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COLLEGE OF SCIENCE AND TECHNOLOGY

African Center of Excellence in Internet of Things (ACEIoT)

IOT BASED NET METERING MONITORING SYSTEM

Master's Thesis

Submitted in partial fulfilment of the requirements for the award of

MASTER OF SCIENCE IN INTERNET OF THINGS-

WIRELESS INTELLIGENT SENSOR NETWORKING

(MSc in IoT-WISENET)

Submitted by

Asaph MUGABO - Reg. No. 220015226

January 2022

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Under the supervision of

Dr. Charles KABIRI

Dr. James RWIGEMA

January 2022

DECLARATION

I, Asaph MUGABO, herewith state that this thesis report is my original work and has not been submitted before for any academic award in either University of Rwanda or other higher learning institutions for academic publication or any other purpose.

Asaph MUGABO

January 2022

BONAFIDE CERTIFICATE

This is to indorse that the thesis report titled "IOT BASED NET METERING MONITORING SYSTEM" is the genuine work of Asaph MUGABO registered to 220015226 in partial fulfilment of the requirement for the award of a Master degree in Internet of Things - Wireless Intelligent Sensor Networking (MSc in IoT-WISeNet) from College of Science and Technology at University of Rwanda.

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Dr. James RWIGEMA

Signature: ……………   Date:……………………

DEDICATION

I dedicate this Thesis to my wife Winnie and my children Gianna and Garvin without whom this work would not have been possible.

To my late Uncle, may your soul rest in peace

ACKNOWLEDGEMENT

I am deeply indebted to my supervisors for their continued support and encouragement: Dr. Charles KABIRI the main supervisor and Dr. James RWIGEMA the co-supervisor. I would like to express my gratitude and appreciation to the management of the African Centre of Excellence in Internet of Things that provided with me the opportunity to pursue my masters. I also acknowledge that my completion of this project could not have been easy without the support of my classmates, in the cohort two of IoT-WISENET.

Lastly, to my beloved wife. Thank you for your words of encouragement and strength that inspired me to move on when times were not easy.

ABSTRACT

The rapid increase of the interest for renewable green energy has led energy industry and environmental groups to invest in net metering. This interest in driven by the simplicity in the management of net metering and the low cost that encourage the investment in renewable energy technologies**.** PV solar energy producers currently rely on utility company meters to find out how much energy they consume and how much energy they export to the grid and the billing depends on utility companies. However, by using internet of things, utility customers are able to record the real time data of their energy production, consumption and what they export to the grid. There is a need for the IoT based monitoring system for both utilities and customers where data collection on electricity consumed by the customer and electricity exported to the grid is required. This study proposes an IoT Based Net Metering monitoring system that will enable the PV Solar energy customers to be able to monitor how much energy they produce, how much they consume and how much they export to the grid. Real time data analysis will allow them make future decisions.

Key words*: IoT, Net meter monitoring, Smart Energy, Energy management*

LIST OF ACRONYMS

AC: Alternate Current

ACEIoT: African Centre of Excellence in Internet of Things

CT: Current Transformer

DC: Direct Current

GPRS: General Packet Radio Service

GSM: Global System for Mobile

IDE: Integrated Development Environment

IoT: Internet of Things

LAN: Local Area Network

LCD: Liquid Crystal Display

LED: Light Emitting Diode

MSC: Master of Science

NMMS: Net Metering Monitoring System

PV: Photovoltaic

REG No: Registration Number

RFID: Radio Frequency Identifier

USB: Universal Serial Bus

UTP: Unshielded twisted pair

WISENET: Wireless Intelligent Sensor Networking

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CHAPTER 1: INTRODUCTION

1.1 Introduction

The energy produced by the sunlight in 1 hour is believed to be more than the energy we use in the entire year. The world’s focus is to produce the carbon free energy and this therefore puts the attention toward solar electricity and photovoltaic technology for sustainable energy production.

In 2019 the solar electricity market was estimated at 10 billion US Dollars per year and this increases at a rate of 30% annually [1] .However, there are challenges associated with solar energy production and usage.

Many solar energy customers mostly produce more electricity than they consume; This becomes a challenge for them and may lead to wastage of this clean energy.Net metering allows Solar energy producers to export their excess production to the grid. This enables them to reduce on their electricity bills and sometimes generate income.

Net metering minimizes losses in long-distance electricity distribution and transmission.it also eases the distribution strain on utility companies. The customers of net metering only pay for the difference in the amount of electricity produced and consumed for billing [2].

Many solar energy users do not monitor the quantity of power they generate and the power they consume. With net metering technologies they are able to make income from their generation or at least reduce the costs on power usage. The introduction of Internet of things in energy industry will address these issues. Energy monitoring system like the one proposed in [3][4] only focuses on monitoring the energy consumption and design of smart meters but no emphasis on monitoring the solar energy production. IoT based Net metering monitoring system will monitor both the production and consumption of energy by the users.

By using Internet of Things based net metering monitoring system the inability by the customers to know the energy they produce, the energy they consume and the energy they send back to the grid is addressed. Utility companies also need to collect and analyze this data for proper planning. PV solar panels, current sensors, voltage sensors, Arduino UNO microcontroller, GSM module and data analytics technologies will be used to provide the real time data required for monitoring the energy production and consumption trends. The system is different from the existing solutions as it combines both the production and consumption energy monitoring.

The rest of the document is organized as follows; in the next sections a Literature review is presented, this is followed by the research methods and tools in section III, System Analysis and design is outlined in section IV, in section V the Results & Analysis are shown, and there after a Conclusion drawn and Recommendation given.

1.2 The scope of the research

The scope of the research is to design and develop a prototype system that will monitor the energy production from solar PV system, monitor energy consumption by the customer home appliances and monitor the excess power exported to the grid. The data collected will be recorded through cloud platform that will enable both the customer and the utility company to make better future decisions and actions.

1.3 Problem statement

Many solar panel users who have the right size solar energy system can generate more electricity than they use. When this happens, net metering allows these users to export their excess energy back to the grid. However, there is no IoT based smart system in place that helps such solar energy customers know the accurate data on how much energy they produce from their solar system, how much energy they consume, how much energy they fetch from the grid and how much energy they export to the grid. PV Solar energy producers only depend on the utility company meters to know the energy they consume and the energy they export to the grid. This does not provide the actual data on the energy produced by customers and does not provide to the consumers the actual records of their consumption and production behavior so that they decide on the future trends. IoT based solutions to address the problem were proposed [5][6] but they do not provide a solution that combines the production and consumption monitoring.

IoT Based Net Metering Monitoring System will address the problem where by customers will be able to monitor the solar energy production, consumption and how much they export to the grid. The real time recorded data will allow the customers make the right future plans on the production and consumption behavior.

1.4 General objectives

The objective of this project to design and develop an IoT based Net metering monitoring system that will help both the utility companies and their customers who also have secondary source of energy in PV solar energy to be able to have a smart way of managing their resources.

1.5. Specific objectives

1. To monitor the energy generated by Solar system using Internet of Things
2. To monitor the energy consumption by users using Internet of Things
3. Data analysis and visualization of a net metering monitoring system

1.6 Significance of the study

The system will contribute to proper management between the involved parties where the data collected will categorize the contribution of each party. Energy efficiency is vital for the environment and global sustainability. IoT based net metering monitoring system will also encourage many electricity users to step up the generation of energy through installation of solar system which in the end will lead to green energy. Companies who deal in solar business can also benefit from customers acquiring solar systems. The collected data will enable the utility companies to make better future energy plans.

1.7 Output

When the IoT based net metering monitoring system is introduced it will encourage people to use solar system to generate electricity and through this, expenses on electricity will be minimal, some income will be generated through Net metering and most importantly this will ensure green energy since by generating electricity using solar system the environment is protected as the methods used for energy generation are environment friendly. The better data collection and analysis will lead to efficient energy management.

1.8 Impact

IoT based net metering monitoring system will have a huge impact on energy industry through easy and efficient energy management, where satisfaction by different parties will result in many customers become prosumers where they will consume and produce electricity at the same time. Other sources of energy especially solar system which will have a significant impact on the environment since solar energy is the better option for green energy. The system will also have an impact on the monthly electricity bills whereby generating solar energy consumers pay less to the utilities company and sometimes makes profits.

CHAPTER2: LITERATURE REVIEW

2.1 Net Metering

Net metering system credits owners for their power addition to the grid. When they produce more than what they consume, the excess power is added to the grid. This process benefits the owners of solar system to gain income through selling the energy they generate.Net metering compensates the owners for the green energy they add to the grid.

This encourages the many users of renewable energy. With the use of green energy electricity bills are reduced. Meters that measure generation of solar panels are used and the measurement is based on annual consumption [7].

2.2 IoT in Energy Monitoring

IoT Energy Monitoring System[3] implements a cheap monitoring system used in electricity bills system management of smart grids and automated homes. A PZEM-004T, CT sensors, SD3004 and ESP8266 microcontroller are used. Data is sent to the server through internet.

IoT-based ad hoc networks [8] monitors energy and categorize different energy monitoring approaches. The overview of enablers like sensors and handheld devices including its practical nature and issues of performance is analyzed.

IoT enabled device for Monitoring Electrical Energy Consumption [9] presents a developed device to monitor how a building consumes electrical energy. It uses modules including PZEM-004T, electrical sensors, Arduino Nano microcontroller and ESP8266.

The IoT based Electrical Energy Consumption Monitoring System [10] , utilizes current and voltage sensors for real-time measurement of the energy consumption. Web based system displays the processed data.

Using IoT to monitor energy consumption and provide alerts [11] collects data for home energy consumption and send data to cloud using Ubidots cloud services .IoT framework was implemented for monitoring the energy consumption.

The application that uses IoT to monitor power consumption [12] monitors home appliances electricity consumption by using the Wi-Fi enabled device that also helps to analyze the consumption on a daily and weekly basis.

These researchers worked on different IoT energy monitoring systems but none has combined monitoring energy generation, consumption and data analysis.

2.3 Net Metering monitoring solutions

IoT Based Smart Energy Metering System [4] propose a system that a consumer uses to monitor time to time usage of energy. Cloud services are used to update data by using internet.

IoT Based Smart Energy Meter [13] has a system that allows electricity suppliers be able to know meter readings without the need to be physically on the meter readings.

IOT Based Smart Energy Monitoring project [14] allows a consumer manage timely the energy usage. Another project on IoT Based Smart Meter [5] uses IoT ,Arduino and Wi-Fi module to access internet for notification.

A control system and monitoring of energy using IoT [6] allows the access of the energy meter remotely. A microcontroller based bidirectional meter is designed and developed [15] to monitor energy in both directions.

Different projects on smart energy meters were introduced but no specific project focused on net metering.

A Review on Solar-Net metering [16] defines net metering as an integrated application of renewable resources worldwide.it presents the detailed net meter architecture.PV solar system using net metering [17] does the financial analysis of the solar pv system on rooftop using net metering scheme. Energy production estimation [18] focuses on the arrangement of the net metering circuit .RET Screen Expert and PVWatts software tools are used.

The analysis on net metering is introduced both in production and financial but the contribution of the consumer is not highlighted.

Big data analytics, IoT and management system are used for the management of energy in smart homes [19] .It applies data acquisition modules and the interfaces between the ip address that produce devices that are networked wirelessly.

The research focused on only energy management in home consumption but no work was done on the management of energy generation by the consumers using PV Solar systems.

The analysis of data collected from different parts of the grid [20] is achieved by using IoT based machine to machine architecture and IoT based metering infrastructure. Smart grid is used to acquire and analyze data which are gathered from different parts of power grid.

The research analyzed the introduction of IoT in the grid, however no smart analysis was made on energy consumption by the users of the electricity form smart grid.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Methodology

IoT Based Net Metering Monitoring System will use PV solar panels for electricity generation from the sunlight, voltage and current sensors will be used to monitor the produced energy. Pzem-004T module will be used to monitor the energy consumption. Arduino microcontroller will be used to read the data from the sensors.

The system will be used to monitor solar electricity produced, electricity, energy consumption by appliances and the excess will be sent to the grid. Data information from devices will be sent to the gateway and by using GSM-SIM900A communication data is sent to the cloud for analytics and report generation.

The proposed research plan involves gathering all required knowledge and information on IoT based Net metering monitoring system, that is requirement gathering, acquire all IoT devices that are essential to the system. Prototype design for the system will be done, data collection and implementation will be performed. IoT Platforms will be used for real time data analytics and visualization.

3.2 Net metering

Net metering system allows owners of the solar energy production to export the excess electricity they generate to the grid. This process generates income for the users through selling their excess electricity.

3.2.1 How net metering works

The PV solar panels convert the energy from the sun to electricity. Inverter converts the solar electricity from DC to AC for use in homes or business, the converted energy is consumed in home appliances or offices.Net meter measures the consumed energy and the excess energy from solar panels that is not used goes back to the grid.

Net metering eases pressure on the grid shortfalls by adding the power from other sources.it also provides the opportunity to find solutions for renewable energy.

3.2.2 Benefits of Net metering

Net metering has many benefits that include;

- Encourages customers to move towards renewable energy
- Benefit for the environment
- Preserves natural energy resources
- Encourages energy independence
- Awareness on power consumption will be increased
- Reduced electricity bills
- No need to install expensive battery storage system
- Take some pressure off electric grids

3.3 Architectural System

The architecture of a system is a high-level description of the entire system that explains the required architecture elements and their services as well as the principles that the elements shall maintain while communicating and working together [21].

IoT is well-rooted to embedded systems as well as several technologies like pervasive systems and sensor networks. IoT is a system where the “things” used as an individual or as a group are connected via a network (over Internet protocol) to collaborate and perform some tasks while interacting with the digital and physical world [21].

To design the IoT Based Net Metering Monitoring System, the IoT architecture model was adopted.

3.3.1 IoT architecture

The development of a complete IoT system and service includes several components. A key aspect of the IoT Architecture is the data sampling [21], which can be:

Periodic sampling: based on digital signal processing and control with time-series data. Power is needed for sensing and communication; while wireless communication requires large amounts of power. Bandwidth demand is high since data from the sensor has to be communicated at every k^{th} period, regardless of the data quality.

Aperiodic sampling: based on event; hence useful to relax the resource (e.g. power and bandwidth) constraints. Sampling here refers to the acquisition of data from the environment which reflects a certain state that is relevant for the system (input), e.g., temperature, motion, speed, etc.

Important considerations in IoT development may include power and bandwidth constraints, as well as data validation and verification: Is the data valid to be sent? (What is the relevance of reporting the same value at every k^{th} period if the value is not changing)? Is the data coming from the right source?

The data captured at the sensor might need filtering, and need to be pre-processed before sending it for use (application).

Since the application of IoT is not limited to a particular domain, the complexity and requirements also vary across various systems. In some applications, it may need to monitor the various remotely deployed devices and also make use of cloud computing, while for some applications this only sensing and actuation are enough [21]. For example, an IoT system meant to control home appliances in a smart-house may not have the same requirements as a smart irrigation system that make use of weather information processing (using cloud service).

IoT requirements can be broadly classified to [21];

- Perception: collecting data from the physical world with less or no intervention of the user, hence various sensors are used.
- Pre-processing: collected data can be pre-processed before relayed over a network; this also includes data filtering.
- Communication: different entities, the “things” need to accomplish the task, need to communicate using various protocols and standards.
- Application: the data collected and communicated ultimately need to be processed to meet the end-user (business/individual user) needs while improving the user experience. This may include taking action with less or no intervention by the user, hence actuators can be used.
- Monitoring: it is important to monitor the environment and resource (a scarce resource).

These requirements can be addressed if architectural elements are delivering the respective service, and the architecture of IoT systems may vary across the application domain.

Though no particular consensus on the architecture, the layered approach has become predominant in IoT, particularly three-layered or five-layered.

Table 1: Generic system requirements in IoT

Feature	**Description**
Flexibility	The system should ensure its services components and services reusability and composability
Compatibility	Integrate numerous information from several devices and protocols in an easy way
Responsiveness	Respond and/or allow rearrange IoT platform components.
Security	Take security measurement of IoT system
Privacy	Allow access to personal information to only authorized users.
Service-Oriented	Offered services in front.

Table 2: Generic user requirements in IoT

Goal	**Description**
Usability	User friendly
User experience	Enjoyable to use
Personalisation	Allow customisation
Unobtrusiveness	Not remarkable
Minimum user input	Minimum possible inputs from the user

3.3.1.1 Three-layered model

This architecture organizes the services needed to meet the requirement into three levels [21].

- Perception Layer: Responsible for delivering application-specific service.
- Network Layer: Responsible for connectivity and processing the raw data captured from sensors in such a way it is meant for use.

- Application Layer: Capturing information from the environment. Predominantly sensors are used to sense and gather information from the physical environment.

1. **Perception Layer**

Any computing is about collecting data (input), processing, and delivering information for further processing or action (output). But how the data collection, processing, and actuating the action might vary across technologies and computing principles [21].

Data can be collected explicitly as user input or implicitly by observing the environment (physical environment, user environment, and/or the digital environment). In IoT, sensors are widely used to collect data from the physical environment, human or digital.

Sensors (electrical sensors) are key players at the perception layer, they are the bridge between the physical world and the digital world. The phenomena in the physical world, which is made of atoms, are in the form of physical variable and is based on analog signals. Whereas, the computing world demands information to be digital. Sensors bridge this gap as they are devices that convert a physical variable into an electrical signal [21] . For example, even a speaker can be called a transducer as it converts the electrical signal to pressure waves (sound).

A wide range of variables can be perceived from the environment for digital processing (temperature, humidity, soil moisture, light intensity, sound, pressure, wind (speed, direction), position, proximity, displacement, acceleration, orientation, heath, smoke, motion, vibration, RF, water (level, flow, quality, turbidity, PH, pollution, particulates), gas, radioactivity, etc.).

2. **Network Layer**

Stimuli from the environment can be received by the sensor and will be converted into digital information, however, this information has to be interpreted in such a way it is meaningful to the desired application. The information (often after interpretation) shall be communicated for decision making and/or further processing [21]. In the three-layered model, the network layer is mainly responsible to connect the "things" and process the data captured from the sensor and communicate the data to the upper layer.

3. **Application Layer**

The data after captured and interpreted in the context of the user can be then used to make a decision and/or as input for further processing, and this is done at the application layer [21].

For instance, in the ultrasonic, the calculated distance may require actuation on a vehicle brake system.

3.3.1.2 Five layered architecture

In the five-layered model, the services provided at the network layer of the three-layered model split into two layers – the Transport Layer and Processing Layer. Also, a Business Layer is newly added as management would become important when the IoT system becomes wider and complicated [21].

1. **Transport Layer**

This layer transport data from the perception layer to the application layer. Various wireless and/or wired mediums could be used such as UTP-LAN, Bluetooth, RFID, Wi-Fi, NFC, etc [21].

2. **Processing Layer**

Data processing as per the user (system) requirements is done at this layer. The processing may employ various storage and computing models and technologies; such as cloud computing, web services, big data, database systems, etc [21].

3. **Business Layer**

As the IoT system becomes complex, management will become an important aspect to consider. All four layers focus on responsibilities to meet the functional requirements

- Perception layer – data input
- Processing layer – does the processing
- Application layer – information output as specific service
- Transport layer – connecting and three layers to relay data between the layers

The management on the other hand handles the non-functional requirements aspect to assure the proper delivery of the functional requirements. Therefore, the business layer is responsible for managing applications, remotely devices (e.g., does the device function properly), business and process models, and privacy and security [21].

The processing segment may include various processing strategies such as distributed or centralized. Cloud computing has become one important platform to support processing demands in IoT, especially when the processing comes to large and complex data processing.

This often demands to follow a client-server model where the clients are thin-client. However, the system requirement might demand faster processing and response time. In such case, additional layers could be required to do additional processing, storage, and monitoring; and also, to maintain security [21].

The additional layers, while creating fat-client or servers at the edge of networks, they also lead to the Fog Computing model. Monitoring and pre-processing are done at the gateway level on the edge of the network before the data is sent to the cloud. These layers come between the transport and the perception (physical) layers [21].

Security Layer: Performs encryption/decryption and ensures data integrity and privacy.

Temporary Storage Layer: Provides storage functionalities such as data replication, distribution, and caching.

Pre-processing Layer: Performs data filtering, processing, and analytics over sensor data.

Monitoring Layer: Monitors power, resources, responses, and services.

3.4 IOT based net metering monitoring system three layered architecture

From the above perspective of IoT architecture, the IoT based Net Metering Monitoring System (NMMS) adopted three-layered architecture as its IoT architecture with its three layers distributed as follows: The NMMS system high-level architecture consists of sensors at the perception layer, wireless communication at the network layer.

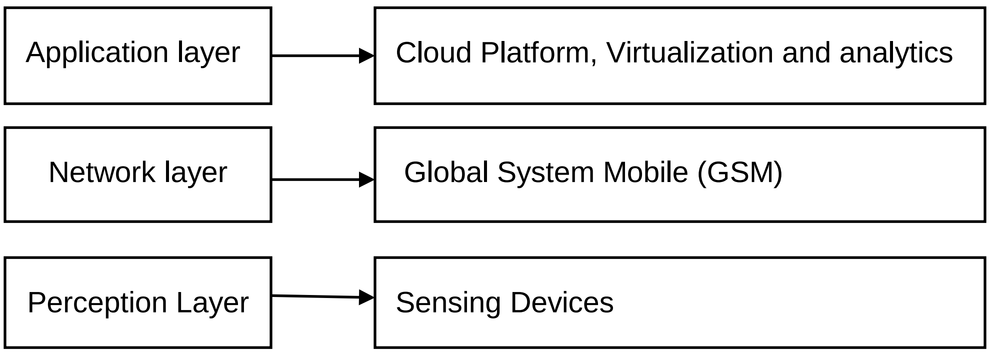


Figure 1***:*** NMMS Three layered architecture

The three layered architecture of NMMS system is composed of the following components

- Solar energy harvesting component: This component has PV solar panel and an inverter
- Energy production monitoring component: This component is comprised of sensors and microcontrollers. This is a perception layer where the sensing is done. Current and voltage sensors are used
- Energy consumption monitoring component: The consumption monitoring component is composed of microcontroller and Load. This is also a perception layer part where sensing modules are used. PZEM-004T module is used for consumption data collection
- GSM SIM900 Component: This is a network layer component used for communication between the Arduino UNO and the cloud services.it uses GPRS/GSM technology to establish the communication.

– Cloud Component: Data engine of the system from cloud services such as data storage, security, privacy and execution of instructions. It is an application layer where cloud platforms like thingspeak are used for visualisation and analytics.

3.5 IoT Based Net Metering Monitoring System design

The NMMS is a hybrid system, it combines different components with different technologies, and this gives the system be heterogeneous design system. The system design is likely to be intelligible and does not necessitate explicit familiarity or working out. The main NMMS feature allows a programmed way of thing fitting together, and at the same time, it delivers straight or circuitously always responsive services because it offers unified interconnectivity between computation and non-user interface devices.

3.5.1 General System architecture

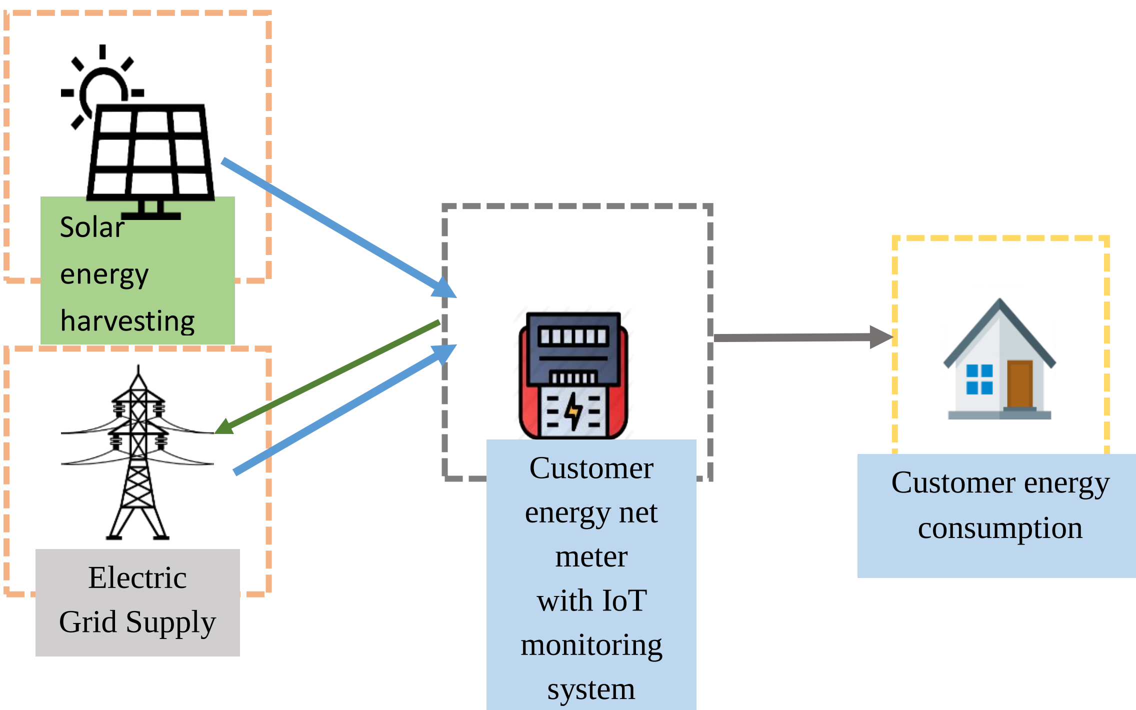


Figure 2**:** General System Architecture

The general system consists of solar energy harvesting using PV panel. The IoT monitoring system will monitor the energy generated by the solar PV system. The monitoring system will also monitor the customer consumed energy. The energy in surplus that is between the generated energy and consumed energy will be exported to the utility grid through the net meter.

3.5.2 Block diagram of IoT based Net Metering Monitoring System

The block diagram of the system has different sensors, GSM module connected to the Arduino UNO board

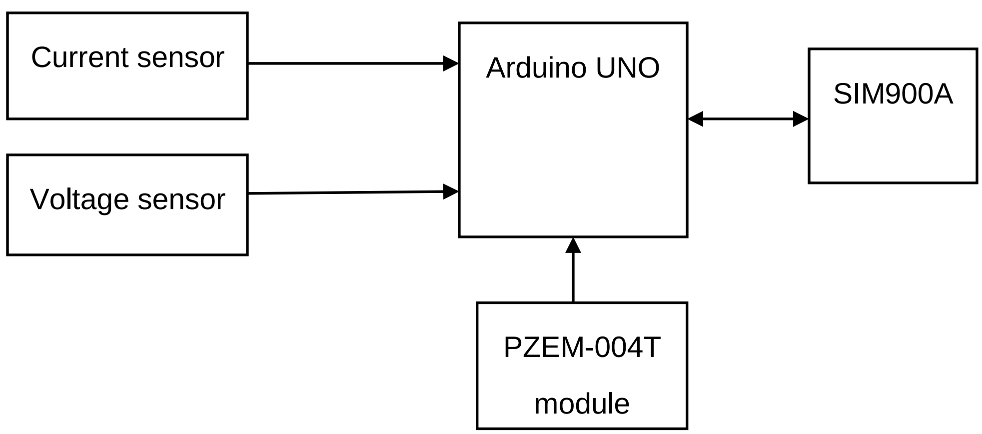


Figure 3: Embedded system Block Diagram

3.5.3 Components Specifications and features

Table 3: Hardware components specifications

N^{O}	Components	Description
1.	PV Panel, TDC-M20-36 model	Maximum power: 20 W Voltage at Pmax: 18.76 V Current at Pmax: 1.07 A Temperature coefficient Kv: − 0.35%/ °C Number of cells: 36

2.	B25 voltage sensor module; Voltage sensor,	Input Voltage Range: DC 0-25 V Voltage Detection Range: DC 0.02445 V - 25 V Analog Voltage Resolution: 0.00489 V
3.	INA169 module; Current sensor,	Common mode voltage range: DC 2.7–60 V Full-scale sense input voltage: 500 mV Supply voltage range: DC 2.7–60 V Operating temperature range: − 40 to 85 °C
4.	Arduino UNO	Microcontroller: ATMega328 Operating Voltage: 5V Input Voltage (recommended): 7 – 12 V Input Voltage (limits): 6 – 20 V DC Current per I/O Pin: 40 mA DC Current for 3.3V Pin: 50 Ma
5.	PZEM-004T	Test Voltage: 80-260V (AC) Max. Operating Current (mA): 100A Power rate (W): 100A/22KW Operating Frequency: 45-65Hz

6.	SIM900A GSM Module, GSM module	Single supply voltage :3.4V-4.5V Power saving: Sleep mode 1.5mA Frequency Bands: SIM900A Dual Band: EGSM900, DCS1800 Transmitting Power: Class4 (2W) at EGSM 900, Class1 (1W) at DCS 1800 GPRS Connectivity: GPRS multi-slot class 10, GPRS multi slot class 8, GPRS mobile station class B

3.5.4 System architecture design

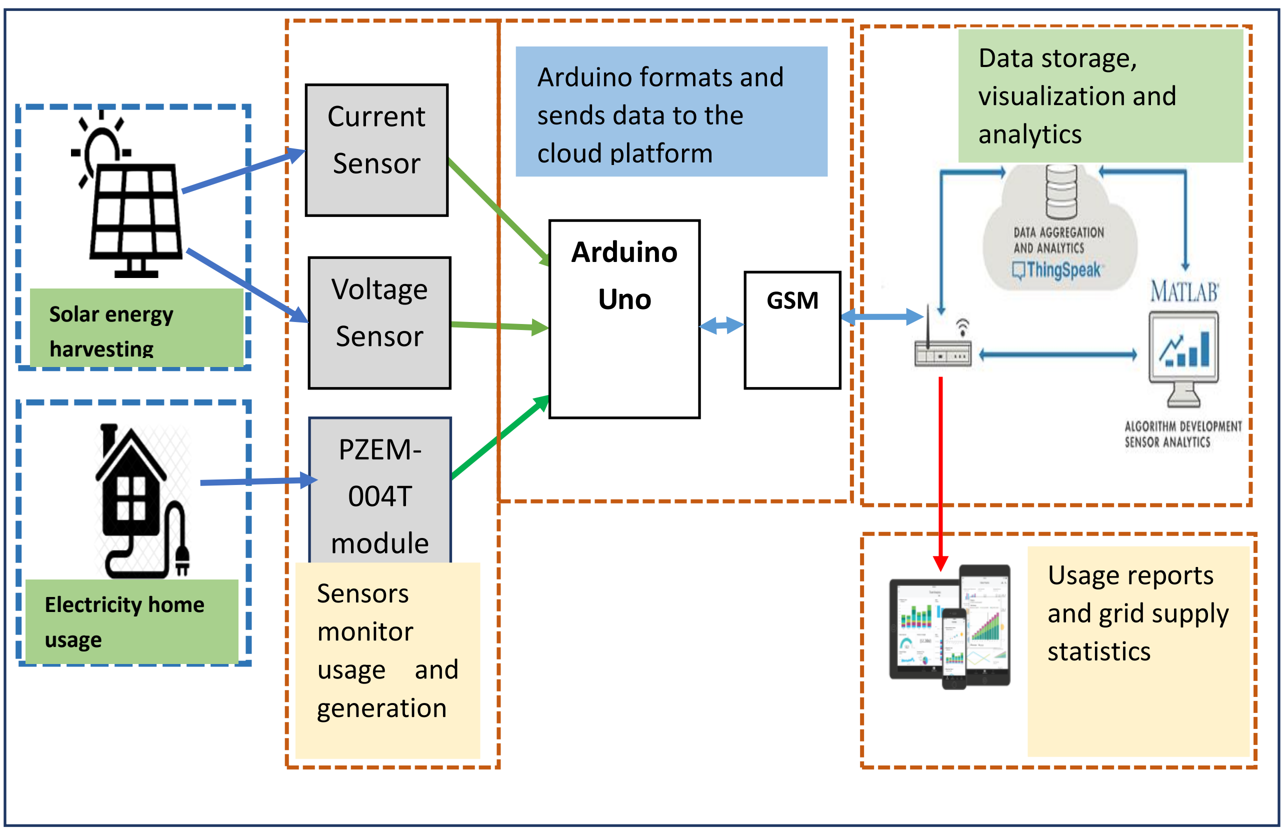


Figure 4: System architecture design

The system will monitor the power generated by Photo volatile (PV) system and monitor the power usage by the consumer. Net metering system means that the difference from the power generated by the consumer solar system and the energy consumed by the customer is exported to the grid. The utility company will be able to monitor the energy added to the grid by the customer through the net meter.

This system design provides real-time monitoring of the PV panel characteristics; voltage, current and power. The system design is based on Arduino Uno board. The acquisition is made through voltage and current sensors. Data are presented to the cloud through GSM connection.

The output of the voltage and current sensors is transmitted to the microcontroller of the Arduino Uno board. The data obtained are stored in real-time to cloud.

Arduino board is connected through GSM and data recorded to the cloud. The microcontroller is programmed to measure successively in each second the PV current, voltage and power.

PZEM-004TAC Module measures AC voltage, current, active power, frequency, power factor, and active energy. PZEM-004TAC measures the energy consumption by the load (customer home appliances in this case) and the output will be read by the microcontroller and data is sent to the cloud for analysis and visualization through GSM connection.

3.5.5 Main components of IoT Net Metering Monitoring System

The main components of the system are PV Panel, Voltage sensor, Current sensor, Arduino Uno, PZEM-004T, GSM connection, cloud platform.

3.5.5.1 PV Panel, TDC-M20-36 model

PV panels convert solar energy into electrical energy. It is the major part for the generation of solar energy. The dependents of solar energy generation are direction of the sunlight, temperature spectrum and irradiance.

The manufacturers of PV panels determine their characteristics and the measurements of these characteristics are required [22].

3.5.5.2 Voltage sensor, B25 voltage sensor module

Voltage sensor monitors the voltage produced by object. The levels of DC and AC are measured and the sensor input is the voltage.

F031-06 is used to measure PV panel's output voltage. Figure above shows the F031-06 voltage sensor module, The F031-06 voltage sensor uses the principle of the voltage divider[23].

Table 4***:*** Connectors of the F031-06 voltage sensor module

Pin symbol	**Descriptions**
VCC	Positive terminal of the voltage to be measured (0-25V)
GND	Negative terminal of the voltage to be measured
S	Analog Input
+	Not connected (N/C)
-	GND

3.5.5.3 Current sensor, INA169 module

Current sensors, measure the current running through a wire by using magnetic field to detect the current and generate a proportional output. They are used with both AC and DC current. Current sensors allow us to be able to measure current passively, without interrupting the circuit in any way. They are placed around the conductor that's current we want to measure.

To measure the PV panel current, current sensor is used. Specific current sensor, INA169 is used. Current sensor measures a drop in voltage across a resistor. The output voltage of the amplifier is converted to a current by the internal transistor, and this current is converted back to a voltage (Vo) when it passes through the load resistor (RL) to the ground. Note that the Vo range depends on the voltage supplied by CC (5 V in our case) [22].

Table 5***:*** INA169 sensor module connections [22]

Pin symbol	**Descriptions**
VCC	VCC (+ 5 V)
GND	To the ground,
VIN+	Positive side of the source
VIN−	Positive side of the load
VOUT	To an analog input, this is the measured Output

3.5.5.4 Arduino UNO

This is a programmed microcontroller that can be reprogrammed, deleted anytime. Arduino Uno is used to program electronic devices and acts as a mini computer. Information can be sent and received through internet by using Arduino microcontroller. Arduino takes in input and provides a controlled output. The software used for programming Arduino is known as Arduino integrated development environment and are programmed using C or C++ languages [24].

The monitoring of sensors is possible with Arduino microcontroller. Wireless or Bluetooth is used to establish communication between electronic devices.

Memory is used by Arduino to store data and ATmega328P for instructions programming .it is powered by DC 5V and 3.3V. 0 and 1 pins are used to receive and send data from and to other devices. The communication with computer is done through USB connection. The Arduino has both digital and analog pins for conversion between analog and digital signals. LED lights are used to indicate ON, OFF, TX and RX. The Arduino microcontroller has a reset button for the restart. Many projects can be developed using Arduino Microcontroller [25].

3.5.5.5 PZEM-004T

This is the module that measures current, voltage power and frequency .It is used in experiments to measure power especially on a networked building [26].

Energy monitoring is done by using PZEM-004T. A 100 A AC current transformer coil acts as a sensor. Voltage and current are used to calculate the power consumption. The PZEM-004T measurement accuracy is very good [3].

The important outputs for PZEM-004T are Vcc,Gnd, Transmit (TX) and Receive (RX).The later output are used on Arduino for reading [27].

3.5.5.6 GSM module, SIM900A

Global System for Mobile Communication is used for transmitting voice and data. GSM carries data rates of 64kbps to 120Mbps and can operate at 850MHZ,900MHZ,1800MH [13].

This module enable computer and a GSM communication. Many countries use the architecture for mobile communication using GSM modems. Arduino microcontroller use GSM to send and receive data by using the designated pins of Arduino and GSM [28].Just like a phone, GSM makes calls, send messages and can use GPRS to send data.it is a plug /play modem that supports serial communication. SIM900 can be used to develop data transfer and SMS control applications. It also supports SMS, voice call ,GPRS and Data features [29].

Table 6**:** SIM900A key features [30]**.**

Feature	**Implementation**
Power supply	Single supply voltage 3.4V-4.5V
Power saving	Typical power consumption in SLEEP mode is 1.5Ma(BS-PA-MFRMW=5)
Frequency Bands	• SIM900A Dual-band: EGSM900, DCS1800.The SIM900A can search the 2 frequency bands automatically. The frequency bands also can be set by AT command • Compliant to GSM Phase 2/2 +
GSM class	Small MS
Transmitting power	• Class 4 (2W) at EGSM 900 • Class 1 (1W) at DCS 1800
GPRS connectivity	• GPRS multi-slot class 10 (default) • GPRS multi-slot class 8 (option) • GPRS mobile station class B

3.5.6 Software architecture

Ultimately, the software is used at the business layer for management, control, security, etc. (i.e. adding new supplier on the smart gas controller system or registering assets in the system on the asset tracking system) at the application layer to meet the requirement by exercising the use case and at processing layer for data filtering, aggregation, etc [21].Software architecture is therefore important to be considered, especially to describe the structure of the system at the upper layers.

Software architecture mainly is based on modularity and the concept of modules that may vary between programming languages:

- The module can refer to the encapsulation of data and functions;
- In some cases, it might also refer to the collection of several functions/classes, which is also referred to as a package.

Whichever concept is considered, it is about the decomposition of the larger system into smaller and manageable systems, which can be called a subsystem.

Modularity is about a logical partitioning of a system considered as a technique for systematically slicing complex software to be manageable for implementation and maintenance. The logic of partitioning, often, is based on functional dependency or data dependency [21].

Decomposition might focus on the grouping use cases related to specific actors, and common use cases can be grouped into subsystems based on the various cohesion and coupling consideration or the functional relationship of the use cases. Note that an actor can have roles in unrelated functions. Subsystem creation can be applied by grouping classes as an approach. Mainly subsystem is characterized by the service it provides

A system needs to be modularized yet the modules need to be interdependent. A good system is required to be loosely coupled with highly cohesive [21].

The coupling can be done either by *data coupling* with parameter = unit data, by *stamp coupling* with parameter = data structure, by *control coupling* based on control flags passed between modules, or by *common coupling* with global variable or by c*ontent coupling* with passing by reference [21].

While cohesion can be smoothly done either *functional*, *sequential*, where instructions within are related to data, communicational where sequence does not matter, procedural where instructions sequence matter plus the flow of control or instructions within the module can be related to other modules, temporal where instructions are related through the flow of control but the order, doesn't matter or instructions are not functionally related but appears at the same time, *logical* where it consists of several sets of instructions, but the particular set that is executed is determined from outside the module or flag that specifies what to do is passed in from outside, *coincidental* where instructions have no relationship, the worst type of cohesion result of disorganized programming [21].

3.5.6.1 Software architecture

This is a high-level description of the software focus on how the low-level design elements (modules/subsystems) are arranged, structured solution meets the technical and operational requirements while optimizing common quality attributes such as performance, security, and manageability.

Software architecture is about describing how the software is organized. This description includes structural and behaviour elements.

The focus of architecture is on application elements and components, design and selection of data algorithms. However, some of the low-level design concerns could be dictated by the high-level decision.

Architecture and Design concerns very often overlap, in some cases, decisions are more architectural, in other cases, the decisions are more about design, and how they help to realize that architecture. Architecture helps to provide a solid foundation for the software, though failing to consider key scenarios may affect functionality, failing to design for common problems - may affect end-user criteria, failing to appreciate the long-term consequences of key decisions – may affect dependability and maintainability. Such failures put your application at risk.

3.5.7 NMMS Software Architecture

The NMMS software architecture and design took into consideration for the users: who are going to use it, system: the IT infrastructure and its cost, and business goals: provide the real monitoring of energy production and consumption.

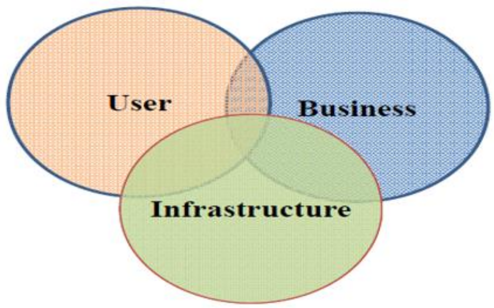


Figure 5: Key considerations in Software Architecture

3.5.7.1 NMMS system algorithm

The system has the objective of monitoring the energy production and energy consumption. To achieve the target, the system needs to carry out three main tasks: energy production, energy consumption and monitoring.

NMMS system algorithm is guided by its architecture. It has three main software modules integrated into one application on the server: Production, consumption and monitoring.

1 Energy production software module
2 Energy consumption software module
3 Monitoring module

3.5.8 Arduino IDE

IDE is an Arduino software used for code compiling in the Arduino module. It consists of editor and compiler. Editor is used for writing the codes while the compiler is used to upload codes in Arduino [31].

A sketch is a code written to be used in Arduino and IDE is a software used to develop sketches. Text editor, message area, text, console toolbar are the parts of IDE software [32].

IDE relies on its internal engine called Arduino Builder to compile the code into executable binary and upload it to target processor.

3.5.9 IOT Prototype

IoT prototype is the first step taken to develop an internet of things product. However, preparations for what is required in terms of goals and constraints need to be defined properly for successfully producing IoT Prototype. The goals of the prototype must be clear and tools to use should be carefully selected [33] . Hardware requirements also need to be well defined and the right choice of hardware vendors identified.

3.5.10 IoT based Net Metering Monitoring System Prototype

The prototype for IoT based Net Metering Monitoring System has different components wired together to provide the result required. PV solar panel, current sensor, voltage sensor, pzem-004T module, Arduino UNO microcontroller, GSM module are connected to provide the monitoring output required. IoT cloud platforms are used for data analysis and visualization.

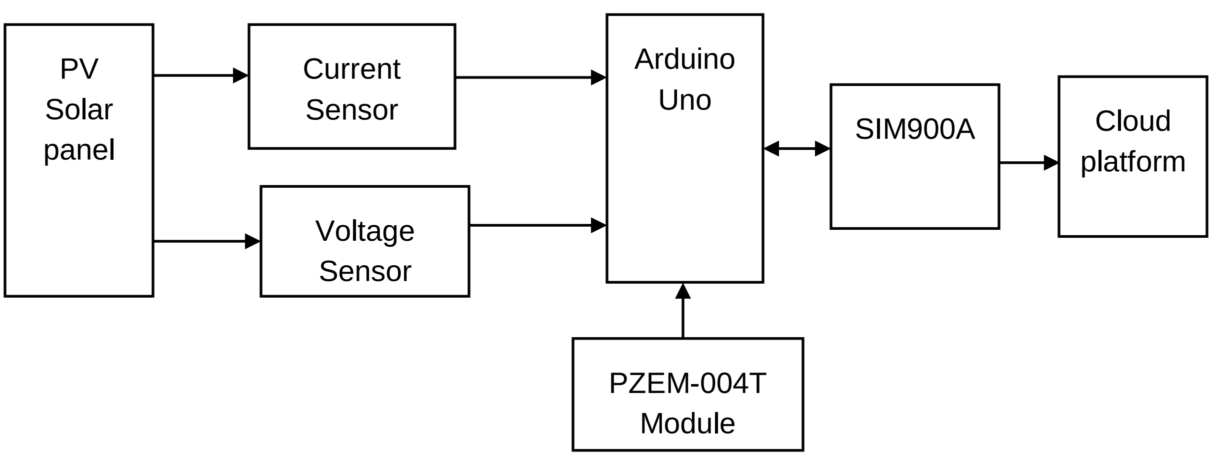


Figure 6: Prototype circuit diagram

CHAPTER 4: DESIGN ANALYSIS AND RESULTS

4.1 The realization of the Prototype

To realize the NNMS, requires connecting all modules with the microcontroller Arduino UNO, and this requires jumper wires, breadboard, and extra power source for the GSM module. Before making the NMMS prototype, testing each module separately was the first step, if all modules tested positively worked, the next step was to realize the prototype main objective which is generation of electricity using PV solar panel, monitoring the production of electricity and monitoring the consumption, and using SIM900 GSM connection to send data to the cloud.

4.2 Prototype pin connection

The table below shows how the prototype devices are connected to each other. Many devices are connected to the Arduino .

Table 7: Prototype pin connection

PV Solar panel	
+	+ of charge controller
-	- of charge controller
Charge controller	
+	+ of solar panel
–	- of solar panel
Inverter	
+	+ solar panel
-	- solar panel
Current Sensor	
Vin (-)	+ Load

Vin(+)	+ Load
Vcc	Vcc of Arduino UNO
GND	GND of Arduino UNO
OUT	A1 of Arduino UNO
Voltage Sensor	
VCC	+ of solar
GND	-of solar
1	GND of Arduino UNO
S	A0 of Arduino UNO
PZEM-004T	
+	+ of CT and Load
-	- of CT and Load
GND	GND of Arduino UNO
RX	9 of Arduino UNO
TX	10 of Arduino UNO
5V	5V of Arduino UNO
GSM SIM900	
GND	GND of Arduino UNO
TX	2 of Arduino UNO
RX	3 of Arduino UNO
Load	
+	+ PZEM-004T
-	- PZEM-004T

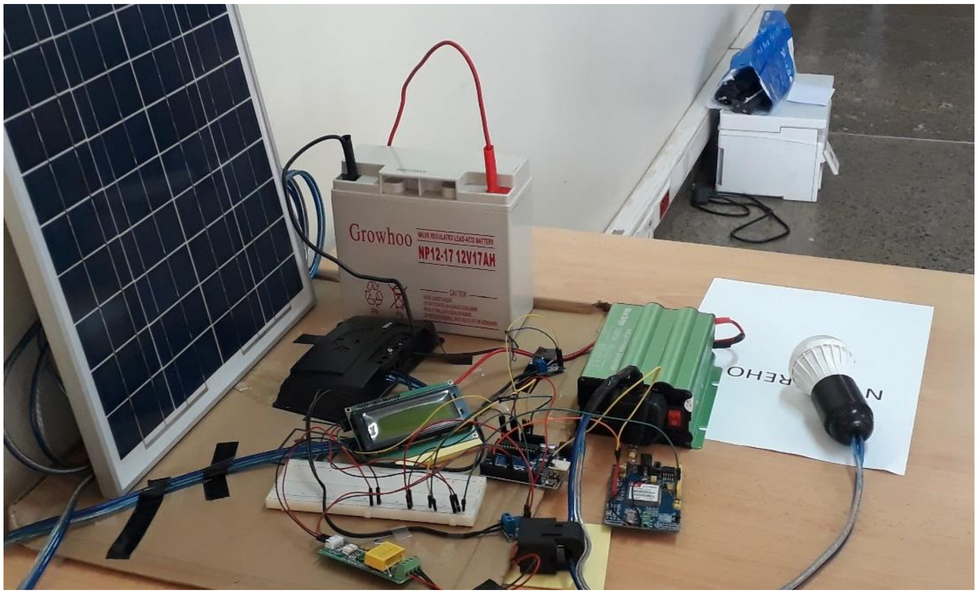


Figure 7: NMMS Prototype

4.3 The NMMS data set analysis

The IoT Net Metering Monitoring prototype provides three key services: generating electricity from solar system, monitoring the production of electricity, monitoring the consumption of electricity and sending data captured to the cloud for further analysis.

To generate electricity, a 20W PV solar panel is placed to the sunlight by positioning to the direction of sunlight to maximize the quantity generated. Charge controller is connected with the solar panel so that the battery is optionally used to store electricity in case it is required when there is no sunshine. The inverter is also connected to the solar system so that the generated direct current (DC) electricity is converted to alternate current(AC) required by the load.

INA169 current sensor module and F031-06 voltage sensor module are connected to the solar system to gather data generated electricity. The sensors are also connected to the Arduino UNO for processing.

PZEM-004T module is also connected to the Arduino UNO and load to measure the consumption of electricity. The Arduino UNO is connected to all sensors and GSM SIM900 so that is processes the sensors inputs

4.4 Results obtained

The prototype successfully monitored and provided the required data for both production of the electricity generated by the pv solar panel and the electricity consumed by the load, where we used a light bulb in our case. Therefore, the primary objective was achieved. The output data is displayed by using the Serial monitor, LCD Display and online through Thingspeak platform. Below are the images of the results obtained.

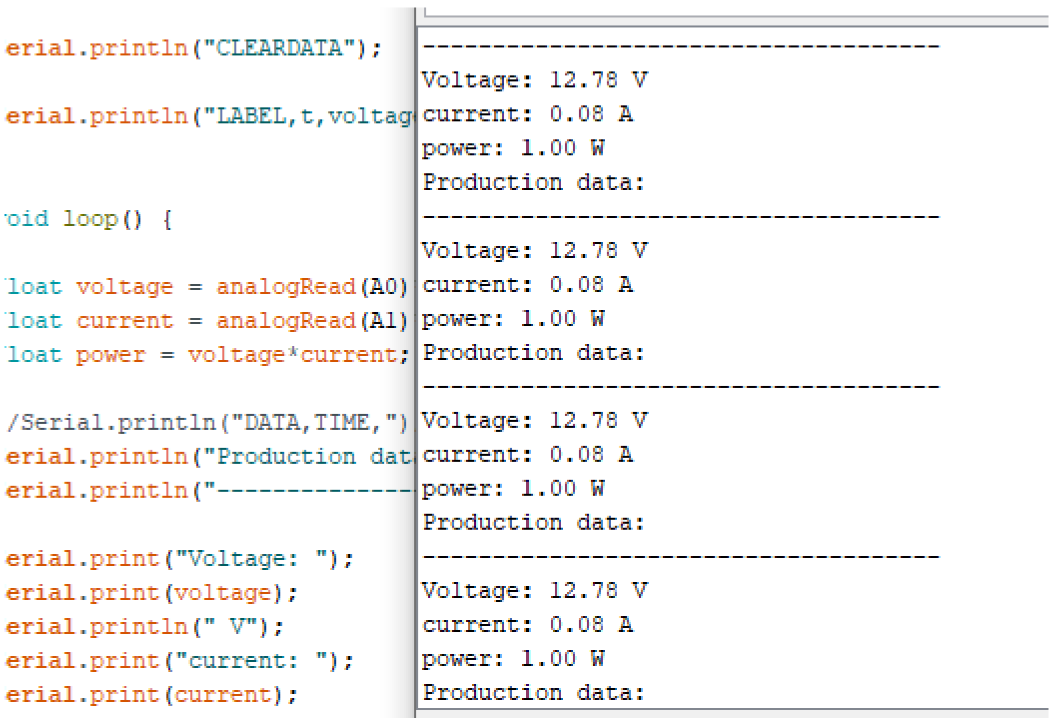


Figure 8: Production data (screenshot)

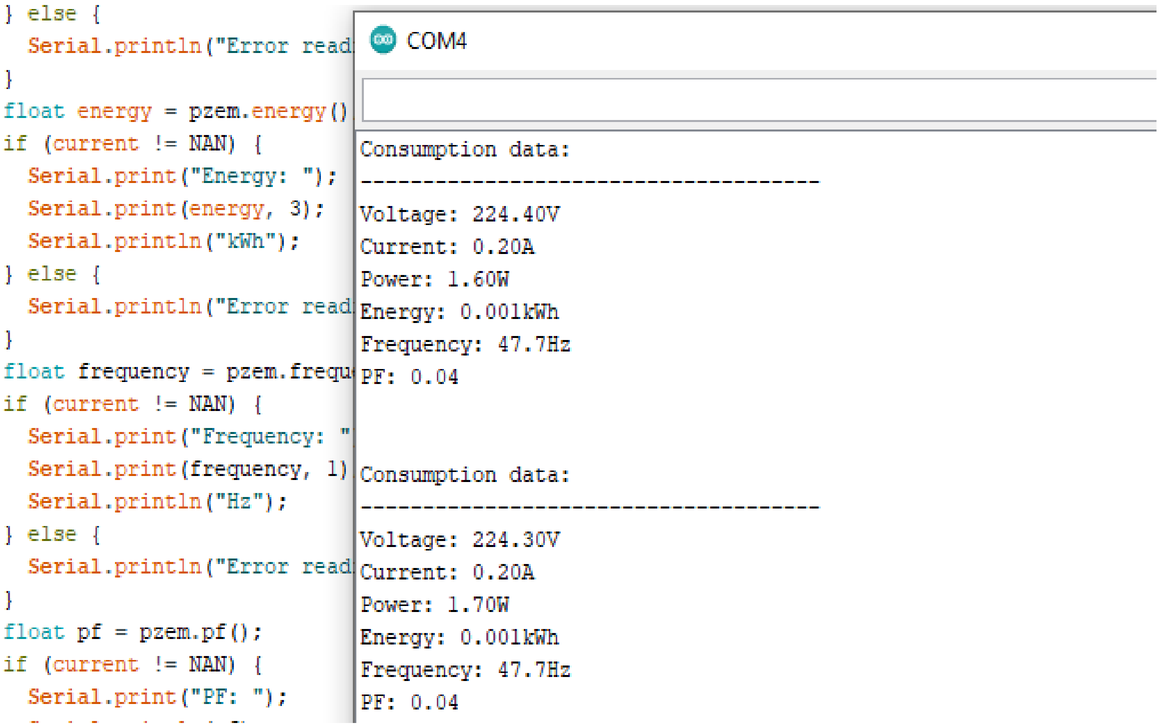


Figure 9: Consumption data (screenshot)

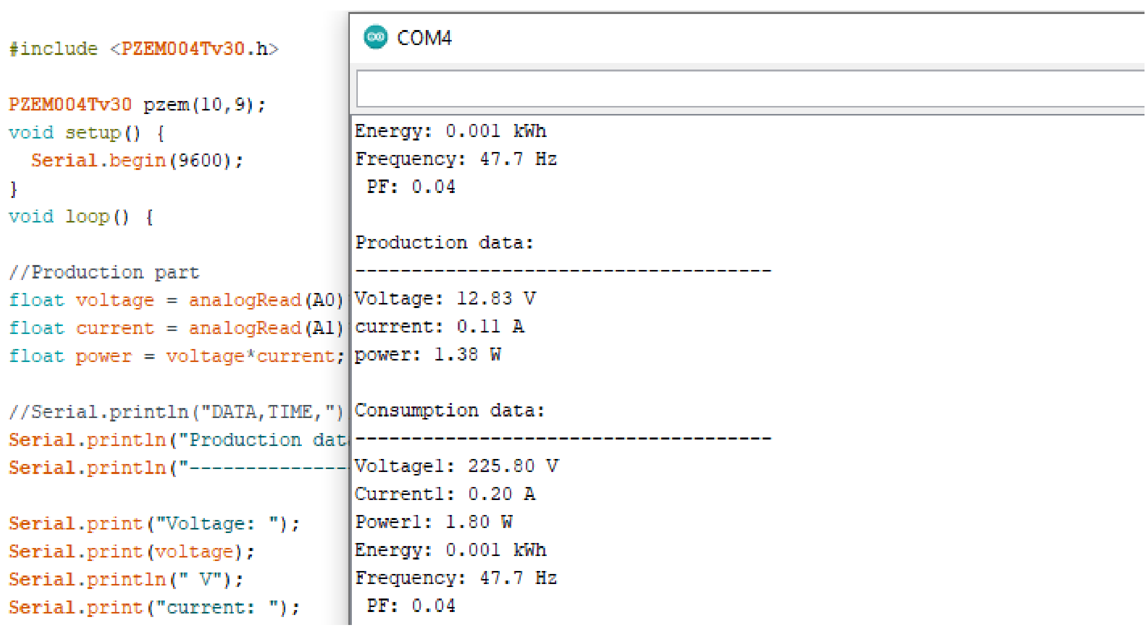


Figure 10: Production and Consumption data (screenshot)

By uploading the codes in the Arduino IDE, it can be seen from the serial monitor that both the production data and Consumption data are produced and recorded in a clear way. The system is able to record the produced voltage, current and power and as well the consumed voltage, current and power.

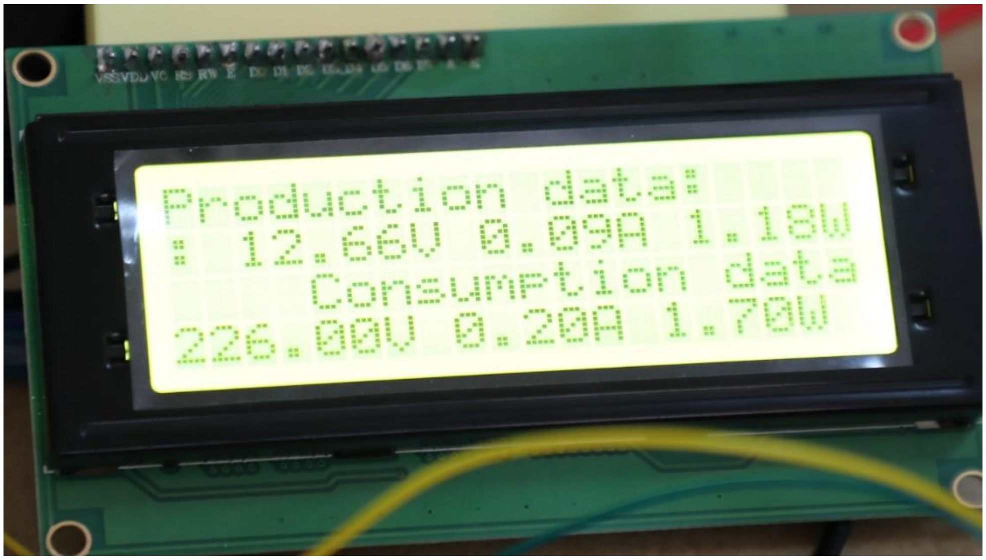
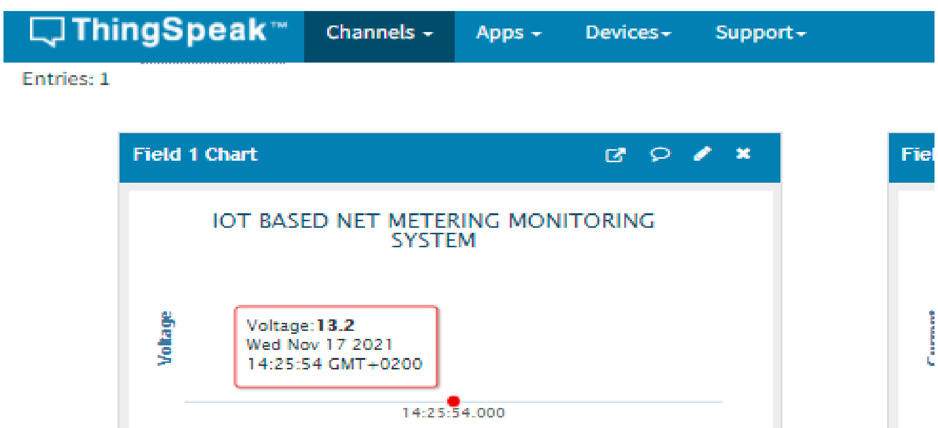


Figure 11: LCD Display results

By connecting 20*4 LCD Display, recorded data is also displayed clearly where the production data in terms of voltage, current and power and consumed data in terms of voltage, current and power are displayed.



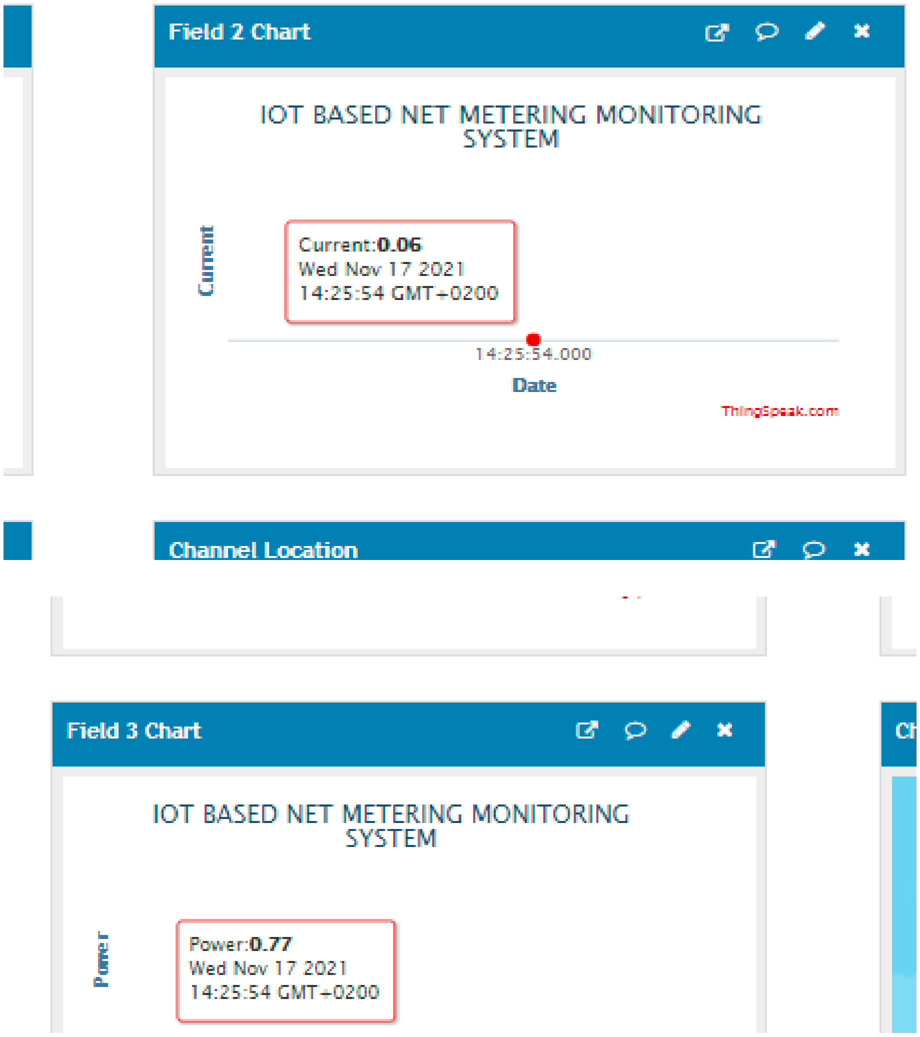


Figure 12: IoT analytics platform

By using the Arduino microcontroller, SIM900 GSM Module for connection and the right codes the data generated is sent to the cloud for records and analysis. The real time data for voltage, current and power is recorded.

4.5 Findings from the realization of the prototype

- The generated electricity varies depending on the quantity of the sunlight
- Positioning the solar panel is essential. It must be positioned such that it is in the same direction of the sunlight

- Consumption of electricity varies depending on the load used
- Real time data is recorded
- The 2G network connection provided by SIM900 GSM module is not very stable and fast.
- Internet of things devices need to be approached with caution due to their delicacy

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Net metering is the new technology in energy industry and it has never been fully consumed especially in Rwanda. Once this technology starts to be applied, IoT based net metering monitoring system has proved to be of valuable contribution towards the better management of electricity production and consumption especially to the consumers of Solar energy. Real time data analysis will allow the consumers make better future decisions.

This study has successfully proposed and implemented an IoT Based Net Metering monitoring system that will enable the PV Solar energy customers be able to monitor how much energy they produce, how much they consume and how much they export to the grid. The study also proved that energy and IoT can be integrated to produce better results and management. The system will ensure the independence of all parties involved and will undoubtedly encourage more consumers to invest in green energy production.

5.2 Recommendation

Since the IoT is new in Rwanda, it was always not easy to get the required components/devices for prototype realization and sometimes the cost of such devices was found to be high. We therefore recommend that the University of Rwanda-College of Science and Technology – African Center of Excellence can avail these devices so that during the period of students' research, the devices can easily be found and at the cheaper price. This will help the students realize their projects on time and at a cheaper cost. The Centre can help the students where possible to improve and make the projects more profitable whereby after school, students are facilitated to improve the projects into a finished product that can be sold to companies and individuals who may need product.

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