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Science and Technology Faculty

Electrical Engineering Department



MASTER THESIS

Sciences and Technologies

Electrotechnics

Electrical Network

Ref:

Presented and supported by:

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Realization of a multifunctional smart energy meter

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ملخص

يأتي هذا العمل في إطار تصميم وتنفيذ عداد ذكي متعدد الوظائف يهدف إلى مراقبة استهلاك الكهرباء والمياه في الوقت الحقيقي داخل المنزل، مع دمج نظام للكشف عن تسربات الغاز. يعتمد النظام على لوحة ESP32 والعديد من المستشعرات المتخصصة (الجهد، التيار، تدفق المياه، الغاز) التي تسمح بقياس الكميات الفيزيائية الأساسية بدقة. تُعرض البيانات التي تم جمعها محلياً على شاشة LCD وتُنقل عن بُعد عبر تطبيق Blynk المحمول، مما يسمح بالمراقبة المستمرة من خلال الهاتف الذكي. يتم أيضاً توليد تنبيهات في حالة حدوث حالة حرجة، وخاصة في حالة وجود تسرب للغاز، مما يؤدي تلقائياً إلى إيقاف تشغيل النظام. يشمل المشروع مرحلة دراسة نظرية، وتصميم مادي وبرمجي، بالإضافة إلى تنفيذ عملي كامل. يقترح هذا النظام حلاً متصلاً واقتصادياً وقابلاً للتطوير لتحسين الكفاءة الطاقية، وتعزيز الأمان المنزلي، وزيادة وعي المستخدمين بالاستهلاك المسؤول للموارد.

الكلمات المفتاحية

عداد ذكي، المراقبة عن بُعد، استهلاك الكهرباء والمياه، كشف تسربات الغاز، تنبيهات الأمان، تطبيق الهاتف المحمول

Abstract

This work is part of the design and implementation of a multifunctional smart meter intended to monitor real-time electricity and water consumption in a household, while also integrating a gas leak detection system. The system is based on an ESP32 board and several specialized sensors (voltage, current, water flow, gas) that allow for precise measurement of essential physical quantities. The collected data is displayed locally on an LCD screen and transmitted remotely via the Blynk mobile application, allowing for continuous monitoring from a smartphone. Alerts are also generated in case of a critical situation, particularly in the presence of a gas leak, automatically triggering the shutdown of the installation. The project includes a phase of theoretical study, hardware and software design, as well as complete practical implementation. This system thus offers a connected, economical, and scalable solution to improve energy efficiency, enhance home security, and raise user awareness of responsible resource consumption.

Keywords:

Smart meter, Remote monitoring, Electric and water consumption, Gas leak detection, Security alerts, Mobile application.

Résumé

Ce travail s'inscrit dans le cadre de la conception et de la réalisation d'un compteur intelligent multifonctionnel destiné à surveiller en temps réel la consommation électrique et hydrique dans une habitation, tout en intégrant un système de détection des fuites de gaz. Le système repose sur une carte ESP32 et plusieurs capteurs spécialisés (tension, courant, débit d'eau, gaz) permettant de mesurer avec précision les grandeurs physiques essentielles. Les données collectées sont affichées localement sur un écran LCD et transmises à distance via l'application mobile Blynk, permettant une supervision continue à partir d'un smartphone. Des alertes sont également générées en cas de situation critique, notamment en présence d'une fuite de gaz, déclenchant automatiquement la mise hors tension de l'installation. Le projet inclut une phase d'étude théorique, de conception matérielle et logicielle ainsi qu'une réalisation pratique complète. Ce système propose ainsi une solution connectée, économique et évolutive pour améliorer l'efficacité énergétique, renforcer la sécurité domestique et sensibiliser les utilisateurs à une consommation responsable des ressources.

Mots Clés :

Compteur intelligent, Supervision à distance, Consommation électrique et hydrique, Détection de fuites de gaz, Alertes de sécurité, Application mobile.

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*Our warmest thanks also go to the people dearest to us, **our parents**, who have played a vital and continuous role in our success.*

*Finally, we cannot conclude these acknowledgements without turning to our **friends**, whose moral support was invaluable during the preparation of this thesis.*

ABDI Abderrahmane

BAARIR Mustafa Siraj Eddine

Dedication

*I dedicate this humble work to the memory of my paternal uncle **Mohamed Lamine**, his wife **Malika**, and my paternal grandparents.*

*It is with great pleasure and deep joy that I dedicate this work to my dear **father**, a symbol of respect and wisdom, as a token of my profound gratitude for his constant support and tireless efforts throughout my journey.*

*To my **mother**, a source of love, courage, inspiration, and trust.*

*To my brothers **Ishak** and **Nidhal**, who have been my first pillar of strength, always there to support me,*

*To my sisters **Arij** and **Ritaj**, who have brought beauty and tenderness into our home, To my **maternal grandparents**.*

*To my **uncles**, **aunts** and **cousine** especially to my big brother **Mohamed taissir** may God protect them.*

*To **all my friends**, and especially to my dear friends **Zaki Aiche** and **Chathouna Takj Eddine**, who were my main support throughout my university journey. They were like teachers to me, helping me with my studies, exams, and assignments. I sincerely thank them for all these years of friendship and support.*

*And not to forget my project partner **Abdi Abderrahmane**, for his constant moral support throughout this project.*

BAARIQ Mustafa Siraj Eddine

Dedication

*With great pleasure and immense joy, I dedicate my work to My dear father **Djouidi**, a source of respect, as a token of my deep gratitude for the effort and unwavering support he has always given me.*

*To my beloved mother **Louiza** the heart of our family, whose endless affection, strength, and inspiration have been my greatest motivation throughout this journey. Her sacrifices and unconditional love have shaped the person I am today.*

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Abbreviation list

ADC: Analog-to-Digital Converter.....	6
GPRS: General Packet Radio Service.....	7
PLC: Power Line Communication.....	7
GSM: Global System for Mobile Communications.....	8
IoT: Internet of Things.....	8
MV: Medium Voltage.....	10
LV: Low Voltage.....	10
DR: Direction Régionale.....	11
RCN: Réseau de Consommation Nationale (National Consumption Network).....	11
UART: Universal Asynchronous Receiver-Transmitter.....	35
BLE: bluetooth low energy.....	35
DAC: Digital-to-Analog Converter.....	35
GPIO: general purpose input/output.....	35
I2C: Inter-Integrated Circuit.....	35
PWM: Pulse Width Modulation.....	35
SPI: Serial Peripheral Interface.....	35
SoC: system on chip.....	35
AES: Advanced Encryption Standard.....	37
MCU: Microcontroller Unit.....	37
SHA: Secure Hash Algorithm.....	37
RSA: Rivest–Shamir–Adleman (encryption algorithm).....	37
TTL: Transistor-Transistor Logic.....	44
LCD: Liquid Crystal Display.....	48
SCL: Serial Clock Line.....	49
SDA: Serial Data Line.....	49
SSR: Solid State Relay.....	51
SPDT: Single Pole Double Throw.....	51
PCB: Printed Circuit Board.....	53
IDE: Integrated Development Environment.....	55
SDK: Software Development Kit.....	59
PMD: Puissance Maximale Disponible (Available Maximum Power).....	64
DGD: Décompte Général Définitif (Final General Statement).....	64

General introduction

General introduction

In a context characterized by the continuous growth in energy demand, the depletion of natural resources, and the increasing domestic risks associated with technical installations, the efficient management of energy and the safety of residential environments have become critical challenges. In response to these issues, emerging technologies offer innovative solutions that not only enable real-time monitoring of energy consumption but also enhance user comfort and safety.

It is within this framework that our project has been developed. The objective is to design and implement a multifunctional smart meter capable of monitoring both electrical and water consumption, as well as detecting gas leaks. The primary goal is to develop a connected, autonomous, and responsive system that can collect and display data in real time, while also issuing alerts in the event of critical situations.

The execution of this project followed several key stages: a theoretical study, the design of the electronic schematic, component wiring, programming of the ESP32 microcontroller, and the practical implementation of the prototype. This project addresses two main requirements: the control of energy and water consumption, and the enhancement of household safety through the development of an integrated, cost-effective, and scalable solution.

To better contextualize our work, this thesis is structured into three chapters:

- **Chapter One** is devoted to general concepts related to electricity and water meters, including billing and tariff systems. It lays the theoretical foundations necessary for understanding metering systems.
- **Chapter Two** discusses the hardware and software design of the project, detailing the technical choices and components utilized.
- **Chapter Three** focuses on the practical implementation of the smart meter, highlighting system integration, testing procedures, and particularly the communication protocol between the meter and a smartphone, which enables real-time remote monitoring.

In an era of increasing resource consumption and persistent domestic risks, the adoption of connected, responsive, and accessible solutions has become essential. The multifunctional smart meter developed in this study addresses these pressing needs by offering a comprehensive

platform for monitoring, control, and protection, tailored to the requirements of modern households.

This study concludes with a general summary of the work carried out, a presentation of the results obtained, and potential avenues for improvement or future development of the system.

Chapter 1:
General Overview of
smart Energy Meters

I. Introduction

Previously, electricity and water consumption were measured using mechanical or electromechanical meters, these devices have several limitations. In this context, the shift towards smart meters marks a true technological revolution. These new devices provide both network managers and consumers with advanced tools to monitor, analyze, and optimize energy and water usage.

In this chapter, we will explore a state-of-the-art overview of electricity and water meters in general, their characteristics, operating principles, and their tariff systems.

Part 1: General Concept of the Electric Meter

1.1. Electric Meter

The electric meter is an electrotechnical device designed to measure the electrical energy consumed, expressed in kilowatt-hours (kWh). Integrated directly into the electrical circuit, it records the amount of electricity used, whether in a residential, commercial, or industrial setting. This device allows the energy provider to accurately quantify the customer's consumption for the purpose of generating the corresponding bill. [1]

1.2. History

1.2.1 Development of Electrical Energy Meters

The evolution of the electric meter is part of a rich technical history, marked by significant advances that reflect the progressive development of electrical grids and measurement technologies. From the rudimentary beginnings of electrification in the late 19th century to modern smart systems, this device has undergone several key stages. Each generation of meter has accompanied the growing needs for precision, automation, and energy management, contributing to better control of consumption and constant adaptation to the requirements of users and energy providers. Below is a concise timeline highlighting the most important advancements: [1]

- In 1872, Samuel Gardiner filed the first known patent for an electric meter. It was a DC lamp-hour meter, which was essentially a clock with an electromagnet that started and stopped the mechanism.[2]



Figure 1. 1 First innovation of the electric meter [2]

- **In 1878, Jim. B. Fuller** files a patent for an AC lamp hour meter which is a clock operated by a vibrating armature between two coils.

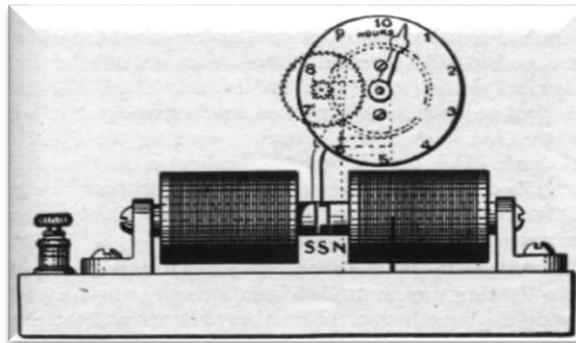


Figure 1. 2 AC lamp-hour [2]

- **In 1894, Oliver Shallenberger** patented the first practical induction watt-hour meter. This model has become standard for AC power measurement.

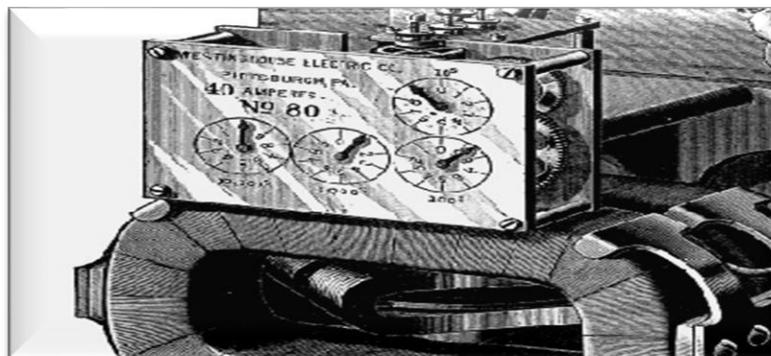


Figure 1. 3 Oliver Shallenberger Induction Meter [2]

- **In 1938, Harold Stephen Black** developed the first electronic meter, known as the Electronic Demand Register (EDR). It marked the beginning of the transition from electromechanical to electronic meters in the 1980s and 1990s. In the mid-1980s, manufacturers offered hybrid meters with electronic registers mounted on induction meters.[3]



Figure 1. 4 electronic meter [3]

1.3. Types of energy meters

1.3.1. Electromechanical meters

Electromechanical meters are the oldest and most traditional meters installed thanks to its high quality, robustness and ease of use. This is the first generation of installed meters and they use a mechanical metering device to display a single consumption index which is energy. [1]



Figure 1. 5 Electromechanical meter [1][5]

1.3.1.1. Operating Principle

The essential and main components of the meter are visible through the transparent cover, namely:

- (A) The "Current" inductor, consisting of a few turns of thick wire. [1][3]
- (B) The "Voltage" inductor, consisting of a coil with many turns of thin wire.
- (C) The aluminum disk, which acts as the rotor.
- (D) The braking magnet.
- (E) The energy totalizer, made up of a set of gears that drives a display device.

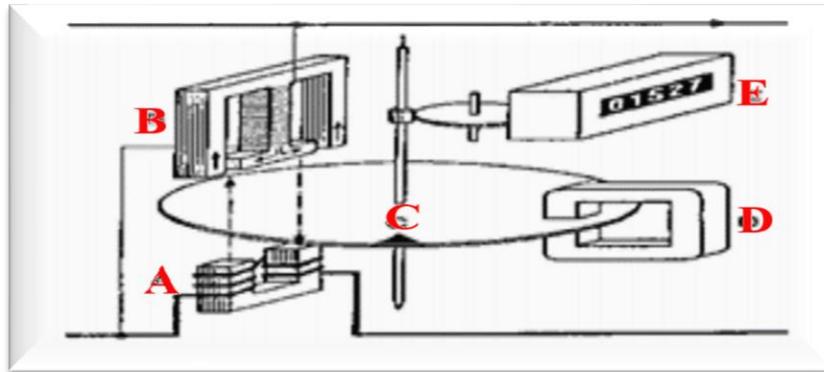


Figure 1. 6 Electromechanical Meter Operating Principle [3]

The function of the electromechanical meter is to calculate the amount of electricity consumed by a location powered by this energy source. It is a box with a handle on its side, and it is mounted on the wall using three attachment points. It is equipped with a mechanical scrolling index. This index includes [3]:

- 5 digits
- A serial number (delivery point), which corresponds to the last three digits and is provided when subscribing to a service. This number helps distinguish the meter when it is in the same place as those of neighbors.
- A rotating aluminum disk provides a real-time visualization of the household's consumption.

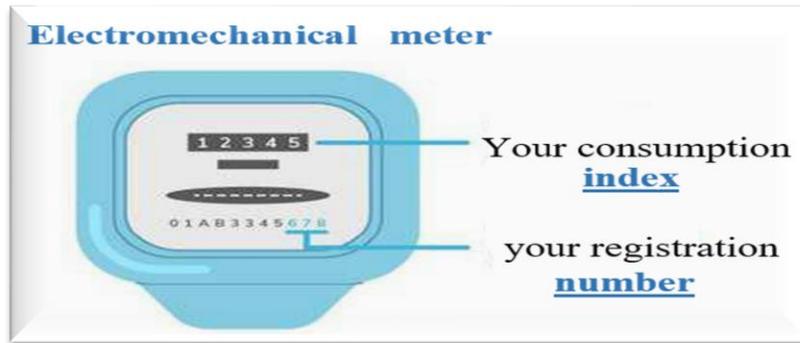


Figure 1. 7 Electromechanical meter index [1]

1.3.2. Electronic meter (digital)

An electronic meter is a digital device used to measure, record and display electricity consumption in homes, businesses, or industrial facilities. Unlike electromechanical meters, which rely on physical mechanisms, electronic meters use integrated circuits and sensors to collect and process energy consumption data.[3]



Figure 1. 8 Electronic watthour meter [1]

1.3.2.1. Operating Principle

The electronic meter measures electrical energy consumption **in real time** through **electronic components** instead of a mechanical system. Its operation is based on several steps:

- ***Current and voltage measurement:*** The meter senses instantaneous values of current (I) and voltage (U) via internal current and voltage sensors.
- ***Analog-to-digital conversion (ADC):*** This makes it possible to transform electrical signals into usable digital data.

- **Power and energy calculation:** A microcontroller or signal processor calculates the instantaneous power, then adds this power over time to obtain the **energy consumed (in kWh)**.
- $P=U \times I \times \cos(\varphi)$ (1)



Figure 1. 9 Electronic meter index [3]

1.3.3. Smart meter

A **smart meter** (also called a **communicating meter**) presents a new generation of meters that is characterized by advanced communication technologies that measure the power consumption of a building, a company or a household in a detailed and accurate way in real time and **automatically communicate** this data to the energy supplier via a communication network (GPRS, PLC, radio, etc.).[4]

1.3.3.1. Operating Principle

- **Real-time measurement:** The smart meter uses sensors to measure energy consumption (current, voltage, active power, etc.) in real time.
- **Data processing:** An integrated microprocessor analyzes the data to calculate total consumption and provides detailed information on energy use at various times (off-peak hours, peak hours, etc.).
- **Local display:** Information is displayed on a digital display built into the meter or on an associated device (e.g., tablet or smartphone).[1][5]

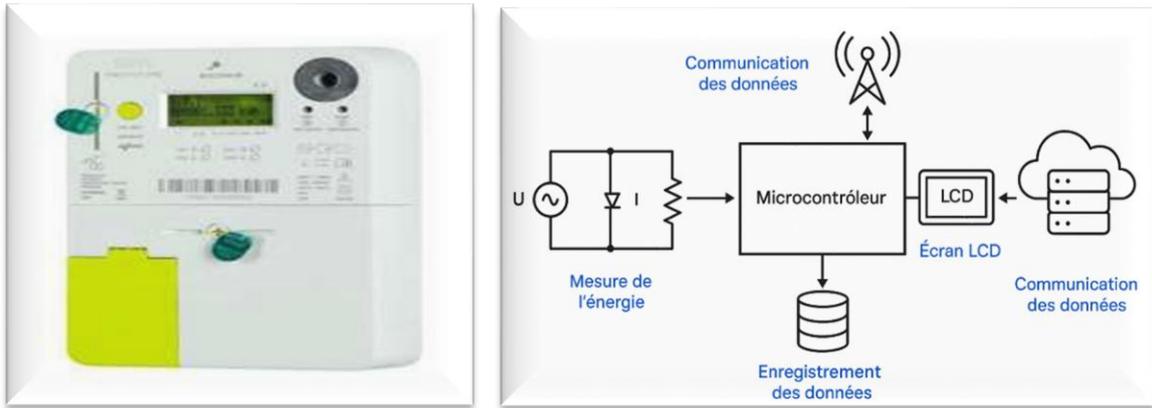
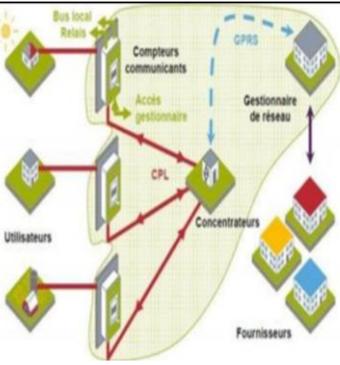


Figure 1. 10 Principle of operation of a smart meter [5]

1.3.3.2. Different Types of Existing Smart Meters

Table 1. 1 Types of Existing Smart Meters

<i>Type of meter</i>	<i>Operating principle</i>	<i>Drawing</i>
<p>The Smart Energy Meter « CPL »</p> 	<p>*Data transmission via existing electrical cables, using power line communication technology. [5] *It provides automatic remote reading, accurate billing, and real-time consumption monitoring.</p>	
<p>Smart energy meter with "GSM" module</p> 	<p>*Use of the mobile phone network to transmit data to the supplier. [1] *It provides reliable communication. *Ideal for areas without power line communication infrastructure.</p>	
<p>Energy meter "IoT"</p>	<p>*Connected meter using IoT communication networks to transmit data to cloud platforms. *It offers extremely low power consumption. *Ideal for rural areas.</p>	<p>1-phase Multi-Function IoT APP/WEB 4G/WiFi/RS485</p> 

I.4. Difference between traditional and smart electricity meter

Table 1. 2 Difference between traditional and smart electricity meter [3]

Criterion	Traditional meter	Smart Meter
Technology	<i>Mechanical/Electromechanical</i>	<i>Digital electronics</i>
Accuracy	<i>Limited</i>	<i>Very Fine</i>
Communication	<i>None</i>	<i>bidirectional</i>
Real Time Monitoring	<i>No</i>	<i>Yes</i>
Invoicing	<i>Based on manual estimates/readings</i>	<i>Based on actual consumption</i>
Renewable compatibility	<i>No</i>	<i>Yes</i>
Initial cost	<i>Low</i>	<i>High</i>

I.5. Impact of smart electricity meters on consumption

Smart electricity meters have a significant and positive impact on consumption, preliminary estimates based on similar projects indicate:[5]

- A study carried out in several countries (e.g. the United Kingdom and the United States) showed that the simple availability of real-time information can reduce electricity consumption by 5% to 15%.
- Expected average reduction in residential consumption in Algeria of 8-12% in the early years.
- Decrease in commercial and technical losses estimated at 15-20% in well-equipped areas.
- Potential invoice savings

I.6. Advantages and disadvantages of each type of electric meter

Table 1. 3 Advantages and disadvantages of electricity meters [1][5]

Type of meter	Advantages	Disadvantages
Electromechanical meter	<ul style="list-style-type: none"> *Operational simplicity *Long-term reliability *Resistance to overvoltage *No risk of remote hacking 	<ul style="list-style-type: none"> *Limited accuracy *No remote reading *Lack of advanced features *No anomaly detection
Electronic meter	<ul style="list-style-type: none"> *Increased accuracy *Multifunctionality 	<ul style="list-style-type: none"> *High initial cost *Technical complexity *Vulnerability to

	<i>*Digital display</i> <i>*Reduction of human errors</i>	<i>interference</i> <i>*Dependence on power supply</i>
Smart meter	<i>*Accurate consumption tracking</i> <i>*Precise billing</i> <i>*No manual readings</i> <i>*Optimization of network management</i> <i>*Reduction of operational costs</i>	<i>*High initial cost</i> <i>*Vulnerability to cyberattacks</i> <i>*Maintenance and updates</i>

I.7. SONELGAZ pricing system

I.7.1. Agreement procedure (customer – SONELGAZ)

Customers requesting a new electricity connection, low voltage (LV) or medium voltage (MV), must follow a specific procedure. For (LV) connections **of less than 25 meters**, considered simple, the local agency takes care of all the steps using a study sheet. On the other hand, if the distance **exceeds 25 meters**, this is considered a network extension, and the file is transferred to the regional management (DR). In this case, the customer must provide a complete file containing the required documents:[4]

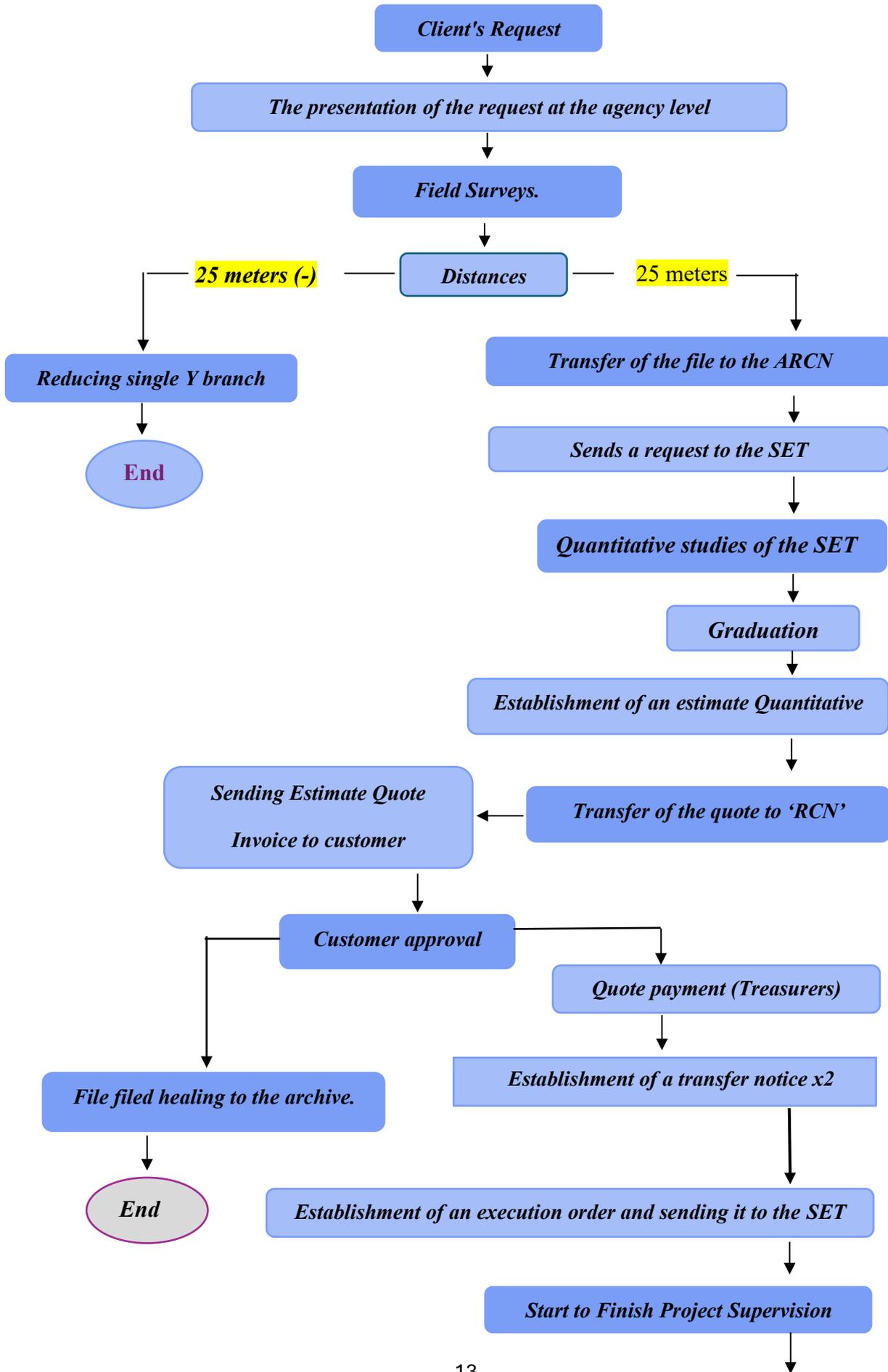
- Electrical energy supply
- Copy of ID card,
- their neighbor’s hand.

After the completion of the study of the file, and the commissioning of the subscriber's meter, the RCN service transmits a complete file to the customer service, to integrate the latter, and to monitor their consumption. For the file to be accessible, it must contain:

- Information sheet
- An Explanatory Subscription Agreement between SONELGAZ and the Subscriber.
- An Advance on consumption.
- A Commissioning Order.

All this information is illustrated in the following flowchart:[4][7]

The documents that represent the contract (SONELGAZ /MT customer) and the information sheet. Are represented in the appendix (...).



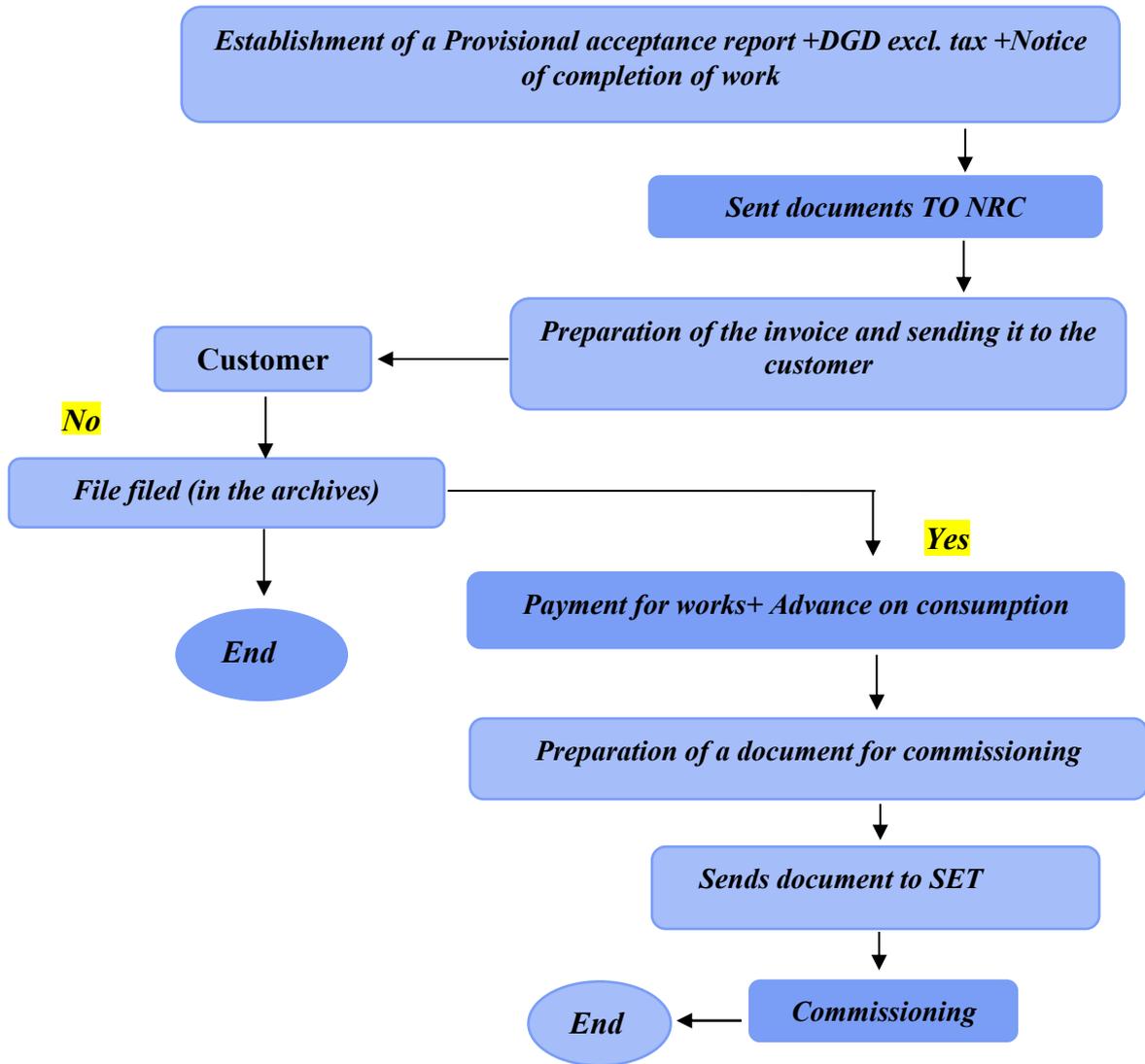


Figure 1. 11 Flow chart of the different stages of the agreement [7].

1.7.2. Electricity tariff system

The pricing of the electricity consumed is carried out according to the power used and hourly and seasonal criteria.

The SONELGAZ tariff system aims to:

- To ensure revenue from the company from the sale of these products to meet these expenses, and particularly the salary of its staff.
- To reduce the costs of making electrical energy available to customers by encouraging them to consume it during the least busy periods.

To ensure equal treatment of all subscribers of the same level of tension or pressure through the implementation of tariffs at the national level. [4] [7]

1.7.3. Pricing periods

Energy prices are differentiated according to hours of use. The hours of the day have been grouped into 3 hourly shifts as follows.

Peak: Every day of the year from 5pm to 9pm (corresponds to the busiest hours).

Plain hours: Every day of the year from 6am to 5pm and from 9pm to 10.30 pm

Off-peak hours: Every day of the year from 10:30 p.m. to 6 a.m. (lightly loaded hours).[8]

The different hours defined above correspond, according to the tariff, to six tariff periods (peak, peak hours, off-peak, off-peak, day, single shift) which will be summarized in the following table.

Table 1. 4 Different tariff periods [7]

Triple tariff (3 tariff periods)	Off-peak hours (22h 30 → 6h) (7h 30/Day)	Peak hours (6h → 17h) (21h → 22h30)	Rush hours (17h → 21h) (4h/Day)
Double tariff (2 tariff periods)	Off-peak hours (21h → 17h) (20h/ Day)		Peak hours (17h → 21h) (4h/ Day)
Double tariff (2 tariff periods)	Night (22h 30 → 6h) (7h 30/ Day)	Day (6h → 22h 30) (16h 30 / Day)	
Standard tariff	Single post (24h/ Day)		

1.7.4. Presentation of tariffs

The electricity tariffs currently in force are classified into three series where each series groups the tariffs specific to a voltage level to which the customer is connected.[8]

- **Series 30 tariffs:** High Voltage subscribers.
- **Series 40 tariffs:** Medium Voltage subscribers.
- **Series 50 rates:** Low Voltage subscribers.

I.7.5. Low Voltage tariffs

The following table presents household energy tariffs in a structured manner, providing a detailed cost analysis as well as a clear description of the tariff structure related to residential consumption. [9]

Table 1. 5 Tarifs de l'énergie à usage domestique

Tarif 51 M	COMMERCIALE	Mid-Peak	Hors pointe
	17h à 21h 811,47 cDA	6h à 17h et 21h à 22h 30 216,45 cDA	22h 30 à 6h 120,50 cDA
Tarif 52 M	COMMERCIALE		Hors pointe
	17h à 21h 811,47 cDA		21h à 17h 178,07 cDA
Tarif 53 M	NIGHT		DAY
	22h30 à 6h 120,50 cDA		6h à 22h30 486,98 cDA
Tarif 54 M	For quarterly consumption		
	Unit 1: from 0 to 125 kWh: 177,87 cDA		
	Unit 2: more than 125 up to 250 kWh: 417,89 cDA		
	Unit 3: more than 250 up to 1000 kWh: 481,20 cDA		
Unit 4: up to 1000 kWh: 547,96 cDA			

I.7.5.1. Energy tariff for non-domestic customers per kWh

The table below presents in a methodical way the energy tariffs applied to non-domestic use, offering a detailed view that systematically sets out the costs and clarifies the tariff structure related to energy consumption excluding domestic use. [9]

Table 1. 6 Energy tariffs for non-domestic customers

Tarif 51 NM	COMMERCIALE	Mid-Peak	Hors pointe
	17h à 21h 811,47 cDA	6h à 17h et 21h à 22h 30 216,45 cDA	22h 30 à 6h 120,50 cDA
Tarif 52 NM	COMMERCIALE		Hors pointe
	17h à 21h 811,47 cDA		21h à 17h 178,07 cDA
Tarif 53 NM	NIGHT		DAY
	22h30 à 6h 120,50 cDA		6h à 22h30 486,98 cDA
Tarif 54 NM	Unit 1: from 0 to 250 kWh: 417,89 cDA Unit 2: more than 250 up to 1000 kWh: 481,20 cDA Unit 3: more than 1000 kWh: 547,96 cDA		

1.7.5.2. Tariff for electricity and fixed fees for domestic and non-domestic workers

We will summarize in the following table the flat fee rate for domestic and non-domestic services:

Table 1. 7 Electricity tariffs and fixed costs for domestic and non-domestic customers

Tarif 51 M	Energy supply PMD	Fixed fees
	29,85DA/kW/mois	286,44DA/ mois
Tarif 51NM		
Tarif 52 M	Energy supply PMD	Fixed fees
	29,85DA/kW/mois	66,40DA/ mois
Tarif 52 NM		
Tarif 53 M	Energy supply PMD	Fixed fees
	14,81DA/kW/ mois	66,40DA/mois
Tarif 53 NM		
Tarif 54 M	Energy supply PMD 4,37DA/kW/ mois	

1.7.5.3. General tariff formula

The construction or design of all tariffs is built according to a single architecture or structure, it is called: **Tariff formula**.

The general expression of the tariff structure is a polynomial with three parts **is schematized** as follows:[8]

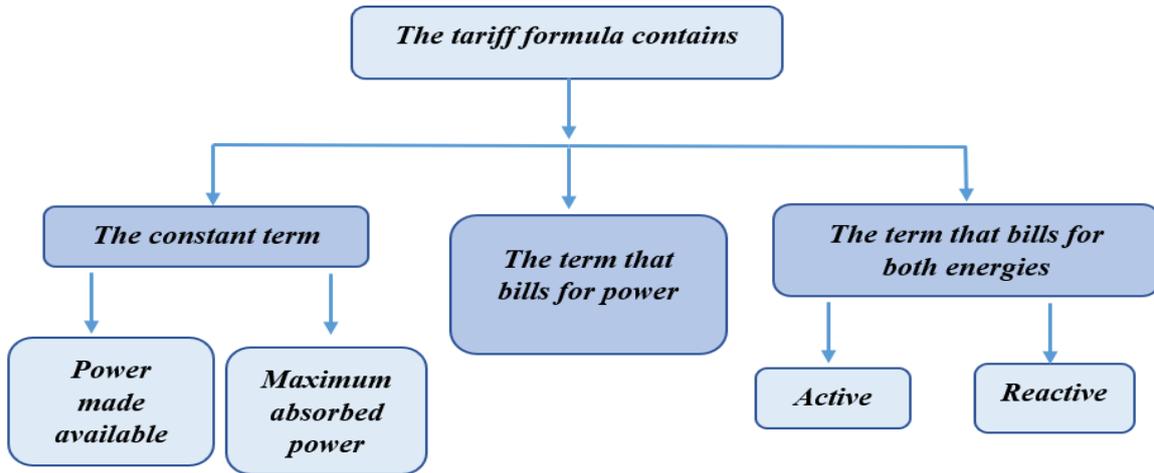


Figure 1. 12 Components of the tariff formula [7]

This formula is applicable to all customers for the following voltages:

High and extremely high Voltage: **60 – 90 – 220 kV**.

Medium Voltage: **5.5 – 10 – 30 kV**.

Low Voltage: **220 – 380 V**.

First term: Charges

$$R = a + c.P_c + d.P_a + \sum eh . Eh + g. (\omega - r.E)$$

Amount
2nd term: Power
3rd term: Energy

A: Monthly invoice amount (PR/month)

a: Flat rate covers the monthly expenses related to customer management (technical and commercial DA)

P_c: Power made available to the customer and to which he can call, if necessary, expressed in kW

Pa: Maximum power absorbed during the billing period measured by a maximum demand indicator reset each time it is read. It is expressed in bar.

c, d: Invoicing price for the power made available and the maximum power absorbed (DA/kW/month).

E: Energy consumed during the month (kWh/month)

Eh: Energy consumed during the month by hourly rate *h* ($E = \sum Eh$)

eh: Energy price per hourly rate *h* (cDA/kWh)

W: Reactive energy consumed during the month (kVAR h/month)

g: Reactive energy price (c DA/kVarh)

r: Concerns the billing of reactive energy: value of the ratio $\text{tg } \varphi = W/E$ beyond which there is a surcharge and below which there is a bonus.

We take ***r*** = **0.5** which corresponds to a $\cos \varphi$ of 0.894.

1.7.5.4. daily load curve

The consumption of electrical energy is dynamic and fluctuates according to the needs at each moment. Thus, to represent evolution, we use load curves that illustrate the variation in demand during the day. [6]

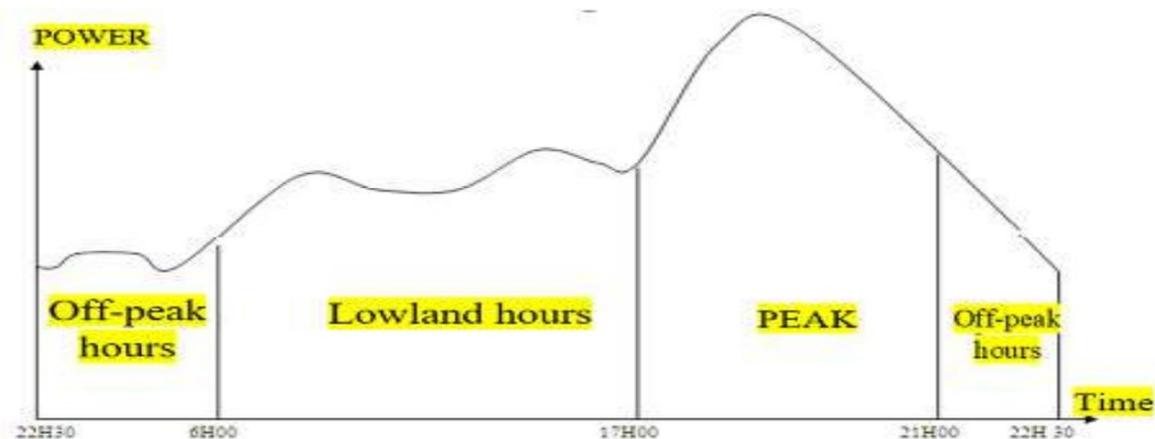


Figure 1. 13 Daily load curve [9]

1.7.5.5. Algeria's electricity and gas consumption bill

The electricity and gas bill contains a wealth of information that we will elucidate in figure (1.17): [9]

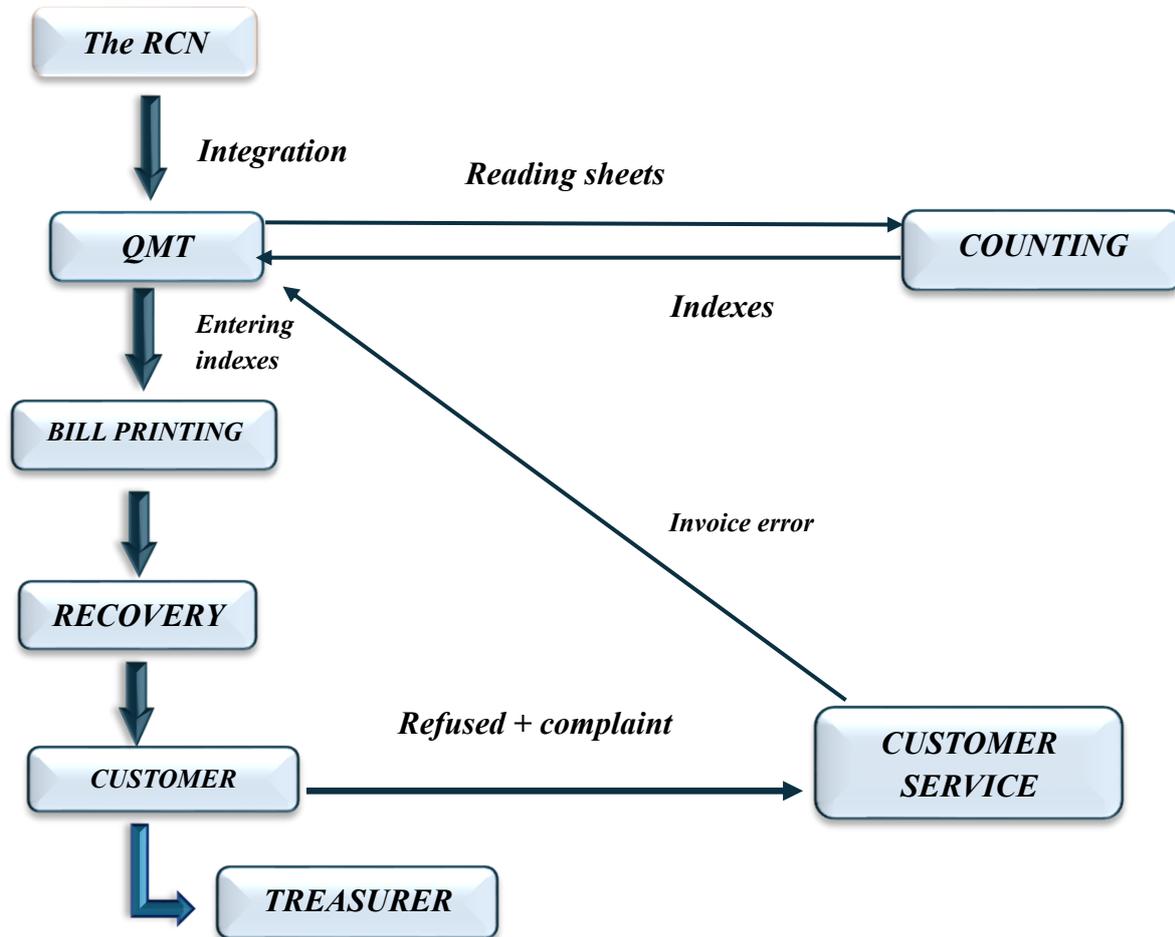


Figure 1. 14 Flowchart of the billing cycle [7].

- 1) Invoice Information
- 2) Distributor Information and Contact Information
- 3) Information and contact details
- 4) Call center number in case of problems (33 03)
- 5) Period of consumption
- 6) Your electricity and gas meter number
- 7) The tariff code

- 8) Available Power (PMD) /Available Flow (DMD)
- 9) The coefficient
- 10) Old Index
- 11) New Index
- 12) Consumption Slices
- 13) Amount of energy excluding taxes (excl. VAT): In the invoice, it is first calculated
- 14) Consumption = (Difference (New Index - Old Index)) Coefficient
- 15) Fixed fees excluding tax (Subscription
- 16) Fees and Benefits
- 17) Total amount excluding tax (DA)
- 18) Total VAT in (DA)
- 19) This tax is provided by Finance Law, its collection has been entrusted to SONELGAZ
- 20) HOUSING TAX
- 21) Contribution (Energy Advantage) (DA)
- 22) rep and GDPR amount (DA)
- 23) Net payable in VAT (DA)
- 24) Stamp (DA)
- 25) Total to be paid (DA)
- 26) Payment deadline
- 27) Reminder of amount of previous invoices (DA)
- 28) EBP and EBB key
- 29) Average daily consumption
- 30) Contribution to current system costs (DA)
- 31) Consumption trends
- 32) Important information



الشركة الجزائرية للكهرباء والغاز - التوزيع
Société algérienne de l'électricité et du gaz - Distribution

Société par action au capital social de: 64 000 000 000,00 DA

Direction de distribution: Biskra

RC N°: 07/010805455806

NIS: 096916010012742

NIF: 000609080545593

RIB N°: 00100386030030016118

RIP N°: 00799999000038010626

AI: 07014118115

Agence commerciale: BISKRA 1
5 BVD FRERES SAOULI

Assistance
Dépannage
Réclamation
Pour Plus d'informations

3303

مساعدة
إصلاح الأعطال
شكوي
التبريد من المعطبات

فاتورة استهلاك الكهرباء والغاز

فاتورة رقم: 821250200857

تاريخ: 02/03/2025

المرجع في: 07901 54 30740 1 55

مكان الاستهلاك: HAY BAB DARB

الرقم القديم حوالي: 8211P005896

Facture de consommation de l'Electricité et du Gaz

Facture n°: 821250200857

Établie le: 02/03/2025

Référence /FDL: 07901 54 30740 1 55

Lieu de consommation: HAY BAB DARB

Prochaine relève vers le: 07/05/2025

Client n°: 8211P005896

MR BARKAT ABDELKRIM

NIF: 07901 54 30740 1 55

RC N°: 07/010805455806

الفترة: الثلاثي الأول 2025

11 عقودكم

نوع الخدمة	رقم العداد	التعرفة	المتن	البيان	البيان	البيان	البيان
الكهرباء	N° Compteur	Tarif	PMD	Coef	A. Index	N. Index	N. Index
الكهرباء	021080727304	54M	20kW	1.0	40 897 R	41 524 R	41 524 R
الغاز	170020047	23M	5m ³ h	9.75	10 024 R	10 419 R	10 419 R

Vos consommations

الإستهلاك	المبلغ بالدينار	الإستهلاك	المبلغ بالدينار
Consommation	Montant en DA HT	Consommation	Montant en DA HT
Electricité	642,00 kWh	2 631,00	الكهرباء
Gaz	3 851,25 Th	1 179,30	الغاز
Redevances fixes HT(Abonnement)(DA)	347,70	الإتاوات الثابتة (اشترك) (د.ج)	15
Frais & Prestation HT(DA)	0,00	رسوم وخدمات (د.ج)	16
Montant HT (DA)	4158,00	المبلغ بدون رسوم (د.ج)	17
TVA à 9% (DA)	155,51	ر.م 9% (د.ج)	18
TVA à 19% (DA)	461,74	ر.م 19% (د.ج)	19
Total TVA (DA)	617,25	ر.م (د.ج)	20
Droit Fixe sur consommation (DA)	200,00	المستحقات الثابتة على الإستهلاك (د.ج)	21
Taxe d'habitation (DA)	150,00	رسوم على السكن (د.ج)	22
Contribution (DA)	1 880,58	مساهمة (د.ج)	23
Montant REPE (DA)	0,00	مبلغ ر.م.م.ت (د.ج)	24
Montant RGPE (DA)	0,00	مبلغ ر.م.ع.م.ت (د.ج)	25
Net à payer TTC (DA)	3 244,67	مبلغ الصافي بعد خصم جميع الرسوم (د.ج)	26

Trois mille deux cent quarante-quatre Dinar(s) et soixante-sept centime(s)

Timbre (paiement en espèces)(DA) 33,00 الطابع (د.ج.ش.د)

Total à payer (en espèces)(DA) 3 277,67 المبلغ المستحق (الجملي) (نقدا) **27**

Date limite du paiement 20/03/2025

Passé ce délai, nous nous réservons le droit de procéder à la suspension de la fourniture d'énergie

Nous vous informons qu'en application des dispositions de l'article 85 du Décret Exécutif 10-95 du 17/03/2010, vous êtes redevable d'un montant de DA. Faute de quoi la fourniture d'énergie sera suspendue

ننصتكم أنه تخلفا لأحكام المادة 85 من المرسوم التنفيذي 85-10 بتاريخ 17/03/2010، أنتم متدينون بمبلغ د.ج.، وإلا سيتم فصل تزويدكم بالطاقة.

Espace information

Montant de votre consommation moyenne par jour 35.66 DA/jour

Contribution au coût permanent du système 7.51 DA

معلومات

مبلغ استهلاككم اليومي

التكلفة الدائمة في النظام

معلومات

مبلغ استهلاككم اليومي

التكلفة الدائمة في النظام

Information Importante: Vous pouvez régler votre facture au niveau de n'importe quelle agence commerciale, au niveau des bureaux d'Algérie poste, par virement, Par chèque bancaire ou postal, par paiement en ligne

يمكنكم تسديد فاتورتكم في أي وكالة تجارية، في مكاتب بريد الجزائر، عبر حصة بنكي أو بريدي، عبر التحويل على الحسابات البنكية، أو عن طريق البريد، أو عن طريق البريد الإلكتروني

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Figure 1. 15 Algeria's electricity and gas consumption bill

Part 2: General concept of the water meter

1.8. Smart water meters

Smart water meters are advanced digital devices that provide real-time monitoring of water consumption and enable two-way communication between consumers and utility providers. These meters offer several benefits, including better water management, leak detection, and potential savings. [12]

1.8.1. History

The concept of measuring water flow dates to the 18th century. In 1790, Giovanni Battista Venturi described the principles of fluid dynamics, paving the way for flow measurement techniques.

The first practical mechanical water meter was developed in 1851 by Carl Wilhelm Siemens in London, meeting the growing demand for accurate billing from water utilities. Its meter uses a piston mechanism to record flow volumes.

Throughout the 20th century, more efficient designs emerged, including the Woltman meter in the 1960s, which featured a rotor aligned with water flow and was suitable for large volumes. In recent decades, smart water meters have been developed. These use ultrasonic or electromagnetic sensors and offer features such as leak detection, real-time monitoring and wireless data transmission. [11]

1.9. Types of water meters

1.9.1. Mechanical water meter

✚ Definition

The mechanical water meter is a measuring device intended to quantify the volume of water consumed in a dwelling, a building, or an industrial site. It works thanks to an internal system of moving parts that rotate under the effect of the passage of water. [11]

✚ Operation

Moving water actuates a mechanical part (often a propeller or piston), the rotations of which are proportional to the volume of water flowing. These rotations are then transmitted to a totalizer (the dial), which displays the consumption in cubic meters (m³).

✚ Types of mechanical meters

1. Francis's turbine

- More suitable for medium to high flows.
- It is commonly used in homes and small buildings.



Figure 1. 16 Mechanical turbine water meter [10].

2. *Swing compressor*

- More accurate at low flow.
- Ideal for single-family homes.



Figure 1. 17 Mechanical water meter with oscillating piston [10]

1.9.2. Electronic water meters

Definition

The electronic water meter is a modern measuring device that uses electronic sensors to detect and record the volume of water consumed, without the need for moving mechanical parts. [11]



Figure 1. 18 Electronic water meters [11]

Operating principle

Unlike mechanical meters, electronic meters measure water flow by exploiting technologies such as:

- Electromagnetism
- Ultrasound
- Pressure or temperature variation.

These technologies allow for more accurate and reliable measurement of water flow, even at extremely low flows.

1.9.3. Ultrasonic water meter

Definition

The ultrasonic meter is a type of high-precision electronic meter that uses ultrasonic waves to measure the flow velocity of water, and therefore the volume consumed. It has no moving parts, which makes it particularly dependable and durable. [11]



Figure 1. 19 Compteur d'eau à ultrasons [11]

✚ Operation

- Two sensors emit and receive ultrasonic waves through the water flow, in two opposite directions.
- The transit time of these waves is influenced by the speed of the water: the wave that goes in the direction of the flow takes less time than the one that goes against the current.
- By comparing these times, the meter accurately calculates the flow rate and then the total volume of water consumed.

1.9.4. Divisional water meter

✚ Definition

The sub-meter is a meter installed downstream of the main meter in a collective building. It makes it possible to measure the individual water consumption of each dwelling or room (apartment, office, business), with the aim of distributing water-related expenses equitably.



Figure 1. 20 Divisional water meter [10]

✚ Principle of Operation

Distribute the overall consumption recorded by the main meter among the different users (co-owners or tenants), based on their actual consumption. [10]

1.9.5. Smart water meter (or communicating meter)

✚ Definition

The smart water meter is an electronic or ultrasonic meter equipped with a communication module. It allows automatic and remote transmission of consumption data, without manual intervention. [13]



Figure 1. 21 Smart water meter [11]

Operation

The meter measures the volume of water consumed like a conventional meter.

An integrated communication module (radio, GSM, Wi-Fi) sends the data:

- Central managing unit.
- Or to a cloud system for consultation by the customer or supplier.

The data is accessible in real time or delayed, via a portal or an application.

1.10. Impact of smart meters on water consumption

Studies have shown that implementing smart water meters can lead to a reduction in household water consumption. For example, a study in Valencia, Spain, found that households with smart water meters achieved an average 8% reduction in water consumption. This reduction is attributed to increased consumer awareness and the ability to monitor water use more closely.

Another study observed that households with home display units connected to smart meters reduced their water consumption by an average of 6.8% over a five-year period compared to a control group. [12]

Chapter 1: General Overview of smart Energy Meters

Table 1. 8 Different types of smart water meters [10-13]

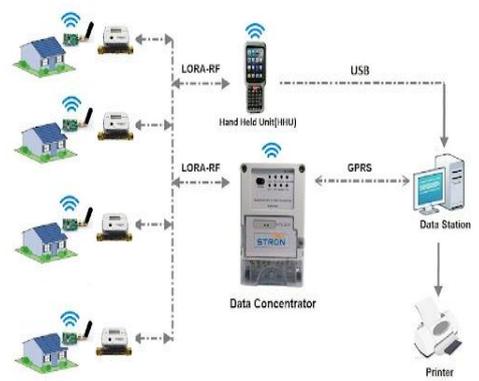
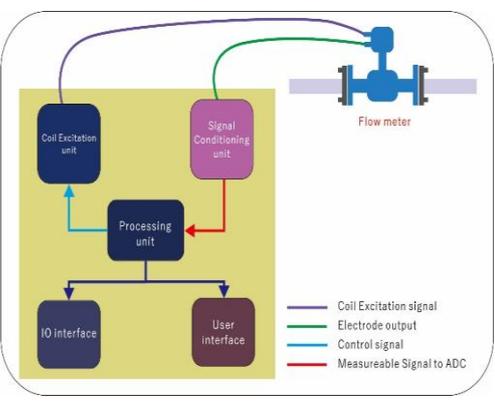
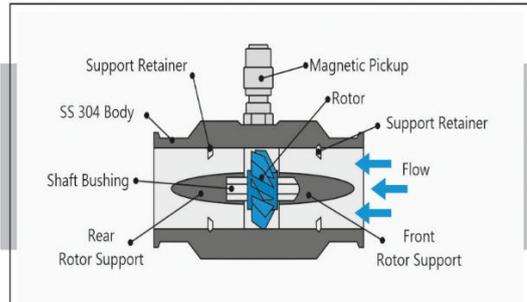
Type of meter	Operating principle	Drawing
<p>Ultrasonic Smart Water Meters</p> 	<p>These meters send ultrasonic pulses through the water and measure the time it takes for the pulses to travel with and against the flow. The difference in transit times is used to calculate the flow rate.</p>	
<p>Electromagnetic Smart Water Meters</p> 	<p>Based on Faraday's Law of Electromagnetic Induction, as conductive water flows through a magnetic field, it induces a voltage proportional to the flow velocity, which is measured by electrodes.</p>	
<p>Photoelectric Direct Reading Remote Water Meters</p> 	<p>The photoelectric sensor detects the position of the mechanical dial, translating it into digital data that can be transmitted remotely.</p>	
<p>Turbine (Mechanical) Smart Water Meters</p> 	<p>As water flows through the meter, it spins the turbine. The rotational speed is proportional to the flow rate, which is measured and recorded.</p>	

Table 1. 9 Comparison between traditional and smart water meters

<i>Characteristic</i>	<i>Water meter</i>	<i>Smart water meter</i>
<i>Instantaneous observation method</i>	Manual reading by utility personnel	Digital transmission
<i>Data frequency</i>	Periodic (e.g., monthly/quarterly)	Temps réel ou fréquent (par exemple, toutes les heures ou tous les jours)
<i>Leak detection</i>	Difficult; often undetected, leading to high bills	Real-time alerts and leak detection
<i>Invoice accuracy</i>	May rely on estimates between readings, which can lead to errors	Based on accurate real-time usage data, it improves billing accuracy.
<i>Relevant feedback from consumers</i>	Limited to cumulative totals, no real-time feedback	Provides detailed, time-stamped usage reports via applications or portals
<i>Network management</i>	Provides minimal data; delays in anomaly identification.	Enables effective network monitoring and loss detection.
<i>Maintenance</i>	Failures or alterations often go unnoticed until manually checked.	It can send automated diagnostics and alerts to utilities.
<i>User commitment</i>	Low; users rarely check or understand consumption.	High; users are more aware and initiative-taking in reducing waste

1.11. Prospects for the use of smart water meters in Algeria

Faced with the challenges related to water management (shortage, losses, approximate billing), the introduction of smart meters in Algeria appears to be a strategic solution.

Multiple benefits:

- Improved billing accuracy.
- Reduced water loss through leak detection.

- Real-time monitoring of consumption.
- Raising users' awareness of responsible consumption.

Challenges

- High initial cost of equipment and infrastructure.
- Staff training requirements
- Need for a clear regulatory framework for data management.

I.12. Advantages and disadvantages of each type of water meter

Table 1. 10 Advantages and disadvantages of water meters [10][11].

Type of meter	Advantages	Disadvantages
Mechanical water meter	<ul style="list-style-type: none"> *Proven and robust technology. *Low cost. *Easy to install and maintain. 	<ul style="list-style-type: none"> *Less accurate at extremely low flow rates. *Prone to mechanical wear over time. *Requires manual reading.
Electronic water meters	<ul style="list-style-type: none"> *Extremely high measurement accuracy. *Easy integration with remote reading or smart management systems. *Ability to provide real-time data. 	<ul style="list-style-type: none"> *Higher cost compared to mechanical meters. *Dependence on electrical power or internal battery. *Sometimes more sensitive to certain environments (interference).
Ultrasonic water meter	<ul style="list-style-type: none"> *Extremely high accuracy, even at incredibly low flow rates. *No mechanical parts: no wear, reduced maintenance. *Can be installed in any position. *Leak and consumption anomaly detection. 	<ul style="list-style-type: none"> *Higher cost compared to mechanical meters. *Requires electrical power or an integrated battery. *Less common in standard domestic installations.
Sub-meter (water)	<ul style="list-style-type: none"> *Enables individualized and fairer billing. *Encourages water savings by making users more accountable. 	<ul style="list-style-type: none"> *Requires compliant installation from the construction phase or during renovation.

	*Possibility of detecting leaks on a per-household basis.	*Installation can be difficult or costly in older buildings. *Requires centralized data management in the case of remote reading.
Smart water meter	*No more need for manual reading. *Better control of consumption by the user. *Real-time billing. *Rapid intervention in case of leaks.	* Higher purchase cost. * Requires a power supply. * Depends on the quality of the communication network.

1.13. Tariff system in Algeria.

Algeria's water tariff system is characterized by a block tariff structure, where the price per cubic meter increases with higher levels of consumption. This approach encourages water conservation and ensures that basic water needs are met at a lower cost.[14]

- ***Domestic users:*** Subject to a progressive rate based on consumption blocks.
- ***Administration and service sectors:*** Responsible for a uniform tariff.
- ***Industrial and tourism sectors:*** have also charged a uniform and higher rate reflecting their substantial use of water.

1.13.1. Rates for potable water and sanitation

are set according to specific schedules for each territorial tariff zone. They are calculated based on the cost of the public services potable water supply and sanitation and are distributed among different user categories and consumption brackets. For each tariff zone, a base rate is determined: for potable water, it corresponds to the consumption of one cubic meter by a category I user within the social quarterly consumption bracket; for sanitation, the rates are linked to the volume of water supplied to users of the potable water service. The base rates, excluding taxes, applicable in the different territorial tariff zones are presented in the table below. [15]

Table 1. 11 The rates for potable water and sanitation [15].

Territorial Tarif Zone	Covered Wilayas	Base Rate (DA/m³)	Sanitation Tarif
ALGER	Alger – Blida – Médéa – Tipaza – Boumerdès – Tizi Ouzou– Bouira – Bordj Bou Arréridj - M’Sila – Bejaia – Sétif.	6,30	2,35
ORAN	Oran – Ain Témouchent – Tlemcen – Mostaganem – Mascara – Sidi Bel Abbès – Saida – Naâma – El Bayadh.	6,30	2,35
CONSTANTINE	Constantine – Jijel – Mila – Batna – Khenchela – Biskra – Annaba – El Tarf – Skikda – Souk Ahras – Guelma – Tebessa – Oum El Bouaghi.	6,30	2,35
CHLEF	Chlef – Ain Defla – Relizane – Tiaret – Tissemsilt – Djelfa.	6,10	2,20
OUARGLA	Ouargla – El Oued – Illizi – Laghouat – Ghardaia – Béchar– Tindouf – Adrar – Tamanghasset.	5,80	2,10

1.13.2. Period and tariff categories in Algeria

The tariff structure is divided into specific consumption blocks for domestic users: [15]

- **Block 1:** 0–25 m³ per quarter – lowest rate.
- **Block 2:** 26–55 m³ per quarter – moderate rate.
- **Block 3:** 56–82 m³ per quarter – higher rate.
- **Block 4:** Above 82 m³ per quarter – highest rate.

Administrative and industrial users are not subject to block tariffs, but pay a flat rate per cubic meter, which is higher than the rates for domestic users.

Table 1. 12 User categories and quarterly consumption brackets [15].

<i>Various categories of users and quarterly consumption brackets</i>				
<i>Categories of users</i>		<i>Quarterly consumption brackets</i>	<i>Multiplication coefficients</i>	<i>Applicable rates</i>
<i>Category 1: Households</i>	<i>First tier</i>	Up to 25 m ³ /quarter	1,0	6,30
	<i>Second tier</i>	From 26 to 55 m ³ /quarter	3,25	04 ,20
	<i>Third tier</i>	From 56 to 82 m ³ /quarter	5,5	34,65
	<i>Fourth tier</i>	More than 82 m ³ /quarter	6,5	40,95
<i>Categories 2 and 3: Administrations, artisans, and services in the tertiary sector</i>		Uniform rate	5,5	34,65
<i>Category 4: Industrial and tourist units</i>		Uniform rate	6,5	40,95

1.13.3. Algeria water consumption bill

The water bill contains a wealth of information that we will elucidate in figure (1.22)

1) *Header section*

2) *Customer and Invoice Information*

3) *Client's info*

4) *Water costs (water)*

5) *Sanitation costs*

6) *Total before taxes (Subtotal before tax)*

7) *Taxes and fees*

Chapter 1: General Overview of smart Energy Meters

8) Final amount

9) Consumption History Chart

10) Electronic Payment Code



فاتورة الماء و التطهير

FACTURE D'EAU ET D'ASSAINISSEMENT

الجزائرية للمياه

ALGÉRIENNE DES EAUX

06/01/2022 تاريخ الكشف Date relevé	OD5544/2022-03 رقم الفاتورة Facture N°	CHLEF الوحدة Unité	
06/04/2022 الكشف المقبل Prochain relevé	Du 05/10/2021 au 06/01/2022 الفترة Période du	CHLEF المركز Centre	
17/07/2023 الفاتورة المقبلة Prochaine Facture	18/04/2023 تاريخ الفاتورة Date Facture	OUMDROU الصندوق Caisse	

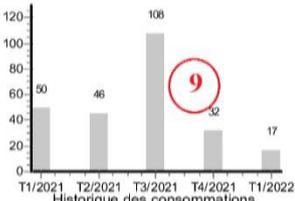
No: ADE17 168095/En marche رقم وحالة العداد N° Etat de compteur 896 الدليل القديم Ancien Index 913 الدليل الجديد Nouvel Index 17 الاستهلاك (3م) Consommation (m3)	02 01 01 OD 5544 (TRN : 401) 10: MENAGE INDIVIDUEL رمز الزبون Code Client نوع الاشتراك Type Client الزبون Client عنوان الزبون Adresse Client
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المبلغ دون رسوم (دج) Montant HT (DA)	سعر الوحدة دون رسوم (دج) Prix unitaire (DA/m3)	الكمية (3م) Quantité (m3)	الماء Eau
240.00			Redevance fixe d'abonnement الاتورة الثابتة للاشتراك
103.70	6.10	17	(0 - 25 m3) Tranche (1) الشطر (26 - 55 m3) Tranche (2) الشطر (56 - 82 m3) Tranche (3) الشطر (>= 83 m3) Tranche (4) الشطر
343.70	(1)	Sous-Total Eau	المجموع الجزئي للماء

المبلغ دون رسوم (دج) Montant HT (DA)	سعر الوحدة دون رسوم (دج) Prix unitaire (DA/m3)	الكمية (3م) Quantité (m3)	التطهير Assainissement
60.00			Redevance fixe d'abonnement الاتورة الثابتة للاشتراك
37.40	2.20	17	(0 - 25 m3) Tranche (1) الشطر (26 - 55 m3) Tranche (2) الشطر (56 - 82 m3) Tranche (3) الشطر (>= 83 m3) Tranche (4) الشطر
97.40	(2)	Sous-Total Assainissement	المجموع الجزئي للتطهير

441.10	(2) + (1)	Sous-Total HT	المجموع الجزئي دون رسوم
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Montant (DA)	المبلغ (دج)	Taux	النسبة	Assiette	القاعدة	Taxes et Redevances	الأتوات و الرسوم
39.70			9.00	441.10		TVA	ض.ق.م (%)
51.00			3.00	17		Redevance de gestion (DA/m3)	أتوة التسيير (دج / 3م)
4.15			4.00	103.70		Redevance qualité eau	أتوة نوعية الماء (%)
4.15			4.00	103.70		Redevance économie eau	أتوة اقتصاد الماء (%)
99.00			(3)	Sous-Total taxes et redevances			المجموع الجزئي للأتوات و الرسوم



Historique des consommations

540.10	Montant de la Facture (3) + (2) + (1)
Cinq cents quarante Dinars 10 centimes	
0.00	Dus antérieurs
540.10	Le montant sans timbre
6.00	الطبع الجملي (في حالة الدفع نقد) Timbre (en cas de paiement en espèces)
546.10	Net à payer

رمز الدفع الإلكتروني
Code de Paiement
Electronique



02010 10D55 4424R 10D55 02010

En cas de non-paiement de votre facture dans un délai de 15 jours, votre alimentation en eau potable sera suspendue et sans aucun préavis

Siège social : Zone Industrielle Oued Smar (Alger)

Compte bancaire
Compte postal

في حالة عدم تسديد مستحقاتكم في مدة 15 يوم، سيؤدي الى توقيف تزويدكم بالماء بدون أي إشعار مسبق

المقر الاجتماعي: المنطقة الصناعية واد السمار (الجزائر)

Registre de commerce
NIF

Numéro article

Figure 1. 22 User categories and quarterly consumption brackets [15].

1.14. Conclusion

The evolution of electricity and water consumption meters, from traditional models to smart meters, reflects a growing desire to optimize resource management. The limitations of older devices have gradually given way to smart meters, capable of accurate measurement, real-time monitoring, and two-way communication. This technological progress accompanies the emergence of new, more flexible, and fairer pricing models, adapted to the current challenges of consumption, energy saving and sustainability. Thus, the development of smart meters is a fundamental lever in the transition to a more rational and responsible management of electricity and water resources.

Chapter2:
Hardware and
Software Design of the
Project

II. Introduction

This chapter is dedicated to the technical design and selection of components necessary for the realization of a multifunctional smart meter, capable of measuring both electrical and water consumption, and detecting gas leaks in real-time. The objective is to design an integrated, efficient, reliable, and economically viable system that meets user requirements and current standards. This context is divided into two parts:

The first part is dedicated to the hardware components used for data detection, measurement, and transmission. The second part describes the various software adopted for the development of the application responsible for communication between the meter and the user.

Part 1: Hardware Part

The hardware design of the energy management system relies on the use of specific electronic components, such as the ESP32, energy consumption sensors (current and voltage), gas detectors, and LCD displays. This subsection describes the technical characteristics of each component, their role in the system, and the selection criteria. It also addresses the overall hardware architecture and the connections between the different elements. [16]

II.1. Used components

II.1.1. Definition of ESP32

The ESP32 is a low-cost, low-power system-on-chip (SoC) microcontroller developed by Espressif Systems. It features integrated Wi-Fi and Bluetooth (Classic and BLE), making it ideal for a wide range of Internet of Things (IoT) applications. The ESP32 includes a dual-core Tensilica LX6 processor, operating at up to 240 MHz, along with a rich set of peripheral interfaces such as GPIOs, ADCs, DACs, UART, SPI, I2C, and PWM. [3]



Figure 2. 1 logo of Espressif [3]

In addition to its powerful processing capabilities, the ESP32 supports deep sleep modes and energy-efficient operation, which makes it suitable for battery-powered devices. It is widely used in smart home systems, wearable electronics, automation, sensor monitoring, and wireless

Chapter2: Hardware and Software Design of the Project

communication projects due to its flexibility, performance, and affordability. Thanks to its open-source development environment (e.g., **Arduino IDE**, ESP-IDF), the ESP32 is accessible to both beginners and professionals, and allows the development of complex embedded systems with wireless capabilities in a relatively short time. [17]



Figure 2. 2 ESP32 card [17]

II.1.1.1. ESP32 Characteristics

The **ESP32** is a highly versatile system-on-chip (SoC) designed for a wide variety of applications, including Internet of Things (IoT) devices. Below are its key characteristics:

- **Dual-Core Processor:** The ESP32 features a dual-core Tensilica LX6 processor, which can run up to 240 MHz, providing high processing power for complex tasks.
- **Wi-Fi and Bluetooth Connectivity:** It integrates 802.11b/g/n Wi-Fi and Bluetooth 4.2 (Classic and BLE), enabling wireless communication for a wide range of devices and applications.
- **Low Power Consumption:** The ESP32 is optimized for low power usage with various sleep modes, making it suitable for battery-operated devices.
- **Wide Range of Peripherals:**
 - Analog-to-Digital Converter (ADC) and Digital-to-Analog Converter (DAC).
 - Multiple General-Purpose Input/Output (GPIO) pins for controlling and reading external devices.

Chapter2: Hardware and Software Design of the Project

- Support for SPI, I2C, UART, and PWM for communication and signal generation.
- **Security:** It includes built-in hardware encryption (AES, SHA, RSA) and secure boot features, making it suitable for applications where security is a priority.
- **Highly Configurable:** The ESP32 supports a variety of development platforms like Arduino, ESP-IDF, and Micro Python, making it flexible for developers.
- **Integrated Sensor Interfaces:** It can interface with external sensors for various applications, including temperature, humidity, and motion sensing. [17]

II.1.1.2. ESP32-WROOM-32 Hardware Component

In our project, we used the ESP32-WROOM-32 board. The ESP32-WROOM-32 is a Wi-Fi + Bluetooth + BLE (Bluetooth Low Energy) MCU module that is powerful and general-purpose, targeting a wide range of applications — from low-power sensor networks to more demanding tasks such as voice encoding, music streaming, and MP3 decoding. At the core of this module is the ESP32-D0WDQ6 chip. This embedded chip is designed to be scalable and adaptive. It features dual-core processors that can be controlled individually, and the processor clock frequency is adjustable between 80 MHz and 240 MHz [18]

II.1.1.3. Board Specifications (ESP32-WROOM-32)

The table below presents the main technical characteristics of the ESP32-WROOM-32 board, used as the central microcontroller in our project.

Table 2. 1 Board Specifications of ESP WROOM 32 [22]

<i>Chip</i>	<i>ESP32-WROOM-32</i>
<i>Microprocessor</i>	Xtensa® dual-core 32-bit LX6 microprocessor
<i>Built-in Clock</i>	Internal 8 MHz oscillator with calibration
<i>SRAM</i>	520 KB
<i>Flash Memory</i>	4 MB
<i>Number of Pins</i>	38 pins
<i>Operating Voltage</i>	3.3 volts
<i>Wi-Fi</i>	Frequency range: 2.4 GHz
<i>Bluetooth</i>	Version 4.2 BR/EDR and Bluetooth Low Energy (BLE)

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II.1.1.4. Inputs and Outputs of the ESP32-WROOM-32 Board

- ***GPIO (General Purpose Input/Output):*** The ESP32-WROOM-32 includes many GPIO pins that can be used as inputs or outputs to communicate with other devices and manage digital signals.
- ***UART (Universal Asynchronous Receiver-Transmitter):*** The ESP32-WROOM-32 supports multiple UART interfaces, enabling asynchronous serial communication with other peripherals.
- ***I2C (Inter-Integrated Circuit):*** It includes pins for I2C communication, allowing connection with sensors, displays, and other I2C-based devices.
- ***SPI (Serial Peripheral Interface):*** ESP32-WROOM-32 supports SPI communication for synchronous serial data exchange with devices such as TFT screens, temperature sensors, and memory modules.
- ***ADC (Analog-to-Digital Converter):*** It has ADC pins to convert analog signals into digital values, enabling the reading of analog sensors like temperature and light sensors.
- ***DAC (Digital-to-Analog Converter):*** The ESP32-WROOM-32 also includes DAC pins to generate analog output signals.
- ***PWM (Pulse Width Modulation):*** It supports PWM signal generation, useful for controlling LED brightness, motor speed, etc.
- ***Capacitive Touch Sensor:*** The ESP32-WROOM-32 integrates dedicated pins for capacitive touch sensing, allowing implementation of touch buttons or gesture-based controls. [18]

II.1.1.5. ESP32 alternative models

Table 2.2 summarizes the main alternatives to the ESP32 board, highlighting their mode of operation, as well as their respective advantages and disadvantages.

Chapter2: Hardware and Software Design of the Project

Table 2. 2 ESP32 alternative models

<i>Name of the Model</i>	<i>How it Works</i>	<i>Advantages</i>	<i>Disadvantages</i>
<p>ESP8266</p> 	<p>A Wi-Fi microcontroller like ESP32 but with fewer features; mainly used for IoT projects.</p>	<ul style="list-style-type: none"> * Low cost, * Simple setup, * Large community support. 	<ul style="list-style-type: none"> * Limited GPIO pins, * No Bluetooth, * Lower processing power than ESP32.
<p>Raspberry Pi Pico W</p> 	<p>Microcontroller board with Wi-Fi capability, using RP2040 chip.</p>	<ul style="list-style-type: none"> * Dual-core processor, * Affordable, * Flexible for both IoT and embedded projects. 	<ul style="list-style-type: none"> * No native Bluetooth, * Requires more setup for wireless tasks compared to ESP32.
<p>Arduino MKR Wi-Fi 1010</p> 	<p>Arduino board with Wi-Fi and Bluetooth connectivity, designed for IoT apps.</p>	<ul style="list-style-type: none"> * Easy integration with Arduino ecosystem, * Bluetooth & Wi-Fi included. 	<ul style="list-style-type: none"> * Higher price, * fewer GPIOs than ESP32.

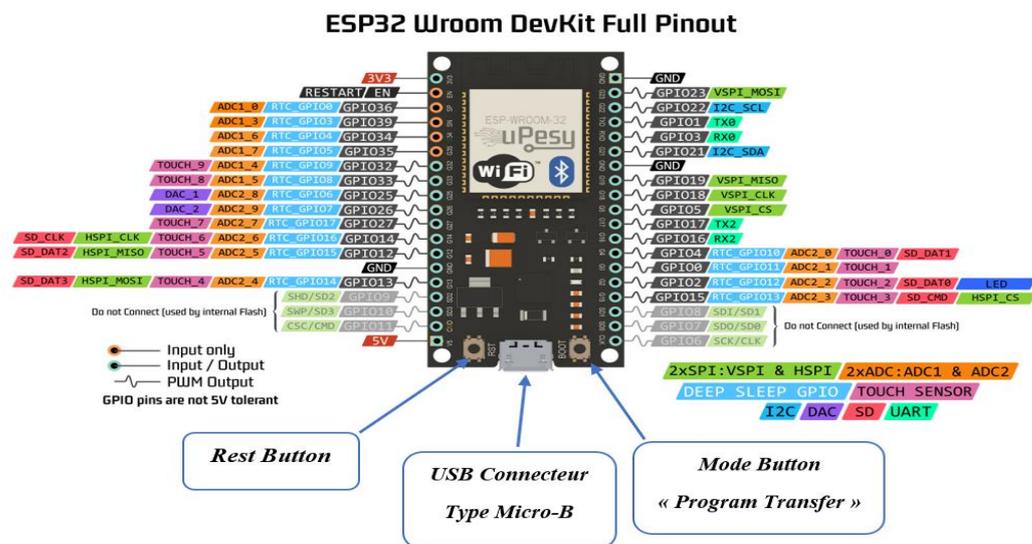


Figure 2. 3 Brochure of the ESP32-WROOM-32 (ESP32-DevKitC). [19]

Chapter2: Hardware and Software Design of the Project

II.1.2. ACS712 20A Current Sensor Module

The ACS712 20A is a current sensor module based on the Hall effect principle. It is used to measure both AC and DC current up to 20 Amperes and provides an analog voltage output proportional to the current flowing through the circuit.

➤ *Characteristics*

- Current measurement range: $\pm 20\text{A}$
- Supply voltage: 5V DC
- Output type: Analog voltage
- Sensitivity: 100 mV/A
- Response time: $< 5 \mu\text{s}$
- Galvanic isolation between the measured circuit and the output signal
- Size: Compact and easy to mount on breadboards

➤ *Functional Principle*

The ACS712 uses the Hall effect to sense the magnetic field created by the current passing through a conductor. This magnetic field is converted into a proportional analog voltage output. This signal can be read by a microcontroller like Arduino to determine the actual current flowing in the system. [20]

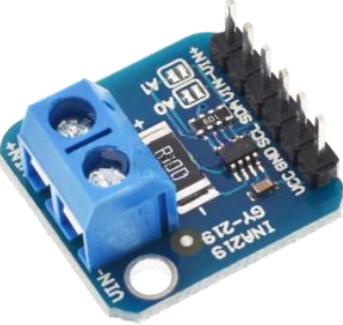


Figure 2. 4 ACS712 20A Current Sensor Module [20]

Chapter2: Hardware and Software Design of the Project

➤ *Current sensor alternatives*

Table 2. 3 current sensor alternatives

<i>Name of the Model</i>	<i>How it Works</i>	<i>Advantages</i>	<i>Disadvantages</i>
<p>ACS758</p> 	<p>A Hall-effect current sensor that measures higher currents (up to 200A), with analog voltage output proportional to the sensed current.</p>	<p>*Supports higher current range, *Robust, *Good accuracy.</p>	<p>*More expensive, *Physically larger than ACS712.</p>
<p>INA219</p> 	<p>A current and voltage sensor that uses I2C communication, provides high-side current measurements with high precision.</p>	<p>*Very accurate, measures both voltage and current, *Easy to interface with microcontrollers.</p>	<p>*Lower maximum current compared to ACS712, *More complex to set up.</p>
<p>Hall Effect Sensor WCS1800</p> 	<p>Uses Hall effect principle to measure AC or DC current, outputs an analog signal proportional to the current.</p>	<p>*Good for isolated measurements, *Cheaper than ACS758.</p>	<p>*Lower precision and current range than ACS758.</p>

II.1.3. ZMPT101B Voltage Sensor

The ZMPT101B is a high-precision voltage sensor module designed for measuring AC voltage. It uses a small voltage transformer to safely and accurately sense voltage changes, often used in energy monitoring and automation systems.

➤ *Characteristics*

- **Dimensions:** 51 mm x 21 mm x 21 mm
- **Voltage measurement range:** Up to 250V AC

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- **Output signal:** Analog voltage
- High-precision operational amplifier built-in
- **Operating voltage:** 5V to 30V DC
- **Operating temperature:** -40°C to +70°C
- Lightweight and compact design

➤ **Functional Principle**

The module uses a ZMPT101B transformer to step down the AC voltage. The voltage is then amplified by the onboard op-amp and converted to an analog signal that a microcontroller (like Arduino) can read and analyze. [21]

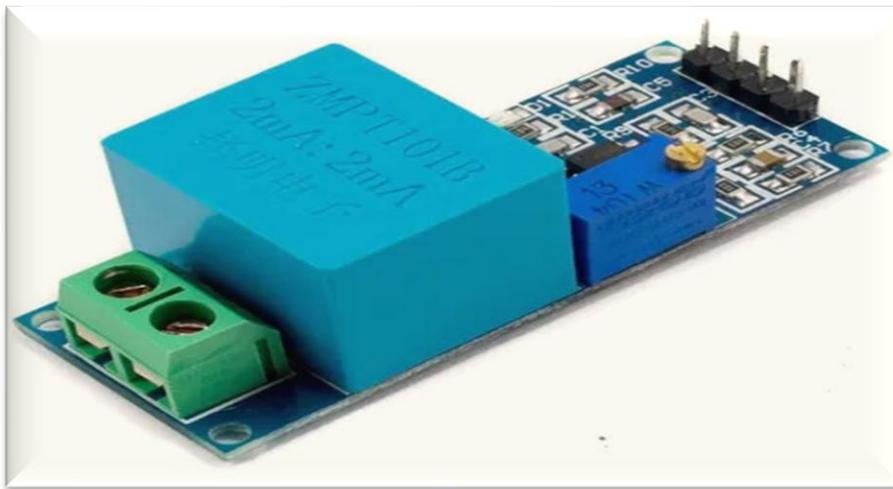


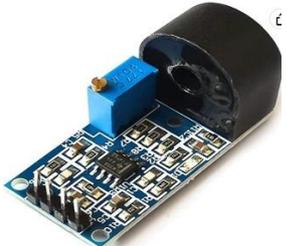
Figure 2. 5 ZMPT 101B Voltage Sensor [21]

➤ **Voltage sensor alternatives**

To facilitate the selection of the appropriate sensor for the application, the table below compares several voltage sensors by detailing their operating principles, as well as their main advantages and disadvantages. [22]

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Table 2. 4 voltage sensor alternatives

<i>Name of the Model</i>	<i>How it Works</i>	<i>Advantages</i>	<i>Disadvantages</i>
<p>PZEM-004T</p> 	Measures AC voltage, current, power, and energy via UART interface; ideal for AC mains monitoring.	<ul style="list-style-type: none"> *Multifunctional (voltage + current + power), *Accurate, *Easy integration. 	<ul style="list-style-type: none"> *Larger size, *More expensive than basic sensors.
<p>ADE7753</p> 	Specialized IC that measures voltage, current, real and apparent power, and energy via SPI interface.	<ul style="list-style-type: none"> *Very precise energy metering, *Used commercially. 	<ul style="list-style-type: none"> *Complex to integrate, *Needs external components and calibration.
<p>ZMCT103C + Burden Resistor</p> 	Current transformer sensor combined with a resistor to indirectly measure voltage by Ohm's law.	<ul style="list-style-type: none"> *Very cheap, *Flexible for DIY AC voltage measurements. 	<ul style="list-style-type: none"> *Less precise, *Requires additional circuitry and calibration.

II.1.4. YF-S201 Water Flow Sensor

The YF-S201 is a water flow sensor designed to measure the rate of flow of water in a pipe. It is commonly used in DIY electronics, automation, and fluid monitoring systems. [24]

➤ *Characteristics*

- **Working voltage:** 4.5V–18V DC
- **Flow range:** 1–30 L/min
- **Output:** 5V TTL, Pulse signal (Hall Effect sensor)
- **Accuracy:** ±10%

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- **Connection type:** 3-pin (VCC, GND, Signal)
- **Material:** Plastic body, suitable for cold water
- **Thread size:** 1/2 inch
- **Pulse rate:** \approx 450 pulses per liter (may vary with model)

➤ **Functional Principle**

The YF-S201 uses a Hall effect sensor to detect the rotation of a turbine inside the flow body. As water flows through, the turbine rotates, generating electrical pulses. These pulses are counted and converted into flow rate by a microcontroller. [23]



Figure 2. 6 YF-S201 Water Flow Sensor [24]

➤ **Different Water Flow Sensor**

In order to choose the most suitable flow sensor, the table below (2.5) presents several versions, along with an analysis of their operating principles, advantages, and limitations.

Table 2. 5 Water Flow Sensor alternatives [24]

<i>Name of the Model</i>	<i>How it Works</i>	<i>Advantages</i>	<i>Disadvantages</i>
 <i>YF-B5 Water Flow Sensor</i>	Measures water flow using a plastic valve body, a rotor, and a Hall-effect sensor to generate pulses proportional to flow rate.	*Higher pressure resistance, *More durable than YF-S201.	*Slightly more expensive than YF-S201.

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<p><i>G1/2 Water Flow Sensor</i></p>  A compact, black, cylindrical water flow sensor with a threaded inlet on the left and a multi-colored cable (red, yellow, green, blue) extending from the top.	<p>Similar principle with Hall-effect sensor; adapted for smaller pipe sizes (1/2 inch).</p>	<p>*Compact design, *Easy to install.</p>	<p>*Lower maximum flow rate supported.</p>
<p><i>FS300A Water Flow Sensor</i></p>  A larger, black, cylindrical water flow sensor with a threaded inlet on the left and a black cable with a connector extending from the top.	<p>Generates electrical pulses as water flows through; designed for household and industrial applications.</p>	<p>*High sensitivity, *Suitable for a wider range of liquids.</p>	<p>*Slightly larger, *May require calibration.</p>

II.1.5. Gas sensor MQ-2

The MQ-2 is an analog gas sensor that can identify the presence of smoke and flammable gases like butane, propane, and methane. It functions because of a heating element (tin oxide wire, or SnO₂) whose electrical resistance varies when gas is present. An electrical signal is generated that is proportional to the concentration of the detected gas. [30]

The MQ-2 is capable of detecting smoke as well as various other gases, including liquefied petroleum gas (LPG), alcohol, propane, hydrogen, methane, and carbon monoxide, with detectable concentration ranges between 200 and 10,000 ppm. [30]



Figure 2. 7 MQ-2 Gaz sensor [30]

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➤ *Characteristics*

- *Operating Voltage:* 5 V
- *Load Resistance:* 20 kΩ
- *Heater Resistance:* 33 Ω ± 5%
- *Heater Power Consumption:* Less than 800 MW
- *Sensing Resistance:* 10 kΩ
- *Detection Range:* 200 to 10,000 ppm
- *Preheating Time:* More than 24 hours [30]

➤ *Functional Principle*

- The sensor's **sensitive material is typically tin dioxide (SnO₂)**, which exhibits low conductivity in clean air.
- When **reducing gases** (like LPG, methane, CO, alcohol, hydrogen) are present, they react with oxygen ions adsorbed on the surface of SnO₂.
- This chemical reaction **releases electrons back into the conduction band**, reducing the resistance of the sensor.
- The **change in resistance is proportional to the concentration** of the gas, allowing detection and estimation of gas levels. [31]

➤ *MQ-2 Gaz Sensor alternatives*

Each sensor in the MQ family is tuned for specific gases or applications:

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Table 2. 6 MQ-2 Gaz Sensor alternatives [31]MQ-2 Gaz Sensor alternatives [31]

<i>Name of the Model</i>	<i>How it Works</i>	<i>Advantages</i>	<i>Disadvantages</i>
<p>MQ-3</p> 	<p>*MQ-3 detects alcohol vapors based on changes in the resistance of a tin dioxide (SnO₂) semiconductor.</p>	<p>*High sensitivity to alcohol. *Useful for breathalyzer applications.</p>	<p>*Sensitive to other gases like benzene and smoke, *Which can lead to false positives.</p>
<p>MQ-4</p> 	<p>The MQ-4 is designed to detect methane (CH₄).</p>	<p>*High selectivity for methane, *Making it suitable for natural gas leak detectors.</p>	<p>*Requires a preheating time of 24 hours for stable results.</p>
<p>MQ-5</p> 	<p>The MQ-5 detects LPG (liquefied petroleum gas), natural gas, and town gas.</p>	<p>*Versatile sensor that can detect multiple combustible gases.</p>	<p>*Less specific than other sensors, *Making it harder to isolate one gas in mixed environments</p>

II.1.6. LCD1602 display with I2C

The **LCD1602 with I2C** is a 16x2 character liquid crystal display module that uses the I2C communication protocol to simplify wiring and control using only two data lines (SDA and SCL). It displays alphanumeric characters on two rows of 16 characters each.

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➤ *Characteristics*

- **Display:** 2 lines × 16 characters
- **Controller:** HD44780 compatible
- **Communication:** I2C (uses PCF8574 I/O expander)
- **Voltage:** 5V DC
- **Backlight:** LED (usually blue with white characters)
- **Contrast adjustment** via potentiometer on I2C board
- **Dimensions:** ~80mm × 36mm × 12mm



Figure 2. 8 The LCD1602 [22]

➤ *Functional Principle*

The I2C module (based on PCF8574) acts as an I/O expander that communicates with the microcontroller via the I2C protocol. It sends commands and data to the LCD's internal controller (usually HD44780), which manages the display of characters. Only two pins (SDA and SCL) are needed, reducing the required GPIO pins on the microcontroller. [22]

➤ *Deferent types of LCD*

The following table presents the main types of LCD screens, describing their operation, as well as their respective advantages and disadvantages.

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Table 2. 7 LCD alternatives models [22]

<i>Name of the Model</i>	<i>How it Works</i>	<i>Advantages</i>	<i>Disadvantages</i>
<p><i>OLED Display 0.96" (I2C)</i></p> 	<p>Displays data using organic (LEDs), communicates over I2C, no backlight needed.</p>	<p>High contrast, low power consumption, very sharp text and graphics.</p>	<p>Smaller screen size compared to LCD 1602.</p>
<p><i>TFT 1.8" SPI Display</i></p> 	<p>Uses thin-film transistor LCD to show colorful text and images via SPI communication.</p>	<p>Supports color graphics, better visuals.</p>	<p>More complex wiring and coding, higher power consumption.</p>
<p><i>Nokia 5110 LCD</i></p> 	<p>Monochrome LCD originally used in Nokia phones; communicates via SPI.</p>	<p>Low cost, very low power, simple graphics/text.</p>	<p>Limited resolution (84×48 pixels), monochrome only.</p>

II.1.7. Two channel Relay Module (5V)

The **5V 2-Channel Relay Module** is an electronic switching device that allows a microcontroller (like Arduino or ESP32) to control two high-voltage AC or DC devices using 5V signals. It acts as an interface between low-power logic circuits and high-power loads.

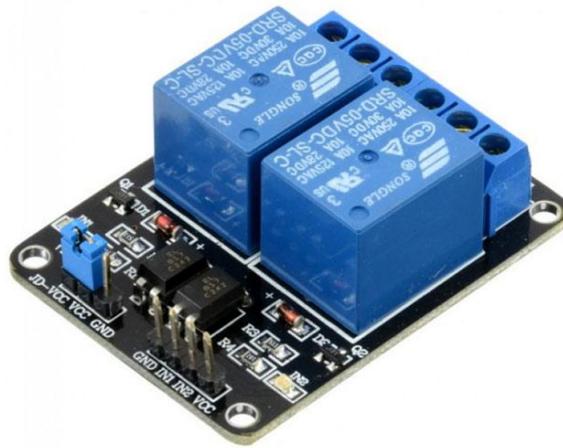


Figure 2. 9 5V 2-Channel Relay Module [23]

➤ *Characteristics*

- **Operating Voltage:** 5V DC
- **Channels:** 2 (can control two devices)
- **Relay Type:** SPDT (Single Pole Double Throw)
- **Max Load:** 10A at 250V AC or 10A at 30V DC
- **Trigger Level:** Low-level trigger (can be triggered with 0V signal)
- **Optocoupler Isolation:** Yes, for safer operation
- **Indicator LEDs:** Shows the status of each relay

➤ *Functional Principle*

Each relay on the module is triggered by a control signal from the microcontroller. When the input pin receives a LOW signal, it activates the transistor and energizes the relay coil, causing the normally open contact to close and power the connected device. Optocouplers isolate the microcontroller from high voltages. [23]

➤ *different types of relays*

To select the most suitable relay for the application, the table below presents the different relay technologies along with their operating principles, advantages, and limitations.

Table 2. 8 Alternatives Relay Module [23]

<i>Name of the Model</i>	<i>How it Works</i>	<i>Advantages</i>	<i>Disadvantages</i>
<p>8-Channel 5V Relay Module</p> 	<p>Uses electromagnetic relays to switch multiple high-voltage devices using low-voltage signals.</p>	<p>Controls up to 8 devices, ideal for large projects.</p>	<p>Bulkier size, higher power consumption</p>
<p>Solid State Relay (SSR) 5V Module</p> 	<p>Uses semiconductors to perform switching without moving parts, triggered by a low voltage.</p>	<p>Silent operation, faster switching, longer lifespan.</p>	<p>More expensive, sometimes limited to AC load switching.</p>
<p>Single Channel 5V Relay Module</p> 	<p>Same working principle as 2-channel but only controls one device.</p>	<p>Compact, cheaper, simple wiring.</p>	<p>Can only control one device.</p>

II.1.8. Light Emitting Diode (LED)

A Light Emitting Diode (LED) is an optoelectronic device capable of emitting light when an electric current flows through it. Like a conventional diode, the LED allows current to pass in one direction (forward bias) and blocks it in the opposite direction (reverse bias). Thus, each LED has its own characteristic threshold voltage. [30]



Figure 2. 10 Light Emitting Diode (LED) [30]

II.1.9. Buzzer

A buzzer is an audio signaling device that produces a sound when activated. There are two main types of buzzers: electromechanical buzzers and piezoelectric buzzers.

- Electromechanical buzzers are typically housed in a small rectangular or cylindrical casing, with either rigid electrical terminals for direct mounting on a printed circuit board (PCB) or flexible wire leads. They operate with a direct current (DC) voltage, usually ranging from 3 V to 28 V. [30]
- Piezoelectric buzzers consist of a piezoelectric diaphragm, a cavity with an acoustic opening, and terminals for electrical connections. These buzzers require an alternating voltage between 3 V and 30 V, with a frequency ranging from 2 kHz to 10 kHz to function. Piezoelectric buzzers are commonly used to produce beeps, tones, and alerts.



Figure 2. 11 Piezoelectric buzzers [30]

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Table 2. 9 Deferent types of buzzers

<i>Type of buzzers</i>	<i>How it Works</i>	<i>Advantages</i>	<i>Disadvantages</i>
<i>External-Drive</i>  A cylindrical black buzzer with a circular top and a base with two pins. The top is shown in two views: one showing the internal coil and diaphragm, and another showing the top surface with a small hole.	Requires an external AC signal (usually from a microcontroller) to operate.	Allows flexible sound design (custom tones).	Needs a separate driving circuit.
<i>Magnetic Buzzer</i>  A cylindrical black buzzer with a circular top and a base with two pins. The top has a small hole in the center.	Operates using magnetic force on a diaphragm, driven by AC or pulsed DC.	Compact and reliable for simple alerts.	Limited sound range.
<i>Mechanical Buzzer</i>  A rectangular black buzzer with a red and black wire attached to the top. It has a small hole on the top surface.	Uses physical contact and mechanical vibration to produce sound.	Can produce louder sounds.	Bulky and less durable than electronic types.

Part 2: Software Part

In this section, we delve into the software tools employed in our project, focusing on the **Arduino IDE** and the **Blynk application**, both of which were integral to our development process. Additionally, we explore similar platforms that offer comparable functionalities.

II.2.1. Arduino IDE

Arduino IDE (Integrated Development Environment) is an open-source software tool used to develop programs using the Arduino language (based on C/C++). It is designed to be simple and beginner-friendly, allowing users to write, compile, and upload code to microcontrollers like Arduino Uno or ESP32 via USB. In our project, we utilized the Arduino IDE to write and upload code to our microcontroller, enabling us to control various hardware components effectively. [25]



Figure 2. 12 logo of the Arduino IDE [25]

➤ ***Advantages***

- ***User-friendly interface:*** Simple and easy for beginners.
- ***Large community support:*** With plenty of tutorials and pre-built libraries.
- ***Free and open source:*** Fully customizable and accessible.
- ***Supports multiple hardware boards:*** Including ESP8266, ESP32, and others.

➤ ***Disadvantages***

- Not ideal for managing large or complex projects.
- Less customizable compared to modern IDEs like VS Code.

➤ ***Operating principle***

- The user writes the source code in the Arduino language using the IDE.
- Pressing "Verify" compiles the code into machine-readable hex format.
- Clicking "Upload" transfers the code to the microcontroller via USB.
- The board immediately starts executing the uploaded code. [25]

II.2.2. Blynk Application

Blynk is a platform that allows developers to create mobile apps for controlling and monitoring IoT (Internet of Things) devices remotely. It provides a drag-and-drop interface to build interactive dashboards for devices like ESP32, Arduino, or Raspberry Pi via cloud or local servers. [26]

Chapter2: Hardware and Software Design of the Project

We employed Blynk in our project to facilitate remote monitoring and control of our system via a user-friendly mobile interface.



Figure 2. 13 logo of the Blynk application [26]

➤ *Advantages*

- Easy mobile app creation without coding.
- Immediate interaction with devices.
- Works with most popular microcontrollers.
- Devices can be accessed and controlled from anywhere. [26]

➤ *Disadvantages*

- Devices must stay connected to the Blynk server.
- The transition from Blynk Legacy to Blynk IoT can cause compatibility or adaptation issues.

➤ *Operating principle*

- The user creates a new project inside the Blynk mobile app.
- A unique Auth Token is generated and linked with the IoT device (e.g., ESP32).
- Widgets such as buttons, sliders, and graphs are added to the interface.
- Communication between the mobile app and the device is handled through Blynk Cloud or a local server. [26]

➤ *Similar Applications to Blynk*

II.2.3. Arduino IoT Cloud

An integrated platform by Arduino that enables users to build connected objects quickly and securely. It supports real-time data visualization, remote device control, and integration with services like Amazon Alexa and Google Assistant. [27]



Figure 2. 14 logo of the Arduino IoT cloud [27]

➤ *Operating principle*

- Define a "Thing" representing your device and its variables.
- Link your Arduino or compatible board to the platform.
- Use widgets to create a dashboard for monitoring and control.
- Upload the generated sketch to your device and monitor its performance remotely. [27]

➤ *Advantages*

- Simplifies IoT project development with minimal coding.
- Generates Arduino sketches automatically when setting up new devices.
- Allows remote firmware updates for supported devices. [27]

➤ *Disadvantages*

- The free tier has restrictions on the number of devices and data retention.
- Requires a stable internet connection for real-time operations.
- May lack some advanced features found in other IoT platforms. [27]

II.2.4. Thing Speak

Thing Speak is an IoT analytics platform service that allows users to aggregate, visualize, and analyze live data streams in the cloud. It enables real-time data collection and analysis using MATLAB integration, making it ideal for prototyping and proof-of-concept IoT systems. [28]



Figure 2. 15 Logo of thing speak application [28]

➤ ***Operating principle***

- Define channels to collect and store data from devices via HTTP or MQTT protocols.
- The platform stores the data in the cloud and provides tools to visualize it using charts.
- Utilize MATLAB integration for data analysis and visualization.
- It can also trigger actions or alerts based on specific conditions (e.g., send email or control a device). [28]

➤ ***Advantages***

- Allows execution of MATLAB code for online analysis and data processing.
- Supports data collection via REST and MQTT APIs.
- Ideal for prototyping and proof-of-concept IoT systems. [28]

➤ ***Disadvantages***

- The free version may have limitations on data storage and processing capabilities.
- Advanced analysis requires familiarity with MATLAB.
- Requires an internet connection for data transmission and analysis. [28]

II.2.5. Flutter

Flutter is a free and open-source mobile user interface framework developed by Google and released in May 2017. It allows developers to create native mobile applications for both iOS and Android using a single programming language and a single codebase.



Figure 2. 16 logo of Flutter [29]

➤ *Operating principle*

Flutter uses a **Software Development Kit (SDK)** to help developers compile their code into native machine code for iOS and Android. It also provides a **Framework** based on reusable UI components (widgets), allowing developers to build customized interfaces. Programming is done using **Dart**, a typed object-oriented language created by Google, which focuses on front-end development. [29]

➤ *Advantages*

- One programming language and one codebase for both iOS and Android apps.
- The widget-based framework and hot reload features.

➤ *Disadvantages*

- Developers must learn Dart, a less commonly used language compared to JavaScript or Java.
- Flutter apps can have larger file sizes compared to native apps.
- Some specific platform features might require native code integration.

II.3. CONCLUSION

The design of a smart meter mainly relies on a rigorous selection and an optimized integration of hardware components as well as the interface used for programming the communication system. The choice of sensors, such as the **ACS712 20A** for current measurement and the **ZMPT101B** for voltage, the **YF-S201** for measuring water consumption flow rate, and the **MQ-2** for gas leak detection, is crucial to ensure the accuracy and reliability of energy parameter measurements. These components, combined with a high-performance microcontroller 'ESP32' and suitable communication modules, enable efficient real-time data collection.

All of this has been successfully integrated to ensure that our project runs smoothly. This sets the stage for the results that we will explore in more detail in the next chapter.

Chapter 3:
Realisation and
Practical Results

III. Introduction

After having thoroughly detailed in the previous chapter the design of the necessary elements for the realization of a multifunctional smart energy meter. This section will allow us to move from theory to experimentation by creating and configuring the system for real-world use. We will discuss programming, implementation, and testing to verify the operation of our meter while adhering to well-studied specifications.

III.1. Synoptic diagram

Figure 3.1 presents the synoptic diagram of the implementation of a multifunctional smart meter based on the ESP32. This diagram highlights the various components and modules required, such as the measurement sensor, data processing circuits, and communication interfaces 'Blynk'. It also illustrates the interactions and the flow of information between the elements, allowing for a visualization of the overall architecture and the key processes of the smart meter's operating system.

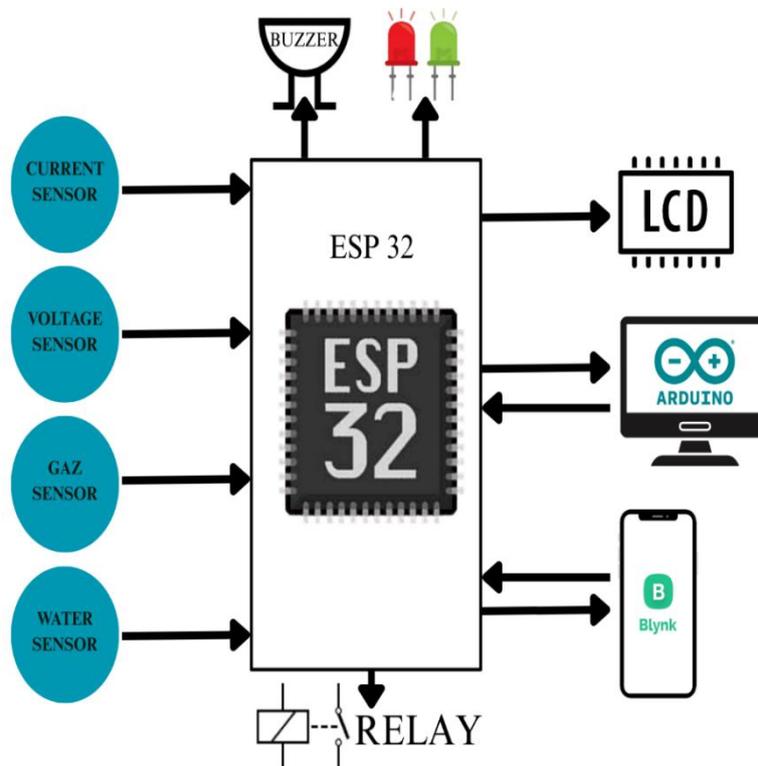


Figure 3. 1 Synoptic diagram of the multifunctional smart meter

III.2. Communication protocol

The multifunctional smart meter offers customers the ability to monitor their consumption from anywhere, in addition to allowing them to control it. In our multifunctional smart meter system (electricity, water, gas detection), communication between the microcontroller (ESP32) and the user is ensured through the Blynk platform. The measured data (voltage, current, water flow, gas detection) is transmitted via Wi-Fi to the Blynk Cloud server, which acts as an intermediary between the microcontroller and the mobile application. The Blynk application thus allows the user to visualize energy and water consumption in real-time and to be notified immediately in case of an anomaly (e.g., gas leak). Moreover, remote commands (such as automatic shutdown via relay) can be sent from the mobile interface to the ESP32, making the system interactive and responsive.

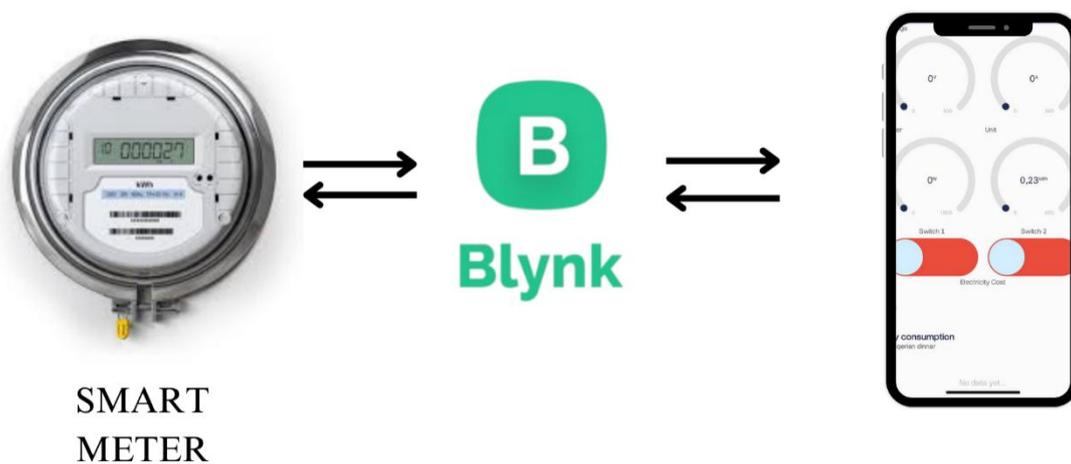


Figure 3. 2 Block Diagram of Communication Protocol

II.3. Design and development of the 'Blynk' application

II.3.1. Blynk Application

Blynk is an application optimized to work on Android and iOS devices. This solution allows us to easily manage various IoT-based applications by leveraging the power of our smartphones. We can create a fully customized graphical user interface tailored to our specific IoT applications. As part of our project, we want to display the data from our IoT electric energy meter within the Blynk application.

So, we downloaded and installed the Blynk app from the Google Play Store (iOS users can download it from the App Store). Once the installation is complete, we opened the application and registered via email.



Figure 3. 3 Blynk App Logo

III.3.2. Blynk Library

Blynk is the most popular Internet of Things platform for connecting any hardware to the cloud, designing applications to control them, and managing your products deployed on a scale. With the Blynk Library, you can connect over 400 hardware models, including Arduino, ESP8266, and ESP32, to the Blynk Cloud.

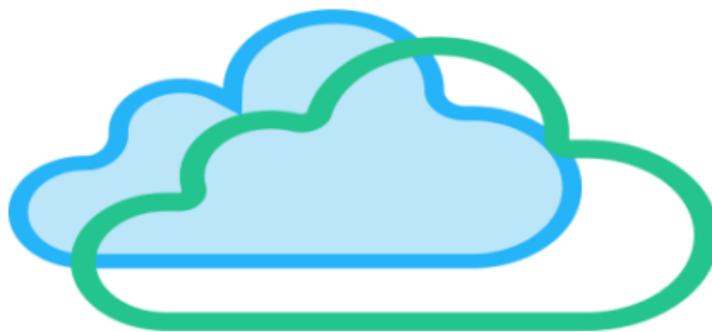


Figure 3. 4 Blynk Library Logo

III.3.3. Installation of the Blynk library

The Blynk library can be installed using the Arduino IDE's library manager. Simply search for "**Blynk**" and click "**Install**" to integrate it into your project. This library enables communication between a microcontroller "**ESP 32**" and the Blynk mobile application, enabling remote control of electronic components via a smartphone interface.

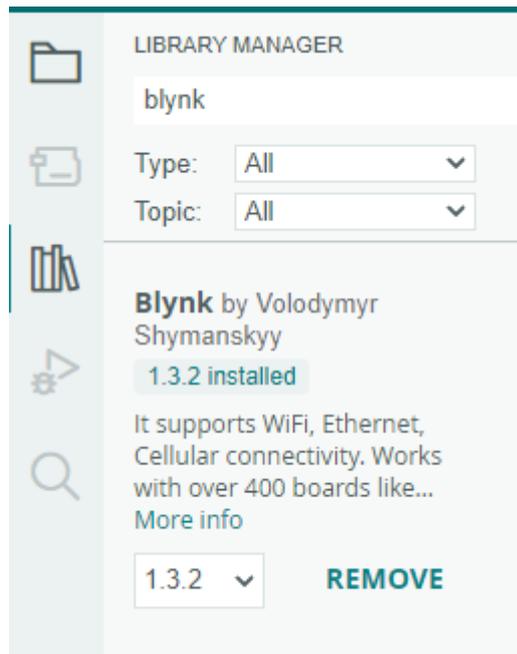


Figure 3. 5 Blynk Library

The project starts by including several libraries. These libraries enable communication with hardware modules and external services:

- **ACS712:** The library simplifies the reading of current (AC or DC) using the ACS712 sensor, automating the calculations and compensation of the analog signal.
- **LiquidCrystal_I2C:** Controls a 16x2 LCD with I2C communication.
- **BlynkESP32_BT_WF:** Extends blynk to support both Wi-Fi and Bluetooth on ESP32
- **Blynk:** Core library for managing communication with the blynk cloud or local server.
- **Http Client:** Allows the ESP32 to make HTTP requests (GET, POST...)
- **Ace Wire:** A lightweight Arduino library for I2C communication.

Chapter 3: Realization and Practical Results

The screenshot displays the Arduino IDE Library Manager interface. It features a grid of library cards, each with the library name, author, version, and a 'REMOVE' button. The libraries shown are:

- HttpClient** by Adrian McEwen... (2.2.0 installed)
- Blynk** by Volodymyr Shymanskyi (1.3.2 installed)
- BlynkESP32_BT_WF** by Khoi Hoang (1.2.2 installed)
- AceWire** by Brian T. Park (0.4.1 installed)
- LiquidCrystal I2C** by Frank de Brabander (1.1.2 installed)

On the right side, a 'LIBRARY MANAGER' sidebar is visible, showing a search filter for 'ACS712' and a list of search results, including 'ACS712' by Rob Tillaart and Pete Thompson (0.3.9 installed).

Figure 3. 6 Project Libraries

➤ *Boards manager*

To use the ESP32 with the Arduino IDE, you first need to add it via the board manager. This is done by inserting the configuration URL into the preferences, then installing the ESP32 package to make the board compatible with the development environment.

The screenshot shows the 'esp32' package in the Board Manager. It includes the package name, author (Espressif Systems), version (3.2.0 installed), a list of boards included in the package (unPhone 7, Namino Arancio, SparkFun ESP32-C6 Thing Plus, etc.), and a 'REMOVE' button.

Figure 3. 7 board manager of project we needed

III.3.4. Create a project in Blynk

In this section, we will demonstrate the creation of a new project steps.

- To create a new project in the Blynk application by selecting the control device 'ESP32', then choosing the type of connection.

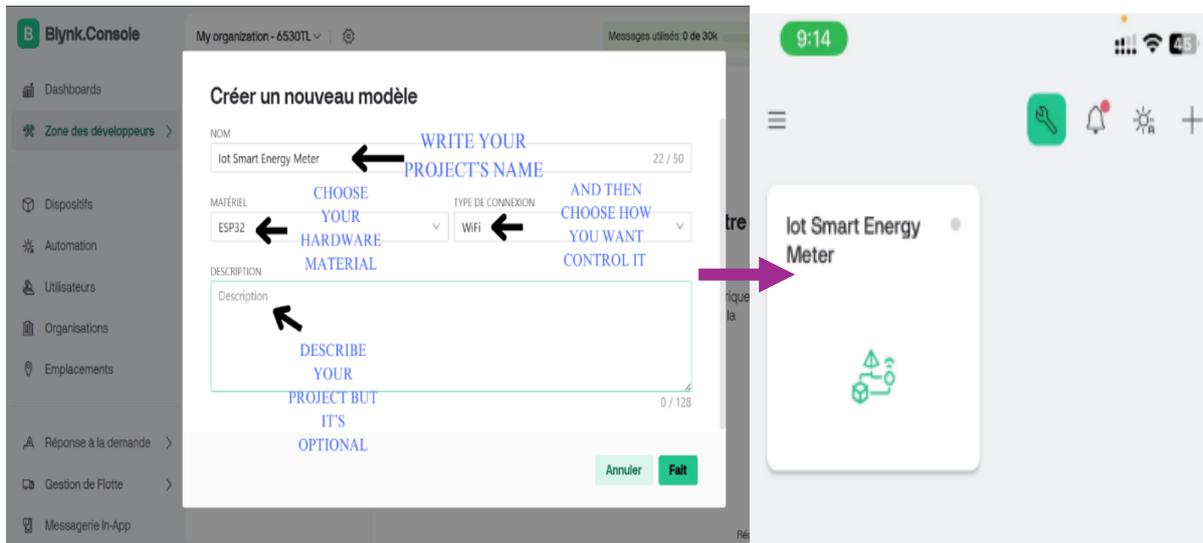


Figure 3. 8 Creation of a new project

Blynk's virtual pins facilitate interaction between the mobile app and hardware components, enabling control and data display. They act as a bridge between interface elements and physical devices like sensors, LEDs, or relays, allowing real-time monitoring. We take an example, the voltage value read from a sensor can be sent to the app using a virtual pin to monitor it in real time.



Figure 3. 9 Creation of a new virtual pin

III.3.5. Create a widget in Blynk

Widgets in Blynk let users interact with hardware through the app. for example, to monitor voltage, you can use a Gauge or Label widget linked to a virtual pin that receives voltage readings from the sensor.

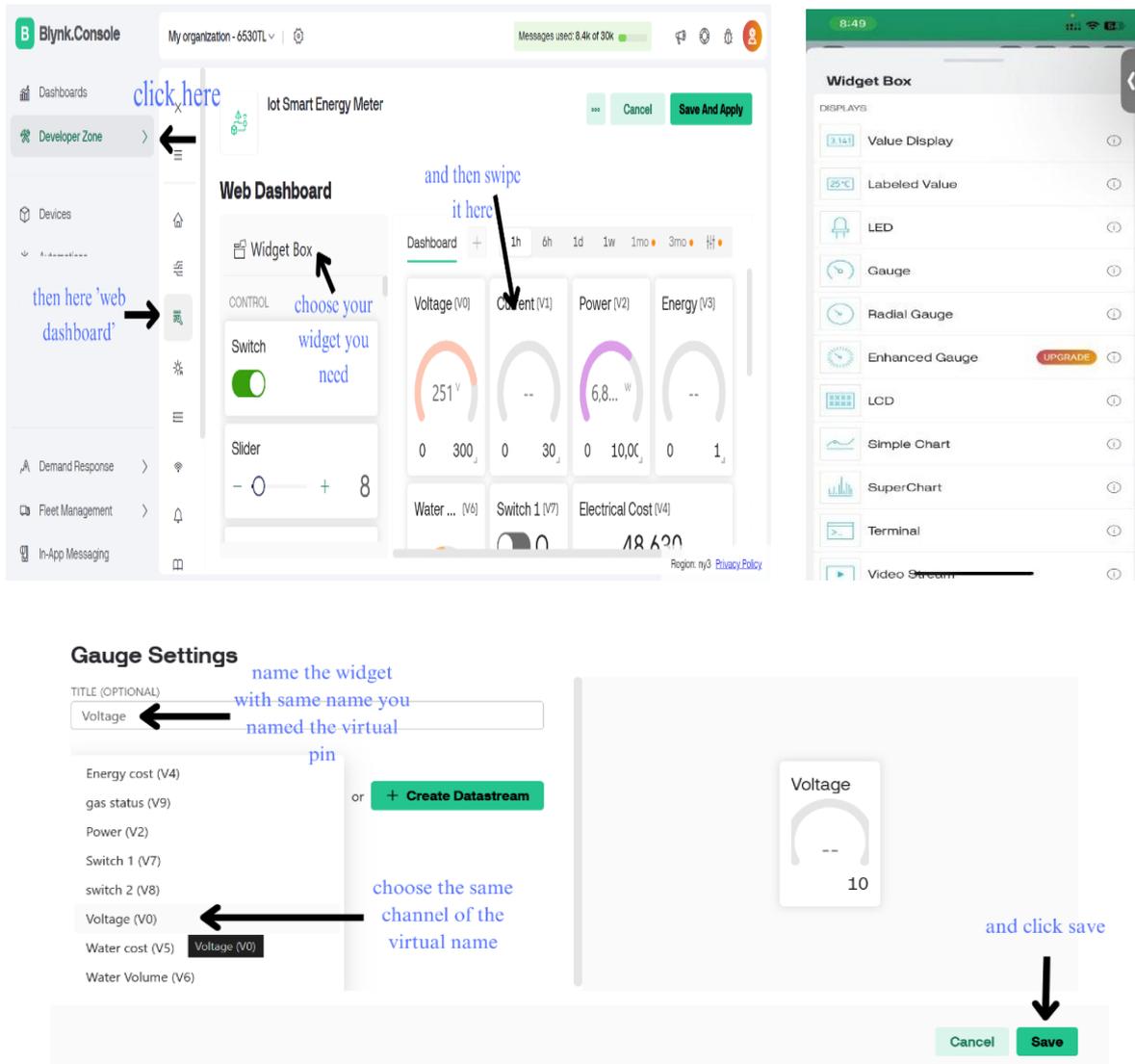


Figure 3. 10 creation of THE new widgets

III.4. System flowchart

Our multifunctional Smart Energy Meter is a device designed to monitor and manage the consumption of electricity and water, and to detect gas leaks. It operates based on three main principles:

- **Complete Monitoring:** Real-time display of electricity, water, and gas consumption, along with their costs, both on an LCD screen and smartphone.
- **Remote Access and Control:** Full control of the system anytime, anywhere through the Blynk mobile app.
- **Home Safety:** built-in gas leak detection that instantly alerts the user and takes automatic action to ensure household protection.

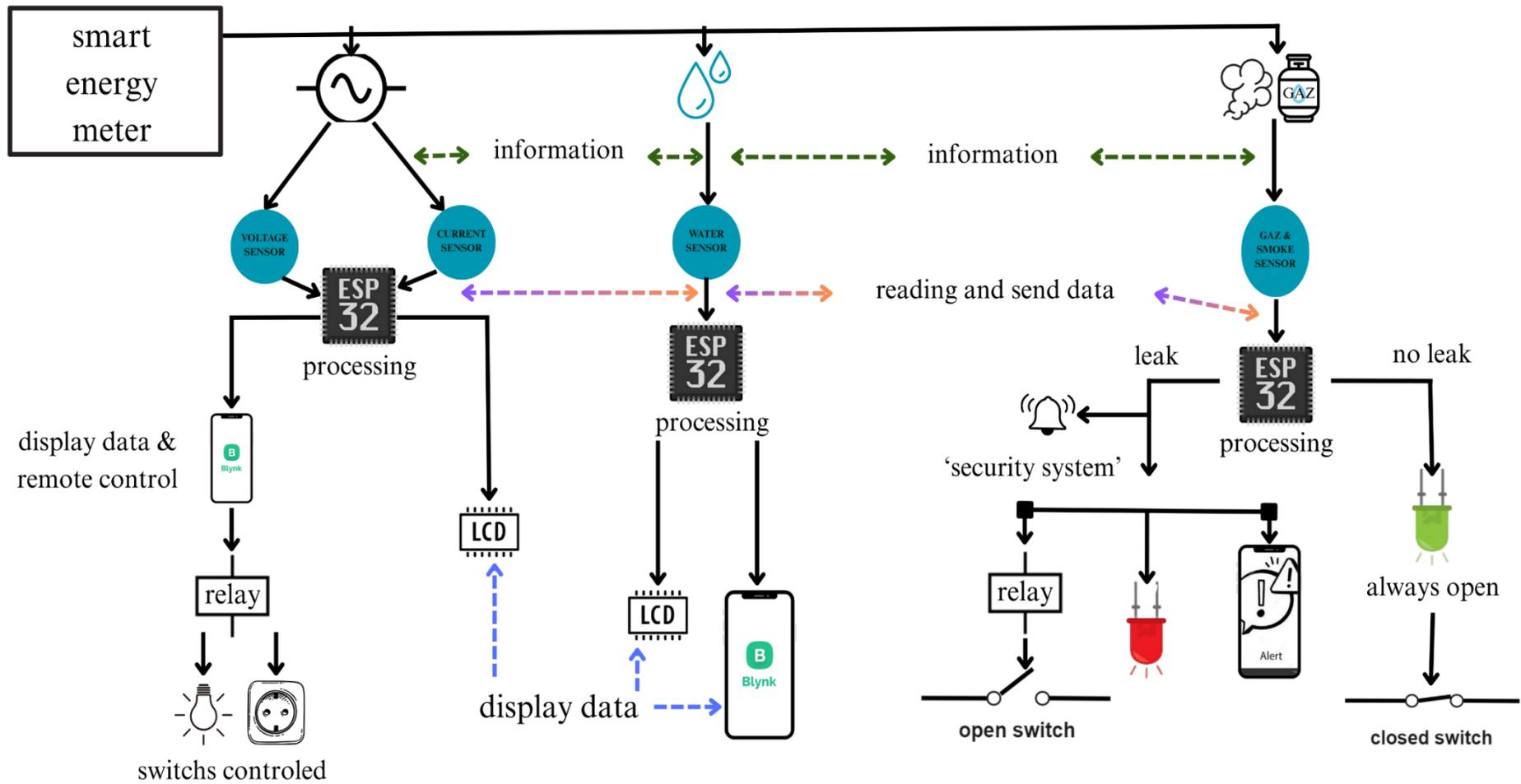


Figure 3. 11 Flowchart of the Operation of Our System

III.5. Main Parts of Smart Meter Code

III.5.1. Connecting ESP32 with Blynk and WIFI

First, Blynk credentials are defined (template ID, device name, auth token), which link the ESP32 to the correct Blynk project and the correct WIFI.

```
1  #define BLYNK_TEMPLATE_ID "TMPL2JRwKXPM"
2  #define BLYNK_TEMPLATE_NAME "Iot Smart Energy Meter"
3  #define BLYNK_AUTH_TOKEN "mGfC378daLagZxAFOzAEK8tIgr1cKdr"

14 const char* ssid = "D-Link";
15 const char* pass = "Anes 1234";
```

Figure 3. 12 ESP32 Wi-Fi and Blynk Connectivity Setup Diagram.

III.5.2. Pin and Sensor Configuration

We define pins for each component: voltage sensor, current sensor, gas sensor, water sensor (interrupt), relays, green and red LED, and buzzer.

```
20  const int voltagePin = 35;
21  const int currentPin = 34;
25  const int flowSensorPin = 27;
39  const int relay1Pin = 25;
40  const int relay2Pin = 26;
42  const int gasSensorPin = 36;
44  const int greenLedPin = 16;
45  const int redLedPin = 17;
46  const int buzzerPin = 18;

12  LiquidCrystal_I2C lcd(0x27, 16, 2);
```

Figure 3. 13 Hardware Pin Configuration and Mapping in ESP32-Based Smart Meter.

III.5.3. Tariff and Cost Variables

These hold electricity and water prices used to calculate cost based on usage.

```

60 float calculateEnergyCost(float totalEnergy) {
61     if (totalEnergy <= 125) return totalEnergy * rate1 / 10000;
62     if (totalEnergy <= 250) return (125 * rate1 + (totalEnergy - 125) * rate2) / 10000;
63     if (totalEnergy <= 1000) return (125 * rate1 + 125 * rate2 + (totalEnergy - 250) * rate3) / 10000;
64     return (125 * rate1 + 125 * rate2 + 750 * rate3 + (totalEnergy - 1000) * rate4) / 10000;
67 float calculateWaterCost(float totalVolume) {
68     float cost = 0.0;
69     float volume_m3 = totalVolume / 1000.0;
70     if (volume_m3 <= 25) {
71         cost = volume_m3 * baseTariff;
72     } else if (volume_m3 <= 55) {
73         cost = (25 * baseTariff) + ((volume_m3 - 25) * 20.48);
74     } else if (volume_m3 <= 82) {
75         cost = (25 * baseTariff) + (30 * 20.48) + ((volume_m3 - 55) * 34.65);
76     } else {
77         cost = (25 * baseTariff) + (30 * 20.48) + (27 * 34.65) + ((volume_m3 - 82) * 40.95);
78     }
79     int full_m3 = (int)volume_m3;
80     cost += full_m3 * sewageFee;
81     return cost;

```

Figure 3. 14 Data Structure for Electricity and Water Tariff Calculations.

III.5.4. LCD Display Update

Cycles through different pages showing voltage, current, power, energy, water, and gas.

```

84 void updateLCD() {
85     lcd.clear();
86     if (gasLeakDetected) {
87         lcd.setCursor(0, 0); lcd.print("!!! GAS LEAK !!!");
88         lcd.setCursor(0, 1); lcd.print("Shutting Down...");
89         return;
90     }
91     static int screen = 0;
92     switch (screen) {
93     case 0:
94         lcd.setCursor(0, 0); lcd.print("Smart Energy");
95         lcd.setCursor(0, 1); lcd.print("& Water Meter");
96         break;
97     case 1:
98         lcd.setCursor(0, 0); lcd.print("V="); lcd.print(voltage, 2);
99         lcd.print(" I="); lcd.print(current, 2);
100        lcd.setCursor(0, 1); lcd.print("P="); lcd.print(power, 2);
101        lcd.print(" E="); lcd.print(energy, 3);
102        break;
103     case 2:
104        lcd.setCursor(0, 0); lcd.print("Water:"); lcd.print(waterVolume, 1); lcd.print("L");
105        lcd.setCursor(0, 1); lcd.print(waterVolume / 1000, 3); lcd.print("m3");
106        break;
107     case 3:
108        lcd.setCursor(0, 0); lcd.print("ECost="); lcd.print(cost, 2); lcd.print(" DA");
109        lcd.setCursor(0, 1); lcd.print("WCost="); lcd.print(waterCost, 2); lcd.print(" DA");

```

Figure 3. 15 LCD Interface Showing Cyclical Display of Electrical and Water Measurements.

III.5.5. Gaz Sensor Readings

Reads gas level and safety response.

```
167     static bool eventSent = false;
168     if (gasLevel > gasThreshold) {
169         if (!gasLeakDetected) {
170             gasLeakDetected = true;
171             digitalWrite(relay1Pin, LOW);
172             digitalWrite(relay2Pin, LOW);
173             digitalWrite(redLedPin, HIGH);
174             digitalWrite(greenLedPin, LOW);
175             if (!eventSent) {
176                 Blynk.logEvent("gas_leak", "Gas Leak Detected!");
177                 eventSent = true;
```

Figure 3. 16 Gas Detection Workflow and Safety Response Mechanism Using MQ2 Sensor.

III.5.6. Send Data to Blynk

Sends real-time values to the Blynk app through virtual pins.

```
238     Blynk.virtualWrite(V0, voltage);
239     Blynk.virtualWrite(V1, current);
240     Blynk.virtualWrite(V2, power);
241     Blynk.virtualWrite(V3, energy);
242     Blynk.virtualWrite(V4, cost);
243     Blynk.virtualWrite(V5, waterVolume);
244     Blynk.virtualWrite(V6, waterCost);
```

Figure 3. 17 Real-Time Data Transmission from ESP32 to Blynk via Virtual Pins.

III.6. Calculation of energy consumed

In this project, was adopted for both electricity and water consumption. This system is chosen because it ensures fairness in pricing users pay more per unit as their consumption increases. It also encourages responsible usage and helps reduce waste.

III.6.1. Selected electrical Tariff

we used **Tarif 54M from SONELGAZ**, which applies to residential low-voltage consumers. It follows a **progressive pricing system**, where the rate increases with higher electricity usage. This tariff was chosen to ensure realistic billing aligned with national standards.

Table 3. 1 Tarif 54M from SONELGAZ

1st Bracket: from 0 to 125 kWh	177,87 cDA
2nd Bracket: more than 125 up to 250 kWh	417,89 cDA
3rd Bracket: more than 250 up to 1000 kWh	481,20 cDA
4th Bracket: up to 1000 kWh	547,96 cDA

➤ *Formula of energy consumption:*

$$E = \frac{P_a \cdot t}{3600000000}$$

➤ *Formula of consumption cost:*

To compute the total electricity bill: Total Bill = $\sum_{i=1}^n (E \times Ri)$

Where:

- Pa: Active power
- t: Time in hour
- 3600000000: 1000*3600*1000 (ms) to hour and joule to kwh.
- E: Quantity of electricity consumed in bracket
- Ri: Rate per kWh for bracket i
- n: Number of applicable brackets

III.6.2. Selected water Tariff

We used the **base water tariff of 6.30 DZD per cubic meter (m³)** in our calculations because the wilaya of **Biskra** is included in the **Constantine tariff zone**, which this rate applies to. This base tariff is assigned to the first consumption bracket, commonly referred to as the

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social bracket. The pricing model follows a progressive structure to ensure affordability for essential water needs while encouraging responsible consumption. The applicable coefficients for each bracket are:

Table 3. 2 coefficient of social bracket ‘Constantine tariff zone’

1st Bracket (up to 25 m³)	Coefficient 1.0
2nd Bracket (26–55 m³)	Coefficient 3.25
3rd Bracket (56–82 m³)	Coefficient 5.5
4th Bracket (above 82 m³)	Coefficient 6.5

➤ *Formula of consumption cost*

To compute the total water:

$$\text{Tarif of social bracket} = \sum_{i=1}^n (Q_i \times (\text{Tbase} \times C_i))$$

$$\text{Sanitation Tarif} = Q_i \times S_i$$

$$\text{Total bill} = (\text{Tarif of social bracket}) + (\text{Sanitation Tarif})$$

Where:

- Q_i : Quantity of water consumed in ‘social bracket’
- T base: Base tariff per m³ (in our Tarif is: **6.30 DZD**)
- C_i : Coefficient for ‘social bracket’
- S_i : Base Sanitation Tarif for ‘social bracket’ (in our tariff is: 2.35 DZD)
- n : Number of applicable brackets

III.7. Implementation and Practical Results of the Smart Meter

The implementation phase focused on assembling the selected components, programming the ESP32 microcontroller, and integrating the system with the Blynk mobile application. Once assembled and configured, the smart meter was tested in a real environment to evaluate its functionality and efficiency.

III.7.1. Project Prototype on Cirkuit Designer:

The smart meter circuit was designed using Cirkuit Designer to visualize component connections. This schematic offers a clear overview of the hardware setup, like a Simulink model, and supports the project's practical implementation

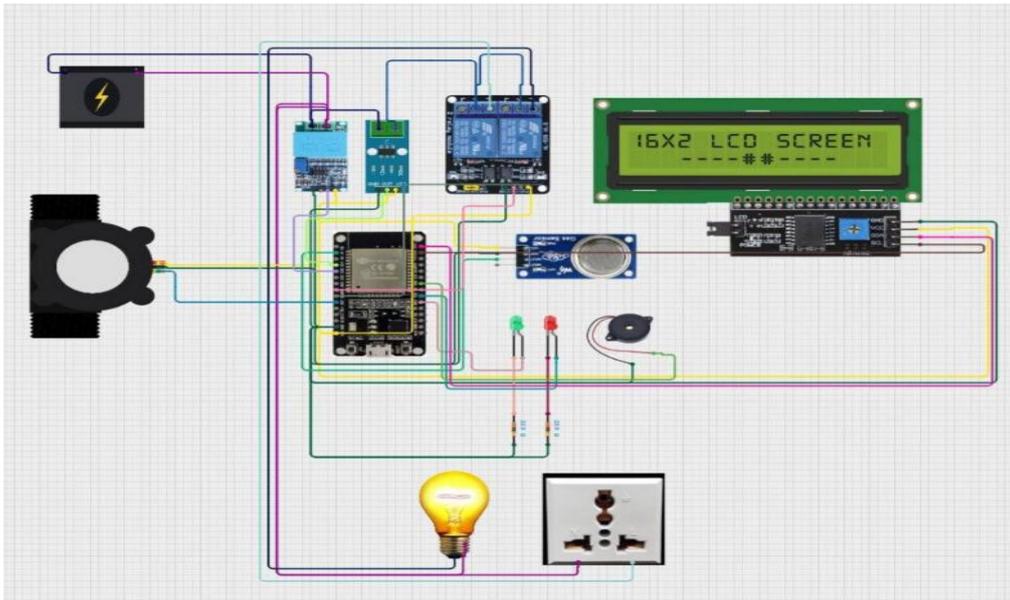


Figure 3. 18 Electrical Schematic of Our Project on Cirkuit Designer

This

section provides more detailed schematic overview.

- The output pin of the ACS712 is connected to GPIO34 of the ESP32 for current measurement.
 - The ZMPT101B is connected to GPIO35 for voltage measurement.
 - YF-S201 is connected to GPIO27 for measuring the The water.
 - MQ-2 is connected to GPIO36 for gas measurement.
 - The 5V relay, used to control the power supply, is connected to GPIO25 and P26.
 - Display LCD 16x02 uses the SCL pin on the and the SDA pin on GPIO21 and 22 of the ESP32 to communicate the information.
 - The buzzer, used for the sound alert, is connected to GPIO18.
- Green and red LED, used for visual alert, and connected to GPIO16 and GPIO17.

III.7.2. Components Used in Our Project

To ensure the proper operation of our smart metering system, it is crucial to select hardware components that meet the specific needs of the project. The selection was based on criteria such as performance, compatibility, power consumption, and cost.

- **(1) ESP32** – The main processor of this project, responsible for data processing and communication.
- **(2) Breadboard** – For prototyping and assembling the electronic circuit without soldering.
- **(3) 16x2 LCD Display** – Used to display the data sent by the ESP32 in real time.
- **(4) ZMPT101B Voltage Sensor** – Similar in function to a current sensor, but measures voltage instead.
- **(5) ACS712 20A Current Sensor** – Measures the current and sends the data to the ESP32.
- **(6) 2-Channel Relay Module** – Enables control of electrical devices through the ESP32.
- **(7) MQ-2 Gas Sensor** – Detects gas leaks to ensure home safety.
- **(8) Buzzer** – Provides audible alerts, especially in case of gas leaks.
- **(9) Meter Enclosure** – Protective cover that houses the system components.
- **(10) Green & Red LEDs** – Indicate system status (e.g., normal operation or alerts).
- **(11) YF-S201 Water Flow Sensor** – Measures water consumption in real time.
- **(12) Switch 1: Lamp** – Simulates a controllable electrical load (e.g., lighting).
- **(13) Switch 2: Type F Socket** – Represents a standard controllable power outlet.



Figure 3.19 Components Used in Our Project

III.7.3. Key Practical Results:

- **Accurate Data Display**

The system successfully displayed real-time electricity, water, and gas consumption on both the LCD screen, the Blynk app and multimeter.

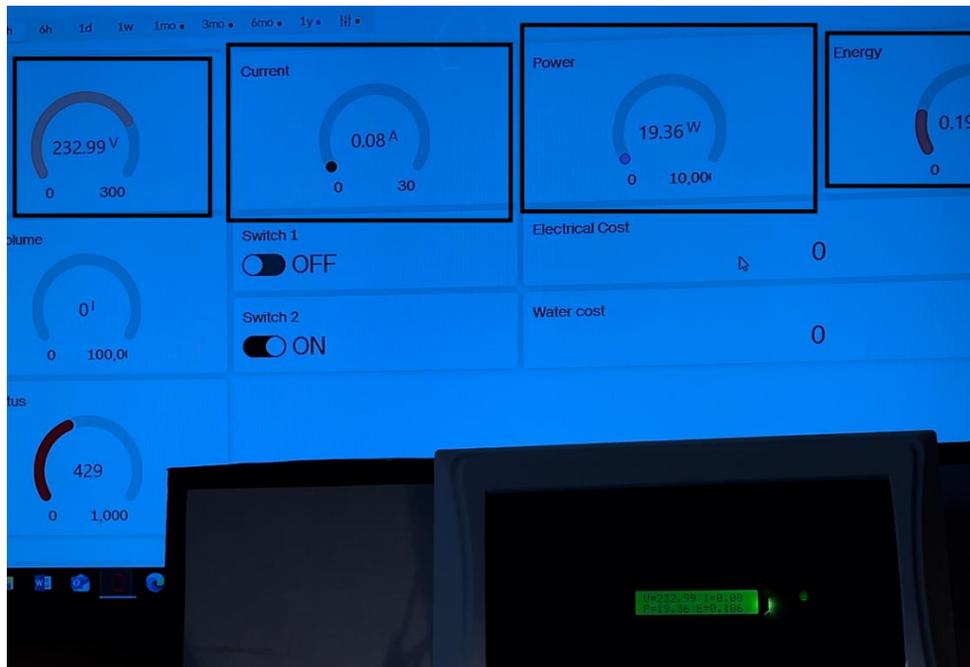


Figure 3.20 Comparison of Our Smart Meter Readings with Blynk Interface

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This figure shows the real-time electricity monitoring feature of our smart meter. Voltage, current, power and energy readings are clearly displayed on both the LCD screen and the Blynk app, demonstrating accurate measurement and smooth communication between the hardware and software components.

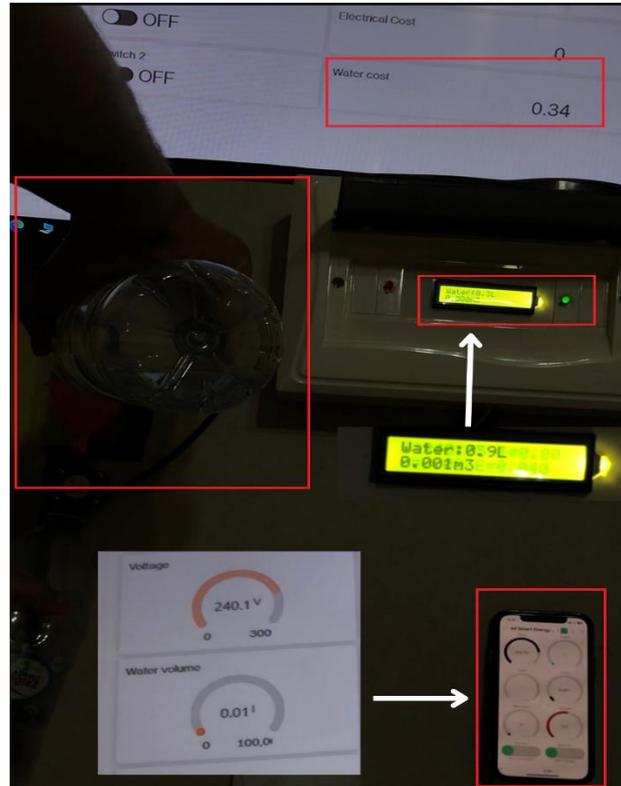


Figure 3. 21 Comparison of Our Smart Meter Reads water volume with Blynk Interface

This figure illustrates the water consumption tracking capability of the system. Real-time flow data is presented simultaneously on the LCD and the Blynk interface, confirming the system's ability to monitor water usage with precision and responsiveness.



Figure 3. 22 Comparison of Our Smart Meter Readings with Multimeter

This figure includes a comparison between the smart meter's electrical readings and those obtained from a standard digital multimeter. The exact match between the values confirms the accuracy and reliability of the system's electricity measurement functions.

- **Reliable Gas Leak Detection:**

The MQ-2 sensor accurately detected gas leaks, triggering alerts via the buzzer and smartphone notifications. In addition, a **green LED lights up when no gas is detected**, indicating normal conditions, while a **red LED turns on when a leak is detected** and the system automatically shuts off the gas supply through the relay to ensure maximum home safety.

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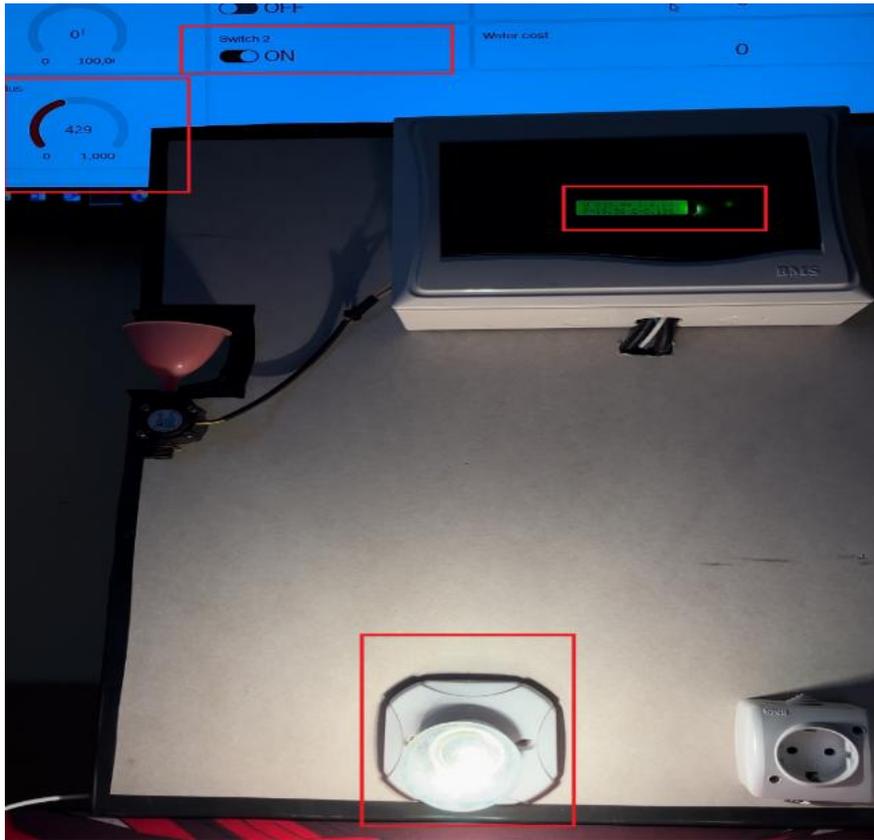


Figure 3. 23 Smart Meter Operating Under Normal Gas Levels

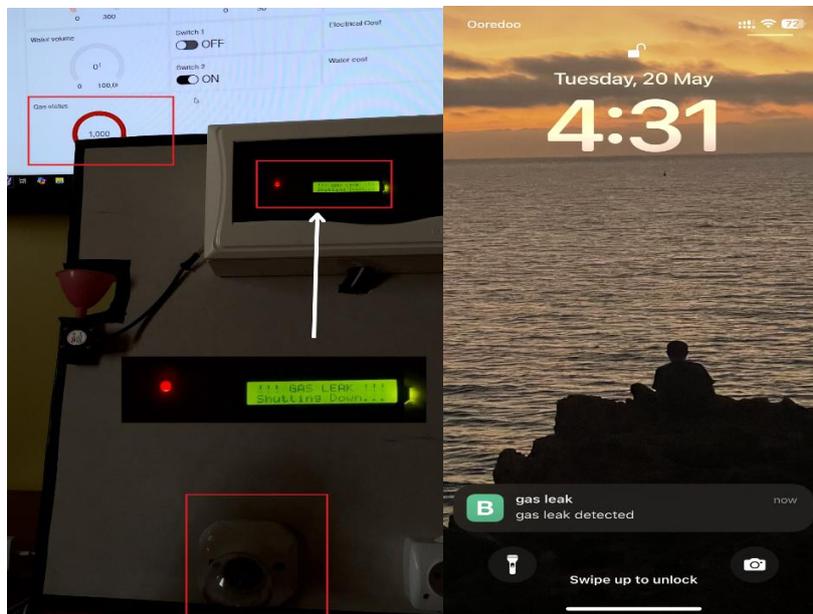


Figure 3. 24 Smart Meter Response During Gas Leak Detection

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These figures present a comparison between the smart meter's operation under normal gas levels and its response during a gas leak. When no gas is detected by the MQ-2 sensor, the system indicates normal conditions through a green LED, and all safety mechanisms remain inactive. In contrast, when a gas leak is detected, the sensor triggers a red LED warning, activates a buzzer alarm, sends an immediate smartphone notification, and automatically shuts off the electrical system supply via a relay.

This comparison highlights the system's ability to switch seamlessly between monitoring and emergency response modes to ensure household safety.

III.8. Conclusion

The practical realization of our multifunctional smart energy meter marks a significant step from theoretical design to functional, real-world application. Through careful integration of hardware components and thoughtful programming, the system successfully monitors electricity and water consumption while ensuring gas leak detection and safety intervention. The real-time synchronization between the LCD, Blynk app, and multimeter demonstrates high measurement accuracy and interface reliability. Moreover, the smart response to gas leaks with automatic alerts, LED signaling, and gas shutoff via relay, highlights the system's capacity for proactive home safety. These outcomes confirm not only the system's effectiveness but also its potential for real-life deployment in modern smart homes, offering both convenience and enhanced security.

General conclusion

General conclusion

In a world where intelligent energy management and home security are becoming essential priorities, our project is fully aligned with the search for innovative technological solutions that are both effective, accessible, and sustainable.

Through this project, we designed a multifunctional smart meter prototype, which constitutes a concrete solution capable of simultaneously monitoring electrical and water consumption, as well as detecting gas leaks, while ensuring quick and reliable real-time feedback to the user.

The core of the system is based on an ESP32 board, chosen for its processing capabilities, integrated Wi-Fi connectivity, and compatibility with various types of sensors. These ensure the real-time collection of environmental and consumption data, which are then processed and displayed locally on an LCD screen and remotely via the Blynk application to a smartphone, allowing the user to continuously monitor their consumption status. In case of gas or smoke detection, the system triggers a sound alarm (buzzer), a light alert (flashing LED), and sends an immediate notification to the user's smartphone. To enhance safety, a power relay automatically cuts off the general electrical supply of the house, thereby minimizing the risks of fire or explosion.

The evolution prospects of this system could include improvements, particularly through the integration of new features (consumption history, voice control, multi-user management) or the use of artificial intelligence for predictive analysis.

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