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Specialty: Electrical Engineering and Renewable Energies

TOPIC: Development of Power Quality Monitoring System for ASECNA Power Plants in Burkina Faso.

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Dedicaces

I dedicate this work to:

My family

Who believes in me and helps me to improve myself each day.

Brothers and sisters

Who encourage me to go forward with studies.

My teachers and mentors

Who spared no effort in teaching me and supervising my work.

Finally, to all my friends

I wear you in my heart.

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BIT Presentation

Burkina Institute of Technologies (BIT) is a higher education institution located in Palogo, in the city of Koudougou, at the heart of the Centre-West region of Burkina Faso.

BIT stands out with its course offerings in Computer Science, Electrical Engineering, and Mechanical Engineering. In a country where French is the official language, BIT makes a difference by delivering courses in English, thus providing its students with a valuable language skill in today's globalized professional world.

The mission of BIT is to train a new generation of leaders. The institute is committed to providing quality education that prepares its students to excel in their respective fields and make significant contributions to our ever-changing world.

BIT is under the leadership of Professor François ZOUGMOURE, with his staff , they bring their expertise and dedication to the institution, thereby contributing to its vision and mission.

Abstract

This study presents a design of a power quality monitoring system that underscores the importance of power quality analysis within the operational context of the Agency of Air Navigation Safety in Africa and Madagascar (ASECNA) power plant at Ouagadougou airport. ASECNA operates within a critical infrastructure framework where power quality is of utmost significance. Voltage, frequency, and power factor variations can significantly impact electrical equipment performance and the quality of energy supplied. Thus, the implementation of a robust monitoring system is indispensable for assessing and preserving power quality. The study's system integrates technology components, including the ESP32 microcontroller, the high-precision PZEM-004T-100A V3 sensor, and a user-friendly web page. Data acquisition, analysis, and visualization are the system's core functionalities. The ESP32 acts as the central data hub, capturing crucial electrical parameters, while the PZEM sensor ensures accurate measurements. Data analysis yields critical power quality metrics, such as voltage fluctuations, frequency variation, and power factor, all vital for assessing power supply stability and efficiency. The web app facilitates data visualization, simplifying complex power quality information for users. To enhance responsiveness to critical events, the system employs alerts, including a buzzer mechanism. This study serves as a testament to the power quality monitoring system's efficacy, tailor-made for the ASECNA power plant at Ouagadougou airport. It underscores the indispensable role of power quality monitoring in ensuring a reliable and efficient power supply, thus contributing significantly to the enduring success and sustainability of critical infrastructure operations.

Keywords:

1 - Power Quality Monitoring

2 - ASECNA Power Plant

3 - Voltage Fluctuations

4 - Frequency Variation

5 - Power Factor

Résumé

Cette étude présente un système de surveillance de la qualité de l'énergie conçu pour montrer l'importance primordiale de l'analyse de la qualité de l'énergie dans le contexte opérationnel de la centrale électrique de l'Agence pour la sécurité de la navigation aérienne en Afrique et à Madagascar (ASECNA) à l´aéroport de Ouagadougou. L'ASECNA opère dans un cadre d'infrastructure critique où la qualité de l'énergie est de la plus haute importance. Les variations de tension, de fréquence et de facteur de puissance ont un impact significatif sur les performances des équipements électriques. La mise en œuvre d'un système de surveillance robuste est donc indispensable pour évaluer la qualité de l'énergie. Le système de l'étude intègre des composants, notamment le microcontrôleur ESP32, le capteur PZEM-004T-100A et une interface conviviale pour la visualisation des données. L'acquisition, l'analyse et la visualisation des données sont les principales fonctionnalités du système. L'ESP32 joue le rôle de hub de données central, traitant les paramètres électriques cruciaux, tandis que le capteur PZEM assure des mesures précises. L'analyse des données permet d'obtenir des mesures critiques de la qualité de l'énergie, telles que les fluctuations de tension, les variations de fréquence et le facteur de puissance, essentiels pour évaluer l'efficacité de l'alimentation électrique. L'interface Web facilite la visualisation des données, simplifiant ainsi les informations complexes sur la qualité de l'énergie pour les utilisateurs. Pour améliorer la réactivité aux événements critiques, le système utilise un mécanisme d'alarme sonore (buzzer). Cette étude témoigne de l'efficacité du système de surveillance de la qualité de l'énergie, conçu pour la centrale électrique de l'ASECNA à l´aéroport de Ouagadougou.

Mots clés :

1 - Surveillance de la qualité de l'énergie

2 – Centrale Electrique ASECNA

3 - Fluctuations de tension

4 - Variation de la fréquence

5 – Facteur de puissance

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List of Acronyms and Abbreviations

AC : Alternating Current

ADC : Analog-to-Digital Converter

AI : Artificial Intelligence

ASECNA : Agency for Aerial Navigation Safety in Africa and Madagascar

BIT : Burkina Institute of Technology

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DFT : Discrete Fourier Transform

DC : Direct Current

ELB : Energy and Lighting Unit

FFT : Fast Fourier Transform

GPL : General Public License

HTTP : Hypertext Transfer Protocol

IDE : Integrated Development Environment

IEC : International Electrotechnical Commission

IEEE : Institute of Electrical and Electronics Engineers

JSON : JavaScript Object Notation

LED : Light Emitting Diode

MFM : Mean Frequency Monitor

MIRE-I : Radio Electrical and IT Infrastructure Maintenance

PF : Power Factor

PQ : Power Quality

THD : Total Harmonic Distortion

VOR : Very high frequency Omni directional Range

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GENERAL INTRODUCTION

Electrical energy is a vital factor in the development and progress of human societies, contributing to improvements in quality of life and the advancement of industrial activities. The customers use more sensitive and sophisticated electronic devices which demand a reliable high-quality power supply. On the contrary, these devices produce distortions in the power supply due to their nonlinear characteristics [1]. Therefore, the issue of power quality (PQ) has become a subject of relevance for both distributors and consumers of electricity [2][3]. By definition, a PQ problem is a deviation from ideal values of voltage or current signals, resulting in a failure or malfunction of the equipment [4][5]. A study conducted as part of the Leonardo Energy Initiative revealed that engineers in charge of electrical installations often neglect to address power quality (PQ) issues. In the rare instances when they address these problems, they tend to rely on conventional solutions [6][7]. Frequently, the absence of adequate information leads to incorrect decisions, such as installing equipment that may not be the most suitable for resolving power quality issues. Power quality is of essential importance in critical installations like airport infrastructures, such as runway lighting, communication networks, and navigation equipment, by ensuring safe and efficient aircraft operations. These systems rely on a consistent and high-quality supply of electrical energy to operate optimally. A power quality monitoring system can allow comprehensive monitoring and analysis of various parameters related to the quality of electrical power according to specific norms. It enables engineers and technicians to identify, troubleshoot, and resolve power quality issues, ensuring the efficient and reliable operation of electrical systems and equipment.

So, this study presents the "**Design of a power quality monitoring system for the Agency for Air Navigation Safety in Africa and Madagascar (ASECNA) power plant at Ouagadougou airport"**.

To carry out our work, first, we will conduct theoretical studies related to the monitoring of power quality of electrical systems, secondly, we will move to the design and finally conclude and propose some perspectives.

PART I: THEORETICAL STUDIES

CHAPTER 1: GENERAL INFORMATION ON POWER QUALITY MONITORING

Introduction

In the domain of modern air transportation, the integration of the most sophisticated electronic devices has elevated air travel to unprecedented levels of safety, efficiency, and cost-effectiveness. However, this ascent is not without its challenges. The use of non-linear loads, particularly in air navigation systems, makes power quality concerns take an important place. In this chapter, we will talk about the concept of power quality monitoring and present the context in which the study is made.

I) Fundamentals of power quality monitoring

1. Introduction to power quality analysis in electrical systems

In the book "Electrical Power Systems Quality" [4], Alex McEachern one of the pioneers in the field of power quality monitoring and analysis, recounts his first encounter with a power quality problem involving a minicomputer (a minicomputer was a refrigerator-sized device with the computing horsepower of a cheap calculator and the storage capacity of a couple of floppy disks). Despite being believed to be affected by a power issue, this minicomputer would crash daily around 3:00 p.m. Despite attempts to solve the problem by installing a transient suppressor, the crashes persisted and then left everyone confused. In the past, power quality was a topic that was not understood by many people. Those claiming to know about it often had ulterior motives, such as selling products, and only a few engineers could comprehend the rare and random events occurring on power lines. However, as time went on, the proliferation of sensitive electrical devices highlighted the importance of power quality. The introduction of graphic recording instruments, including François Martzloff's automatically photographed oscilloscopes and Alex McEachern's digital PowerScopes, provided engineers with visual representations of what was happening in power systems [4]. These instruments allowed them to see and analyze the various electrical phenomena, providing valuable insights for troubleshooting and improving power quality. Power quality can have different definitions depending on one's perspective. The providers of electrical power may focus on reliability, while manufacturers may prioritize the characteristics that enable equipment to function properly. However, the end user's viewpoint is essential in determining power quality. Power quality is then defined as «Any power problem manifested in voltage, current, or frequency deviations that results in failure or misoperation of customer equipment» [4].

2. Advancements in Power Quality Monitoring

a. Shifting from Traditional Metering to Comprehensive Monitoring

The transition from traditional metering to comprehensive power quality monitoring marks a significant advancement in our ability to manage electrical power effectively. Traditional meters, primarily designed for billing purposes, provided limited insights into the quality of power. They measured only basic parameters, leaving power quality issues largely undetected until they caused problems.

Comprehensive monitoring systems, on the other hand, offer a holistic view of power quality. They continuously collect and analyze a wide range of parameters, including voltage and current waveforms, harmonics, transients, flicker, power factor, and more. These real-time data allow organizations to proactively identify and address power quality issues before they disrupt operations.

b. Key Functions and Benefits of Power Quality Monitoring Systems

Power quality monitoring systems play a crucial role in modern electrical systems. They provide real-time insights into the health of the electrical network. Key Functions of Power Quality Monitoring Systems are:

- **Continuous Data Collection**: these systems collect real-time data on electrical parameters like voltage, current, frequency, and harmonics, offering an in-depth view of system performance.
- **Event Logging**: they log and timestamp power quality events, such as voltage fluctuations, and interruptions, aiding issue diagnosis and resolution.
- **Power Factor Measurement**: monitoring systems measure power factor, aiding in understanding power efficiency and facilitating corrective actions for improvement.

The monitoring of power quality has a lot of benefits that will be explained below:

- **Issue Identification:** rapid detection of power quality problems like voltage fluctuations and harmonics, preventing equipment failures and downtime.
- **Proactive Maintenance:** early issue detection allows for cost-effective preventive maintenance, minimizing the risk of equipment failures.

- **Energy Efficiency:** provides insights into energy consumption and power factor, leading to energy-saving strategies and lower operational costs.
- **Data for Analysis**: collected data enables in-depth system analysis and optimization for sustained efficiency improvements.
- **Support for Energy Transition:** critical for a smooth shift to cleaner energy sources, ensuring stability for distributed energy resources.
- **Environmental Impact Reduction**: optimizing power quality and efficiency reduces energy consumption, aligning with sustainability goals and reducing environmental impact.

II) Place of study

1. ASECNA Presentation

ASECNA is an international organization based in Dakar, Senegal. Established in 1959, it manages and coordinates air traffic in the African region and Madagascar, ensuring flight safety and preventing collisions. The agency enforces stringent standards and regulations for secure air operations, conducts inspections on navigation equipment, and offers communication and meteorological services to aircraft, providing accurate information to pilots. ASECNA also conducts training for aviation professionals, enhancing skills and elevating aviation standards. By embracing advanced technologies, the agency modernizes air navigation systems to enhance operational efficiency and reduce costs. It operates with member countries collaborating to ensure reliable and effective air operations across Africa and Madagascar.

ASECNA is organized as shown in the following chart [9]:

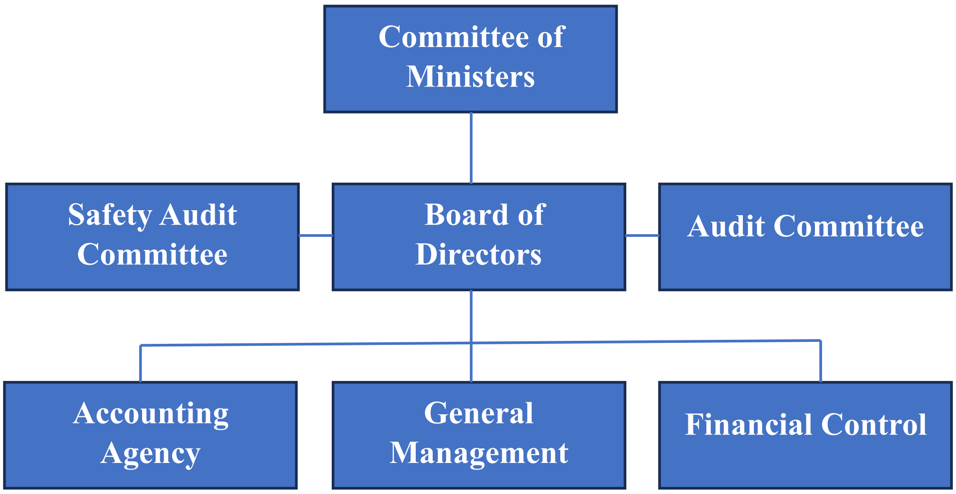


Figure 1:ASECNA organization chart

a) ASECNA Representation in Burkina Faso

The ASECNA Representation Office in Burkina Faso, located in Ouagadougou on Avenue de la Resistance du 17 Mai, was inaugurated on November 13, 1997. The Representation's missions include air traffic control and aircraft guidance in Burkina Faso airspace, transmission of technical and traffic messages, in-flight information and data collection, as well as forecasting and transmission of meteorological information. These services encompass enroute, approach, and landing traffic.

ASECNA representation in each member country is organized as shown in the following chart [10]:

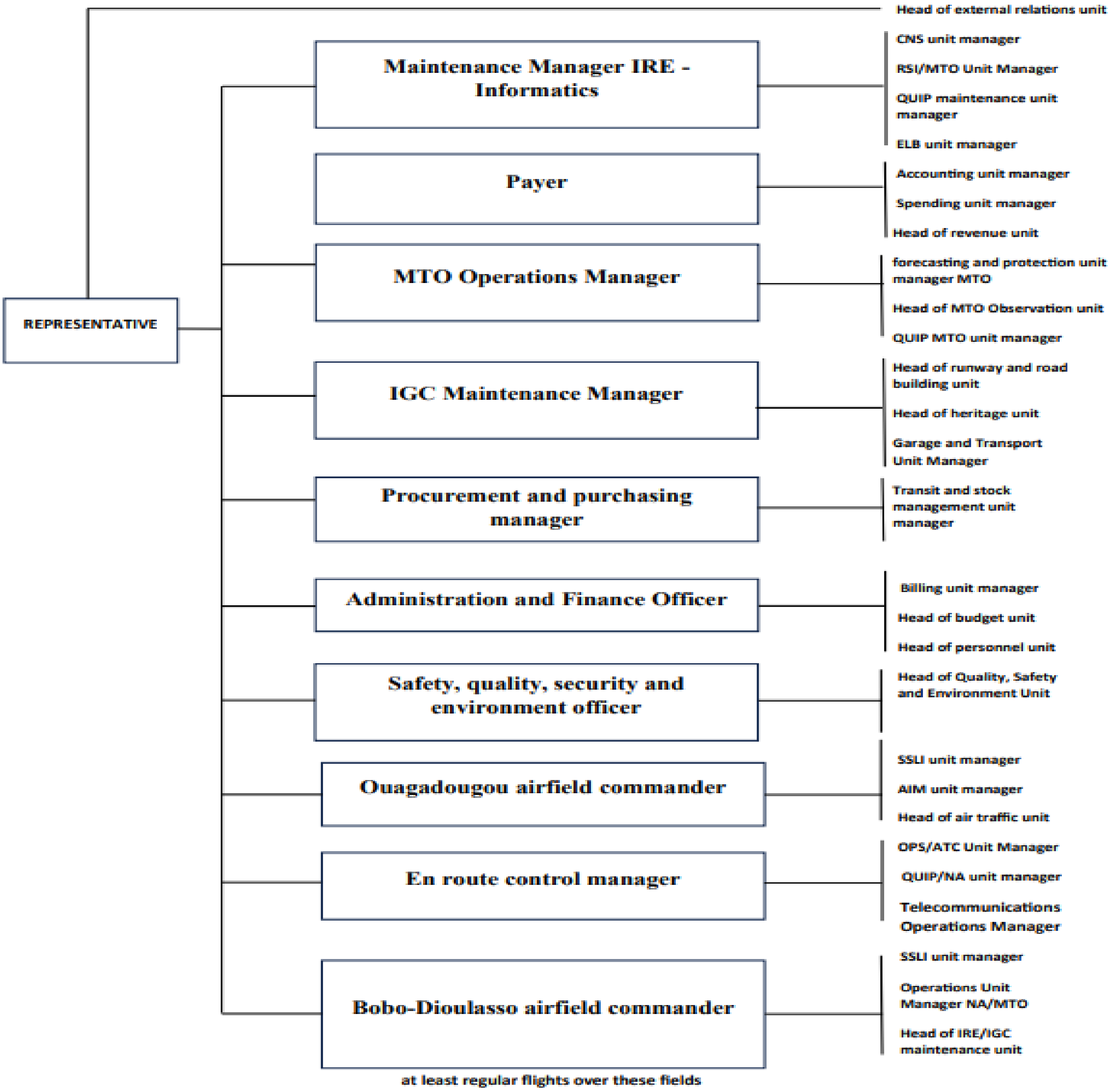


Figure 2: ASECNA Representation organization chart

Our study is based on the ELB (Energy and Lighting unit) service, which is a sub-unit of the MIRE-I (Radio Electrical and IT Infrastructure Maintenance) service as shown in the chart.

b) Energy and Lighting Unit:

Under the responsibility of the MIRE-I manager, the role of the Energy and Lighting unit is to maintain all the installations under which it is responsible in good working order, to monitor the installation of new equipment for which it is responsible, and to install any new equipment entrusted to it. In all cases, priority must be given to the operation of existing installations, which are essential to the operators in carrying out their tasks properly. To this end, it is responsible for:

- Production and distribution of electrical energy at the airport;
- Bright visual aids;
- Obstacle lighting;
- The optical multiplexer network, which carries information for equipment control and supervision;
- Programmable logic controllers for equipment control and supervision;
- Various electrical and lighting materials;
- Technical building lighting.

c) The Power Plant equipments

The Energy and Lighting unit has a Power Plant which is composed by:

- Generators
- Electrical Power Distribution Equipment;
- Illuminated Visual Aids;
- Obstacle lighting
- Optical Multiplexers
- Programmable Logic Controllers(PLCs)
- Other electrical equipment

2. Problematics, objectives, and expected results.

a) Problematic

Technological advancements such as digital electronics, computing, and production development have made air transportation the safest, the most efficient, and the most cost-effective mode of transportation [11]. Traditionally at the ASECNA power plant at Ouagadougou, the main concerns are the non-interruption of the energy supply and the conservation of the voltage and frequency within some limits considered acceptable. When voltage variations are greater than +10% or -15% of nominal voltage, and frequency variations greater than +4% or +6% an automatic startup of diesel generators in response to grid instability is implemented [12]. While this reactive approach provides a level of reliability, it does not indicate the causes of power quality problems or propose measures for improving overall grid stability and quality. Then by implementing a power quality monitoring system, the power plant can monitor and analyze the electrical parameters including the voltage fluctuation rate, frequency variation, and Power factor. This allows a proactive identification of power quality issues, a determination of their root causes, and the implementation of corrective measures to enhance grid stability and overall power quality. This transformation promises a more efficient, reliable, and sustainable energy supply for the ASECNA power plants in Burkina Faso and serves as a crucial step forward in the context of contemporary air transportation technology and energy standards.

b) Objectives

General objective

The general objective of this study is to design a power quality monitoring system to monitor electrical parameters such as voltage, current, power, energy, frequency, and power quality parameters (voltage fluctuations rate, frequency variation, and power factor). The aim is to showcase the importance of power quality analysis in some structures like the ASECNA power plants in BURKINA FASO.

Specifics objectives

Design of the Data Acquisition Board(hardware): the first specific objective involves the design of a data acquisition board for our power quality monitoring system. This objective entails selecting an appropriate sensor, such as PZEM_004T V3 integrated with an ESP32 microcontroller to accurately retrieve instantaneous data.

Design of the Data Processing Software: the second specific objective is to develop a comprehensive data processing software that operates synergistically with the data acquisition board and presents a user-friendly web interface.

c) Expected Results

The Data Acquisition Board is Designed: a fully functional data acquisition board is successfully designed and assembled and can accurately retrieve real-time data related to power quality parameters.

Comprehensive Data Processing Software is done: a comprehensive data processing software system is developed, meeting the specified requirements and objectives.

Conclusion

Within the heart of the ASECNA power plant at Ouagadougou airport lies a duo of paramount concerns: ensuring uninterrupted energy flow and maintaining voltage and frequency within acceptable bounds. The plant has a reactive response, starting diesel generators in response to grid instability, although overlooking the intricate landscape of power quality issues. The introduction of a power quality monitoring system permits a new era of proactive vigilance. This system will permit the monitoring of voltage fluctuation rate, frequency variation, and power factor. By doing so, it pioneers the art of predictive problem identification, deciphers the enigma of root causes, and empowers the implementation of corrective measures. This proactive stance not only fortifies grid stability but elevates the overarching quality of power.

CHAPTER 2: METHODOLOGY AND CONCEPTUAL APPROACHES

Introduction

Power quality monitoring is essential in ensuring power systems' reliable and efficient operations. In this chapter, we delve into the methodologies and conceptual approaches employed to underscore the significance of power quality monitoring within the context of the ASECNA power plants. This chapter outlines the structured approach to designing, simulating, and monitoring power quality parameters.

I) Data Acquisition Board design method

1. ESP32 microcontroller the Intelligent Core of Power Analysis

Our power quality monitoring system includes hardware for real-time data acquisition. The ESP32's built-in Analog-to-Digital Converter (ADC) converts the analog signals from sensors into digital values. The ESP32 microcontroller emerges as a cornerstone of this power quality monitoring. Its versatility, computing power, and integrated wireless capabilities make it an ideal platform for processing, aggregating, and transmitting data. In this context, the ESP32 serves as the analytical hub, orchestrating the acquisition of electrical parameters and generating insightful data.

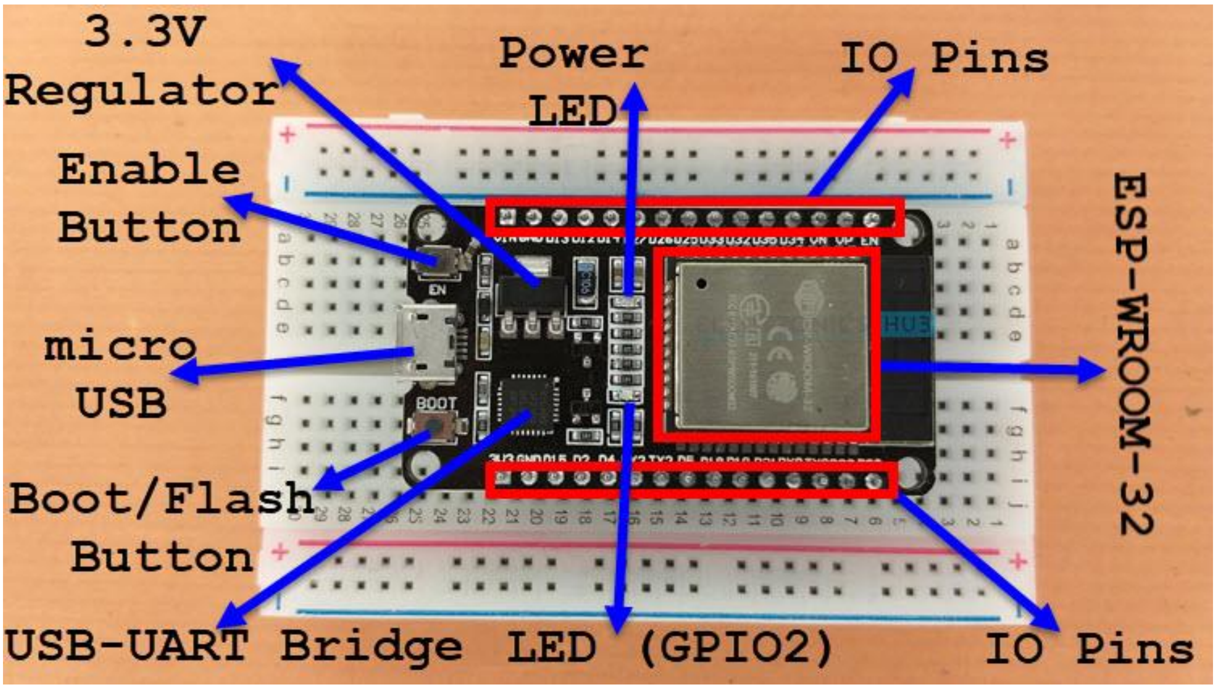


Figure 3: ESP 32 board

2. PZEM-004T sensor

The PZEM-004T sensor is an advanced electrical parameter measurement device designed for power quality monitoring and energy management applications. It is specifically engineered to measure various critical parameters in electrical systems with high accuracy and reliability. The PZEM-004T-100A module combines an external current sensor PZCT-02_100A for current measurement. The current sensor has the same operating principle as an ammeter clamp and therefore makes it possible to measure the intensity of the current flowing in a conducting wire without having to open the circuit. This module is used to determine the alternating voltage, current, frequency, power factor, active power, and active energy of an installation.

Figure 4: PZEM-OO4T-100A sensor

The main technical parameters of the PZEM-004T-100A v3 sensor [13]：

Table 1: The PZEM-004T-100A features

Model	PZEM-004T-100A
Test Voltage	80 – 260 V (AC)
Maximum Operating Current	100 A
Rated Power	0～23kW
Operating Frequency	45Hz-65Hz
Active Energy	0～9999.99kWh
Operating temperature	-20’C～+60’C

II) Data Processing software design method

1. The software design method

In power quality monitoring, accurate data collection is half the battle. Effective analysis of the collected data is essential for deriving meaningful insights. This section presents the conceptual framework of a data processing solution that integrates ESP32, PZEM-004T-100A sensor, as well as a Web interface. This approach ensures data analysis and visualization, facilitating comprehensive power quality assessment. The solution consists of three core modules, synergistically working together to empower the monitoring process:

Data acquisition code:

A developed Arduino code for the ESP32 microcontroller helps retrieve essential measurement data from the PZEM-004T-100A sensor. These data are then processed and prepared for further analysis.

Data Analysis code: a developed Arduino code helps the collected data to be processed by algorithms that compute critical power quality metrics such as voltage fluctuation rate, frequency variation, and power factor over a sampling period.

Visualization code: once the data is analyzed, it is translated into visually meaningful representations. Numerical summaries are generated to provide an intuitive understanding of complex power quality information. These visualizations are displayed on a Web page, allowing users to access and explore the data effortlessly.

2. Data Analysis Formula

In power quality analysis, the accurate calculation of various parameters plays an essential role.

Harmonic Analysis and Total Harmonic Distortion (THD) Calculation:

Harmonic analysis is a technique used to study the composition of a complex waveform by decomposing it into its constituent sinusoidal components, known as harmonics. It helps in identifying the presence and magnitudes of frequency components that are integer multiples of the fundamental frequency. The Fourier Transform plays a crucial role in harmonic analysis. When applied to a periodic signal, it decomposes the signal into its fundamental frequency and its harmonic components. For instance, in power systems, voltage, and current waveforms are often analyzed to determine the presence and magnitude of harmonics. By performing the Fourier Transform on these waveforms, engineers can identify the frequencies of harmonic components and their corresponding magnitudes. By precisely identifying and quantifying the presence of harmonics in the electrical signal, harmonic analysis allows us to understand the potential sources of distortion and evaluate their impact on power quality.

The Fourier Transform of a signal is given by the formula:

$$F(\omega) = \int [f(t) \times e^{-jwt}]dt \qquad (1)$$

Where:

F(ω) is the complex frequency-domain representation of the signal.

f(t) is the time-domain signal you want to transform.

ω is the angular frequency (**2π** times the frequency in Hertz).

j is the imaginary unit.

Fast Fourier Transform (FFT):

The Fourier Transform is a mathematical operation, and it can be implemented numerically using algorithms like the **Fast Fourier Transform (FFT).** The FFT algorithm significantly reduces the number of operations required to calculate the discrete Fourier transform (DFT), making it faster and more efficient, especially for larger datasets. FFT decomposes a signal into a sum of sinusoidal components, allowing the identification of various frequency components present in the signal [14].

Voltage Harmonic Components:

The magnitude of the n^{th} voltage harmonic component (V_n) can be calculated as:

$$V_n = \sqrt{(\mathrm{Real}(FFT[V_n])^2 + \mathrm{Imaginary}(FFT[V_n])^2)} \qquad (2)$$

Current Harmonic Components:

The magnitude of the nth current harmonic component (I_n) can be calculated similarly as:

$$I_n = \sqrt{(\mathrm{Real}(FFT[I_n])^2 + \mathrm{Imaginary}(FFT[I_n])^2)} \qquad (3)$$

Where:

FFT[V_n] represents the FFT coefficient of the nth voltage harmonic component.

FFT[I_n] represents the FFT coefficient of the nth current harmonic component.

Real(x) represents the real part of a complex number x.

Imaginary(x) represents the imaginary part of a complex number

Total Harmonic Distortion (THD):

Formula:

$$THD = (\sqrt{(V^2h + I^2h)}) / Vrms \quad (4)$$

$$V^2h = (V_1)^2 + (V_2)^2 + ... + (V_n)^2 \quad (5)$$

Where: $V_1, V_2, ..., V_n$ are the magnitudes of individual voltage harmonic components.

$$I^2h = (I_1)^2 + (I_2)^2 + ... + (I_n)^2 \quad (6)$$

Where: $I_1, I_2, ..., I_n$ are the magnitudes of individual current harmonic components.

$$Vrms = \sqrt{(V_1^2 + V_2^2 + ... + Vn^2)} \quad (7)$$

Where: $V_1, V_2, ..., Vn$ are the voltage samples of the waveform.

Explanation: THD quantifies the distortion caused by harmonics in the current and voltage waveforms. V^2h represents the sum of squared harmonic voltages, I^2h represents the sum of squared harmonic currents, and Vrms is the root mean square of the voltage waveform.

In our Power quality monitoring system, we didn’t include harmonic analysis because they have PLC in the power plant that has electronic filters that have suppressed harmonics. But they can be used in similar projects.

Voltage Fluctuations:

Voltage, on the other hand, represents the electrical potential difference between two points in a circuit. It is a static parameter that indicates the force or "pressure" behind the flow of current. Deviations in voltage can also affect the performance of electrical equipment, especially those with specified voltage requirements. The formula for voltage fluctuations quantifies the difference between the maximum and minimum voltage levels observed over a period as a percentage of the nominal voltage. This percentage change reflects variations in the electrical potential, which can lead to issues like voltage drops or surges in a power supply.

Formula: Voltage Fluctuations = (Vmax - Vmin) / Vnomimal * 100% **(8)**

Explanation: (Vmax - Vmin) is the difference between the maximum and minimum voltage levels observed during the event. This difference represents the magnitude of the deviation from the nominal voltage level. Vnominal is the nominal voltage level, which is used as a reference point. The 100% parts of the formula is used to express the voltage deviation as a percentage of the nominal voltage. So, when you plug in the values for Vmax, Vmin, and Vnominal into this formula, you'll get a percentage that tells you how much the voltage deviated from its nominal level during the event.

Frequency variation:

Frequency is a dynamic parameter that represents the number of cycles (or oscillations) of an alternating current or voltage per unit of time (usually measured in Hertz, Hz). Deviations in frequency can have a significant impact on the performance of many electrical devices and equipment, especially those that rely on precise timing, such as electric motors or clocks. Frequency variation is a crucial aspect of power quality analysis, especially in power systems where maintaining a stable frequency is essential.

Formula:

Frequency Variation = (f_measured - f_nominal) / f_nominal * 100%. (9)

Frequency variation is determined by comparing the measured frequency (f_measured) to the nominal or reference frequency (f_nominal) of the power system. The formula calculates the difference between the measured frequency and the nominal frequency. This difference represents the frequency deviation from the expected or nominal value. To express this deviation as a normalized percentage relative to the nominal frequency, the difference is divided by the nominal frequency (f_nominal). The result is then multiplied by 100% to represent the magnitude of the frequency variation as a percentage. A positive value indicates that the measured frequency is higher than the nominal frequency, while a negative value indicates that the measured frequency is lower.

Power Factor: the power factor is a critical parameter in power quality analysis because it indicates how effectively electrical energy is being used. A power factor of 1(un) represents a purely resistive load where all the power is converted into useful work, while a lower power factor indicates that a portion of the power is being wasted due to reactive components in the circuit. Power factor correction is often employed to improve the efficiency of electrical systems and reduce wasted energy.

The formula for calculating the power factor (PF) is:

Power Factor (PF) = Apparent Power (S)/ Active Power (P) (10)

Where: Power Factor (PF) is a number between 0 and 1.

Active Power (P) is measured in watts (W) and represents the actual power consumed or utilized in an electrical circuit. Apparent Power (S) is measured in volt-amperes (VA) and represents the total power flow in the circuit, which includes both active power and reactive power. Monitoring power factor is an approach that promotes efficiency, cost-effectiveness, and environmental responsibility within electrical systems.

Conclusion

In summary, this chapter provides an overview of our methodologies for constructing a power quality monitoring system. By utilizing an ESP32 microcontroller, PZEM-004T-100A sensor, and a Web app, we've presented the process of collecting, analyzing, and visualizing power quality data. This approach ensures accurate power quality assessment, contributing to the efficiency and reliability of our power plant system.

PART II: DESIGN AND IMPLEMENTATTION

CHAPTER3: POWER QUALITY MONITORING SYSTEM MODELLING AND CONCEPTUAL APPROACH

Introduction

In this chapter, we explore the design and conceptual approach of a power quality monitoring system developed to underscore the importance of power quality analysis within the ASECNA power plant context. This chapter provides insights into the systematic framework employed to demonstrate the capabilities of the prototype.

I) Design

1. Circuit

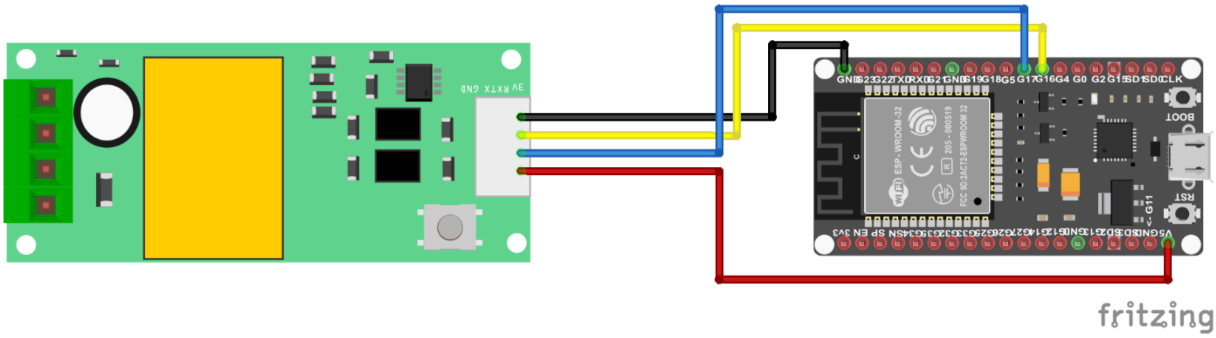


Figure 5: Fritzing wiring of the data acquisition board

2. The Flow Chart

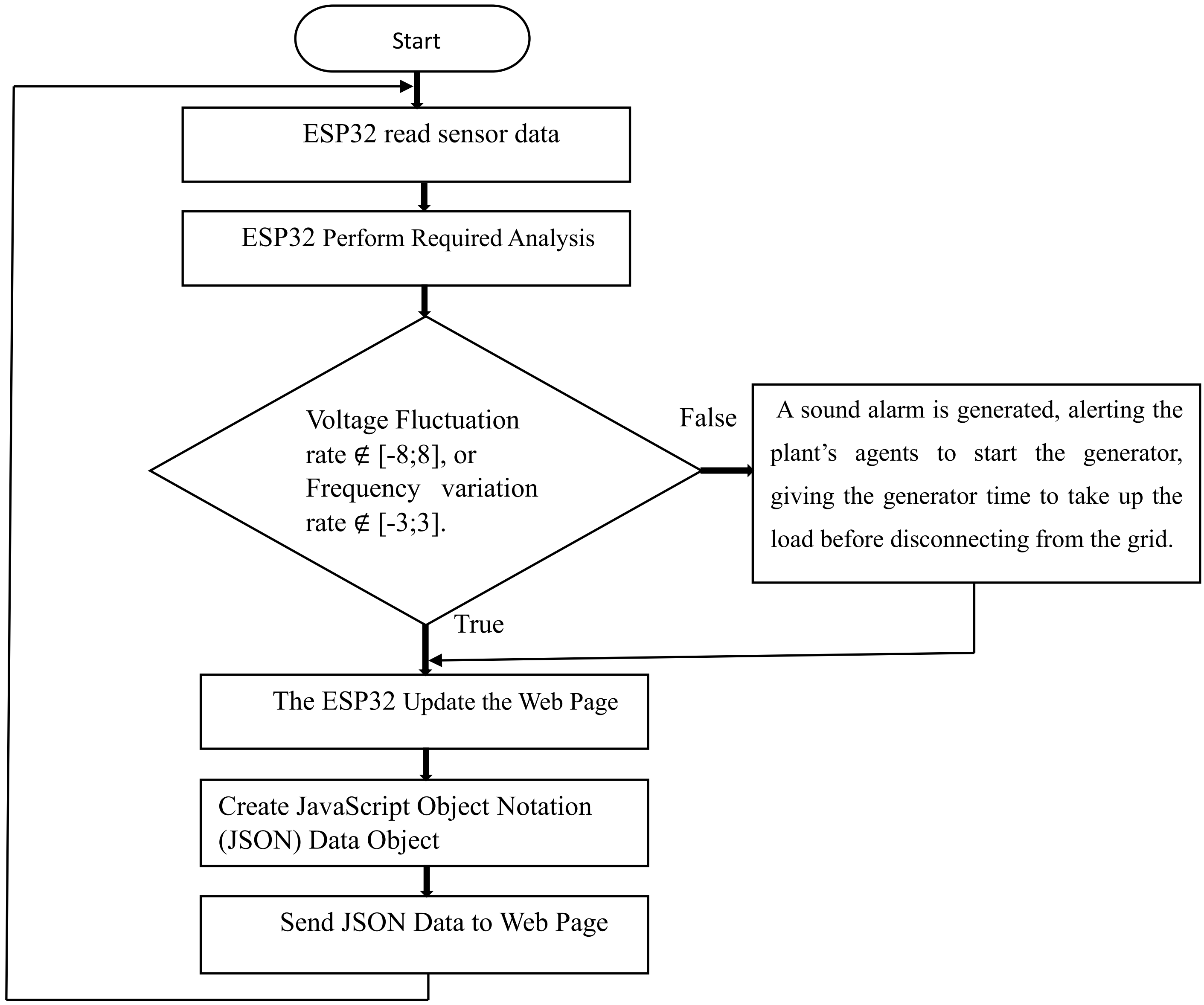


Figure 6: Data Processing and Visualization Workflow for the Power Quality Monitoring

II) Conceptual Approach

1. Circuit explanation

The circuit connects an ESP32 microcontroller with a PZEM-004T-100A sensor. The PZEM-004T-100A v3 sensor permits to have the instantaneous value of the alternating voltage, current, frequency, power factor, active power, and energy. ESP32 reads analog outputs from the sensor, processes the data, and transmits via its Wi-Fi module, the analysis results to the Web page interface. The circuit is made by using Fritzing software. The code that allows the ESP 32 to read the data is written on Arduino Integrated Development Environment (IDE).

Presentation of the fritzing software: Fritzing is an Open-source software for creating electronic projects without hardware access. Ideal for tutorials, design creation, and sharing prototypes. Fritzing is supported by an active community and is suitable for electronics students, teachers, and professionals. It's a Cross-platform (Mac OS, Linux, Windows), initiated by Potsdam University. Released under a General Public Licence (GPL) 3.0 or higher with component images under Creative Commons Attribution-ShareAlike (CC BY-SA) 3.0, it has multilingual support such as German, English, Spanish, French, etc.

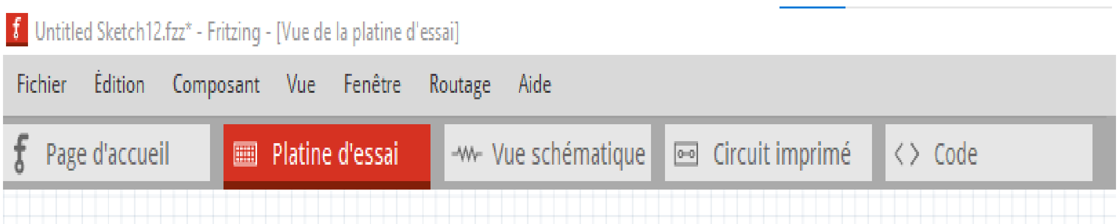


Figure 7: Fritzing Software Interface

Presentation of Arduino IDE: the Arduino software, also known as the Arduino Integrated Development Environment (IDE), is open-source software that allows you to write and upload code to Arduino boards. You can use the ESP32 microcontroller board with the Arduino IDE to program it too. It is developed by arduino.cc and consists of many libraries and a set of examples of mini projects. The Arduino IDE is designed to be easy to use for beginners, yet flexible enough for advanced users. It runs on Mac, Windows, and Linux. With the Arduino IDE, you can tell your board what to do by sending a set of instructions to the microcontroller on the board.

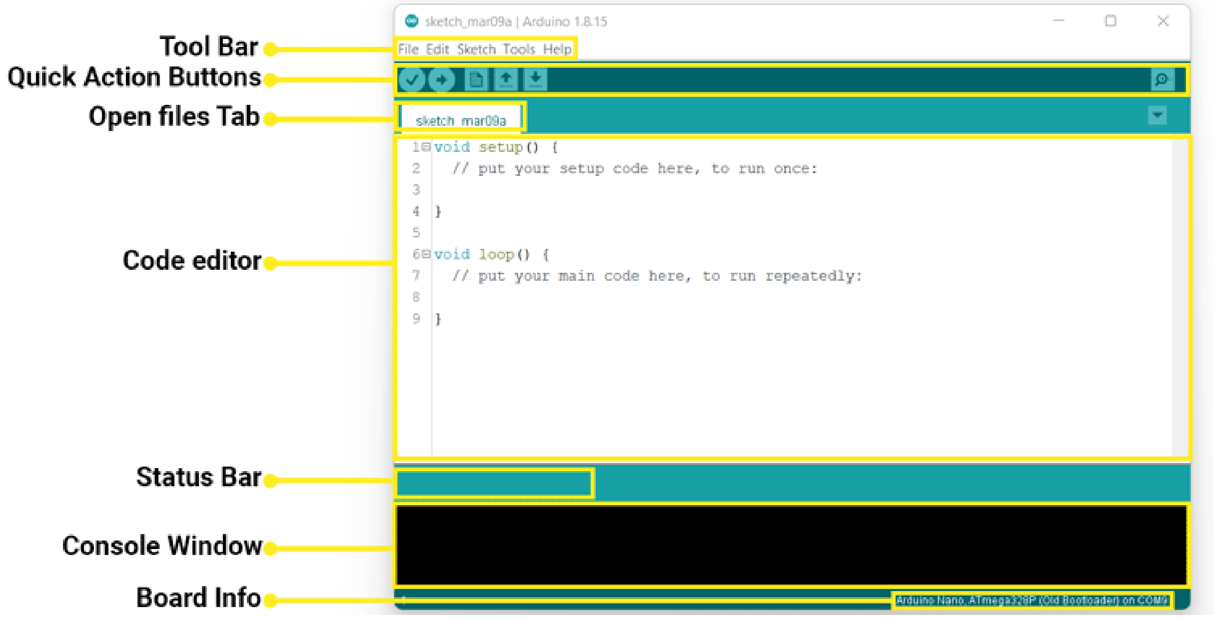


Figure 8: Arduino IDE Interface

2. Flow Chart Explanation

This flowchart illustrates the journey of data from sensor capture to comprehensive analysis and visualization through the integration of the ESP32, and the Web page.

Start: The process begins with the initiation of the power quality monitoring system. The ESP32 is initialized with necessary configurations, including serial communication, the buzzer pin, WiFi access point settings, web server setup, and variable initialization.

ESP32 Collects Data from the sensor: The ESP32 microcontroller interfaces with the PZEM-004T-100A v3 sensor to collect instantaneous valuable data for the monitoring system. The sensor ensures precise measurements of the electrical parameters. Voltage and frequency are collected over a sampling period of 10 ms [1/(2*50)] with a frequency of 50Hz based on the Nyquist-Shannon sampling theorem. This theorem states that the sampling frequency should be at least twice the maximum frequency of the signal to avoid aliasing distortion [15].

ESP32 Performs Analysis: Using the collected data, the ESP32 performs crucial analyses:

Voltage Fluctuation Analysis: the ESP32 evaluates voltage fluctuations to assess the stability of the power source.

Frequency Variation Analysis: the ESP32 conducts in-depth frequency variation analysis to monitor the stability of the power system's frequency. By comparing the measured frequency to the nominal frequency, this analysis detects deviations and variations. This information is crucial for ensuring the synchronization and performance of time-sensitive systems.

Power Factor Analysis: ESP32 carries out a comprehensive power factor analysis to evaluate the efficiency of electrical energy utilization within the power system. Power factor analysis is essential for optimizing energy consumption, reducing utility costs, and improving the overall efficiency of electrical systems.

“If condition”: after making the required analysis, we evaluate the variation in frequency and voltage. If the variation approaches acceptable limits, a sound alarm is generated to alert the plant's agents to start the generator so that it is ready to take over the load, thus avoiding any interruption to the power supply.

The ESP32 Update the Web Page: the ESP32 updates the web page with the measured data to make it accessible remotely.

Create JSON Data Object: data is organized into a JSON object containing voltage, current, power, energy, frequency, power factor, voltage fluctuation, and frequency variation.

Send JSON Data to Web Page: data is organized into a JSON object containing voltage, current, power, energy, frequency, power factor, voltage fluctuation, and frequency variation and a new cycle begins.

Conclusion

This chapter presented the modeling and conceptualization behind the power quality analyzer. The integration of hardware components, and algorithm implementation for required analysis highlights the systematic approach adopted to demonstrate the monitoring capabilities. In the following chapter, we move on to the results and perspectives, building upon the foundation laid in this chapter.

Chapter 4: Results and Perspectives

Introduction

In this chapter, we delve into the heart of our power quality analysis project by presenting the outcomes of our data acquisition and processing efforts. By showcasing the results and conducting an in-depth analysis, we aim to gain valuable insights into the power quality characteristics.

I) Results

1. The data acquisition board

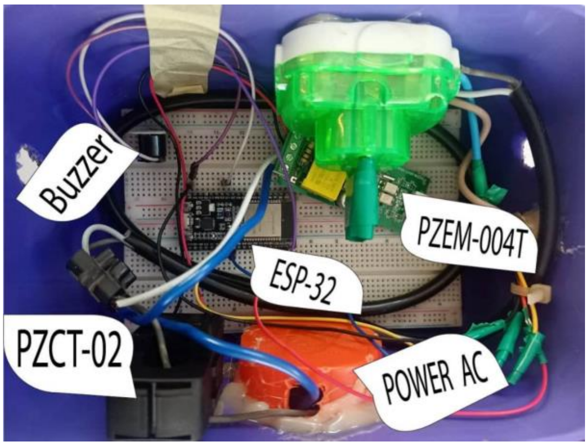


Figure 9: Layout of the components installed in the data acquisition

2. Simulation with an electrical load

Figure 10:Data Acquisition board during the Arduino code uploading.

Figure 11:Welding machine connected to our prototype

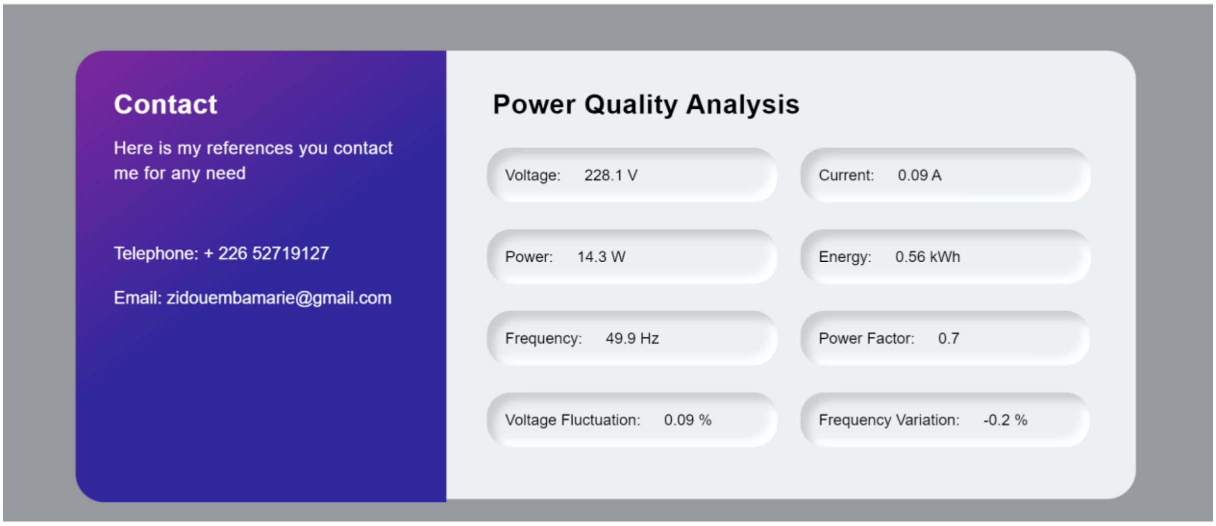


Figure 12:Data of the welding machine displayed in real time on the web page.

3. Contribution of our Power Quality Monitoring System

At the end of our prototyping, we can measure and visualize the values of voltage, current, power, energy, frequency, power factor, voltage fluctuation, and frequency variation. It should be noted that at the ASECNA power plant of Ouagadougou airport, they have a visualization of parameters such as voltage, current, power, energy, frequency, and power factor, but they don't have a visualization of voltage fluctuation and frequency variation. When voltage variations are greater than +10% or -15% of nominal voltage, and frequency variations are greater than +4% or +6%, automatic start-up of diesel generators in response to network instability is implemented. The relay's action is delayed by 2s, in addition to the generator start-up time of 7s, which means that from the grid to the generator we have a 9s power cut. For a critical infrastructure like Ouagadougou International Airport, a 9s power cut can have enormous consequences. But with our monitoring system, before even reaching the limits mentioned above, when these limits are approached, the alarm is generated to alert the agents to start the generator, giving it time to take over the load before we disconnect from the power grid. Our power quality monitoring system for the ASECNA power plant of Ouagadougou airport offers several important advantages and benefits:

Improved Grid Stability: our system provides real-time monitoring of voltage fluctuations and frequency variations. This proactive approach helps identify potential power quality issues before they escalate, allowing for timely intervention and reducing the risk of grid instability.

Preventive Measures: by generating alarms as voltage and frequency approach critical limits, our system enables operators to take preventive measures, such as starting the generator, well in advance of a power cut. This ensures the continuous operation of critical infrastructure.

Improved Safety: timely generator start-up and load transfer improve safety at the airport. It ensures that essential systems, such as air traffic control and security, remain operational even during power fluctuations.

Data Visualization: our system provides comprehensive data visualization, enabling operators to monitor various parameters related to power quality. This data can be used for analysis, trend identification, and informed decision-making to optimize grid operations.

II) Perspectives

The successful development of the power quality analyzer project lays a strong foundation for expanding its capabilities to meet the demands of modern power systems. As the project is still in progress, the following recommendations outline potential directions for advancing power quality monitoring.

1. Improve Performance with Raspberry Pi

Although the ESP32 microcontroller provides a solid foundation for the current system, the use of a more robust hardware platform can significantly enhance performance, especially when dealing with larger datasets or complex algorithms. The Raspberry Pi, renowned for its processing power and versatility, presents an attractive alternative. By migrating the project to a Raspberry Pi, the system can improve its computational performance to handle advanced data processing tasks, machine learning algorithms, and even more intricate graphical visualizations.

This upgrade ensures that the monitoring system can accommodate future scalability requirements and maintain responsiveness even as the complexity of the analysis grows.

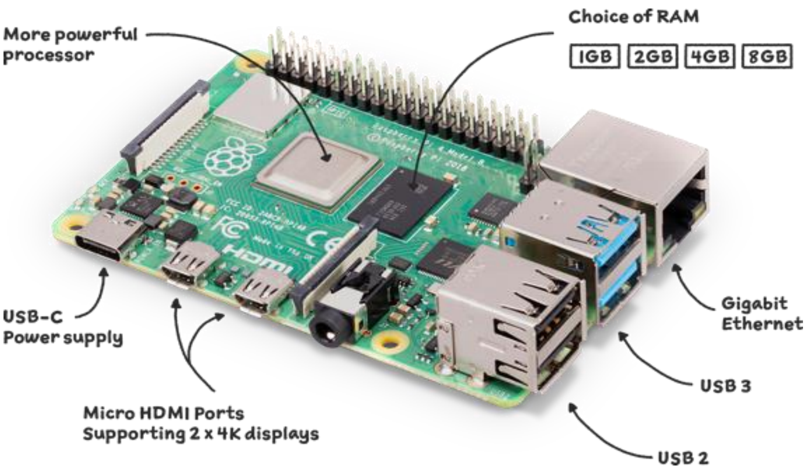


Figure 13:Raspberry Pi 3 Model B board.

2. Use of Robust Data Storage System InfluxDB

As the volume of collected data increases over time, the need for an efficient and reliable data storage solution becomes paramount. One recommendation is the integration of InfluxDB, a purpose-built time-series database designed for handling large volumes of time-stamped data. InfluxDB's architecture aligns seamlessly with the requirements of power quality data, enabling fast and optimized storage, retrieval, and analysis. InfluxDB has high write and query speeds, which are crucial for real-time monitoring systems. It also supports real-time analytics, which is essential for immediate detection and notification of power quality issues By using InfluxDB, the system can organize and manage historical data effectively, facilitating long-term analysis and trend identification [16].

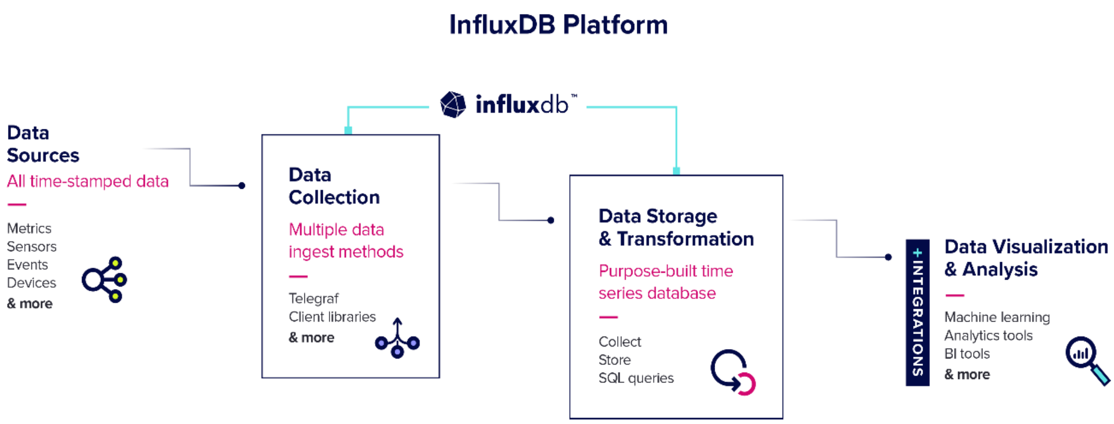


Figure 14: InfluxDB Platform

3. Artificial Intelligence (AI) Based Power Quality Forecasting - Enhancing Grid Stability and Reliability

Integrating AI-based power quality forecasting into the ASECNA power plant offers numerous advantages. Through improved root cause analysis, AI's ability to correlate data from various sources aids in identifying the underlying reasons for anomalies, enabling more targeted solutions and preventive maintenance. Additionally, by providing actionable perspectives, AI empowers operators and engineers to make informed decisions, optimizing grid operations and minimizing the financial impact of costly emergency responses. These benefits, including reduced downtime and optimized operations, ultimately lead to significant cost reduction, enhancing the plant's efficiency and financial autonomy.

Conclusion

In this chapter, we presented the results of our power quality monitoring implementation, demonstrating its efficacity in retrieving, analyzing, and visualizing key parameters related to voltage, current, power, energy, frequency, power factor, voltage fluctuation, and frequency variation. Through the integration of sensors, an ESP32 microcontroller, and data processing software, we successfully achieved our specific objectives of designing a data acquisition board and developing comprehensive data processing software. We have also proposed suggestions to improve the performance of the power quality analyzer.

GENERAL CONCLUSION

In conclusion, this project has delved into the parameters of power quality analysis, addressing key factors such as voltage fluctuations, frequency variation, and power factor monitoring. By designing a data acquisition board coupled with sophisticated data processing software, we've achieved the capability to accurately monitor and assess power quality in real time.

The numerical representations of monitored data displayed through a user-friendly Web app, help users to make informed decisions based on the health of their electrical systems.

Furthermore, as the project is still in progress, the incorporation of machine learning techniques for anomaly detection and predictive analysis, along with the utilization of advanced hardware such as Raspberry Pi for performance improvement, holds the promise of revolutionizing power quality monitoring. The integration of a robust data storage system ensures the secure retention and accessibility of critical data.

As we are moving toward a future where energy efficiency and system stability are essential, ideas and innovations from this project stand as a beacon, guiding us toward a resilient and electrifying tomorrow.

Bibliography

[1]: Bhattacharyya, Sharmistha, JMA Myrzik, et WL Kling. « Consequences of poor power quality-an overview ». In *2007 42nd International Universities Power Engineering Conference,* 651-56. IEEE, 2007.

[2]: Bollen, Math HJ, Ratan Das, Sasa Djokic, Phil Ciufo, Jan Meyer, Sarah K Rönnberg, et Francisc Zavodam. « Power quality concerns in implementing smart distribution-grid applications ». *IEEE Transactions on Smart Grid* 8, nº 1 (2016): 391-99.

[3]: Yan, Shuo, Siew-Chong Tan, Chi-Kwan Lee, Balarko Chaudhuri, et SY Ron Hui. « Use of smart loads for power quality improvement ». *IEEE Journal of Emerging and Selected Topics in Power Electronics* 5, nº 1 (2016): 504-12.

[4]: Santoso, Surya, Mark F McGranaghan, Roger C Dugan, et H Wayne Beaty. *Electrical power systems quality*. McGraw-Hill Education, 2012.

[5]: Sankaran, C. *Power quality*. CRC Press, 2017.

[6]: De Keulenaer, Hans. « The hidden cost of poor power quality ». *European copper institute* 5, nº 07 (2003).

[7]: Targosz, R. « Leonardo energy E-learning program on power quality ». In *2010 Modern Electric Power Systems*, 1-5. IEEE, 2010.

[8] : Silva, Pedro LM, José A Afonso, Vítor Duarte Fernandes Monteiro, JG Pinto, et João L Afonso. « Development of a monitoring system for electrical energy consumption and power quality analysis », 2017.

[9]:https://www.asecna.aero/index.php/fr/2014-03-31-16-47-51/gouvernance/direction-generale/14-l-agence/gouvernance/109-instances-statutaires [visited 2023 August 11 at 6.05 am].

[10]: « Manuel d'exploitation de l'unité Energie et Balisage de l'aéroport de Ouagadougou »

[11]: Vasconcellos, Arnulfo Barroso de, JA Lambert, BC Carvalho, Erika Tiemi Anabuki, Teresa Irene R de C Malheiro, et Josoé Moreira. « Analysis of the power quality on the busbar that feeds the equipment of instrument at the Marechal Rondon airport ». In *2012 IEEE 15th International Conference on Harmonics and Quality of Power*, 190-96. IEEE, 2012.

[12]: « Manuel de procédures de travail de l'unité Energie et Balisage de l'aéroport de Ouagadougou », Troisième Edition, Septembre 2020.

[13]: Manuel de l'utilisateur du module de communication AC PZEM-004T V3.0 - Manuels + [Internet]. Manuals+. 2021 [visited 2023 September 11 at 6.05 am]. Available from: https://manuals.plus/fr/gourou-des-innovateurs/module-de-communication-ca-pzem-004t-v3-0-manuel

[14]: Fast Fourier transform - Wikipedia, [visited 2023 September 18 at 6.15 am].

[15]: «Nyquist–Shannon sampling theorem - Wikipedia» [visited 2023 September 18 at 7.09 am].

[16]: Compare InfluxDB vs MySQL (influxdata.com) [visited 2023 September 18 at 6.15 am].

Appendices

Annex 1: Power quality standards and regulations [5]

Institute of Electrical and Electronic Engineers (IEEE); Piscataway, NJ;

IEEE 902: Guide for Maintenance, Operation, and Safety of Industrial and Commercial Power Systems IEEE C57.110: Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load

IEEE P1433: Power Quality Definitions IEEE P1453 Voltage Flicker IEEE P1564 Voltage Sag Indices

IEEE 1159: Recommended Practice for Monitoring Electric Power Quality

IEEE 141: Recommended Practice for Electric Power Distribution for Industrial Plants

IEEE 142: Recommended Practice for Grounding of Industrial and Commercial Power Systems

IEEE 241: Recommended Practice for Electric Power Systems in Commercial Buildings

IEEE 602: Recommended Practice for Electric Systems in Health Care Facilities

International Electrotechnical Commission (IEC); Geneva, Switzerland;

IEC/TR3 61000-2-1: Electromagnetic Compatibility — Environment

IEC/TR3 61000-3-6: Electromagnetic Compatibility — Limits

IEC SC77A: Low-Frequency EMC Phenomena

IEC TC77/WG1: Terminology

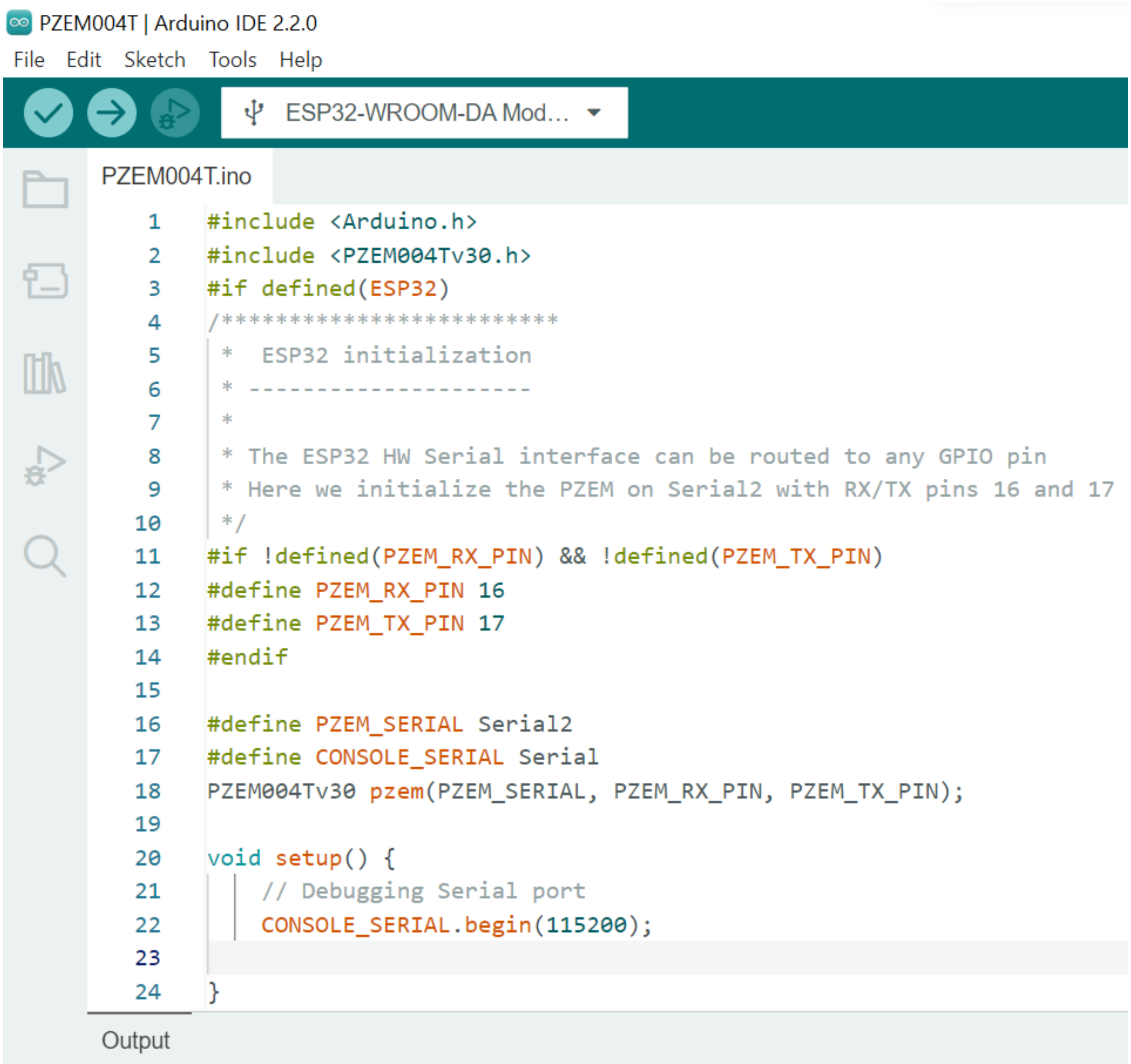
IEC SC77A/WG6: Low Frequency Immunity Tests

IEC SC77A/WG8: Electromagnetic Interference Related to the Network Frequency

Annex 2: **Financial Estimation of the System**

Nature of expense	**Cost of expense**
ESP 32 microcontroller	20 000 FCFA
PZEM_004T V3 sensor	15 000 FCFA
Cables	1 000 FCFA
Socket	1 000 FCFA
Breadbord	2 000 FCFA
Buzzer	1000 FCFA
Connexion for the software development	10 000 FCFA
Total	**50 000FCFA**

Annex 3: Codes for connecting the PZEM_004T V3 sensor with ESP 32



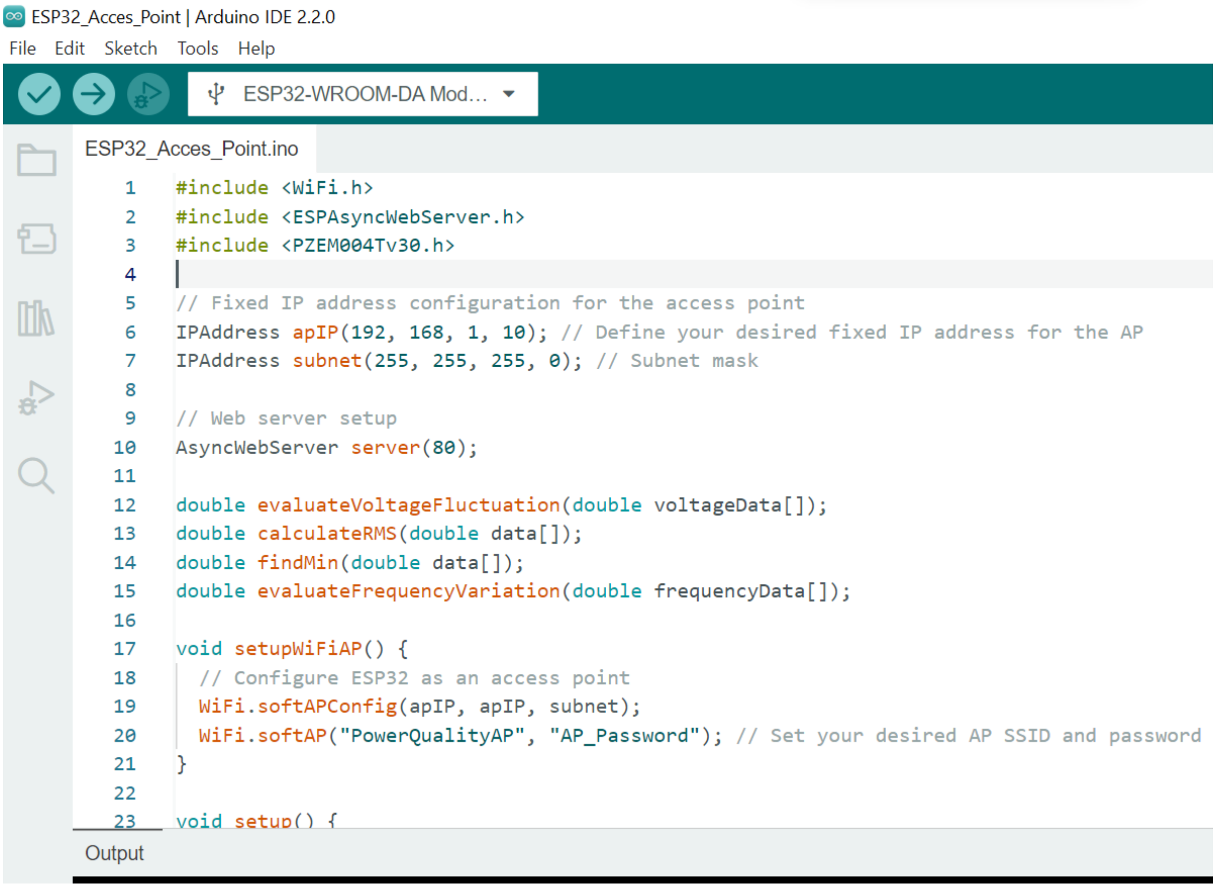

```
#include <Arduino.h>
#include <PZEM004Tv30.h>
#if defined(ESP32)
/*************************
 *  ESP32 initialization
 * ---------------------
 *
 * The ESP32 HW Serial interface can be routed to any GPIO pin
 * Here we initialize the PZEM on Serial2 with RX/TX pins 16 and 17
 */
#if !defined(PZEM_RX_PIN) && !defined(PZEM_TX_PIN)
#define PZEM_RX_PIN 16
#define PZEM_TX_PIN 17
#endif

#define PZEM_SERIAL Serial2
#define CONSOLE_SERIAL Serial
PZEM004Tv30 pzem(PZEM_SERIAL, PZEM_RX_PIN, PZEM_TX_PIN);

void setup() {
    // Debugging Serial port
    CONSOLE_SERIAL.begin(115200);

}
```

Annex 4: Codes for creating an Accees Point in the ESP32



ESP32_Acces_Point | Arduino IDE 2.2.0

File Edit Sketch Tools Help

ESP32-WROOM-DA Mod...

ESP32_Acces_Point.ino

```
#include <WiFi.h>
#include <ESPAsyncWebServer.h>
#include <PZEM004Tv30.h>

// Fixed IP address configuration for the access point
IPAddress apIP(192, 168, 1, 10); // Define your desired fixed IP address for the AP
IPAddress subnet(255, 255, 255, 0); // Subnet mask

// Web server setup
AsyncWebServer server(80);

double evaluateVoltageFluctuation(double voltageData[]);
double calculateRMS(double data[]);
double findMin(double data[]);
double evaluateFrequencyVariation(double frequencyData[]);

void setupWiFiAP() {
  // Configure ESP32 as an access point
  WiFi.softAPConfig(apIP, apIP, subnet);
  WiFi.softAP("PowerQualityAP", "AP_Password"); // Set your desired AP SSID and password
}

void setup() {
```

Output