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Design And Implementation Of an Auto Control System for Energy Consumption

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Abstract

Abstract:

Over the past two decades, the world has experienced an exponential increase in energy consumption driven by the world population and economic growth. Energy management systems, specifically automated control systems for energy consumption provide an effective solution, due to their influence on the power consumption patterns of users. This project aims to design and implement an IoT-based auto control system for energy consumption. The system leverages the ESP32 microcontroller for power measurement, internet connectivity, bill generation, and controlling and protecting appliances. A phone application was developed as an interface for the system, users can monitor their power usage and associated costs, empowering them to remotely control appliances both manually and automatically, the Direct Load Control and Time-Dependent Pricing in Tariff Management techniques were adopted in this system. The application connects to ESP32 through a Firebase real-time database. Furthermore, measurement data and calculated bills are recorded in Google Sheets. Measurements and calculations resolution of the system were discussed. along with a vision for the system's future.

Kay words: energy consumption, IoT, auto-control, distance control, power monitoring.

résumé:

Au cours des deux dernières décennies, le monde a connu une augmentation exponentielle de la consommation d’énergie, entraînée par la population mondiale et la croissance économique. Les systèmes de gestion de l'énergie, en particulier les systèmes de contrôle automatisés de la consommation d'énergie, constituent une solution efficace en raison de leur influence sur les modèles de consommation électrique des utilisateurs. Ce projet vise à concevoir et mettre en œuvre un système de contrôle automatique basé sur l'IoT pour la consommation d'énergie. Le système exploite le microcontrôleur ESP32 pour la mesure de la puissance, la connectivité Internet, la génération de factures ainsi que le contrôle et la protection des appareils. Une application téléphonique a été développée comme interface pour le système, les utilisateurs peuvent surveiller leur consommation d'énergie et les coûts associés, leur permettant de contrôler à distance les appareils manuellement et automatiquement. Les techniques de contrôle direct de la charge et de tarification en fonction du temps dans la gestion tarifaire ont été adoptées dans ce cadre système. L'application se connecte à ESP32 via une base de données en temps réel Firebase. De plus, les données de mesure et les factures calculées sont enregistrées dans Google Sheets. Les mesures et la résolution des calculs du système ont été discutées. Ainsi qu'une vision de l'avenir du système.

Mots Kay : consommation d'énergie, IoT, contrôle automatique, contrôle de distance, surveillance de la puissance.

ملخص:

على مدار العقدين الماضيين، شهد العالم ارتفاعًا كبيرًا في استهلاك الطاقة مدفوعًا بنمو عدد السكان والنمو الاقتصادي .تمثل أنظمة إدارة الطاقة، وخاصة أنظمة التحكم الآلي في استهلاك الطاقة، حلاً فعالًا، وذلك بفضل تأثيرها على أنماط استهلاك الطاقة للمستخدمين .يهدف هذا المشروع إلى تصميم وتنفيذ نظام تحكم آلي لاستهلاك الطاقة قائم على تكنولوجيا الIoT. يستفيد النظام من متحكم ESP32 لقياس الطاقة والاتصال بالإنترنت وإنشاء الفواتير والتحكم في الأجهزة وحمايتها .تم تطوير تطبيق هاتف كواجهة للنظام، حيث يمكن للمستخدمين مراقبة استهلاك الطاقة والتكاليف المرتبطة بها، مما يمكّنهم من التحكم في الأجهزة عن بعد يدويًا أو تلقائيًا .تم اعتماد تقنيات التحكم المباشر بالحمولة وتسعير الوقت في إدارة التعرفة في هذا النظام .يتصل التطبيق بـ ESP32 من خلال قاعدة بياناتFirebase real-time. علاوة على ذلك، يتم تسجيل بيانات القياس والفواتير المحسوبة في ورقة جوجل. تمت مناقشة دقة القياسات النظام والحسابات، إلى جانب رؤية مستقبلية للنظام.

الكلمات المفتاحية: استهلاك الطاقة، IoT, التحكم الالي, التحكم عن بعد, مراقبة الطاقة

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List of abbreviations

EEM	Energy Efficient Measures
EMS	Energy Management Systems
SCADA	Supervisory Control and Data Acquisition
BEMS	Building Energy Management Systems
IEMS	Industrial Energy Management Systems
CEMS	Commercial Energy Management Systems
FEMS	Facility Energy Management Systems
ISO	International Organization for Standardization
HVAC	heating, ventilation, and air conditioning
AI	Artificial Intelligence
DLC	Direct Load Control
DLM	Dispatch Load Management
IoT	Internet of Things
HMI	Human-Machine Interface
PMD	" La Puissance Mise à Disposition " Remuneration for Available Capacity
GSM	Global System for Mobile Communications
SMS	Short Message Service
ADC	Analog to Digital Converters
CT	Current Transformer
P	Active power
V	Voltage
I	Current
Q	Reactive power
S	Apparent power
RMS	root mean squirt
E	energy
t	time
SSID	Service Set Identifier
V_{ref}	Reference voltage

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General introduction

General introduction

With the growing world population, the increase in living standards, and the emphasis on large-scale production in developing countries, global energy consumption is rapidly increasing [1]. This leads to a noticeable rise in electricity pricing, blackouts during peak demand, and more frequent power curtailment, despite the growth of energy production capability over the last decade [2]. According to Our World in Data organization, the world's global electric generation has increased in the past two decades by 14,202.09 TWh, reaching 29,479.05 TWh in 2023, and the Algerian annual demand has also significantly increased by more than a third. Multiple solutions were applied to address this problem, such as using renewable energies, energy management systems, efficient appliances, and green buildings.

One of the energy management techniques is using Auto control systems for energy consumption, these systems provide a comprehensive approach to energy conservation, by making the users aware of their consumption and energy cost in real-time, empowering them with full control of their usage, resulting in efficient use of energy and reducing energy wastage which ultimately contributes in minimizing the global energy consumption increasing rate.

This project aims to design and implement an auto-control system for energy consumption based on IoT technology, using the ESP32 microcontroller to measure the power consumption and calculate the bills based on various tariffs, and send this data to a dedicated application, this system also allows to control the appliances remotely, either manually or automatically.

This thesis is divided into three chapters:

Chapter 1 presents the concept of energy management, its objectives, and benefits. it describes the energy management systems’ techniques, functions, and applications, and provides an overview of auto-control systems and their role in optimizing power consumption.

Chapter 2 describes the proposed system design. furthermore, components, measurement and controlling, communication technique between the system and the application, the interface of the application, and the data recording method.

Chapter 3 details the design and implementation of the system circuit, along with the result. It discusses the measurements and energy calculation accuracy, as well as some additional correction factors.

Chapter 01

Energy management

1.1 Introduction

The rapid growth of electricity consumption, especially residential electricity consumption, poses major challenges to power generation and aggravates fossil fuel consumption and environmental pollution. The increase in residential consumption is driven by factors such as population growth, urbanization, and widespread use of equipment, which places a huge burden on the distribution network. Feeders and transformers need to be upgraded to meet peak demand, resulting in significant expenditure on additional network infrastructure, and reduced utilization, especially during peak hours. Furthermore, despite these efforts, pollution remains a pressing problem, making options for improving infrastructure less feasible [3].

Energy management became a requirement for addressing this challenge, it emphasizes a strategic approach for optimizing energy use while maintaining the comfort and productivity of the individuals [4]. this chapter covers the energy management fundamentals and its objective along with its techniques and applications, in addition to an overview on automated control systems for energy consumption.

1.2 Energy Conservation

The concept of energy conservation is manifested in the use of a set of procedures and technologies aimed at reducing energy consumption without compromising the comfort or productivity of individuals. Conservation involves using energy more efficiently, which contributes to reducing waste and saving costs associated with this consumption. Although energy consumption is increasing exponentially year after year, the concept of conservation is considered an effective solution to this increase. Energy conservation strategies include a range of measures and technologies that can be applied in various sectors to achieve savings and efficiency goals. These strategies require continuous awareness and training for energy users to promote awareness of the importance of sustainable and effective energy use [5].

1.3 Energy Management

Energy management systems have been a central topic in the literature in recent years in general, the primary goals of these investigations are related to the monitoring of power flow and optimization, examples of solutions include the implementation of sensing, automation, and demand side management. These investigations also propose several approaches that can be undertaken to enhance energy efficiency, for example, actions pertaining to improving physical facilities or the utilization of more effective electrical devices. In general, effective energy management strategies are crucial to reducing energy consumption and utilizing energy effectively. Additionally, some investigations have dedicated their efforts to complex models that require information about the static environment's perception. One of the essentials of energy management is providing accurate measurement of real energy consumption to achieving effective consumption awareness. Admittedly there are still questions and issues regarding the use of IoT in relation to energy management, for example. In general, few efforts have been documented in the literature that attempt to convert building energy management platforms into a support system for data analysis, this adds value to the process of electric energy management [4].

1.3.1 History of Energy Management

The roots of power control originate from the 1920s, when ABB released its first controller for a power plant that lacked a computer, this was not until the 1960s that computers were introduced to the process of power control, which led to the modern system of power network control that is common today. At that point, the majority of the EMSs were intended for a single client. Power systems were susceptible to attacks and necessitated the development of applications and instruments to prevent accidents and failure modes from becoming large-scale. The liberation of the power sector from regulation, the interconnection between the power sector and other sectors, and the privatization of the sector all began in the 90's, this was the largest change in the sector's history. Specialization became more prevalent and many utilities began to focus on generation, transmission or distribution. Energy trading systems were necessary to allow independent system operators to operate real time markets for energy trading. Generation companies required an interface with the energy market - and the capacity to plan/optimize supply in order to meet demand at the spot market - transmission companies required advanced systems to manage their high voltage networks and prevent a fault in one part of the system from spreading across the entire network and distribution companies needed to take network management to the level of the individual customer connection point in order to minimize customer outages [6].

1.3.2 Benefits of Energy Management

Energy management is essential for minimizing costs associated with electrical energy procurement and consumption fees. It involves employing various techniques to optimize energy usage within a system. Implementing Energy Efficient Measures (EEM) like valley filling and peak trimming, along with strategically maintaining electrical systems, can effectively reduce energy costs. These methods not only increase off-peak hours but also improve the system's load factor, enhancing overall efficiency. Beyond conventional approaches, advanced methods such as power wheeling, adopting energy-efficient processes and equipment, integrating energy storage, co-generation, utilizing renewable energy, and implementing reactive power control have gained popularity. These strategies not only cut costs but also promote environmental sustainability and resilience against energy market fluctuations. Embracing these approaches enables organizations to boost energy efficiency, shrink their carbon footprint, and achieve substantial long-term savings [7].

1.3.3 Energy Management Systems Objective

Energy Management Systems (EMS) play a crucial role in modern energy infrastructure, ensuring efficient and reliable operation of power systems. The objectives of an EMS are multifaceted, evolving in tandem with the increasing volume of available data for integration and the expanding demands of the industry. Here are some key objectives of an EMS:

1.3.3.1 Generation Planning, Scheduling & Dispatch

- Economic and Environmental Dispatch: Minimizing costs while adhering to environmental regulations
- Load Modeling and Management: Accurately predicting and managing electricity demand.
- Loss Minimization: Minimizing energy losses during transmission and distribution.
- Peak Shaving: Reducing peak demand through various strategies.

1.3.3.2 Operators Power Flow

- Network Security Studies: Analyzing system vulnerabilities and implementing security measures.
- Voltage or Reactive Power Scheduling: Managing voltage levels for system stability.
- Transmission Loss Minimization: Minimizing losses during power transmission.
- Direct Operations Control: Real-time monitoring and control of power system operations.

1.3.3.3 Automatic Generation Control

- Interruptible Load Management: Managing interruptible loads to balance supply and demand.
- Voltage Reduction Control: Adjusting voltage levels to improve system efficiency.
- Load/Frequency Control: Maintaining system frequency within acceptable limits.
- Monitoring and Analysis: Continuous monitoring and analysis for proactive management.

1.3.3.4 Network Topology

- Security Constrained Dispatch: Dispatching power while considering system security constraints.
- Intelligent Alarm Processing: Analyzing alarms and providing intelligent responses.
- Contingency Selection and Analysis: Identifying and analyzing potential system contingencies.

1.3.3.5 Economy Analyses

- Accounting and Performance Evaluation: Monitoring and evaluating system performance.
- Interchange Transaction Scheduling: Scheduling energy exchanges between different entities.

1.3.3.6 Dispatcher Simulator

- SCADA Simulation: Simulating SCADA (Supervisory Control and Data Acquisition) systems for training and testing.
- Disturbance Replay: Replaying system disturbances for analysis and training purposes. [6]

1.3.4 Energy Management Systems Functions

Today's complex energy management systems allow them to perform multiple tasks and operations compared to before when highly centralized systems were common. Each task is divided into several groups according to the job category that is the main job. Here is an overview of the advanced functions of energy management systems:

1.3.4.1 Basic Functions

The fundamental purpose of Energy Management Systems (EMS) is to effectively monitor energy consumption across entire sites and individual facilities while striving to achieve energy management and conservation goals. EMS functionalities are categorized into three main types: Building Energy Management Systems, Industrial/Commercial/Facility EMS, and EMS for specific equipment. Each type serves distinct purposes tailored to their respective applications.

1.3.4.2 Control Functions

Building upon effective energy monitoring capabilities, various control functions have been developed for managing energy usage across equipment, buildings, or factories. This entails a comprehensive set of control functions and related function blocks aimed at optimizing energy consumption. These functions encompass real-time monitoring, automated adjustments, scheduling, and predictive maintenance, among others. By integrating advanced algorithms and data analytics, these systems enable precise control over energy usage, leading to significant cost savings and environmental benefits. Moreover, they facilitate remote monitoring and control, allowing for seamless management of energy resources across diverse facilities and locations. Overall, the control function group plays a pivotal role in ensuring efficient and sustainable energy management practices.

1.3.4.3 Analysis Functions

The analysis function group within Energy Management Systems (EMS) encompasses a suite of tools and methodologies developed through meticulous scrutiny of industrial processes, daily operational routines within companies, and the functioning of factories or equipment. Its primary objective is to foresee variations in future energy consumption, formulate optimal control settings, and devise effective management strategies. This function group serves multifaceted purposes, including forecasting future energy usage patterns, refining control parameters, diagnosing equipment operation statuses, detecting potential faults, and recommending maintenance schedules. Despite its crucial role, scholarly publications on this particular aspect are notably scarce, largely owing to the intricate nature of analyzing entire site energy management systems.

1.3.4.4 Group Management Functions

The functions of Energy Management Systems (EMS) within the management function group encompass several critical aspects. These functions primarily focus on organizing staff, managing databases, and implementing control mechanisms.

In the realm of Building Energy Management Systems (BEMS), the behavior management function block plays a pivotal role. Here, socio-economic behavior management integrates data on both economic factors and energy consumption costs. This integration incentivizes staff members to actively engage in energy management practices. Moreover, when coupled with control functions, it facilitates effective energy conservation measures. Similarly, in Industrial/Commercial/Facility (I/C/F) EMS, the behavior management function block offers operational procedure recommendations. These recommendations serve as guidance for operators and company personnel, encouraging proactive participation in energy-saving initiatives. Adhering to the ISO standard norms, the implementation of standardized procedures such as planning, checking, executing, and evaluating ensures the efficacy of staff management. Consequently, this approach enhances the efficiency of production systems while promoting sustainable energy practices.

1.3.4.5 Advanced Functions

The advanced function group of Energy Management Systems (EMS) encompasses a range of developed functions that integrate model analysis and control mechanisms to enhance energy management capabilities. advanced computational logic leveraging expert systems and artificial intelligence (AI) can further refine energy usage management. These functionalities enable EMS to not only analyze energy patterns but also implement intelligent control strategies for more efficient energy utilization.

1.3.4.6 Specific Functions

Energy Management Systems (EMS) perform various functions tailored to specific sites and their unique requirements. One such function involves optimizing HVAC systems equipped with cool storage technology. This system effectively chills indoor spaces by storing cold energy during off-peak electricity hours and releasing it during on-peak times. This not only ensures comfortable indoor temperatures but also minimizes electricity costs.

In regions with ample sunlight, EMS can implement daylight-assisted management techniques. These methods involve directing natural light into indoor spaces to reduce reliance on artificial lighting, thereby achieving significant energy savings. These functions are categorized as specific-site functions, as they are designed to meet the demands of particular environments or utilize specific equipment [8].

1.3.5 Energy Management Techniques

Energy management involves a multifaceted approach spanning engineering, design, application, utilization, and operational maintenance of electrical power systems. Its primary goal is to optimize electrical energy usage while adhering to international standards. In utility industries, load management plays a pivotal role, encompassing strategies aimed at influencing consumers to use electricity in a manner that shapes the electrical load to align with the utility service's requirements.

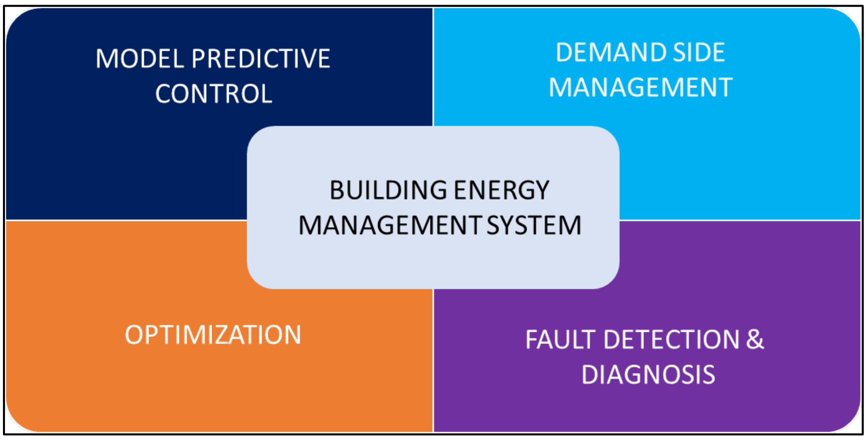

Figure 1.1: BEMS management strategies

1.3.5.1 Direct Load Control

Direct Load Control (DLC) involves utilities remotely controlling certain appliances or equipment at consumers' premises during peak demand periods. By adjusting or cycling these loads, utilities can alleviate strain on the grid, avoiding potential blackouts or brownouts.

1.3.5.2 Time-Dependent Pricing in Tariff Management

This technique involves varying electricity prices based on demand levels throughout the day. Through dynamic pricing structures, consumers are incentivized to shift their electricity usage to off-peak hours when rates are lower, reducing overall demand during peak times.

1.3.5.3 Dispatch Load Management (DLM)

DLM focuses on optimizing the dispatch of loads within a utility's service territory. By strategically scheduling and prioritizing loads, utilities can minimize grid congestion and improve overall system efficiency.

1.3.5.4 Thermal Energy Storage

Thermal energy storage systems utilize off-peak electricity to store thermal energy, which can then be utilized during peak demand periods for heating or cooling purposes. This helps to shift energy consumption away from peak times, reducing strain on the grid and lowering overall energy costs [7].

1.4 Energy Management Systems Applications

1.4.1 Building Energy Management Systems (BEMS)

The concept of BEMS comprises various systems and technologies that are developed to increase building energy efficiency and enhance the indoor comfort of us, the occupants. Building Energy Management Systems is a key element of the intelligent electricity grid that enables monitoring and controlling the amounts of energy consumed in buildings and eventually bringing the amount of electricity down, the overall demand of energy. The flexibility of BEMS in the usage is very high in residential buildings and non-residential units. There are two kinds of BEMS methods: active, and passive. Passive strategies utilization indirectly leads to reduced energy usage in buildings. They are methods that depend on equipping the user with future strategies and improving the user's energy awareness. The systems involved in active approaches will make use of a mixture of sensors and actuators infrastructure installed in the building. They accomplish this goal by minimizing energy losses in application contexts by managing the controller actuators and devices. BEMS are classified into four management strategies: model predictive control, demand-side management, optimization, and fault detection and diagnosis [9].

1.4.2 Home Energy Management

Home energy management is the user demand side management solution that enables individuals to turn off appliances such as water heaters and televisions remotely to save on energy costs, postpone the power usage till the peak times are over to enable peak savings, and when the demand unexpectedly is low. The idea of a home management system began from the AMI to develop demand side management, end-user energy efficiency, response of demand, and general improvement in power generation and supply efficiency. IoT advancement and improved communication technologies have brought back the seen in recent times in home energy management solutions which it is hoping to provide more flexibility in use as well as intelligent services [10].

1.4.3 Energy Management in Smart Grid

The smart grid offers a groundbreaking opportunity to revolutionize the modern power grid, boasting numerous advantages such as distributed generation, self-healing capabilities, and digital two-way communication. Leveraging advanced information and communication technologies, it efficiently adjusts renewable energy generation and manages electricity markets while overseeing decentralized energy resources. However, as energy demand escalates, there's an urgent need to expand the smart grid's capacity, requiring robust power infrastructure installation despite potential increases in complexity and costs. In this context, integrating demand-side management programs becomes paramount. Demand-side management supports smart grid functionalities by analyzing market dynamics, identifying cost-effective energy options, and managing system loads, thus enhancing grid sustainability. These initiatives also have the potential to alleviate peak load demand, reshape load profiles, and reduce overall costs and carbon emissions, further enhancing the environmental credentials of the smart grid infrastructure [11].

1.4.4 Energy Management in Microgrid

The Energy Management System plays a crucial role in overseeing, controlling, and optimizing microgrid operations. However, managing microgrids presents unique hurdles compared to conventional distribution systems, primarily due to the integration of distributed generation, distributed storage, and controllable loads. Su and Wang have highlighted these challenges and discussed the pivotal role of EMS in microgrid applications. They have identified four key applications that microgrid EMS should support: forecasting, development, data analysis, and human-machine interface (HMI). These applications are critical for ensuring effective microgrid operation and management. Essentially, microgrid EMS encounters complexities arising from the variety of energy sources, storage options, and load management within the system. Overcoming these challenges necessitates innovative approaches and advanced technologies to ensure efficient and reliable operation, ultimately contributing to the success of microgrid deployments [12].

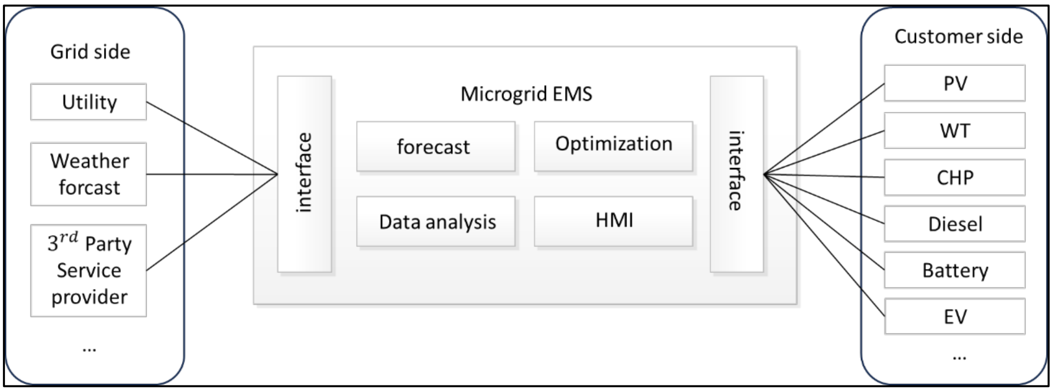

Figure 1.2: An Energy management systems

1.5 Electrical Energy Tariffs in Algeria

To promote energy conservation in Algeria, the Electricity and Gas Distribution Company has implemented various tariff options. These tariffs allow customers to select the most suitable option for their needs, enabling them to pay for electricity at the most affordable rate while also playing a part in reducing overall energy consumption. This tariff is defined as follows [13]:

Table 1.1: Energy Tariffs for Residential users in Algeria [13].

Tariff 51 M	**Peak**	**Full**	**Night**
	17h to 21h 811,47 cDA	6h to17h and 21h to 22h30 216,45 cDA	22h 30 to 6h 120,50 cDA
Tariff 52 M	**Peak**	**Off-Peak**	
	17h to 21h 811,47 cDA	21h to17h 178,07 cDA	
Tariff 53 M	**Night**	**Day**	
	22h 30 to 6h 120,50 cDA	6h to 22h30 486,98 cDA	
Tariff 54 M	**For consomption per quarter**		
	Tranche 1: from 0 to 125 kWh: 177,87 cDA Tranche 2: from 125 to 250kWh: 417,89 cDA Tranche 3: from 250 to 1000 kWh: 481,20 cDA Tranche 4: More than 1000 kWh: 547,96 cDA		

Table 1.2: Energy fees for Residential users in Algeria [13]

Tariff Code	Fixed fee DA/mois	PMD DA/kW/mois
51 M	286.44	29.85
52 M	66.40	29.85
53 M	66.40	14.81
54 M	-	4.37

The electric bill is calculated as follows [14]:

Bill amount per season (DA)

=

Fixed Fee + PMD Billing Rate × Available Power

+

Sum of (Energy Consumed per Time Slot/Tranche x Energy Tariff per Time Slot/Tranche)

+

Taxes set by the State

• Fixed fee: covers management expenses (meter reading, billing, reception) and metering.
• Remuneration for Available Capacity "PMD": a portion of the investment made by the management companies of the transmission and distribution networks to provide you with capacity that you can call upon at any time.

• Energy tariffs: the electricity consumed according to the tariff periods or tranches.

• Taxes set by the State.

1.6 Automatic Control Systems

Automatic control systems have become essential in modern civilization and technology, serving various purposes from regulating heating and air conditioning in homes to industrial automation and quality control. They are utilized in a wide range of applications including space technology, weapon systems, transportation, and robotics, addressing challenges like inventory control and environmental management.

The main goal of automatic control systems is to regulate variables in a predefined manner using input signals. These systems rely on principles like feedback control loops to enhance efficiency and safety across different domains, contributing to the advancement of modern technology [15].

1.6.1 Literary Review

Given the increasing popularity of home automation systems over the past few decades, and their significant contribution to enhancing comfort and improving the quality of life, Muhammad Asadullah and Ehsan Raza presented a paper containing an overview of both existing and emerging home automation systems. The paper delves into the operational mechanisms of various wireless communication techniques, such as ZigBee, Wi-Fi, Bluetooth, EnOcean, and GSM. By studying these techniques, the authors aim to provide a comprehensive understanding of their functionalities, enabling users to make informed decisions when building their own home automation systems. The comparative analysis of these communication methods allows users to select the technology that best suits their preferences and requirements. Furthermore, the research discusses a survey conducted on different home automation systems, shedding light on their respective advantages and drawbacks. This analysis aids in providing insights into the diverse range of options available to users, allowing them to make informed choices based on their specific needs and preferences [16].

There are numerous studies and research that have implanted auto-control systems. L.A Akinyemi et al, have designed and developed an automated home control system aiming to control devices remotely using mobile phone number, taking into account the possibility of monitoring the status and usage of these devices [17]. Further, a similar study was done by j. Deny et al were they created a smart IoT-based energy meter, which is used to track energy consumption via a GSM module, the system was capable of generating bills and controlling the load by sending an SMS from the user’s phone [16].

An updated system was designed and implemented, the purpose of the system is to develop an energy meter with the ability to communicate with the phones via the internet, in order to knowledge the consumers of their bills time-to-time the ESP32 microcontroller and Blynk platform were used so they can monitor the consumption on their smartphones [18].

V.Barnes et al, have added two options to the previous method of controlling, which are scheduling and controlling with a user interface on the mobile device, communicating with a power management system via integrated Raspberry Pi server using Wi-Fi protocol for communications, the user was able to interact with the power monitor, power control, power scheduling, power usage plan, and tariff or price manager. [19], this method of controlling was also implemented by K.L Tsai et al, using wireless smart socket and IoT, the results of the experiment show that the proposed scheme in this study can save around 33% at an average of 133kWh/week [20].

1.7 Conclusion

In conclusion, with the growing energy demand in the world, the energy management system is key for optimizing energy consumption. applying the EMS fosters effective power usage and raises consumer awareness, ultimately reducing energy wastage and its significant environmental impact.

This chapter highlighted energy management concepts, objectives, strategies, and functionalities, along with Algerian residential bill tariffs, in addition to some applications of the EMS in buildings and homes. Further, research on the integration of automated control systems in EMS and its role in reductions in energy consumption and costs was mentioned

Chapter 02
Automated control system design

2.1 Introduction

Energy Management Systems (EMS) aim to optimize energy efficiency, minimize energy wastage, and reduce associated costs with its consumption. Taking into account the comfort and productivity of the individuals. The Direct Load Control (DLC) and Time-Dependent Pricing in Tariff Management techniques were adopted in this system.

This system enables manual and automatic remote control of electrical loads using a device that measures current and voltage to accurately calculate consumed energy, providing the users with comprehensive information on their energy consumption. Based on this data, the electricity bill can be calculated according to various tariffs. This system can also protect devices from network or device malfunction.

Through the smartphone application, the user can control their appliances and set them to turn on or off automatically. This system aims to help the customer reduce their energy consumption, contributing to overall energy conservation, avoiding power outages caused by excessive consumption, and helping lower their electricity bill.

2.2 System Hardware

2.2.1 Used Components

1) **ESP32**

ESP32-WROOM-DA 38 Pins is a powerful Wi-Fi + Bluetooth + Bluetooth LE MCU module, with two complementary PCB antennas in different directions, and an Xtensa® 32-bit LX6 dual-core processor with a maximum clock frequency of 240 MHz, and two 12-bit Analog to digital converters (ADCs). ESP32-WROOM-DA can be used to develop IoT applications that need stable connectivity over a broad spectrum. This module is an ideal choice for indoor and outdoor devices for smart homes, industrial control, consumer electronics, etc. [21].

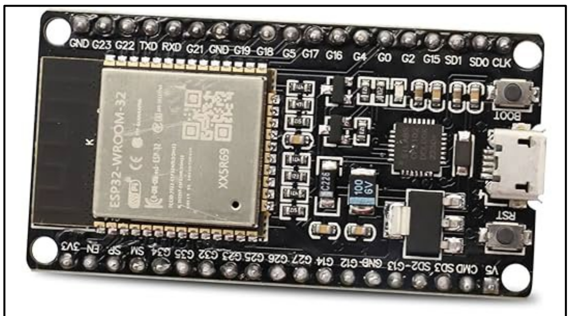

Figure 2.1: ESP32 WROOM-DA

2) **RTC DS1302**

The DS1302 trickle-charge timekeeping chip contains a real-time clock/calendar and 31 bytes of static RAM. It communicates with a microprocessor via a simple serial interface. The real-time clock/calendar provides seconds, minutes, hours, day, date, month, and year information. The end of the month date is automatically adjusted for months with fewer than 31 days, including corrections for leap year. The clock operates in either the 24-hour or 12-hour format with an AM/PM indicator [22].

Figure 2.2: RTC DS1302

3) **Relay Optocoupler (opt-isolated relay)**

An optoelectronic device that combines the functionality of a relay with optical isolation. It consists of a light-emitting diode (LED) and a photodetector (usually a phototransistor) enclosed in a single package [23].

Figure 2.3: Relay optocoupler

4) **Current Transformer:**

5A Range AC Current Transformer, the current sensor module can measure AC currents up to 5A, and the corresponding analog output is a 1000:1 ratio. It has an Onboard sampling resistor (R1) and precision microcurrent transformer (CT) to do accurate sampling for the signal-appropriate compensation. The module can measure within 5A current communication, corresponding to output analog quantity that can be adjusted [24].

Figure 2.4: ZMCT103C Current sensor

The next figure describes the circuit of current sensing:

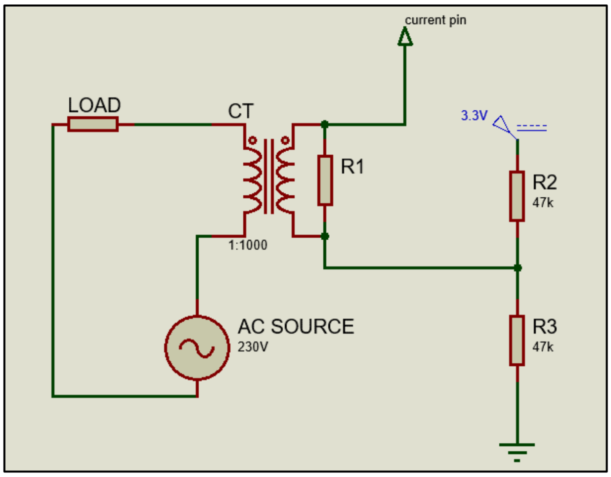

Figure 2.5: Reading the signal from the current transformer

ESP32 uses the "map" function to convert the input value on the current pin to the actual value that passes through the load, the function is used as follows:

$$instant\ current = map(current\ pin, 0, 3300, -5 \times \sqrt{2}, 5 \times \sqrt{2}) \qquad (2.1)$$

5) **Voltage Sensor**

for voltage sensing, a transformer with an approximate 14:1 ratio is used to step down the voltage from 230V to 16V. then, a potentiometer of 10k ohm decreases the voltage to 2.5V, then the signal passes through a second potentiometer to decrease it to around 0.824V, then the signal is lifted by 1.65V so the ESP32 can read the alternating signals since its reading range is 0 to 3300mV. As a result, the signal at the voltage pin oscillates between $1.65 + 0.824 \times \sqrt{2}\, V$ and $1.65 - 0.824 \times \sqrt{2}\, V$.

The "map" function is also used to retrieve the actual voltage value from its image on the pin. Therefore, the instantaneous voltage is calculated as follows:

$$inst\ voltage = map\left(voltage\ pin\ ,0{,}3300, -250 \times \sqrt{2} \times 1.286, 250 \times \sqrt{2} \times 1.286\right) \quad (2.2)$$

The correction factor 1.286 is used for safety purposes during testing, the maximum measured RMS voltage would be around 321.5 V.

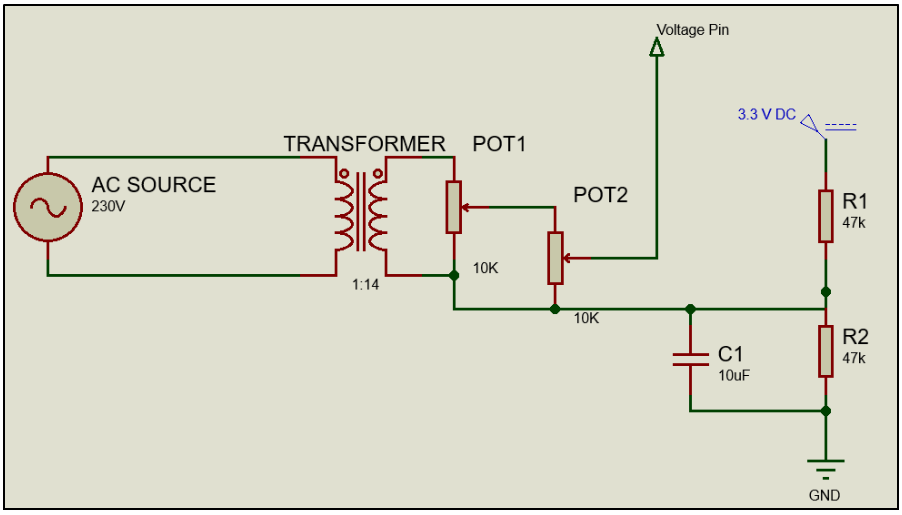

Figure 2.6: Voltage reading circuit

2.2.2 System software

The ESP32 microcontroller was chosen for multiple reasons, the essential one is that it has a dual-core. Core 0 was dedicated to communications, while Core 1 was for energy and bill calculation, and control algorithms. this method ensures the energy calculation functionality due to its sensitivity to timing

2.2.2.1 Power Calculation

Electrical power has several types: real power (P), reactive power (Q), and apparent power (S). They are defined as follows [25]:

$$P = V.I.\cos(\theta) \quad (2.3)$$

$$Q = V.I.\sin(\theta) \quad (2.4)$$

$$S = V.I \text{ or } S = \sqrt{P^2 + Q^2} \quad (2.5)$$

The following figure shows an example describing the difference between the power types:

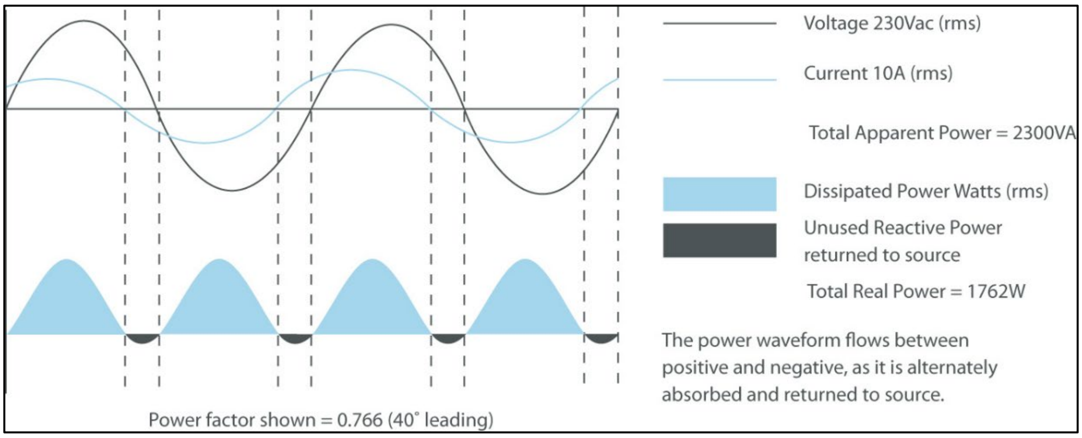

Figure 2.7: The active and reactive power signal [26].

To obtain the real power value, the ESP32 measures instantaneous power by multiplying the instantaneous current with instantaneous voltage and summing only the positive results, for 15 cycles (15 × 20ms). after the loop ends, the sum of instantaneous power values is divided by the number of samples to get the real power value. the real powers of Appliance1 and Appliance2 are calculated using the same method.

For calculating the RMS value of current (I) and voltage (V) the following formula is used [27]:

$$RMS = \sqrt{\frac{1}{n}\sum_{i=0}^{n} a_n^2} \quad (2.6)$$

Were:

n: Number of samples.

a: The instant values of current or voltage signal.

Applying this formula to the system is by taking measures of instant current and the sum of the squared measure values, this value is divided by the number of samples, and Irms is the square root of the previous result. The same thing is done to Vrms. The “micros()” function was used for determining the time. The next diagram describes the previous algorithm

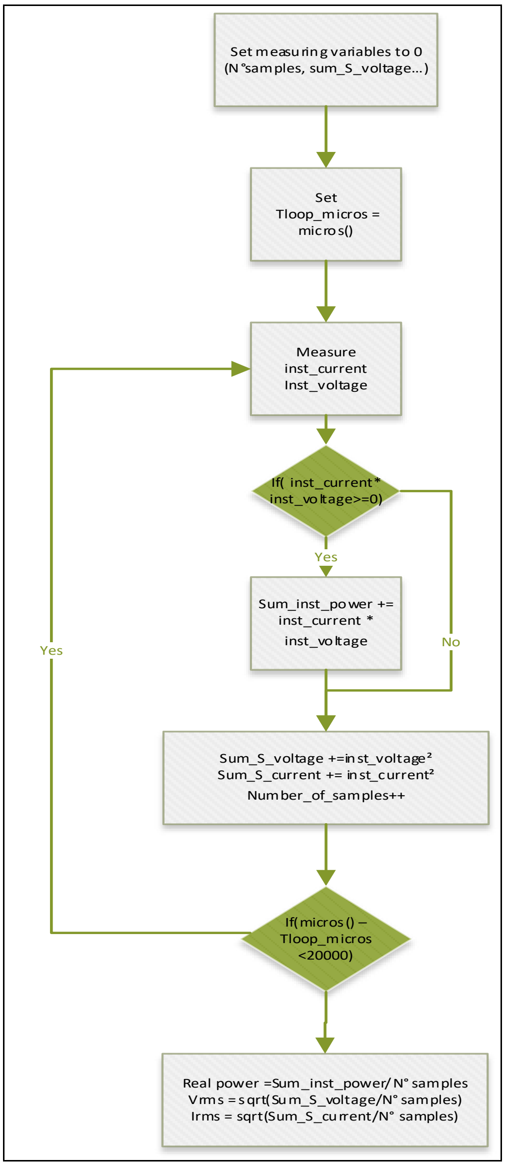

Figure 2.8: Real power and RMS value of voltage and current algorithm

2.2.2.2 Energy Calculation

Electrical energy involves two key concepts: power and time, it is calculated using this formula [28]:

$$E = P \times t \tag{2.7}$$

E: electrical energy [kWh]

P: electrical power [kW]

t: time [h]

in the system, real power is frequently added to energy value– each 1s-, the next diagram explains the algorithm to calculate energy.

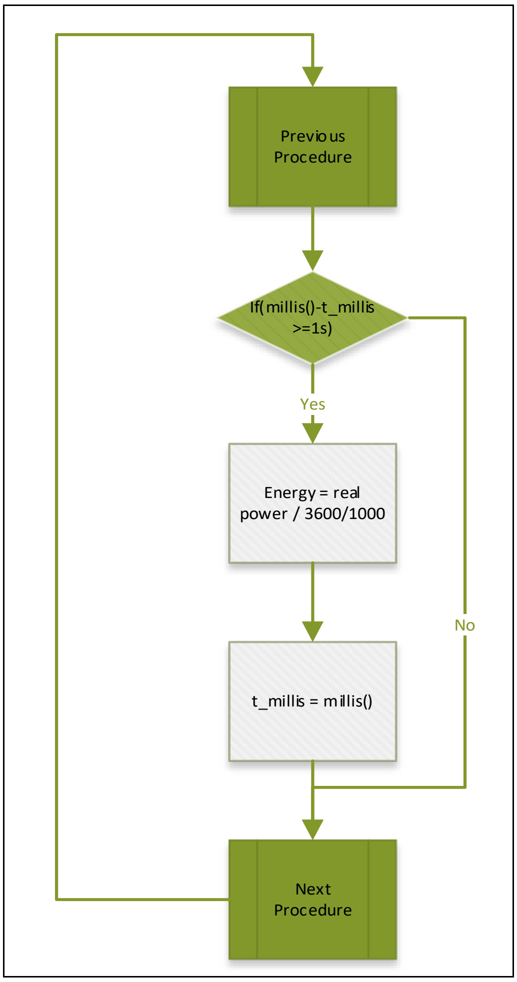

Figure 2.9: Energy calculation algorithm

2.2.2.3 Protection

The appliances are protected from over-voltage and voltage drops and current, by continually monitoring the voltage and the current, in case of perturbation in the voltage or the current exceeds 9.99 A (since the maximum of the sensor is 10A), the system will cut off the supply. when the power stabilizes for more than 30 seconds, the system will power back the appliances.

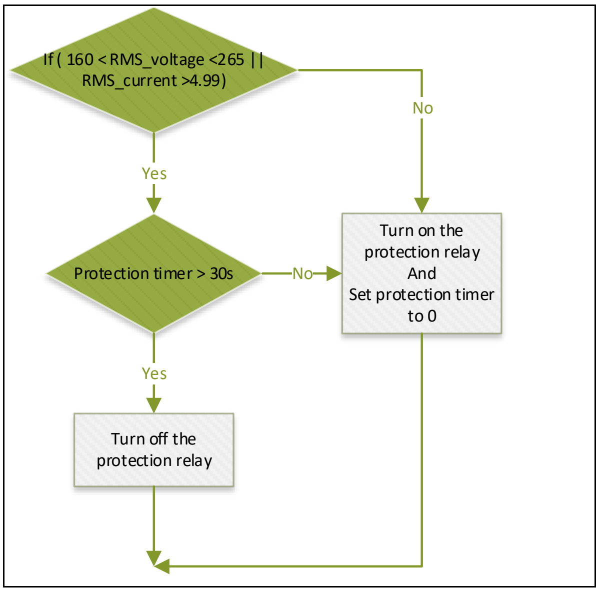

Figure 2.10: Voltage and current protection algorithm

2.2.2.4 Manual Control

In the system, the appliances (e.g. sockets, lighting, …), can be controlled manually remotely through the application on the user's phone, by disabling the auto-control option

2.2.2.5 Auto Control

if manual control is disabled, the system will proceed to automated control, this automated control system uses Load-shifting for energy consumption optimization, by creating schedules for appliances or setting power consumption limits during preset timing (off-peak, off-day, or off-night), these times are made according to tariff timing in Algeria.

2.2.2.6 Scheduling

The system is capable of establishing up to six schedules for each appliance. The user can set the start time and the end time of the schedule. They are also able to choose the days of the week when the auto control works. and set the start day of the schedule, specify when it will be disabled, or define the interval during which the schedule will be activated (this option is used only with appliance3 -third relay-). To prevent any interference between the schedules the system prioritizes the first schedule. Additionally, if the same time was set for both turning an appliance on and off, that particular schedule would be disabled. in addition to the ability to select a preset timing, in which the appliance will be forced to turn off as long as the time is in the preset period.

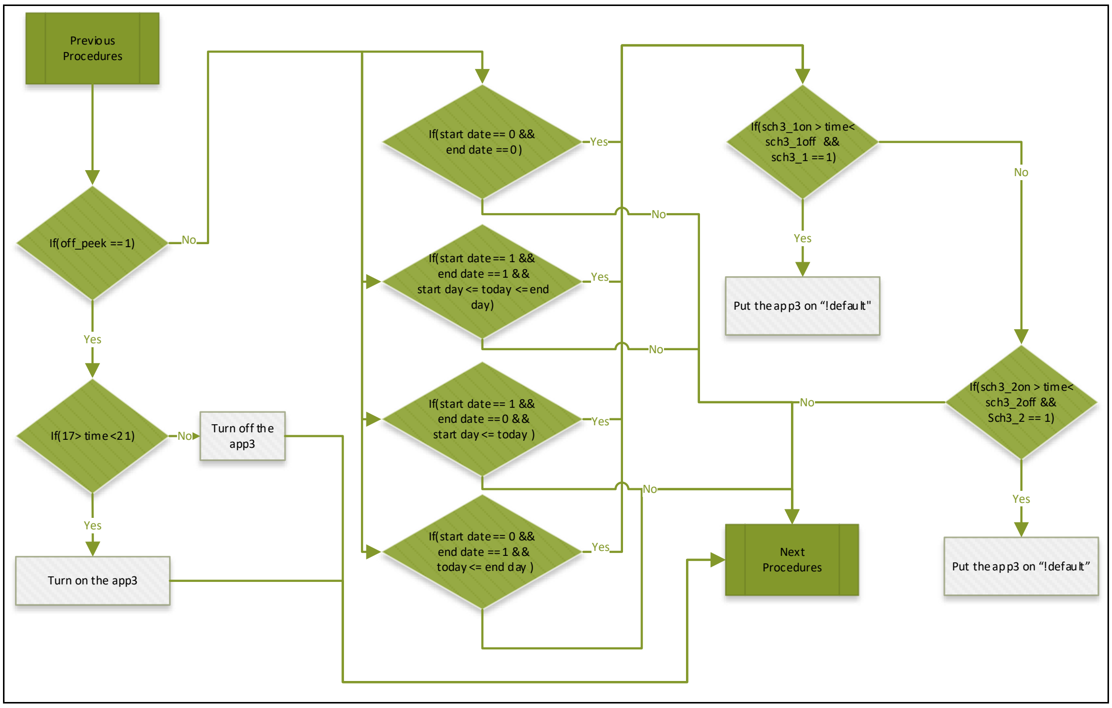

Figure 2.11: Scheduling algorithm of the appliance3

2.2.2.7 Power Limit

The system is designed with the capability of setting a limit on power consumption during off times. when the user sets a power limit on an appliance, the system will monitor its power consumption, in case the appliance passes the limit, the system will notify the user on their phone that the appliance has exceeded the set limit and it will be turned off soon, meanwhile, the system starts a timer of 10s, ensuring that the appliance is continuously above the limit then it shuts down the appliance until the end of the chosen period.

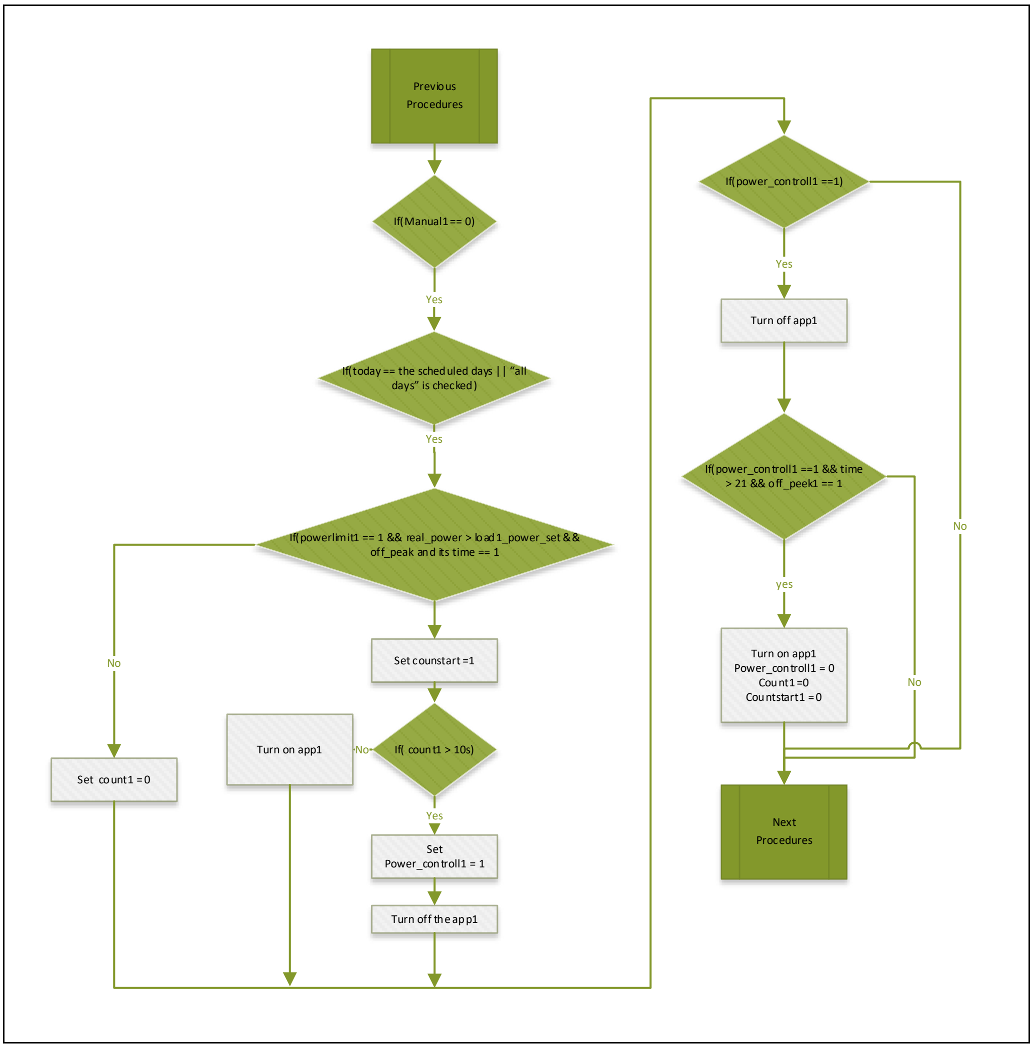

Figure 2.12: The algorithm of power limitation

2.2.2.8 Bill Calculation

To obtain accurate information on energy consumption, the system generates real-time bills according to the residential tariffs in Algeria which are 51 M, 52 M, 53 M, and 54 M with a PMD of 12kW (single phase) that are described in the first chapter. The user enters the old index from the last bill and the current index from the meter, according to the tariff they are using, and the bill will be generated based on that information, for the bills that are based on timing, the system gets the real-time from the RTC1302, checks the current tariff period then the energy that is consumed in second is added to the new index of that period. For the bill that uses parts, after the user sets the old and current index the system will verify the current part, and then energy is added to the new index. The next diagrams (Figure 2.13, 2.14) describe the calculation of the M54 and M51 bills method

2

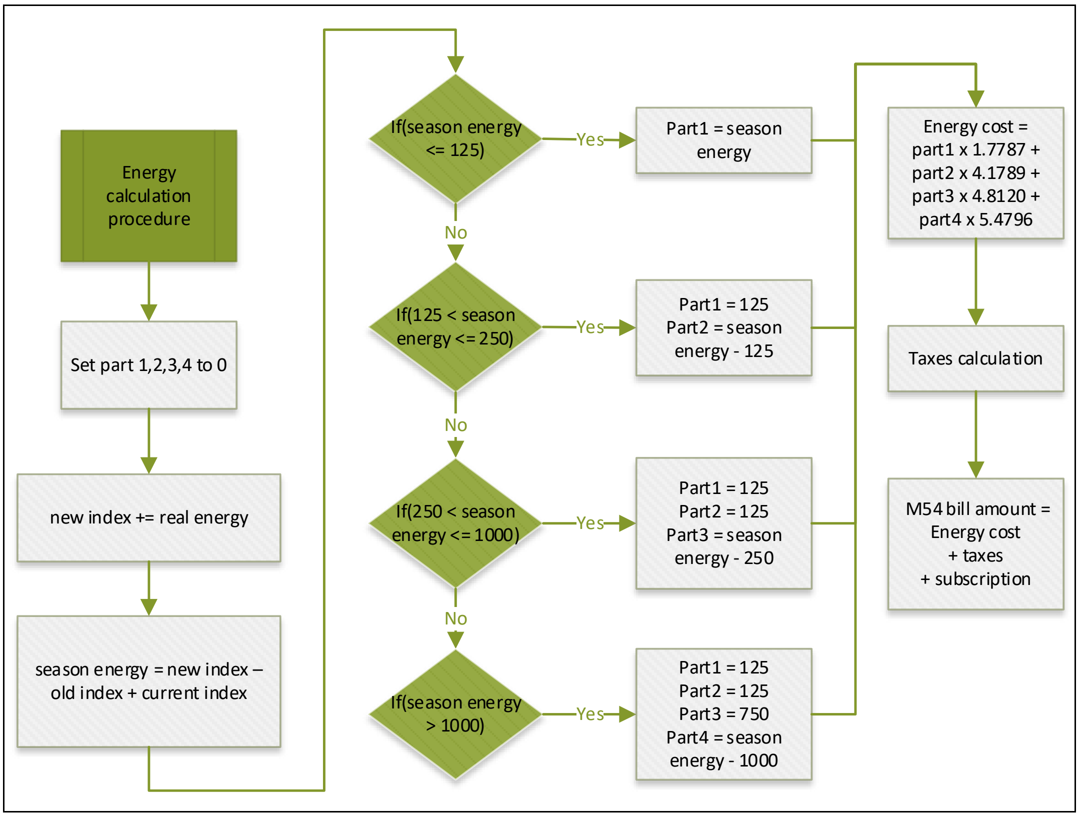

Figure 2.13: The algorithm for calculating the bill of 54M tariff

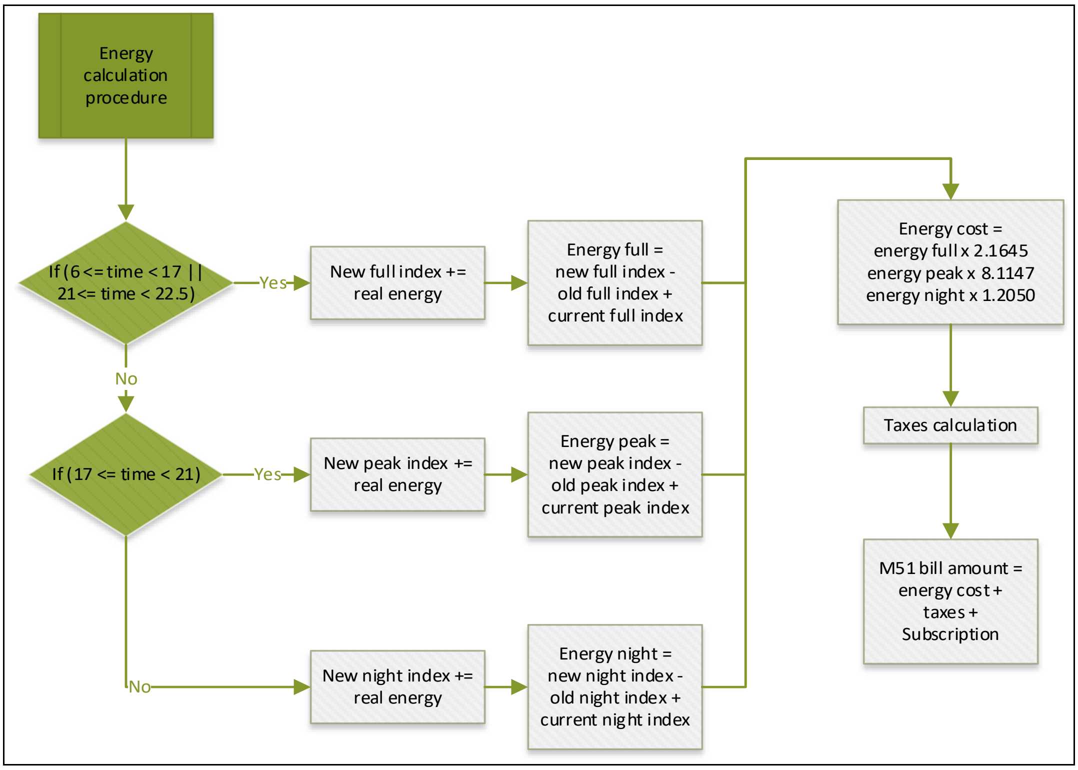

Figure 2.14: The algorithm for calculating the bill of 51M tariff

2.2.3 Data Streaming and Distance Controlling

2.2.3.1 Internet Connection

The “Wi-FiManager” library is used to utilize the Wi-Fi capabilities of the ESP32 microcontroller for internet connectivity. By establishing a temporary web server after startup, this library simplifies the configuration process. Users can then access this server through a web browser on a connected device and provide their Wi-Fi network authorizations, including the SSID and password. Once this information is securely stored within the ESP32's memory, the Wi-Fi Manager library facilitates a switch to station mode, enabling the ESP32 to connect to the designated Wi-Fi network and access the internet.

2.2.3.2 Firebase

Google Firebase is a collection of cloud-based development tools that aid developers in building, deploying, and scaling their apps. It offers features like authentication, real-time database, Firestor database, and Crashlytics. e.g.

The Real-time database serves as the central point of communication between the application on the user’s phone and the ESP32. The ESP32 sends measurements and bill amounts to the database and checks for orders from the user, using the “Firebase_ESP_Client” library. On the other side, the application reads these measurements and displays them while also sending commands, settings, and parameters.

To optimize response time on the ESP32 The database is structured as follows:

- **Action**: These include activating the auto or manual control, setting the power limits, enabling the schedules, semaphores for the ESP to get orders, and pre-scheduled times (off-peak, off-night, off-day), etc.
- **Data**: contains measurements and bills
- **app1, app2, and app3**: these nodes contain the starting and ending times of the schedules.
- **stat1, stat2, and stat3**: these nodes, the status of the schedules (enabled or disabled), and the working days of the week, in addition to the default statutes of the appliances
- **setting**: in this section the old and current energy indexes of the bills.
- **status**: this part contains the tariff periods for the tariffs M51, M52, and M53, whether it is on full, peak, day, or night. For the M54 tariff, at which part of the consumption has the user reached (part1, part2, part3, or part4).

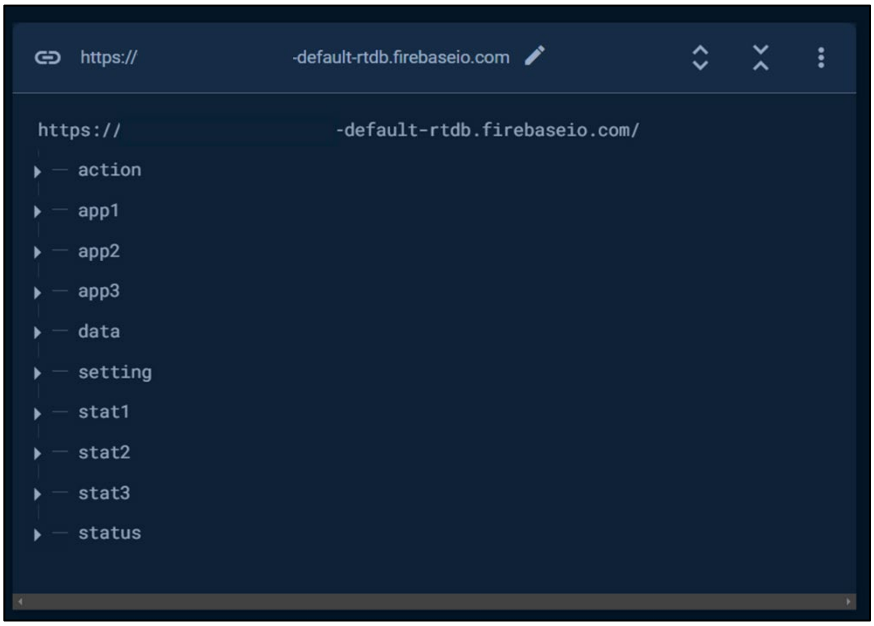

Figure 2.15: Firebase real-time database

2.2.3.3 Data Recording

Energy consumption data are essential for future studies as it helps in determining and analyzing power consumption patterns. To achieve this purpose, a Google Sheets document was created for saving the measurement and bill amounts. Data are sent from the ESP32 to this database every one and a half minutes to this database, using the “HTTPClient” library.

2	date	time	get data	Voltage	Current_total	Power	Power_Load1	Power_Load2	apperent_power	energy	F_M51	F_M52	F_M53	F_M54
4299	25/05/2024	00:38:44	write	234.2	0.23	48.13	50.6	3.98	55.3	0.09	982.77	1524.29	982.77	264.16
4300	25/05/2024	00:40:16	write	233.73	0.24	51.54	51.7	3.47	56.66	0.1	982.77	1524.29	982.77	264.16
4301	25/05/2024	00:41:49	write	233.26	0.23	47.75	49.01	3.91	53.44	0.1	982.78	1524.3	982.78	264.16
4302	25/05/2024	00:43:27	write	233.66	0.28	59.77	62.41	3.66	60.63	0.1	982.78	1524.3	982.78	264.16
4303	25/05/2024	00:44:57	write	233.42	0.23	47.64	48.83	3.69	53.4	0.1	982.78	1524.3	982.78	264.16
4304	25/05/2024	00:46:33	write	233.9	0.22	46.27	46.21	4.53	52.04	0.1	982.78	1524.3	982.78	264.16
4305	25/05/2024	00:48:04	write	233.85	0.22	46.14	47.65	4	59.54	0.1	982.78	1524.31	982.78	264.16
4306	25/05/2024	00:49:42	write	234.01	0.21	43.78	44.01	3.85	49.64	0.1	982.78	1524.31	982.78	264.16
4307	25/05/2024	00:51:22	write	234.18	0.2	42.12	44.76	3.92	48.23	0.1	982.78	1524.31	982.78	264.16
4308	25/05/2024	00:53:00	write	233.84	0.22	46.8	59.97	3.96	52.45	0.1	982.79	1524.31	982.79	264.16
4309	25/05/2024	00:54:40	write	233.92	0.19	39.37	39.24	3.91	44.74	0.11	982.79	1524.32	982.79	264.16
4310	25/05/2024	00:56:19	write	233.71	0.2	42.33	41.32	3.72	47.6	0.11	982.79	1524.32	982.79	264.16
4311	25/05/2024	00:57:59	write	233.89	0.28	60.37	60.9	3.82	66.53	0.11	982.79	1524.32	982.79	264.16
4312	25/05/2024	00:59:39	write	233.68	0.2	40.81	40.44	4.12	51.78	0.11	982.79	1524.32	982.79	264.16
4313	25/05/2024	01:01:10	write	233.67	0.21	44.17	45.67	4.1	46.93	0.11	982.79	1524.32	982.79	264.16
4314	25/05/2024	01:02:41	write	233.29	0.21	42.82	42.09	3.5	48.38	0.11	982.79	1524.33	982.79	264.16
4315	25/05/2024	01:04:22	write	233.46	0.26	54.92	45.24	4.14	60.87	0.11	982.8	1524.33	982.8	264.16
4316	25/05/2024	01:05:54	write	234.47	0.23	49.97	52.78	2.85	54.87	0.11	982.8	1524.33	982.8	264.16

Figure 2.16: Energy Tracking Table in Google Sheets for Data Storage

2.2.4 Application Design

2.2.4.1 Home Page

The interface of this system is an application on the user's phone, it displays the bill amounts, measurements (power, voltage, current, power of appliance1 and appliance2), control settings, and the indexes settings. The application’s interface also includes switches for manual control, In the bill section, the tariff type and the bill amount are displayed, along with the current period or part of the tariff and the amount of energy consumed.

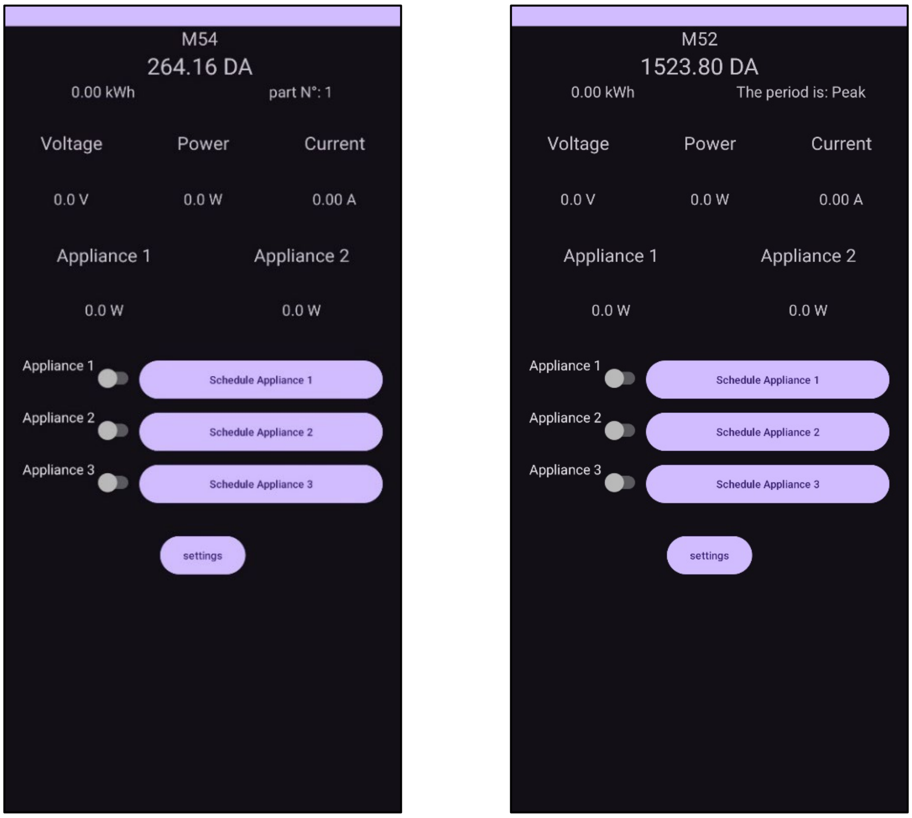

Figure 2.17: Home page

2.2.4.2 Scheduling Page

On the interface of Appliance scheduling, the switch "schedule activation" is responsible for toggling between the auto and manual control. On Appliance 3 the date scheduling was applied instead of the power limit feature, which provides the ability to set the starting and ending date, or just one of them. To enable the schedules for the entire week, the "All week" must be checked, and for specific weekdays, those days have to be checked. The next section is for setting the timing of the schedules. the switches on the right are for activating and deactivating the schedule, the status of the appliance will be the opposite of the default status (e.g. if the default is On, the schedule will turn off the appliance). additionally, the preset times (off-peak, off-day, off-night) checkboxes are below the scheduling or power limit section, for activating the power limit in off-times, the desired power value has to be set in the edit text, and "limit active" must be checked along with the preset times.

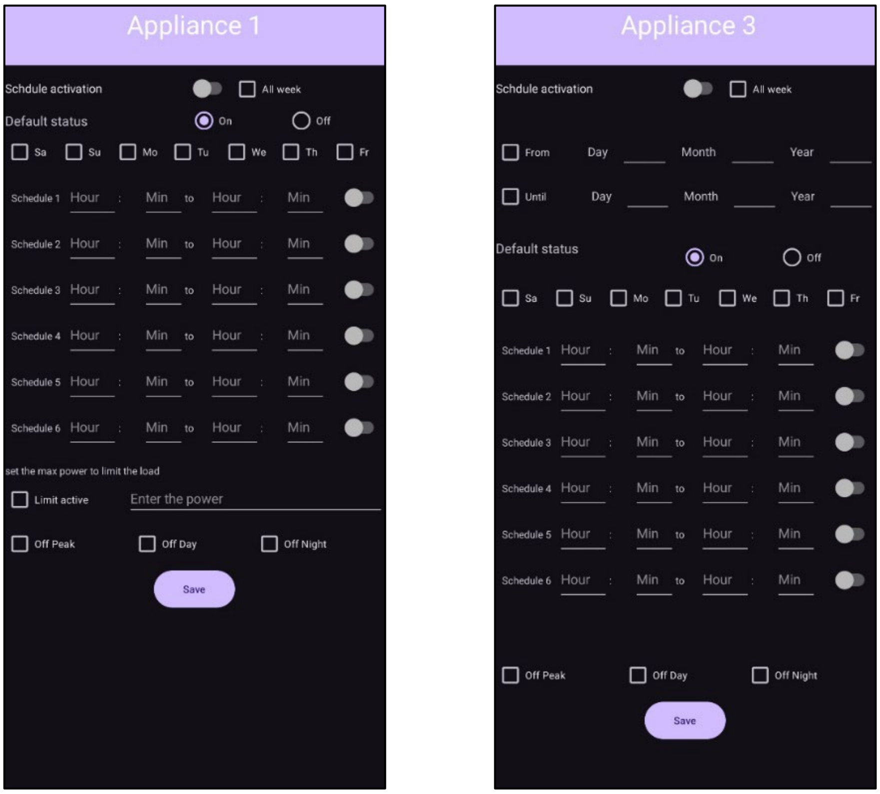

Figure 2.18: Appliances settings page

2.2.4.3 Settings

on the settings interface, the user enters the old and the current index according to the tariff they are using along with the used tariff

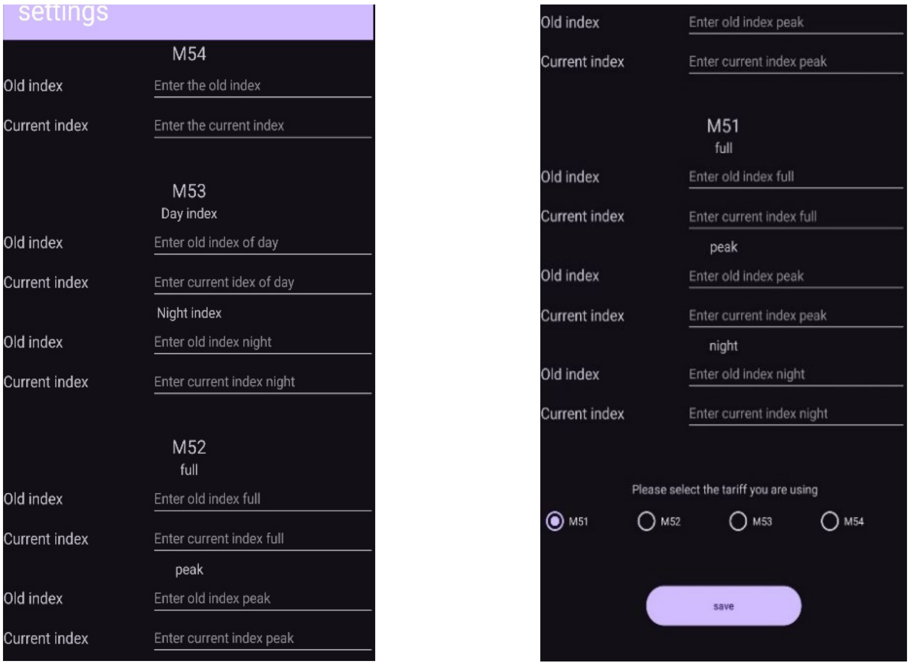

Figure 2.19: Bills settings page

2.3 Conclusion

In conclusion, the energy management system designated here aims to enhance energy efficiency, minimize wastage, and reduce costs while ensuring user comfort and productivity. By adopting techniques such as Direct Load Control (DLC) and Time-Dependent Pricing in Tariff Management, the system provides both manual and automatic remote control of electrical loads. Through accurate measurements of current and voltage, it provides users with comprehensive data on their energy consumption, which can be used to calculate electricity bills according to various tariffs.

The system also protects devices from malfunctions and offers a user interface via a smartphone application, enabling users to schedule their appliances to turn on or off automatically. This functionality helps in reducing overall energy consumption, preventing power outages due to excessive usage, and ultimately lowering electricity bills. The integration with a real-time database ensures efficient communication between the user's application and the ESP32, optimizing response times and maintaining accurate records of energy use for future analysis. By implementing these advanced features, the system supports both individual energy savings and broader energy conservation efforts.

Chapter 03
System implementation

3.1 **Introduction**

Automated control systems significantly contribute to enhancing energy management systems' efficiency, by providing users with comprehensive information on their energy consumption. Besides that, the auto-controlling system empowers the user to fully manage their usage remotely, helping with reducing energy wastage and saving costs, considering the productivity and comfort of the users.

the designed system in this project aims to provide users with real-time information on their energy usage, by monitoring their use, calculating electricity bills with various tariffs, and displaying them on a dedicated application on their phone. This application allows the user to control their appliances remotely, either manually or automatically by setting schedules and power limits. The proposed circuit and its implementation of this system will be provided in this chapter, alongside some improvements that should be considered in future implementations.

3.2 **System Circuit**

Aiming to achieve the proposed system, the following circuit was designed:

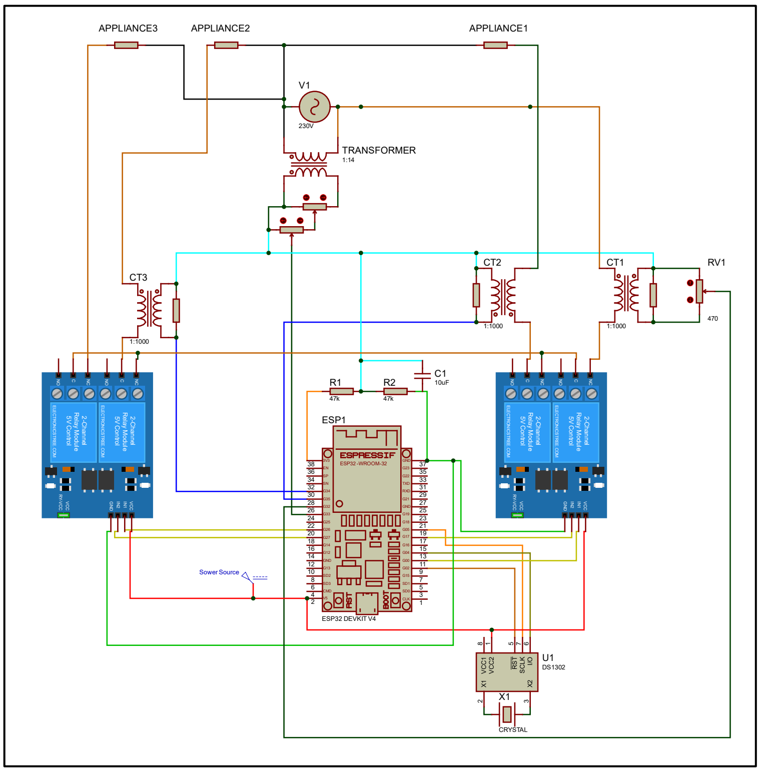

Figure 3.1: The system circuit diagram

The first current transformer (CT1) is used for monitoring the total power consumption of the system, while other current transformers (CT2 and CT3) are for calculating the power of appliances 1 and 2, respectively. Relay 1 is responsible for supplying power to the other relays. The potentiometer (RV1) is used to divide the sensor's signal, instead of changing the sensor's resistor, which expands the current sensor range to 0 to 10 A.

As a power source, a rectifier and voltage regulator were used to obtain 12V DC from the voltage transformer, this 12V is used to charge a battery -to supply the circuit in case the power got shut down- and power a Back converter “LM2596 DC-DC model” to reduce the voltage down to 5V to feed the ESP32 and its attachments.

3.3 System Implementation

The following figure represents the circuit board of the implementation of the previous circuit

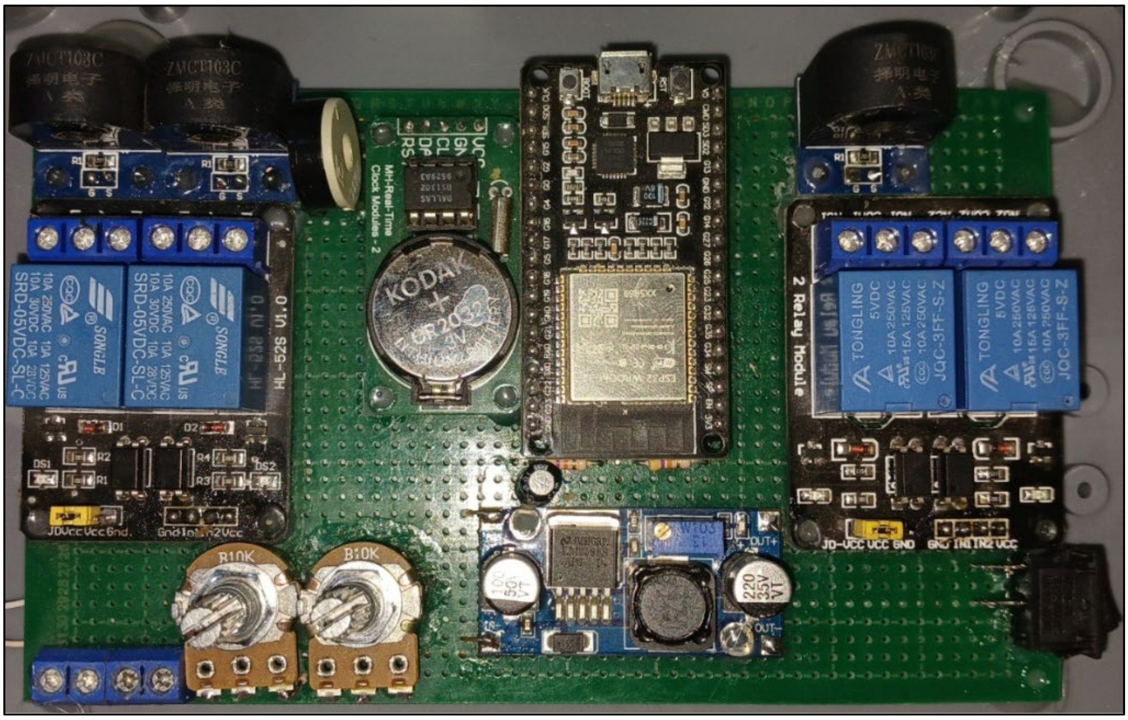

Figure 3.2: The implemented circuit

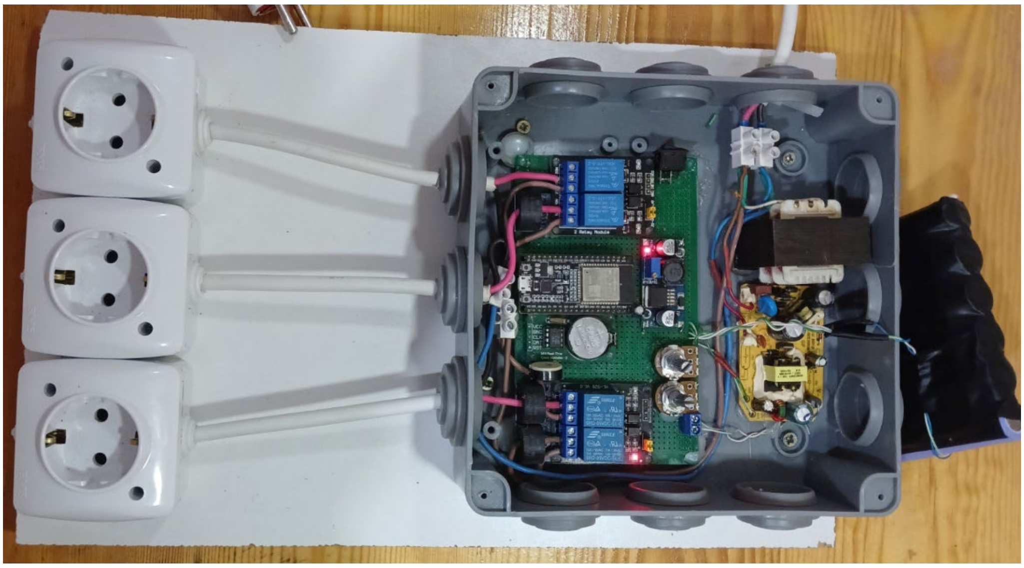

Figure 3. 3: System implementation (prototype)

3.4 Implementation Results

after implementing the system, three sockets were connected to be controlled by the system. The system was fully functional, capable of measuring, sending data to the application through Firebase, recording them in Google Sheets, and receiving data and orders from the application on the user's phone. However, some issues were noted related to measurements, calculation accuracy, and response time.

For testing purposes, a laptop charger was plugged into the first socket for 24 hours, the results were as follows:

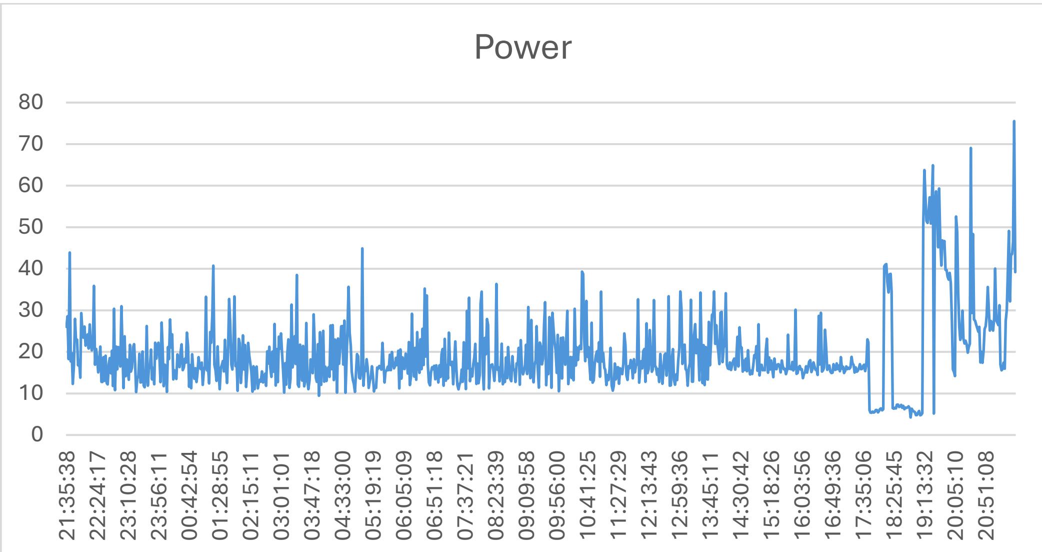

Figure 3.4: The laptop’s power consumption

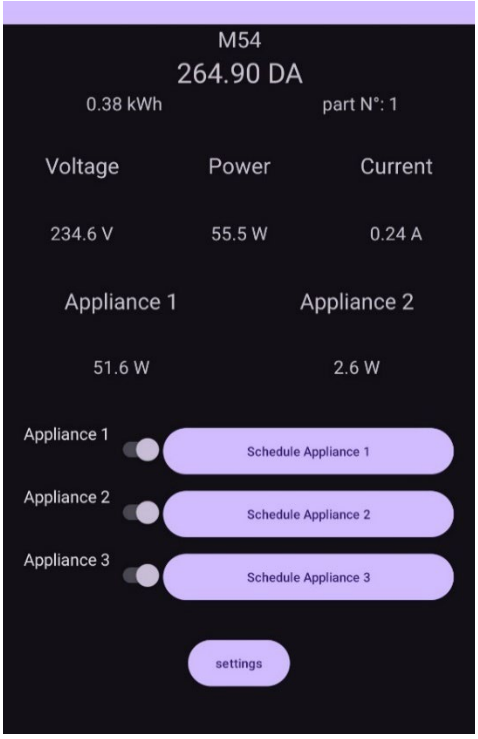

Figure 3.5: The application interface

3.5 System Accuracy

3.5.1 Voltage and Current Readings

For measuring the voltage and the current, the system takes samples of the signal for 15 cycles, resulting in approximately 1140 samples, about 76 samples per cycle. To visualize the waveform of the signal, MATLAB/Simulink software was used to create the following figures:

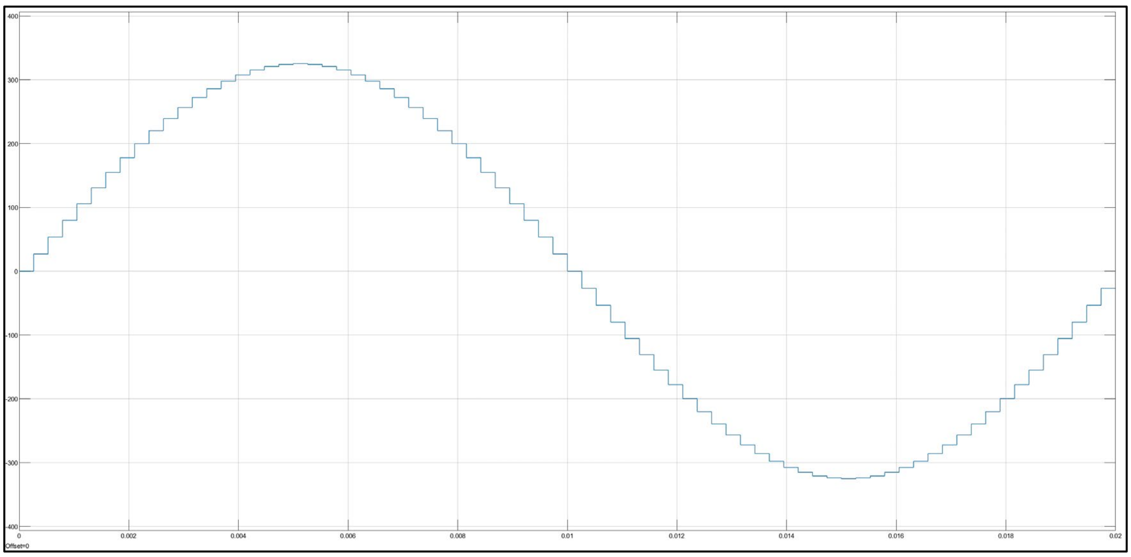

Figure 3.6: A simulation of the voltage signal

The Analog-to-Digital converter (ADC) of the ESP32 has a resolution of 12bit, the accuracy of the reading would be as follows:

- For voltage reading resolution:

$$\frac{2 \times 250\,\sqrt{2} \times 1.285}{2^{12}} = 0.222V$$

- For the current reading resolution at the CT1:

$$\frac{2 \times 10\sqrt{2}}{2^{12}} = 0.007A$$

- For the current reading resolution at CT2 and CT3:

$$\frac{2 \times 5\sqrt{2}}{2^{12}} = 0.00035A$$

The ESP32 (ADC) is sensitive to noise, leading to discrepancies in ADC readings [21], in our case, this affects the readings only when there is no appliance plugged in, as a primary solution, a threshold was set at 0.045A, 5W for the total power consumption, and 2W for the appliances. The load power will not be counted if it is less than the thresholds.

External ADCs can be used to provide more accurate measurements, especially when high-range current transformers such as 30A are used for large loads. using high-resolution and frequency 16bit ADC would enhance the voltage and current reading resolution to be 0.014V and 0.0013A respectively.

Note: determining the resolution of the measurements is also related to the ADC speed. Due to the ADC limitation at 3.8 kHz, the voltage readings are 26.8V at maximum and 1.1V at the minimum per step. This range is influenced by the changing speed and amplitude of the measured signal.

To enhance signal readings, the average value of the reference voltage was measured using pin GPIO39 to calculate the input range of the signal since the reference voltage (V_{ref}) is used for lifting the signal.

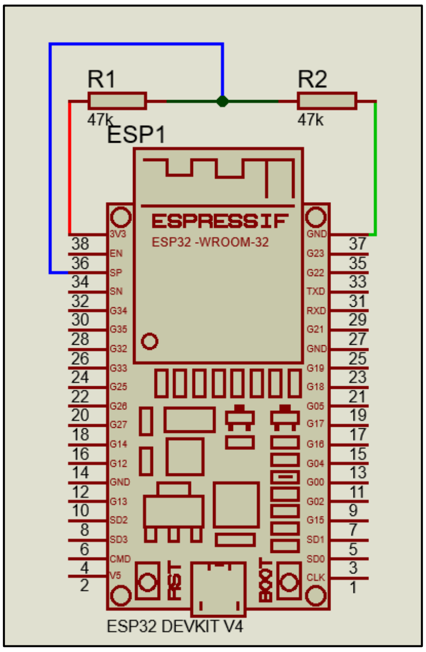

Figure 3.7: Reference voltage reading circuit

The instantaneous value of the voltage and the current will be as follows:

$$inst\ voltage = map\left(voltage\ pin\ ,0, 2 \times V_{ref}, -250 \times \sqrt{2} \times 1.286, 250 \times \sqrt{2} \times 1.286\right)$$

$$inst\ current = map\left(current\ \ pin\ ,0, 2 \times V_{ref}, -5 \times \sqrt{2}, 5 \times \sqrt{2}\right)$$

3.5.2 Energy Calculation

The accuracy of Energy calculation depends on the precise timing. The method used by the system involves adding the real power value to the energy value when one second has passed, the issue is that the period must be exactly one second, which cannot always be guaranteed, as a solution, a correction factor was introduced to handle this issue, this factor calculates the period of 1 cycle of the program (from the end of energy calculation until it starts again). After implementing this method, the energy calculation was adjusted by the correction factor of 1.3. The algorithm for calculating the factor is as follows:

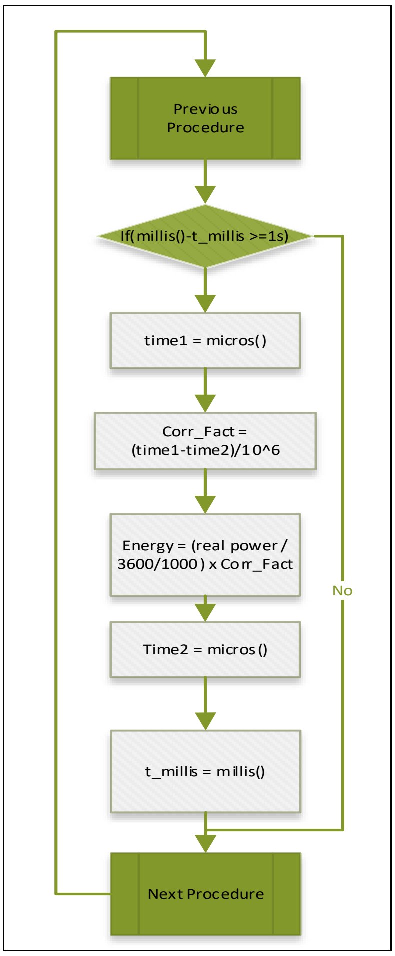

Figure 3.8: Energy calculation with correction factor algorithm

3.5.3 System Response Time

Sending and receiving data to Firebase requires a considerable amount of time, for manual control, the required time is about 5 to 20s, and for receiving schedules or setting data, the response time can reach up to one minute. These delays can result in triggering the watchdog timer of the possessor, causing the system to freeze and restart. we disabled the watchdog of Core 0 to prevent the system from malfunctions.

3.6 App Using

3.6.1 Home Screen

When you open the app, you will see a glance of everything you need to see (see fig3.8). The home screen shows the current electricity bill amount (1), You can see the amount of energy consumed in this quarter (2) and the tranche in which the bill is in (3), along with real-time measurements such as power usage, voltage, and current (4), in addition to the power utilization of specific appliances like Appliance 1 and Appliance 2 (5). The home screen also contains quick-access switches for turning on and off the appliances (6).

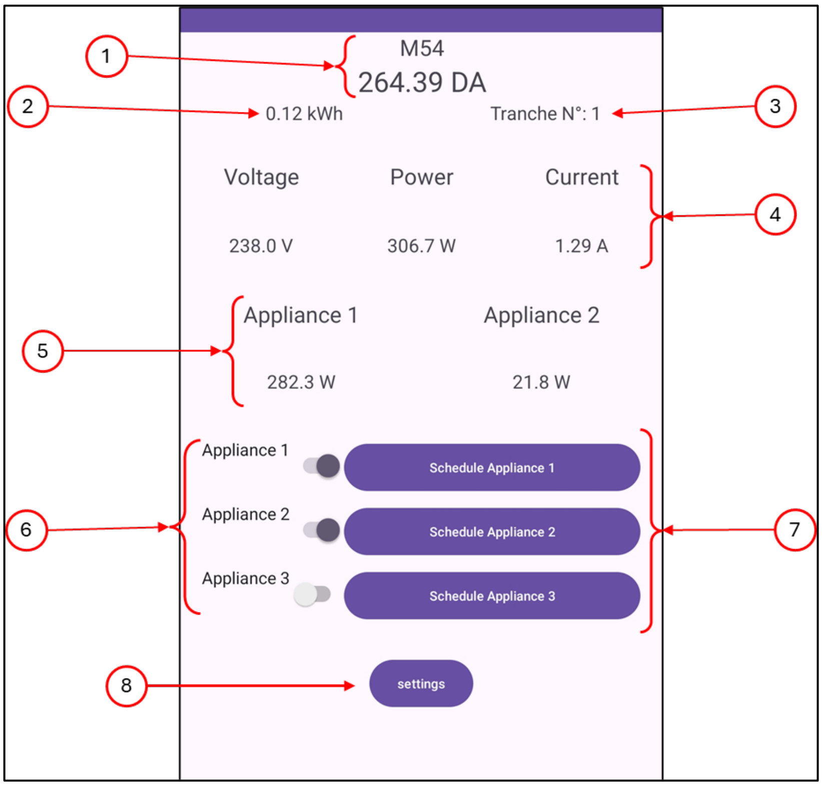

Figure 3.9: Home screen of the application

3.6.2 **Appliances Scheduling**

On the home screen, each appliance on the home screen has a scheduling button (see (7) figure 3.8), and clicking on it, takes you to the schedule page. The appliances' scheduling page lets you switch between automatic and manual control, if you want to activate automatic control, you just toggle the switch (1), and the appliance will behave as it is programmed, else it will return to its default status (on/off) which you define (3). If you need to set up the working days of the schedule, simply select individual weekdays (4) or check the "All Week" box (2). The app also let you define the timing of the schedules (5), and activate or deactivate them with a tap (6). (the system will change the appliance status to opposite to its default status). In addition to that, the app offers you pre-set options (9) for off-peak, off-day, and off-night. You can even set power limits during these off-times, simply enter your desired value (7) and activate the "limit active" option (8) along with the chosen pre-set time.

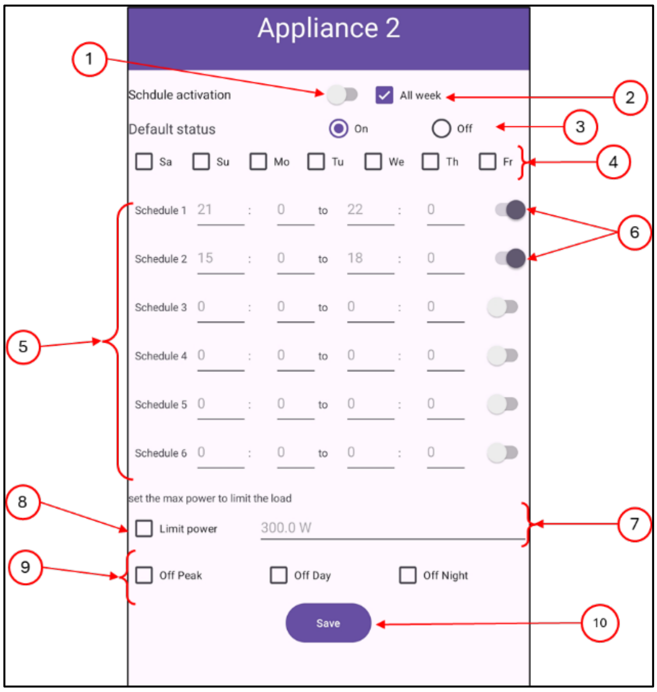

Figure 3.10: Appliance 1,2 scheduling screen

For appliance 3, the power limit option is exchanged by setting a specific date range for operation (7), you can set the starting date and the ending date or only one of the options (8).

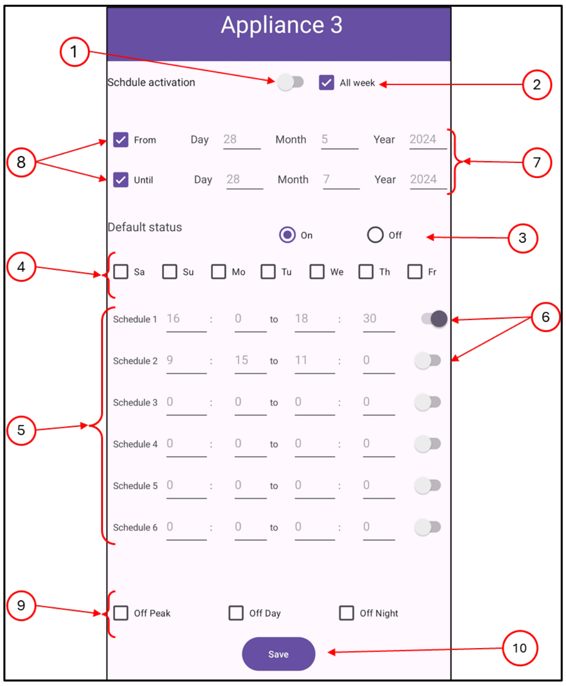

Figure 3.11: Appliance 3 scheduling screen

3.6.3 Setting

When you install this device for the first time or enter a new quarter, this section is for entering the current index from the utility's meter and the old index from the last bill (1) (see figure 2.17), this way ensures the current bill amount is provided on your phone.

الفترة : الثلاثي الثاني 2024

Vos contrats عقودكم

	رقم العداد N° Compteur	تعريفة Tarif	إستطاعة PMD	المعامل Coef	البيان السابق A. index	البيان الجديد N. index
الكهرباء Electricité		54M	20kW	1.0	58 702 R	60 208 R

		الشطر 1 Tranche 1	الشطر 2 Tranche 2	الشطر 3 Tranche 3	الشطر 4 Tranche 4
N° Compteur/ رقم العداد					
Quantité / الكمية		125,00	125,00	750,00	506,00
Prix unitaire/ ثمن الوحدة		1,7787	4,1789	4,8120	5,4796

Montant HT (9%) 744,70 المبلغ د.ر (9%)

Montant HT (19%) 6 381,68 المبلغ د.ر (19%)

	رقم العداد N° Compteur	تعريفة Tarif	التدفق DMD	المعامل PCS	البيان السابق A. index	البيان الجديد N. index
الغاز Gaz		23M	$5m^3h$	9.23	6 313 R	6 535 R

	الشطر 1 Tranche 1	الشطر 2 Tranche 2	الشطر 3 Tranche 3	الشطر 4 Tranche 4
N° Compteur/ رقم العداد				
Quantité / الكمية	1 125,00	924,06	0,00	0,00

Figure 3.12: The old index in the last bill

3.7 Implementation in Real World

The core of the system is the smart meter, which is a control unit installed in the power distribution box, at the source line directly after the utility company's meter. This device measures and monitors the user’s power consumption, protecting their appliances. The user downloads the system's app from the website, the user registers in the app, and then scans the QR code on the device to connect to its Wi-Fi to set their router information to connect it to the internet, along with linking the serial number of the device with the user’s profile.

The system offers two additional devices for the user to control their appliances: Smart Sockets and Smart Switches, which connect wirelessly to the control unit. To add a new accessory to the system, the user should synchronously press the connection button on both the accessory and the smart meter; after adding the accessory, it should appear automatically in the application.

The Smart Socket monitors the power consumption of appliances and controls their state (on/off) according to the user's preferences or conditions. It also provides protection and detects unusual behavior. In contrast, Smart Switches are used to control appliances like refrigerators and lights that do not require power monitoring.

3.8 Conclusion

The implemented automated control system enhances energy management by providing real-time information on energy consumption, allowing users to monitor their power consumption, calculate electricity bills with various tariffs, and control appliances remotely via a dedicated phone application. The system employs current transformers to monitor total and individual appliance power consumption and includes a power supply setup to ensure continuous operation during outages. Despite its successful implementation, measurement accuracy and response time issues were noted, and mitigated by setting thresholds and using a correction factor for precise energy calculations.

Challenges remain, such as the ESP32's ADC sensitivity to noise and delays in data transmission to Firebase. These issues were partially addressed by using thresholds and disabling the watchdog timer on Core 0. Future improvements include using external ADCs for more accurate measurements and optimizing the system's response time. Overall, the system offers a practical solution for real-time energy management with identified areas for enhancement.

General conclusion

General conclusion

In conclusion, the growing concern of rising energy consumption was addressed by proposing an auto-control system for energy consumption utilizing Internet of Things (IoT) technology. The system, built upon the ESP32 microcontroller, tackles this challenge by offering real-time energy consumption monitoring, cost calculations based on variable residential tariffs in Algeria, and remote appliance control capabilities (both manual and automated). This empowers users with informed decision-making, fosters energy-efficient practices, and ultimately contributes to mitigating the escalation in global energy demands.

This thesis explored the subject in three chapters:

The first chapter delved into the theoretical foundations of energy management, outlining its objectives, advantages, and established techniques.

The second chapter meticulously detailed the proposed system design, encompassing its components, measurement and control functionalities, communication protocols, application interface, and data recording methods.

Finally, chapter 3 presented the practical realization of the system circuit, along with its performance evaluation. This evaluation included assessments of measurement and energy calculation accuracy, incorporating discussions on potential correction factors for enhanced precision.

By implementing this auto-control system for energy consumption, this thesis proposes a solution with the potential to empower individuals and contribute to a more sustainable energy future.

Future research directions could explore advancements in data analysis for personalized recommendations using AI technology, and integration with smart grids for a more comprehensive energy management approach.

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Annexes

الجمهورية الجزائرية الديمقراطية الشعبية
République Algérienne Démocratique et Populaire
وزارة التعليم العالي والبحث العلمي
Ministère de l'Enseignement Supérieur Et de La Recherche Scientifique
جامعة غرداية

Faculté des sciences et Technologies
Département d'automatique et d'électromécanique

كلية العلوم والتكنولوجيا
قسم الآلية والكهروميكانيك

Université de Ghardaia

غرداية في: 09/05/2024

إذن بالطباعة (مذكرة ماستر)

بعد الاطلاع على التصحيحات المطلوبة على محتوى المذكرة المنجزة من طرف الطلبة التالية أسماؤهم:

الطالب (ة): سيفي محمد

الطالب (ة): أهوبابه حمزة

تخصص: طاقات متجددة في الكهروتقني

تمنح محل الاسناد (ة)

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		مصحح (2)	
خطارة عبد الوهاب	أستاذ محاضر أ	مؤطر	
حزاوي محمد	أستاذ محاضر ب	رئيس اللجنة	

الإذن بطباعة النسخة النهائية لمذكرة ماستر الموسومة بعنوان

Design and implementation of an auto control system for energy consumption

إمضاء رئيس القسم

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