International Journal of Science and Healthcare Research
Vol. 8; Issue: 4; Oct.-Dec. 2023
Website: ijshr.com
Research Paper *ISSN: 2455-7587*

Designing An Appliance Load Monitor with Programmable Counter for Energy Efficiency

B. Kossi Imbga[1,2], W. Rodrigue Kabore[3], Emmanuel Ouedraogo[1,5], Ablasse W. Zoungrana[4]

[1]Laboratory of Renewable Thermal Energy, Joseph Ki-ZERBO University, Burkina Faso
[2]Laboratory of Research in Energetics and Meteorology, Norbert Zongo University, Burkina Faso
[3]Institute of Computer Engineering and Telecommunication Polytechnic, School of Ouagadougou, Burkina Faso
[4]Burkina Institute of Technology
[5]Department of Physic and Chemistry, University of Ouahigouya, Burkina Faso

Corresponding Author: B. Kossi Imbga

DOI: https://doi.org/10.52403/ijshr.20230431

ABSTRACT

The decentralization of production sources is a way to increase the energy efficiency of domestic buildings. Energy is indeed an important source of human activity, but due to its limitation and mismanagement, energy is becoming increasingly scarce, especially in developing countries. The use of electrical energy is mainly concentrated in electrical installations for domestic, administrative use and in industry. We are faced with wasting energy and increasing electricity bills. To solve these problems, we propose a solution that involves designing an appliance load monitor with a programmable meter for energy efficiency to manage and track electrical energy consumption in high energy consumption buildings. New technologies are changing the way we live, in transportation, communications, commerce and even the way we design our homes, providing the technology that allows us to improve our quality of life in our homes, providing the technology necessary to communicate, send and receive messages. The Internet makes it possible to observe and download consumption data over long distances. We have integrated a system for controlling and monitoring our electricity consumption via a mobile interface that we designed. This system will allow us to see the different electrical values of our consumption and to control the operating time of the device.

Keywords: Microcontrollers, sensors, Arduino, Raspberry Pi, energy management, mobile application.

INTRODUCTION

The growing demand for electricity in Burkina Faso, with an increase of more than 13% per year, has created major challenges for the availability and efficient management of electrical energy. The gap between the supply of electricity by the Société Nationale d'Electrcité du Burkina Faso (SONABEL) and the initial demand has led to costly imports of electricity from neighboring countries. However, these import measures do not completely resolve energy problems, leading to load shedding and instabilities in the distribution network. At the same time, the lack of accurate monitoring of energy consumption has led to high costs and energy overloads. In order to address this crucial energy issue, it becomes imperative to adopt measures aimed at reducing energy consumption, encouraging energy management and optimizing the management of energy resources. It is in this context that we propose an innovative project focused on the design of an instant energy audit system using advanced electronic technologies, including the Raspberry Pi 4 microcontroller and various sensors.

The main objective of this project is to develop an intelligent electronic device capable of monitoring energy consumption of electrical appliances and systems, overload detection, efficient energy management, preventive maintenance and accurate measurement of energy consumption. While providing accurate data on consumption units, associated costs. With the current energy problem in Burkina Faso, this project aims to provide concrete solutions to encourage responsible use of energy and thus contribute to the efficiency and sustainability of the electricity network in the country.

Thanks to this innovative technological solution, users will be able to effectively control and manage their energy consumption from their smartphone, thereby optimizing the use of energy resources and contributing to the stabilization of the electricity network.

MATERIALS AND METHODS

The design and implementation of the device in this project is based on the use of various carefully selected advanced electronic equipment. These components, each with specific methods, are essential for the proper functioning of the system and the accurate collection of energy data.

I.1Materials

I.1.1Raspberry Pi 4 Model B

The Raspberry Pi 4 Model B is the latest addition to the popular Raspberry Pi line of computers. It brings revolutionary improvements in processor speed, multimedia performance, memory and connectivity over the previous generation, the Raspberry Pi 3 Model B+, while maintaining similar backwards compatibility and power consumption. For the end user, the Raspberry Pi 4 Model B delivers desktop performance comparable to entry-level x86 PC systems. Its main features are: a high-performance 64-bit quad-core processor, support for dual displays with resolutions up to 4K via two micro-HDMI ports, hardware video decoding of up to 4Kp60, up to 8 GB of RAM, dual-band 2.4/5.0 GHz wireless, Bluetooth 5.0, Gigabit Ethernet, USB 3.0, and Power over Ethernet (PoE) capability via a separate PoE HAT module [1] . Dual-band wireless and Bluetooth have received Modular Compliance Certification, allowing the board to be integrated into finished products with significantly reduced compliance testing, improving costs and time to market [1].

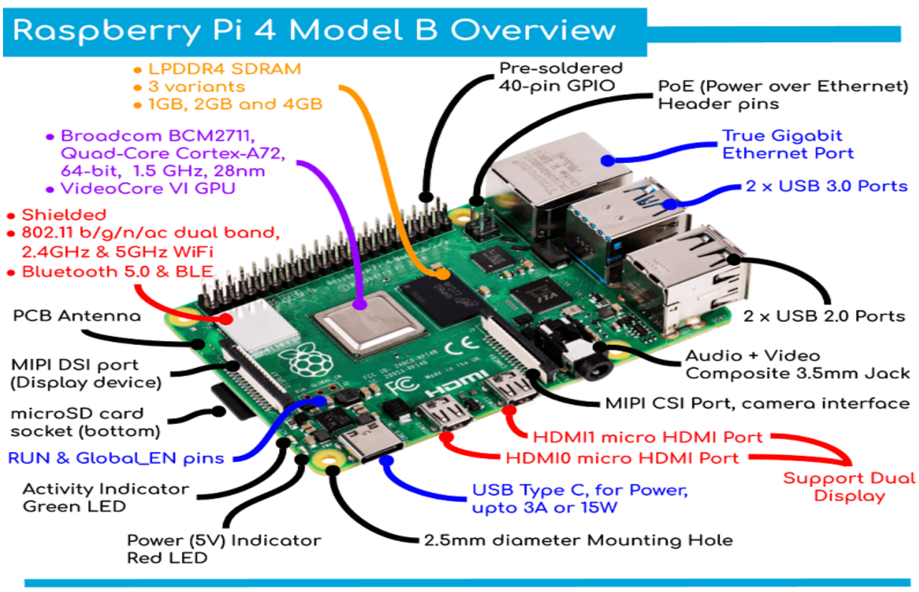

Figure 1: Raspberry Pi 4 Model B

I.1.2 The current sensor

The current sensor is an essential component that accurately measures the intensity of electric current using the current-to-voltage conversion technique. This process makes it possible to transform the current, whether alternating or direct, into a voltage signal proportional to the measured current. This technology is widely used in various fields such as inverters, battery chargers, solar panels and energy consumption monitoring systems. These sensors are available in a diverse range of currents, from 5A to 30A, providing flexibility of use in diverse applications [2].

When measuring energy consumption, the current sensor is particularly useful. It allows you to quantify the electrical consumption of an electronic device or a lamp by applying the power formula P = VI, where V represents the voltage and I the current intensity [2] . Additionally, these sensors are essential in monitoring electrical systems, where they can detect alternating currents, thereby signaling overloads or short circuits. Likewise, in battery charging systems, the current sensor helps measure the battery charging current, helping to optimize energy management and extend battery life.

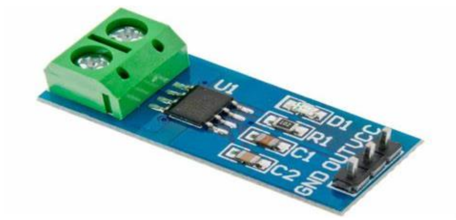

Figure 2: The current sensor ACS712

The ZMPT101B AC voltage sensor is a step-down transformer module specially designed to measure AC voltages up to 250V. It works using an integrated operational amplifier mounted on the module to ensure accurate readings [3]. For optimal operation, it requires a 5 volts supply, application of AC voltage to the transformer and connection of the analog output to any available analog pin.

Here is an overview of the essential technical characteristics of this sensor:

- Weight: 20 g;
- Dimensions: 51 × 21 × 21 mm;
- Transformer model: ZMPT101B;
- Supply voltage: 5 V;
- Rated current: 2 mA;
- Measuring voltage range: 195-250 V;
- Operating temperature: -40°C to +70°C [3]

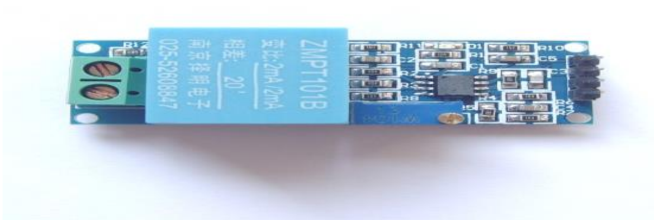

Figure 3: The voltage sensor ZMPT101B AC

I.1.3 The Arduino microcontroller

The Arduino microcontroller, a central element of our project, has an essential set of elements and is programmed using a language specific to each microcontroller [4]. These components include memories crucial for the operation of the microcontroller, namely RAM, Flash memory, EEPROM (comparable to a hard disk for the microcontroller) and cache memory, serving as a communication center between RAM and registers, used by the processor. For the realization of our project, we chose to use the Arduino card Mega 2560. This card, based on the ATmega2560 microcontroller, offers all the functionalities necessary for our application. It has a physical configuration comprising 54 digital input/output pins, 14 of which can be used as PWM (pulse width modulation) outputs, as well as 16 analog inputs, which can also function as digital inputs/outputs. Additionally, the board has 4 UARTs (hardware serial ports), a 16 MHz quartz crystal, a USB connection, a power jack connector, an ICSP (in-circuit programming) connector, and a reset button [4]. The integration of the Arduino board into our system has a specific function: the conversion of analog values into digital values coming from various sensors. The card is connected to our Raspberry Pi via a serial port, allowing the latter to read analog data transformed into digital values by our analog-to-digital converter. This interaction between the Arduino board and the Raspberry Pi constitutes an essential link for the collection and routing of data to our energy audit system.

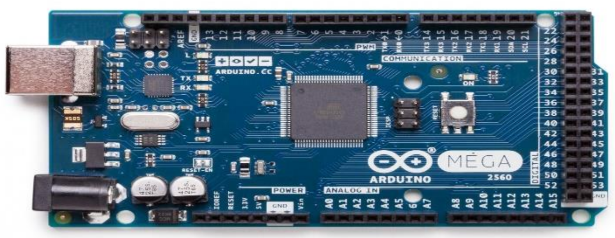

Figure 4: The Arduino microcontroller

I.1.4 DS-1307 RTC module

The clock module that provides a clock and calendar. It is based on the Maxim Integrated DS-1307 integrated circuit. The DS-1307 has a 32.768 Hz quartz clock and calendar with battery backup. Even when the power is turned off, the DS-1307's clock accuracy remains within ±2 ppm. DS-1307 has an I2C interface, which can be easily connected to other development boards. The DS-1307 is a useful module for projects requiring a real-time clock. It can be used to keep time, record date and time data, or synchronize time with other devices [5].

The features of the DS-1307 are as follows:

- Real-time quartz clock 32,768 Hz
- Integrated calendar
- Replacement battery
- I2C interface
- Low energy consumption
- Accuracy ± 2ppm

The DS-1307 is a reliable and easy-to-use module, ideal for projects requiring a real - time clock [5].

Figure 5: DS-1307 RTC module

I.1.5 The control system (relay)

To use devices operating on alternating current (220V), the microcontroller operating on low voltage (5V), we will use a relay that can withstand up to 220V. Connecting the relay If we decide to control heavy loads running on AC current, we need to use the Raspberry Pi 4 microcontroller. This module allows us to control AC current of up to 250 volts with loads of up to 10 amps.

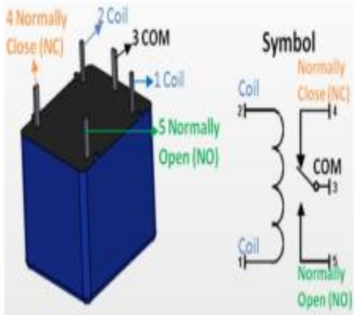

Figure 6: The relay and its characteristics

II. System operation and flowchart

The operating scheme of our device's load monitor is based on a well-defined sequence of operations to measure, collect and transmit essential electrical data, ensuring accurate monitoring of energy consumption. Here is in detail how this process works:

- Measurement of electrical quantities with voltage and current sensors:
  Initially, voltage and current sensors are employed to obtain the instantaneous current and voltage values of the electrical system or device under monitoring. These sensors ensure precise measurement of electrical quantities.
- Transferring data to the Arduino board:
  The current and voltage values obtained are read by the Arduino board. The latter functions as a central processor, receiving data from the sensors and preparing this data for subsequent transmission to the Raspberry Pi board.
- Transmission of data to the Raspberry Pi card via serial connection:
  The Arduino board transfers the measured current and voltage data to the Raspberry Pi board through the serial connection established between the two boards. This allows essential information to be routed to the central processing system.
- Calculation of electrical quantities on the Raspberry Pi card with DS1307 RTC:
  On the Raspberry Pi board, current and voltage data are received and used to calculate different electrical quantities such as electrical power, active power and electrical energy consumed. The time is synchronized using the DS1307 RTC module, making it easy to correlate data with time.
- Transferring data to the mobile interface via Wi-Fi connectivity:
  Once the electrical quantities have been calculated, the Raspberry Pi uses its Wi-Fi connectivity to transmit this data to a dedicated mobile interface. This allows users to track their energy consumption and electrical parameters in real time from their mobile device.
- Data storage on the Raspberry Pi SD card:
  The data collected is also stored on the SD card integrated into the Raspberry Pi, ensuring local backup of the information for possible future consultation or retrospective analysis.
- Periodic transfer of data to the mobile application:

- When the time reaches one hour (3600 seconds), the data collected during this period is transmitted to the mobile application. This periodicity allows regular monitoring and recording of energy consumption data.

Thanks to this well-designed system, we are able to detect anomalies in electrical installations, monitor power factors and identify energy-hungry devices, thus facilitating the efficient management of energy consumption.

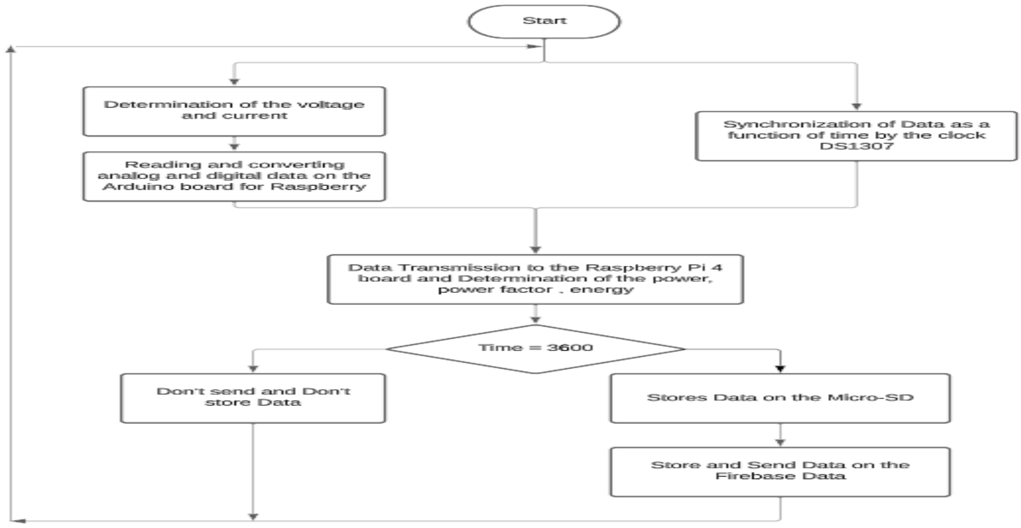

Figure 7: The system operation

For the consistency of our system, it is better to integrate a time-based intelligent control subsystem. In fact, the device management (control) system via the mobile interface is based on different states, that is, two states that will allow us to turn our devices on and off. Our microcontroller is all we need to control devices i.e.

- The ON state, which is an instruction to close the circuit and allow current to flow.
- The OFF (open) state is the opposite of the ON (closed) state.

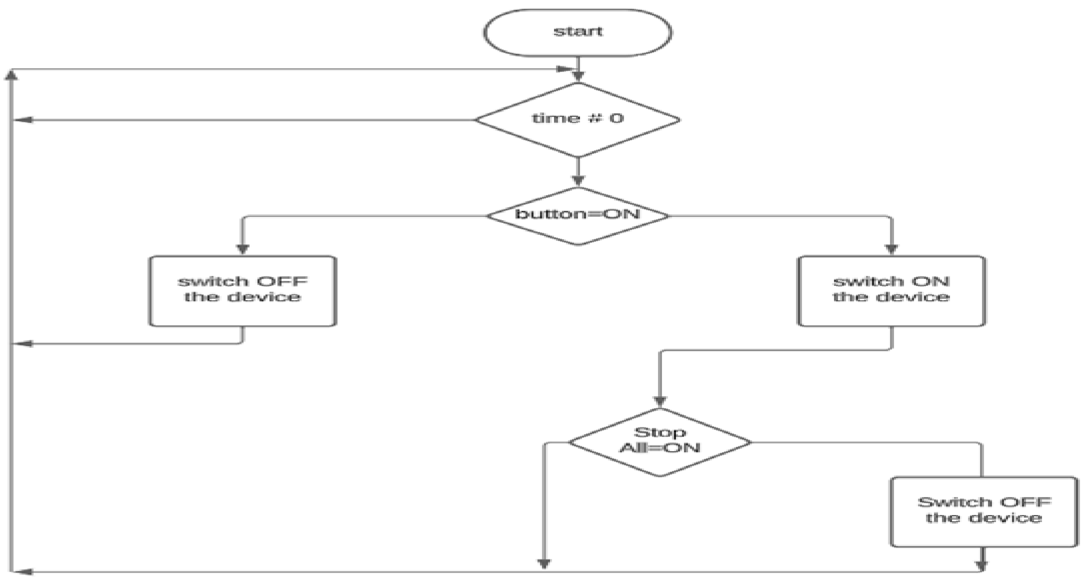

Figure 8: The device management system and intelligent control flowchart

III. Technologies and tools for database management

Our choice for the development of the interfaces of our mobile application was Flutter, a multiplatform framework recognized for its ease of use and performance. With Flutter, we can design interactive and engaging user interfaces that will provide an optimal user experience. We opted for Flutter because of its ability to generate apps for both Android and iOS from a single source code, thereby reducing complexity and development time [6]. When it comes to database management, Firebase has been our preferred choice as it offers a real-time database, which is essential for our application as it will allow us to store, update and retrieve data of the load monitor efficiently and in real time. By using Firebase , we can ensure fast and synchronized access to data, thus providing a smooth user experience [7]. For code development, we opted for Visual Studio Code (VsCode). VsCode is a lightweight yet powerful integrated development environment equipped with advanced features for Flutter development. It offers a wide range of Flutter-specific extensions, making it easier to write, debug, and test code. VsCode is also known for its efficiency and versatility, making it an optimal choice for our development team.

In summary, using Flutter for application interfaces, Firebase for database management, and VsCode as a development environment is a good combination. It will allow us to develop a high-performance, efficient and aesthetically pleasing mobile application for our users, while facilitating the development process for our team.

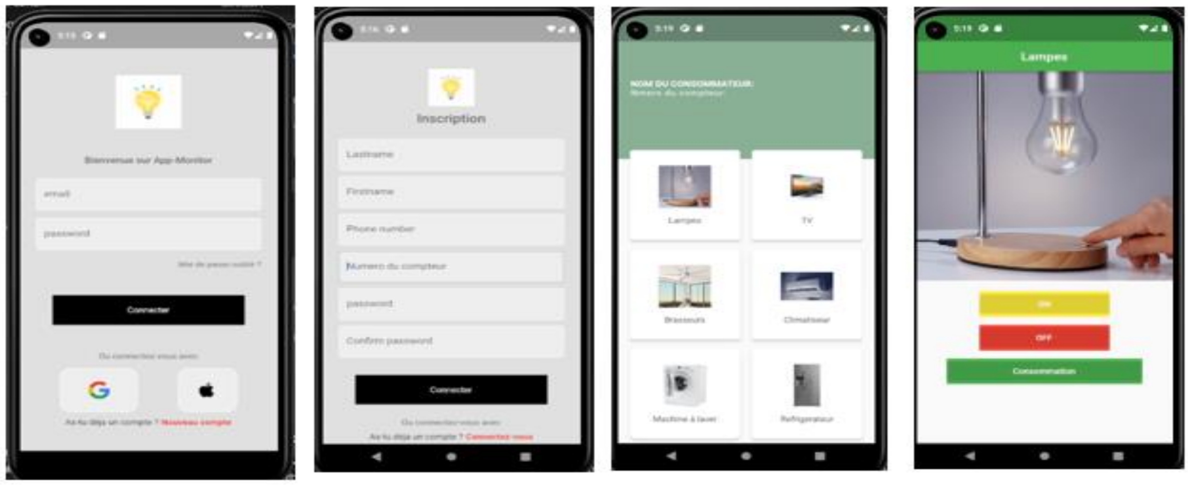

Figure 9: Mobile application interfaces

IV. RESULTS

Overall presentation of the intelligent system in a model

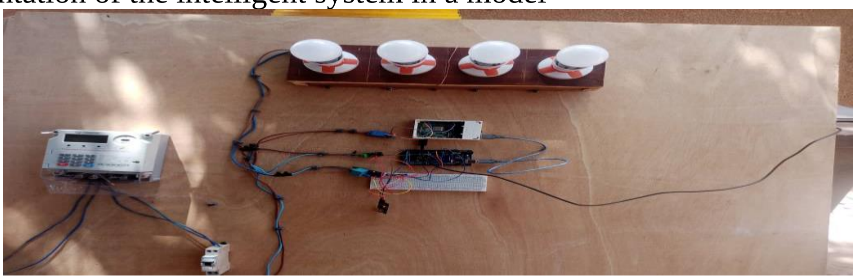

Figure 10: Experimental setup

This image represents the completed prototype of our monitor. We can observe the various connections of our equipment, as well as the intelligent system designed, which constitutes the heart of this prototype. This intelligent system allows us to test the energy consumption of lamps in an installation. It facilitates the reading and identification of the different electrical values, which are then transmitted to our data management system to guarantee their visibility on our mobile interface, as you will see in the rest of our project.

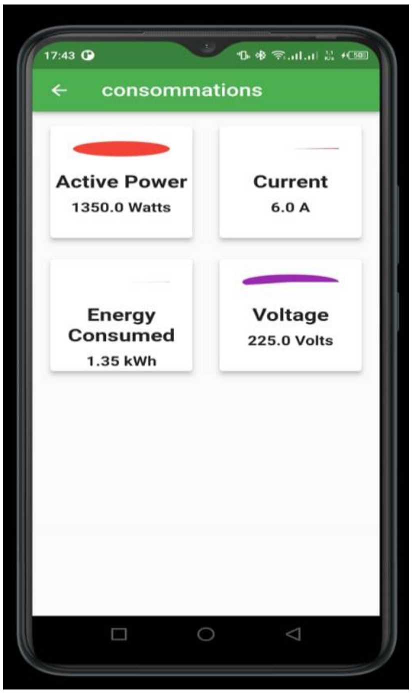

Figure 11: Energy consumption taken at 2:30:45p.m

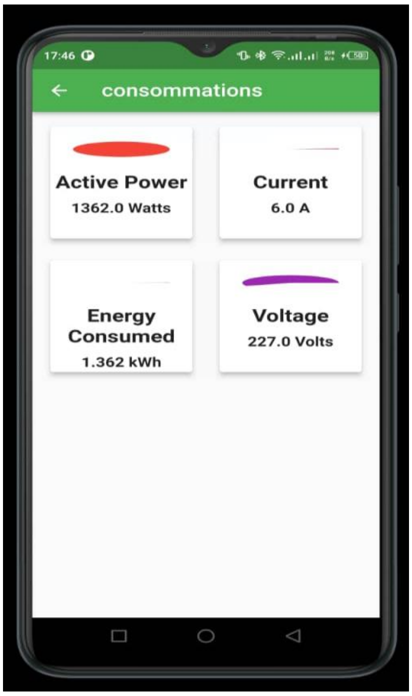

Figure 12: Energy consumption taken at 3:30:50p.m

The data provided appears to be electrical energy consumption readings at two different times, likely sent from a metering device to a mobile app. Here is a separate explanation for each reading based on time:

- First Measure (Timestamp: 2023-09-15 14:30:45) on screen 1:

At 2:30:45 p.m., a power consumption measurement was sent. The electrical current was constant at 6 amps (A), and the measured voltage was 225 volts (V). This gives an active power of 1350 watts (W). Up to that point, 1.35 kilowatt hours (kWh) of energy had been consumed.

- Second Measure (Timestamp: 2023-09-15 15:30:50) on screen 2:

At 3:30 p.m. and 50 seconds, another consumption measurement was sent. The electrical current remained constant at 6 amps (A), but the voltage increased slightly to 227 volts (V), which led to an active power of 1362 watts (W). Up to that point, total energy consumption had reached 1,362 kilowatt hours (kWh).

This data makes it possible to monitor the evolution of energy consumption, thus providing useful information for the management and optimization of electricity use.


*donnes.txt - Bloc-notes

Fichier Edition Format Affichage Aide

Timestamp: 2023-09-15 14:30:45, Current: 6 A, Voltage: 225 V, Active Power: 1350 W, Energy Consumed: 1.35 kWh
Timestamp: 2023-09-15 15:30:50, Current: 6 A, Voltage: 227 V, Active Power: 1362 W, Energy Consumed: 1.362 kWh

Figure 13: Experimental data recorded

The data provided represents periodic measurements of electrical energy consumption recorded on the Raspberry Pi memory card. Each recording is characterized by a precise timestamp, indicating the exact moment of the measurement. Measurements include electrical current in amps (A) and voltage in volts (V) which remain constant, as well as active power in watts (W) calculated based on the product of current and voltage. This data is essential for monitoring energy usage in real time and analyzing consumption trends, enabling informed decisions for more efficient energy management.

These readings are integrated over time to calculate the total energy consumed up to each moment, expressed in kilowatt hours (kWh). All the records form a consumption trajectory, a valuable resource for assessing energy use habits and identifying ways to optimize energy efficiency. The entire process, from data collection to analysis, relies on the Raspberry Pi's memory, providing a standalone solution for monitoring and improving energy consumption.

CONCLUSION

Considering the challenges of SONABEL in the field of transport and distribution of electrical energy and the rate of loss on energy consumers in Burkina Faso, we plan to reduce the consumption of electrical energy and allow SONABEL to increase the supply of electrical energy. Therefore, this paper focuses on the design of an equipment load monitor for managing and monitoring electrical energy consumption in energy-intensive buildings. In this work, we first carried out energy consumption management and optimization, general intelligent system research, then project research, and finally project implementation.

Fundamental to this article is programming the Raspberry Pi 4 using several libraries and using the Raspbian operating system. In addition, we have integrated IT systems, i.e. mobile developments to monitor energy consumption and control devices remotely. We also discovered very useful modules for the implementation of interconnected systems

Declaration by Authors
Acknowledgement: None
Source of Funding: None
Conflict of Interest: The authors declare no conflict of interest.

REFERENCES

1. “raspberry-pi-4-product-brief.pdf”. Accessed: September 6, 2023. [Online]. Available at: https://datasheets.raspberrypi.com/rpi4/raspberry-pi-4-product-brief.pdf
2. “How to use ACS712 Arduino current sensor - Moussasoft ”. Accessed: July 4, 2023. [Online]. Available at: https://www.moussasoft.com/acs712-capteur-de-courant-arduino
3. “TN Active AC voltage sensor ZMPT101B TN Best price in Tunisia”. Accessed: September 1, 2023. [Online]. Available at: https://www.didactico.tn/produit/capteur-de-tension-ac-actif-zmpt101b/
4. “Arduino_Mega.pdf”. Accessed: September 20, 2023. [Online]. Available at: http://jltimin.free.fr/1sti2d_2012_2013/projet2/Arduino_Mega.pdf
5. Yida , “Arduino RTC Tutorial: Using DS1307 RTC with Arduino”, Latest Open Tech From Seeed . Accessed: August 22, 2023. [Online]. Available at: https://www.seeedstudio.com/blog/2019/11/19/arduino-tutorial-using-ds1307-rtc-with-arduino/
6. “flutter_tutorial.pdf”. Accessed: September 6, 2023. [Online]. Available at: https://www.tutorialspoint.com/flutter/flutter_tutorial.pdf
7. “firebase.pdf”. Accessed: September 6, 2023. [Online]. Available at: https://riptutorial.com/Download/firebase.pdf

How to cite this article: B. Kossi Imbga, W. Rodrigue Kabore, Emmanuel Ouedraogo, Ablasse W. Zoungrana. Designing an appliance load monitor with programmable counter for energy efficiency. *International Journal of Science & Healthcare Research.* 2023; 8(4): 217-225. DOI: *10.52403/ijshr.20230431*

******