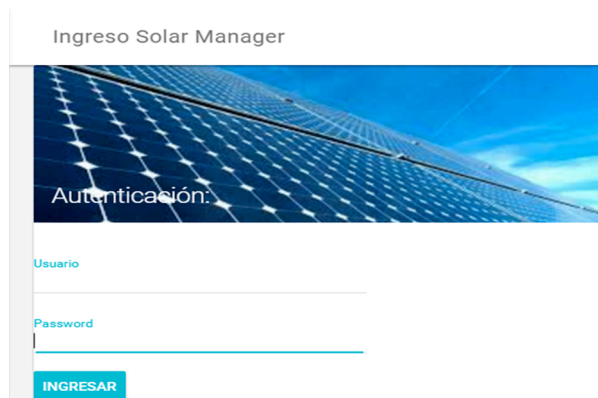

Figure 14. User identification system.

A data base is established on the cloud server by using PostgreSQL allowing the information processed by the Arduino Mega to be stored. This storage has a data acquisition frequency of one minute. The IEC-61724 standard establishes that sampling frequency can be over one minute and under ten minutes [12]. Figure 15 shows the internal configuration of the data base implemented in the Cloud Computing platform.
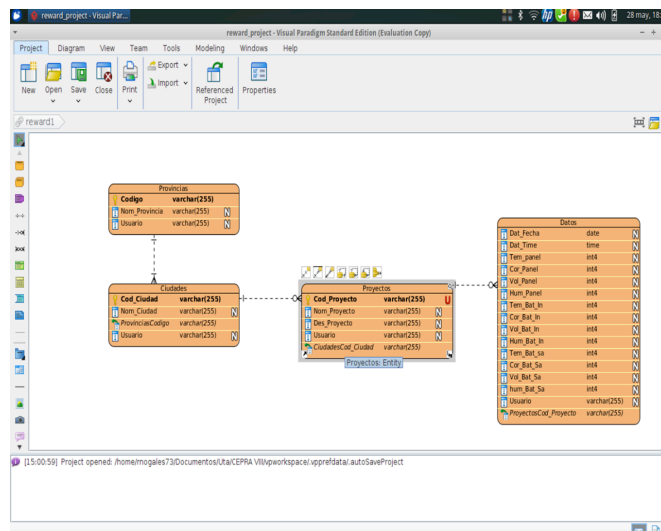

Figure 15. Data Base configuration in PostgreSQL.

The data base includes city, province, date, hour, and user codes and the code of the photovoltaic installation to be monitored. Likewise, it contains the fields that store the properties of the information obtained from each of the monitored devices. Which make up the photovoltaic system.

4. Results

The use of the *SOLAR MANAGER*, *the* Acquisition, Treatment, and Visualization of Isolated Photovoltaic *Systems* Cloud *Platform* allows the acquisition of information about electric properties of a photovoltaic generator system. This way, the user can monitor the property values through the Internet. The implemented platform offers several options for visualizing the data values acquired by remote measurement, figure 16.
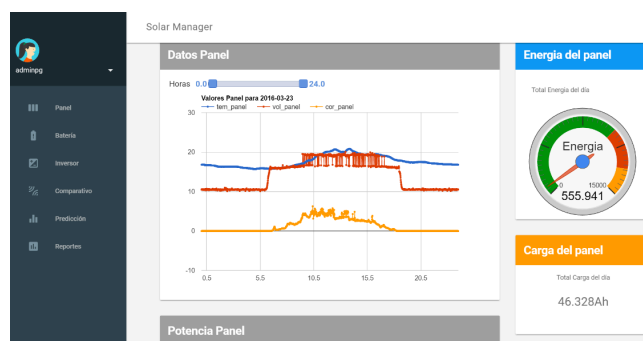

Figure 16. Monitored value visualization options.

The user may monitor an initial parameter which implies the visualization of only one of the renewable generator system's variables. The comparative option allows the user to choose between three different properties to monitor. Figure 17 shows the power property of the panel. The values measured permits the calculation *of the power generated* by the photovoltaic system over a determined

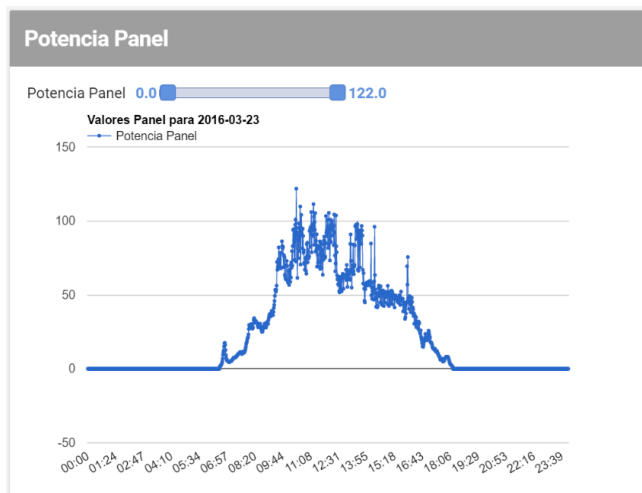period of time indicating the energy provided by the photovoltaic system installation.

Figure 17. Comparison of the photovoltaic system's voltages.

5. Conclusions

The monitoring of electric variables by use of the Cloud Computing platform allows users to know the operative and performing status of isolated photovoltaic systems in real time. The use of a cloud monitoring platform is a power tool for viewing electric property information facilitating operation, control and maintenance of isolated photovoltaic installations.

The most innovative characteristic of the Solar Manager platform is that it integrates into a hybrid Cloud Computing model which is based on open-source programming. The Cloud Solar Manager platform for acquisition, treatment, and visualization of isolated Photovoltaic systems presents the following advantages:

• Reduction of energy consumption and equipment costs.

• Remote access.

• Automatic updates.

• High capacity options for scalable storage.

• System improvement through open-source programming.

• Personalized configuration of the platform's features.

The Technical University of Ambato's Solar Manager platform presents graphic representation of the values measured remotely and provides a quick assessment of the photovoltaic system's components' current status. Moreover, users may browse registries of the values measured over a time established by the users themselves which is similar to the commercial photovoltaic monitoring systems. The graphic analysis of the monitored variables facilitates the study of the photovoltaic modules' energy performance. Additionally, it allows users to know generation values of the photovoltaic installation and the users' energy consumption.

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