REMOTE MONITORING AND ANALYSIS OF ELECTRICAL PARAMETERS OF A TRANSFORMER USING INTERNET OF THINGS (IoT)

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SEPTEMBER 2023.

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A PROJECT SUBMITTED IN PARTIAL FUFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BACHELOR OF ENGINEERING (B.ENG.) IN THE DEPARTMENT OF ELECTRICAL/ELECTRONICS ENGINEERING UNIVERSITY OF BENIN, BENIN CITY, EDO STATE, NIGERIA.

DEPARTMENT OF ELECTRICAL\ELECTRONICS ENGINEERING

FACULTY OF ENGINEERING UNIVERSITY OF BENIN, BENIN CITY, EDO STATE.

SEPTEMBER 2023.

CERTIFCATION

This is to certify that this project was developed by the following students listed above, and prepared in accordance with the rules governing its creation under proper supervision and was presented at the department of electrical/electronic engineering, faculty of engineering, university of Benin, Edo state, Nigeria.

Signature: …………………. Date: …………………….

ENGR. P. T. AIKHOJE

(PROJECT SUPERVISOR)

Signature: …………………. Date: …………………….

ENGR. PROF. K.O OGBEIDE

(HEAD OF DEPARTMENT)

DEDICATION

This project work is dedicated to God almighty for making it possible for us to begin this project and also bring the project to a close. It is also dedicated to our families for being a strong support both financially, emotionally, physically and spiritually during the course of our project.

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ACKNOWLEDGEMENTS

Our sincere gratitude goes to Almighty God, for bestowing his wisdom, grace and strength, understanding, empowerment and perseverance to complete this project. We also want to express our sincere gratitude to our project supervisor, ENGR. P. T AIKHOJE.

We also wish to appreciate ENGR. DR S.O. OMOROGUIWA our course adviser for his support. We sincerely appreciate the Head of Department of Electrical/Electronic engineering, ENGR.PROF. K.O OGBEIDE and other members of staff of the department for their support and encouragement.

Finally, we also want to thank our families (fathers, mothers, brothers and other relatives), friends and well-wishers for the support, advice and ideas during the period of our project work. I pray God bless you all abundantly.

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LIST OF ABBREVIATIONS

2G- Second generation

3G- Third generation

4G- Fourth generation

5G- Fifth generation

AC- Alternating Current

ADC- Analog Digital Converter

AMI- Advanced Metering Infrastructure

AMR- Automated Meter Reading

API- Application Programming Interface

CNG- Compressed Natural Gas

CT- Current Transformer

DC- Direct Current

DHCP- Dynamic Host configuration Protocol

EMF- Electromotive Force.

Gbit/s- Gigabit per second

GHz- Gigahertz

GIS- Geographical Information System

GPRS- General Packet Radio Service

GSM- Global System for Mobile Communication.

HMI- Human-Machine Interface

HSPA- Evolved High-Speed Packet Access

ICCID- Integrated Circuit Card Identification

ID- Identification

IEEE- Institute of Electrical and Electronics Engineers

IMSI- International Mobile Subscriber Identity

IO- Input Output

IoT- Internet of Things

IP- Internet Protocol

ITU- International Telecommunication Union

Kbps- Kilo byte per second

KHz- kilohertz

KWh- Kilo Watt Hour

LCD- Liquid Crystal Display

LDPC- Low Density Parity Check

LED- Light Emitting Diode

L-N- Line-Neutral

L-L- Line-Line

LTE- Long-Term Evolution

LTE-M- Long-Term Evolution for Machines

M2M- Machine 2 Machine

Mbps- Megabits per Second

MDMS- Meter Data Management Systems

MIMO- Multiple Input Multiple Output

OECT- Optical Electric Current Transformer

OFDM- Orthogonal Frequency Division Multiplexing

OT- Operational technology

MySQL- My Structured Query Language

NTL- Non-technical losses

PIN- Personal Identification Number

PC- Personal Computer

PCA- Principal Component Analysis

PLC- Power Line Communication

PLCC- Power Line Carrier Communication

PUK- Personal Unblocking Key

PVC- Polyvinyl chloride

RF- Radio Frequency

RFID- Radio-Frequency Identification

RTC- Real Time Clock

RTU- Remote Terminal Unit

SIM- Subscriber Identity Module

SMS- Short Message Service

SM- Smart Meter

SSN- Serial SIM Number

STBC- Space Time Block Coding

TCP- Transmission Control Protocol

USB- Universal Serial Bus

V_{line}- Line Voltage

V_{ph}- Phase Voltage

WI-FI- Wireless Fidelity

WiMAX- Worldwide Interoperability for Microwave Access

WLAN- Wireless Local Area Network

ABSTRACT

This project focuses on remotely measuring and analyzing electrical parameters of a 3-phase transformer, with primary objectives including assessing line and phase voltage, Real and Reactive Power and power factor remotely, transmitting the data to the cloud, and conducting comprehensive data analysis.

The methodology involved utilizing a 3-phase meter with a CT clamped to the three-phase output on the control panel, configured to communicate with a 4G IoT gateway for internet connectivity. Data was transmitted to the cloud, extracted, and processed using machine learning libraries such as pandas, numpy, seaborn, and scikit-learn on Kaggle web data analysis platform. A linear regression model was constructed to forecast sum of reactive power based on real power and reactive power values.

The results of the project showcase the effectiveness of remote monitoring and data analysis techniques in predicting electrical parameters. The linear regression model exhibited high performance, with a mean squared error of 16.97 and an R-squared value of 0.98, indicating precise predictions. Minimal deviations were noted when comparing actual and predicted values. These findings underscore the potential of such techniques in enhancing system efficiency and reliability through informed decision-making.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Electric power system plays a crucial role in modern society, providing energy necessary for industrial and domestic use. With the increasing demand for reliable and efficient power systems, there is a growing need for real-time monitoring, analysis of power quality and system performance. Presently, the distribution network lacks the capability to provide real-time monitoring and analysis which makes it difficult to detect and resolve issues that may arise in the power system.

In addition, the distribution network is limited in its ability to support integration of renewable energy sources, such as solar and wind power integration. Renewable sources comes with their own challenges due to the varying conditions of wind speed and irradiance hence, the need for a sophisticated monitoring system.

To meet these challenges, it is essential to develop and deploy a remote smart grid monitoring system capable of continuously measuring and analyzing key electrical parameters. The system provides valuable insights into power quality and grid performance enabling more efficient management and proactive decision-making.

The monitoring system comprises Advanced Metering Infrastructure (AMI), Long-Term Evolution for Machines (LTE-M) IoT gateway, Remote Terminal Unit (RTU) and Human-Machine Interface (HMI) technologies to provide real-time monitoring and analysis of power system parameters such as voltage, current, power factor, reactive power and frequency

Advanced metering infrastructure (AMI) is a technology that enables two-way communication between the utility and the customer, allowing for real-time monitoring of energy consumption and power quality. Long-term Evolution Machine Type Communication (LTE-M) is a type of low-power wide-area network communication technology designed specifically for Internet of things (IoT) devices. It provides a low-power, cost-effective way for these devices to connect to the internet. LTE-M networks have better coverage and can work in remote areas, making them suitable for IoT applications. LTE-M IoT gateway is a communication technology that enables the transmission of data from the smart meter to the RTU using the cellular network. RTU is a device that collects data from the smart meter and transmits it to the HMI for analysis. HMI stands for "Human-Machine Interface." An HMI is a user interface or a graphical display that allows humans to interact with and monitor power systems, such as electrical grids, substations or industrial control systems. It serves as a means for operators or engineers to visualize and control the various components and processes within the power distribution network. It combines real-time data visualization, control capabilities, alarms, historical data storage and security features to facilitate efficient and safe management of power systems.

1.2 PROBLEM STATEMENT

Electric power systems are crucial infrastructures that play a significant role in modern societies. In recent years, the increasing demand for electricity and the growth of renewable energy sources have put a strain on the power grid. This has resulted in challenges such as voltage fluctuations, frequency variations and power quality issues which can lead to power outages, equipment damage and reduced system reliability. Moreover, traditional power grid monitoring systems are limited in their ability to provide real-time analysis of power quality and system performance, which makes it difficult to detect and address problems in a timely manner.

To address these challenges, there is a need to develop a comprehensive monitoring and analysis system that can provide real-time information about power system parameters such as voltage, current, power factor and frequency. Such a system can enable utilities to identify and respond to issues promptly, improve system efficiency and optimize energy usage. In addition, the integration of advanced metering infrastructure (AMI), Long-Term Evolution for Machines (LTE-M) IoT gateway, Remote Terminal Unit (RTU) and Human-Machine Interface (HMI) can facilitate the acquisition, processing and visualization of power system data, thereby enabling better decision-making and efficient management of power systems.

This study provides a comprehensive approach to monitoring and analyzing power system parameters, enabling better decision-making and more efficient management of power systems. The proposed system will be tested and evaluated to assess its effectiveness in improving the efficiency and reliability of power systems.

1.3 AIM

The aim of this project is to implement a real-time data acquisition system, transmit the acquired data to the cloud using IoT technology and perform in-depth analysis of the system parameters to improve the efficiency and reliability of power systems.

1.4 OBJECTIVES

The objectives of this study are:

1. To obtain a real measurement of phase parameters of a transformer (Secondary end) Voltage, Power factor, active power factor and reactive power
2. To develop a data acquisition and transmission network for monitoring
3. To develop a real time measured data presentation for real time monitoring

4. To carry out data analysis and simulation.

1.5 METHODOLOGY

1. The measured electrical parameters of each phase of a three-phase transformer is done using a 3-phase spark electro XHD331-R rail type multifunctional smart meter.
2. The real-time data of the measured three-phase electrical parameters is acquired and stored in the cloud using a CWT-LT120 4G M2M IoT gateway.
3. Remote monitoring of acquired data from the M2M IoT gateway website Http://m2m-iot.cc is done using sensors and meters synced with the personal computer (PC) and the data is extracted as an excel file.
4. Data analysis was done by converting the data set into a .csv file and loading unto kaggle.com. While the simulation was done using python scripts and basic machine learning models.

1.6 SCOPE OF STUDY

This project focuses on a structured workflow, ranging from initial measurements and data acquisition to continuous monitoring, periodic data extraction and thorough analysis of pertinent transformer data at designated intervals in order to facilitate data-driven decision-making, specifically focused on optimizing grid maintenance practices and enhancing the sustainability and reliability of power grids. Furthermore, the project entails meticulous phase-wise monitoring of the transformer to assess load distribution; a critical factor in ensuring the delivery of optimal power services to end-users.

1.7 OVERVIEW OF RELATED RESEARCH WORK

T. Vinothkumara et al., carried out an efficient and reliable data gathering infrastructure using Internet of thing (IoT) and smart grids. The findings concluded that the IoT provide instantaneous assessment and care for extensive data while advocating for the modernization of the power grids.

Suhad Qasim Naeem (2023), in her paper proved that well designed power-monitoring system is effective and when integrated with IOT devices it increased the effectiveness. However, this study also revealed that smart power monitoring systems have a positive influence on security and technological disruption.

Mr. Y. Rajeshbabu (2023), in his article designed a prototype which monitored daily consumption in smart phone application interfaced with Blynk server using IoT in tandem with an automated device known as the smart meter. The current and Voltage sensor were selected and measured so that the power consumption could be determined using these devices. The system used ESP32 as a micro controller with Wi-Fi module to provide IoT communication.

Lei Yu et al (2020), in his paper analyzes and discusses the determination of monitoring objects, the selection and placement of monitoring points in the smart power monitoring system. The article introduced a smart building design utilizing internet of things (IoT) technology. The integration of indoor electrical Internet of things (IoT) and public facilities creates a comprehensive building database, enabling various data analysis algorithms to offer decision-making support for managing building operations. Following numerous experiments, the power supply device incorporating intelligent monitoring, as detailed in the paper, successfully met its intended objective.

D. Alahakoon and X. Yu, "Smart Electricity Meter Data Intelligence for Future Energy Systems" (2015) analyzes the comprehensive survey of smart electricity meters and their utilization with a focus on key aspects of the metering process, various stakeholder interests and the technologies employed to meet these interest. Additionally, challenges and opportunities stemming from the emergence of big data and the growing adoption of cloud environment were highlighted.

Md. Tanvir Ahammed and Imran khan in the article "Ensuring power quality and demand-side management through IoT-based smart meters in a developing country" (July, 2022) analyzes the difficulties in maintaining supply between supply and demand of electricity suppliers due to the increased electrical demands which led to frequent load shedding and a drop in power quality. To solve this existing limitations, the proposition of an IoT-centered smart meter (SM) was put forth, with a showcased practical application in Bangladesh households serving as a case study. The suggested SM focuses on local and remote monitoring, two-way data transfer and demand-side Management (DSM) for consumers, ensuring power quality and peak–clipping. Utilizing My Structured Query Language (MySQL) cloud database facilitates data storage and bidirectional transmission between consumers and the utility. Additionality, web applications were created for real-time data visualizations, granting consumers' access to track their energy usage on an hourly, daily and monthly basis via a web interface.

1.8 RELEVANCE OF WORK

The following areas are where this project is relevant:

1. Power Grid Management: This project significantly contributes to the efficient management of power grids by providing real-time data and insights for better decision-making in grid operations.

2. Energy Sustainability: It supports sustainability efforts by optimizing energy distribution, reducing waste and contributing to a more sustainable energy ecosystem.

3. Grid Reliability: Enhancing grid reliability is critical for minimizing power outages and disruptions and this project aids in achieving this by identifying areas for improvement.

4. Infrastructure Maintenance: It helps in planning and executing preventive maintenance of transformers and related infrastructure, reducing downtime and maintenance costs.

5. Energy Conservation: By analyzing load distribution, this project promotes energy conservation by ensuring that power resources are used efficiently.

6. Smart Cities: As cities become smarter and more interconnected, this project aligns with the development of smart grid technologies that are essential for modern urban areas.

CHAPTER TWO

LITERATURE REVIEW

With the increasing demand in electricity, the use of equipment in monitoring, analyzing and executing the data to make profound decisions becomes crucial in power systems.
Through metering devices, such as smart meters in Advanced Metering Infrastructure (AMI) systems, essential information on energy consumption, load profiles and power quality parameters is collected in real-time. This data serves as the basis for monitoring and assessing the performance of power systems. AMI is a comprehensive infrastructure that integrates various technologies, such as smart meters, communication networks, and data management systems, enabling efficient data collection, analysis, and communication between utility providers and consumers. R.R Mohassel, et al., (2014).

Metering serves as a fundamental component in power system monitoring, enabling comprehensive analysis and effective management of power systems. It provides crucial insights into system behavior, allowing operators to identify abnormal conditions, track energy usage patterns, and detect faults. By integrating metering technologies with advanced monitoring systems, power system operators gain the ability to make informed decisions, optimize grid operations, and ensure the reliability and efficiency of electrical networks.

AMI is not a single technology, rather a carefully designed infrastructure that incorporates multiple technologies to achieve its objectives. This infrastructure consists of various components, including smart meters, communication networks at different levels, Meter Data Management Systems (MDMS), and mechanisms to integrate the collected data into software applications and interfaces.

Smart meters, within this infrastructure, have the capability to transmit the data collected through different types of fixed networks like Broadband over Power Line (BPL), Power Line Communications, Fixed Radio Frequency and public networks such as landline, cellular, and paging. The consumption data recorded by these meters is received by the AMI host system, which then forwards it to an MDMS. The MDMS is responsible for managing data storage and analysis, as well as providing the utility service provider with relevant and meaningful information.

In summary, The AMI enables two way communication between the utility and the meters or Load controlling devices through the use of signals and commands to manage the load and interact with the devices.

2.1 DATA MEASUREMENTS

This is the process of quantification, description and representation of data in terms of numbers. Different levels of data were obtained and these data affected the analysis carried out in this regard. Data Measurements are divided in two types: Qualitative and Quantitative.

Qualitative data is non-numerical. It refers to information that cannot be measured. It is also an important part of data collection and analysis, a major factor to getting useful insights from textual data and finding subtle patterns.

Moreover, in quantitative data which could either be discrete or continuous refers to information that are measured or counted and expressed in numerical terms. It was used in this research to draw conclusions and make predictions.

2.1.1 METER

An electric meter is a device used to measure the electrical energy usage of a home, building, or other electrically powered device. Electric meters operates by constantly monitoring the immediate voltage (volts) and current (amperes) to determine energy consumption (measured in joules, kilowatt-hours, etc.).

For smaller services, like residential customers with lower power needs, meters can be directly connected in-line between the power source and the customer. However, for larger loads exceeding approximately 200 amperes, current transformers are employed.

The two (2) major types of meter includes

- Analog meter
- Digital meter

2.1.2 ANALOG METERS

Also known as electromechanical meters is a permanent magnet moving coil (PMMC) instrument in which the output is a continuous function of time and has a constant relation to the input. These meters are used to measure quantities like voltage, current, energy, and power. The analog meter has a pointer or dial that shows the magnitude of the quantity being measured (Dr. Arvind Kulkarni, 2022)

When electrical power is consumed, the needle on analog meters rotates either clockwise or counterclockwise. These meters feature a dial with printed numbers, and the value indicated by the needle's position represents the measured quantity. In essence, the final location of the needle on the dial corresponds to the specific value of the measured quantity.

Analog meters are broadly categorized according to the quantity they measure. They can be categorized into three types:

- Indicating instrument
- Recording instrument
- Integrating instrument

Indicating Instruments: These analog instruments directly indicate the quantity that is being measured. The dial or pointer of the analog meters shows the magnitude of the respective quantity. Voltmeters and ammeters are examples of analog indicating instruments.

Recording Instrument: These analog instruments give a record of the quantity that is being measured over a specific time period. The variation in the quantity being measured are recorded on paper. A voltmeter that keeps on recording the variations of the supply voltage is an example of analog recording instrument.

Integrating Instruments: These instruments measure the summation of the electric quantity over a specified period of time. Ampere-hour and watt-hour meters are examples of these types of instruments.

Applications of analog meter

- It is employed for measuring voltage, current, energy, and power.
- Utilized in the measurement of radiofrequency transmissions.
- Commonly used for measuring 3-phase power.
- Applied in power control and motor control panels.
- It is also found in relay and control panels.
- Capable of measuring speed, weight, and acceleration

Figure 2.1: An Analog meter

2.1.3 DIGITAL METERS

Also called electric meters, is a measuring tool together with polarity symbols (+ and –) and a decimal point that automatically appears between the correct pair of digits that measures, offering connectivity and some instant functionalities like current, resistance and voltage. The meters tells you the exact meter reading on the display without any calculations required.

Digital meters measures the voltage and current in an electrical circuit and they integrate these measurements over time to calculate the total energy consumed. These meters employ electronic components like microcontrollers, ADCs and digital signal processing for accurate measurements and calculations. The acquired energy consumption data is usually shown in an LCD or LED display and may be sent to a utility company for billing.

Electronic energy meters provides several advantages over traditional electromechanical meters, including:

1. Enhanced accuracy: Electronic energy meters exhibit high precision and a lower error rate in comparison to electromechanical meters.

2. Expanded measuring range: They have a broad measuring range, enabling accurate measurement of energy consumption even at lower levels.

3. Tamper resistance: Electronic energy meters are challenging to tamper with due to advanced anti-tampering features, designed to detect and record any tampering attempts.

4. Remote communication: These meters can be equipped with communication modules, allowing for remote monitoring, data collection, and analysis, enhancing convenience for utility companies.

5. Additional features: Electronic energy meters may include extra features like time-of-use metering, load profiling, and power quality analysis, offering more information to both utility companies and customers.

6. Lower maintenance: With fewer moving parts compared to electromechanical meters, electronic energy meters require less maintenance.

Figure 2.2: A Digital meter

2.1.4 SMART METER

The smart meter stands as a pivotal component within the framework of the smart grid (SG), representing a cutting-edge energy measurement device. Functioning as an advanced metering tool, it retrieves comprehensive data from the various load devices utilized by end-users, meticulously quantifying the energy consumption of consumers.

Subsequently, this acquired data is leveraged to furnish supplementary insights and information to both the utility company and/or system operator, enhancing their ability to manage and optimize the overall energy distribution and consumption process (Jixuan Zheng et al. 2013).

Smart meters work in a similar way to mobile phones - by using a wireless network connection. In simple terms, the electricity smart meter is connected to the mains and monitors how much electricity is used in real time.

The smart meter contains two main elements:

- The meter**:** It is a secure, intelligent data network linked wirelessly, transmitting details regarding energy consumption to the supplier.
- The in-home display (IHD): resembling a tablet device, it functions as a monitor, enabling observation of energy usage to make necessary adjustments or decisions.

Smart meters come in two different configurations:

1. Single-phase
2. Three-phase.

A notable differentiation between these variants lies in their energy capacity. Businesses such as commercial and industrial entities, which necessitate substantial power consumption, commonly utilize the three-phase connection.

In contrast, residential electricity demand is usually markedly lower compared to industrial and commercial needs. Consequently, utility providers commonly deploy single-phase energy meter connections for households.

Beyond these typical metering options, there are also comparable CT-PT (Current transformer-power transformer) and distribution transformer-operated meters available, tailored to specific usage necessities.

2.1.5 SINGLE PHASE METER

A single-phase smart meter also referred to as credit meters, KWh meters, or check meters is a sophisticated measuring instrument employed for overseeing and documenting the utilization of electrical power within a singular electrical phase. These technologically-advanced meters are outfitted with communication features, empowering them to gather and send instantaneous information concerning electricity consumption.

This functionality facilitates access for both consumers and utility companies to comprehensive insights into energy usage trends.

Typically installed in residential settings and smaller commercial enterprises relying on a single-phase electrical system, these smart meters furnish precise and prompt data essential for billing procedures, energy supervision, and the evaluation of efficiency within the broader electrical grid infrastructure.

These meters work by measuring the amount of electrical energy passing through the system. Using either electromechanical or digital technology to calculate the amount of energy consumed in kilowatt-hours (KWh).

Types of single phase meters electrical distribution circuits includes:

- Surface or Wall Mounted Meters
- DIN-Rail Meters
- Prepayment Meters
- Smart meters

The surface or wall mounted meters is a single phase meter used by utility companies for measuring power consumption. With a rating of 100Amp, this type of meter is simple to read as it only shows the power consumed in KWh units

The DIN-Rail meters: A DIN Rail meter is a standard-type metal rail used for mounting circuit breakers and industrial control equipment in equipment racks. Furthermore, it acts as a mechanical support structure for different types of small electrical parts.

Prepayment meter: Originally called coin meters, accept card payments and cuts off the electrical supply if the customer doesn't add credit.

Smart meters are made to use different types of SIM cards, just like a mobile phone. This allows data to be read remotely, eliminating the need for manual meter readings. Smart meters also give consumers extra real-time data and information remotely via a home display.

Moreover, single-phase meters also consists of current and voltage transformers, a measuring element, a register or digital display, and communication interfaces. The current transformer steps down the current to a level suitable for the meter, while the voltage transformer scales down the voltage. The measuring element records the energy consumption and the digital display displays the data gotten.

2.1.6 THREE PHASE METER

A three-phase smart meter represents an advanced measurement device employed for monitoring and evaluating electrical energy consumption within a three-phase electrical system. These sophisticated meters are equipped with cutting-edge technology enabling precise measurement and recording of electricity usage across the three distinct electrical phases.

Features of a three-phase smart meter include:

- Measurement Capabilities: These meters are engineered to measure voltage, current, power factor, and various electrical parameters across each of the three phases. They furnish comprehensive data concerning energy consumption within a three-phase power supply.

- Communication Abilities: Similar to single-phase smart meters, three-phase smart meters are outfitted with communication modules facilitating the real-time transmission of data. This data can be forwarded to utility companies for billing purposes or accessed by consumers to monitor their energy usage.

- Accuracy and Efficiency: Renowned for their precision in measuring electricity consumption, three-phase smart meters ensure accurate billing, particularly for commercial and industrial entities with higher power demands.

- Deployment and Utility: These meters are predominantly installed in larger commercial and industrial settings utilizing a three-phase electrical system, playing a pivotal role in optimizing energy management, enabling enhanced control and analysis of power consumption patterns.

- Remote Accessibility and Monitoring: It commonly offers remote access, enabling utility companies and consumers to remotely monitor, analyze, and manage energy usage. This functionality promotes energy efficiency and improved load management.

Types

The two (2) main types of smart meters includes

1. Automated Meter reading (AMR)
2. Advanced Metering infrastructure (AMI)

2.1.7 AUTOMATED METER READING (AMR)

Automated meter reading (AMR) refers to the automated process of gathering consumption, diagnostic, and status data via wired communication from various metering devices, such as water, gas, or electric meters. The acquired information is transmitted to a centralized database for the purpose of billing, troubleshooting, and comprehensive analysis. The primary goal of this technology is to streamline data collection process and enhance efficiency in managing utility services.

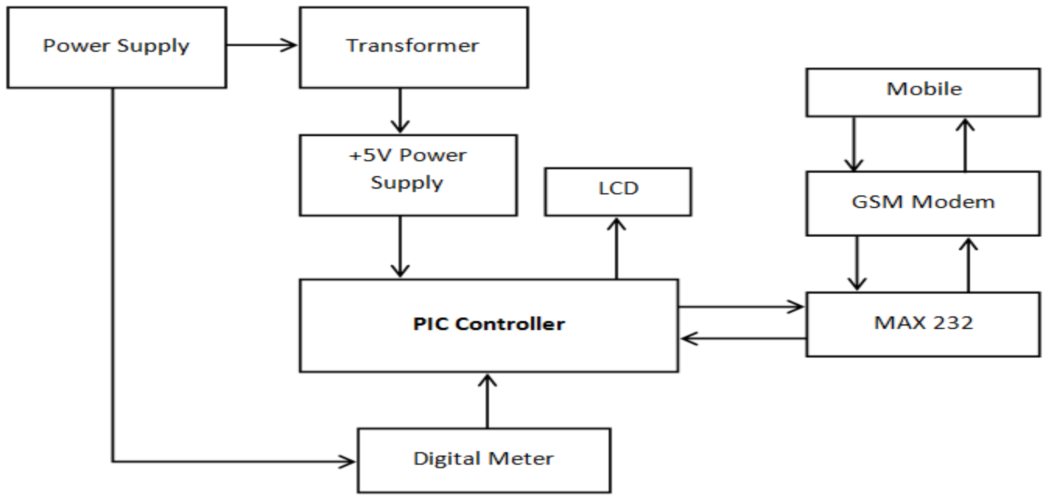


Figure 2.3: Block diagram of the automated wireless meter reading system (amr) (M.M. Mohamed Mufassirin, 2016)

ADVANCED METERING INFRASTRUCTURE (AMI)

The AMI comprises an integrated system incorporating smart meters, communication networks, and sophisticated data management systems. The setup facilitates bi-directional communication between utility providers and customers. Notably, the system introduces a range of crucial functionalities which were previously unattainable or required manual intervention.

These novel capabilities include the automated and remote monitoring of electricity consumption, identification and isolation of power outages along with voltage monitoring. When paired with consumer-oriented technologies like in-home displays and programmable communicating thermostats, AMI empowers utility companies to introduce innovative time-based rate programs and incentives. These initiatives aim to encourage customers to actively reduce peak demand, manage energy consumption more effectively, and ultimately control associated costs (U.S department of energy, 2016).

At the core of the advanced metering infrastructure (AMI) are smart meters, pivotal in performing various tasks such as monitoring customer electricity usage at intervals of 5, 15, 30, or 60 minutes, gauging voltage levels and tracking the on/off status of electric services. These smart meters effectively relay this data to utility providers for further processing, analysis and subsequent communication back to customers.

Smart meters provides additional functions including remote connection and disconnection, detecting tampering, the ability to initiate and terminate service connections remotely and facilitating bidirectional measurement of electricity consumption. These features play a pivotal role in fostering the uptake of distributed generation. With the absence of smart meters along with the communications and information management systems binding them, many of the cost-savings and demand-reducing impacts and benefits from AMI would not be realized.

Smart meters introduce two fundamental communication technologies for smart meter systems:

1. Power Line Carrier (PLC)
2. Radio Frequency (RF).

1. Power line carrier (elprocus.com)

Power Line Carrier, also known as Power Line Communication (PLC), constitutes one of the technologies employed for the transmission and reception of communication signals. Also abbreviated as PLCC (Power line carrier communication), goes by various names such as main communication, power line digital subscriber line and power line networking.

It has the capability to economically and rapidly establish a system by leveraging on an electrical supply network as its communication infrastructure. Through utilizing existing electrical power lines as the communication medium, PLCC networking technologies eliminate the requirement for additional wire installations, facilitating seamless connectivity among devices connected to the alternating current (AC) mains without the need for new wiring installations.

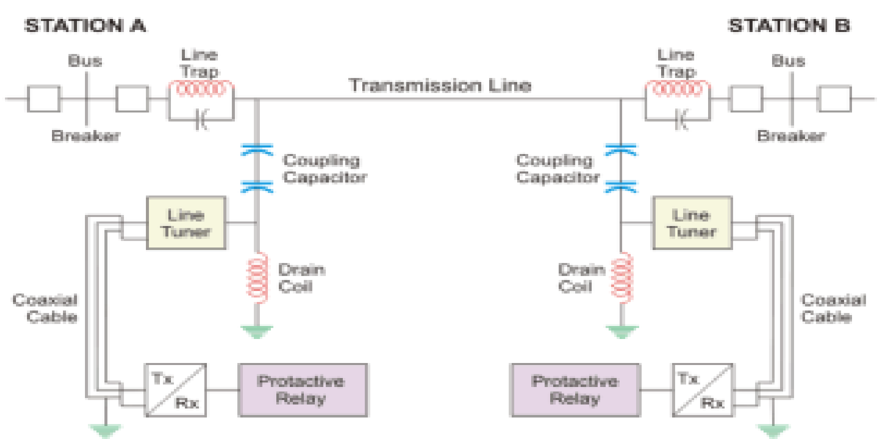


Figure 2.4: Power Line Carrier Communication Circuit Diagram

2. Radio Frequency (genuspower.com)

Radio frequency (RF) represents the oscillation rate of the electromagnetic radiation spectrum or electromagnetic radiation waves. It covers frequencies ranging from 9 kilohertz (kHz) to as high as 300 gigahertz (GHz). RF is generated by a transmitter and identified by a receiver. The transmitter antenna converts electrical signals into radio waves, allowing them to cover considerable distances. The receiver antenna captures the radio waves and converts them back into electrical signals, which are then input into devices like radios, televisions and telephones. The electrons in the electric current move back and forth along the antenna, which creates electromagnetic radiation in the form of radio waves.

Radio frequency interference (RFI) happens when undesired electromagnetic signals disturb the regular functioning of a communication system or electronic device functioning within the radio frequency spectrum.

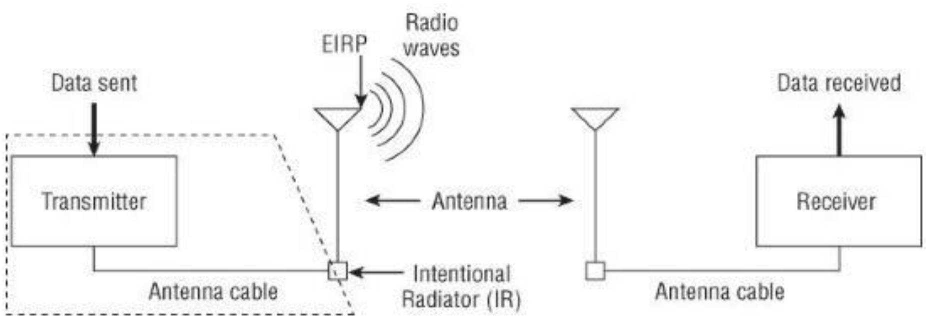


Figure 2.5: Radio Frequency Transmission

In contrast to wired communication technologies such as Power Line Carrier (PLC), RF mesh technology stands out as a pivotal aspect of automatic meter reading (AMR), offering wireless communication capabilities. Specifically designed for smart homes, it emerges as one of the most adaptable communication solutions for metering purposes. The RF system operates by integrating dedicated modules into meters, allowing data collection and precise measurement of power consumption.

Applications of Radio Frequency:

Telecommunication Services

- Cellular telephones
- Radio and television broadcasting
- Radio communications for police and fire departments
- Amateur radio
- Satellite communications

Non-Communication Applications

- Microwave ovens
- Radar
- Traffic enforcement
- Air traffic control
- Military
- Industrial heating and sealing
- Molding plastic materials
- Gluing wood products
- Sealing items, such as shoes and pocketbooks
- Processing food products

Medical Applications

- MRI
- Cosmetic treatments

2.1.8 REAL TIME MEASUREMENT DEVICES

Real time measurement is essential for implementing different work tactics because they feed timely data to the decision-making process. Real time measurement systems provides data quickly enough to effect the progress of field work. This section analyses several instruments used to carry out real time measurements on feeders. Which includes:

1. SDE430-C three phase power analyzer

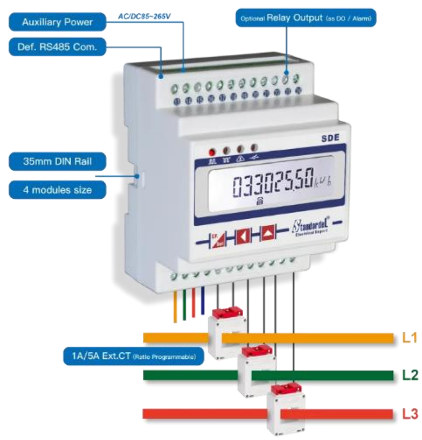


Figure 2.6: SDE430-C Three Phase Power Analyzer

SDE430-C mini DIN rail 3 phase power analyzer is designed special for renovation project of energy management (EMS) (aIibaba.com, 2021). It has 3 external spilt core CTs (5~600A) or 3 Rogowsi coli (200~6000A), so we don’t need to dismantle just to install it. By its DIN rail installation, it is very suitable to be used with breakers and contactors

SDE430-C has good cost performance, as an intelligent unit and a digital electrical data collection unit it has been widely used in many intelligent systems

See Features of SDE430-C Three Phase Power Analyzer are in Appendix 1

2. SPARK ELECTRO XHD331-R SMART METER

It is a 3-phase smart meter with Modbus communication. The XHD331-R represents an innovative energy meter meticulously engineered to ensure precise measurement and facilitate remote data access within three-phase electrical systems. It serves as a multifaceted rail type meter, adept in accurately measuring and presenting a multitude of power parameters across both three-phase three-wire and three-phase four-wire power grids. These parameters encompass voltage, current, power, frequency, demand, active power, reactive power, forward power, backward power, total harmonic content, and more. Its functionality aims to provide comprehensive insights into the intricate aspects of energy consumption and power quality within these electrical systems.

Figure 2.7: Spark Electro XHD331-R Smart Meter

See Features of Spark Electro XHD331-R Smart Meter in appendix 2

2.1.9 CURRENT TRANSFORMER

A current transformer (CT) is an essential electrical apparatus utilized for measuring alternating current (AC) by converting high currents into standardized, manageable values suitable for use in measuring instruments and protective mechanisms. CTs comprise a primary winding, through which the current intended for measurement flows, and a secondary winding that connects to instruments or protective devices.

Typically, the primary winding is linked in series with the electrical circuit carrying the current to be assessed, while the secondary winding is attached to instruments or devices responsible for monitoring, measuring, or regulating the current. CTs operate based on electromagnetic induction, utilizing the ratio between primary and secondary windings to establish a transformation ratio, thereby enabling accurate and proportional current measurement.

These devices hold paramount importance across various applications, especially in electrical power systems, as it ensure safe operations by delivering precise current readings essential for metering, monitoring, and protective functions. CTs serve as an integral components within diverse electrical systems, including distribution networks, industrial machinery and power generation facilities where precise current measurements play a pivotal role in maintaining operational efficiency and ensuring safety standards.

The working principle of current transformers;

Current transformers (CTs) function based on Faraday's principle of electromagnetic induction, wherein a changing magnetic field around a conductor—like the primary winding of the CT—generates a voltage or electromotive force (EMF) in a nearby conductor, namely the secondary winding of the CT.

Operational mechanism of a current transformer:

- Primary and Secondary Windings: CTs are comprised of two sets of windings: the primary and secondary. The primary winding is interconnected within the electrical circuit carrying the current to be measured, while the secondary winding is linked to measuring or protective devices.

- Transformer Action: When an alternating current passes through the primary winding, it produces an alternating magnetic field surrounding the primary coil and this field extends to the secondary winding.

- Induced Voltage in Secondary Winding: According to Faraday's law, the changing magnetic field induces a voltage in the secondary winding. This induced voltage is directly proportional to the rate of change of current in the primary winding.

- Transformation Ratio: The ratio of turns between the primary and secondary windings establishes the transformation ratio of the CT. The ratio dictates the extent to which the primary current is reduced in the secondary winding. For instance, if a CT has a ratio of

100:5, 100 amps in the primary winding translates to 5 amps in the secondary winding (a 20-fold reduction).

- Accuracy and Current Measurement: The output from the secondary winding is then linked to measuring devices or protective mechanisms. This downscaled current in the secondary winding offers an accurate depiction of the primary current and is utilized for measurement, monitoring, or control purposes.

Applications of Current Transformer

- CTs find application in power plants, businesses, grid stations and industrial control rooms to measure electricity for metering, analysis and safeguarding purposes.
- CTs play a crucial role in circuit control and current measurement for power assessment.
- It also provides safety protection and current limiting, controlling and safeguarding relays, circuit breakers, and similar components.
- Additionally, CTs are employed in measurement and protective applications in conjunction with relays and meters.

Uses of CTs includes

- Monitoring and measuring current in power systems.
- Providing overcurrent and fault protection for electrical equipment.
- Energy metering and billing in utility applications.
- Detecting ground faults in electrical systems.
- Protecting motors and generators.
- Analyzing and monitoring power quality.
- Sensing current in industrial automation and control systems.

- Implementing current-based relay operation in electrical protection schemes.
- Monitoring and controlling electrical loads.
- Tracking current in renewable energy systems.

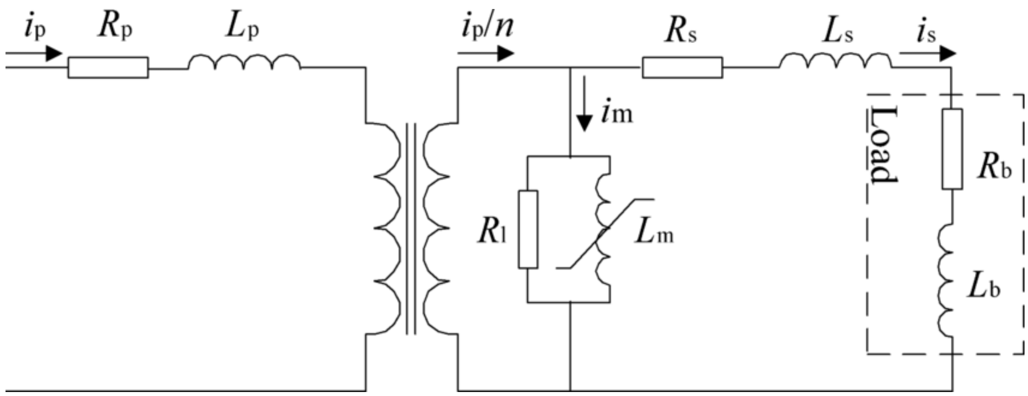


Figure 2.8: Current Transformer Circuit Diagram (Fernando J. T. E. Ferreira et al 2006)

1 RS PRO CURRENT TRANSFORMER

RS Pro CT’s are square type and encapsulated with polycarbonate. These CT’s features terminal encloses a wide range of current ratings. They are available in different bus bar sizes, case widths, and mounting options.

Figure 2.9: RS Pro Current Transformer

See appendix 3 for specifications of RS Pro Current Transformer

2 RS 150 CURRENT TRANSFORMER

The RS 150 current transformer, equipped with 3-phase clamps and operable with a 12-30 VDC power supply, stands as a compact and portable instrument meticulously crafted to deliver precise and dependable current measurements in industrial and commercial settings. This current transformer (CT) generates an alternating current in its secondary winding, ensuring accurate portrayal of the primary current.

Moreover, the turn's ratio of a CT can be adjusted by employing multiple turns in its winding configuration. This feature enables users to modify the transformer's transformation ratio, allowing for versatile adaptation to diverse current measurement requirements.

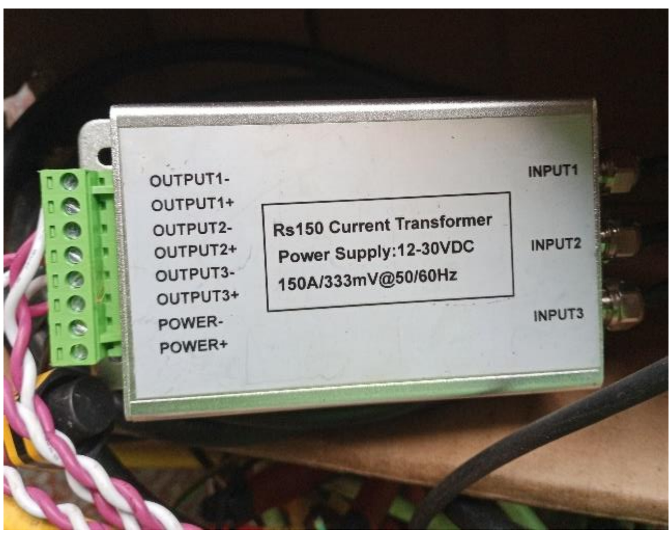


Figure 2.10: Rs150 Current Transformer.

See Features of Rs150 Current Transformer in appendix 4

2.2 RELATED WORKS ON REAL TIME MEASUREMENT

Rajendu Mitra, et al (2015), his work shows that voltage time series measurements collected from customer smart meters exhibit correlations that are consistent with the hierarchical structure of the distribution network. Utilizing these correlations which serve as a valuable method, customers were grouped together based on shared lineage, enabling the verification and potential refinement of an established connectivity model.

Additionally, by grouping customers together and using voltage information measurements from circuit meters, location data from maps, and an imperfect connection model, data related to how customers are connected to transformers and different phases were accurately stated.

W. Luan et al, "Smart Meter Data Analytics for Distribution Network Connectivity Verification,"(2015) in his article, proposed that many utilities have the data quality problem with the geographical information system (GIS) records at distribution level. In other to correct this error in the GIS representation of the distribution network topology, an in-house algorithm was developed. This in-house algorithm leverages smart meter interval measurements and identifies the neighboring meters by voltage profile correlation analysis. It also forecasts how customers are connected in terms of location before and after by measuring and comparing the strength of the voltage.

T. S. D. Ferreira et al, (2020) in his work "Load Flow-Based Method for Nontechnical Electrical Loss Detection and Location in Distribution Systems Using Smart Meters," presents an innovative load flow-based approach that uses measurement data from smart meters to detect and locate non-technical losses (NTL). This method aims to pinpoint unauthorized loads connected to the distribution system, relying on measurements potentially available from smart meters such as voltage magnitude, active and reactive powers.

Tatsuya Furukawa et al, (2008) proposed a voltage-current sensor embedded in a ceramic insulator for the real time observation of the power factor in the three-phase power distribution systems and carried out the infinite element analysis to investigate its characteristics and verify its feasibility. However, the ceramic sensor has problems in cost and a burning process in manufacturing to result in the deformation from the designed form.

Lisa Ehrlinger and Wolfram Wöß, (2022) examined and carried a survey of Data quality measurement and monitoring tools to close the gap between data quality research and practical implementations with a detailed investigation on how data quality measurement and monitoring concepts are implemented in state-of-the-art tools.

Ondrej krejcar and Robert frischer, (2012) examined and discussed the development of a measuring device for analyzing reactive power. The device created was designed for analyzing power circuit. Different other issues were examined such as the accuracy and measurement speed while designing the device.

Li, Jingxiang et al, (2023) in his article “Optical Electric Current Transformer for Monitoring Its Performance in the Substation” used the optical electric current transformer (OECT) as a measuring and protective equipment in the power system. Its accuracy and reliability are vital to the power system’s safe, reliable, and economical operation.

2.3 DATA ACQUISITION AND TRANSMISSION.

This is the process of acquiring electrical phenomena such as frequency, power and voltage and converting the resulting sample from the sources into digital numerical values (processing) that can be manipulated by the computer. The process is attained via the use of various sensors or equipment which transforms the data and processes them.

While data transmission is moving data from one point to another via the use of networks and devices.

Data acquisition system can be further divided into different types;

- Transducers- which converts physical quantities into electrical signals.
- Signal conditioners- This amplifies the selected portion of the signals.

Pertaining to this work, the data acquired is transmitted to the cloud for remote monitoring via a PC. This is achieved by a point to point connection from the meter to the IoT gateway. Port 7 on the gateway is connected to port B on the meter while port 8 on the gateway is connected to port A on the meter. The gateway contains a sim slot for connectivity to the internet and is powered by a 12V adapter. For data acquired to be transmitted to the cloud, a number of configurations is done in order to match the communication protocols of both the meter and the IoT device.

M2M IoT GATEWAY

Gateways are emerging as a key element of bringing legacy and next generation devices to the Internet of Things (IoT). They integrate protocols for networking, help manage storage and edge analytics on the data and facilitate data flow securely between edge devices and the cloud.

A 4G IoT (Internet of Things) gateway is a specialized device that serves as a bridge between different machines, devices and the internet using 4G cellular network technology to a wired or wireless broadband connection. It enables IoT devices, which may include sensors, meters, cameras, or other connected devices, to transmit data and communicate with cloud-based servers or other remote systems via 4G cellular networks.

The core role of an M2M IoT gateway is to enable the exchange, control and organization of data across diverse devices, sensors, or machinery. Serving as a central nexus, it gathers data from interconnected devices, undertakes processing and subsequently transmits the processed information to the cloud or specified destinations.

Key characteristics and functions of a 4G IoT gateway include:

1. Wireless Connectivity: It uses 4G (fourth-generation) cellular networks to establish wireless connections, providing a reliable and wide-area network coverage.

2. Data Transmission: The gateway collects data from connected IoT devices and sends it to a central server or cloud platform for storage, analysis and further processing.

3. Protocol Translation: It often includes protocol translation capabilities, allowing it to communicate with various types of IoT devices that may use different communication protocols.

4. Security: Security features are crucial in 4G IoT gateways to protect data during transmission. These features may include encryption and secure authentication methods.

5. Remote Management: Remote configuration and management capabilities allow administrators to control and monitor the gateway from a central location.

MODE OF TRANSMISSION

GPRS

General Packet Radio Service (GPRS) functions as a packet-switching technology, enabling the transmission of information through mobile networks. It is employed for tasks such as internet connectivity, multimedia messaging service and various forms of data transmission. GPRS is compatible with GPRS-enabled cellphones, laptops and handheld devices equipped with GPRS modems.

GPRS use to be the fastest network-accessible option. Its speed and reliability have diminished compared to the superior performance of 3G and 4G networks. Nevertheless, GPRS continues to find utility in various areas, particularly in rural regions and emerging nations where more advanced technologies are not widely adopted. In instances where a GPRS network is the only option, many smartphones may still utilize it, though users accustomed to faster connections will likely experience significantly slower bandwidth and longer wait times.

Features

- GPRS is a wireless communication service that allows data to be transmitted over a cellular network.
- GPRS uses packet-switching technology to transmit data, which means that data is divided into small packets and sent over the network in a more efficient way.
- GPRS offers always-on connectivity, which means that a user can stay connected to the network at all times, without having to establish a connection every time they want to send or receive data.
- GPRS provides faster data transfer rates compared to the earlier generation of cellular networks, such as GSM.
- GPRS enables new applications and services to be developed, such as mobile internet browsing and email.
- GPRS is a precursor to modern cellular data technologies, such as 3G and 4G.

4G SERVICE

4G, the fourth generation of broadband cellular network technology powered by MIMO (Multiple Input Multiple Output) and Orthogonal Frequency Division Multiplexing (OFDM) technologies, follows 3G and precedes 5G. To qualify as 4G, a system must meet the capabilities outlined by the International Telecommunication Union (ITU) in IMT Advanced. Its potential and existing applications encompass enhanced mobile web access, IP telephony, gaming services, high-definition mobile TV, video conferencing, and 3D television.

However, in December 2010, the ITU broadened the definition of 4G to encompass technologies such as Long Term Evolution (LTE), Worldwide Interoperability for Microwave Access (WiMAX), and Evolved High-Speed Packet Access (HSPA+).

The initial WiMAX standard was commercially deployed in South Korea in 2006 and has since been implemented in various parts of the world. The inaugural LTE standard was commercially launched in Oslo, Norway and Sweden in 2009 and has subsequently been rolled out across many regions globally.

Nonetheless, there has been ongoing debate about whether the first-release versions should be classified as true 4G.

Key Features

1. Speed: 4G networks deliver accelerated data download and upload speeds when contrasted with 3G. Theoretically, 4G can attain speeds of up to 100 megabits per second (Mbit/s) for high-mobility communication and 1 gigabit per second (Gbit/s) for stationary users.

2. Latency: Decreased latency contributes to more responsive user experiences.

3. Capacity: Improved network capacity facilitates a greater number of simultaneous connections.

4. Advanced Antenna Techniques: Implementation of MIMO (Multiple Input Multiple Output) and beamforming enhances signal quality and optimizes spectral efficiency.

Wi-Fi

Wi-Fi, a standard wireless networking technology, enables devices such as computers (both laptops and desktops), mobile devices (smartphones and wearables), and additional equipment like printers and video cameras to connect with the Internet. This standard facilitates the exchange of information among these devices, establishing a network.

The connection to the Internet is established through a wireless router. Accessing Wi-Fi entails connecting to a wireless router, enabling your Wi-Fi-compatible devices to interface with the Internet.

Wi-Fi Connection Standards and Options:

The range of wireless connectivity options for home use is expanding, particularly with the integration of mobile networks into home internet services. Similar to traditional internet services, each type of wireless connection has its own set of advantages and disadvantages, including considerations such as speed and signal strength. Overview of several Wi-Fi connection standards includes:

- Mobile Hotspot or Jetpack:

  Mobile and dedicated hotspots are increasingly popular for on-the-go connectivity. Common hotspot devices include smartphones and jetpacks. While using a smartphone as a temporary hotspot is convenient and doesn't require additional devices, it may drain the battery and data quickly. Conversely, a jetpack functions as a dedicated mobile hotspot, offering a broader Wi-Fi range and the ability to connect more devices. However, this option involves purchasing the jetpack and a separate data plan.

- LTE Home Internet:

  For those residing in rural areas with limited internet options, 4G LTE Home Internet is a viable choice. This service provides high-speed internet delivered via cell phone towers and mobile networks, boasting average download speeds of around 25 Mbps. LTE has advantages over satellite options, offering better speeds and reliability depending on the carrier.

SIM-CARD

A SIM card, an abbreviation for Subscriber Identity Module or Subscriber Identification Module, serves as an integrated circuit (IC) designed to securely store an international mobile subscriber identity (IMSI) number and its corresponding key. This functionality is crucial for identifying and authenticating subscribers on various mobile devices, including mobile phones and laptops. Technically referred to as a universal integrated circuit card (UICC), the SIM card is typically constructed from PVC with embedded contacts and semiconductors with the SIM serving as its primary component. In common usage, the term 'SIM card' encompasses the entire unit, not just the IC.

The information contained within a SIM card includes a unique serial number, integrated circuit card identification (ICCID), international mobile subscriber identity (IMSI) number, security authentication and ciphering details, temporary information pertaining to the local network, a list of accessible user services, and four passwords.

These passwords consist of a personal identification number (PIN) for routine use, a personal unblocking key (PUK) for PIN unlocking, and a second set (PIN2 and PUK2) utilized for managing fixed dialing numbers and other functionalities. In Europe, the serial SIM number (SSN) may be accompanied by an international article number (IAN) or a European article number (EAN) during online registration for prepaid card subscriptions. Additionally, many SIM cards offer the capability to store contact information.

IOT (INTERNET OF THINGS)

The inception of the concept and term "Internet of Things" can be traced back to a speech delivered by Peter T. Lewis during the Congressional Black Caucus Foundation 15th Annual Legislative Weekend in Washington, D.C., published in September 1985. In Lewis's description, the Internet of Things, abbreviated as IoT, represents the integration of individuals, processes, and technology through connectable devices and sensors. This integration facilitates remote monitoring, status assessment, manipulation, and trend evaluation of such devices.

Independently, the term "Internet of Things" was coined by Kevin Ashton, initially affiliated with Procter & Gamble and later associated with MIT's Auto-ID Center, in 1999. Ashton, however, expresses a preference for the term “Internet for Things”. During this period, he regarded radio-frequency identification (RFID) as a crucial element for the Internet of Things, envisioning a scenario where computers could manage all individual things. The core concept behind the Internet of Things revolves around embedding short-range mobile transceivers in various gadgets and daily necessities, thereby enabling novel forms of communication between people and things, as well as among the things themselves.

IoT constitutes a network of interconnected devices that communicate and share data among themselves and with the cloud. These devices are commonly equipped with technology like sensors and software, encompassing both mechanical and digital machines as well as consumer objects. IoT are termed a misnomer because devices do not need to be connected to the public internet, they only need to be connected to a network and be addressable individually.

The broad range of applications for IoT devices is commonly divided into

- Industrial
- Manufacturing
- infrastructure domains

Industrial Internet of Things

Referred to as IIoT, devices within the industrial Internet of Things gather and analyze data from interconnected equipment, operational technology (OT), locations, and personnel. Paired with monitoring devices for OT, IIoT plays a pivotal role in overseeing and controlling industrial systems. Furthermore, this implementation can extend to automated updates of asset placement in industrial storage units, addressing the varying sizes of assets—from small screws to entire motor spare parts. Misplacement of such assets can result in the loss of manpower time and financial resources.

Manufacturing

The Internet of Things (IoT) facilitates the connectivity of diverse manufacturing devices equipped with sensing, identification, processing, communication, actuation, and networking capabilities. Network control and management of manufacturing equipment, along with asset and situation management, enable the utilization of IoT in industrial applications and smart manufacturing. Intelligent IoT systems empower swift manufacturing, optimization of new products, and prompt responses to product demands.

Digital control systems for automating process controls, operator tools and service information systems are encompassed within the scope of IIoT. Asset management benefits from IoT through predictive maintenance, statistical evaluation and measurements aimed at maximizing reliability. Integration of industrial management systems with smart grids allows for energy optimization. Networked sensors provide functionalities such as measurements, automated controls, plant optimization, health and safety management, among others.

Beyond general manufacturing, IoT is also instrumental in processes related to the industrialization of construction.

2.4 RELATED WORKS ON IOT

R Subhashini and Alex Khang (2023) in the book "The Role of Internet of Things (IoT) in Smart City Framework" talked about the advantages and disadvantages of IOT and its entirety from fundamental, design, applications, and security parts of IoT used in modern age network.

BB Sinha et al, (2022) in his article "Recent advancements and challenges of Internet of Things in smart agriculture" highlighted key elements and essential technologies employed in IoT-driven smart agriculture, sensors, application domains, software and hardware in the context of IoT-driven smart agriculture, security considerations and additional challenges associated with the utilization of IoT components in smart agriculture and prospective avenues to tackle the research challenges inherent in smart agriculture. The aim of the survey was to help potential researchers detect IoT problems and adopt suitable technologies

Ravi Pratap Singh et al, (2020) in his article "Internet of things (IoT) applications to fight against COVID-19 pandemic" highlighted The Internet of Things (IoT) as an advanced technology utilized for information dissemination and monitoring systems during the COVID-19 epidemic. This technological platform also proves valuable in addressing challenges that arise during lockdown-like situations. IoT can contribute to establishing an automated and transparent treatment process to effectively manage the COVID-19 pandemic situation.

Jumana A Hassan and Basil H Jasim, (2021) proposes a system on the basis of a wireless sensor network which helps to monitor and control varieties of electrical and environmental variables like power consumption, weather temperature, flame humidity and lightning cut in the cable.

Based on the designs and implementation of internet of things-based monitoring system, the data acquired by these sensors is displayed, monitored on a web page and saved in a server database.

Ting-Jie Lu et al, (2010) expressed that three-layer structure can't express the whole features and connation of the IoT. Which brought about the establishment of a five new layer architecture of the internet of things after reanalyzing the technical framework of the IoT and the logical layered architecture of the telecommunication network.

SGX 5150 IoT GATEWAY

Lantronix SGX 5150 is a wireless Iot device gateway that allows seamless connection of networks and data securely to a network. Its sophisticated design allows for easy configuration to enterprise network while its unique ID feature makes the device visible to authorized users.

Figure 2.11: SGX 5150 IoT Gateway

Product Model and Features

Model #	10/100 Ethernet & Wi-Fi	USB 2.0	Serial 1	Serial 2	POE	8 GB eUSB Flash
SGX51500x0	✓	✓	---	---	---	---
SGX51501x2	✓	✓	RS232	---	---	---
SGX51501x3	✓	✓	RS232	---	✓	---
SGX51502x2	✓	✓	RS232	RS232	---	---
SGX51502x5	✓	✓	RS232 RS485	RS232 RS485	✓	---
SGX5150xN2	✓	✓	RS232	RS232	---	✓
SGX5150xN5	✓	✓	RS232 RS485	RS232 RS485	✓	✓

Table 2.1: SGX 5150 Models

See SGX 5150 features in appendix 5

CWT-L series IoT M2M Gateway

CWT L series IOT M2M Gateway helps machine to access internet via GPRS, 4G or Wi-Fi and establish TCP/IP connection with server.

It can be widely used in industrial automatic control, base station / computer room monitoring, environmental monitoring, water conservancy project, power industries, agriculture and many more.

Basic Features

1. RS485 to GPRS/4G/Wi Fi to server

Mode A:

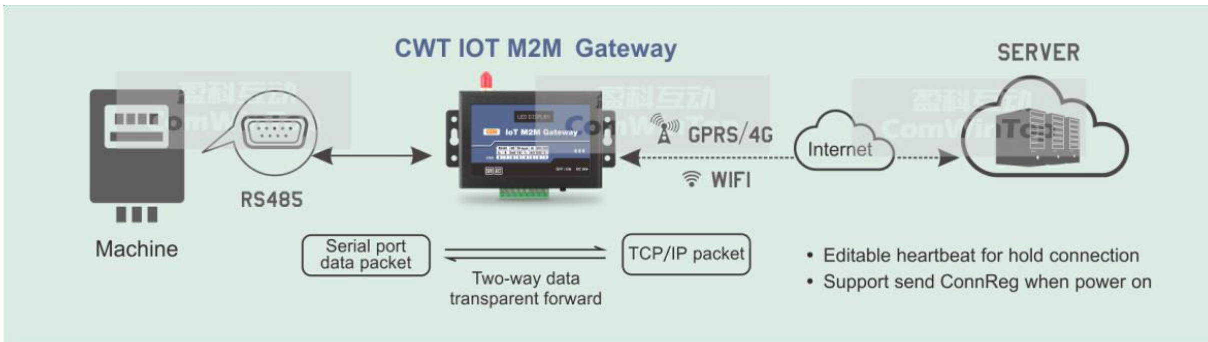


Figure 2.12: Two Way Data Transparent Forward Between RS485 and Server

Mode B:

CWT M2M IoT Gateway (RTU) as Modbus master read slave over RS232/RS485

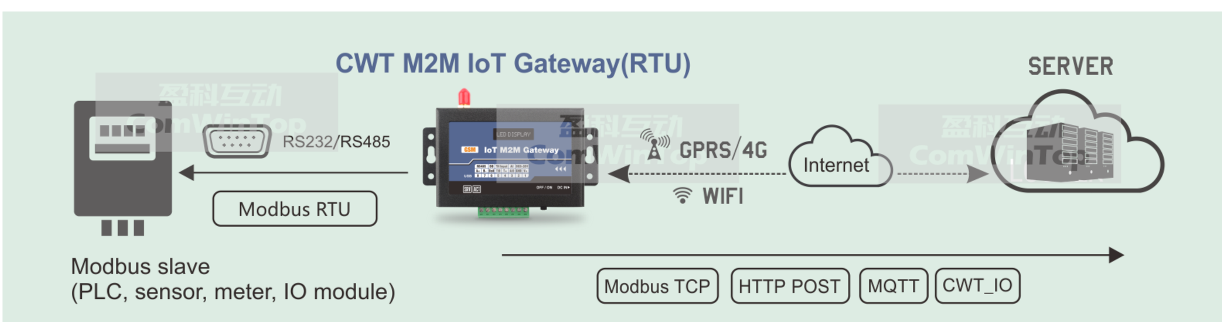


Figure 2.13: Modbus Master Mode on RS485

2. IO to GPRS/4G/Wi Fi to server

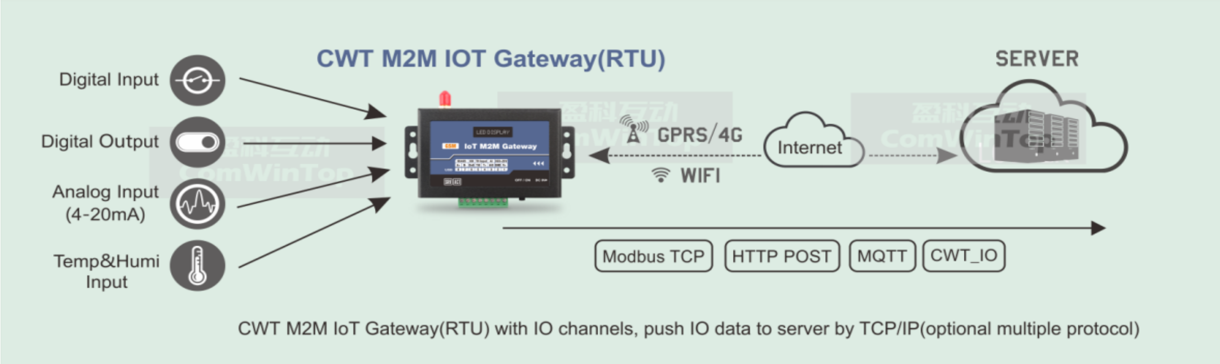


Figure 2.14: IO to IoT Gateway (RTU) to Server

See Features of Communication Features of CWT-L IoT M2M gateway in appendix 6

CWT-L series model list

- CWT L0000S
- CWT L0111S, L0111
- CWT L2020S, L2020
- CWT L1101S, L1101
- CWT L0040S, L0040
- CWT L1120S, L1120

NO.	Model No.	IO channel	Remark
1	CWT-L0000S	RS485	DI: digital input (dry contact) DO: digital output (transistor output) AI: analog input (4-20mA) TI: temperature humidity input RS485: modbus, read 16 registers network Option: 2G or 3G/4G or Wi-Fi Standard package list gateway×1, antenna×1， USB cable×1, configure software, Free cloud service
2	CWT-L1101S	1DI+1DO+1TI+RS485	
	CWT-L1101	1DI+1DO+1TI	
3	CWT-L0111S	1DO+1AI+1TI+RS485	
	CWT-L0111	1DO+1AI+1TI	
4	CWT-L0021S	2AI+1TI+RS485	
	CWT-L0021	2AI+1TI	
5	CWT-L0040S	4AI+RS485	
	CWT-L0040	4AI	
6	CWT-L2020S	2DI+2AI+RS485	
	CWT-L2020	2DI+2AI	
7	CWT-L1120S	1DI+1DO+2AI+RS485	
	CWT-L1120	1DI+1DO+2AI	

Table 2.2: CWT-L Series Model List

CWT-L0000S

Options and basic Features.

Model No.	Port	Network	Remark	Simcard needed	MQTT
CWT-L0000S-2G	1 RS485	2G(GSM)	support sms and gprs	✔	✖
CWT-L0000S-4G	1 RS485	4G	if 2G has been shut down in your area, please choose 4G, include 3G and 2G	✔	✔
CWT-L0000S-4G-GPS	1 RS485	4G+GPS	with GPS	✔	✔
CWT-L0000S-wifi	1 RS485	Wi-Fi	don't support sms	✖	✖

Table 2.3: CWT-L0000S Features

CWT-L0111S

Options and basic features

Model No.	Port	Network	Simcard needed	MQTT	Remark
CWT-L0111S-2G	1 DO (digital output) 1 AI (analog input) 1 TI (temp&humidity input) 1 RS485	2G(GSM)	✓	✗	1. 4G include 3G and 2G, if 2G has been shut down in your area, please choose 4G 2. Wi-Fi version don't need simcard, but without sms features
CWT-L0111S-4G		4G	✓	✓	
CWT-L0111S-4G-GPS		4G+GPS	✓	✓	
CWT-L0111S-wifi		Wi-Fi	✗	✗	
CWT-L0111-2G	1 DO (digital output) 1 AI (analog input) 1 TI (temp&humidity input)	2G(GSM)	✓	✗	
CWT-L0111-4G		4G	✓	✓	
CWT-L0111-4G-GPS		4G+GPS	✓	✓	
CWT-L0111-wifi		Wi-Fi	✗	✗	

Table 2.4: CWT-L0111S Features

CWT L2020S

Options and basic features

Model No.	Port	Network	Simcard needed	MQTT	Remark
CWT-L2020S-2G	2 DI (digital input) 2 AI (analog input) 1 RS485	2G(GSM)	✓	✗	1. 4G include 3G and 2G, if 2G has been shut down in your area, please choose 4G 2. Wi-Fi version don't need simcard, but without sms features
CWT-L2020S-4G		4G	✓	✓	
CWT-L2020S-4G-GPS		4G+GPS	✓	✓	
CWT-L2020S-wifi		Wi-Fi	✗	✗	
CWT-L2020-2G	2 DI (digital input) 2 AI (analog input)	2G(GSM)	✓	✗	
CWT-L2020-4G		4G	✓	✓	
CWT-L2020-4G-GPS		4G+GPS	✓	✓	
CWT-L2020-wifi		Wi-Fi	✗	✗	

Table 2.5: CWT-L2020S Features

CWT L0040S

Options and basic features

Model No.	Port	Network	Simcard needed	MQTT	Remark
CWT-L0040S-2G	4 AI (analog input) 1 RS485	2G(GSM)	✔	✖	1. 4G include 3G and 2G, if 2G has been shut down in your area, please choose 4G 2. Wi-Fi version don't need simcard, but without sms features
CWT-L0040S-4G		4G	✔	✔	
CWT-L0040S-4G-GPS		4G+GPS	✔	✔	
CWT-L0040S-wifi		Wi-Fi	✖	✖	
CWT-L0040-2G	4 AI (analog input)	2G(GSM)	✔	✖	
CWT-L0040-4G		4G	✔	✔	
CWT-L0040-4G-GPS		4G+GPS	✔	✔	
CWT-L0040-wifi		Wi-Fi	✖	✖	

Table 2.6: CWT-L2020S Features

CWT L1120S M2M IoT Gateway

CWT-L1120S IOT M2M Gateway used in this research helps the machine to access internet via GPRS/4G/Wi-Fi and establish TCP/IP connection with server. CWT-L1120S can be widely used in industrial automatic control, base station or computer room monitoring, environmental monitoring, water conservancy project and power industries.

CWT-L1102S IoT M2M Gateway device is used to transmit readings from the smart meter to cloud. Device network options are 2G, 4G, Wi-Fi.

Options and basic features

Model No.	Port	Network	Simcard needed	MQTT	Remark
CWT-L1120S-2G	1 DI (digital input) 1 DO (digital output) 2 AI (analog input) 1 RS485	2G(GSM)	✔	✖	1. 4G include 3G and 2G, if 2G has been shut down in your area, please choose 4G 2. Wi-Fi version don't need simcard, but without sms features
CWT-L1120S-4G		4G	✔	✔	
CWT-L1120S-4G-GPS		4G+GPS	✔	✔	
CWT-L1120S-wifi		Wi-Fi	✖	✖	
CWT-L1120-2G	1 DI (digital input) 1 DO (digital output) 2 AI (analog input)	2G(GSM)	✔	✖	
CWT-L1120-4G		4G	✔	✔	
CWT-L1120-4G-GPS		4G+GPS	✔	✔	
CWT-L1120-wifi		Wi-Fi	✖	✖	

Table 2.7: CWT- L1120S Features

RS485 (MODBUS)

RS485 (MODBUS) is a communication protocol widely used in industrial applications for serial communication over long distances. It combines the characteristics of the RS485 electrical standard with the MODBUS protocol, creating a robust and efficient system for transmitting data between multiple devices.

RS485 is a balanced, differential signaling standard that allows for reliable communication in noisy industrial environments. It supports multi-drop configurations, enabling multiple devices to communicate on the same network. The differential signaling of RS485 enhances noise immunity, making it suitable for long-distance communication.

On the other hand, it is a popular protocol used in industrial automation and control systems. It operates over RS485 and defines the structure of the messages exchanged between devices. It uses a master-slave architecture, where a master device initiates communication with one or more slave devices. The communication frames in MODBUS include address information, function codes, data and error checking.

RS485 (MODBUS) ensures that data is presented in a structured format, adhering to the MODBUS protocol specifications. This structured presentation includes details such as function codes, data addresses, and error-checking mechanisms, ensuring accurate and reliable data transfer. In a typical RS485 (MODBUS) setup, a master device communicates with various slave devices, such as sensors, actuators, or controllers. The master device sends requests to the slaves, and each slave responds to the master's requests. This protocol is known for its simplicity, reliability, and ease of implementation, making it a standard choice for industrial automation and process control systems.

Overall, RS485 (MODBUS) provides a versatile and efficient solution for real-time communication, efficient data presentation in industrial settings, also facilitating the exchange of data between different devices on a network.

RELATED SEARCH WORKS ON MODBUS

You-jie Ma, Gui-dong Wang and Xue-song Zhou, (2017) in his article analyzed the functions and role of remote terminal units (RTUs) which played a crucial role in distribution automation to increase power supply, reliability, quality, accepts more distributions generations and improve assets utilization. The result was that the achievement of distribution automation is a necessary way to increase power supply reliability and quality.

H.M.K.K.M.B. Herath et al (2020) developed a data acquisition and monitoring system based on MODBUS Communication Protocol The aim of the study was to develop a system for acquiring and analyzing measured values from the power measuring device and display those on C# developed GUI. The main objective is to develop an algorithm for MODBUS communication protocol for data acquisition and presentation. A single power measuring device was used. The results were observed and verified and data was collected from the power measuring device.

Jin-feng Li; Shun Cao (2022) in his academic journal carried out a remote monitoring and management system of CNG flow based on Modbus Protocol. The system realizes parameter settings, CNG cumulative flow collection, history record inquiry, remote data transmission, real-time display, and sound and light alarm also the upper computer serially communicate with the microcontroller through the RS485 interface based on Modbus protocol. The test results showed that the system can smoothly run, present, acquire and transmit data.

Hafidh and Shihab (2021) provided a comprehensive overview of industrial monitoring and control systems based on the Modbus protocol. The paper also highlights the potential of HMI and IoT in such systems. It focuses on industrial monitoring and control systems, which are widely used in various industrial applications such as manufacturing, power plants, and chemical processing. It uses various sensors and actuators to monitor, control and present the industrial processes.

2.5 CONNECTORS AND CONNECTING WIRES

Connectors and connecting wires are essential components in electrical and electronic systems, enabling the establishment of electrical connections and the transmission of signals and power between devices and components. Connectors provide a secure and often standardized interface for linking different devices, while connecting wires facilitate the flow of electricity or data between these devices.

In electrical engineering, a connector serves as a vital device that enables the linkage of two or more electrical conductors, cables, or devices. These connectors are fundamental in establishing dependable and secure electrical connections, offering the flexibility for disconnection when required. Engineering standards define connectors based on various criteria these standards are in place to ensure seamless interoperability, reliability, safety and operational efficiency across a multitude of applications. Key aspects and considerations regarding connector's standards include:

- Types and designs: Connectors comes in various types like plugs, sockets, jacks and terminals each tailored for specific functions and environments. Standards outlines the design specifications, encompassing physical dimensions and pin configurations.

- Construction and Materials: Standards specify materials utilized in connector construction, aiming for durability, efficient electrical conductivity, and resilience against environmental elements like moisture, temperature, and mechanical stress. Materials span from metals to plastics, insulators, and protective coatings.

- Electrical Specifications: Connector standards meticulously define electrical parameters such as voltage ratings, current-carrying capacity, impedance, and signal integrity. These specifications ensure safe and reliable transmission of electrical signals or power without degradation.

- Mechanical and Environmental Specifications: Encompassing mechanical aspects such as mating cycles, insertion and extraction forces, environmental safeguarding (like IP ratings for dust and water resistance), and resilience against vibrations and shocks.

- Testing and Certification: Rigorous testing procedures and criteria within connector standards validate compliance with specified performance characteristics. Certified connectors undergo comprehensive testing to ensure reliability and safety.

- Compatibility and Interchangeability: Standards strive for compatibility and interchangeability between connectors and devices from diverse manufacturers, allowing seamless utilization without compatibility issues.

- Safety Compliance: Compliance with safety regulations is imperative to mitigate hazards like electrical shocks, short circuits, and fire risks. Standards incorporate guidelines for insulation, grounding, and protection against overcurrent or overvoltage scenarios. One of the connectors includes:

Alligator Clips

It is a spring loaded toothed clip located at the ends of electrical wires. Resembling the jaws of an alligator, these clips are hinged near the back. They are occasionally referred to as crocodile clips.

These clips have two metal strips on each end, with one directly connected to the other.

For instance take wires or batteries the jaw acts as the connection point between the components, while the clasp holds them. This connection is known as a “jumper.”

A complete circuit between two points is formed by attaching one end of the alligator clip to each connected device. Both ends have contact with metal surfaces. The clamp will form an electrical connection when properly closed, serving as a bridge between the two components of your circuit or device in return.

It comes in various types of metal and insulation colors, depending on the use. Which are:

- Insulated: It is designed for establishing electrical connections with user safety in mind, featuring insulation. Typically, it comes with soft red or black plastic boots for added protection.

- Heavy-duty: Suited for tasks involving high currents or substantial industrial equipment, such as power generators, battery chargers, or welding tools.

- Micro: Valuable for smaller wires where deformation is undesirable. The clips has a smooth, flat metal blades that securely clamp onto the wire, ensuring a reliable connection with thinner wires. Additionally, it include strain-relief crimp points and a solder hole at the clip's end.

- Plastic: Equipped with a durable plastic sheath for robust insulation, commonly made of high-quality PP material. Frequently utilized in the clothing industry to secure shirts and maintain the position of delicate garments.

Figure 2.15: Alligator Clip

2.6 RELATED SEARCH WORK ON DATA ACQUISITION AND TRANSMISSION

Qian Zhu et al, (2010) in his paper, proposed an IoT Gateway system aligned with standard IoT application scenarios and the specific needs outlined by telecom operators. This involved demonstrating data transmission between wireless sensor networks and mobile communication networks, converting protocols from various sensor network protocols, integrating control functionalities for sensor networks, and finally gave an implementation of prototyping system and system validations.

Alireza Izaddoost and Matthew Siewierski in this paper "Energy Efficient Data Transmission in IoT Platforms" (2020) propose a data transmission model using internet of things transferred to a gateway server, aggregate data and send it to a cloud platform for further data processing to develop a next node selection forwarding factor to balance data transmission throughout the network. The proposed model considered workload in addition to the available power level to select the next forwarding node. The results showed the selected next forwarding node will operate for a longer period of time even if it has lower power level compared to the other node

Jisi Chandroth et al, (2022) in his article centers on the implementation of the Discontinuous Reception (DRX) mechanism in IoT gateways. The introduced DRX technique in IoT gateways significantly lowers power consumption and enhances their energy efficiency. The proposed approach elevates gateway energy efficiency by nearly 30% in contrast to the Relay Energy Efficiency (REE) based scheme.

Liang Wang (2023) in his article, "Computer hardware and network data transmission based on internet off things communication technology" evaluates the performance of data transfers with lengths of 20 byte, 30 byte, 50 byte and 70 byte over a distribution network using the 4G IoT gateway. It also evaluate the efficiency of Wi-Fi access configuration by sending data packets of varying sizes. The result showed that in each case, the network takes 0.6692s, 1.3546 and 2.8600 to deliver each packet with success rates of 100%. The systems increased network distribution efficiency is observed from the experimentation.

2.7 DATA PRESENTATION AND ANALYSIS

Data presentation involves presenting the data in a clear and concise way to communicate the research findings. It involves the process visually portraying data sets to effectively communicate information to an audience. Data can be represented through methods like diagrams, graphs, and charts. Each method has its strengths and is often used depending on the type of data being used and the message conveyed.

Data was acquired from the M2M IoT gateway website Http://m2m-iot.cc and downloaded in a document format for 16 registers; Vph A, Vph B, Vph C, Vline AB, Vline BC Vline CA, QA, QB, QC, SA, SB, SC, Pf A, Pf B, Pf C and Qsum. Each data acquired was copied into a single spreadsheet for further analysis.

A spreadsheet is a computer program designed for the computation, organization, analysis and storage of data in a tabular format. Examples include: Lotus 1-2-3, Microsoft Works Spreadsheet, Open Office Calc and Google Drive Spreadsheet. These programs enable users to manipulate data in diverse ways, facilitating the creation of budgets, forecasts, inventories, schedules, charts, graphs and various other worksheets based on data. The spreadsheet utilized was Microsoft excel spreadsheet

.

Microsoft Excel Spreadsheet

Microsoft Excel is a spreadsheet application developed by Microsoft. It is part of the Microsoft Office suite of productivity software. Excel provides a grid interface where users can organize data in rows and columns. It is used for tasks such as calculations, data analysis and creating visual representations of data. Excel bolster a variety of formulas and functions, making it a sophisticated tool for both basic and advanced data manipulation.

DATA ANALYSIS TOOLS

Data analysis refers to the process of converting, examining and modeling data to uncover useful information and assist decision making with the derived data. A collection of data gotten from websites are called datasets.

While data set of the work were gotten from measurement of electrical parameters of the transformer using a smart meter and using a gateway to monitor online which was converted to .csv and uploaded to kaggle, other data can be sourced in form of datasets such as

- Data.gov
- Google datasheet
- datahub.io
- Kaggle

DATA.GOV

It functions as a comprehensive online repository, offering a wealth of policies, tools, case studies and various resources. This platform is designed to provide robust support for the implementation of effective data governance, management and utilization across the federal government. It serves as a centralized hub for fostering best practices and facilitating the seamless integration of data-related initiatives within the federal sector. Users can access a diverse range of materials aimed at enhancing their understanding and capabilities in the realm of data governance and management.

GOOGLE DATASET SEARCH

Google Dataset Search represents a specialized iteration of google's search engine tailored for the exploration of datasets across various domains, including machine learning, social sciences, government data, geosciences, biology, life sciences, agriculture and more. This dedicated search platform facilitates the discovery of datasets from around the globe, providing researchers, scientists, and professionals with a comprehensive tool to locate relevant and diverse data sources within their respective fields of interest.

DATAHUB.IO

DataHub is a contemporary data catalog designed to facilitate comprehensive data discovery, observability, and governance throughout the data lifecycle. Crafted as an extensible metadata platform, it empowers developers to navigate the intricacies of dynamic data ecosystems seamlessly. Simultaneously, data practitioners can harness the full value of organizational data, making DataHub an integral solution for streamlined and effective data management within any project or organization.

KAGGLE

It’s a machine learning website where collaborators, data analyst and scientist uses different programming languages lab to work on data sets. It allow users to find datasets in building technical models and work with other machine learning engineers to solve data science challenges. Kaggle Kernels serve as an invaluable resource for data scientist and machine learning enthusiasts, providing a collaborative platform hosted on the kaggle website. They offer an interactive computing environment that enables users to create and share executable code.

Kaggle kernels provide a seamless and efficient way to develop, experiment and collaborate on data science and machine learning projects. Data for this work was converted to .csv and uploaded to kaggle with analysis carried out on kaggle. Kaggle supports various programming languages, with a strong emphasis on python and R, allowing users to execute code in a step-by-step fashion, it also supports data visualizations libraries, making it convenient to create plots and graphs for a comprehensive understanding of data.

In other to solve and analyze a specific problem in kaggle with a dataset, the following steps are considered:

- Understanding the Problem: Analyzing the objective, evaluation metric and any specific requirements or constraints.

- Exploratory Data Analysis (EDA): The dataset provided is explored to gain insights into the data's structure, distributions and potential patterns. This step helps in making informed decisions during modeling.

- Data Preprocessing: Cleaning and preprocess the data, handling missing values, outliers, and converting data types if necessary. This step is crucial for improving the model's performance.

- Feature Engineering: New features are created or existing ones are transformed to enhance the model's ability to capture patterns. Feature engineering is often a key factor in improving model accuracy.

- Model Selection: A suitable machine learning algorithm is chosen based on the nature of the problem (classification, regression, etc.) and the characteristics of the data.

- Model Training: The selected model is trained on the training dataset, using techniques like cross-validation to assess performance and avoid overfitting.

- Hyper parameter Tuning: The model's hyper parameters is optimized in order to improve performance. This can be done using techniques like grid search or randomized search.

- Evaluation: The model's performance is assessed on a separate validation dataset or through cross-validation. This step helps in fine-tuning the model and ensuring it generalizes well to new data.

- Predictions: The trained model is applied to make predictions on the test dataset or new data. These predictions are submitted to Kaggle to see how well the model performs against others.

- Iterative Improvement: Based on Kaggle leaderboard feedback and insights gained, the approach is refined to enhance model performance.
- Documentation: The process is documented in tandem with choices and insights in a clear and concise manner. This is important for sharing knowledge and learning from the experience.

Programming languages utilized in kaggle:

- C++
- R
- Mat lab
- Python

C++

A cross platform language developed by Bjarne stroustrup as an extension to the C language are used to create high performance applications. The language has two main components: a direct mapping of hardware features and zero overhead abstractions.

C++ brings object-oriented (OOP) capabilities to C, incorporating classes that encompass the four typical OOP features- abstraction, encapsulation, inheritance and polymorphism. Notably, C++ classes stands out by supporting deterministic destructors.

R

R is a programming Language dedicated for statistical computing and data visualization, finding applications in domains such as data mining, bioinformatics and data analysis. The fundamental R language is enhanced by an extensive array of extension packages, encompassing reusable code, documentation and sample data

MAT LAB

Developed by Mathworks, is a proprietary programming language and numeric computing environment with support for multiple paradigms. It facilitates matrix manipulations, function and data plotting, algorithm implementation, user interface creation and interaction with programs written in other languages.

It can call functions and subroutines written in the programming languages C or FORTRAN.

PROGRAMMING LANGUAGE UTILIZED:

PYTHON

Python is a high-level, versatile programming language known for its readability and simplicity. Created by Guido van Rossum and first released in 1991, Python has gained widespread popularity for its emphasis on code readability and ease of use. It supports multiple programming paradigms, including procedural, object-oriented and functional programming.

Python's syntax is clear and concise, making it accessible for beginners while providing advanced features for experienced developers. It has a comprehensive standard library that facilitates various tasks, from web development and data analysis to artificial intelligence and machine learning.

One notable feature over other programming Language is its dynamic typing, allowing variables to change types during runtime, enhancing flexibility. Python's community-driven development and open-source nature contribute to its extensive ecosystem of libraries and frameworks, such as Django for web development, NumPy for scientific computing and TensorFlow for machine learning.

Overall, Python is widely employed in diverse domains, including web development, data science, automation, analysis, scientific research and more making it a versatile and powerful programming language

PYTHON LIBRARIES

Python libraries play a crucial role in enhancing the capabilities of the language and accelerating the development process by providing ready-made solutions for a wide range of tasks and domains they are collections of pre-written code modules that extend the functionality of the Python programming language.

These libraries provide developers with a set of tools, functions and classes to perform specific tasks without having to write the code from scratch. Some key aspects of Python libraries:

- Modularity: Libraries are modular, meaning they consist of separate modules or packages that focus on specific functionalities. Developers can import and use only the modules needed promoting code modularity and reusability.

- Task-Specific Functionality: Each library is designed to address particular tasks or domains. For example, there are libraries for numerical computing (NumPy), data manipulation (pandas), machine learning (scikit-learn), web development (Django, Flask), and more.

- Ease of Integration: Python libraries are designed to work seamlessly with each other. The interoperability allows developers to combine functionalities from different libraries to create comprehensive solutions. For instance, a data science project might use NumPy for numerical operations, pandas for data manipulation, and scikit-learn for machine learning.

- Community Contributions: Python's open-source nature encourages community collaboration, resulting in a vast ecosystem of libraries. Developers from around the world contribute to these libraries, adding features, fixing bugs and enhancing overall functionality.

- Documentation: Libraries typically come with comprehensive documentation that guides developers on how to use the provided functions and classes. This documentation includes examples, explanations, and details on parameters and return values, making it easier for developers to integrate the library into their projects.

- Standardization: Certain libraries become standard choices within specific domains. For instance, NumPy and pandas are often considered standard for data science and analysis, while requests is a standard library for handling HTTP requests. This standardization simplifies the development process by providing widely adopted solutions for common tasks.

- Performance Optimization: Many libraries are optimized for performance, often leveraging lower-level languages like C or FORTRAN under the hood. The optimization ensures that tasks are executed efficiently, making Python competitive in performance-intensive domains.

- Open Source and Licensing: Most Python libraries are distributed under open-source licenses, allowing developers to use, modify, and distribute the code freely. This fosters a collaborative and sharing culture within the programming community.

Examples of python libraries includes:

TensorFlow and PyTorch, SQLAlchemy, NumPy, Pandas, scikit-learn, Matplotlib and Seaborn

While Libraries utilized in this work includes Numpy, pandas, scikit-learn, Matplotlib and Seaborn

TensorFlow and PyTorch

These deep learning frameworks are widely used for building and training neural network models. TensorFlow, developed by Google, and PyTorch, developed by Facebook, are both powerful tools in the field of artificial intelligence.

SQLAlchemy

This SQL toolkit and Object-Relational Mapping (ORM) library simplifies database interactions in Python projects. It supports various database systems and enhances database management.

NumPy

Created by Travis Olliphant in 2005, is essential for numerical computing, NumPy provides support for large, multi-dimensional arrays and matrices, along with mathematical functions to operate on these arrays. It is a foundation for scientific computing in Python.

Key Features

Arrays:

- Multidimensional Arrays: NumPy provides an efficient array object, ndarray, for handling multidimensional data.
- Homogeneous Data Types: Arrays store elements of the same data type, allowing for optimized operations.

Mathematical Operations:

- Element-Wise Operations: Supports element-wise operations on arrays, enhancing computational efficiency.
- Broadcasting: Facilitates operations on arrays of different shapes and sizes.

Random Number Generation:

- Random Module: NumPy includes a robust random module for generating random numbers and distributions.

Linear Algebra Operations:

- Linear Algebra Functions: NumPy offers a comprehensive set of linear algebra operations, including matrix multiplication and eigenvalue computation.

Integration with Other Libraries:

- Integration with SciPy: Works seamlessly with SciPy, another scientific computing library, extending functionality.

Interoperability: Integrates well with libraries like Pandas for data analysis and Matplotlib for visualization.

Performance:

- Vectorized Operations: NumPy operations are vectorized, optimizing performance and minimizing the need for explicit looping.
- C and Fortran Integration: Critical functions are implemented in C or FORTRAN, enhancing computational speed.

Indexing and Slicing:

- Advanced Indexing: Supports advanced indexing techniques, including Boolean indexing and fancy indexing.

Broadcasting:

- Efficient Broadcasting: Efficiently handles operations on arrays of different shapes and sizes, eliminating the need for explicit looping.

Community and Documentation:

- Active Community: A vibrant community contributes to the development and support of NumPy.
- Comprehensive Documentation: NumPy provides detailed documentation with examples and explanations.

Use Cases

- Scientific Computing: Essential for numerical and scientific computations in various domains.
- Data Analysis and Machine Learning: Frequently used in data analysis pipelines and machine learning workflows.
- Signal Processing: Applied in signal processing tasks due to its efficient array operations.

PANDAS

Pandas developed by Wes McKinney is a data manipulation and analysis library. It introduces data structures like Data Frames, which simplify handling and analyzing structured data, making it a valuable tool for data scientists and analyst.

Key Features

Data Structures:

- Data Frame: Central to pandas, it's a two-dimensional table with labeled axes (rows and columns).
- Series: A one-dimensional labeled array capable of holding various data types.

Data Manipulation:

- Data Cleaning: Pandas facilitates cleaning tasks, including handling missing data and converting data types.
- Data Transformation: It supports operations like merging, reshaping, and pivoting.

Data Import/Export:

- Input Formats: Reads data from various sources, including CSV, Excel, SQL databases, and more.
- Output Formats: Allows exporting data to different file formats.

Indexing and Selection:

- Label-Based Indexing: Supports selecting data using labels (column names, indices).
- Positional Indexing: Enables selection based on numerical indices.

Statistical Analysis:

- Descriptive Statistics: Provides summary statistics for numerical columns.
- Aggregation: Supports aggregation functions like mean, sum, count, etc.

Time Series and Date Functionality:

- Date Range Generation: Generates date ranges and frequencies.
- Time Zone Handling: Supports time zone conversion and handling.

Plotting:

- Integration with Matplotlib: Pandas seamlessly integrates with Matplotlib for data visualization.

- Quick Plotting: Provides easy-to-use plotting functions for exploratory data analysis.

Group By:

- Split-Apply-Combine: Allows grouping data by one or more columns and applying functions to each group.

Merging and Joining:

- Database-Like Operations: Supports merging and joining datasets similar to SQL operations.

Performance:

- Optimized for Performance: Pandas operations are optimized for speed, making it efficient for large datasets.

Community and Documentation:

- Active Community: A large and active community contributes to the library's development.
- Comprehensive Documentation: Pandas has extensive documentation with examples and explanations.

Use Cases

- Data Analysis and Exploration: Ideal for exploring and analyzing structured data.
- Data Cleaning and Transformation: Efficiently handles tasks like cleaning and transforming messy datasets.
- Time Series Analysis: Widely used for time series data due to its robust time-related functionality.

MATPLOTLIB AND SEABORN

Crucial for data visualization, matplotlib allows the creation of a wide range of static, animated, and interactive plots, while Seaborn provides a high-level interface for creating attractive and informative statistical graphics and it is built on top of matpotlib

Matplotlib:

- Basic Plotting: Matplotlib enables the creation of line plots, scatter plots, bar plots, histograms, and more.
- Customization: Users can customize plot elements like colors, labels, titles, and styles.
- Subplots: Matplotlib supports the creation of multiple plots in a single figure using subplots.
- 3D Plots: It allows the creation of 3D plots for visualizing three-dimensional data.

Seaborn:

- Statistical Visualization: Seaborn simplifies the creation of statistical visualizations, including box plots, violin plots, and pair plots.
- Color Palettes: Offers aesthetically pleasing color palettes for enhancing visualizations.
- Facet Grid: Facilitates the creation of multiple plots based on subsets of the data, allowing for easy comparison.
- Regression Plots: Seaborn provides specialized functions for visualizing linear regression models.

Scikit-learn

It was initiated by David Cournapeau in 2007 abbreviated as sklearn. For machine learning tasks, scikit-learn offers a simple and efficient set of tools for data mining and data analysis. It includes various algorithms for classification, regression, clustering, and more.

Key Features:

Supervised and Unsupervised Learning:

- Classification: Provides algorithms for classifying data into predefined categories.
- Regression: Supports predictive modeling for continuous outcomes.
- Clustering: Offers unsupervised learning algorithms for grouping similar data points.

Model Selection and Evaluation:

- Cross-Validation: Includes functions for assessing model performance through techniques like k-fold cross-validation.
- Metrics: A variety of evaluation metrics, such as accuracy, precision, recall, and F1 score.

Preprocessing and Feature Extraction:

- Data Preprocessing: Tools for preprocessing data, including scaling, encoding categorical variables, and handling missing values.
- Feature Extraction: Methods for extracting relevant features from raw data.

Ensemble Methods:

- Random Forests: Implements ensemble methods like random forests for improved predictive performance.
- Gradient Boosting: Supports gradient boosting algorithms for building robust models.

Dimensionality Reduction:

- Principal Component Analysis (PCA): Offers PCA for reducing the dimensionality of datasets.

Hyper parameter Tuning:

- Grid Search: Facilitates hyper parameter tuning through exhaustive grid search.

Integration with NumPy and SciPy:

- Compatibility: scikit-learn integrates seamlessly with NumPy and SciPy, enhancing its capabilities.

Extensibility and Interoperability:

- API Consistency: Maintains a consistent API, making it easy to switch between different algorithms.
- Integration with Other Libraries: Compatible with other Python libraries, such as Pandas and Matplotlib.

Active Community and Documentation:

- Community Support: A thriving community actively contributes to the library's development.
- Detailed Documentation: scikit-learn provides extensive documentation with examples and explanations.

Use Cases:

- Classification and Regression Tasks: Ideal for tasks where the goal is to predict a specific outcome.
- Clustering: Applicable in unsupervised learning scenarios where grouping similar data points is required.

- Dimensionality Reduction: Useful for reducing the number of features in high-dimensional datasets.
- Model Evaluation: Provides tools for assessing and fine-tuning machine learning models.

2.8 RELATED WORKS ON MACHINE LEARNING MODELS

Mohammed Hamid abdulraheem and Najla badie ibraheem (2019) used different machine learning model or techniques to detect anomaly or misused detection; intrusion Detection system (IDS) this was due to the increasing threats and attack as the demand for internet networks increases.

Matthew Abiola Oladipupo et al (2023) in his article "An automated python script for Data cleaning and labelling using machine learning" obtained a financial dataset from kaggle and created a machine learning (ML) approach in python that intends to automate the financial dataset cleaning ingesting data, addressing incomplete data and anomalies due to the noise, inefficacy and poor characterization of large amount of data which made presentation of data ambiguous and information become inaccessible. The result showed that the ML technique improved the performance of the audit data and also classified the data after cleaning it.

Ali Raza et al (2022) in his study developed an artificial neural network-based system for anticipating maternal health risk using health data records. Python and WEKA toolkit platforms were used for model building. The results shows that the model used could predict heath risk associated with pregnant women thus mitigating the risk of health complications which helps to save lives.

Alaa H ahmed et al (2022) in his article discusses of how machine learning algorithms were applied to patient diagnosed with corona virus to estimate the severity of the disease. Different machine learning techniques used here includes: random forest, decision tree, linear regression, binary search and k-nearest neighbor.

2.9 OVERVIEW OF RELATED SEARCH WORK ON REMOTE MONITORING AND ANALYSIS OF ELECTRICAL PARAMETERS OF A TRANSFORMER USING INTERNET OF THINGS (IoT).

A.R. Al-Ali et al, "An IoT-Based Smart Utility Meter," (2018) proposes in his article the design, development, and testing of an integrated IoT-based smart utility meter that remotely monitors and acquire real-time data acquisition system of the consumption of electricity, water and gas. The meter boasts of an exclusive network identity and can be wirelessly customized to monitor three utility usages at intervals tailored by service providers. Users effortlessly interacts with the meter using either a personal computer (PC) or a mobile device.

Jithin Krishnan et al (2013) in his article presented a system for real time data acquisition and monitoring device for medical applications which was based on an android platform. It serves as a remote monitor for measuring and analyzing along with logging of data from patients.

The system comprises a Data Acquisition (DAQ) component linked to the patient's side and an android-based display device on the receiving end. The DaQ component includes sensors to capture vital signals and a Bluetooth transceiver for wireless data transmission to display device. Subsequently, the display device presents the received data in a readable format and records it in an excel format for extraction and analysis.

Giacomo Cappon et al, (2022) presented a new mobile platform to be used in clinical trials aimed at both collecting data and assessing new technologies and treatments for diabetics care. The core component; the mobile app collects data from glucose monitoring sensors and activity trackers, it also allows users to log daily events; a cloud database for storage and a web interface which allows users to monitor patients' status in real time.

Prophet Tepu and onyero Ofuzim in the article "Design and construction of a remote battery monitoring and control device using the internet of things" (2023) explores the potential of the IoT in designing and constructing a remote battery monitoring and control device. The aim was to monitor the state of charge (SOC) of the battery and control its charging remotely. By tasking the microcontroller with the system's various functions and the GPRS for communication, the implementation of the remote battery monitoring and control demonstrates the potential of IoT in creating practical and efficient solutions for power monitoring and control.

Abdullah Na et al (2016), analyses soil parameters; pH value, temperature and moisture content by remotely monitoring pH measurement using antimony electrode and temperature using the DS18B20 sensor. The system is integrated with the Bluetooth transfer of data to a mobile or PC while parameters measured helped in characterizing the soil and in making proper decision regarding fertilization application and choice of crop sown.

Kazi Zehad Mostofa and Mohammad Aminul Islam, (2023) in his energy reports created an IoT system for the live and real-time remote monitoring of solar photovoltaic installations. The acquired data is stored in the IoT cloud and accessible through an application from anywhere in world via internet. As a result, it gives immediate insights into the installation status facilitating maintenance and immediate fault detection.

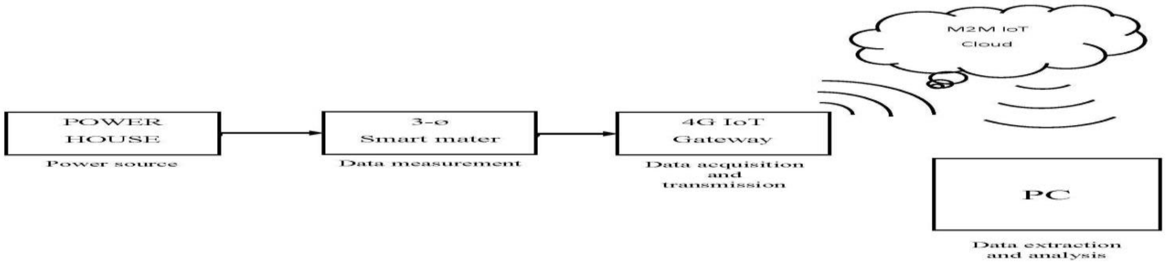
CHAPTER THREE

METHODOLOGY

This chapter presents materials and methods used for the work. It entails a 4G IoT gateway connected to a smart meter, which is installed on the 3-phase incomer to a power house control panel. The smart meter continuously measures crucial electrical parameters like voltage, power factor, reactive power and apparent power. The data collected by the smart meter is securely transmitted to a remote server or cloud platform via the 4G network. This data can be accessed remotely from anywhere with an internet connection through a user-friendly interface, typically provided by a web-based or mobile application. This interface displays real-time data through graphs, charts, and numerical values, enabling operators to monitor the transformer's performance in real-time. The collected data is stored in a secure cloud-based database or data lake, with data retention policies in place to manage storage effectively and ensure historical data accessibility.

Data analysis is a critical aspect of this setup. Extracted data undergoes comprehensive analysis, including data cleansing, preprocessing, and feature engineering. Exploratory Data Analysis (EDA) techniques are used to uncover trends, anomalies, and patterns in the data. Moreover, historical and real-time data can be used to develop predictive maintenance models. Machine learning algorithms can be trained to predict transformer health and performance, enabling proactive maintenance scheduling, reducing downtime and costly failures.

In summary, remote monitoring of electrical parameters using a 4G IoT gateway connected to a smart meter, coupled with data analysis, is a powerful approach to ensure reliable and efficient power distribution. It provides real-time visibility into transformer performance, empowers data-driven decision-making, and facilitates proactive maintenance, ultimately enhancing the reliability of power supply systems.



3.1 BLOCK DIAGRAM

Figure 3.1 Block diagram of the entire setup

This block diagram contains the 4 sections required to achieve the set aim of the work. The sections are Power Source, Data Measurement, Data Acquisition and Transmission, Data extraction and Analysis.

3.1.1 Power Source: The primary source of electrical power was derived from the 3-phase control panel located within the power house. This strategic choice of obtaining power from the 3-phase control panel allowed us to tap into a stable and robust electrical supply, ensuring that the project activities ran smoothly and with minimal disruptions.

3.1.2 Data Measurement: Data measurement was carried out with precision using the XHD331-R 3-phase smart meter. This meter was expertly connected to the 3-phase supply at the powerhouse.

3.1.3 Data Acquisition And Transmission: For data acquisition and transmission, the CWT-L1102S M2M 4G IoT device was used to facilitate the real-time transmission of collected data to the cloud. Its seamless integration ensured that data was efficiently acquired and promptly relayed to the cloud-based storage, enabling constant and up-to-date data monitoring and analysis.

3.1.4 Data Extraction And Analysis: In the data analysis and extraction phase, a PC was utilized for data extraction. Data was meticulously extracted from the source using this computer. Furthermore, Python scripts, in conjunction with Kaggle data analysis cloud software, were employed for in-depth data analysis. This comprehensive approach allowed for meaningful insights and thorough data analysis, enhancing the quality of results.

3.2 DATA MEASUREMENT

The XHD331-R 3 phase rail type multifunctional smart meter was connected to the 3-phase line input and neutral for measurement, the parameters measured were voltage, current, power factor, reactive power, apparent power among others (see Table 3.1 for others). Figure 3.1 presents the smart meter connected to the incomer to the control panel. See Appendix 1 for the technical parameters of the meter.

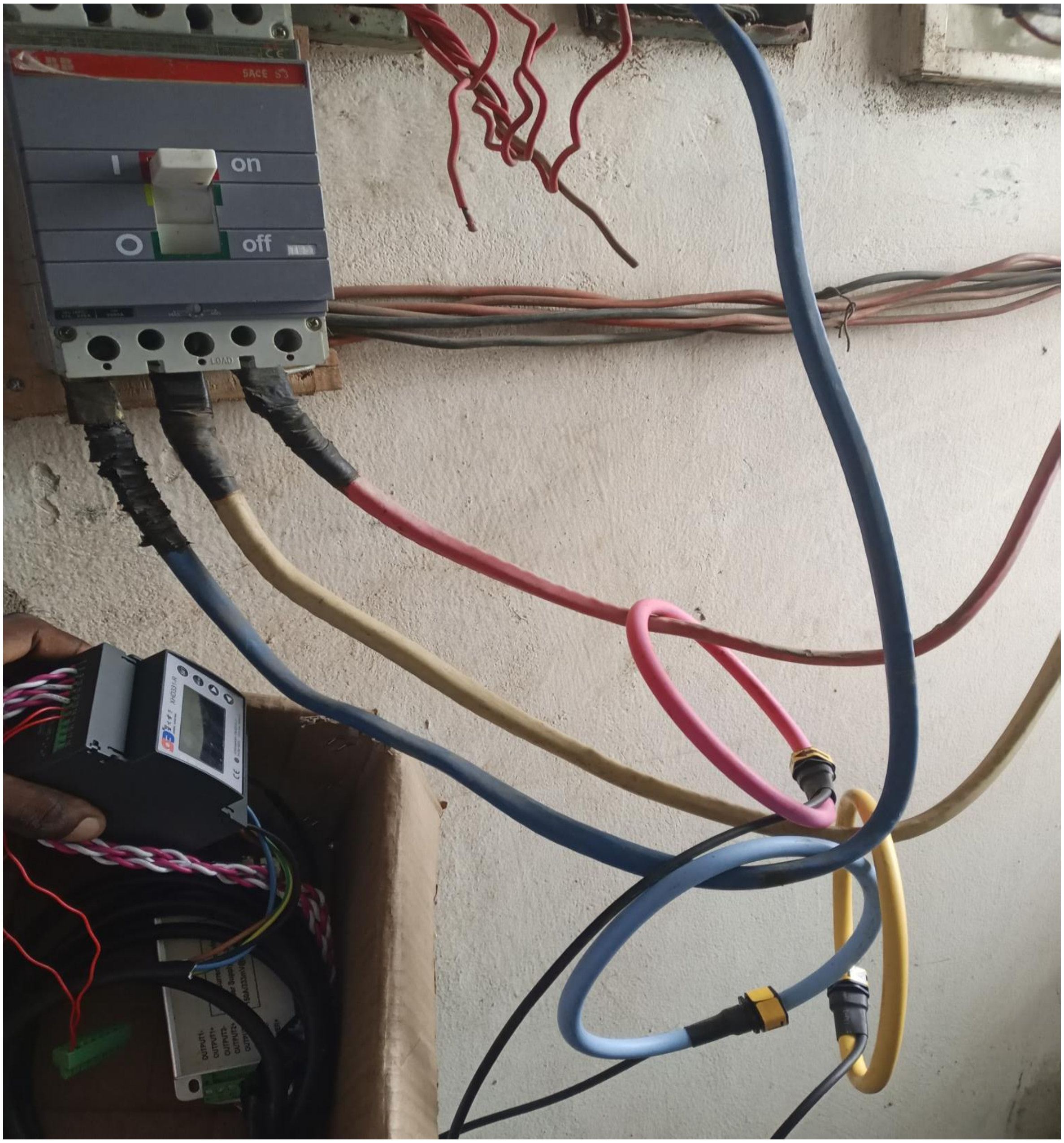


Figure 3.1 Smart meter connected to the incomer to the control panel

Table 3.1 Parameters Measured

S/N	Parameters Measured	Unit of measurement
1	Phase Voltage	V
2	Line Voltage	V
3	Line Current	Amps
4	Phase Current	Amps
5	Active Power	Watts
6	Total Active Power Power	Watts
7	Reactive Power	Var
8	Total Reactive Power	Var
9	Apparent Power	VA
10	Total Apparent Power	VA
11	Power Factor	-
12	Total Power Factor	-
13	Active Electric Energy	Wh
14	Reactive Electric Energy	Varh
15	Absolute Active Electric Energy	Wh
16	Absolute Reactive Electric Energy	Varh
17	Phase Power Demand	Watts
18	Phase Current Demand	Amps
19	Frequency	Hz

3.2.1 Communication Protocol

The standard communication protocol chosen in the setup is Modbus-RTU which is the same as that of the gateway, the selected baud rate was 9600. The baud rate represents how data is transmitted between both devices, 9600 is a moderate speed in this application. In order for the data to be properly transmitted, registers that represent containers for the needed data were created, renamed and formatted on the M2M iot cloud, there are placeholders for the several registers that hold different data in the smart meter however, only 15 are available on the cloud. Table 3.2 shows the selected registers that hold relevant data for this project. (see Appendix 2 for overview of communication protocol)

Table 3.2 Selected Registers

Address	**Default Name**	**New name**
16-17	Uan	Vph A
18-19	Ubn	Vph B
20-21	Ucn	Vph C
22-23	Uab	Vline AB
24-25	Ubc	Vline BC
26-27	Uca	Vline CA
44-45	Qa	QA
46-47	Qb	QB
48-49	Qc	QC
52-53	Sa	SA
54-55	Sb	SB

56-57	Sc	SC
60-61	Pfa	Pf A
62-63	Pfb	Pf B
64-65	Pfc	Pf C
42-43	Qsum	Qsum

3.3 DATA ACQUISITION AND TRANSMISSION:

The essence of this work is to acquire and transmit measured data remotely for monitoring and analysis. The data measured using the XHD331-R smart meter was acquired and transmitted using the CWT-L1102S M2M 4G IoT gateway device. After measurement, the data was transmitted to the cloud using the 4G iot gateway for remote monitoring via a PC. This was achieved by a point to point connection from the meter to the 4G iot gateway. Figure 3.2 - Figure 3.4 shows the communication ports of the meter, gateway and the connection between the meter and the gateway. Port 7 on the gateway was connected to port B on the meter while port 8 on the gateway was connected to port A on the meter. The gateway has a sim slot for seamless connectivity to the internet and it is powered by a 12V adapter. For data to be transmitted to the cloud, a number of configurations were done in order to match the communication protocols of both the meter and the 4G IoT device. Figures 3.5-3.14 present the detailed configuration of the CWT-L1102S M2M 4G IoT gateway device.

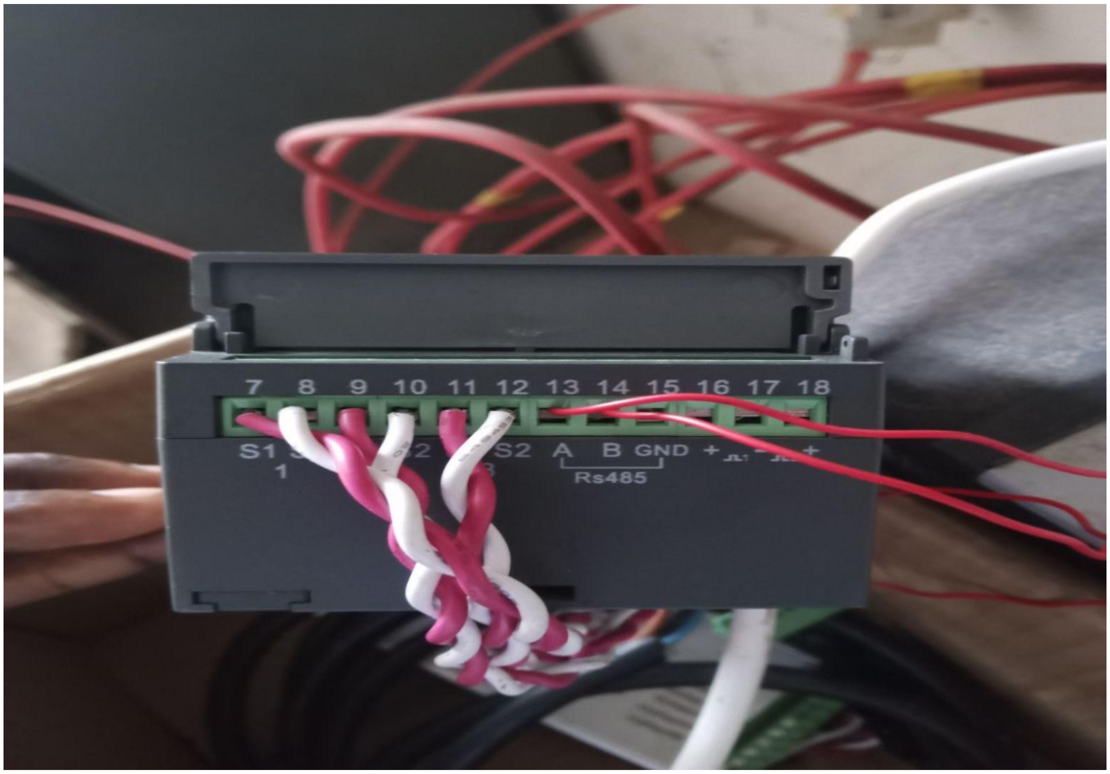


Figure 3.2 Smart meter communication ports

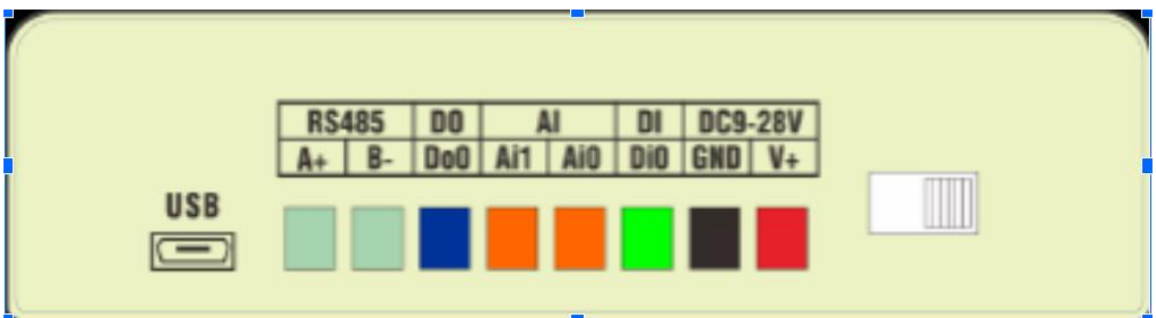


Figure 3.3 CWT-L1102S 4G IoT gateway communication ports

Figure 3.4 Connection between the smart meter and the gateway

3.3.1 Configuration of CWT-L1102S 4G IoT Gateway for Data Transmission

For data acquisition and transmission, The CWT-L1102S gateway was configured to ensure compatibility in data transmission from the Modbus (RS485) port, digital input, analog input and/or digital output to the cloud. The device has a configuration software for setting it in setup mode and configuring the device. Figure 3.5 presents the configuration software interface for configuring CWT-L1102S IoT gateway.

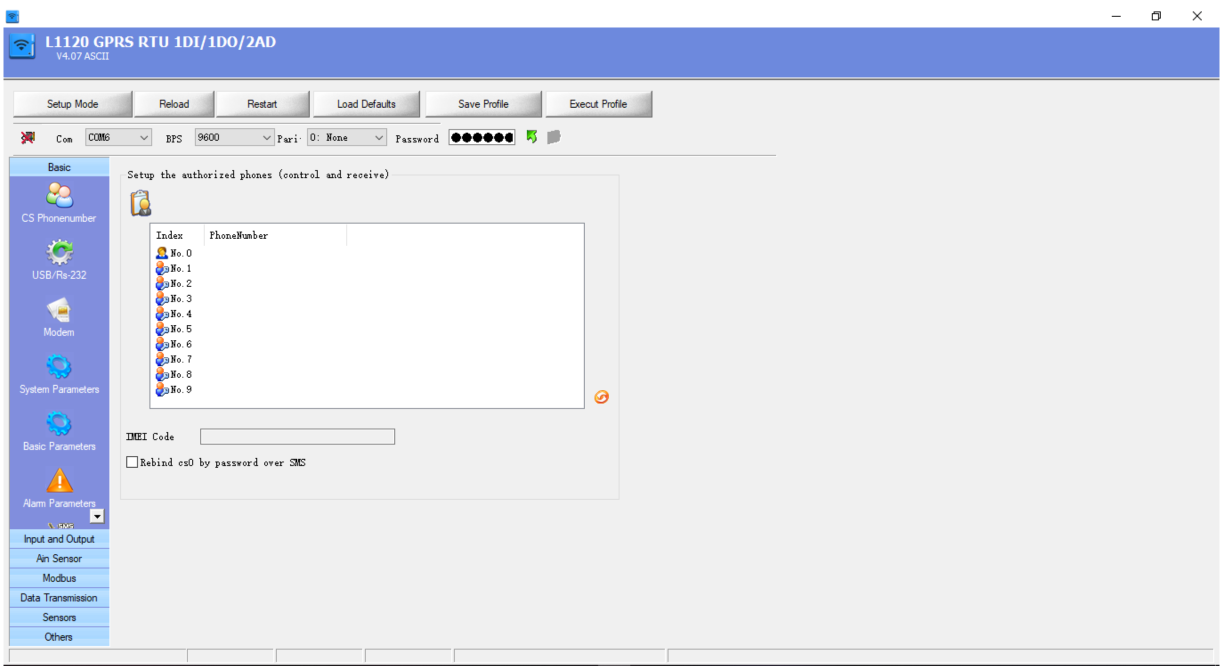


Figure 3.5: CWT-L1102S Configuration Software User Interface

The processes involved in configuring the 4G IoT Gateway device are presented in the following steps.

***Step 1: Connect the CWT-L1102S IoT device to the configuration Software**

The Gateway was connected to a power source, powered ON and then connected via USB to the PC running the configuration software. The com port it was connected to can be found from the device manager of the PC and then selected on the configuration software, in this case, it was com port 6. (Figure 3.6).

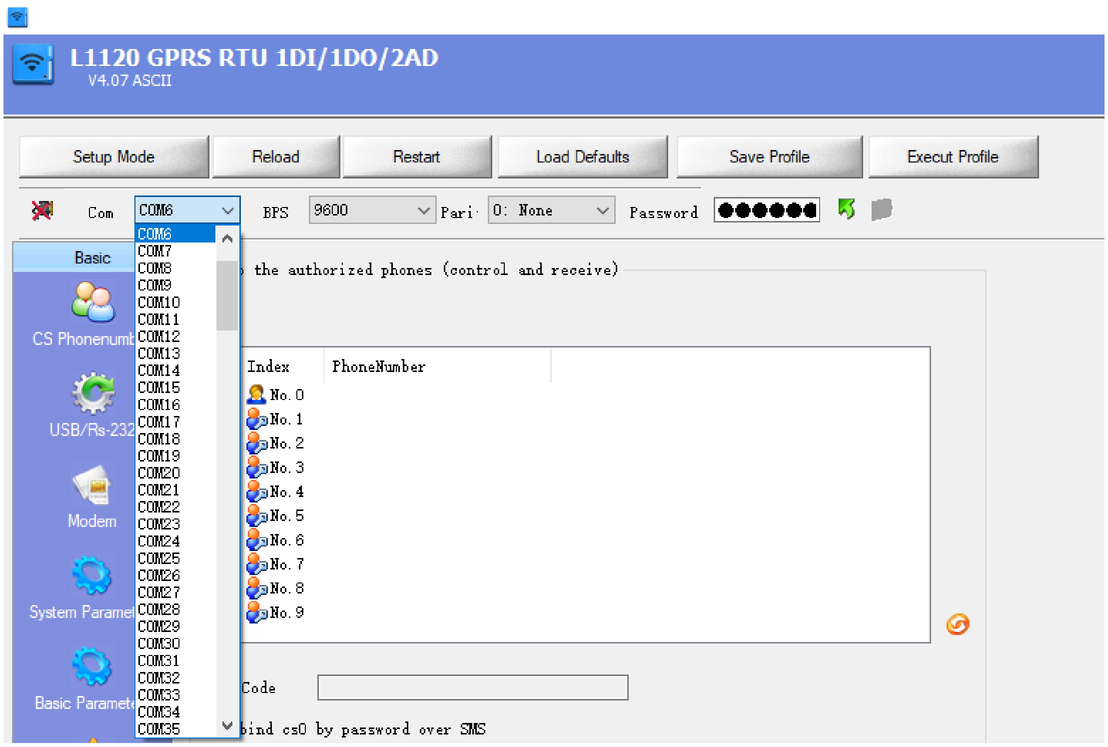


Figure 3.6: Com Port Selection

To check that the device was properly connected to the com port selected on the configuration software, the com icon close to the com drop box of the configuration tool (Figure 3.7) was closely observed to ensure consistency in the setup.

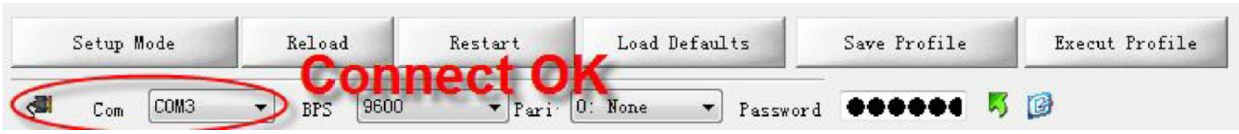


Figure 3.7: Connection Check

***Step 2: Put the Gateway in Setup Mode**

After connecting the IoT gateway to the configuration software, the gateway was placed in setup mode by clicking the setup Mode button on the configuration software and restarting the device. The red LED on the device changes to green and starts to blink.

***Step 3: Configure the Device to Send Data to Server using GPRS**

In setup mode, the device was configured to send data to the server using GPRS by clicking on Data Transmission on the menu bar and clicking on GPRS setup. (Figure 3.8)

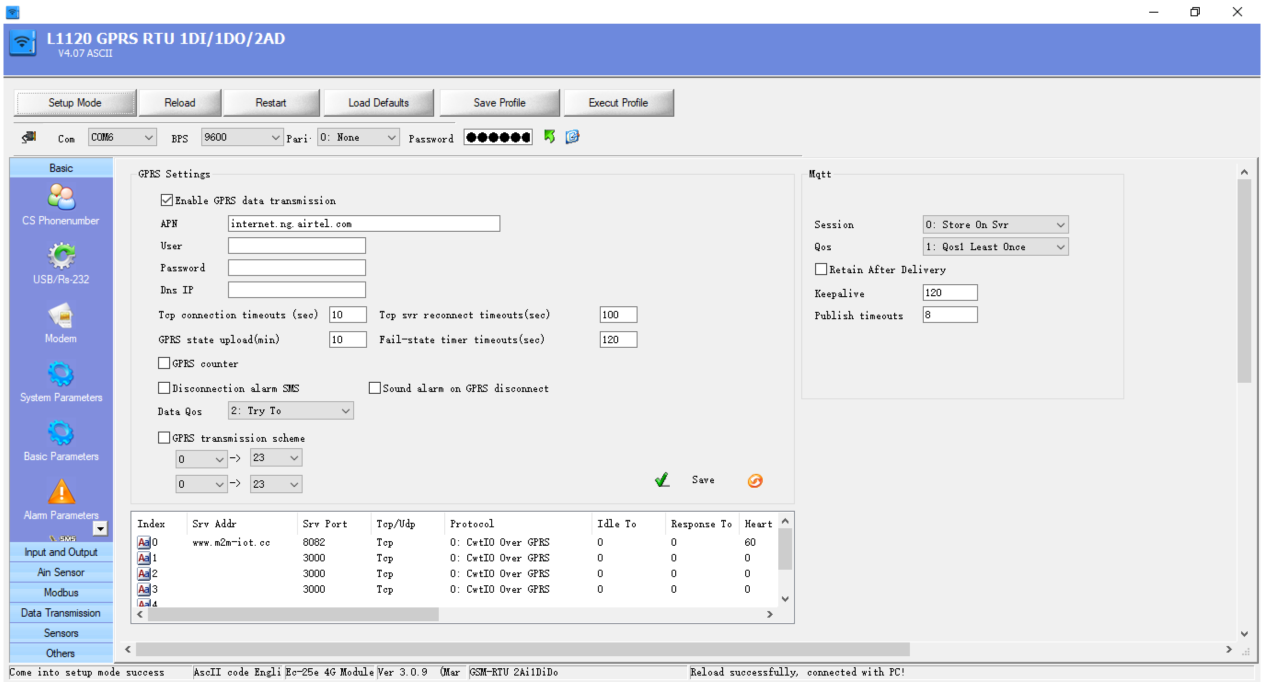


Figure 3.8: APN Configuration

The device was configured for GPRS by first setting the APN of the network provider, Airtel APN was used as the sim card used with the device was Airtel network, every other field was left as default. The server for cloud transmission is configured next. The default server was used as it is the company's server (www.m2m-iot.cc) . For server configuration the entire setup of the GPRS server of the device, double-click the company's server (www.m2m-iot.cc). This is presented in Figure 3.9.

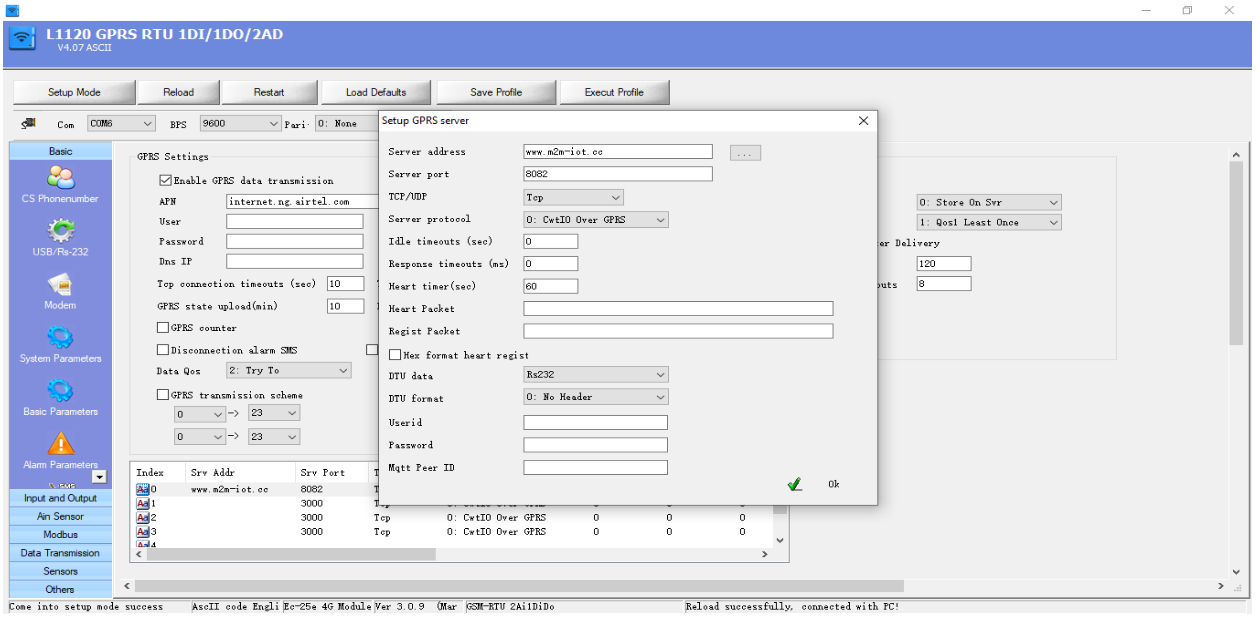


Figure 3.9: Server Configuration

***Step 4: Creation of device ID on CWT cloud platform.**

An email was sent to the device administrator to edit the device ID.

***Step 5: Configure Protocol**

To configure the data transmission protocol, The protocol icon was clicked. All fields excluding the CwtIO / Http unit ID were left at default. The Http unit ID represents the name of the device ID created on the CWT cloud platform. Figure 3.10 shows the device ID used in the configuration.

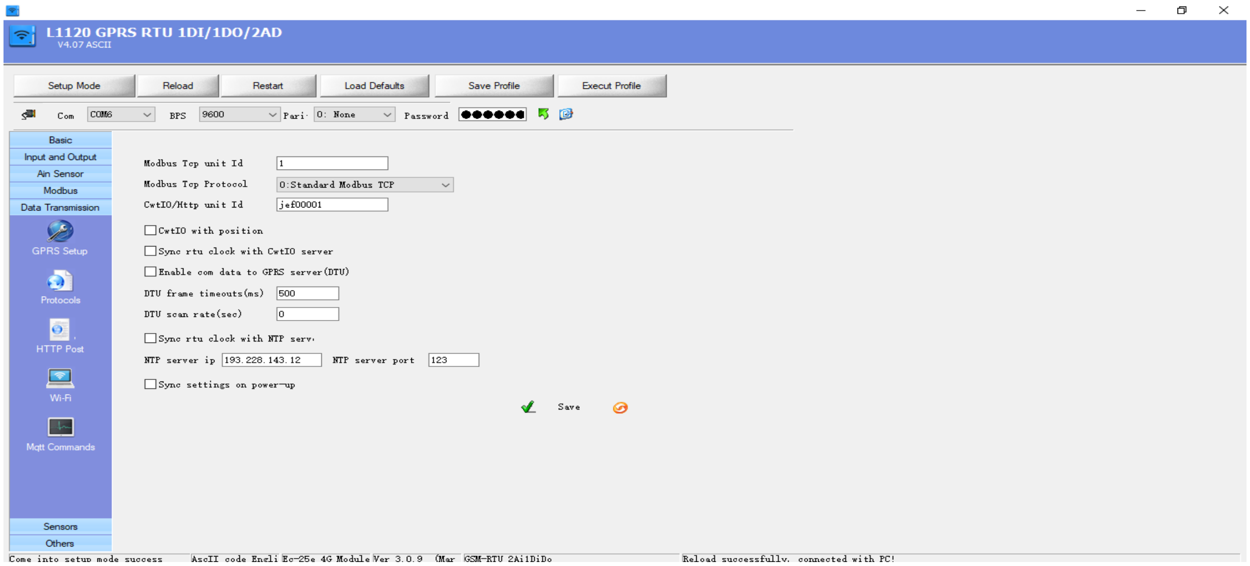


Figure 3.10: Protocol Configuration

***Step 6: Upload Timer Configuration**

The upload timer was configured by clicking on Others from the menu and then Timers. There are three timers; the minutes timer, seconds timer and daily timer. These timers control how often the gateway sends information to the cloud. For this project, Modbus data was sent to the cloud per minute. This was done by double-clicking the Timers icon. Figure 3.11 shows the timer setup configuration.

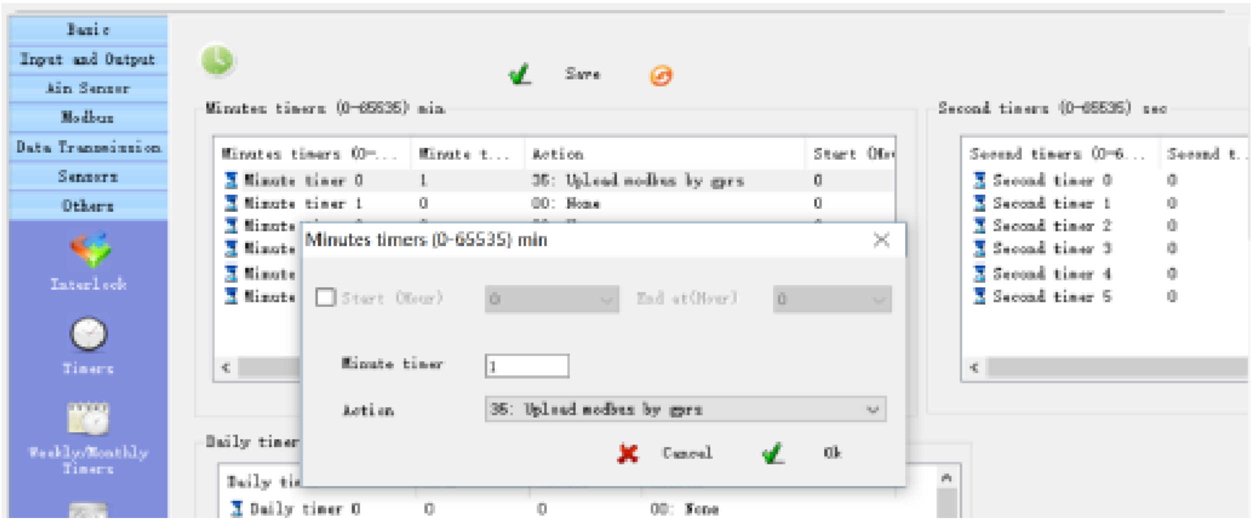


Figure 3.11: Timer Setup

***Step 7: Set Modbus Master**

To configure the Modbus Master, the protocol icon was clickedIn MODBUS protocol, there exist master and slave devices. For the purpose of this project, the Meter was set as slave while The CWT-L1102S IoT gateway was set as the master for Modbus (RS485). As master, the gateway device reads registers on RS485 from the slave (smart digital meter). The registers of the gateway were configured by manually editing the name for each register presented in Table 3.1, The maximum number of registers available on the Modbus protocol is Sixteen(16) . Slave address was set as 1 for all registers; register type was set as input; and all other fields were left at default. Figure 3.12 shows the configuration of the Modbus registers.

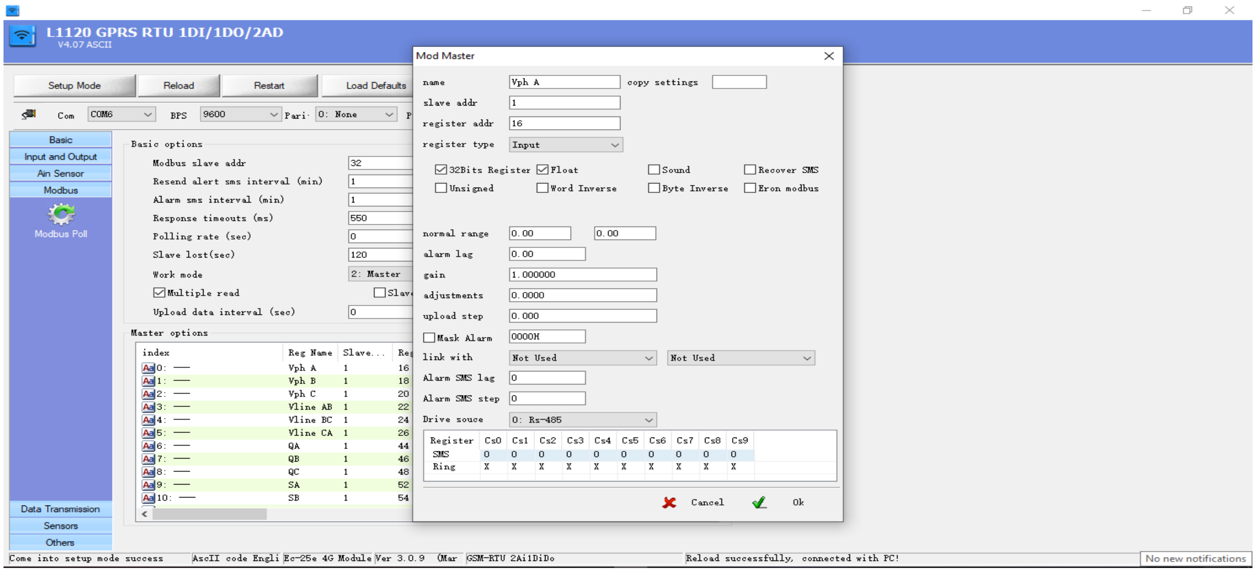


Figure 3.12: Modbus Registers Configuration

*Step 8: Sign up to CWT Cloud

An account was opened and activated by the administrator on www.m2m-iot.cc using a web browser, a new device group and template was created by clicking on Device manager, then All devices, then add new, after which the template and device groups were created and saved The template used was 02 and the group was test. The device ID generated was inputted into the CwtIO/Http unit ID (step 5). Figure 3.13 and figure 3.14 shows the new device and the template respectively.

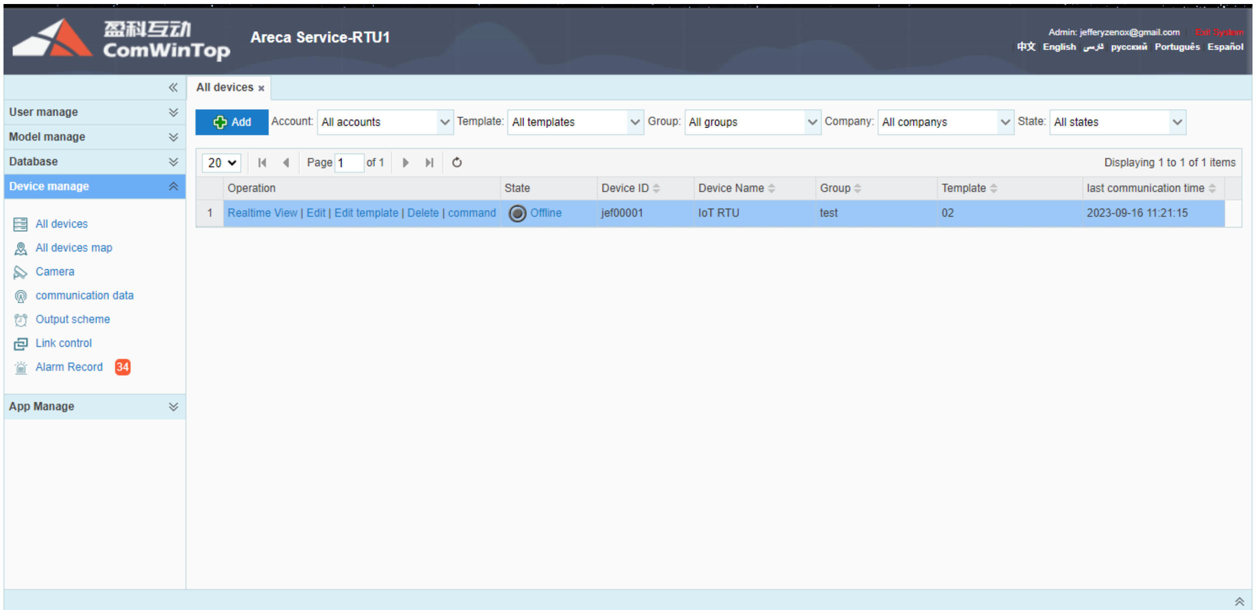


Figure 3.13: Adding New Device

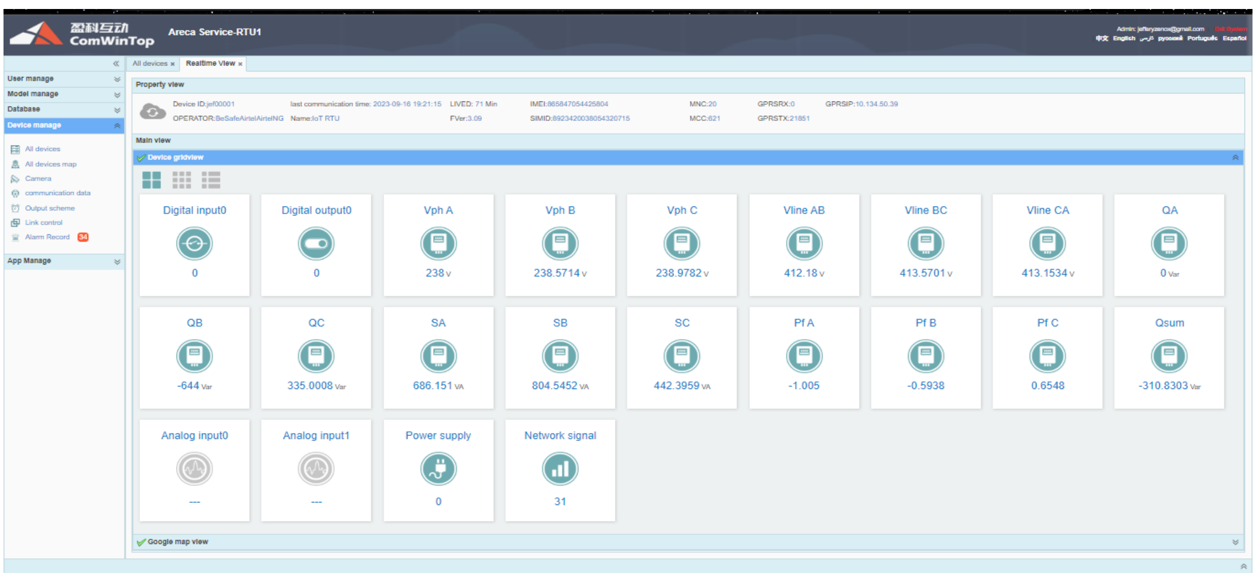


Figure 3.14: Template of Device showing Modbus registers, DI, DO, AI, power and signal

***Step 9: Insert SIM card and Restart the Device**

After the above configurations, the Gateway device was powered OFF. An Airtel sim card was inserted into the device (since it was configured with airtel APN). The device was switched back ON to exit setup mode into working mode. At this point, the device was connected to the smart meter. Terminal 8 and 7 was connected to the smart meter terminal A and B respectively. When the Gateway is connected to the network and transmitting data, the green led starts blinking twice per second.

3.3.2 MEASURED DATA

The data measured was acquired remotely by connecting the XHD331-R smart meter to the gateway's communication ports using connecting wires. Figure 3.15 shows the connection between the devices.

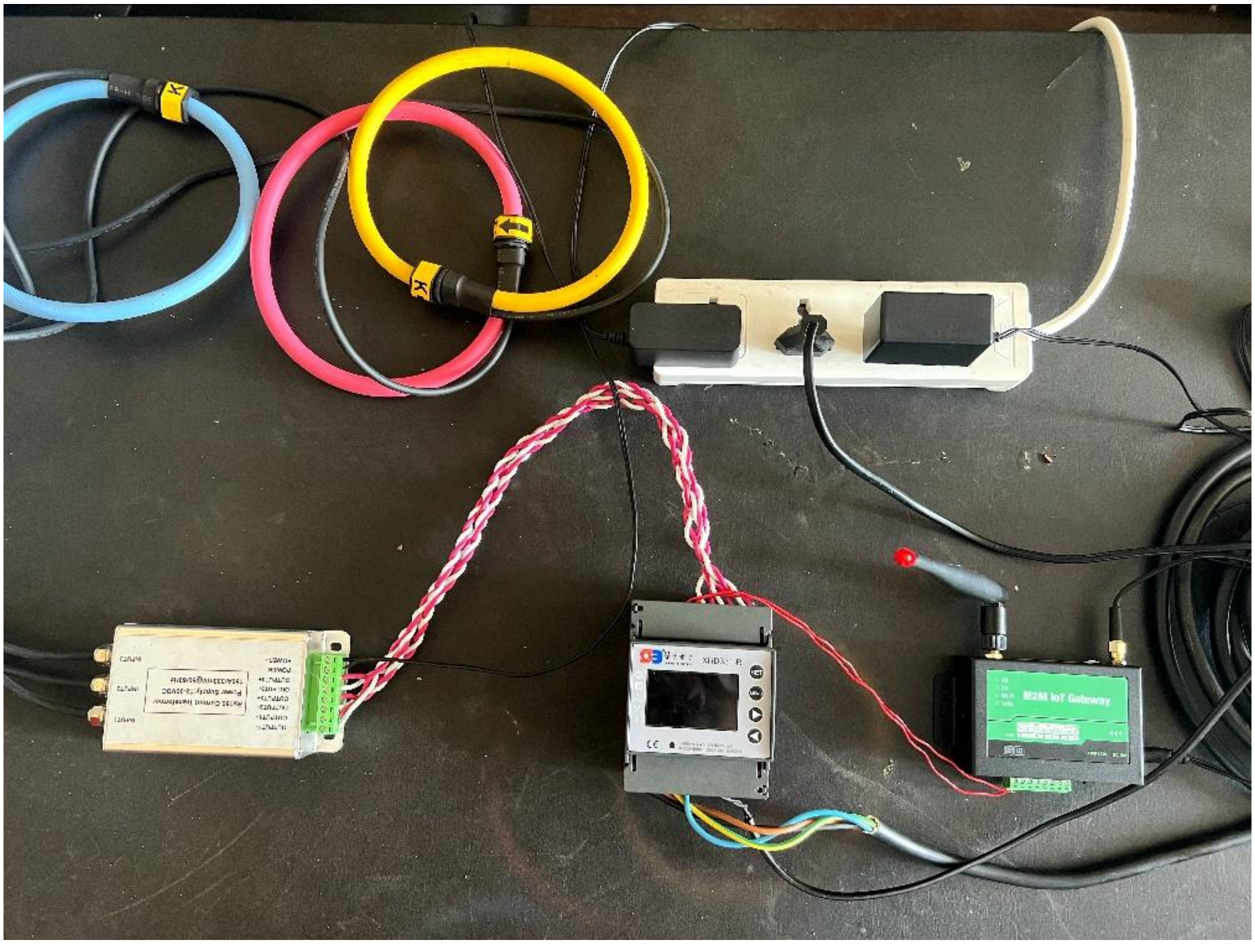


FIGURE 3.15 connection between the devices

Figure 3.16a to Figure 3.16j shows excerpts of the data measured daily from 29th September 2023 to 13th October 2023. Data was uploaded on a per minute basis.

comm time	VPh A	VPh B	VPh C	Vline AB	Vline BC	Vline CA	QA	QB	QC
2023-10-13 23:59:48	241	241.4294	239.1347	416.2365	415.9128	417.9125	0	-560	0
2023-10-13 23:58:47	241	241.3738	239.0166	416.2043	415.7624	417.7961	0	-560	0
2023-10-13 23:57:48	241	240.1532	239.9819	416.6092	415.5413	417.9411	0	-560	0
2023-10-13 23:56:48	241	240.1702	239.0998	416.091	414.7924	414.9524	0	-560	0
2023-10-13 23:55:48	240	240.9544	237.5237	416.8416	412.9723	415.915	0	-560	0
2023-10-13 23:54:48	241	240.0028	237.5959	416.7021	413.0768	415.9174	0	-560	0
2023-10-13 23:53:48	239	240.6587	237.4948	415.1547	415.8253	412.0251	0	-556	0
2023-10-13 23:52:47	239	239.9271	237.4553	415.3753	413.1574	413.2189	0	-556	0
2023-10-13 23:51:47	240	239.0646	236.6162	415.7981	413.4158	412.6766	0	-556	0
2023-10-13 23:50:48	240	239.1309	237.4073	414.3017	413.2924	412.713	0	-556	0
2023-10-13 23:49:47	239	239.7869	236.5708	415.7597	413.136	412.6205	0	-556	0
2023-10-13 23:48:50	239	239.7471	236.4326	415.7913	412.9818	412.5143	0	-556	0
2023-10-13 23:47:47	239	240.291	237.377	414.0264	413.405	413.4355	0	-556	0
2023-10-13 23:46:48	239	240.2442	237.2154	414.1533	413.2245	413.35	0	-556	0
2023-10-13 23:45:47	239	240.075	237.2208	414.9451	413.0828	413.6969	0	-552	0
2023-10-13 23:44:48	239	240.1127	237.2777	414.9027	413.1647	413.7279	0	-556	0
2023-10-13 23:43:48	239	239.1083	236.3098	415.5438	412.3222	412.3008	0	-552	0
2023-10-13 23:42:48	239	239.0695	237.3471	414.448	412.321	412.7241	0	-552	0
2023-10-13 23:41:47	239	239.0143	237.5588	414.4348	412.4566	412.902	0	-552	0

Figure 3.16a Measured Data

SB	SC	PfA	PfB	PfC	Qsum
609.5895	413.6877	-1.0001	-1.0001	1.0005	-561.5848
611.9772	413.9198	-1.0052	-1.0052	1.0043	-562.093
609.2988	413.5733	-1.0054	-1.0054	1.0035	-561.2075
609.8632	410.4679	-1.0022	-1.0022	1.0042	-563.6034
608.3266	408.7792	-1.0034	-1.0034	1.0009	-562.3483
610.1366	408.6062	-1.0077	-1.0077	1.0018	-561.5362
604.8631	406.5234	-1.0065	-1.0065	1.0025	-558.2457
600.6083	407.9334	-1.0044	-1.0044	1.0035	-557.8536
600.9459	407.8529	-1.0049	-1.0049	1.0047	-559.7297
601.8234	407.6321	-1.0043	-1.0043	1.0071	-556.3152
603.5493	405.6185	-1.0039	-1.0039	1.0008	-558.7021
600.5073	405.5462	-1.0006	-1.0006	1.0044	-559.4932
603.4387	405.7388	-1.0064	-1.0064	1.0057	-558.608
600.886	405.8831	-1.0041	-1.0041	1.0069	-558.2168
603.8813	405.7416	-1.0025	-1.0025	1.0028	-553.4798
606.1373	404.0709	-1.0012	-1.0012	1.0029	-557.0291
602.595	402.746	-1.0058	-1.0058	1.0067	-555.0528
602.2716	404.762	-1.0034	-1.0034	1.007	-553.3602
600.14	402.461	-1.0076	-1.0076	1.004	-552.2691

Figure 3.16b Measured Data

A1 fx comm time

	A	B	C	D	E	F	G	H	I	J
21	2023-10-13 23:40:47	238	238.3772	236.8037	413.0587	411.2508	411.652	0	-548	0
22	2023-10-13 23:39:48	238	239.1955	236.9955	415.1445	412.1265	410.7234	0	-552	0
23	2023-10-13 23:38:48	238	239.4338	236.9054	415.4695	412.2546	410.7855	0	-552	0
24	2023-10-13 23:37:48	238	240.2744	236.4636	414.9798	412.6007	411.0586	0	-552	0
25	2023-10-13 23:36:48	238	240.1635	236.2889	415.4418	412.3533	411.1064	0	-552	0
26	2023-10-13 23:35:48	238	239.4202	236.2603	412.8336	411.6837	411.9509	0	-552	0
27	2023-10-13 23:34:48	238	238.8261	236.5248	413.4146	411.398	411.5641	0	-548	0
28	2023-10-13 23:33:48	238	238.8951	236.4136	413.6124	411.3615	411.5532	0	-548	0
29	2023-10-13 23:32:48	239	238.036	236.493	413.2869	411.5523	411.4813	0	-552	0
30	2023-10-13 23:31:48	238	239.927	236.2834	415.1837	412.1424	410.1222	0	-552	0
31	2023-10-13 23:30:48	238	238.3935	236.8457	412.8933	411.3014	411.617	0	-548	0
32	2023-10-13 23:29:48	236	237.6106	234.4057	411.9121	408.5103	409.0791	0	-540	0
33	2023-10-13 23:28:48	236	237.9058	234.3413	411.7691	408.7101	408.9615	0	-540	0
34	2023-10-13 23:27:48	237	237.0958	234.6698	411.7924	409.1592	409.2566	0	-544	0
35	2023-10-13 23:26:48	236	236.6217	235.8835	410.9187	408.0675	409.0615	0	-540	0
36	2023-10-13 23:25:48	236	237.7047	234.3502	411.735	408.5438	408.9544	0	-540	0
37	2023-10-13 23:24:48	236	237.4671	234.0271	411.9661	408.0582	408.7741	0	-540	0
38	2023-10-13 23:23:48	235	236.8007	234.6135	408.8247	407.1229	407.9219	0	-536	0
39	2023-10-13 23:22:48	235	237.476	234.4028	409.0103	409.5262	406.6869	0	-536	0
40	2023-10-13 23:21:48	235	237.2053	234.3161	409.1471	409.2169	406.6708	0	-536	0

Figure 3.16c Measured Data

A1 fx comm time

	K	L	M	N	O	P	Q	R	S	T
21	462.9977	596.1672	401.3181	-1.0077	-1.0077	1.0019	-548.4238			
22	460.1068	601.7571	400.3391	-1.0018	-1.0018	1.0023	-555.4726			
23	460.1479	603.7056	402.4052	-1.0068	-1.0068	1.0016	-553.0939			
24	460.4225	601.5334	402.6059	-1.0048	-1.0048	1.001	-555.815			
25	460.2061	600.6997	400.4272	-1.0046	-1.0046	1.0024	-555.2697			
26	463.1611	596.8373	401.5812	-1.003	-1.003	1.0066	-555.957			
27	464.5868	596.2479	403.1944	-1.0006	-1.0006	1.0055	-548.2338			
28	464.614	597.9771	403.3481	-1.0078	-1.0078	1.0011	-548.2822			
29	464.9793	598.3436	403.689	-1.0076	-1.0076	1.0069	-553.6884			
30	465.9898	600.889	402.652	-1.0015	-1.0015	1.0042	-552.53			
31	462.7404	596.7906	401.3091	-1.002	-1.002	1	-550.3189			
32	454.1356	588.3571	394.3574	-1.0071	-1.0071	1.0015	-541.2277			
33	454.7021	590.8268	394.975	-1.0061	-1.0061	1.0056	-543.3882			
34	457.1555	588.0479	395.4805	-1.0002	-1.0002	1.0063	-547.8489			
35	455.7973	589.8882	394.1877	-1.0046	-1.0046	1.0005	-543.0609			
36	454.2203	589.3878	394.4781	-1.0021	-1.0021	1.0054	-542.6736			
37	455.8573	588.0463	394.0372	-1.0043	-1.0043	1.0041	-541.9711			
38	450.3268	586.2334	392.4876	-1.0072	-1.0072	1.001	-537.2312			
39	451.0903	584.2014	393.182	-1.0008	-1.0008	1.0053	-536.9799			
40	448.811	586.749	392.882	-1.002	-1.002	1.0065	-536.5127			

Figure 3.16d Measured Data

A1 fx comm time

	A	B	C	D	E	F	G	H	I	J
41	2023-10-13 23:20:48	234	236.7429	234.993	408.4161	408.5368	406.0745	0	-536	0
42	2023-10-13 23:19:48	234	236.6694	234.9479	408.5631	408.4341	406.0988	0	-536	0
43	2023-10-13 23:18:48	234	236.8998	234.2933	408.6859	406.0658	407.5841	0	-532	0
44	2023-10-13 23:17:48	234	236.9786	234.3236	408.9084	406.1602	407.7066	0	-536	0
45	2023-10-13 23:16:48	234	235.6561	234.6543	406.0283	407.301	404.7456	0	-532	0
46	2023-10-13 23:15:48	234	236.8525	234.1018	406.1287	407.8589	407.1772	0	-532	0
47	2023-10-13 23:14:48	233	236.9169	234.3599	406.4284	407.2734	405.5305	0	-532	0
48	2023-10-13 23:13:48	233	236.6851	234.6072	406.1092	407.2877	405.6071	0	-532	0
49	2023-10-13 23:12:48	233	236.7151	233.5584	407.9376	407.2713	405.4906	0	-532	0
50	2023-10-13 23:11:48	233	236.5797	234.3843	406.1736	407.0032	405.4416	0	-528	0
51	2023-10-13 23:10:48	234	235.0658	233.5668	407.8529	406.7144	404.5939	0	-528	0
52	2023-10-13 23:09:48	233	235.7692	233.1906	407.5968	406.1318	404.157	0	-528	0
53	2023-10-13 23:08:48	233	235.7914	233.0844	407.1449	404.0589	405.8694	0	-528	0
54	2023-10-13 23:07:48	233	234.4667	233.8058	404.9687	405.5364	405.5517	0	-524	0
55	2023-10-13 23:06:48	233	234.4372	233.6381	404.5847	405.3655	405.2402	0	-524	0
56	2023-10-13 23:05:48	232	234.2903	232.6416	405.2715	404.3766	402.6753	0	-524	0
57	2023-10-13 23:04:48	232	234.4655	232.7657	405.3305	404.6357	402.8084	0	-524	0
58	2023-10-13 23:03:48	232	234.198	232.5773	404.7887	404.241	402.4108	0	-520	0
59	2023-10-13 23:02:48	232	234.4642	232.5381	405.4296	404.4372	402.6539	0	-524	0
60	2023-10-13 23:01:48	232	233.5292	232.4904	403.2167	403.5851	403.6536	0	-524	0

Figure 3.16e Measured Data

A1 fx comm time

	K	L	M	N	O	P	Q	R	S	T
41	446.002	583.1372	391.9569	-1.0045	-1.0045	1.0067	-538.0789			
42	447.959	583.1907	391.9322	-1.003	-1.003	1.0048	-533.2209			
43	449.7162	582.0258	391.8537	-1.005	-1.005	1.0069	-537.9661			
44	449.6771	582.3543	391.7721	-1.0066	-1.0066	1.0068	-539.2844			
45	446.4879	582.7659	388.6042	-1.0072	-1.0072	1.0015	-535.9191			
46	447.1167	583.6074	391.1619	-1.0004	-1.0004	1.0071	-532.9968			
47	442.8095	583.2505	388.5197	-1.0044	-1.0044	1.006	-535.9437			
48	442.5794	581.1983	388.3486	-1.0042	-1.0042	1.0056	-529.5418			
49	442.8322	581.5308	388.6038	-1.004	-1.004	1.0022	-534.0073			
50	442.4601	580.0096	388.1236	-1.0023	-1.0023	1.0004	-529.0262			
51	445.9841	581.9076	388.0533	-1.0039	-1.0039	1.0025	-529.9861			
52	442.7774	578.042	386.79	-1.0052	-1.0052	1.0042	-531.7543			
53	445.1733	576.2375	389.1828	-1.007	-1.007	1.0066	-531.9594			
54	442.3744	576.4095	386.3508	-1.0049	-1.0049	1.0007	-530.5099			
55	442.3556	576.0887	386.37	-1	-1	1.004	-524.9651			
56	436.8174	573.895	382.5531	-1.0068	-1.0068	1.007	-527.0178			
57	437.2941	574.9749	384.9557	-1.0035	-1.0035	1.0032	-524.5234			
58	436.9467	575.4818	382.7147	-1.0005	-1.0005	1.0065	-526.9255			
59	440.6519	572.3811	384.5753	-1.0024	-1.0024	1.0074	-524.722			
60	438.0248	570.5815	385.9237	-1.0007	-1.0007	1.0077	-522.6189			

Figure 3.16f Measured Data

A1 fx comm time

	A	B	C	D	E	F	G	H	I	J
61	2023-10-13 23:00:48	231	232.8074	232.6209	402.0901	402.207	400.4126	0	-516	0
62	2023-10-13 22:59:48	231	232.3537	231.419	401.268	401.6393	401.8819	0	-516	0
63	2023-10-13 22:58:48	231	232.2849	231.4908	400.5524	401.6419	401.6344	0	-516	0
64	2023-10-13 22:57:48	230	232.8747	231.9485	400.8506	403.684	400.1602	0	-516	0
65	2023-10-13 22:56:48	231	233.1517	231.2066	402.5379	402.1474	400.2488	0	-516	0
66	2023-10-13 22:55:48	231	232.1268	231.8109	400.5453	401.7828	401.9089	0	-516	0
67	2023-10-13 22:54:48	231	231.1737	231.8585	400.3062	400.9979	400.98	0	-516	0
68	2023-10-13 22:53:48	230	231.7287	230.2649	401.764	400.0983	398.231	0	-512	0
69	2023-10-13 22:52:48	231	231.1679	231.6342	400.6896	400.7985	400.9516	0	-516	0
70	2023-10-13 22:51:48	231	231.454	231.9768	401.0745	401.343	401.415	0	-516	0
71	2023-10-13 22:50:48	231	232.5046	231.0042	400.4131	401.4104	401.1524	0	-516	0
72	2023-10-13 22:49:48	230	232.7305	231.2871	400.1451	400.9858	399.2817	0	-512	0
73	2023-10-13 22:48:48	230	232.5175	230.0855	401.2782	400.6268	398.732	0	-512	0
74	2023-10-13 22:47:48	229	231.9925	230.2966	398.6591	399.4886	399.7803	0	-510	0
75	2023-10-13 22:46:48	230	231.2046	230.3589	399.7125	401.7261	398.2901	0	-512	0
76	2023-10-13 22:45:49	230	230.1653	230.2721	398.6439	398.7505	398.8861	0	-510	0
77	2023-10-13 22:44:48	230	230.4011	230.3358	398.3849	399.0099	398.8292	0	-510	0
78	2023-10-13 22:43:48	230	230.4279	230.2665	398.8155	398.9731	398.9556	0	-510	0
79	2023-10-13 22:42:48	230	229.2737	230.9873	398.5141	398.5978	398.5833	0	-510	0
80	2023-10-13 22:41:48	229	230.645	230.4528	398.4089	398.4565	398.9409	0	-508	0

Figure 3.16g Measured Data

A1 fx comm time

	K	L	M	N	O	P	Q	R	S	T
61	436.1365	564.6761	381.97	-1.0001	-1.0001	1.0067	-523.0516			
62	432.662	567.2211	378.4314	-1.0019	-1.0019	1.0005	-518.48			
63	432.6772	567.8243	378.4394	-1.007	-1.007	1.0011	-517.8022			
64	430.6421	567.6725	378.2394	-1.0052	-1.0052	1.0042	-517.5418			
65	433.2331	566.2437	378.916	-1.0013	-1.0013	1.0037	-518.4675			
66	432.8893	566.9401	378.5627	-1.0024	-1.0024	1.0013	-517.3588			
67	432.1245	560.5835	379.7897	-1.0074	-1.0074	1.0041	-516.3916			
68	433.9913	556.5317	377.8754	-1.0065	-1.0065	1.0034	-512.5208			
69	435.1596	561.9875	379.2307	-1	-1	1.0006	-512.9257			
70	436.3281	565.6329	380.2453	-1.005	-1.005	1.002	-517.0668			
71	437.8405	564.5678	378.0661	-1.0055	-1.0055	1.0006	-517.5254			
72	433.2649	563.4474	377.469	-1.0071	-1.0071	1.002	-514.0816			
73	431.7921	559.786	375.8038	-1.0013	-1.0013	1.0044	-512.1905			
74	430.8048	557.8495	374.8685	-1.0017	-1.0017	1.0062	-510.282			
75	431.1705	559.9561	375.3009	-1.0029	-1.0029	1.0077	-511.241			
76	433.9646	558.6011	374.2141	-1.0016	-1.0016	1.0043	-510.7108			
77	432.0706	559.0403	374.4525	-1.0028	-1.0028	1.0052	-510.4882			
78	434.1456	556.5583	374.5972	-1.0008	-1.0008	1.0017	-510.2447			
79	433.6495	555.21	375.9952	-1.0078	-1.0078	1.0054	-510.7054			
80	431.5092	553.3608	373.6383	-1.0031	-1.0031	1.0031	-509.975			

Figure 3.16h Measured Data

A1 fx comm time

	C	D	E	F	G	H	I	J	K	L
81	231.7956	229.0306	399.9826	399.0877	399.257	0	-508	0	431.9589	557.1008
82	230.6685	230.8083	398.1026	398.785	399.1163	0	-510	0	430.0779	558.9026
83	230.0123	230.4713	398.1423	398.7905	398.8415	0	-510	0	432.3095	558.2778
84	229.4892	229.8156	397.4874	397.7696	397.99	0	-508	0	431.3618	555.5775
85	229.8536	229.5456	396.7769	397.8514	397.4486	0	-508	0	432.6732	554.3698
86	229.9598	229.5588	397.5881	397.9549	399.8113	0	-506	0	431.8592	555.2079
87	229.7036	229.5901	397.9484	397.76	399.9944	0	-508	0	432.6191	552.4492
88	229.7514	229.949	399.6839	398.1122	398.1906	0	-508	0	432.3046	554.6974
89	231.7618	229.0139	399.2241	399.0439	396.9143	0	-510	0	430.0575	558.7809
90	230.6522	229.7611	399.1027	398.73	396.6427	0	-508	0	431.9836	559.0204
91	230.4499	229.4103	398.2199	396.2508	397.9567	0	-508	0	431.3627	553.4774
92	230.7297	229.2711	398.3488	396.3725	397.8919	0	-508	0	431.2705	555.7213
93	229.7764	229.5439	396.0088	397.7831	397.1146	0	-508	0	430.1485	555.7856
94	229.9307	229.6502	398.6511	396.0088	397.4847	0	-508	0	432.7133	554.6672
95	229.0207	229.5958	399.1509	396.0396	399.654	0	-508	0	435.0389	552.3498
96	229.0874	229.8307	399.188	396.3008	399.8734	0	-508	0	433.2098	555.2087
97	230.764	229.4937	399.48	398.595	396.5742	0	-508	0	432.2126	557.1707
98	231.1717	230.0443	398.7544	399.425	399.6028	0	-510	0	434.8503	556.1927
99	231.967	230.0752	399.1647	399.2746	399.8072	0	-510	0	432.8474	558.9595
100	230.0118	230.3972	398.0783	398.726	398.7496	0	-508	0	433.6606	558.3421

Figure 3.16i Measured Data

A1 fx comm time

	K	L	M	N	O	P	Q	R	S	T
81	431.9589	557.1008	372.1814	-1.0036	-1.0036	1.0011	-511.2896			
82	430.0779	558.9026	372.3054	-1.005	-1.005	1.006	-509.5597			
83	432.3095	558.2778	374.6486	-1.0047	-1.0047	1.0008	-510.1819			
84	431.3618	555.5775	373.7016	-1.0008	-1.0008	1.0006	-509.2324			
85	432.6732	554.3698	373.1311	-1.0026	-1.0026	1.0018	-508.7531			
86	431.8592	555.2079	372.2126	-1.0029	-1.0029	1.0015	-509.3263			
87	432.6191	552.4492	373.0933	-1.0059	-1.0059	1.0005	-508.6575			
88	432.3046	554.6974	372.8255	-1.0036	-1.0036	1.0033	-509.0981			
89	430.0575	558.7809	372.452	-1.0073	-1.0073	1.0044	-511.056			
90	431.9836	559.0204	372.3689	-1.0013	-1.0013	1.0062	-509.0439			
91	431.3627	553.4774	373.739	-1.0026	-1.0026	1.0036	-508.153			
92	431.2705	555.7213	373.6977	-1.0007	-1.0007	1.0075	-510.6614			
93	430.1485	555.7856	370.6415	-1.0058	-1.0058	1.0023	-509.906			
94	432.7133	554.6672	373.3086	-1.0065	-1.0065	1.0063	-508.3829			
95	435.0389	552.3498	373.6261	-1.0033	-1.0033	1.0046	-508.7883			
96	433.2098	555.2087	373.7778	-1.0074	-1.0074	1.0013	-509.4724			
97	432.2126	557.1707	372.6438	-1.0037	-1.0037	1.004	-509.4981			
98	434.8503	556.1927	375.3233	-1.0058	-1.0058	1.0059	-510.3675			
99	432.8474	558.9595	375.2993	-1.0052	-1.0052	1.0016	-510.3254			
100	433.6606	558.3421	374.0717	-1.0021	-1.0021	1.0073	-510.0549			

Figure 3.16j Measured Data

The remaining data can be accessed through the open-source google sheet link: https://docs.google.com/spreadsheets/d/1e42RthCsjfuCdLt7QRFQ17Sg6KqLsmUwfyamYvpJzgo/edit?usp=sharing.

CHAPTER FOUR

RESULTS, CONCLUSION AND ANALYSIS

In this chapter, the results of analyses using machine learning algorithms are presented in a comprehensible manner through tables, charts, and graphs. This was achieved by running

Python scripts on Kaggle kernel. Through a meticulous analysis, the patterns, correlations, and noteworthy trends are unraveled, placing a critical lens on the data obtained. While the limitations of this study are well acknowledged, the implications of these findings offer insights that extend beyond the confines of this project. This chapter serves as a pivotal point, where raw data transforms into meaningful insights, contributing to the broader discourse within the field.

4.1 DATA ANALYSIS WITH KAGGLE

Kaggle Kernels serve as an invaluable resource for data scientists and machine learning enthusiasts, providing a collaborative platform hosted on the Kaggle website. They offer an interactive computing environment that enables users to create and share executable code. Kaggle Kernels provide a seamless and efficient way to develop, experiment, and collaborate on data science and machine learning projects. It supports various programming languages, with a strong emphasis on Python and R, allowing users to execute code in a step-by-step fashion, it also supports data visualization libraries, making it convenient to create plots and graphs for a comprehensive understanding of the data.

4.2 MACHINE LEARNING LIBRARIES UTILIZED

1. Pandas: Widely used for data manipulation and analysis, Pandas provides data structures like DataFrames that simplify tasks such as cleaning and exploring datasets.

2. NumPy: A fundamental library for numerical operations in Python, NumPy provides support for arrays, matrices, and mathematical functions, making it essential for scientific computing.

3. Matplotlib and Seaborn: These libraries excel in data visualization, offering a plethora of options for creating insightful and aesthetically pleasing plots and charts.

4. Scikit-learn: A powerful machine learning library, Scikit-learn provides tools for data mining, classification, regression, and clustering, making it a versatile choice for building and evaluating machine learning models.

4.3 ANALYSIS ON MEASURED DATA

This segment of the project involves navigating through the intricate landscape of analyzing the measured data, unraveling patterns, relationships, and meaningful insights across key stages. The process unfolds seamlessly, encompassing the following essential steps:

4.3.1 Data Loading

All analyses were done on kaggle.com an online data analysis tool. On the kaggle homepage, a new notebook was created by clicking the plus symbol shown in figure 4.1.

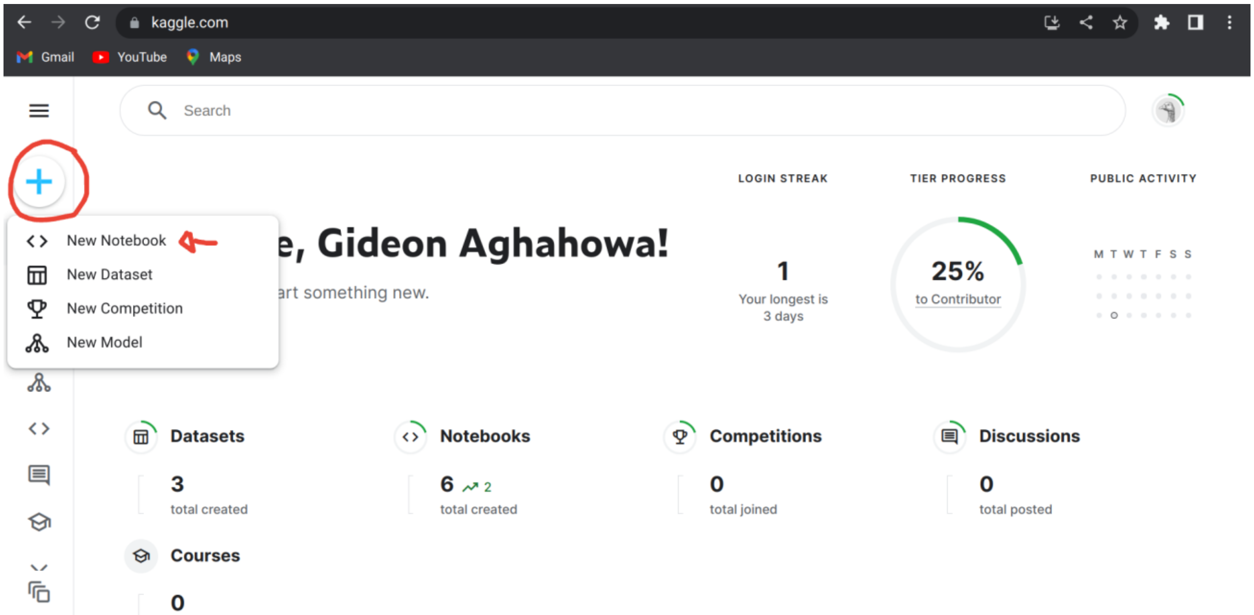


Figure 4.1 Kaggle Homepage

After creating the notebook, the measured data was uploaded from the computer into the analytical framework by converting it to a .csv file. This was done by expanding the sidebar at the bottom-right corner and then clicking the upload button, as shown in figure 4.2.

Figure 4.2 Data Upload

Cells were created to write Python scripts by clicking on 'Code' below the page, creating cells foster a structured workflow conducive to efficient data exploration, hypothesis testing, and visualization. Subsequently, all the relevant libraries such as pandas, numpy, matplotlib, scikit-learn, seaborn and random were imported and tested by clicking on the play symbol. Additional cells were created and tested using the same prompt.

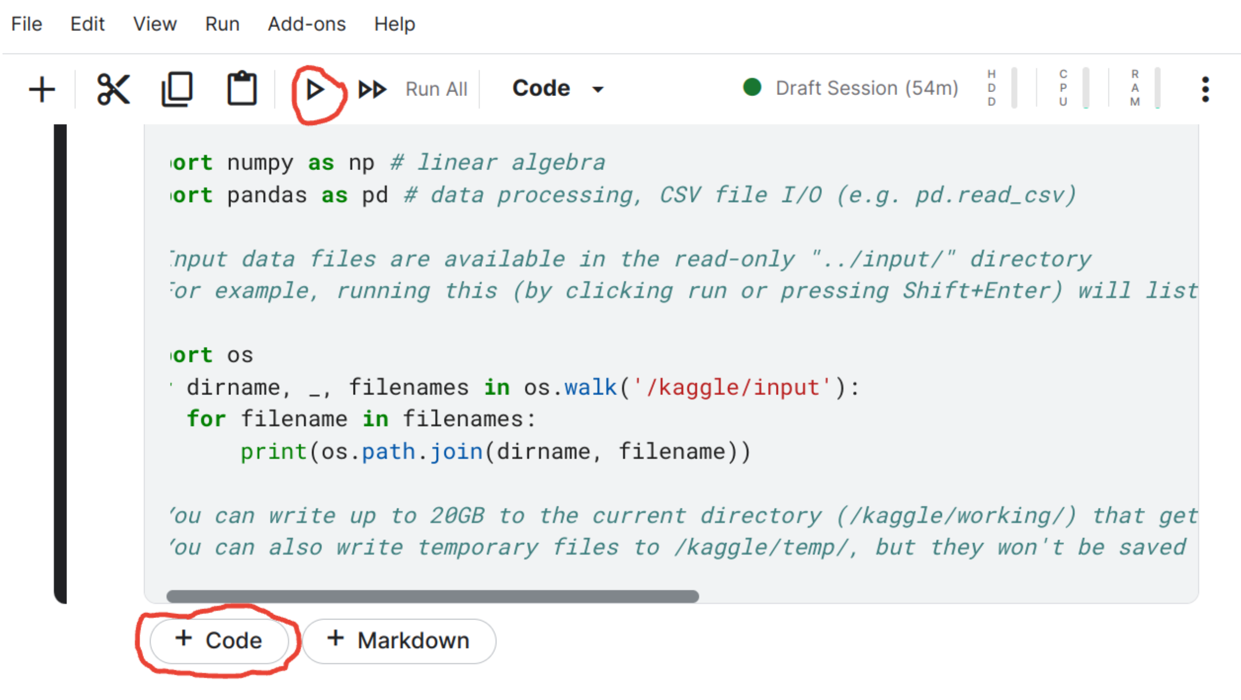


Figure 4.3 Creating Cells

The code used to import all libraries is given below, also shown in the image below. Importing libraries beforehand enables analysts to access the powerful functionalities seamlessly within their code, streamlining the analysis process and ensuring accuracy and reliability in their results; otherwise, there would be errors in the code output.

```
import pandas as pd

import numpy as np

import matplotlib.pyplot as plt

%matplotlib inline

from sklearn.model_selection import train_test_split

import seaborn as sns

import random
```

There was no error encountered, so the data was loaded into the notebook using the functions in the Pandas library already imported, using the code;

dataset = pd.read_csv('/kaggle/input/final-year-data-analysis/Copy of Data Analysis Project - Sheet1 (1).csv')

This code encompasses the folder name as well as the file name which can be found by expanding the sidebar and copying the file path.

Folder name: final-year-data-analysis

File name: Copy of Data Analysis Project - Sheet1 (1).csv

In [2]:

```
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
from sklearn.model_selection import train_test_split
import seaborn as sns
import matplotlib.pyplot as plt
import random
```

In [3]:

```
dataset = pd.read_csv('/kaggle/input/final-year-data-analysis/Copy of Data Analysis Project - Sheet1 (1).csv')
```

Figure 4.4 Data Loading

It is essential to load the data with Pandas because it efficiently stores data in DataFrame objects, which offer versatile data structures for organizing and analyzing tabular data, including features for filtering, sorting, and aggregating data

4.3.2 Data Preprocessing

Data preprocessing involves cleaning, transforming, and organizing raw data into a format suitable for analysis. This typically includes tasks such as handling missing values, removing outliers, standardizing or normalizing data, and encoding categorical variables. The goal of data preprocessing is to ensure that the data is accurate, consistent, and relevant for analysis, thus improving the performance and reliability of machine learning models and other data-driven techniques. For data preprocessing, it is imperative to assess the structure of the dataset, examining its dimensions in terms of columns and rows.

The script dataset.shape(), returned a tuple representing the dimensions of the DataFrame, where the first element denotes the number of rows and the second element represents the number of columns.

```
In [4]:  dataset.shape

Out[4]:  (19972, 17)
```

Figure 4.5 Data Shape

The examination of the results in figure 4.2 elucidates that the entire dataset comprises 19,972 rows and encompasses 17 columns of data. This dataset represents the unprocessed information derived from real-time measurements and transmissions occurring between the gateway and smart meter.

The script data.head() by default, displayed the first 5 rows of the DataFrame. To specify the number of rows, passing an integer argument to the head() method, like dataset.head(10) displays the first 10 rows. This method is commonly used to quickly inspect the structure and contents of a DataFrame when working with large datasets.

```
[5]: dataset.head()
```

[5]:

	comm time	VPh A	VPh B	VPh C	Vline AB	Vline BC	Vline CA	QA	QB	QC	SA	SB	SC	PfA	PfB	PfC	Qsum
0	2023-10-13 23:59:48	241	241.4294	239.1347	416.2365	415.9128	417.9125	0	-560	0	471.6494	609.5895	413.6877	-1.0001	-1.0001	1.0005	-561.5848
1	2023-10-13 23:58:47	241	241.3738	239.0166	416.2043	415.7624	417.7961	0	-560	0	471.7205	611.9772	413.9198	-1.0052	-1.0052	1.0043	-562.0930
2	2023-10-13 23:57:48	241	240.1532	239.9819	416.6092	415.5413	417.9411	0	-560	0	473.1057	609.2988	413.5733	-1.0054	-1.0054	1.0035	-561.2075
3	2023-10-13 23:56:48	241	240.1702	239.0998	416.0910	414.7924	414.9524	0	-560	0	473.8928	609.8632	410.4679	-1.0022	-1.0022	1.0042	-563.6034
4	2023-10-13 23:55:48	240	240.9544	237.5237	416.8416	412.9723	415.9150	0	-560	0	472.2258	608.3266	408.7792	-1.0034	-1.0034	1.0009	-562.3483

Figure 4.6 Data Head

Utilizing the code dataset.head() provided a preliminary glimpse of the values within the initial five columns. Notably, an observation reveals that both Column QA (reactive power A) and Column QC (reactive power C) exclusively contain zero values.

The script dataset.info(), provided details such as the data type of each column, the number of non-null values in each column, and the memory usage of the DataFrame. This summary aids in understanding the data structure, identifying missing values, and assessing the DataFrame's memory consumption, especially useful during data exploration and preprocessing tasks.

```
In [6]: dataset.info()

<class 'pandas.core.frame.DataFrame'>
RangeIndex: 19972 entries, 0 to 19971
Data columns (total 17 columns):
 #   Column     Non-Null Count  Dtype
---  ------     --------------  -----
 0   comm time  19972 non-null  object
 1   VPh A      19972 non-null  int64
 2   VPh B      19972 non-null  float64
 3   VPh C      19972 non-null  float64
 4   Vline AB   19972 non-null  float64
 5   Vline BC   19972 non-null  float64

 6   Vline CA   19972 non-null  float64
 7   QA         19972 non-null  int64
 8   QB         19972 non-null  int64
 9   QC         19972 non-null  int64
 10  SA         19972 non-null  float64
 11  SB         19972 non-null  float64
 12  SC         19972 non-null  float64
 13  PfA        19972 non-null  float64
 14  PfB        19972 non-null  float64
 15  PfC        19972 non-null  float64
 16  Qsum       19972 non-null  float64
dtypes: float64(12), int64(4), object(1)
memory usage: 2.6+ MB
```

Figure 4.7 Data Info

It is noteworthy that the communication time is categorized as an object data type. In Python, the object data type represents any data that isn't explicitly recognized as a built-in type like integers, floats, or strings. It's a generic data type that can hold any Python object, including custom-defined classes and instances. This flexibility allows for handling diverse types of data within

Python structures like lists, dictionaries, and Pandas DataFrames. Also, the data types Vph A, QA, QB, and QC are integers, while the others are floats or decimal values. Given these insights, it became imperative to address the zero values in the dataset. Considering their potential impact on subsequent analyses, it is recommended to either drop these entries or replace them with randomly generated values to ensure the dataset's reliability and integrity.

Furthermore, dataset.describe() generated descriptive statistics for the numerical columns of the DataFrame. These statistics include count, mean, standard deviation, minimum, quartiles (25th, 50th, and 75th percentiles), and maximum values for each numerical column.

In [7]:
```
dataset.describe()
```
Out[7]:

	VPh A	VPh B	VPh C	Vline AB	Vline BC	Vline CA	QA	QB	QC	SA	SE
count	19972.000000	19972.000000	19972.000000	19972.000000	19972.000000	19972.000000	19972.0	19972.000000	19972.0	19972.000000	19
mean	231.262568	232.606307	233.343456	402.142258	403.529790	402.799263	0.0	-511.613859	0.0	355.856910	58
std	7.209731	6.616683	5.587004	11.867762	10.468374	10.888025	0.0	31.778562	0.0	42.706461	42
min	206.000000	209.133800	213.026500	362.069400	368.011400	366.221800	0.0	-612.000000	0.0	266.861000	45
25%	228.000000	229.192000	230.149300	396.582500	397.761975	397.566350	0.0	-532.000000	0.0	322.589925	54
50%	232.000000	233.185100	233.729750	403.606800	404.375650	403.940550	0.0	-512.000000	0.0	340.398700	58
75%	236.000000	237.240575	237.290225	410.567150	410.825875	410.665950	0.0	-488.000000	0.0	396.950975	61
max	245.000000	246.839100	245.829500	425.931300	425.980200	425.950800	0.0	-412.000000	0.0	474.516900	69

In [7]:
```
dataset.describe()
```
Out[7]:

e CA	QA	QB	QC	SA	SB	SC	PfA	PfB	PfC	Qsum
72.000000	19972.0	19972.000000	19972.0	19972.000000	19972.000000	19972.000000	19972.000000	19972.000000	19972.000000	19972.000000
.799263	0.0	-511.613859	0.0	355.856910	584.484273	392.911198	-1.003913	-1.003913	1.003875	-513.126580
388025	0.0	31.778562	0.0	42.706461	42.083867	25.136961	0.002251	0.002251	0.002353	32.210934
.221800	0.0	-612.000000	0.0	266.861000	459.520500	313.741200	-1.007800	-1.007800	0.912200	-616.859700
.566350	0.0	-532.000000	0.0	322.589925	549.920650	374.675725	-1.005900	-1.005900	1.001900	-533.653425
.940550	0.0	-512.000000	0.0	340.398700	588.617750	395.083800	-1.003900	-1.003900	1.003900	-513.351050
.665950	0.0	-488.000000	0.0	396.950975	614.013225	409.895050	-1.002000	-1.002000	1.005900	-489.173150
.950800	0.0	-412.000000	0.0	474.516900	691.816300	473.454000	-1.000000	-1.000000	1.007800	-410.734500

Figure 4.8 Data Description

This method provides a summary of the central tendency, dispersion, and shape of the distribution of the data in the DataFrame's numeric columns, facilitating initial insights into the dataset's numerical characteristics. It's commonly used during data exploration and analysis to understand the distribution and variability of numerical data.

4.3.3 Data Cleaning

The primary focus lies in addressing outliers or zero-value entries within the dataset. These unusual data points are handled with care, either by eliminating them or substituting them with suitable values, such as the mean or randomly generated numbers. The decision between elimination and replacement depends on the characteristics of the data and its impact on subsequent analyses. This thorough cleaning procedure guarantees that the dataset is polished and free from anomalies, enhancing the reliability of subsequent analytical efforts.

The zero values in column QA and QC were replaced with random values within a the range of values recorded in QB using the code below

```
# Define the range for QA and QC
min_value_A = -612.000000
max_value_A = -412.000000
min_value_C = -612.000000
max_value_C = -412.000000

# Generate random values for QA and QC for each row
```

random_values_A = [random.uniform(min_value_A, max_value_A) for _ in range(len(dataset))]

random_values_C = [random.uniform(min_value_C, max_value_C) for _ in range(len(dataset))]

 # Assign the generated random values to the DataFrame

dataset['QA'] = random_values_A

dataset['QC'] = random_values_C

After replacing the zero-values, the dataset.head() function was called again to preview the replacements.

[8]:

```
# Define the range for QA and QC
min_value_A = -612.000000
max_value_A = -412.000000
min_value_C = -612.000000
max_value_C = -412.000000

# Generate random values for QA and QC for each row
random_values_A = [random.uniform(min_value_A, max_value_A) for _ in range(len(dataset))]
random_values_C = [random.uniform(min_value_C, max_value_C) for _ in range(len(dataset))]

# Assign the generated random values to the DataFrame
dataset['QA'] = random_values_A
dataset['QC'] = random_values_C
```

Figure 4.9 Data Replacement

```
In [9]: dataset.head()
```

Out[9]:

	comm time	VPh A	VPh B	VPh C	Vline AB	Vline BC	Vline CA	QA	QB	QC	SA	SB	SC	PfA
0	2023-10-13 23:59:48	241	241.4294	239.1347	416.2365	415.9128	417.9125	-521.506357	-560	-446.167637	471.6494	609.5895	413.6877	-1.0001
1	2023-10-13 23:58:47	241	241.3738	239.0166	416.2043	415.7624	417.7961	-561.787735	-560	-572.199503	471.7205	611.9772	413.9198	-1.0052
2	2023-10-13 23:57:48	241	240.1532	239.9819	416.6092	415.5413	417.9411	-577.432824	-560	-558.432985	473.1057	609.2988	413.5733	-1.0054
3	2023-10-13 23:56:48	241	240.1702	239.0998	416.0910	414.7924	414.9524	-575.410634	-560	-564.906165	473.8928	609.8632	410.4679	-1.0022
4	2023-10-13 23:55:48	240	240.9544	237.5237	416.8416	412.9723	415.9150	-452.467483	-560	-541.478257	472.2258	608.3266	408.7792	-1.0034

Figure 4.10 Data Cleaning

4.3.4 Data Visualization

As shown in figure 4.10 above, the zero values in QA and QC have been replaced with plausible and representative data. The subsequent step involves engaging in data visualization to discern patterns that could serve as the foundation for comparisons and analyses. Continuing with the analytical process, the Matplotlib library was used to generate histograms for columns with both integer and float data types. This approach allowed for visual representation of the frequency distribution for each column, providing valuable insights into the distribution patterns of the dataset. The histograms serve as a powerful tool to observe the occurrence frequency of specific values within numerical columns, contributing to a deeper understanding of the underlying data dynamics. The codes are given in Figure 4.11

 # Iterate through all columns in the dataset

```
for column in dataset.columns:
    if dataset[column].dtype in ['int64', 'float64']:
        plt.figure(figsize=(8, 6))
        dataset[column].hist(bins=20)
        plt.xlabel(column)
        plt.ylabel('Frequency')
        plt.title(f'Histogram of {column}')
        plt.show()
```

Figures 4.11 to 4.25 display the code prompts and the corresponding histogram results.

```
[10]:
# Iterate through all columns in the dataset
for column in dataset.columns:
    if dataset[column].dtype in ['int64', 'float64']:
        plt.figure(figsize=(8, 6))
        dataset[column].hist(bins=20)
        plt.xlabel(column)
        plt.ylabel('Frequency')
        plt.title(f'Histogram of {column}')
        plt.show()
```

Figure 4.11 Code Prompt for Histogram

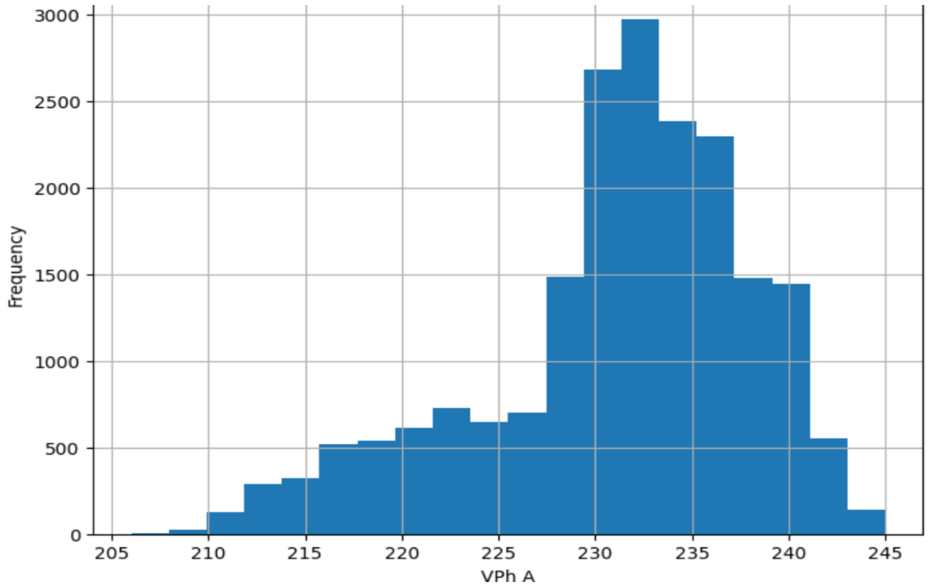


Figure 4.12 Histogram VPh A

The histogram profile of Phase Voltage A reveals a dataset spanning from a lowest recorded value of 205V to a peak at 245V, indicating a 40V range. Notably, the mode at 233V suggests a central tendency, signifying the most frequently occurring voltage level.

Observing the histogram's shape, a left-skewed distribution emerges, indicating a prevalence of higher voltage values and a lesser occurrence of lower ones. While not perfectly left-skewed, this distribution prompts considerations about potential anomalies or irregularities in the lower voltage range.

The range of 40V implies variability in voltage levels, suggesting diverse conditions during the measured period. Despite the skewness, the histogram portrays a certain level of stability and consistency, particularly in the higher voltage range.

In summary, the left-skewed profile of Phase Voltage A's histogram highlights a prevailing trend toward higher voltage values. Further investigation into potential anomalies and the consistent stability observed in the higher voltage range is recommended for a comprehensive understanding of the electrical system's reliability and performance.

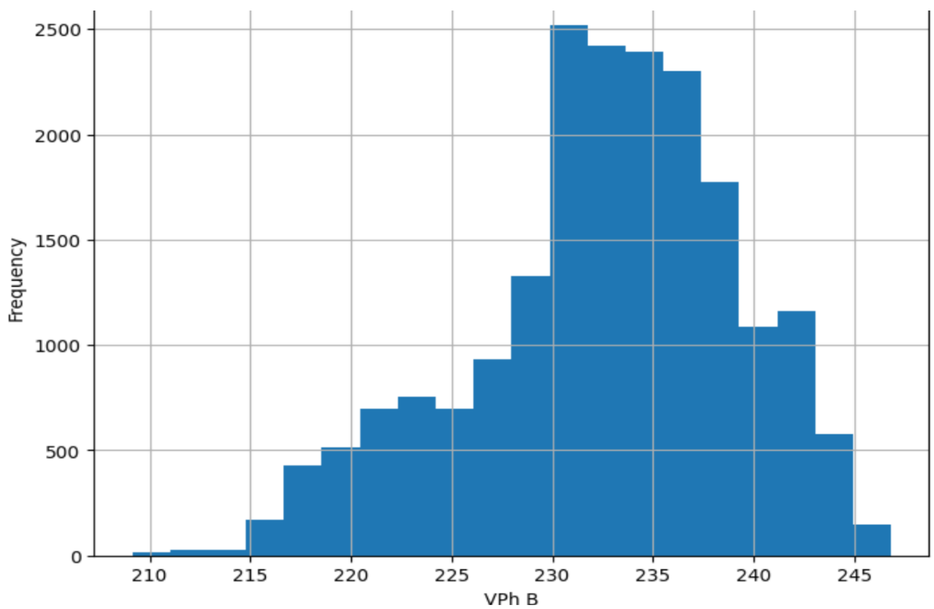


Figure 4.13 Histogram VPh B

The histogram profile of Phase Voltage B shares similarities with Phase Voltage A but presents some distinctive characteristics. The dataset spans from a minimum voltage of 210V to a highest recorded value, mirroring Phase Voltage A, at 245V, with a 35V range. Notably, the mode at 230V signifies the most frequently occurring voltage level, providing a central tendency.

Similar to Phase Voltage A, the histogram exhibits a left-skewed distribution, implying a prevalence of higher voltage values and a relative scarcity of lower ones. This skewness, while not perfect, prompts considerations about potential anomalies or irregularities in the lower voltage range.

The reduced range of 35V compared to Phase Voltage A suggests a narrower variability in voltage levels. Despite this, the left-skewed distribution implies a consistent trend toward higher voltage values.

In conclusion, the left-skewed profile of Phase Voltage B's histogram indicates a concentration of occurrences in the higher voltage range, particularly around the mode at 230V. As with Phase Voltage A, further investigation into potential anomalies in the lower voltage range is advisable for a comprehensive assessment of the electrical system's reliability and performance.

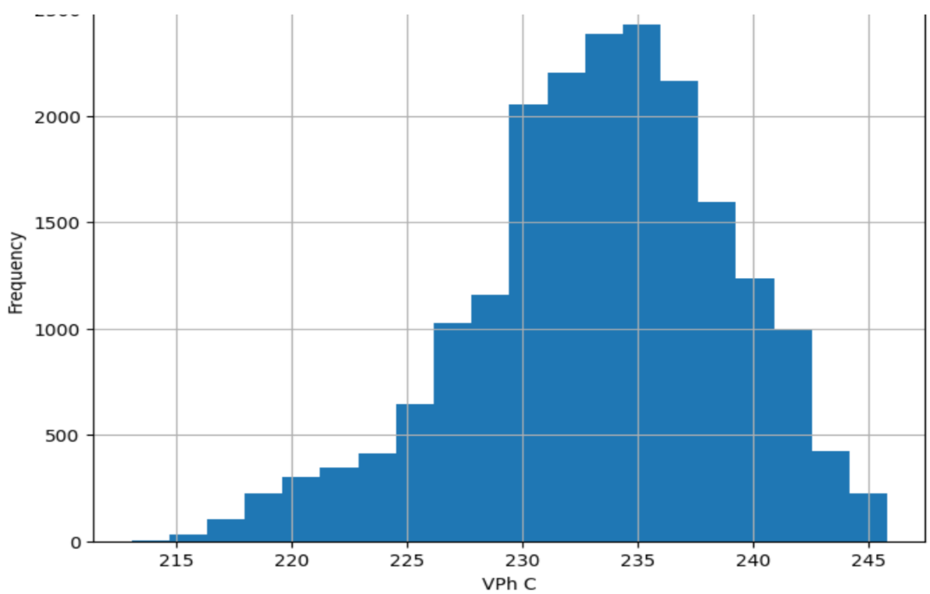


Figure 4.14 Histogram VPh C

The histogram profile of Phase Voltage C presents a distinctive contrast to the left-skewed distributions observed in Phase Voltages A and V. In this case, the histogram approaches symmetry, suggesting a balanced distribution of occurrences across the voltage range.

With a minimum recorded voltage of 215V and a maximum of 245V, the dataset spans a 30V range. Notably, the mode at 235V indicates a central tendency, representing the most frequently occurring voltage level.

The nearly symmetrical nature of the histogram implies a balanced occurrence of both higher and lower voltage values. This balance suggests a more even distribution of voltage occurrences throughout the measured period, potentially reflecting a stable and consistent electrical environment.

In summary, the nearly symmetrical profile of Phase Voltage C's histogram, coupled with a central tendency around the mode at 235V, indicates a more evenly distributed occurrence of voltage values. This balance in distribution may signify a stable and consistent electrical supply throughout the measured period for Phase Voltage C. Further analysis and monitoring will provide a comprehensive understanding of the reliability and performance of this phase in the electrical system.

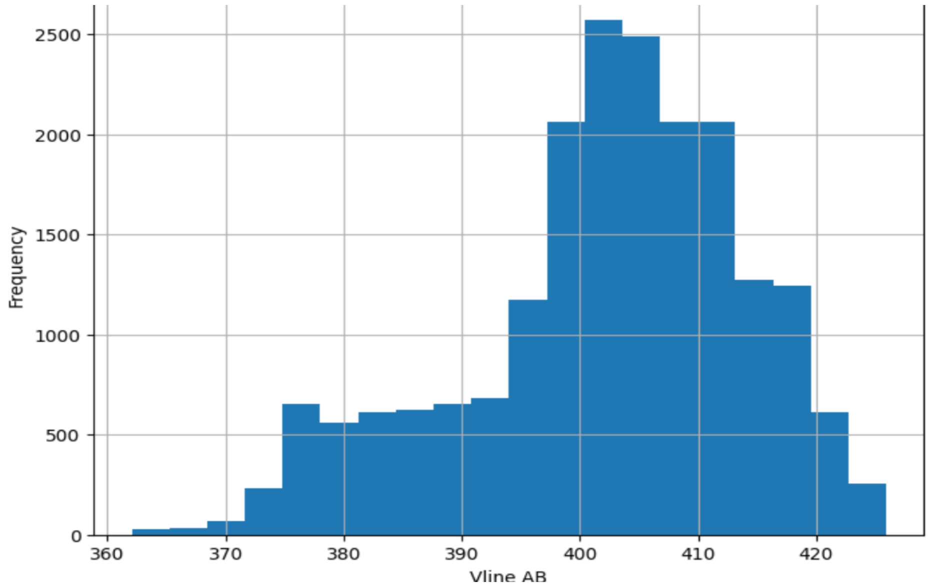


Figure 4.15 Histogram Vline AB

The histogram profile of Line Voltage AB provides interesting insights into the overall distribution of voltage values across the system. With a minimum voltage of approximately 362V and a maximum of around 425V, the dataset spans a range of 63V. Notably, the mode at about 408V signifies a central tendency, representing the most frequently occurring voltage level.

The left-skewed nature of the histogram indicates a prevalence of higher voltage values and a relative scarcity of lower ones, aligning with the trends observed in the phase voltages (A, V, and C). However, the additional observation of "some ups and downs in between" suggests fluctuations or variations within the left-skewed distribution.

These fluctuations may be indicative of dynamic changes in voltage levels, possibly influenced by external factors or operational conditions. The range of 63V suggests variability in the voltage supply, and the mode at 408V implies a concentration of occurrences around this central value.

In summary, Line Voltage AB's left-skewed histogram with fluctuations suggests dynamic variations in voltage levels. The prevalence of higher voltage values, as well as the observed ups and downs, may be associated with changing operational conditions. Understanding these patterns is crucial for assessing the stability and reliability of the electrical system, especially in comparison to the left-skewed but relatively stable phase voltages (A, V, and C). Further investigation into the factors influencing these fluctuations is recommended for a comprehensive analysis.

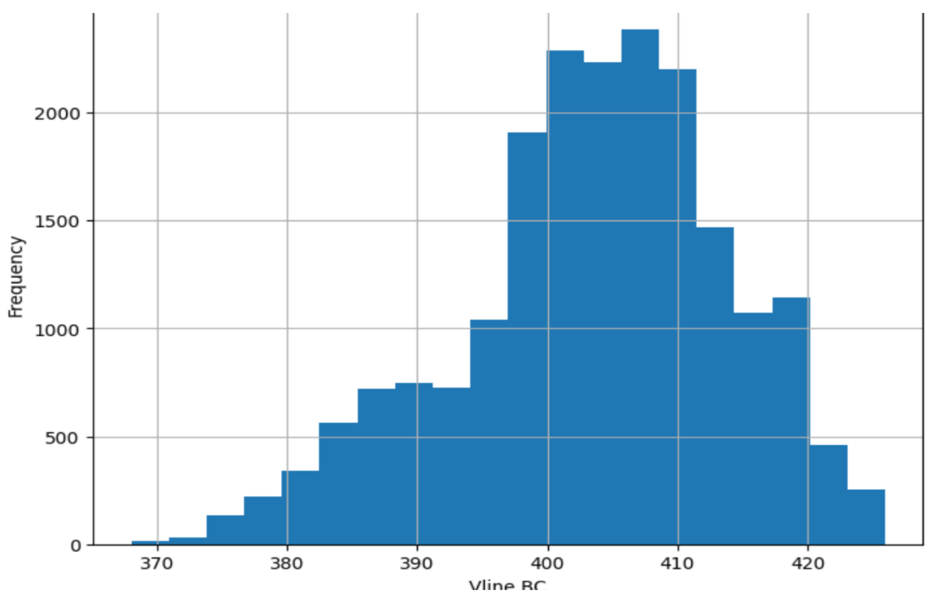


Figure 4.15 Histogram Vline BC

The histogram profile of Line Voltage BC exhibits similarities to Line Voltage AB, with no significant differences in terms of overall distribution characteristics. However, the minimum voltage for Line Voltage BC is slightly higher at 370V, and the overall range spans from this minimum to a maximum voltage of an unspecified value.

In the context of the previously discussed histograms, the left-skewed nature with some fluctuations observed in Line Voltage AB seems to extend to Line Voltage BC. The commonality in distribution patterns across line voltages and phase voltages (A, V, and C) suggests a systemic influence on the electrical environment. Furthermore, the similarities in the left-skewed distribution patterns across line and phase voltages suggest a consistent systemic influence. Monitoring line voltage histograms is integral to assessing system stability, load balancing, and the overall performance of electrical equipment, contributing to the reliability and efficiency of the electrical system.

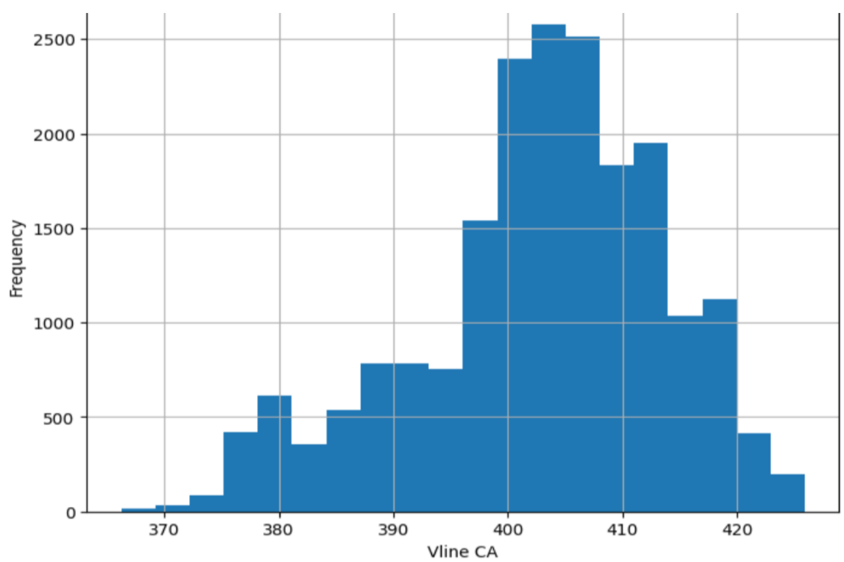


Figure 4.16 Histogram Vline CA

The histogram profile of Line Voltage CA appears to align closely with the characteristics observed in both Line Voltages AB and BC. While no significant differences were noted, the minimum voltage for Line Voltage CA is specified at 370V, maintaining a parallel with Line Voltage BC.

The left-skewed distribution with fluctuations observed in Line Voltage AB seems to extend consistently to Line Voltage CA. This similarity in distribution patterns across line and phase voltages (A, V, and C) implies a systemic influence shaping the electrical environment.

In terms of relevance, analyzing Line Voltage histograms is crucial for Monitoring variations in line voltage, it also helps in assessing system stability, load balancing, equipment performance, and aids in the early detection of faults.

In summary, the consistent left-skewed distribution patterns across line and phase voltages suggest a systemic influence on the electrical environment. Monitoring Line Voltage CA histograms, along with Line Voltages AB and BC, contributes to a comprehensive understanding of the electrical system's stability, performance, and reliability.

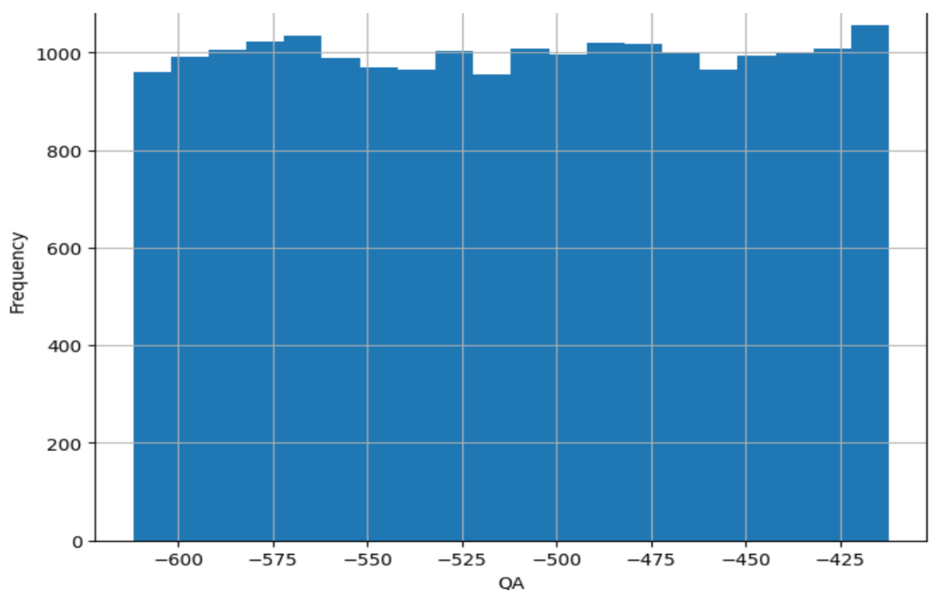


Figure 4.17 Histogram QA

The histogram profile of Reactive Power A reveals a distinctive shape, resembling more of a rectangle with slight deviations at the top. The highest frequency, approximately 1100 occurrences, corresponds to a reactive power of -425Var, while the lowest frequency, around 900 occurrences, corresponds to a reactive power of -450Var.

The rectangular shape suggests a relatively uniform distribution of reactive power values, indicating a consistent range with minimal variations. However, the noteworthy observation is the consistently negative nature of the measured reactive power values. Negative reactive power values, indicative of a lead power factor, are unusual in standard electrical systems and may raise concerns about potential errors in measurement equipment, technical issues, or configuration discrepancies.

To address this anomaly, it is crucial to undertake thorough investigations and consider potential causes. Calibration of measurement equipment, a review of system configuration, and validation checks on the collected data are recommended steps. Additionally, consulting with experts in power systems can provide valuable insights into the observed negative reactive power values and guide the necessary corrections. These measures are essential to ensure the accuracy and reliability of reactive power measurements in the system

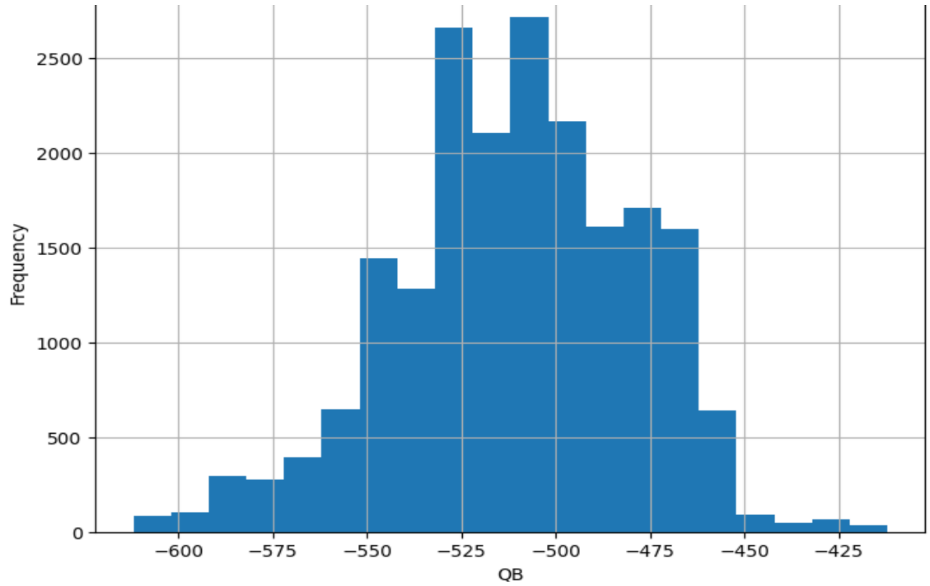


Figure 4.18 Histogram QB

Reactive Power B's histogram profile deviates significantly from the rectangular shape, resembling more of a normal distribution. The bell-shaped curve indicates a broader range of occurrences, with the highest value slightly above -425Var and the lowest value slightly below -600Var. This distribution suggests a greater variability in reactive power values for Phase B compared to Phase A. Understanding the relationship between Reactive Power B and the corresponding phase and line voltages is crucial. Comparing the normal distribution shape of Reactive Power B with the rectangular shape of Reactive Power A provides insights into the interplay between voltage levels and reactive power characteristics. Further analysis and consideration of the system's operational conditions are warranted to comprehensively understand the implications of the observed reactive power distribution.

For both Reactive Powers A and B, addressing anomalies in measurement equipment, system configuration, and implementing thorough data validation processes are recommended steps to ensure the reliability and accuracy of reactive power measurements in the system

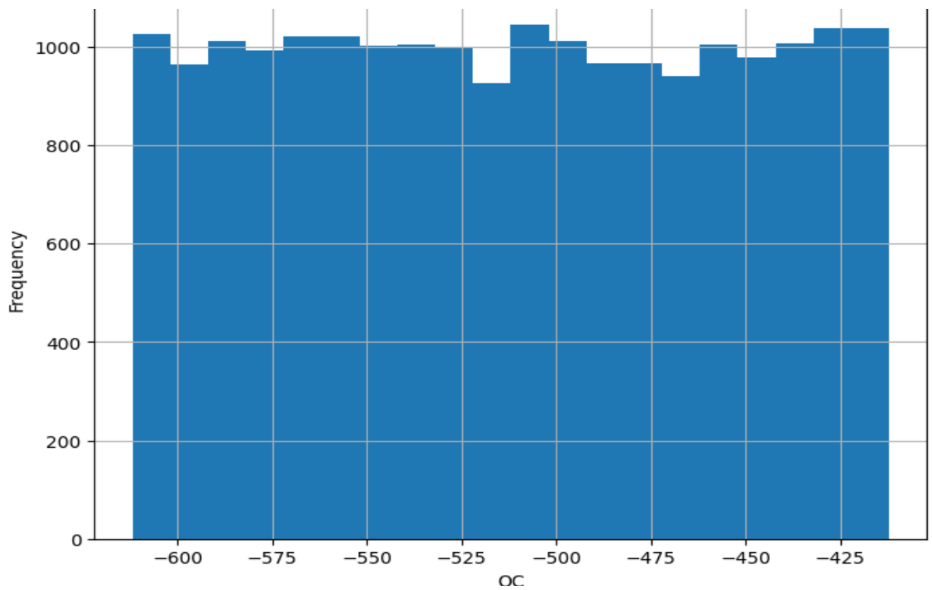


Figure 4.19 Histogram QC

The histogram profile for Reactive Power C closely resembles that of Reactive Power A, presenting a distinctive rectangular shape with slight deviations at the top. Similar to Reactive Power A, the highest frequency, approximately 1100 occurrences, corresponds to a reactive power of -500Var, and the lowest frequency, around 900 occurrences, aligns with a reactive power of -525Var. This uniform distribution shape implies a consistent range of reactive power values for Phase C, with minimal variations.

The similarities in the histogram shapes of Reactive Powers A and C suggest comparable characteristics in the distribution of reactive power values across these phases. However, the consistent negative nature of the reactive power values raises concerns, and further investigation into potential errors in measurement equipment, technical issues, or configuration discrepancies is recommended.

Addressing anomalies in measurement equipment, conducting a thorough review of system configuration, and implementing robust data validation processes are crucial steps to ensure the accuracy and reliability of reactive power measurements in the system.

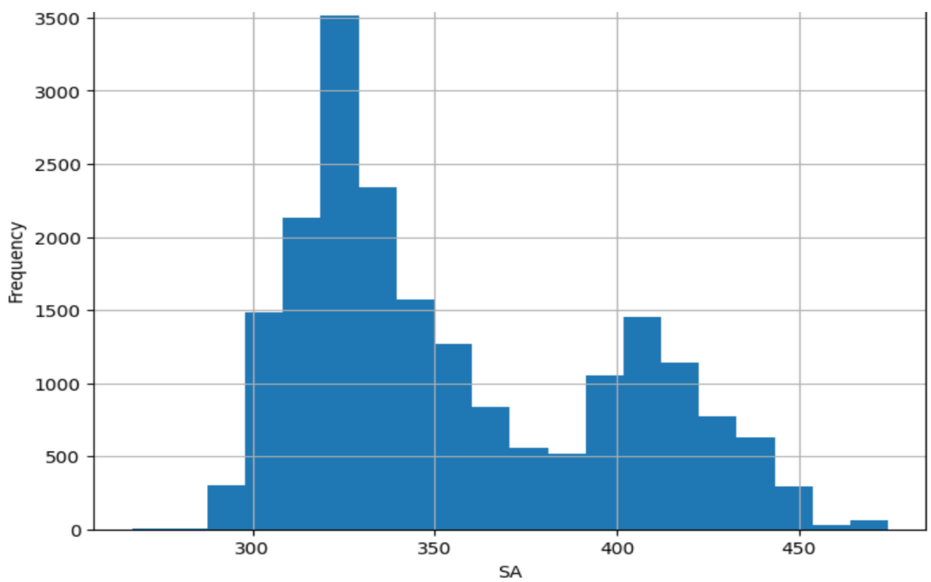


Figure 4.20 Histogram SA

The analysis of Real Power A reveals a consistent distribution within the average range of 280W to 500W, suggesting a stable and reliable power supply for Phase A. The histogram indicates that the majority of occurrences fall within this specified power band, contributing to a relatively uniform distribution.

However, a notable spike at 330W appears as an outlier, diverging from the overall pattern. This outlier raises questions about potential anomalies or specific operational conditions influencing this unique occurrence. Further exploration and investigation into the context behind this spike are essential to ensure accurate interpretation and to address any potential issues affecting the reliability of real power measurements in Phase A

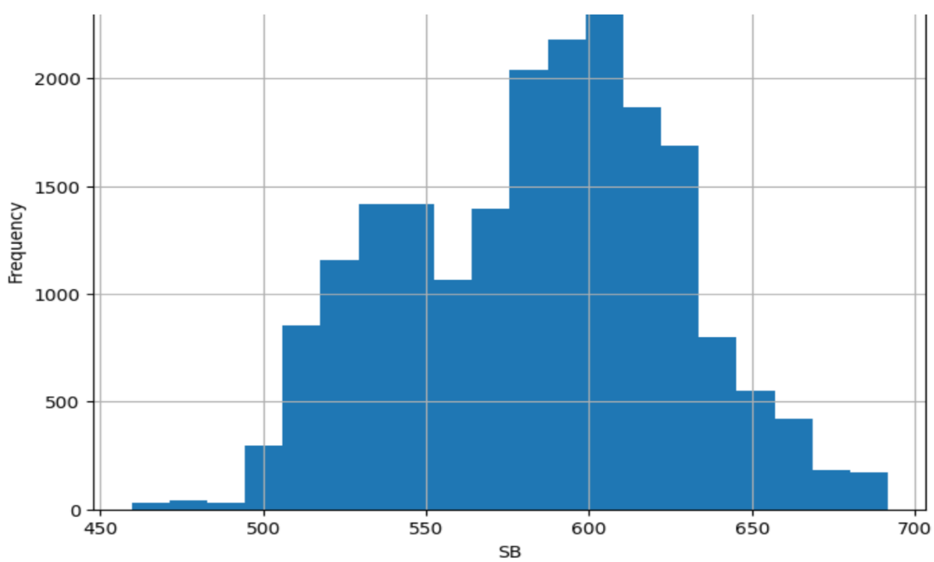


Figure 4.21 Histogram SB

The analysis of Real Power B reveals a consistent distribution within the range of approximately 460W to 690W, with the highest occurrence observed at 600W. This distribution suggests a stable and reliable power supply for Phase B, with the concentration of occurrences at 600W indicating a central tendency. The uniformity within the specified power range signifies a consistent operational state for Phase B, laying the groundwork for further investigation into the factors influencing power supply and operational conditions in this phase.

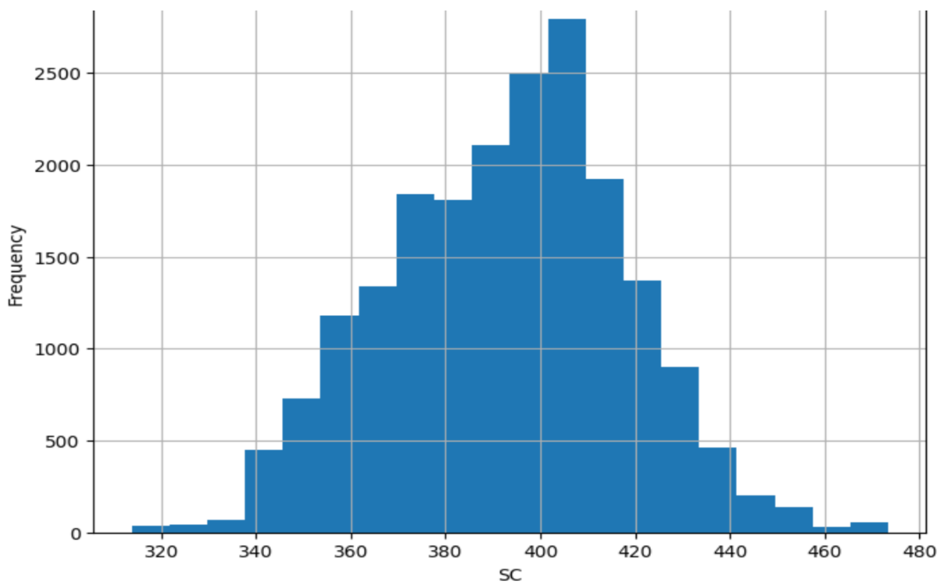


FIGURE 4.16 Histogram SC

The analysis of Real Power C reveals a histogram shaped like a normal distribution, ranging from approximately 320W to 470W, with the peak occurrence observed at 400W. This distribution suggests a balanced and symmetric pattern of real power values for Phase C, contributing to a stable and consistent power supply. The central tendency at 400W indicates a prevalent power level within the system for this phase. This comprehensive understanding of

Real Power C's characteristics lays the foundation for further exploration into operational conditions and factors influencing power supply in Phase C.

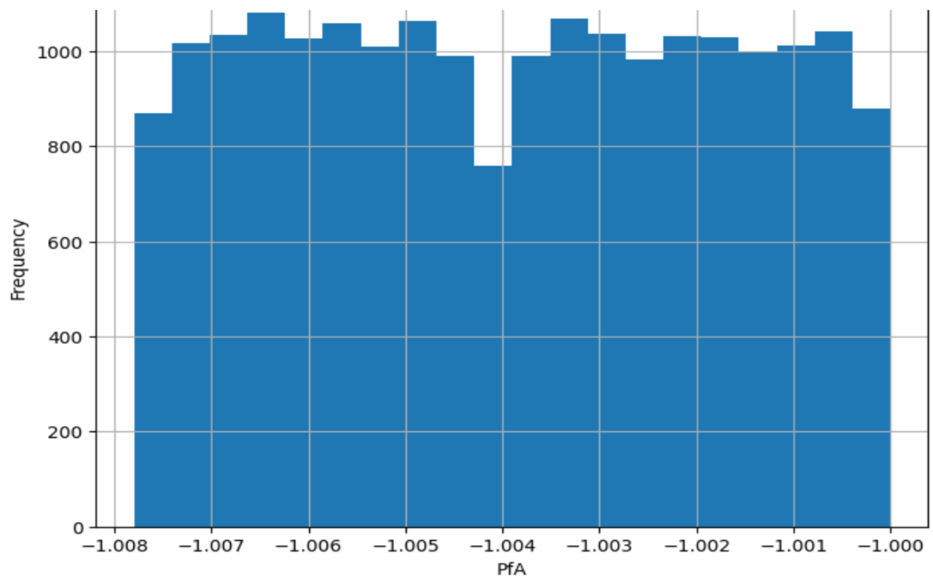


Figure 4.22 Histogram PfA

The analysis of Power Factor A reveals a symmetrical histogram with values ranging from approximately -1.008 to -1, a pattern that suggests a balanced distribution. However, the consistent negativity of the power factor values raises concerns about potential malfunctions or misconfigurations in the measuring instruments. This anomaly necessitates a thorough investigation into the relationship between negative power factors, line and phase voltages, and real and reactive power values of Phase A. Understanding these interconnections is crucial for identifying potential sources of error and ensuring the reliability and accuracy of power measurements in this phase.

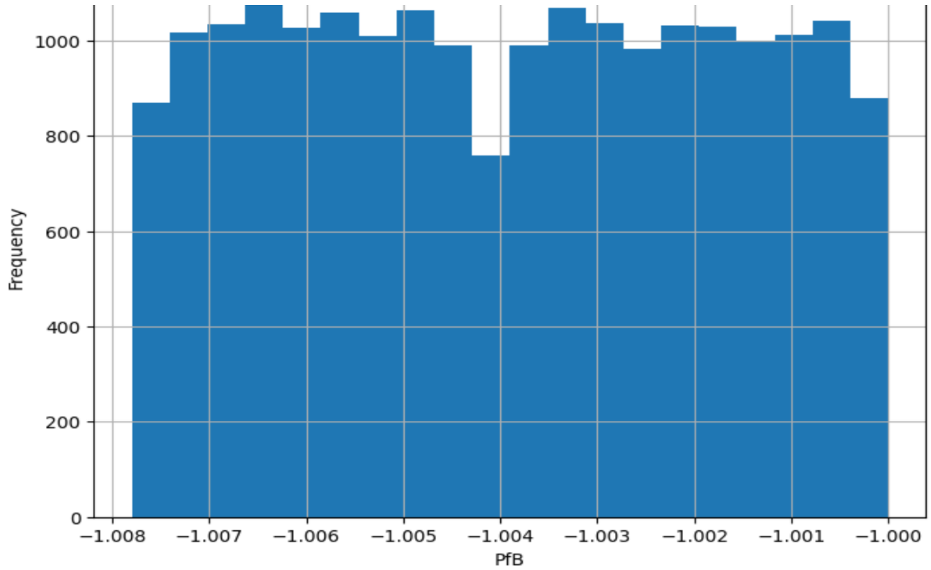


Figure 4.23 Histogram PfB

The identical characteristics observed in Power Factor B, mirroring those of Power Factor A with a symmetrical histogram shape and consistently negative values, strongly indicate a systemic issue affecting both phases. This shared anomaly suggests a common source, likely related to measuring instruments or system configuration. A comprehensive system-wide investigation is imperative to identify and rectify the root cause of this anomalous behavior. Thorough calibration of measuring instruments and a detailed review of the system configuration, particularly in voltage measurements, are essential steps to restore accuracy and reliability in power factor measurements across both Phase A and Phase B.

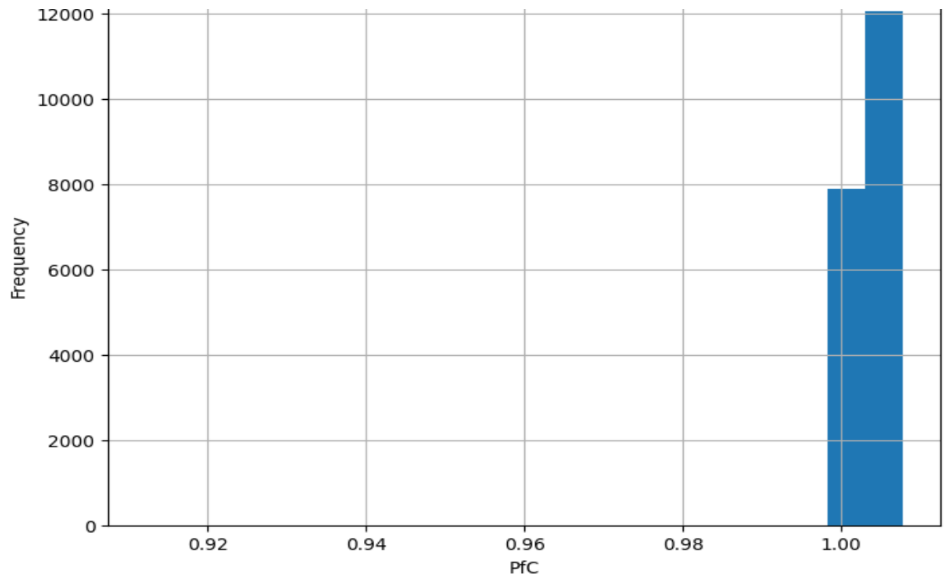


Figure 4.24 Histogram PfC

The constant power factor of 1 observed in Phase C signifies an ideal and efficient use of electrical power, where real power and apparent power are perfectly aligned. This implies stable and high-quality power delivery, contributing to optimal system performance. The contrast with the consistently negative power factors in Phases A and B underscores the need for a thorough investigation into the root causes of the anomalous behavior in those phases. While the unity power factor in Phase C is theoretically ideal, validation and verification processes are recommended to confirm the accuracy of the measurements and ensure the reliability of the entire electrical system.

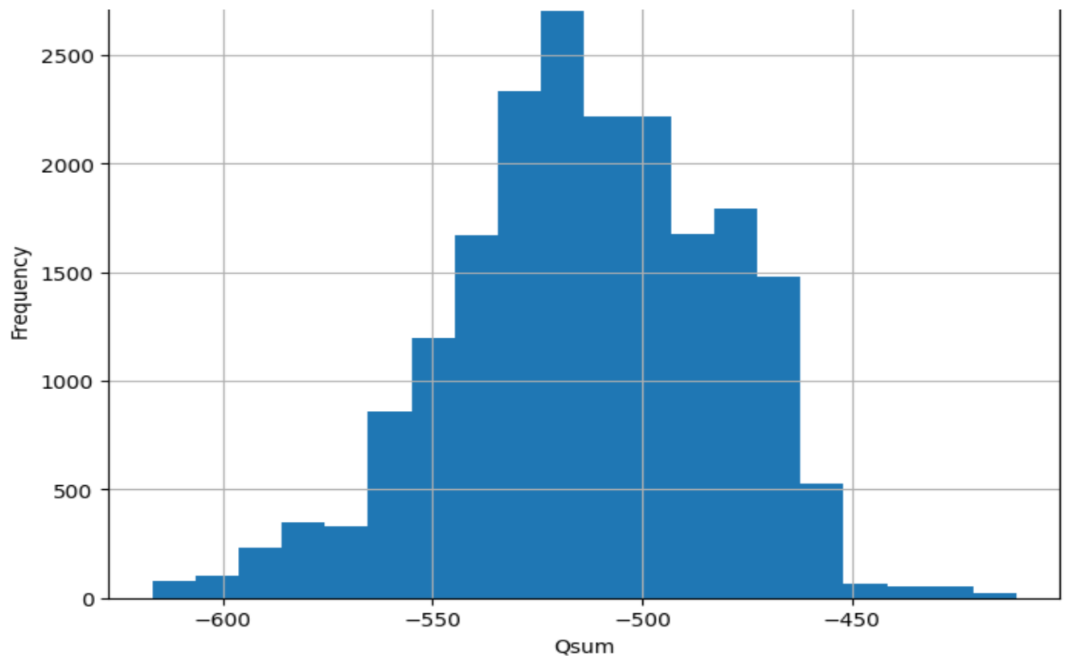


Figure 4.25 Histogram Qsum

The histogram of the vector sum of reactive powers for Phases A, B, and C, taking the shape of a normal distribution curve, implies a balanced and symmetrical distribution of the combined reactive power values. The normal distribution curve suggests that the majority of occurrences fall within a specific range, with a bell-shaped pattern indicative of a central tendency in the reactive power distribution.

In conclusion, the histogram analyses of various electrical parameters, including reactive powers, real powers, and power factors across Phases A, B, and C, have provided valuable insights into the distribution patterns and behaviors within the electrical system. The symmetrical and normal distribution shapes observed in the histograms reflect balanced and consistent characteristics in power factors and reactive powers, while anomalies in certain phases, such as consistently negative power factors in Phases A and B, highlight potential issues requiring attention.

Notably, the unity power factor observed in Phase C signifies optimal power usage and system stability. The vector sum of reactive powers, displaying a normal distribution curve, indicates a harmonious interplay of reactive powers across all phases, contributing to a well-balanced electrical system.

However, it is crucial to acknowledge that the histogram analyses, while informative, are not exhaustive in capturing the intricate relationships between specific or selected parameters. Further analysis, incorporating additional statistical methods, correlations, and possibly machine learning techniques, is necessary to delve deeper into the complex interdependencies among these parameters. This comprehensive approach will provide a more nuanced understanding of the electrical system's dynamics, helping to identify potential root causes of anomalies and optimize system performance.

In essence, while the histograms offer valuable glimpses into the overall distribution patterns, they serve as a stepping stone for more in-depth analyses, emphasizing the need for continued exploration to unveil the intricacies of the relationships among the analyzed parameters.

4.3.5 Correlation Matrix Heatmap

A correlation matrix heatmap is a visual representation illustrating the correlation coefficients between variables in a dataset. This heatmap employs color gradients to depict the strength and direction of correlations, with darker shades indicating stronger relationships. The code prompt for generating the correlation matrix was executed, and the results, depicted in the heatmap, unveil the intricate interconnections among variables, providing a visual guide for understanding their relationships within the dataset.

```
# Select only the numerical columns
numerical_data = dataset.select_dtypes(include=['int64', 'float64'])

# Calculate the correlation matrix for numerical columns
correlation_matrix = numerical_data.corr()

# Create a heatmap
sns.heatmap(correlation_matrix, annot=True, cmap='coolwarm')
plt.title('Correlation Matrix Heatmap')
plt.show()
```

In the code above, only numeric columns were included in the correlation, any other data type such as objects or strings would result in errors in the code output.

In [11]:

```
# Select only the numerical columns
numerical_data = dataset.select_dtypes(include=['int64', 'float64'])

# Calculate the correlation matrix for numerical columns
correlation_matrix = numerical_data.corr()

# Create a heatmap
sns.heatmap(correlation_matrix, annot=True, cmap='coolwarm')
plt.title('Correlation Matrix Heatmap')
plt.show()
```

Figure 4.26 Code Prompt for Correlation Matrix Heatmap

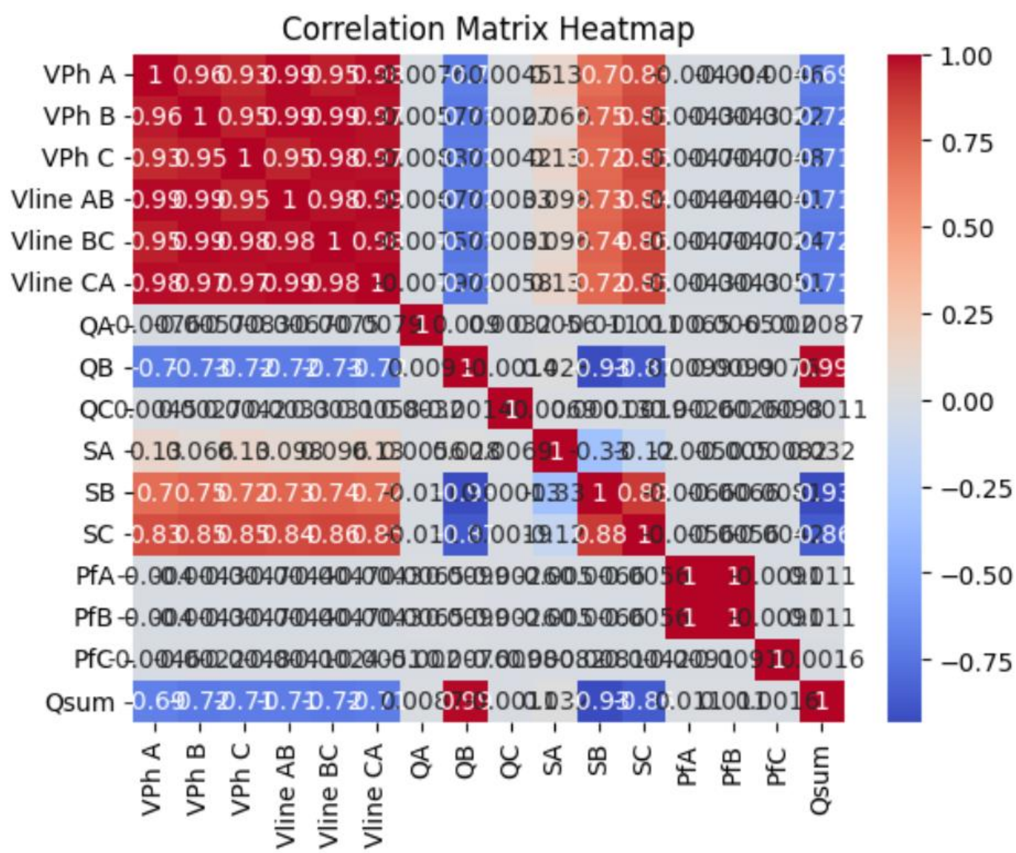


Figure 4.27 Correlation Matrix Heatmap

4.3.6 Pairplots

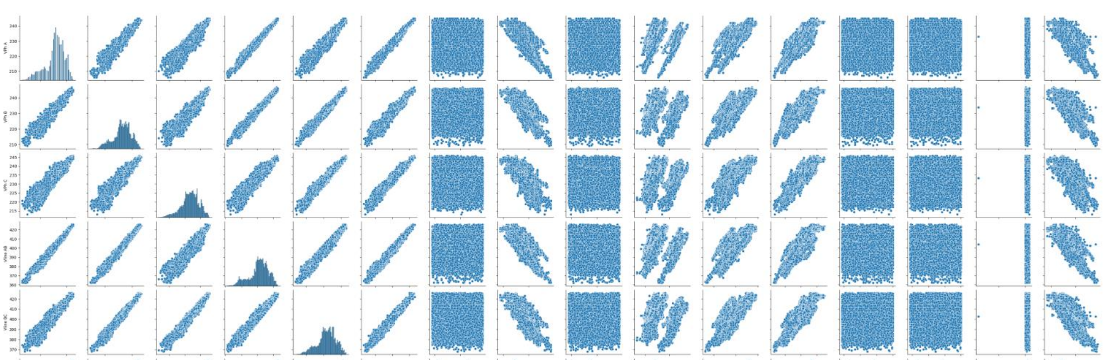
The correlation matrix presented above reveals discernible linear associations among certain parameters, such as PfA and PfB, Qsum and QB, SC and SB, Qsum and SB, Qsum and Vph B and others. Our focus is exclusively on these linear relationships identified within the dataset. We executed a pairplot to visually inspect and confirm the linearity of the identified relationships. The pairplots provided a comprehensive overview, displaying scatterplots for each pair of variables, histograms for individual variables, and correlation coefficients, aiding in further validating and interpreting the observed linear associations within the dataset. The code and output are shown in figure 4.28 below.

sns.pairplot(dataset)

plt.show()

```
In [12]:
sns.pairplot(dataset)
plt.show()
```

```
/opt/conda/lib/python3.10/site-packages/seaborn/axisgrid.py:118: UserWarning: The figure layout has changed
to tight
  self._figure.tight_layout(*args, **kwargs)
```



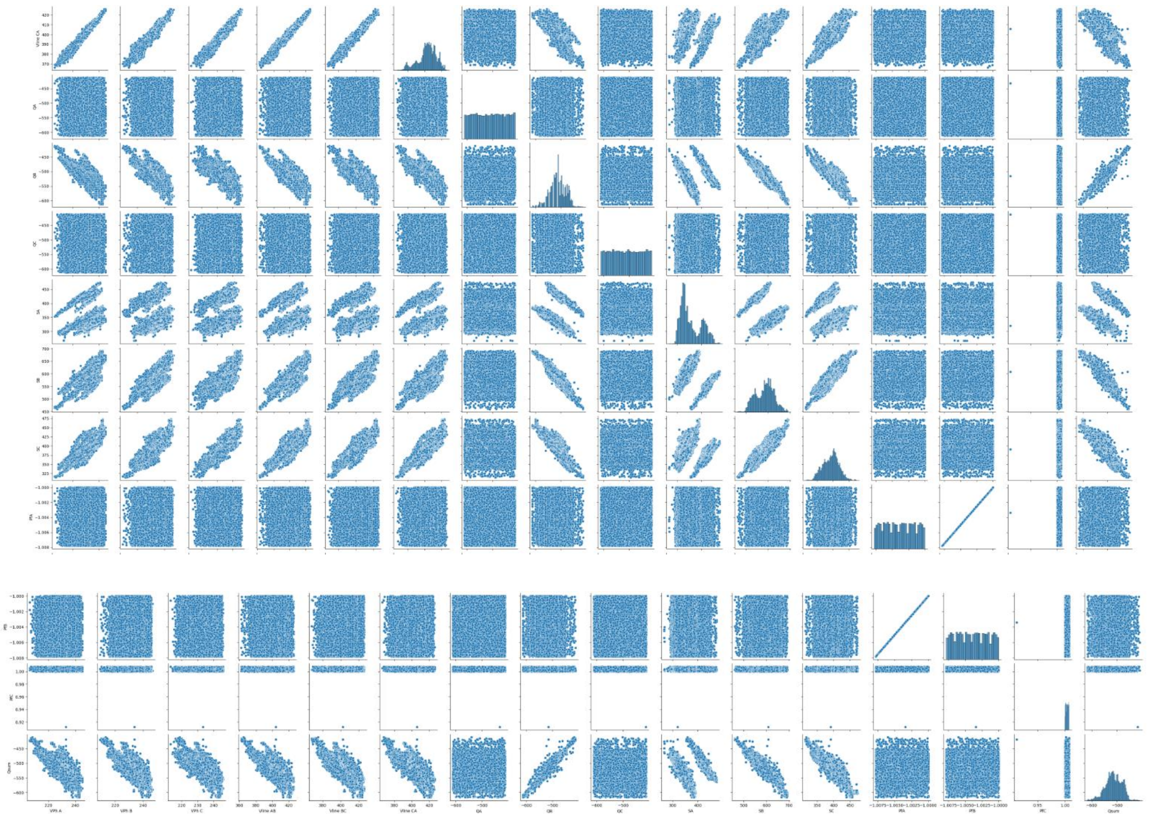


Figure 4.28 Pairplots

4.3.7 Scatter Plots

A scatter plot was also created to visually represent the nature of the linear relationships, offering insights into the direction and strength of the associations between the respective pairs of variables. The codes and results are shown in figure 4.29 to figure 4.33.

```
plt.title('Scatter Plot between Two Numeric Columns')
plt.show()
```

```
plt.title('Scatter Plot between Two Numeric Columns')
plt.show()
```

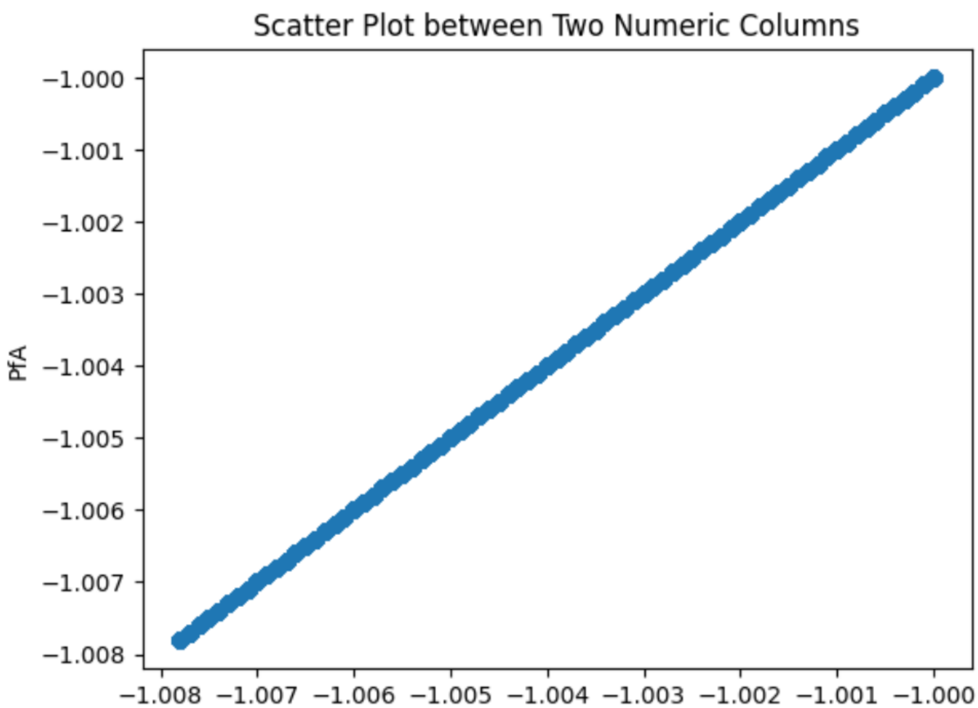


Figure 4.29 Scatter Plot for PfA against PfB

The scatter plot for PfA and PfB illustrates a distinctive pattern where the data points are arranged to form a thin, straight line ascending from the origin (0,0). This alignment indicates a strong positive linear relationship between the power factors PfA and PfB, suggesting a consistent and proportional change in values between the two variables.

```
plt.title('Scatter Plot between Two Numeric Columns')
plt.show()
```

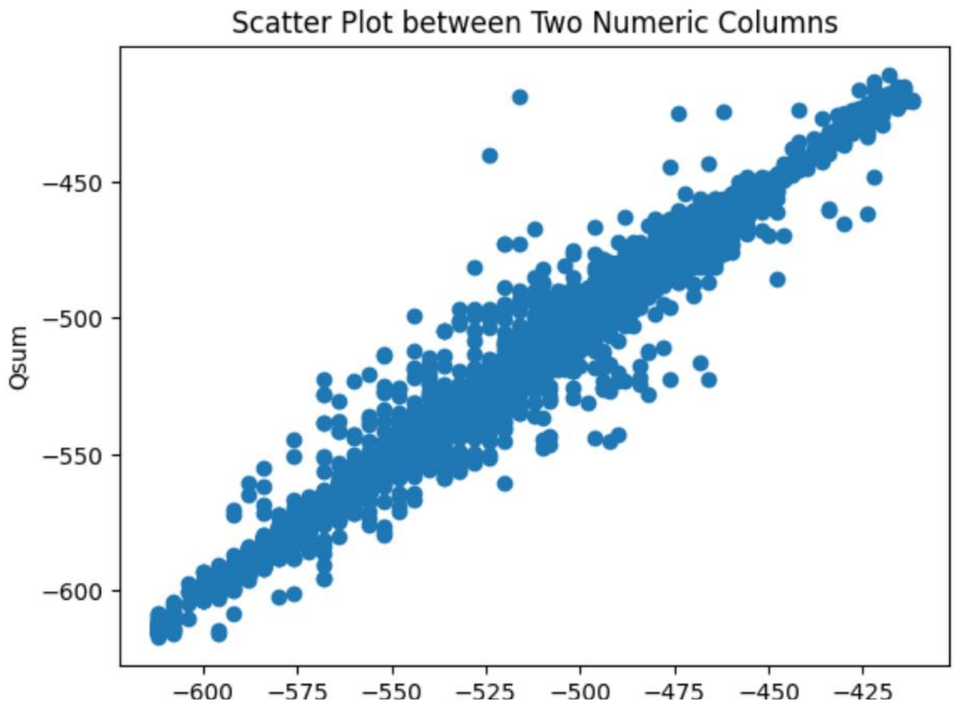


Figure 4.30 Scatter Plot for Qsum against QB

The scatter plot depicting Qsum and QB reveals a unique pattern characterized by wider dots. The majority of these dots form a cluster that ascends from the zero point, suggesting a strong positive linear relationship between Qsum and QB. Notably, there are a few outlier dots that deviate slightly from the main cluster, introducing a nuanced aspect to the relationship between these two variables.

```
plt.title('Scatter Plot between Two Numeric Columns')
plt.show()
```

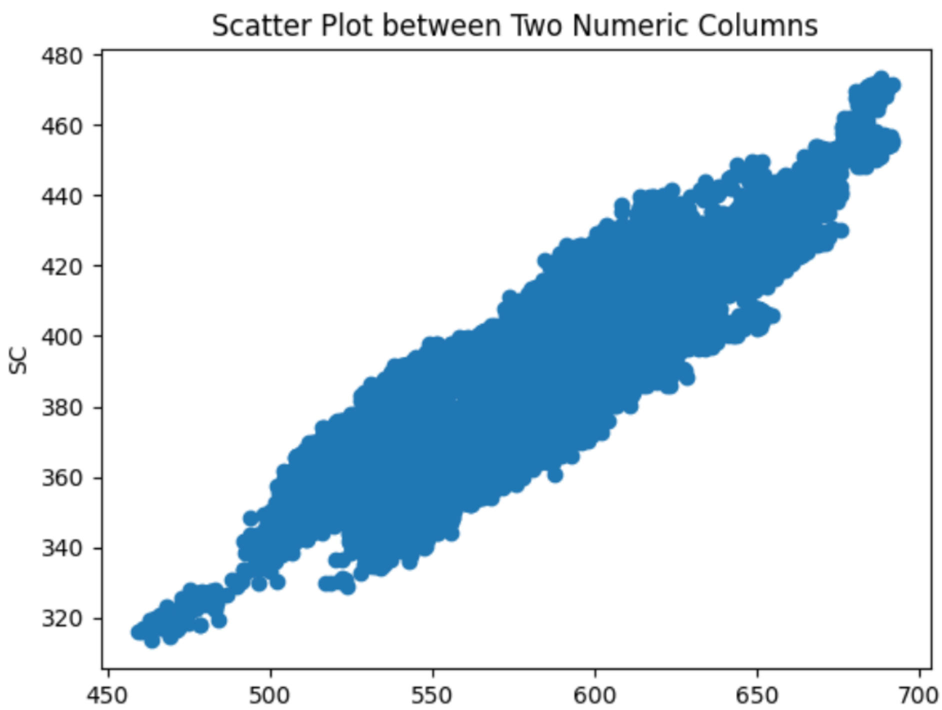


Figure 4.31 Scatter Plot for SC against SB

In the scatter plot for SC and SB, a distinctive pattern emerges with wider dots forming a cluster that ascends from the zero mark. This indicates a strong positive linear relationship between the variables SC and SB. Notably, there are no outliers present in this relationship, signifying a consistent and cohesive association between the two parameters.

```
plt.title('Scatter Plot between Two Numeric Columns')
plt.show()
```

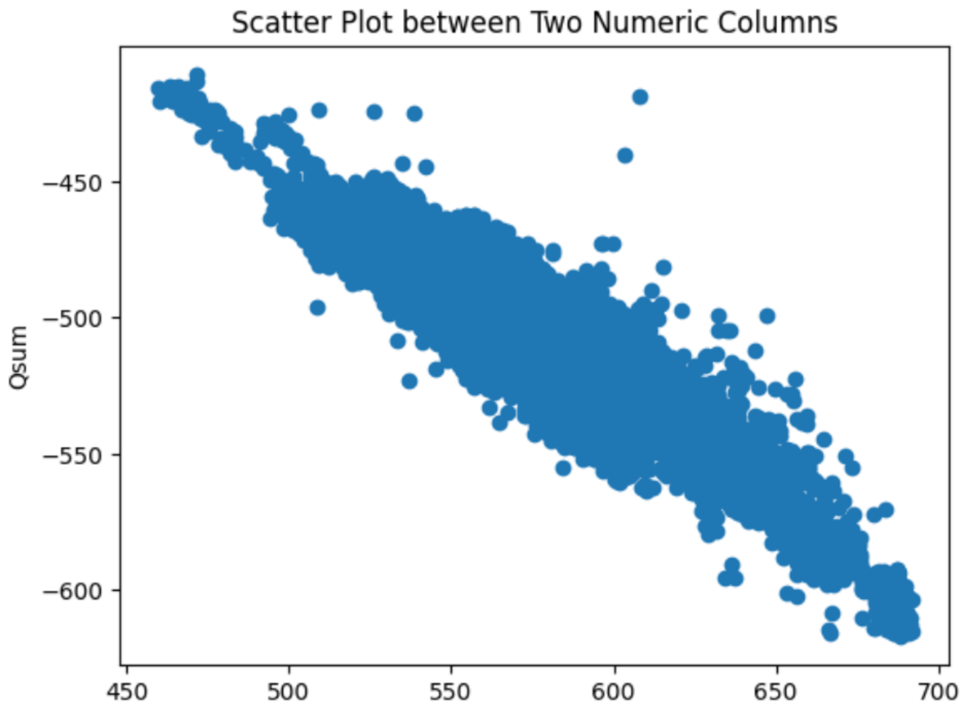


Figure 4.32 Scatter Plot for Qsum against SB

The scatter plot representing the relationship between Qsum and SB reveals a distinct pattern where the dots descend from the zero point. Additionally, the presence of numerous outliers is notable, indicating variations and deviations from the main trend in the association between Qsum and SB. This suggests a potentially complex or non-linear relationship between these two parameters.

```
plt.title('Scatter Plot between Two Numeric Columns')
plt.show()
```

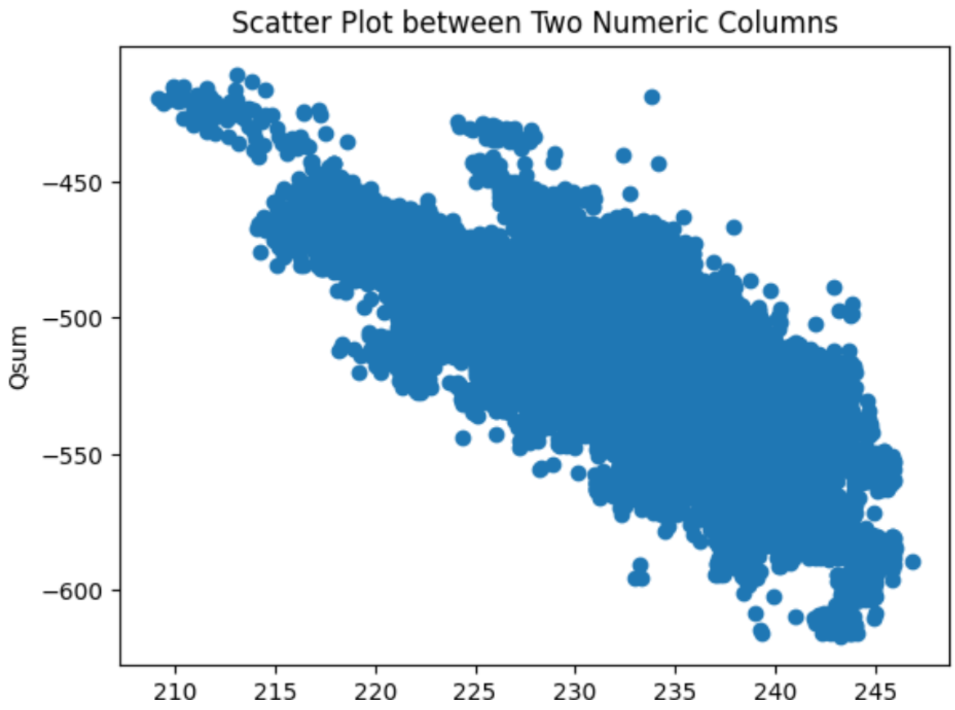


Figure 4.33 Scatter Plot for Qsum against Vph B

The scatter plot depicting the relationship between Qsum and Vph B displays a concentrated cluster of dots predominantly falling within the voltage range of 225V to 240V. While there is a general descent from the zero point, the relationship is not strictly linear, introducing some curvature to the pattern. Moreover, the presence of numerous outlier dots indicates variability and potential non-linearity in the association between Qsum and Vph B.

4.4 MODEL BUILDING AND EVALUATION

All preprocessing and data cleaning tasks have been successfully executed to ensure the dataset's integrity. Subsequently, a Linear Regression model was constructed, utilizing Qsum as the target variable and the other four variables as predictors. The model underwent evaluation, and its performance was assessed using the mean squared error metric. This comprehensive approach ensures that the dataset is prepared and the model is rigorously evaluated for its predictive capabilities. Linear regression is indispensable in this application for its ability to quantify and model relationships between variables, particularly highlighting the linear association between the target variable (Qsum) and the predictors. Through predictive modeling, interpretability of coefficients, and identification of significant predictors, linear regression provides valuable insights. The mean squared error serves as a robust metric for evaluating the model's predictive performance. Additionally, linear regression facilitates assumption testing, ensuring the reliability of results. Acting as a baseline model, it offers a transparent and interpretable framework, essential for understanding the dataset and making informed decisions in the context of the application. The code and output are shown in figure 4.34 below;

```
from sklearn.linear_model import LinearRegression
from sklearn.metrics import mean_squared_error, r2_score

#Select the columns for features and the target variable
features = dataset[['SA', 'SB', 'SC', 'QB']] # Replace with the actual feature column names
target = dataset['Qsum']  # Replace 'target_column' with the actual target column name
```

#Split the data into training and testing sets (80% training, 20% testing)

X_train, X_test, y_train, y_test = train_test_split(features, target, test_size=0.2, random_state=42)

#Create and train a linear regression model

model = LinearRegression()

model.fit(X_train, y_train)

```
In [18]:
from sklearn.linear_model import LinearRegression
from sklearn.metrics import mean_squared_error, r2_score


# Select the columns for features and the target variable
features = dataset[['SA', 'SB', 'SC', 'QB']] # Replace with the actual feature column names
target = dataset['Qsum']  # Replace 'target_column' with the actual target column name

# Split the data into training and testing sets (80% training, 20% testing)
X_train, X_test, y_train, y_test = train_test_split(features, target, test_size=0.2, random_state=42)

# Create and train a linear regression model
model = LinearRegression()
model.fit(X_train, y_train)
```

Figure 4.34 LInear Regression Model Building and Training

The dataset underwent a crucial division into two subsets, with 80% allocated as the training set and the remaining 20% designated as the test set. This partitioning strategy is integral to the model development process, allowing the model to be trained on a substantial portion of the data while preserving a distinct subset for assessing its performance on unseen data. The established linear regression model was then fitted using the training set, enabling it to learn the underlying patterns and relationships within the data. This division and training approach contribute to the model's generalization capability, ensuring its effectiveness when applied to new, unseen data in real-world scenarios.

The trained linear regression model was employed to generate predictions on the test set, and its accuracy was rigorously assessed through two key metrics: the mean squared error (MSE) and the R-squared (R^2) error value. The mean squared error gauges the average squared difference between the predicted and actual values, providing a quantitative measure of the model's precision. Simultaneously, the R-squared value offers insights into the proportion of variance in the target variable (Qsum) explained by the predictor variables, serving as an indicator of the model's explanatory power. This comprehensive evaluation ensures a thorough understanding of the model's performance and its ability to generalize to unseen data. The code and output are shown in figure 4.35 below;

```
#make predictions on the test set
y_pred = model.predict(X_test)

#Evaluate the model
mse = mean_squared_error(y_test, y_pred)
r2 = r2_score(y_test, y_pred)

#Print the evaluation metrics
```

print(f'Mean Squared Error (MSE): {mse:.2f}')

print(f'R-squared (R2): {r2:.2f}')

```
# Make predictions on the test set
y_pred = model.predict(X_test)

# Evaluate the model
mse = mean_squared_error(y_test, y_pred)
r2 = r2_score(y_test, y_pred)

# Print the evaluation metrics
print(f'Mean Squared Error (MSE): {mse:.2f}')
print(f'R-squared (R2): {r2:.2f}')
```

```
Mean Squared Error (MSE): 16.97
R-squared (R2): 0.98
```

Figure 4.35 LInear Regression Model Prediction and Evaluation

The model's mean squared error was 16.97, signifying relatively small prediction errors on average. Additionally, the R-squared score was mentioned as 0.98, indicating that approximately 98% of the variance in the target variable (Qsum) was explained by the predictor variables in the model. This high R-squared score reflects a strong fit, emphasizing the model's effectiveness in explaining and predicting variations in Qsum. Overall, these metrics, including the low mean squared error and high R-squared score, collectively convey that the linear regression model was highly accurate, demonstrating precision in predictions and substantial explanatory power.

4.5 PREDICTION

The model was employed to generate predictions for the target variable Qsum. Subsequently, a data frame was constructed to facilitate a detailed comparison between the predicted values and the original values. The outcomes of this comparative analysis are visually presented in Figure 4.36 below, offering a comprehensive view of the model's predictive performance in relation to the actual values of Qsum.

Comparison.df = pd.DataFrame({'Actual' : y_test, 'Predicted' : y_pred})

#Display the comparison of actual vs. predicted values

print(comparison_df)

```
comparison_df = pd.DataFrame({'Actual': y_test, 'Predicted': y_pred})
```

```
In [20]:
# Display the comparison of actual vs. predicted values
print(comparison_df)
```

```
         Actual   Predicted
11945 -470.3026 -473.394576
3213  -500.0703 -501.164271
18925 -530.6179 -529.705911
9565  -523.8711 -521.701152
16571 -554.3032 -549.731689
...         ...         ...
4449  -460.1964 -457.071347
7816  -499.3725 -499.629808
16645 -552.5148 -553.752318
8561  -500.4862 -501.363886
11741 -521.7057 -513.437251

[3995 rows x 2 columns]
```

Figure 4.36 Comparison Between Predicted and Actual Values

The predicted values for selected rows, as depicted, closely align with the original values, suggesting that the linear regression model is performing effectively. Notably, at the bottom of the dataframe, there are 3995 rows, accounting for 20% of the entire dataset utilized for testing purposes. This substantial volume of test data underscores the robustness of the model's evaluation and affirms its ability to generalize well to unseen observations, contributing to its overall reliability and performance.

CHAPTER FIVE

RECOMMENDATION AND CONCLUSION

5.1 CONCLUSION

This project has successfully demonstrated the capability to conduct thorough data analysis on raw data acquired from a smart meter. Leveraging Python libraries, the dataset underwent meticulous cleaning and preprocessing, ensuring its integrity and reliability for subsequent analysis. The utilization of a linear regression model facilitated accurate predictions for the target variable, Qsum, providing valuable insights into energy consumption patterns.

5.2 RELEVANCE OF THIS PROJECT

The relevance of this project extends across various domains, reflecting its potential impact on both industry practices and societal welfare:

1. **Energy Management and Efficiency**: By analyzing smart meter data and accurately predicting energy consumption patterns, this project contributes to enhancing energy efficiency, reducing wastage, and lowering carbon emissions. These efforts align with global agendas aimed at combating climate change and promoting sustainable development.

2. **Resource Optimization**: Effective energy management not only reduces costs but also optimizes resource allocation. By leveraging insights gleaned from smart meter data analysis, organizations can identify peak usage periods, allocate resources efficiently, and plan maintenance schedules effectively. This leads to improved operational efficiency and enhanced asset utilization, thereby driving economic benefits and competitive advantage.

3. Smart Cities and Infrastructure: As cities worldwide strive to become smarter and more sustainable, the integration of smart metering technologies plays a pivotal role in urban planning and infrastructure development. By analyzing energy consumption data at scale, city planners can make data-driven decisions to design more resilient and energy-efficient infrastructure, leading to enhanced quality of life for residents and sustainable urban development.

4. Consumer Empowerment: Smart meter data analysis empowers consumers by providing them with insights into their energy usage patterns and associated costs. Armed with this information, consumers can adopt more sustainable behaviors, optimize energy usage, and make informed decisions about energy consumption. This fosters a culture of environmental responsibility and contributes to broader efforts aimed at fostering a more sustainable society.

In essence, the relevance of this project lies in its potential to drive positive change across multiple fronts, including environmental sustainability, economic prosperity, urban development, consumer empowerment, and policy formulation. By harnessing the insights derived from smart meter data analysis, stakeholders can work collaboratively towards building a more resilient, efficient, and sustainable energy ecosystem for future generations.

5.3 CHALLENGES ENCOUNTERED

In the course of this project, several challenges were encountered, ranging from difficulties in configuring smart metering devices to network disruptions and measurement errors. These obstacles, while hindering seamless data acquisition and analysis, underscore the complexities inherent in managing and analyzing smart meter data. Addressing these challenges effectively is crucial for deriving accurate insights and ensuring the reliability of the project's findings.

1. Configuration of Smart Meter and IoT Gateway: Difficulties were encountered in configuring the smart meter and the 4G IoT gateway to ensure seamless communication. This required technical expertise and troubleshooting to establish a reliable connection between the devices.

2. Network Issues: Network issues occasionally disrupted the transmission of live transformer data from the meter to the cloud through the gateway. These interruptions hindered real-time data acquisition and posed challenges in ensuring continuous monitoring of energy consumption.

3. Power Failures: Instances of power failures disrupted data acquisition processes, leading to gaps in the dataset and affecting the overall quality of the acquired data. These interruptions necessitated measures to ensure data integrity and consistency despite intermittent power supply.

4. Measurement Errors: Some errors in measurement resulted in zero values in certain fields due to malfunctioning in the meter's performance. These inaccuracies introduced noise and inconsistencies in the dataset, requiring thorough data validation and cleaning processes to mitigate their impact on subsequent analysis.

5.4 RECOMMENDATIONS FOR FUTURE RESEARCH

Certain recommendations emerged from the challenges encountered during the project. These include:

1. Technical Expertise: Investing in training and acquiring technical expertise to effectively configure and troubleshoot smart metering systems and IoT devices, ensuring seamless communication and data transmission.

2. Redundancy Measures: Implementing redundancy measures such as backup power systems or alternative communication channels to mitigate the impact of network issues and power failures on data acquisition.

3. Continuous Monitoring: Establishing robust monitoring mechanisms to detect and address measurement errors promptly, ensuring data integrity and accuracy throughout the data collection process.

By adopting these recommendations, future projects can enhance data quality, streamline analysis processes, and ultimately derive more robust and reliable insights from smart meter data.

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APPENDICES

Appendix 1

Features of SDE430-C three phase power analyzer

- Measuring: 30 parameters on AC electrical network
    - AL1, AL2, AL3(current senses), VL1, VL2, VL3, VL1-2, VL2-3, VL3-1, Fr
    - PL1, PL2, PL3, PL, QL1, QL2, QL, SL1, SL2, SL3, SL, PF1, PF2, PF3, PF
    - Imp & exp kWh,L & C kvarh

- Display: With 8 digits LCD, display range 000000.00~99999999 kWh;
    - Keep kWh value without power;
    - Dot will move according to energy value to 8 integer digits;

- Dimension: 4 modules (72 x 89 x 74mm)

- Current Input:

    - SDE430-C: split core CT (option 5A, 20A, 40A, 60A, 100A, 200A, 400A, 600A);
    - SDE430-R: rogowsi coil (option 200,600A, 1kA, 2kA, 4kA, 6A);
    - (5A split core CT is applied on the secondary cable of the original 5A CT);

- Line & voltage input:
    - 3P4L (3 x 57.7/100V, 3 x 127/220V, 3 x 230V/400V, 3 x 240/415V)
    - 3P3L (3 x 100V, 3 x 220V, 3 x 380V)

- Power supply: Default auxiliary power supply AC/DC85~265V;
    - Optional DC5V/12V/24V/48V

- Communication: With 2 cables isolated RS485 interface up to 38200bps (Def. Modbus-RTU protocol)

- Pulse: kWh impulse output (comply DIN43864);
- Relay output: Optional 1 relay output as remote switch or as alarm code

- Mounting: 35mm standard DIN rail installation

- Software: With free testing software, to easily read its data and set its parameters by computers

- Secondary Develop: provide DLL dynamic library and C# example, to develop your own software;

Appendix 2

Features of Spark Electro XHD331-R Smart Meter

- Input voltage: L-N voltage: 57.5-380V; L-L voltage: 100V-600V
  - Primary voltage: 10V-660V (It is required to be converted to secondary voltage through a voltage transformer and then be connected to the meter)
  - Secondary voltage: 100V/200V/380V
  - Auxiliary power supply AC or DC 85V-265V

- Input current: Primary current: 5A-9999A
  - Secondary input voitage:0.333Vac
  - Short time over-current: 20 times maximum current lasts 0.5 seconds

- Input frequency: Rated value: 50/60Hz

- Withstanding voltage capacity : AC withstanding voltage: 4KV/1min

- Power consumption: 2W
- Communication: Modbus RTU/M-bus
- Pulse output: 1active pulse, 1 reactive pulse, fixed pulse constant is 3200imp/kWh
- Maximum reading: 999999.99MWh/MVar.

Appendix 3

Specifications of RS Pro Current Transformer

- Primary current 5A to 7500A
- Secondary current 1A or 5A
- Accuracy class 1
- Over current limiting factor FS5, FS10, FS15
- Rated frequency 50Hz or 60Hz
- Rated continuous thermal current (standard) 1,2 x in
- Rated short time thermal current with 60 x in, 1 s (Max 40kA)
- Rated isolation level 0.72/3 kV or 0.72/4 kV
- Altitude up to 2000 m

- Degree of protection IP20
- Degree of pollution 2
- Ambient temperature -5°C to + 55°C (0-95% relative humidity, non condensing)
- Storage temperature -25°C to + 70°C
- Applied standards IEC 60044-1 / IEC 61869-1 : Performance,
- IEC - 61010 - 2 : Safety.

Appendix 4

Features of RS 150 Current Transformer

- Power supply: 12-30VDC
- Frequency: 50-60Hz
- Input current: 150A
- Current Ratio: 150:5

Appendix 5

Features of SGX 5150 IoT GATEWAY

Figure 2.12: SGX 5150 Models

Wireless Specifications

- 4G/5G Wi-Fi (IEE 802.11ac)
  - 1 x1 ac (MCS0 – MCS7)
  - 20, 40 and 80MHz Channels with optional SGI

- Advanced 802.11n/ac Features
  - Transit Beamforming
  - Tx/Rx LDPC
  - Rx space time block coding (STBC)

- Bluetooth/WLAN Coexistence
- Compatible with IWW 802.11a/b/g and support IEEE 802.11 d/h/j/i
- Dual band 2.4 GHz and GHz
  - 412 GHz- 2.484 GHz- Channels 1-14
  - U-NII-1 (5.15-5.25GHz) Channels 36,40,44,48
  - U-NII-2 (5.25-5.35GHz) Channels 52, 56, 60, 64
  - U-NII-2e (5.47-5.725GHz) Channels 100- 140

Ethernet Specifications

- IEEE 802.3 MAC and PHY, 10baseT and 100BAseT
- 3at Class 2 Powered device

USB Specifications

- USB device (default setting) powered by a VBUS 5V
- Configurable USB 2.) HS/FS port with USB type C

Protocols

- DHCP client, DHCP server, DHCPv6 Client

- IPv4/Ipv6, TCP, UDP, ICMP, ARP, Auto-IP, DNS, SNMP v2/v3
- uPnP, LCAP(77FE), Telnet, (S) FTP, HTTP(S)

Wireless Specifications

- Soft access point
- Wi-Fi Direct
- Multiple soft AP connections
- Secure Com port Redirector

Power Specifications

- Input: DC barrel, 9-30 VDC (standard)
- Input: Power over Ethernet (optional)
- Input: USB Type C I/O connector
- Power Consumption = 1.9W typical without USB Load
- Power Consumption = 5.5W max with USB

Physical Dimensions

- Dimensions: 10.8 cm (4.3 in) x 7.2 cm (2.8 in) x 3.3 cm (1.3 in)

Appendix 6

Features of CWT-L IoT Gateway

Wireless network communication

- TCP/IP connect at most 4 servers (support Static IP address or domain) Events (e.g. alarm, timer) trigger upload data
- Communication protocol: Modbus TCP http post, Cwt_IO(two way communication)
- Support two way data transparent transmission between RS485 to server

SMS Communication

- Short message service (sms) alarm when value out of preset normal range
- Editable alarm and recover sms with time stamp

- Query status or value via sms command
- sms report status or value on schedule
- Remote setting via sms commands
- Can query SIM card balance, sms forward
- Support power lost sms alarm and recover sms(works with inside battery)

System features:

- Reliable performance with built in double watchdog, 24×7 operation
- With signal filtering mechanisms
- Network reconnect and retransmission to ensure data accurately transmit
- Update RTC automatically or manually, clock source support sms, NTP, CwtIO Server
- Can set multiple timers(second, minute, day, week, month) to upload data
- Provide configure software, visual programming
- Optional inside battery that life is 8 20 hours, cellular module Intelligent sleep when power lost

Appendix 7

OPEN SOURCE LINK FOR THE MANUAL OF SGX 5150 AND CWT-L IoT GATEWAY

https://drive.google.com/drive/folders/1CRNfSWx4fW_urvE5dJuJKQq-HzaFoCga