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MONITORING OF INJECTED ENERGY GENERATED BY AN ON-GRID PHOTOVOLTAIC SYSTEM VIA BLYNK VIRTUAL PLATAFORM WITH ESP32

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ABSTRACT

This Photovoltaic solar energy is obtained by converting solar radiation into electrical energy, and it has stood out among the most significant sources of sustainable energy. Thus is used in Photovoltaic Systems Connected to the Grid, allowing consumers who generate their electrical energy to reduce their bills through the energy injected into the electrical Grid. It uses a bidirectional electrical energy meter to calculate the energy flow. The development of an embedded system to estimate and measure the injected and consumed energies and the generated credit stands out here. The system is integrated with Internet of Things devices, with current and voltage sensors connected to the Esp32 microcontroller board that sends data to the Blynk platform, allowing energy monitoring. This system successfully estimated energy and made the information available on the Blink platform, allowing the monitoring of credit estimates with a positive or negative balance.

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INTRODUCTION

Life on the planet is directly related to energy, with or without human intervention. This is essential for modern society that essentially uses electricity, considered an important commodity related to countries' social and economic development (MAHARAJA *et al*., 2016). Currently, most of the electricity that reaches homes in Brazil is generated through sources classified as renewable, with hydroelectric being the most used. The Brazilian electrical matrix is predominantly renewable, representing 83% of the domestic supply, and 64.9% of this percentage comes from hydraulic sources (ENERGY, 2020). The country's economic development is driven by a growing demand for energy, and thus, it becomes necessary to add new sources of sustainable energy to complement the supply. Among the alternatives, photovoltaic solar energy has been standing out, directly connected to the utility grid, classified as distributed generation (DG). DG deals mainly with individual electricity generation on a small scale (TONY *et al*., 2016). Photovoltaic solar energy has stood out among the most significant sources of energy due to the fact that it is practically inexhaustible, as it generates electricity from solar radiation and stimulates its use, due to the abundant amount of solar radiation, during almost all year. Another critical factor is that it is pollution-free, and its generation is silent, therefore, an excellent solution for homes (PATIL; BHOSALE, 2019). The compensation system, net metering, is a method that allows consumers to be compensated with discounts generated by the energy injected into the electricity grid.

In this way, the Photovoltaic Solar System Connected to the Grid (PV On-Grid) will generate electricity consumed instantly, while the excess will be injected and accounted for by the electric power utility. A mechanism used by utilities to monitor the consumption of energy injected by the system is the bidirectional meter, whose function is to calculate the amount of energy injected by the PV On-Grid into the electricity grid, can is later compensated and billed to the customer's account (PATIL; BHOSALE, 2019; ARUNKUMAR; MURUGAVEL, 2014; THAKUR; CHAKRABORTY, 2019). Therefore, this system allows the customer this compensation, also allows the energy injected into the electricity grid to be used instantly by the nearest consumers (SHARMA *et al*., 2020). However, photovoltaic solar energy generation is limited only to the daytime period. At night, the energy consumed is entirely by the concessionaire. Therefore, it can perceive that the flow of electrical energy has two directions, the first of the energy injected into the grid, generated by the PV On-Grid,and the second of the energy supplied by the electrical grid, generating the energy credit, which is the difference between the injected and consumed (ARUNKUMAR; MURUGAVEL, 2014; DESKAR *et al*., 2016). With the bidirectional meters installed by the concessionaires, it is possible to visualize the total estimate of the consumed and injected energy present on the bidirectional meter display. However, these meters are located in the external area of the residences. Therefore, this structure makes it difficult for the consumer to accompany and monitor the energy injected and consumed instantly. Thus, a bidirectional measurement system (MAHARAJA *et al*., 2016), which records the voltage and electric current through sensors, uses the Arduino platform with the UNO microcontroller as a processing unit to regularly calculate the net energy at intervals, making it available on an Liquid Crystal Display (LCD). However, the system was limited to bench tests. However, posteriorly, a bidirectional system was developed (TONY *et al*., 2016) to provide the user with communication and interaction with some household appliances. These two-way power tracking methods allow the user to compensate for a generation. An alternative compensation system available is D-STATCOM (PATIL; BHOSALE, 2019), capable of efficiently calculating the net margin of the electricity supply with reasonable accuracy. These monitoring alternatives have been successful in tracking the flow of energies through LCD and text messages (MAHARAJA *et al*., 2016; TONY *et al*., 2016; PATIL; BHOSALE, 2019). In this way, to carry out the monitoring of the electric energy generated by the PV On-Grid and injected into the electric network of the concessionaire, estimate the energy consumed and the credit generated. Like this, a system for monitoring the injected energy generated by an PV On-Grid via virtual platform blynk with esp32 was developed. This embedded system has the same characteristics as bidirectional meters. A set of software and hardware is used for the bidirectional calculation, integrated with Internet of Things (IoT) devices, responsible for collecting the data and storing it on an external server for remote access. The IoT allows data transmission from sensors through a wireless network, exchanging information in open network computing (DURANI *et al*., 2018). Thus, it is possible with the Blynk platform to store and visualize the data obtained by the sensors (HASAN *et al*., 2020).

MATERIALS AND METHODS

Overview: The multiple uses of IoT equipment and Microcontrollers allow a universe of development. Thus, these means were adopted to construct a system that provides the monitoring of the energy injected and consumed from the electrical grid. This section presents the installed embedded system's architecture, emphasizing the hardware, software, and data visualization platform. In the assembly of the embedded system, an integrated microcontroller board was used with sensors responsible for collecting the voltage and electric current parameters and the software to encode and structure the data sent and managed by the Blink platform. The resources used in this project fall into the free-of-cost range of Blynk. To record the fundamental physical quantities used to calculate the energy injected, consumed, and credit, the research was applied to a residence powered by secondary and single-phase voltage (380V/220V), which has a grid-connected solar photovoltaic system (PV On-Grid) installed. Furthermore, that meets all the premises of an energy compensation system, net metering, in the distributed generation model. In this case, the embedded system was installed between the Home Circuit Distribution (QDC) and the utility power input pattern. The flowchart in Figure 1 represents this study scenario.

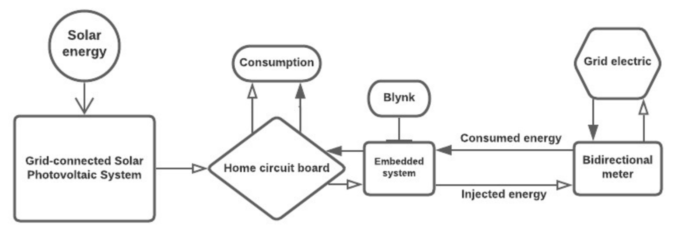


Fig. 1. Study system flowchart

Figure 1 presents the architecture of the study scenario used to carry out the energy monitoring by recording voltage and current parameters. This information is received and processed by the embedded system, composed of the HSTS016 and ZMPT101B sensors integrated into the Esp32 board with expansion that communicates via wifi with the Blink server.

Embedded System: The embedded system is composed of an Esp32 microcontroller board developed for use in robotics, automation, and IoT projects. Esp32 is a board with integrated Bluetooth and wifi and a micro Universal Serial Bus (USB) port for power and programming (ALLAFI; IQBAL, 2017). Several pins with analog signals make it a valuable board for analog sensors, which allows it to send data to the server in real-time (MEGANTORO *et al*., 2021). Become a satisfactory alternative for IoT devices due to performance and cost-effectiveness (MAIER *et al*., 2017; HUSSAIN *et al*., 2019). This board has analog pins that can apply to the control and analysis of sensors, where they operate with a resolution of 12 bits, that is, reading between 0 and 4095. The programmable connections use the procedure used in Arduino boards. C++ language software coding used in Arduino libraries (MEGANTORO *et al*., 2021; MAIER *et al*., 2017) . The Esp32 analog ports operate at approximately 3.3V, but an ESP32 expansion board was used for mounting the embedded system, allowing the sensors' operation and power with 5V. An adequate and compact solution to embed the Esp32 in projects, integrating it with other modules that have pins simply and safely. YHDC's non-invasive HSTS016 AC sensor readout GPIO39 logic port is clamp meter type. This sensor model has versions from 20A, 30A, to 100A. The sensor shown in Figure 2 is ideal for this type of project, as it detects the current without the need to connect in series to the electrical circuit of the residence. This sensor is based on the operation of transformers with an internal coil, capable of measuring an electric current through the operation of the magnetic field. The sensor used detects electrical current up to 30A.

The voltage sensor model ZMPT101B is a high-performance sensor whose purpose is to detect the voltage induced in the circuit and send the readings to the microcontroller that extracts the information and performs the defined operations. This one performs readings of up to 250 Vac (ABUBAKAR *et al*., 2017; GAVHANE *et al*., 2021), is widely used to monitor the electrical voltage. This parameter is needed to calculate electricity consumption. Therefore, ideal for home automation projects, considering that the error is less than 1% in the peak-to-peak method and less than 2.5% in the rapid method, in the case of measurements above 50 V (ABUBAKAR *et al*., 2017). The practicality of this sensor allows manual calibration through a potentiometer used to regulate the ADC output with the AC input voltage (HUSSAIN *et al*., 2019) and widely used in project assembly as a voltmeter, facilitating readings with Arduino IDE development boards and other boards, such as the Esp32 used in this project. The sensor ZMPT101B detects the voltage needed to calculate the active and reactive power of the circuit. In this case, the microcontroller registered the analog signal referring to the load. The maximum detection voltage of 250Vac and peak of 353.55Vac; the instantaneous voltage values are obtained by the RMS method (ABUBAKAR *et al*., 2017). The study environment that is monitored by the sensors and boards described is represented in Figure 2.

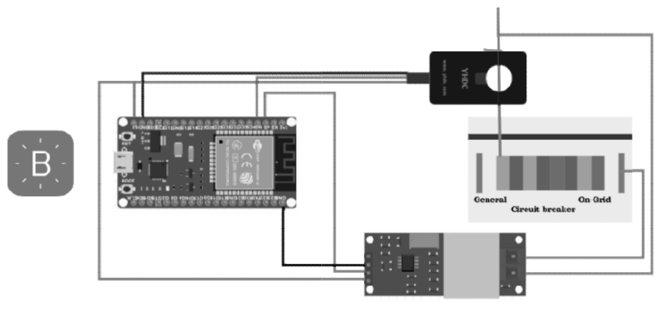


Fig. 2. Schematic of the embedded system with the sensors connected

The embedded system schema represents the part responsible for detecting voltage and current information, thus obtaining estimates of injected and consumed energies and the respective credits generated for possible future compensation. Figure 1 presents the entire electrical circuit of study, with the details of the circuit for obtaining the voltage and electrical current parameters by Figure 2. The information is obtained and forwarded to ESP32, responsible for performing the necessary operations and sending the information generated for the external server accessed by the Blynk application.

Study Scenario: The embedded system can integrate into study scenarios, such as in environments with a Circuit Distribution cadre belonging to a residence with a single-phase installation (phase/neutral) and voltage of 220 V, where the general circuit breaker is limited to a current of 15 A. The connection scheme can see in Figure 2. In this way, it is possible to collect and analyze the interest parameters. Thus, the system applies in the scenario described in two different study situations, detailed in situations 1 and 2.

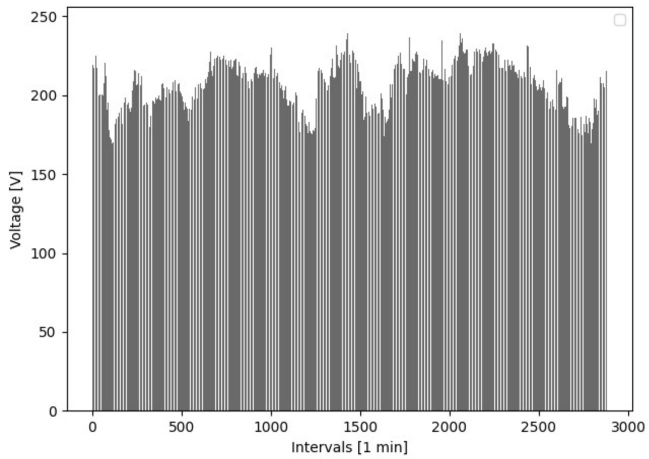
Situation 1: The embedded system integrated into the home circuit, which initially had the voltage sensor calibrated to make the estimate closer and more accurate to the real one. The calibration performer used a multimeter as a reference, and soon after, the recording of electrical parameters started. The monitoring of this situation was carried out in 2 days without interruption. There are no problems in voltage, utility supply, or failure in the power supply of the embedded system.

Situation 2: With the system integrated on a residence circuit for two days, a voltage interruption was simulated, thus forcing the shutdown of the embedded system due to lack of power. After a few moments, the power was restored, and the system restarted, where the voltage sensor had to be calibrated again to start recording within this new scenario for another period of two days. During this new period, the utility voltage drop is simulated every 24 hours, interrupting the power supply to the embedded system. However, when restarting the embedded system within this 24-hour interval, the voltage sensor was not calibrated to record and estimate possible effects of power interruption by the utility or lack of power in the embedded system. Due to the lack of energy from the electrical grid, the On-Grid system switches off automatically, so it is not necessary to keep reading the parameters.

RESULTS AND DISCUSSIONS

The built system collected the voltage and current parameters, used to estimate the injected and consumed energies and the credit, sending this information to the Blynk platform, allowing the monitoring of the parameters. Photovoltaic solar generation is limited to the daytime period, and it is essential to calculate the amount of energy injected into the distribution network. Thus, the embedded system must meet the characteristics of the bidirectional meters installed by the concessionaires. The built system was successful in carrying out the follow-up and instantaneously monitoring the injected energy, which is essential to compensate and deduct the customer's account (PATIL; BHOSALE, 2019; ARUNKUMAR; MURUGAVEL, 2014; THAKUR; CHAKRABORTY, 2019). Real operating situations were performed to analyze real applications of the developed system. Thus, the results of the situations described are presenter in sections 3.1 and 3.2. In the first situation, the embedded system turned on for 48 hours without interruption in the power supply. A power outage was simulated in the second, causing the embedded system to shut down due to lack of power.

Experiment Situation 1: The established monitoring period was 48 hours, where there were no interruptions to obtain continuous data on the necessary parameters and energies. Thus, the voltage sensor was calibrated through a potentiometer integrated into the sensor, called a trimpot. Thus used to adjust the factory waveform, which can be in the waveform cut in the positive half cycle, tending to form a square wave, this compromises the reading made by the analog input of Esp32. Calibration is adjusting the sensor waveform with that of the electrical network in a sinusoidal way. The voltage sensor calibration was necessary due to the initialization of the embedded system. The calibration was performed using a multimeter as a reference to approximate the actual reading value in the 220V range. This sensor's reading fluctuation responds with a sporadic initial value above the expected value, then returns the value reading around zero. There was no need for manual calibration regarding the current sensor, as the reading coding library allows automating the calibration of the current sensor. This activity is performed during the boot period of the built system. Thus, the results of monitoring the PV On-Grid system with a power of 1.64 kWh and the electrical network for the study period obtained time series of voltage and current as shown in Figure 3:



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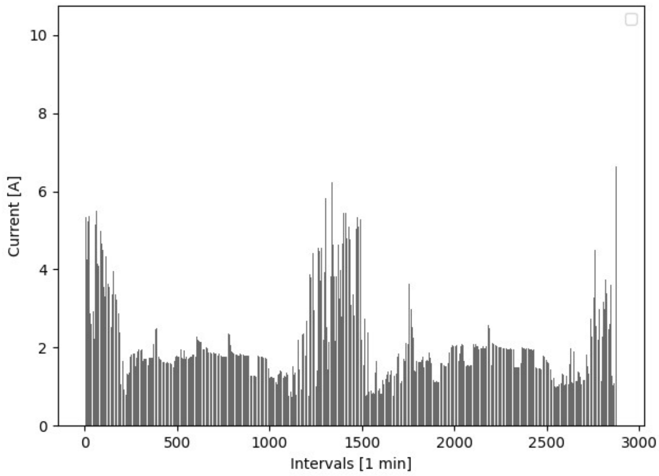
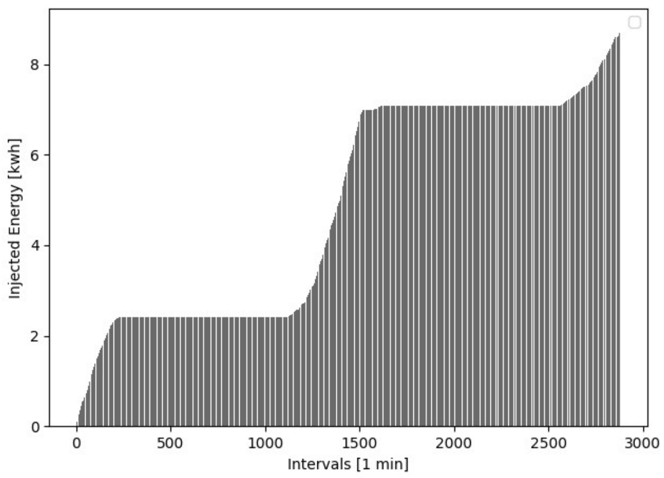


b

Fig. 3. Situation 1 instantaneous RMS voltage and current. (a) depicts instantaneous RMS voltage. (b) the time series of the RMS current

In Figure 3a, the voltage series in the period shows satisfactory fluctuations according to the sensor and electrical network specifications. In Figure 3b, a current peak is observed in relatively non-sporadic periods, implying the generation of energy from the PV On-Grid system and a consequent injection of energy into the electrical grid. This energy injection can see in Figure 4, which deals with the time series of energy injected, consumed, and credits.

The plateaus shown in Figure 4a refers to the period in which there is not enough energy generation for the injection to occur in the electrical grid. It can be seen in Figure 4a that between the period from 0 to 240, energy is injected into the electrical grid. This fact can also be observed between 1200 and 1500 and ranges from 2550 to 2800. In this aspect, we have the time series of the energy consumed represented by Figure In this aspect, we have the time series of the energy consumed represented by Figure 4b, the injected and supplied energies are complementary to supply the load of the study environment. Thus, both do not co-occur. The contrast between the energies treated in Figures 4a and 4b results in the time series of credits. Figure 4c of the study environment that can use for compensation in later months. The credits obtained during the study period can be positive or negative. If the credits obtained are positive, the customer can use them for compensation. However, when in negative credits, the customer has no alternative to accumulating debts with the electric energy concessionaire.



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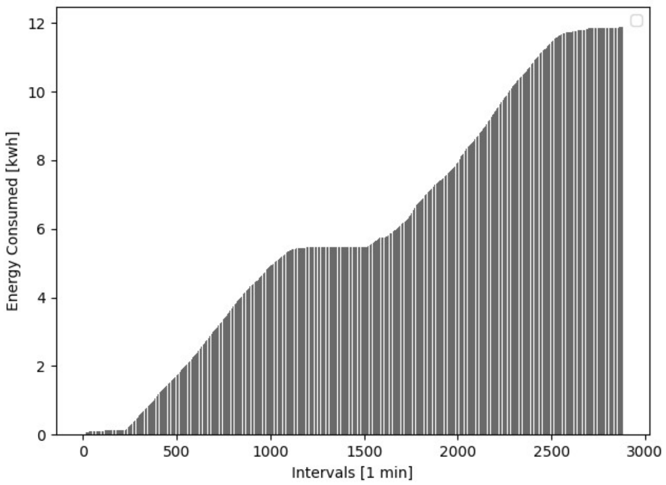

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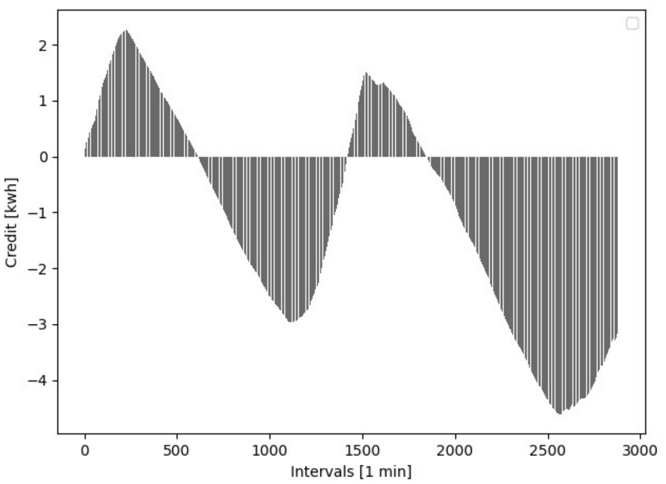
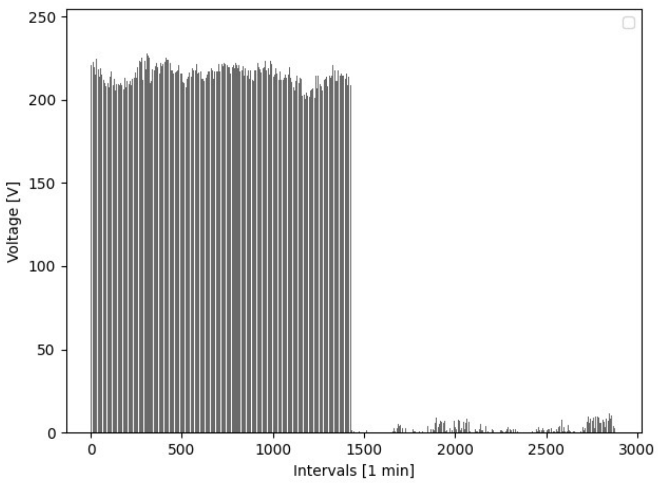


c

Fig. 4. Energies and credits generated from situation 1. (a) Energy injected. (b) Energy consumed. (c) Energy credit.

Thus, the customer must pay the outstanding balance of energy supplied. However, if there is a balance of credits arising from other periods, these are used for offsetting.

Experiment Situation 2: In situation 2, the voltage drop was simulated in 24 hours. It was observed that the embedded system turned on usually after the power was restored. However, to start the collection again, it was necessary to restart the Espe32 through the EN button, where the current sensor returned to detect the current usually, while the voltage sensor started the collection without calibration. As the objective of situation 2 was to simulate the voltage drop, the voltage sensor calibration was not performed in the following period of 24 hours later. The data obtained from the voltage and current parameters are shown in Figure 5.



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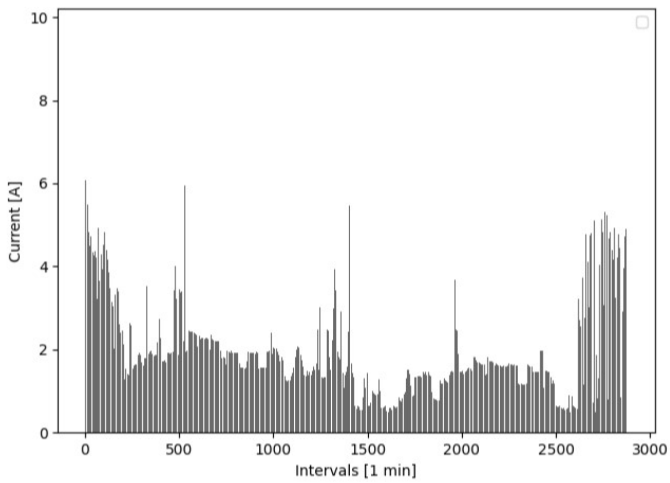
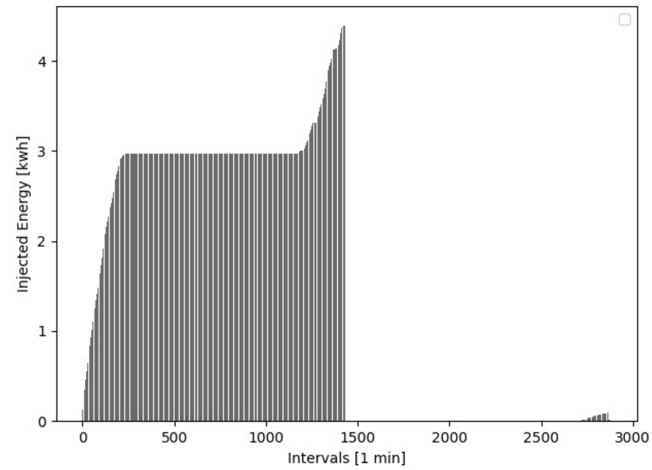


b

Fig. 5. Situation 2 instantaneous RMS voltage and current. (a) depicts instantaneous RMS voltage. (b) the time series of the RMS current

In Figure 5a, the voltage presented a good correlation concerning the situation of study 1, in the first period of 24h. However, in the following 24 hours, unsatisfactory correlation voltage records are observed, caused by the lack of calibration as proposed. In this way, it is identified that the calibration process is fundamental for registering and estimating the parameters resulting, such as energy injected, consumed, and credits. The voltage sensor reading values resulting from the absence of power supply to the circuit is characterized as systematic limitations of the system. The voltage sensor starts with fluctuations and then tends to zero. The current sensor does not need to be calibrated, as it is done from an automatic calibration in the code. Because of the voltage and current time series obtained, the series of injected and consumed energy parameters and the credits are estimated, shown in Figure 6. Figure 6a. Deals with the energy injected into the grid as expected, due to the period, it is within the range of maximum energy generation by the PV On-Grid system. It was observed that the characteristics change soon after the system power supply is turned off; as a result of this action, the parameter estimation is compromised, as seen in Figure 5a. Thus, all energies estimated from the voltage-time series are compromised due to the systematic limitations of this sensor. These implications are observed in Figures 6b of the energy consumed and Figure 6c of the generated credits. Observe that there were current peaks in Figure 5b that correspond to the PV On-Grid system's energy generation, which implies energy injected into the electrical grid. However, the energy parameters are obtained from the product of voltage and current.

These were compromised, as represented in Figure 6. Thus, the results obtained from the study scenario compared to situations 1 and 2 suggest that the developed system satisfactorily meets the proposed purpose of estimating the parameters of voltage, current, injected and consumed energy, and the credits, respectively. The sending of data generated by the system to the external server via Wi-Fi successfully made the time series generated by the developed system available. The accompaniment of energy and credits monitoring is represented in Figure 7.



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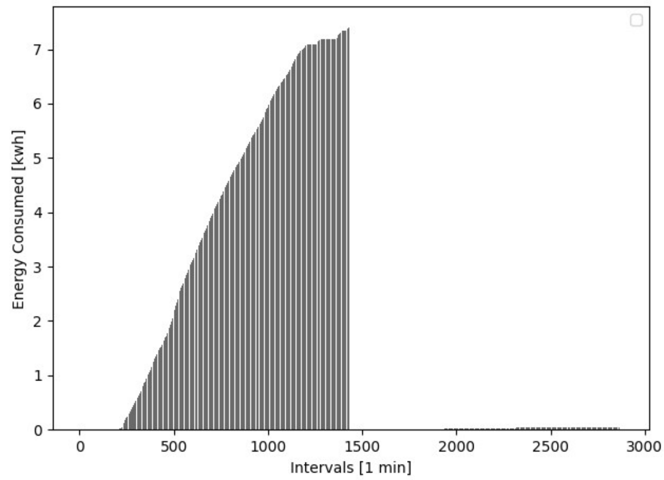

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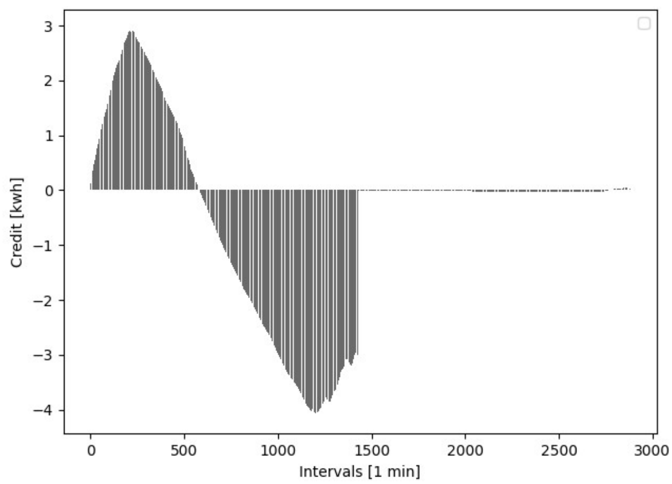

c

Fig. 6. Energies and credits generated from situation 2. (a) Energy injected. (b) Energy consumed. (c) Energy credit

Figure 7a illustrates the monitoring of parameters obtained by the embedded system and made available for viewing in the Blynk application, and the data visualized refer to the 24 hours with the calibrated system. Figure 7b deals with the data generated at the end of the following 24 hours, completing the cycle of the second situation. The embedded system performed the bidirectional measurement, recording the following electrical parameters, such as RMS Voltage (Vac), RMS Current, Real Power (W), Apparent Power (VA), Power Factor (PF), credit, energy consumed, energy injected and the frequency (Hz). The Blynk application allows the smartphone user to configure and monitor the data calculated by the embedded system, in addition to enabling the sending of reports with all parameters by registered email.

a b

Fig. 7. Visualization of generated energies and credits. (a) Situation 2 first 24 hours. (b) Situation 2 last 24 hours

The advances and details presented are based on the tests carried out at this stage of the research, which aimed to analyze and evaluate the development based on the preliminary results obtained. The two sensors were tested, as well as the embedded system and the monitoring platform, to ensure that the information was received satisfactorily.

CONCLUSION

The system allows tracking of the net energy estimate (credits). There are some physical, operational, and electronic limitations. The embedded system circuit of the built-in system provides the collection of the necessary parameters to estimate the injected and consumed energies and the credits, making it available on the blynk server accessed by the blynk application that allows monitoring the voltage, current, and energy parameters. It was identified the reading limitations of the voltage sensor that needs manual calibration because, in situations where there is a lack of power to the embedded system and the respective restoration, the voltage readings are unsatisfactory to estimate the parameters of interest. There is also a loss of data and information in case of instability of communication via wifi/internet due to the absence of a backup system in an offline storage unit such as an SD-Card. The system works to reduce barriers in monitoring the energy injected into the electricity grid by customers who generate energy. One of the contributions is the simplification of identifying the balance of energy injected into the electricity grid and visualization per app. In this way, there is greater accessibility and transparency in monitoring the system and energy consumption of the environment, contributing to efficient energy generation and consumption.

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