



UNIVERSITY of  
RWANDA



**COLLEGE OF SCIENCE AND TECHNOLOGY**

**AFRICAN CENTER OF EXCELLENCE IN INTERNET OF THINGS**

**P.O Box:3900, Kigali Rwanda.**

**Design and Implementation of Smart Energy Monitoring and  
Control System for Traditional Factories**

**PAUL STONE BROWN MACHESO (REF. NO. 219013806)**

Master of Science in Internet of Things (Wireless Intelligent Sensor  
Networking)

November 2020



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**Design and Implementation of Smart Energy Monitoring and  
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Submitted By  
**PAUL STONE BROWN MACHESO**  
(219013806)

A thesis submitted in partial fulfilment of the requirements for the degree of  
**MASTER OF SCIENCE INTERNET OF THINGS WIRELESS INTELLIGENT  
SENSOR NETWORKING**

In the College of Science and Technology

Supervisor : Dr. Louis Sibomana

Co-Supervisor : Dr. Ignace Gatara

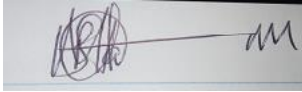
November 2020

## Student Declaration

I declare that this Dissertation contains my own work except where specifically acknowledged

PAUL STONE BROWN MACHESO (219013806)

Signed

A rectangular box containing a handwritten signature in blue ink. The signature is stylized and appears to be 'P. Stone Brown Macheso'.

Date 30<sup>th</sup> November 2020

## **BONIFIDE CERTIFICATE**

This is to certify that the project entitled” **Design and Implementation of Smart Energy Monitoring and Control System for Traditional Factories**” Is a record of original work done by **PAUL STONE BROWN MACHESO** with reg number **219013806** in partial fulfilment of the requirement for the award of Master of Science in Internet of Things Wireless Intelligent Sensor Networking in College of Science and Technology, University of Rwanda, Academic year 2020

This work has been submitted under the guidance of **Dr. Louis Sibomana and Dr. Ignace Gatare**

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**Names: Dr. Didacienne Mukanyiligira**

**Signature:**

## **DEDICATION**

I dedicate this MSc. thesis to Omnipotent God, *El Yeshuati*, the God of my salvation, deliverance, and victory, my strong pillar, my source of inspiration, wisdom, knowledge, and understanding. He has been the source of my strength throughout the postgraduate studies and on His wings only have I soared.

I also dedicate this work to my parents Late Stone Brown Macheso and Chrissie Macheso benefactors of my elementary school, high school, and undergraduate university education. I dedicate this work as well to Prof. Chomora Mikeka, Tadikira Mafubza, Chadzutsa, and Zambezi families for unleashing unconditional support for me to attain postgraduate studies.

Finally, to the Department of Physics & Electronics, The University of Malawi, Chancellor College, and all its faculty members for unwavering support during my studies with University of Rwanda-College of Science and Technology.

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## **ABSTRACT**

The demand for electric energy has escalated in households and industries with the use of different electric and electronic loads day in and out. This has uplifted a concern to be addressed to many developed and developing nations with the demand for an immediate increase of electric energy especially in traditional factories alongside its monitoring parameters and control systems. Thus, there is a call to enhance the reduction of energy consumption and graduate traditional factories to smart factories by imploring real-time energy consumption monitoring techniques and control systems.

An electric energy monitoring system has been used for ultimate purposes such as process scheduling and billing in the traditional industries. The increasing demand especially in intensive industrial energy sectors dictates the development of smarter energy management systems which involves the embedded systems. Industrial end-users need to understand their energy consumption to reduce energy costs, improve company ecological profile, and suggestive feedback scheduling of their production lines. Factory machines to be more efficient and the need to reduce energy costs by the optimization of industrial processes can be satisfied by the use of embedded systems for energy monitoring and control systems.

For traditional factories smart electric energy monitoring has been neglected due to limited knowledge and also lack of expertise in real-time energy monitoring systems to acquire and process both energy and power quality data in real-time through the use of embedded computing. The advent of disruptive technologies such as the IoT, Machine learning, and Big Data has made real-time data acquisition and analysis very practical, reliable, and viable.

The design of the system is based on a low-cost Arduino microcontroller, non-invasive split-core current transformer, relay module, and voltage transformer. The sensor data of the developed system indicated that the prototype can successfully record RMS voltage and current, real and apparent power, power factor, and energy with great accuracy. Through the proposed monitoring system, traditional factories can have an overview of how much energy they are consuming at a particular time which may reduce energy costs, reduce carbon emissions and environmental damage and increase the profit margin of the factory.

## **KEYWORDS**

Split Core Current Transformer, Arduino, Energy Monitoring, RMS Current, RMS Voltage, Real Power, Power Factor, Apparent Power.



## **LIST OF ACRONYMS**

AC	Alternating Current
AMI	Advanced Smart Metering Infrastructure
AP	Access Point
ARM	Advanced Risk Machine
EMS	Energy Management System
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
IDE	Integrated Development Environment
ILM	Intrusive Load Monitoring
IoT	Internet of Things
LCD	Liquid Crystal Display
LoRa	Long Range
M-Bus	Meter Bus
MQTT	Message Queue Telemetry Transport
NILM	Non-Intrusive Load Monitoring
P2P	Peer to Peer
RMS	Root Mean Square
SCT	Split Core Current Transformer
SSMU	Smart Sensor Monitoring Unit
TCP/IP	Transport Control Protocol / Internet Protocol
WAN	Wide Area Network
WI-FI	Wireless Fidelity
WSN	Wireless Sensor Network
4IR	Fourth Industrial Revolution

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## CHAPTER ONE: INTRODUCTION

Electric energy plays a crucial role in the economic and social development across the entire globe and the quality of life of its citizens and consumers as it drives fundamental processes of manufacturing processes in industries [1-2]. It largely contributes to the backbone of the global economy with per capita consumption increasing by 14.3 % from 2005 to 2019 [3]. The manufacturing industry that dominates the global economy accounts for about 42.3 % of world electricity consumption [3,4].

The term *smart energy systems* were defined and used in order to provide the scientific basis for a paradigm shift away from single sector thinking into a coherent and integrated understanding of how to design and identify the most achievable and affordable strategies to design and implement coherent future sustainable smart energy systems [3].

Energy monitoring systems are widely used in industrial plants and buildings to observe energy consumption. In the industrial sector, unlike the commercial and residential sectors, it is largely constituted by large energy users like factories. Research has shown that these industrial energy consumers waste 41% of the power supplied to their industries [4]. The variations of voltage, current, and power factor must be measured from these traditional industries. These measurements lead to fundamental understandings of how energy is consumed, monitored, and controlled. The power measurement parameters are key prerequisites for the efficient energy conservation process. These industrial users know when energy consumption occurs and on which load and can make informed decisions about how to lower their industrial energy consumption rates [4].

Electricity pricing mechanisms can motivate organizations to reduce energy use through the use of smart energy monitoring techniques. The key to reducing high electricity bills is to provide customers with a better understanding of when and where electric energy is consumed, a key benefit of smart power meters. The energy usage data from these devices can also be used to improve the facility and limit the loss of energy much specifically in traditional factories [5,6].

The installation of power meters helps residential customers to understand energy usage at home. Wireless displays in these power meters can display real-time of energy usage and can help customers to budget the energy consumption [6].

Energy crisis, climate change and the overall economy of a country is directly affected by the increase in energy consumption. A significant reduction in energy wastage can be achieved

through a fine-grained smart monitoring of energy consumption and relaying back the information to the consumers. The smart energy monitoring is a measuring instrument used to calculate the amount of electric energy consumed by an electrically powered device [7].

The smart energy metering which measures line voltage, current, and calculating active and apparent power can be used to increase the usage efficiency of electricity more especially in traditional industries. It is very necessary to design a system that is capable of monitoring electrical energy consumption. Therefore, this research aims to design and implement an application based on the Internet of Things (IoT) that can monitor electricity consumption.

## **1.0 BACKGROUND AND MOTIVATION**

There is research interest on energy monitoring systems. The systems have been evaluated as one of the next-generation energy solutions for industries and residential homes. Several prototypes have been designed and implemented that proved the system actually could reduce the entire energy consumption up to 10-30% [10]. Tsuyoshi Ueno et al. [11] developed a monitoring system that was set up at 10 residential houses and its effect on energy consumption is analyzed. The total energy consumption was being reduced by 12% after the installation of the system and about 60% of the houses were able to reduce their standby power consumption.

The smart energy monitoring in traditional manufacturing factories can be regarded as a building event sensor to detect various events occurring at that particular instant in buildings. Woong Hee et al. [8] designed a system composed of two main components a wireless sensor network and an intelligent home gateway for real-time energy monitoring using ZigBee communication protocol. Wireless sensors were used for sensing and transmitting electric energy data and remote monitoring and control of home appliances were provided to users through the intelligent home gateway. The system enabled users to save energy by monitoring and controlling home appliances through web and mobile devices.

James Watt [12] redesigned the steam engine in the 18<sup>th</sup> century which has been the cornerstone for the first industrial revolution and human capability to manufacture products has improved greatly through the decades. The way of manufacturing products in industries has also changed significantly in the following the 2<sup>nd</sup> and the 3<sup>rd</sup> industrial revolutions, which sparked from the usage and popularity of electric energy and new communication technologies, respectively.

Recently, with the availability of big data, the advancement of computational capability, and the influx of smart devices across the globe, the manufacturing industries is marching towards a new era, namely, the 4th industrial revolution (4IR) [13].

The rapid development of sensing, communication, and computing technologies and analytic techniques has led to a shift in the manufacturing industries from traditional factories to smart factories by marching towards a new generation of sustainability digitalization and intelligence. The emerging manufacturing paradigm is often referred as “smart manufacturing”, which combines artificial intelligence, communication technology, and then applies them to production and business so that the production efficiency is enhanced, customized needs are satisfied, and the production costs are lowered while the profit margin is maximized [14].

Traditional factories do not involve the use of technological advancements in communication and computational capability and also the usage of smart devices in the manufacturing processes [15]. Traditional factories do not have enhanced flexibility, automation, intelligence high integration, and sustainability not excluding real-time electric energy monitoring. Big Data, Smart Sensors, IoT are all driving forces for a technological shift from traditional factories to smart factories to fit the current era.

Hermann et al. [15] argues that the characterization of energy consumption in manufacturing systems is denoted as the initial step towards the reduction in overall electric energy consumption. The putting in the task of energy-saving techniques such as load balancing and proactive maintenance depends on the availability of near-real-time data of the energy consumption pattern. The problems in electric energy consumption monitoring rise due to the various energy usage processes where each has its unique characteristics of energy consumption especially in big institutions. The integration of energy monitoring in traditional factories is key in realizing smart energy monitoring hence enhancing electric energy efficiency [16].

The key to reducing electric energy in traditional factories is to provide traditional industries with a better understanding of when and where energy is consumed, a key benefit of smart energy monitoring in traditional factories. The energy usage data from these devices can also be used to improve the facility and limit the loss of energy [17]. The installation of smart energy monitors helps factories to understand energy usage and its profile. LCDs and web dashboards in these smart energy meters can display real-time energy usage, apparent power, power factor, and can help industries to budget energy usage and maximize the profit margin.

## 1.1 PROBLEM STATEMENT

In recent days, the level of electric energy consumption is increasing yearly in the world because there are no immediate actions are being taken to minimize the usage of electric energy and monitoring and control systems being one of them. Energy monitoring and conservation holds a primary key in today's world due to the imbalance between power generated and the user demand. The scenario we are in at hand is that the energy which is mostly contributed by fossil fuels will be depleted in a near future hence there is need to invoke monitoring and control usage techniques [17,18]. Measuring electric energy consumption is advantageous as it provides a clear indication to the cost of running systems which are embedded with technological advancements of new devices which relate to intense resource utilization in this scenario being energy [17]. There is need for smart energy management system (SEMS) to measure, monitor, control and forecast energy consumption in a traditional factory and ultimately benchmark its energy performance.

The SEMS allows the centralized monitoring and control system of energy usage across traditional factories. This implementation controls the use of energy in various sectors operating in the traditional factory setting not limited to electrical machines, lighting and office equipment [18].

Many traditional industries remain on the electrical energy management sidelines due to their inability to grasp energy monitoring driven by the one-dimensional view that traditional factory energy consumption is an unavoidable cost of driven by production activities. Traditional industries are also involved in malpractices common which leads to energy wastage are not limited to treating energy consumption from outside in where electric energy consumption is viewed as lump cost [19]. The other problem commonly present in traditional factories is allocating energy costs evenly across processing activities solely based on the square footing and similar measures, poor power factor, and also poor production operations running electric machines when they are not supposed to. Another example, when using light bulbs, sometimes the user forgets to switch off and leave it open the whole day long even though still there is no production taking place in the factory. This is a contributing factor to the increasing level of electric energy waste in our traditional industries. By using this proposed system, it will help the user to be more sensitive to their level of electricity consumption by displaying the level of electricity usage in the traditional factories.

However, due to the complexity and diversity of IoT devices, integrating energy efficiency into ubiquitous computing is still in its infant stages. The emergence of new, innovative and disruptive



technologies like industrial 4.0, IoT and wireless sensor network provides a shift in standards and quality of manufacturing processes in traditional factories have reached an all-time high and significant part of the modern lifestyle in developing nations is intertwined with the usage of electronic and electrical devices. Furthermore, with the increase in the utilization of electronics and electrical machines have adversely resulted in an unprecedented increase in energy consumption in the traditional factories across developing nations [19,20].

The industry sector uses more delivered energy than any other end-use sector, consuming more of world's total delivered energy. Therefore, there is a need in employing of smart energy monitoring and control systems which in traditional factories as a pivotal factor in electrical energy conservation. The developing countries mostly meet a challenge where there is insufficient energy production to meet demand and it proves to be a challenge hence the little energy generated needs to be managed and used effectively across traditional factories which experience less production due high energy consumption costs. In addition to that most traditional industries in developing nations do not monitor energy consumption in real-time on a web dashboard due to the expensiveness of energy monitoring equipment and also inexperience to implore low-cost energy-saving mechanisms resulting in huge electric energy tariffs monthly to settle.

There have been several approaches for electric power management in factories from the grids. These approaches which have systems and projects of energy monitoring are only focusing on measuring the total amount of energy consumption while not employing the control system [8]. This has led to the need for smart energy monitoring in industries since conventional analog electric energy monitoring system is tedious, less intelligent and time-consuming and difficult for large scale electric energy users to estimate and control the usage of electric energy effectively as the information is provided on monthly basis brings in the factor to employ real-time energy monitoring system and control system for these traditional industries to maximize production and minimize energy consumption.

This research project will provide a plausible solution to design and implement the smart energy monitoring for traditional factories to overcome potential problems like high energy tariffs due to unmonitored energy consumption, inaccuracy of generated energy consumption due to scope of human errors as manpower is employed and further incorporate a control system of controlling running electrical loads connected.

## **1.2 STUDY OBJECTIVES**

The research study objectives are categorized into general and specific objectives

### **1.2.1 GENERAL OBJECTIVES**

This research project aims to design and implement a smart energy monitoring system and control approach to electric loads for traditional factories.

### **1.2.2 SPECIFIC OBJECTIVES**

The general objective of the research study is uplifted by the following specific objectives

1. Design and develop an energy monitoring prototype within a traditional industry.
2. Develop a system that measures sensor data of RMS voltage, RMS current, Real power, Apparent Power, Power factor consumption in Real-time.
3. To test and evaluate the developed system prototype.

## **1.3 HYPOTHESES**

The project thesis is guided by the following null and alternative hypotheses:

H<sub>0</sub>: Employing smart energy monitoring and control system does not affect the energy efficiency of traditional factories.

H<sub>1</sub>: Employing smart energy monitoring and control system has a positive effect on the energy efficiency of traditional factories

## **1.4 STUDY SCOPE**

Smart energy monitoring and control system in traditional factories has a vast scope of study but it can be narrowed to entail the proactive, organized and systematic coordination of procurement, conversion, and distribution requirements while putting in consideration environmental and economic objectives. The implementation requires the traditional factory to develop an energy management strategy that is smart and uses the embedded systems technology.

This study scope includes:

- An assessment of the current situation of energy in institutional frameworks for energy monitoring
- The typical energy saving potentials by the traditional factory sectors (light industries, iron, and steel, petrochemicals) for using the desired energy-saving approach.
- Cost-benefit approach for implementing smart energy monitoring and control systems for traditional factories.

### **1.5 SIGNIFICANCE OF THE STUDY**

Smart energy monitoring outlines enormous opportunities for traditional industries such as reducing costs, stimulating economic growth, increasing productivity, and offering a significant reduction in environmental impact hence providing a certain level of significance to conduct this study [19]. The design and implementation of a smart energy monitoring and control system would enable better insights into the energy and power quality data in the traditional industries. It will lead to having a monitored energy consumption and control system which is quite essential for huge institutions that consume much power like traditional industries that have not yet employed smart energy monitoring.

This research project seeks to monitor energy consumption in real-time on both and also different parameters such as voltage, current, and power of the active supply line. The system must also be able to determine the cost of the energy consumed and also help in controlling loads attached in so doing acting as a control system hence enabling energy-saving instance.

### **1.6 ORGANIZATION OF THE STUDY**

The project thesis outlines how a smart energy monitoring system can be designed and implemented while ensuring that the objectives both general and specific are met. The general thesis organization is as follows:

Chapter 1 discusses the background and motivation under the banner of the introduction. It further narrates the problem statement which underlines the whole purpose which the entire project thesis decides to solve. Chapter 1 is not limited to discussing the objectives both general and specific but also the scope and the significance of the research study in solving societal challenges.

Chapter 2 focuses on reviewing related literature and concisely showing how it is distinguished from existing literature. It is giving an insight into the gaps which need to be addressed to contribute some novelty to the scientific community.

Chapter 3 discusses the research methodological approach and how it will be implemented to meet the desired outcomes. It further stipulates the hardware type which will be used and its properties to take the iterative approach of prototyping concerning validating the thesis statement.

Chapters 4 presents the system analysis design the simulations in proteus software. The design involves the circuit diagrams of the prototype and the algorithms which are put in place to be able to achieve the desired results.

Chapter 5 discusses the results collected in graphical forms and some basic statistical analysis which are essential for the analysis part of the research.

Chapter 6 presents the conclusion of the study and possible recommendations and future work of the smart energy monitoring and control system respectively.

## **1.7 CHAPTER CONCLUSION**

The chapter introduces the development of an energy measuring system that ensures the awareness and economy of energy consumption through an accurate display of energy consumption data for those loads in traditional factories. The capability of monitoring current, voltage, power, and power factor graduates a traditional factory to a smart factory. This makes this system to some extent to answer some power scarcity challenges and reduce consumer costs. To conclude this chapter, we have seen the overview of smart energy monitoring and the need to implement it in traditional factories to enhance energy efficiency with the use of open-source disruptive technologies.

## CHAPTER TWO: LITERATURE REVIEW

A broader view on the scrutiny of literature on smart energy monitoring system revealed that several researchers has similar interests on the metering technology of smart energy systems with the main objectives centered on ensuring power monitoring and help in implementation of the first stage in smart grid [29]. The coined term of the energy monitoring system has for ages been used primarily for identifying the energy consumed by the equipment in an industrial setting.

In [1] the author describes the design and implementation of EnerMon a flexible, efficient and edge computing based on IoT technology to monitor power consumption over a period of time. The proposed system displays the real-time data and descriptive analytics which induces a process which could be used to shape the overview of energy usage over a scheduled time to be able to project the energy waste. The proposed system employs a system based on Arduino microcontroller, split core current transformer as a sensor, raspberry pi as an application server and LoRa as a communication technology [1]. The system induced some potential benefits include easy to install since it utilised non-invasive approach and high range coverage because of LoRa communication modules. The system could be implemented in a variety of settings ranging from residential homes as well as big complex consumers such as traditional industries to measure energy footprints. The limitations of the proposed system included not interfacing a microcontroller with potential transformer to collect sensor data of RMS voltage. The system did not have appliance control unit to be able to switch on and off loads in real time. The system also utilised raspberry pi 3 which is expensive to procure.

In [16], the author proposed an idea for energy monitoring and management system in houses where residents can have an overview picture of energy they are consuming in real-time in their respective houses and also being able to control electrical and electronic appliances remotely using their gadgets like computers and smartphones. This project utilized simple electronic components which are not costly and are more reliable. They also used low power consuming microcontrollers [16]. Having used less expensive integrated circuits if any circuitry problem had occurred, they would easily be replaced. The drawback of the proposed system is that it uses an invasive current

transformer (ACS712) which would require re-wiring of traditional factories if implemented to carry out the task of electric energy monitoring. The system also was implemented in a home setting where high current loads are not used mostly hence not suitable to implement in the industrial environment and furthermore the potential transformer was not interfaced.

In [17], the authors analyzed the existing approaches in the implementation of an energy monitoring system based on Arduino microcontroller and also classifies systems for energy measurement e.g., basing on the type of sensors or the method they employ for data collection of the electronic sensors. The system designed and implemented by the author follows the approach of artwork in monitoring home energy uses using non-intrusive load monitoring (NILM) which proposed measuring current and voltage at the base of the energy distribution network and this seems very complex to implement [17]. The prototype was also using the ZigBee shield and ZigBee module as a communication protocol to the microcontroller which has deficits of low coverage range and low data rates and expensive to purchase as well as low network stability.

In [20] the author proposed the process of managing the energy consumption in intensive energy sectors such as industrial and commercial sectors involved very expensive and complex monitoring of individual equipment to help the operator understanding the energy usage. The proposed system doesn't implement the monitoring using cross-cutting technologies like IoT to display the monitored parameters on a web dashboard for easier monitoring.

In [21] a system to monitor electric energy data in real-time using a powerful energy analyzer has been proposed with capability of measuring many parameters of energy consumed in the building. The real-time data measured by the power analyzer was being transferred to a host computer via RS485 serial communication protocol and then collected in a database continuously. Then the energy parameters like current, voltage, and power factor measured were stored and analyzed into graphical forms. This energy monitoring technique involved serial communication which is slow and unreliable where one bit is sent at a time until all are sent. The system proposed also was costly as it involved using expensive equipment like computers and power analyzers.

In [21], the authors discussed smart metering systems which allows us to monitor the energy consumption of consumers, while provides useful information regarding electric power quality. The design further uses information provided by prototype is used by the system operator to enhance the energy supply, and several techniques, as load scheduling, demand-side management,

non-intrusive load monitoring, can be applied for this purpose. The author also proposed an advanced smart metering infrastructure (AMI) for integration in future smart homes, where not only the electrical consumption was monitored, but also the gas, water, and heating [21]. Therefore, by monitoring all energy systems in the building, the end consumers could be aware of their whole energy consumption, and advanced control techniques can achieve by the Energy Management Systems (EMS). The system is expensive as it used purchased software and used a personal area network of meter bus (M-bus) as a communication protocol. The other limitation was that the system did not display the energy consumption data on a web dashboard.

In [22], the authors proposed development of Arduino based automated household utility power monitoring system. This system had data logging in real-time and Arduino was the interface with the SD card by the SD card shield. The system is also equipped with a real-time clock. For monitoring of power, the microcontroller was connected to the current transformer through the voltage and current sensor circuit. The proposed system was also interfaced with the RTC module (Real Time Clock) responsible for providing real-time clock and dates needed for sensor data logging of the system [22]. The proposed system was not limited to a couple of limitations which involved not employing an enabling disruptive technology of internet of things or wireless sensor network to log the data to a web dashboard and also the system lacked electrical load control mechanism to be able to control the electrical loads remotely in due course of the power monitoring in the household.

In [23], proposed the simulation of the smart meter using Proteus software for the smart grid. Smart meters are the integral parts of the smart grids for enhanced smart metering. In the proposed system it involved a power monitoring sensor node with ZigBee wireless communication protocol. The smart based energy consumption budget was implemented based on the system and the rate of power consumption was sent to the client through mobile phones GSM technology and SMS was received [23]. The system also had an integration of theft prevention mechanism and the sensor node was constructed using the M4 ARM cortex microcontroller and the simulation was done in embedded c proteus software. The limitations of the system involved the use of ZigBee which employs short-range communication and it is costly. The proposed system lacked the internet of things technology to display power consumption on the web dashboard and provide intelligent decisions.

An IoT energy monitoring system has been designed in [24], which could be put in place in many relevant applications in recent time. These applications included the electrical billing system of a smart grid and home automation. The design based on electric meter PZEM-004T which was interfaced with non-invasive CT sensors SD30004 electric energy management chip and ESP8266Wemos D1 mini microcontroller for sensor data retrieval from the sensor node and sent to the web server via the internet [24]. The proposed system displayed voltage, current and active power of the supply line on a web dashboard. The system also utilized the use of WI-FI and MQTT (Message Queuing Telemetry Transport) protocols for communication. The system was important in such a way that it provided detailed measurement of electric usage and the energy consumption patterns which would lead to economic benefits as end consumers would understand energy usage patterns and adapt to reduce energy usage profile [24]. The system was limited by not having an electric appliance load control mechanism to reduce running costs of energy consumption which would help in providing instant real-time action-based using disruptive technology of IoT. The system also utilized expensive energy meter PZEM-004T.

The design and development of energy monitoring which is based on non-invasive current sensing was proposed in [25]. Non-invasive current sensing has numerous merits that it can be located to any point where the desired power is to be measured. The energy consumption details in this case were relayed to servers and displayed in real time on a smart phone. ENC28J60 Ethernet module was used to send data over the internet. The proposed system lacked voltage transformer for measuring RMS Voltage and the Ethernet module was costly to purchase.

The development of a wireless automatic meter reading system (WAMRS) which incorporated the widely used GSM/GPRS mobile communication network was proposed in [26]. The system includes a microcontroller interfaced with a GSM module, which periodically transmits power consumption values calculated from the sensed voltage and current values via an existing GSM/GPRS network, to a master station. The main limitations of this technology were not limited to distance factor but also latency and costs of usage of the service. A strong GPRS or a GSM network coverage at long distances may not be available for use. The system did not involve disruptive technology like IoT to relay data over the internet in real-time.

In [27] proposes an energy monitoring system that monitors the electric power utilization and allows the electric power. The system allows the measured parameters to be accessible to the consumer in this case the client as well as the utility company by employing system interface. The



author proposed a system which employed the use of Arduino microcontroller based on ATMEGA328P microprocessor, current sensor ACS712, 16X2 LCD module and it was powered up by 9V battery supply and LM7805 voltage regulator. The output of the proposed system was displayed on a 16x2 LCD module which was interfaced with the Arduino microcontroller. The proposed system had some merits which would allow it to measure current of any appliance and could also monitor appliance energy consumption. The limitations of the system involved not incorporating crosscutting technologies such as IoT and WSN. The proposed system was not interfaced with potential transformer to measure RMS voltage and furthermore the system did not include appliance control system.

In [28] proposes an automatic energy reporting system which minimizes a lot of human involvement. The power meter system utilizes GSM technology to relay power consumption to clients. The GSM technology is used to establish a full duplex communication between the clients and the server. The end consumer energy meter is on real time communication with the server. The system also involved hardware modules of peripheral interface controller (PIC), power meter. The system had some advantages as it used low-cost hardware platforms like PIC. The limitations of the proposed system included not using disruptive like IoT. The proposed system used electromechanics power meters which need rewiring and expensive to procure. The proposed system did not include appliance control system. The proposed system employed GSM technology which requires base stations to relay data over long distances and may prove to be inefficient.

In [29] proposes a smart energy monitoring system based on PIC18F4620 microcontroller, LCD to display measured parameters and other service information. This part forms the smart sensor monitoring unit (SSMU). The SSMU task was to involve monitoring and storing the measured electrical data. The energy metering unit (EMU) is to measure the energy consumed by the client. The EMU enabled the use of AD7755 metering IC which has high accuracy. The system used serial communication for communication RS232 to communicate with the wireless module which was ZigBee. The drawbacks of the system included not having an appliance control system, not utilizing recent IoT technology like WI-FI and using ZigBee as wireless module which is expensive and costly to setup.

In [30] the author describes the implementation of a monitoring system for renewable energy generation facilities. The system involves various IoT devices not limited Arduino, raspberry pi 3

and LoRa modules as well as LoRa gateway. The proposed system of IoT energy monitoring system was divided into three parts which included IoT sensor node which was collecting power generation status data from the energy device. The second part consisted of the IoT gateway that received and stored data from sensor nodes which were distributed in remote sites. The last part comprised of LoRa which was supporting Wide Area Network (WAN). The merits of the proposed system include the effective design which is based on open IoT platforms of hardware and software. LoRa technology which supports low power of a long-distance networks and do not require base stations of mobile companies. However, the proposed system had some flaws in measuring RMS voltage as it did not include a potential transformer interface. The system had no appliance control system and the system communication technology was using LoRa modules which are costly and the LoRa gateway which is expensive to implement.

In [31] proposed a smart energy system for residential use that had been implemented and modelled results in the management of household appliances during peak hours based on the availability of power sources. The proposed system employed smart algorithms that switched various power sources to improve the distributed system. The author developed an existing automated distribution algorithm that switched between grid supplied power and renewable energy technologies connected to the household based on time. The proposed system rendered a lot of benefits that could be realized by implementation some of them included an automatic switching off of heavy loads, provision of the ability to use alternative sources of energy sources. The proposed system enabled communication between the client and the system using mobile communication GSM technology in particular SMS. The limitations of the system included the use of GSM technology which would require existing base stations which proves inefficient over longer distances and non-usage of disruptive technologies like IoT.

In [32] the author presents a real time energy monitoring system which was implemented in an education institution. The system utilized hardware devices like Arduino microcontroller board, ESP8266 WI-FI module, sensors and emoncms web dashboard. The proposed system was able to measure 3 phase energy consumption of a building which was subdivided into 3 types based on the load type such as lighting, power plug and Air conditioning (AC). The system was able to transmit data through the Wi-Fi module to the web open dashboard monitor at the same instant storing the measured parameters in an SD card through the SD card module. The proposed system was calibrated successfully using fluke 485 power meter to acquire a good result with a much

lower tolerance. The system merits which included high latency of data transmission. Limitations which were accompanied with the proposed system included lack of potential transformer to measure RMS voltage in real-time and also lack of appliance control system which would switch on and off appliances at that particulate instant.

The design and implementation of an IoT energy meter was proposed in [33]. The prototype was used to accumulate power sensor data consumed by different appliances. The main objective of the proposed system of the energy meter was to measure power consumption of load appliances at any desired level. The system would upload data to a designated server and also establish a load control system of any appliance. The proposed system employed the use of Arduino nano, ESP8266 Wi-Fi-module, Split-Core Current Transformer (SCT-013-030). The system would accumulate sensor data from the sensor node and relay it over a web dashboard. The system could be deployed in an industrial setting as well as a residence for monitoring energy footprints. The drawbacks of the system proposed above include not interfacing with potential transformer to sense RMS voltage but rather it was assuming to be 230 V<sub>rms</sub> and computation of power by means of current sensing only which reduces the accuracy of the prototype.

In [34] the author proposed the rapid developments in wireless communication technology and internet of things and embedded systems with the use of microcontrollers there are enormous improvements in automating and monitoring of various industrial aspects by reducing manual approaches which spend much human and material resource [34]. The proposed system consists of two sections mainly the home section and the base station where communication is initiated through a wireless link between these two sections. The system monitors the load to which it is attached to by calculating the power consumed exactly by the user at a particular time. Energy utilized is displayed on the LCD continuously and communicated to the controlling base station. The system utilizes GSM and ZigBee communication which are expensive and doesn't interface a potential transformer to measure RMS voltage.

Referring to the above research works and their limitations this project proposes a smart energy monitoring and control system for traditional factories using a non-invasive technique for RMS current sensing and potential transformer for sensing rms. The internet connectivity is established

through a Wi-Fi module ESP8266. Real-time data for energy consumption and its associated remote monitoring can be implemented by adopting the disruptive concept of IoT.

## 2.0 AC POWER THEORY

### 2.1 Basics of AC power

Power in an electric circuit is the rate flow of energy past a given point in a circuit. In alternating current circuits, energy storage elements such as inductors and capacitors may result in periodic reversals of the direction of energy flow.

#### 2.1.1 Real Power Measurement

Real power is often defined as the power used by a device to produce useful work. The real power is denoted as P measured in Watts (W) and calculated as follows where (V) is the voltage in Volts and (I) current in Amps [35].

$$P = IV \quad (1)$$

The real power of a continuous-time signal is measured as follows where V (t) and I (t) are the instantaneous value of current and voltage [35].

$$P = \frac{1}{T_m} \int_0^{T_m} V(t) \times I(t).dt \quad (2)$$

The real power of a discrete-time signal is measured as follows where V(n) and I(n) are instantaneous discrete values of current and voltage [35].

$$P = \frac{1}{N} \sum_N V(n) \times I(n) \quad (3)$$

#### 2.1.2 Reactive and Imaginary Power Measurement

The power which flows back and forth means it moves in both the directions in the circuit or reacts upon itself. It is a measure of the power going back and forth between the load and the supply that does no useful work.

The magnitude of the reactive power (S) is calculated as follows and is measured in volt-amperes (VA) is calculated by implementing delay between voltage (V) and current (I) signals to base on a phase shift of  $\frac{\pi}{4}$ . [35]

$$S = VI \sin \theta \quad (4)$$

This method holds if signals  $v$  and  $I$  contain the fundamental component of (60Hz) and the phase shift is implemented by shifting the voltage by a quarter a cycle [35].

$$S = \frac{1}{T} \int_0^T V(t) \times I(t + \frac{T}{4}).dt \quad (5)$$

### 2.1.3 Apparent Power

The product of the Root-Mean-Square (RMS) Voltage and the RMS Current is defined as apparent power. For purely resistive loads, real power is equal to apparent power. But for all other loads, real power is less than apparent power.

### 2.1.4 Root Mean Square (RMS) Measurement

The RMS measures the ‘heating’ potential of a signal. The Smart energy monitoring measures RMS of current and voltage signals. RMS measurement of the continuous signal is as follows where  $v(t)$  and  $I(t)$  are the instantaneous values of voltage and current.  $T_m$  is the length of a single period of the measured analog signal [35].

$$V_{RMS} = \sqrt{\frac{1}{T_m} \int_0^{T_m} v^2(t).dt} \quad (6)$$

$$I_{RMS} = \sqrt{\frac{1}{T_m} \int_0^{T_m} I^2(t).dt} \quad (7)$$

RMS measurement of the discrete signal is as follows where  $v(n)$  and  $i(n)$  are the corresponding discrete values of voltage and current.  $N$  is the number of samples in a single period of the discrete signal [29].

$$V_{RMS} = \sqrt{\frac{1}{N} \sum_N v^2(n)} \quad (8)$$

$$I_{RMS} = \sqrt{\frac{1}{N} \sum_N i^2(n)} \quad (9)$$

### 2.1.5 Relationship between real, reactive and apparent power for IDEAL sinusoidal loads

The relationship between real apparent and reactive power is given by the equations (10,11,12) [38]

$$RealPower = ApparentPower \times \cos \Phi \quad (10)$$

$$ReactivePower = ApparentPower \times \sin \Phi \quad (11)$$

$$ReactivePower = ApparentPower \times \sin \Phi \quad (12)$$

$\cos \Phi$  is also known as the power factor.

### 2.1.6 Power Factor

The ratio of active to apparent power in a circuit is called the power factor. When current and voltage are in phase, they have a power factor of 1 [38].

$$PowerFactor = \frac{RealPower}{ApparentPower} \quad (13)$$

### 2.1.7 Electric Energy

Energy is defined, as the ability to do work in the utilitarian perspective of energy []. Monitoring energy consumption provides a benefit to relate to the costs of running electrical systems which have advanced due to technological evolution. This in turn result in intensive energy resource consumption. [52]

The total amount of electrical energy used depends on the total power used by all your electrical devices and the total time they are used in your home. But Energy (E) in Joules (J) is denoted by Active Power (P) in Watts (W) multiplied by Time (T) in Seconds as given in the following equation (14) [29].

$$E = P \times T \quad (14)$$

According to the definition of active power which is denoted as from the equation (15) below [29].

$$P = \frac{1}{T} \int_0^T V(t) \times I(t).dt \quad (15)$$

The equation for calculating electric energy is derived from integrating equation (15) for a specified time (T) [29].

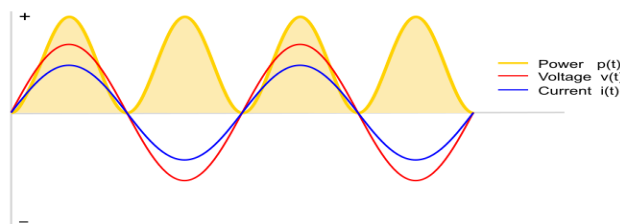
$$E = T \times \frac{1}{T} \int_0^T V(t) \times I(t).dt \quad (16)$$

$$E = \int_0^T V(t) \times I(t).dt = \sum_0^N V(n) \times I(n) \quad (17)$$

## 2.2 TYPES OF LOADS

### I. Resistive Loads

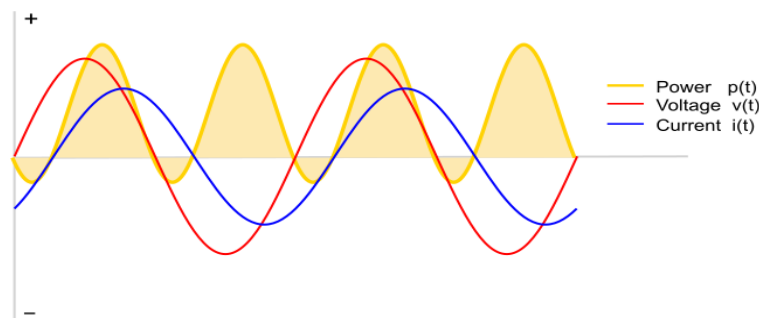
Resistive loads use all the energy supplied to them. These resistive loads current draw is equal to the voltage divided by their resistance (Ohm's Law). A purely resistive load gives a voltage and current waveform output similar to the following: Examples include light bulbs, iron, kettles, and water heaters [38].



*Figure 1.0– Voltage and current phase relationships in a resistive load*

## II. Partially Reactive Load

Straightforwardly, these appliances draw in a certain amount of energy, then release some energy back into the mains supply. These have inductive (e.g., motors) or capacitive (e.g., arc welders) components in addition to the resistive component. A partially inductive load gives a voltage and current waveform output similar to the following [38].



*Figure 1.1 – Voltage and current phase relationships in a partially reactive load*

### 2.3 IDENTIFICATION OF MICROCONTROLLERS AND SENSORS

The design of the smart energy monitoring and control system consists of a hardware part that will comprise sensors and microcontrollers. These include Arduino Uno, ESP8266 Wi-Fi module, Split Core Current Transformer (SCT013), Electromechanical relays, 20 x 4 LCD Display, and Voltage Sensor.

#### a) Arduino Uno

Arduino Uno is a microcontroller board based on ATmega328P. It consists of 14 digital input and output pins. It is an open-source prototype development platform wherein the hardware and software are easy to use. This microcontroller is capable of reading analog inputs. Arduino has been a popular choice for many projects and applications since it is cheap, locally found, and powerful compared to other microcontroller platforms [37]. It is also cross-platform as Arduino IDE runs on Windows, Mac OS, and Linux environments. It is simple with a clear programming environment and has extensible hardware.





*Figure 2.0. Arduino Uno Microcontroller*

### **b) ESP8266 WI-FI module**

The ESP8266 is a low-cost Wi-Fi module that has a TCP/IP stack and also comprises of an inbuilt microcontroller manufactured by a Shanghai-based manufacturer Espressif Systems.

This small module allows microcontrollers to connect to a Wi-Fi network and make simple TCP/IP connections using simple AT commands. The module has 1MB of flash memory consenting the devices capable of connecting to available Wi-Fi [40].

Features of the ESP8266 Wi-Fi Module include:

- 802.11 b/g/n
- Wi-Fi Direct (P2P), soft-AP
- Integrated TCP/IP protocol stack
- 1MB Flash Memory
- Integrated low power 32-bit CPU
- SDIO 1.1 / 2.0, SPI, UART



*Figure 2.1. ESP8266 WI-FI module*

**c) Split Core Current Transformer (SCT013)**

In this project, a Split Core Current Transformer (SCT013) will be used to measure current. It comprises of very precise low offset, linear Hall sensor circuit along with a copper circuitry path near the surface of the cast. Split Core Current Transformer (30A max) is a non-invasive current sensor clamped around the supply line that can measure up to 100 Amps of current and enables users to calculate how much current pass through the supply line. It can be useful for building your energy consumption monitor or for building an over-current protection device for an AC load [38].



*Figure 2.2 Split Core Current Transformer*

**d) Electromechanical Relay Module**

An electromechanical relay is can be defined as an electrically operated switching device. Most electromechanical relays use an electromagnet to mechanically operate a switch. Relays are mostly used where it is necessary to control a circuit by a digital output signal, or where several circuits must be controlled by one signal. In this project, relays will be used to control loads for efficient energy-saving techniques [41].



*Figure 2.3 Electromechanical Relay Module*

#### e) 20 x 4 LCD Display

LCD (Liquid Crystal Display) screen is a display device and has vast applications in electronics. A 20X4 LCD has been selected for display purposes in this energy monitoring research project. It consists of 20 columns and 4 rows. It is cheap and easily found, easy to program, and allows special and custom characters display. 20x4 display can display up to 20 characters in each of the four rows. Each character is displayed in a 5X7 matrix format [42].



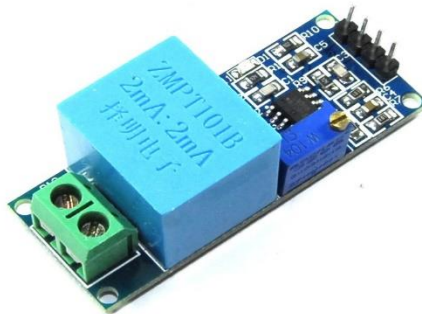
*Figure 2.4. 20X4 LCD*

#### f) ZMPT101B, a voltage transformer

ZMPT101B, a voltage transformer is an ideal device to measure the AC voltage. It has high accuracy, good consistency for voltage, and power measurement and it can measure up to 250V AC. It is simple to use and comes with a multi-turn trim potentiometer for adjusting the ADC output [39].

##### Features

- Measure within 250V AC
- Onboard micro-precision voltage transformer
- Analog output corresponding quantity can be adjusted
- Very efficient and accurate
- Good consistency, for voltage and power measurement
- Output signal: Analog 0-5v

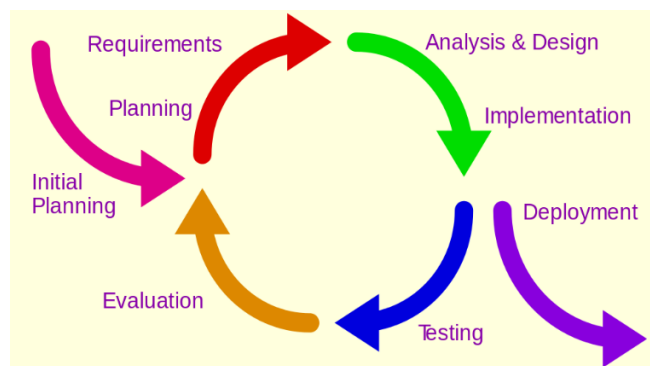


*Figure 2.5. ZMPT101B a voltage transformer*

### CHAPTER THREE: RESEARCH METHODOLOGY

The design and implementation of smart energy monitoring and control system takes an iterative prototyping approach in line with the project-specific objectives. The iteration will involve sequential testing and refinement of the prototype of sensor node monitoring current, voltage, and real and apparent power values.

The iteration of the prototype is a key technique in the methodological approach that will allow gradual achievements of the requirements needed to meet the desired aim of real-time energy monitoring. This prototyping approach involves a set of techniques used to reduce the effort and cost required to design the prototype of smart energy monitoring [44]. The design of the prototype involves several variables such as testing, timing, ideation, fixation, usability and fidelity [43]. The testing section produces a clear and concise testing objective. Early prototyping is most critical aspect which is put in consideration to lead functional ideas. Early prototyping reduces fixation and induces feedback regarding the designed prototype. The fidelity representation leads to accurate interpretation of the designed prototype hence the appropriate level of fidelity must be selected depending on the objective. [43] The benefits of iterative design approach are not limited to cost-effectiveness but also provides on adding value to the design and gives a strongly desired performance framework for acceptance and testing. It also gives stakeholders better visibility of the progress of each iteration [43].



*Figure 3.0. Step by Step Iterative prototyping approach [44]*

The iterative design approach has aspects of rapid prototyping and also called spiral prototyping. It involves a cycle in design and development process. It clearly indicates that iteration is taking place. Prior to the iterative approach it has to deal with initial planning before the actual planning

of the development process cycle. From planning and acquiring the requirements of the prototype analysis and design follows. This is where the prototype viability is validated before the actual design implementation. Testing the prototype if it meets the specified requirements then evaluation based on the feedback is conducted [44]. The cycle is repeated several times before the actual deployment hence acquiring a fine prototype based on iterative process.

The prototype design of a real-time industrial smart energy monitoring and control system would enable better insights into the energy and power quality data in the traditional industries. This will lead to reduced downtime of equipment in an industry-leading to financial benefits of the traditional factories [44]. The smart energy monitoring and control system is a lab-based prototype that will be deployed in a traditional factory setting and be able to gather sensor data involving power consumption of loads in this case an LED light bulb and display on a web dashboard and also display sensor data in real-time.

### **3.0 Interfacing of Microcontrollers and Sensors**

The Arduino Uno microcontroller is interfaced with the split-core current transformer (SCT013) hall effect sensor for measuring current, voltage sensor, electromechanical relays, 20X4 LCD. This part of the sensor node responsible for sensor data collection from the traditional factory in the form of voltage, current and will also provide actuation strategies for the control system of loads.

The split-core current transformer will analyze the current while the voltage sensor will analyze the current and feed the sensor data to the Arduino Uno microcontroller. Both of these sensors provide analog sensor data which is converted to digital using A-D converters in the microcontroller. The current, voltage, energy consumption, and power sensor data will be collected from the Arduino Uno thereby fulfilling the first objective of this research.

The second part of the interfacing is involving a communication protocol to connect the sensor node to the internet which initiates a wireless connection between the web and the sensor node. This stage will involve interfacing the ESP8266 Wi-Fi module with the rest of the sensor node to initialize a connection and enable the sensor node to communicate with the cloud platform. A web-based dashboard is developed to display the energy sensor data and control system for controlling

loads in the traditional factory setting using the interfaced relays. This methodological approach will be able to meet the second objective outlined in this research project.

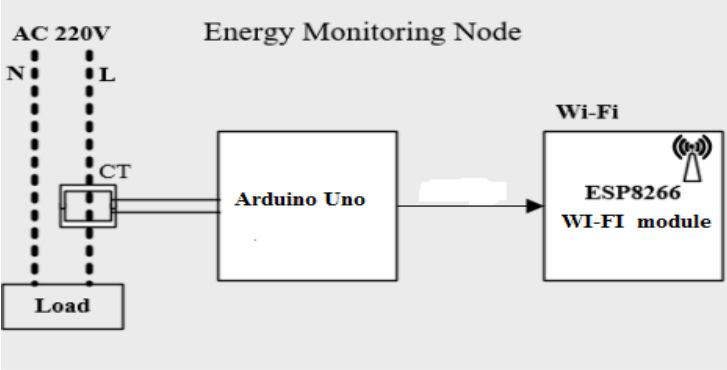


Figure 3.1 Energy monitoring node [24]

The figure 3.1 illustrates simple diagram of the developed IoT energy monitoring node where a current transformer is clamped to a voltage supply line and collects sensor data to the Arduino microcontroller which is interfaced with the ESP8266 Wi-Fi module.

### 3.1 Flow Chart of the Methodological Approach

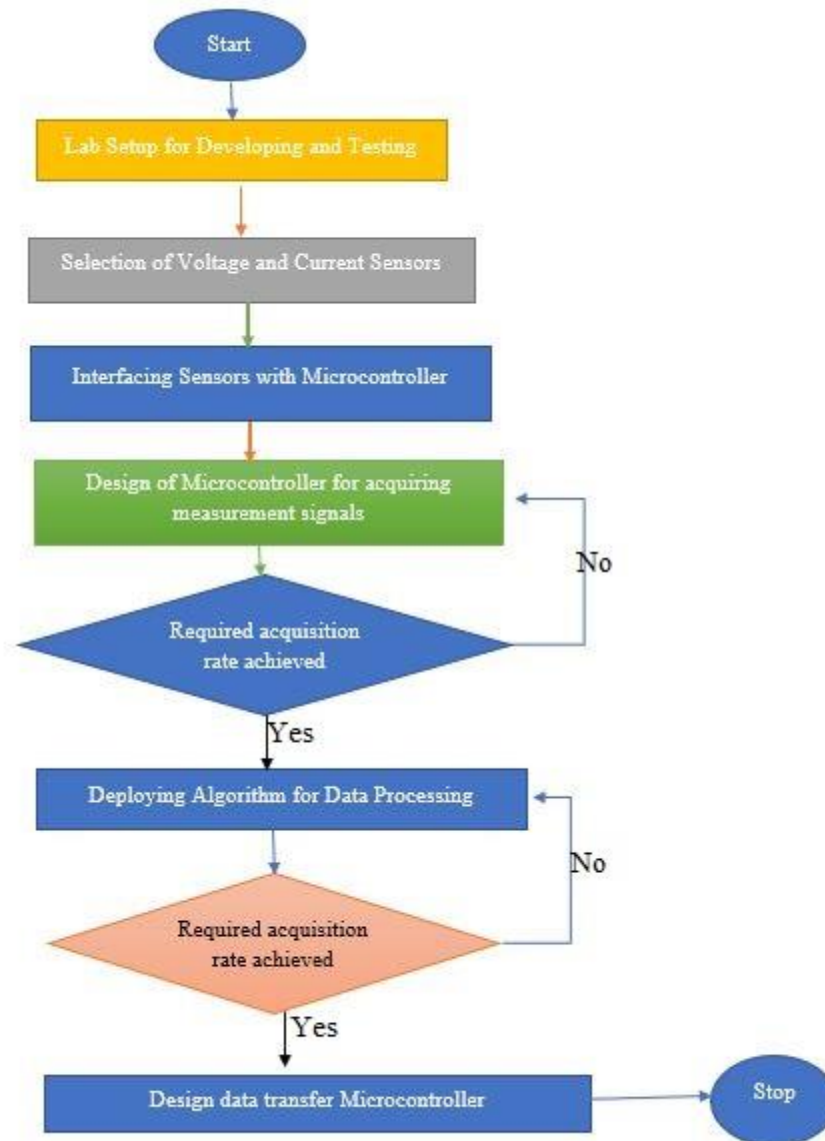


Figure 3.2 Methodological Approach Flow Chart [50]

The general methodology for the project flow is given in Figure 3.2 The details of the flow chart are as follows:

**Step 1**

The Development and Testing of the meter needs a stable laboratory power source with variable voltage and current settings from the start. Digital multimeter and Oscilloscope would be required for calibration and to test the accuracy of the prototype.

**Step 2**

Voltage and Current sensors are to be selected to provide the required accuracy for the calculation of Power Quality parameters. In this case Split Core Current transformer and Voltage transformer.

**Step 3**

The interfacing of the sensors to the microcontroller requires the conditioning of the output analog signal to acquire the desired sensor data.

**Step 4**

The algorithms for calculating the required data from the measured values are to be deployed and optimized to achieve the required processing rate.

**Step 5**

When the required processing rate is achieved sensor, data is transferred to the microcontroller and then the process is stopped.



## CHAPTER FOUR: SYSTEM ANALYSIS AND DESIGN

The smart energy monitoring and control system of traditional factories consists of several modules which collectively work hand in hand to gain desired results of real power, apparent power, power factor, RMS Voltage, and RMS Current. The modules include Power supply, the voltage sensor circuit, current sensor circuit, microcontroller, relay shield, and LCD.

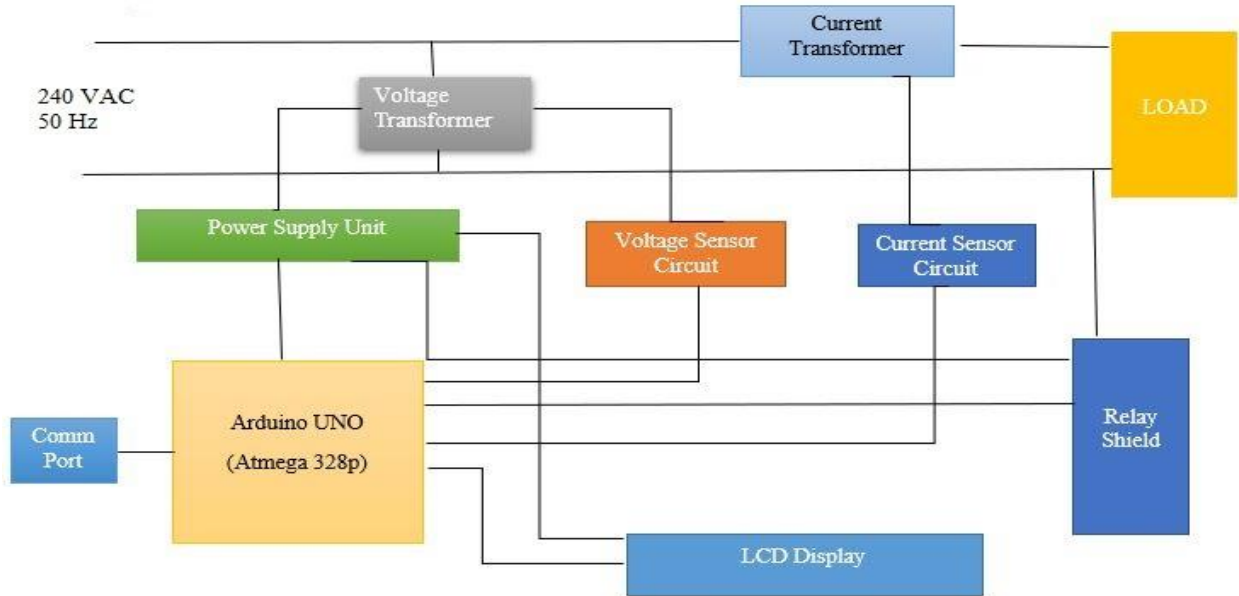


Figure 4.0. Functional System Design Diagram

### 4.0 SYSTEM DESIGN

#### I. Power Supply

The AC mains supplies 230V of AC at the desired frequency of 50Hz. There is a need for rectification and filtering to have smooth filtered DC power to operate the modules. A voltage transformer is used to step down the 230V AC to 12VAC. The AC signal is converted to DC through a full-wave bridge rectifier followed by filter capacitors. The final stable DC outputs are achieved using voltage regulator integrated circuits.

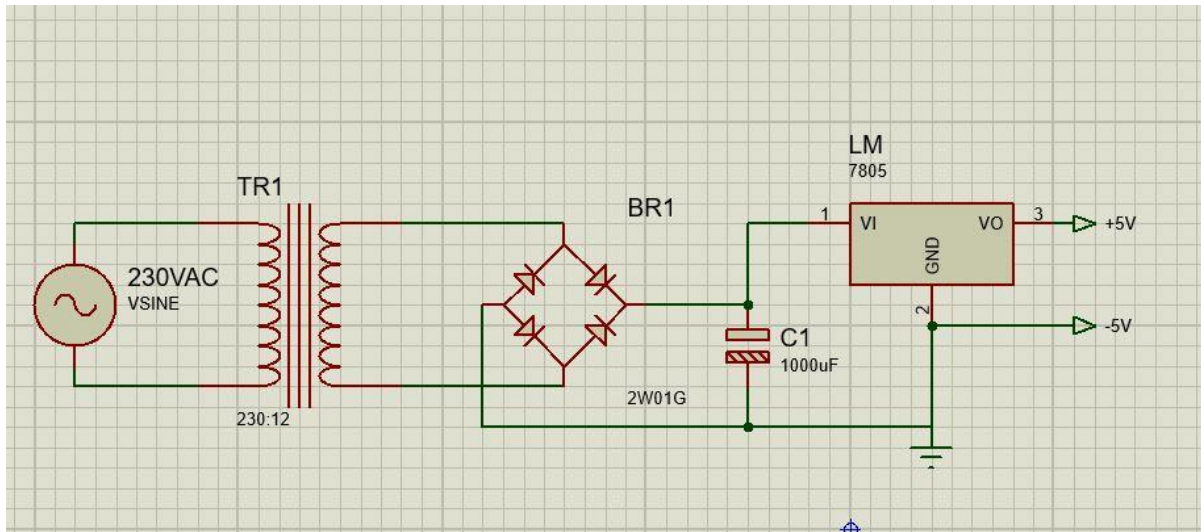


Figure 4.1 Diagram of Power Supply Circuit

## II. Voltage Sensor Circuit

The mains 230v AC is stepped down to 12v AC by the potential transformer. Then a voltage divider circuit divides the 12V into the ratio of 1:10 which induces a sinusoidal signal. A DC offset of 2.5V is applied to the signal which results in the whole sinusoidal signal within a positive boundary of (0-5V) [10]. This in turn can enable the Arduino microcontroller to read the whole sinusoidal signal through its analog input. The circuit diagram of the voltage sensor circuit is shown below.

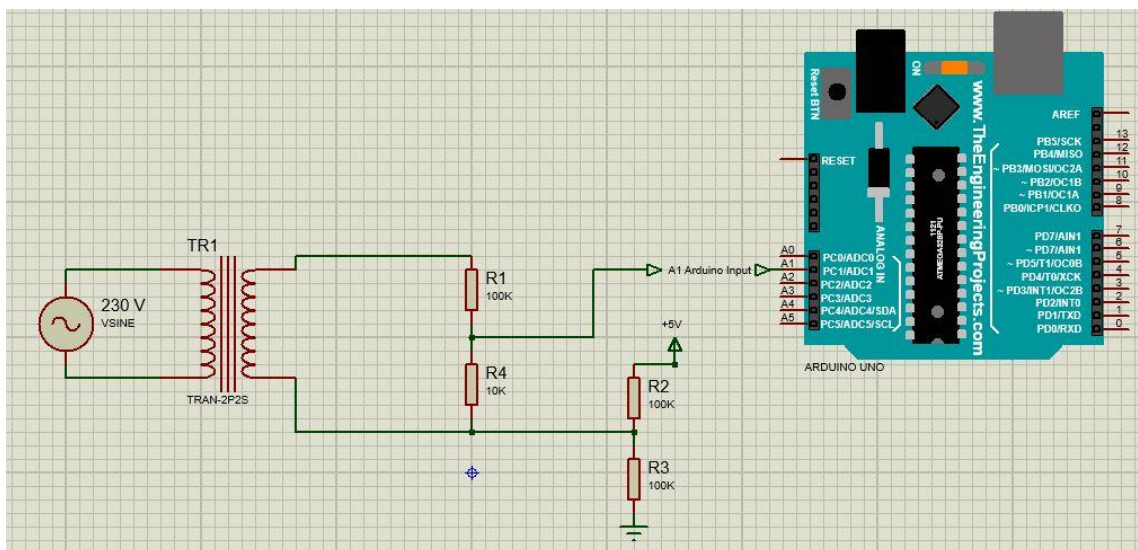


Figure 4.2 Diagram of Voltage Sensor Circuit

**III. Current Sensor Circuit**

The end devices were created using two principal components the SCT (Split-Core Current Transformer) and the Arduino. The signal of the current which is flowing through the mains is retrieved through a split-core current transformer. The burden resistor does the transformation of the current signal into the desired voltage that represents the properties of the current sinusoidal signal. A DC offset voltage is fed to the current sinusoidal signal so the reference is elevated and the whole signal can be read in analog mode in the specified range of 0-5V [10]. The circuit diagram of the current sensor circuit is shown below.

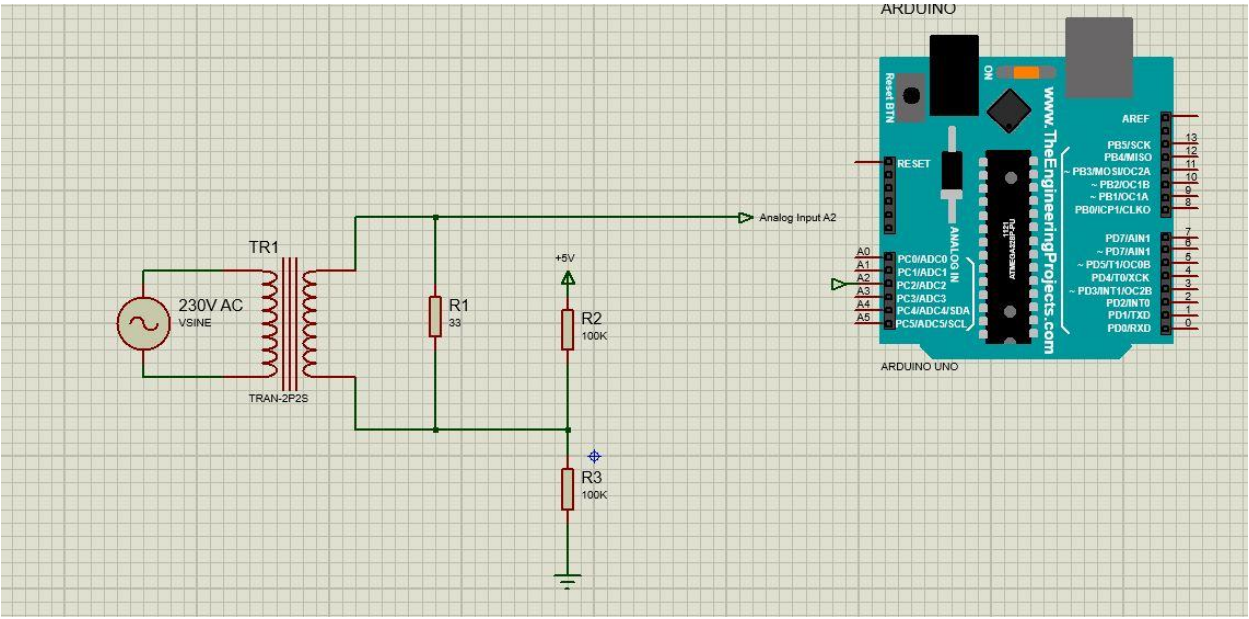


Figure 4.3 Diagram of Current Sensor Circuit

**IV. Microcontroller Interfaced with 20X4 LCD, ESP8266 Wi-Fi Module and Relay Module Circuit Design**

There is need to incorporate the interfacing of the Arduino Uno to the communication protocol which is the ESP8266 Wi-Fi module and the load controlling relay module is connected to the ESP8266 Wi-Fi module through the digital pin D1. The Arduino and the ESP8266WIFI module are connected through serial communication using the digital pins 0 (RX) and 1 (TX). The Arduino Uno Microcontroller is also interfaced with the 20 X 4 LCD from (D4, D5, D6, D7) to digital pins (5,4,3,2).

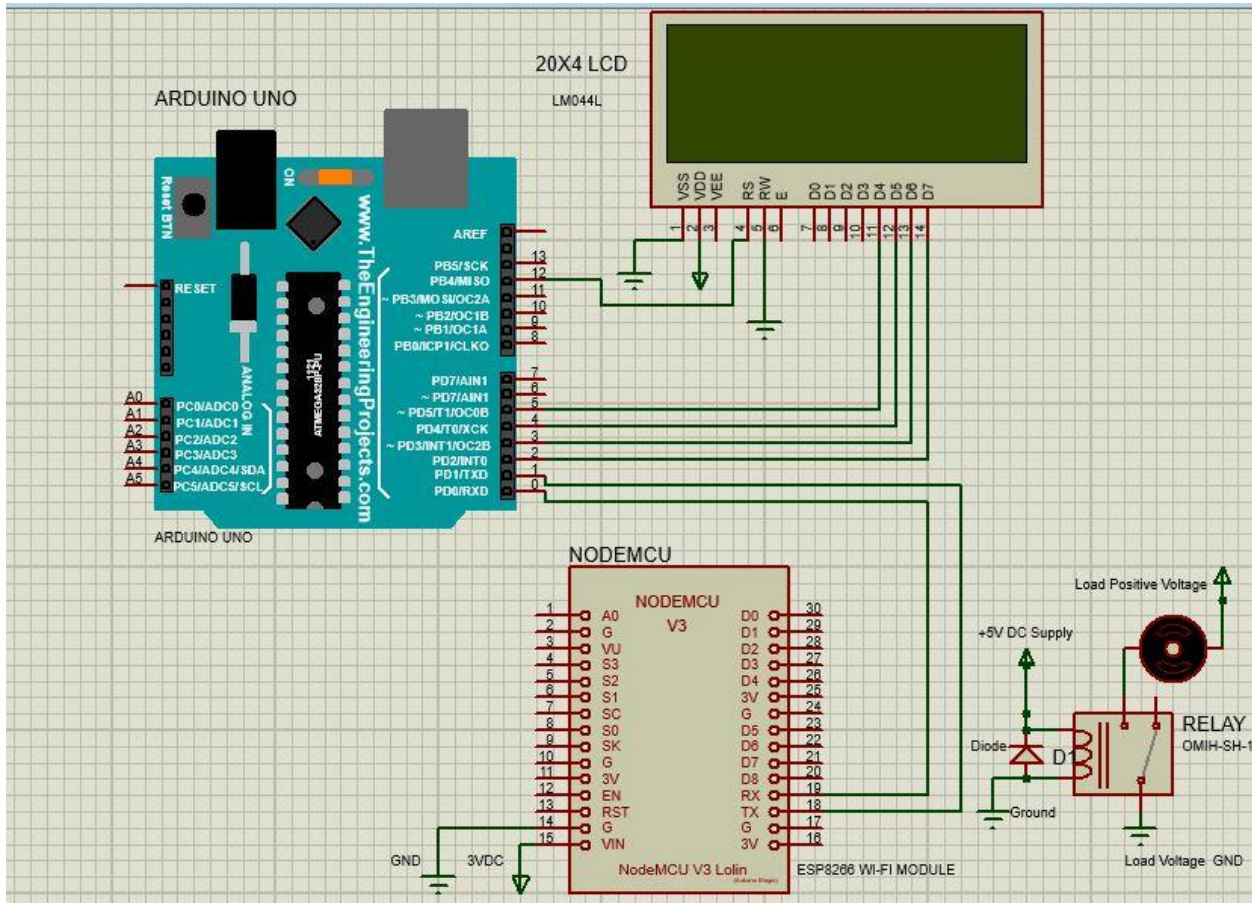


Figure 4.4 Diagram of MCU interfaced with 20X4 LCD, ESP8266 WI-FI module and Relay

## 4.2 TECHNICAL DESIGN

The technical design of the system can be logically described in main two main steps, namely, Emonlib library inclusion, calibration of Emonlib.

### I. Emonlib library inclusion (Arduino Monitoring Library)

Emonlib is an open-source library developed for energy monitoring purpose. This library provides an effective way to transform input analog voltage from ADC into current readable value that can be calibrated and be able to calculate the mains voltage, mains current, real power, reactive power, apparent power and power factor [38].

For each reading number of fundamental samples are defined. The bigger the number of samples the longer the method to calculate RMS current and voltage. The library uses the following equation [1].

$$U_{RMS} = \sqrt{\frac{\sum_{n=0}^{N-1} u^2(n)}{N}} \quad (18)$$

Suppose  $N$  equals the number of samples,  $u(n)$  being the voltage sample we get from ADC input. This  $U_{rms}$  value is then multiplied by the calibration coefficients, based on the value we define at the beginning for each ADC input.

Then using equation (15) [1]

$$U_{RMS} \times calcoef \quad (19)$$

results in the current values which is denoted as  $I_{rms}$  that will be used to calculate apparent power by multiplying with  $V_{rms}$ [1].

## II. Calibration of Emonlib

The components used in the current and voltage circuits lead to some factors which are needed to be determined. These factors are laid as arguments in the EmonLib methods for accurate power calculations. The stepdown and voltage divider ratios of split-core Current Transformer and potential transformers determine the calibration constants for voltage and current. The calibration of sensors it's for each ADC input [1].

Calibration has a theoretical value based on the Current Transformer ratio (CT) and burden resistor used as shown in the equation (16) below [1].

$$CalValue = \frac{CTratio}{BurdenResistor} \quad (20)$$

The sources of errors in these sensors may arise due to factors not limited to;

- Current Transformer Materials
- Burden Resistor ( $\pm 1$ )
- Arduino analog reference
- Power Source

### 4.3 ALGORITHMS FOR THE SYSTEM

#### I. Algorithm RMS Current and Voltage

In the preliminary stage the values of instantaneous current and voltage are received from the analog sensors of split core current transformer and voltage transformer respectively to the Analog to Digital controller of the microcontroller. The digital values are squared and results are accumulated. The accumulated results are multiplied by a stored number (1/N) to produce a final result which have to subjected to a square root operation to produce an RMS value. Calculation of a single RMS current and Voltage requires N additions and 1 multiplication [45]. The Algorithm for RMS Current and Voltage flow is presented in figure 4.5

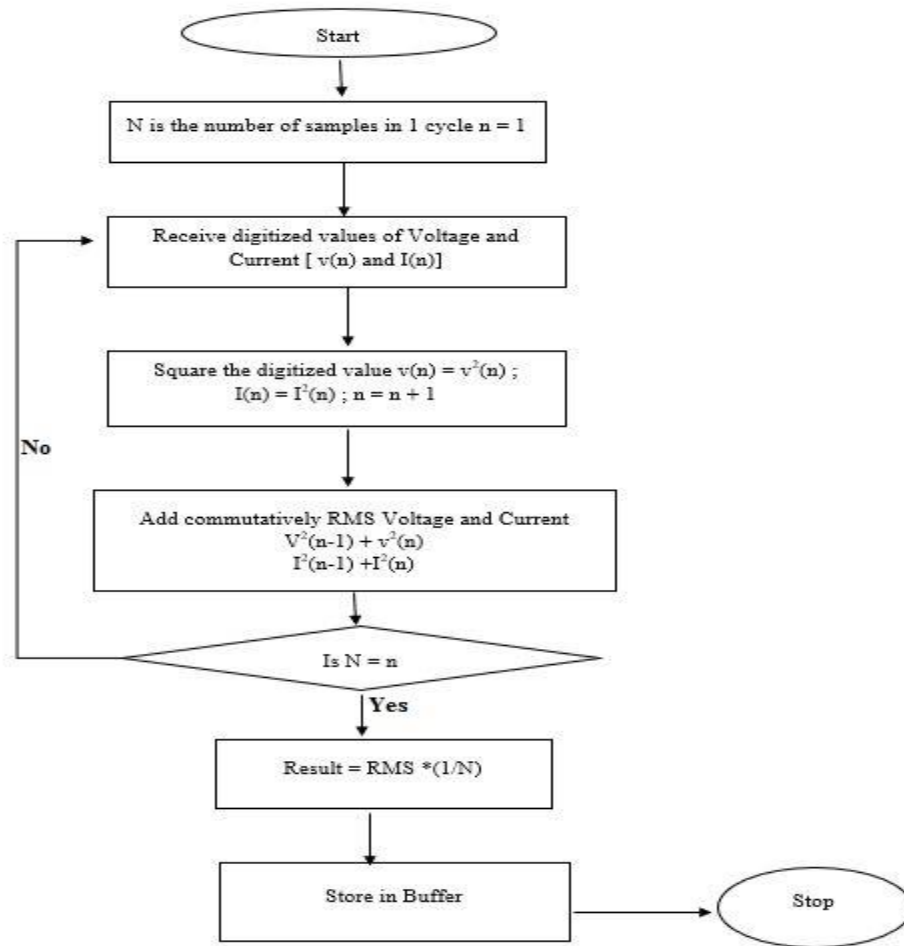


Figure 4.5 Diagram of Algorithm for RMS Voltage and Current Calculation [45]

## II. Algorithm for Real Power

In the algorithm for real power calculation has instantaneous current and voltage values received are multiplied to calculate instantaneous power. Instantaneous values of power are cumulated for a single fundamental component. The resulting power value is multiplied by  $(1/N)$  where  $N$  is the number of samples [45]. The algorithm for real power is represented in figure 4.6.

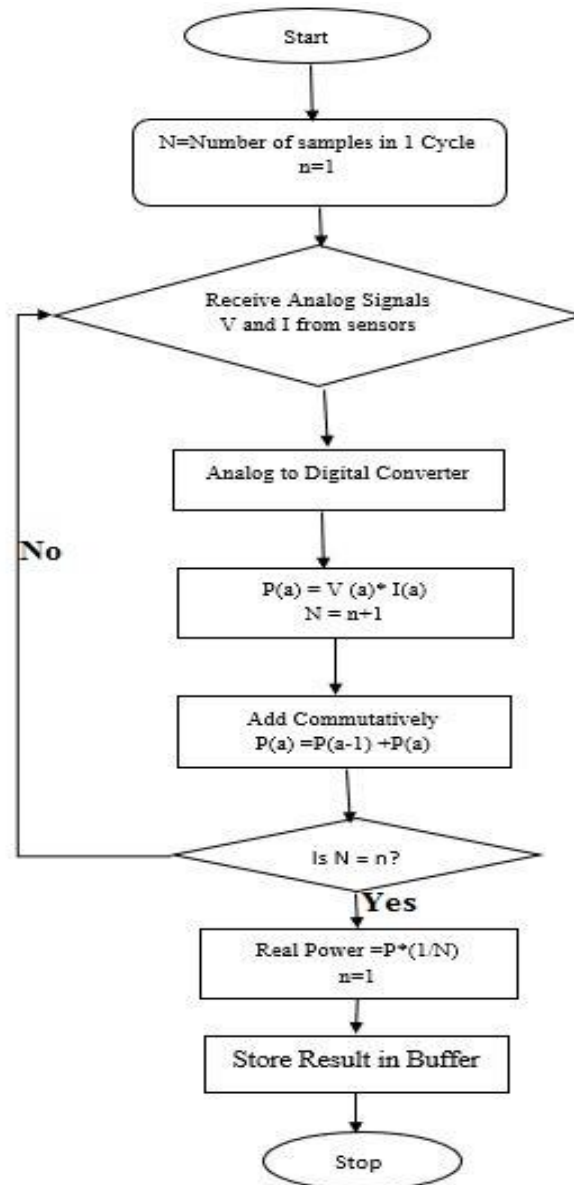


Figure 4.6. Diagram of Algorithm for Real Power Calculation [45]

**III. Algorithm for Apparent Power and Power Factor**

In the algorithm for apparent power calculation. The analog current and voltage signals are processed to digital from analog state. The RMS current, RMS voltage and phase shift between the two signals is measured. The RMS current and Voltage are multiplied to result Apparent Power (S). The power factor is calculated by the ratio of real power to apparent power [45].

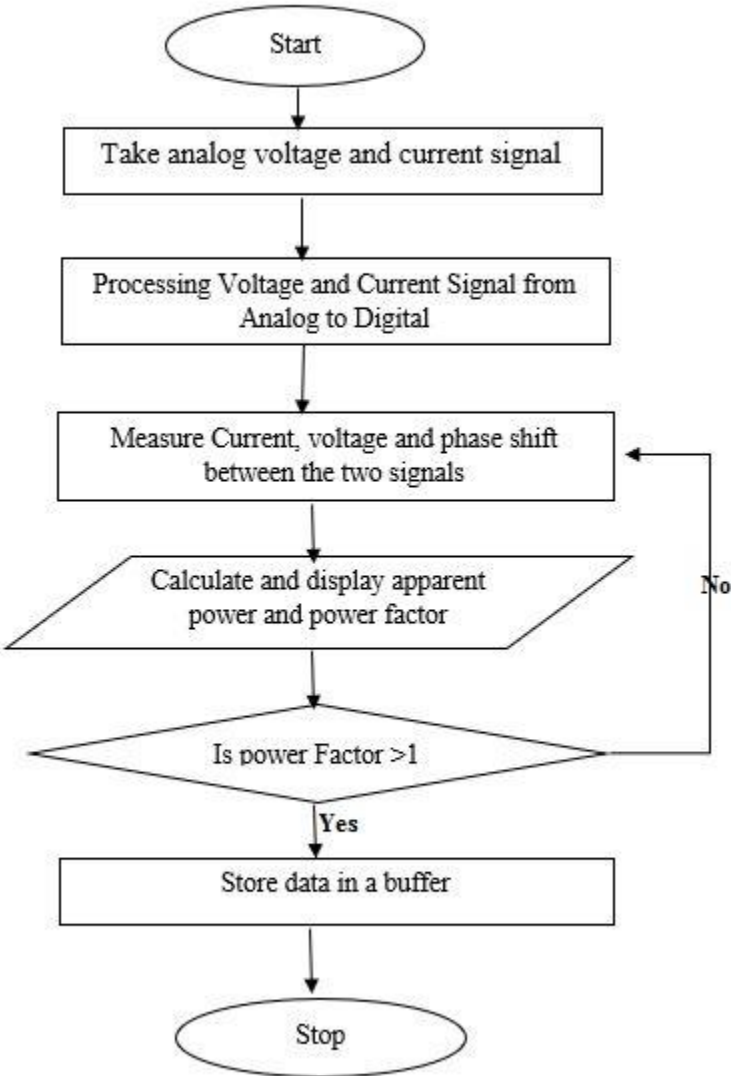


Figure 4.7 Diagram of Algorithm for Apparent Power and Power Factor Calculation [45]



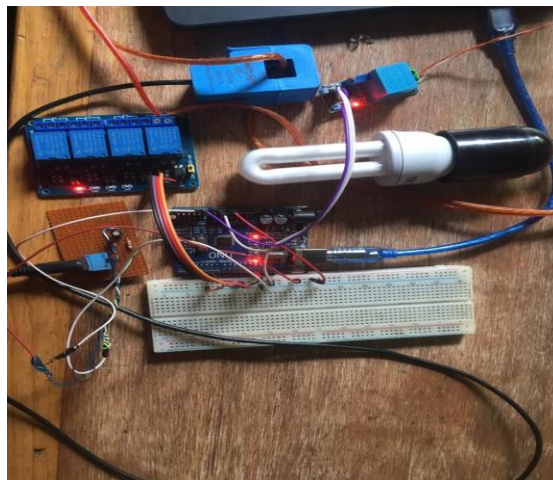
#### 4.4 SYSTEM IMPLEMENTATION

In this section Implementation of system of the designed system is discussed where the programme code is written in Arduino IDE then flashed in the microcontroller. The EmonLib library is utilized which has algorithms to compute several energy parameters starting from RMS Voltage and Current, Real and Apparent power. The split core current transformer is hooked to Load TNT Led (25W) with 220-240 V AC input Voltage. The voltage transformer is connected to the mains supply of the grid.

The sensor signals collected is fed to the analog inputs A0 and A1 of the Arduino microcontroller where algorithms are processed computation of sensor data in the form of RMS Voltage, RMS Current, Real Power, Apparent Power, Power Factor and Energy. The sensor data is collected through serial communication in real time and then plotted the results through MATLAB. The load is also interfaced with relay module for control purposes when threshold energy usage is reached to switch it on and off.

#### 4.5 Implemented Prototype Design for Energy Monitoring

The figure 5.0 shows the implemented prototype design of the energy monitoring system in a traditional factory setting with a TNT LED as a load where SCT013, Voltage transformer and relay module are interfaced with the Arduino microcontroller to get the desired experimental results.



*Figure 4.8. Prototype Design for Arduino Energy Monitoring*

## CHAPTER FIVE: RESULTS AND ANALYSIS

This chapter outlines the implemented prototype design and also discusses the results findings and basic descriptive statistics of the data collected from the prototype. The results range from RMS Voltage, RMS current, Real Power, Apparent Power, and Power Factor.

### 5.2 Results and Discussions

#### 1. RMS Voltage

The microcontroller Arduino Uno collected RMS Voltage which is discussed in the figure 5.0 below. The graph is producing a sinusoidal waveform and giving some kind of heating effect related to DC power. The graph is clearly elaborating time varying sinusoidal voltages where the magnitude is of the waveform is changing over time. The RMS Voltage is measured by considering a cycle of the waveform and can help in calculating Power consumption in traditional factories which is a key player in energy monitoring in traditional factories.

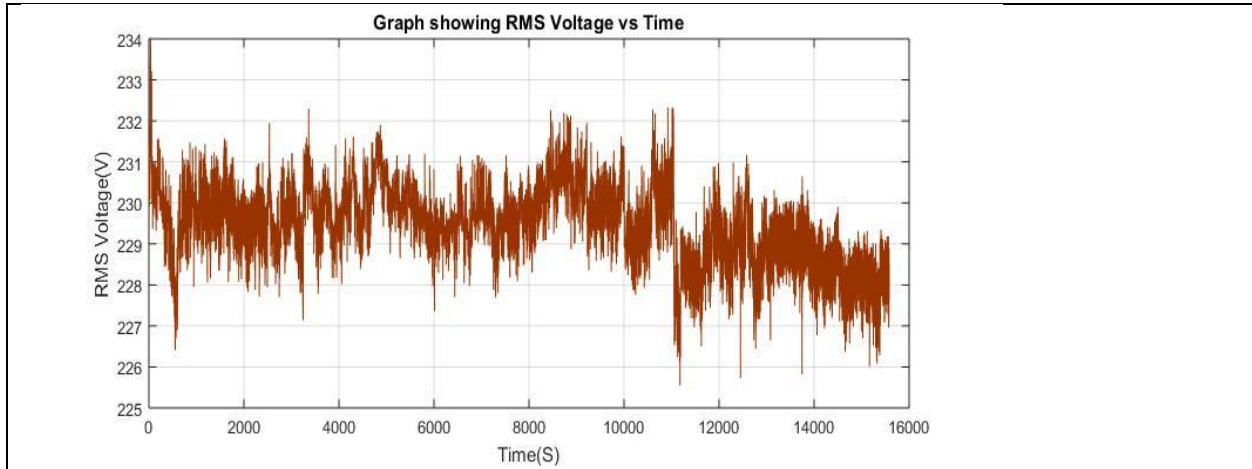


Figure 5.0. Graph showing RMS voltage in Volts (V) against Time (S)

#### Basic Statistical Analysis for RMS Voltage (V)

Parameter	Value
Minimum Value	225.6
Maximum Value	234
Mean	229.5
Median	229.6
Mode	228.8
Standard Deviation	0.9452
Range	8.43

Table 1. Basic Statistical Analysis for RMS Voltage

## 2. RMS Current

The designed prototype was able to collect RMS current data which was accurate and varied from 0 to 0.55 amps and giving a true reflection of the connected load. This shows that the Arduino microcontroller can be used to implement a desirable energy monitoring system which has minimal errors.

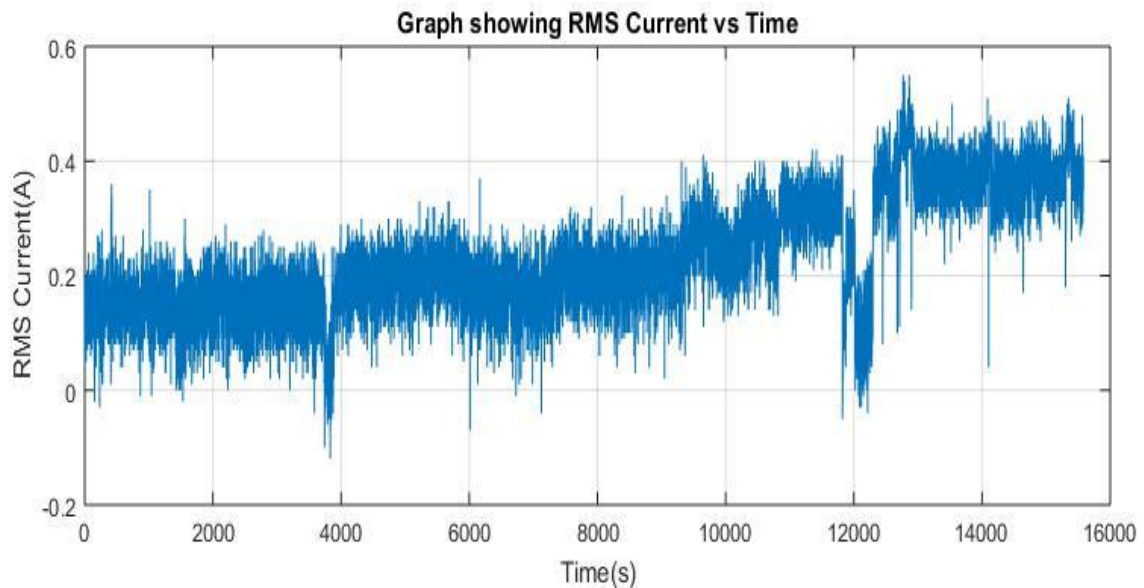


Figure 5.1. Graph showing RMS Current in Amps (A) against Time (S)

### Basic Statistical Analysis for RMS Current (A)

Parameter	Value
Minimum Value	0
Maximum Value	0.55
Mean	0.2304
Median	0.21
Mode	0.81
Standard Deviation	0.1001
Range	0.55

Table 2. Basic Statistical Analysis for RMS Current

## 3. Real Power

The real power was calculated based on RMS current and voltage multiplication and produced results which are in the figure below. The real Power value had some minimum of 0.11 and

maximum of 79.09 Watts. This was depicting the load which was connected and was giving a true reflection hence this prototype can be used to determine energy usage in factories. Minor errors which were encountered could be as a result of calibration errors.

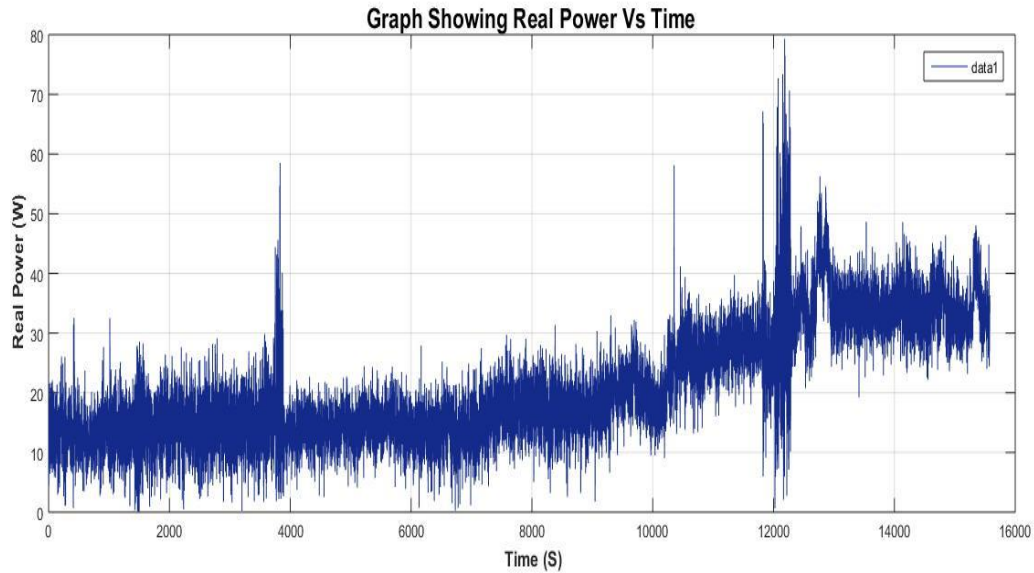


Figure 5.2. Graph Showing Real Power (W) against Time (S)

#### Basic Statistical Analysis for Real Power (W)

Parameter	Value
Minimum Value	0.11
Maximum Value	79.29
Mean	21.08
Median	18.28
Mode	12.84
Standard Deviation	9.71
Range	79.18

Table 3. Basic Statistical Analysis for Real Power (W)

#### 4. Apparent Power

The apparent power which is greater than real power is realized in the figure below. The apparent power is greater than real power in other loads. This clear indicates that the apparent power collected from the prototype gives a true reflection of the power consumption of the system and can show better power quality and aid companies to make informed decisions concerning their

energy usage. The shooting peaks as a result of minimal sensor error range and voltage fluctuations.

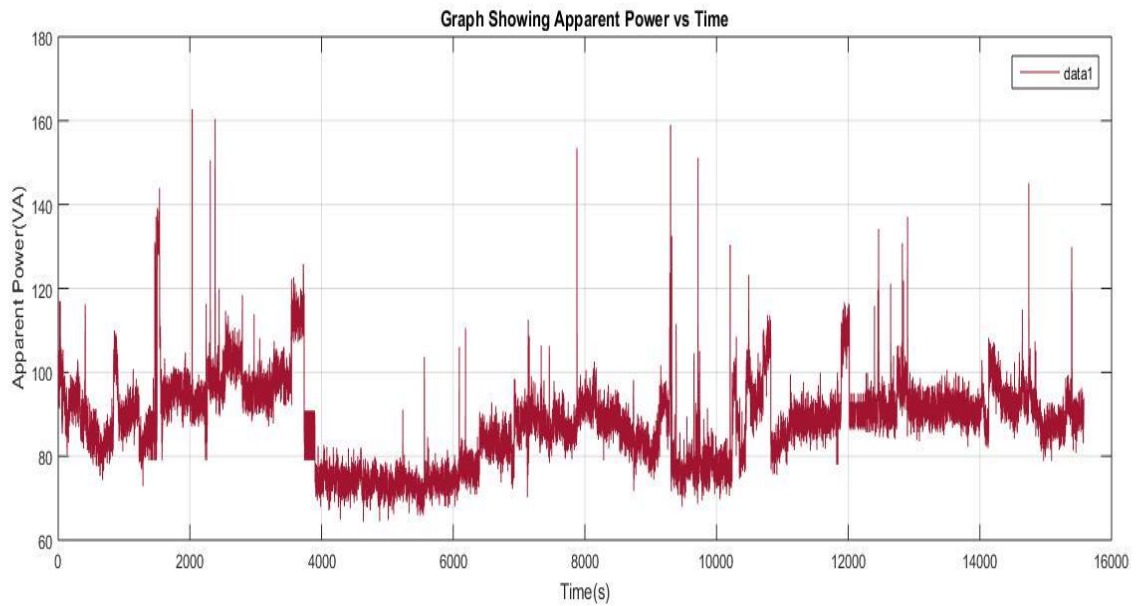


Figure 5.3. Graph Showing Apparent Power (VA) against Time (S)

### Basic Statistical Analysis for Apparent Power (VA)

Parameter	Value
Minimum Value	64.34
Maximum Value	198
Mean	88.47
Median	88.92
Mode	99.04
Standard Deviation	10.58
Range	133.6

Table 4. Basic Statistical Analysis for Apparent Power

### 5. Power Factor

The power factor is calculated and the result is shown in the graph below against time. The real power divided by the apparent power is giving the desired power factor which has the maximum of 1 showing 100%. The power factor shows the power quality of the system can be largely desired hence implementing the system in a traditional setting must be of paramount importance. The peaks outline the maximum power factor induced by voltage fluctuations.

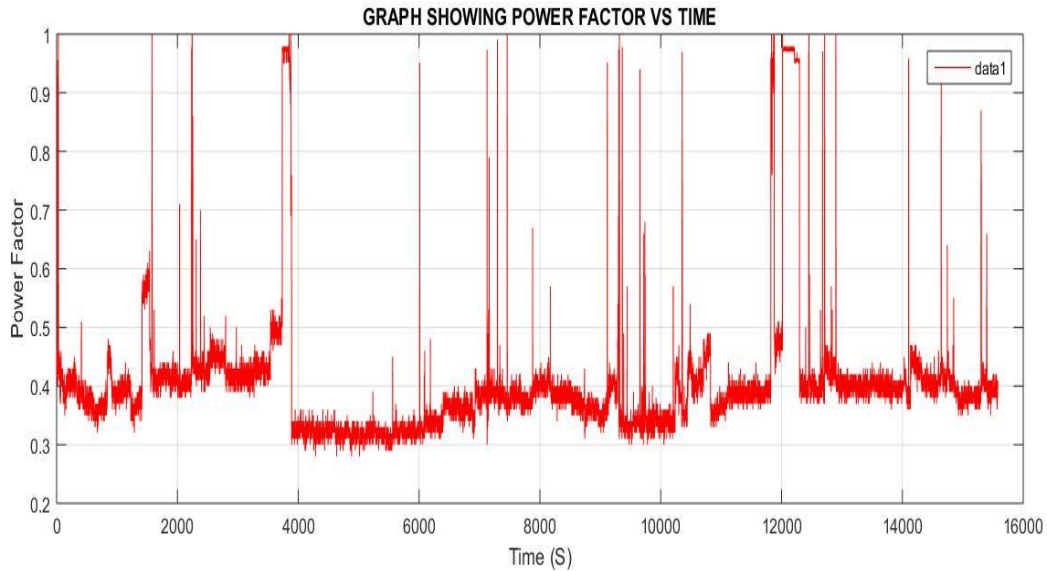


Figure 5.4. Graph Showing Power Factor against Time (S)

### Basic Statistical Analysis for Power Factor

Parameter	Value
Minimum Value	0.28
Maximum Value	1
Mean	0.4044
Median	0.39
Mode	0.4
Standard Deviation	0.1137
Range	0.72

Table 5. Basic Statistical Analysis for Power Factor

### 6. Energy Consumption

The energy is shown in the graph below where real power in watts and time in seconds are multiplied and the result is in watt second. The graph clearly shows the energy consumption of a load LED which was connected. The graph shows the best quality depicted of energy consumption and can be utilised in large industrial setting without problems. The fluctuations of the peaks are as a result of voltage changes of the grid due to the nature of the wires used and the voltage fluctuations from the utility company.

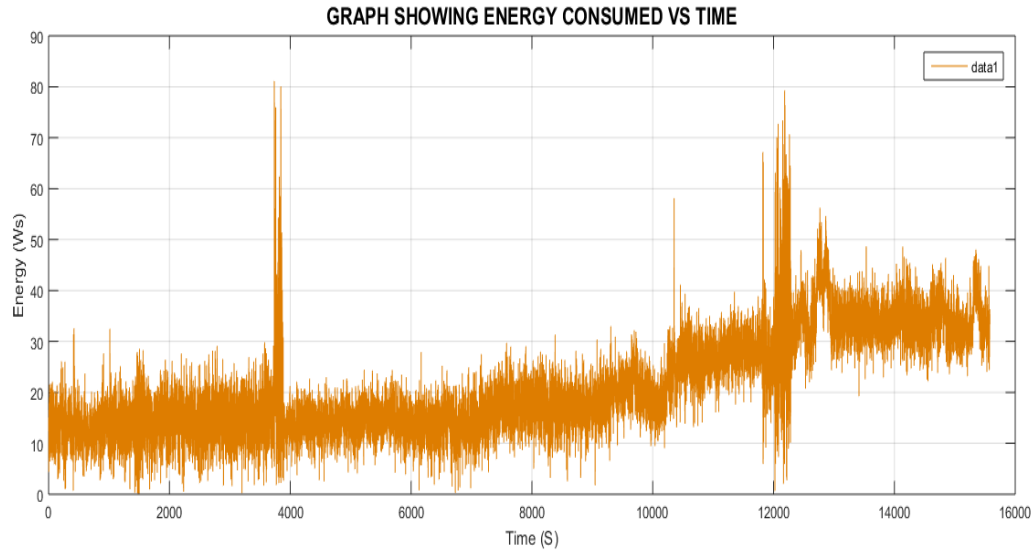


Figure 5.5 Graph Showing Energy (Watt Second) against Time (S)

### Basic Statistical Analysis for Energy Consumption

Parameter	Value
Minimum Value	0.11
Maximum Value	81.14
Mean	21.15
Median	18.33
Mode	15
Standard Deviation	9.83
Range	81.03

Table 6. Basic Statistical Analysis for Energy Consumption

## **CHAPTER 6: CONCLUSION AND RECOMMENDATION**

### **6.1 Conclusion**

In this research work the smart energy monitoring system with low-cost microcontrollers for traditional factories is presented with great accuracy. This system provides a platform in which traditional factories are able to collect sensor data easily and be able to make decisions to optimize their energy usage. The smart energy monitoring and control system for traditional factories takes a step further and improves previous works on energy monitoring systems where only current sensor data was used to calculate energy and power related parameters while neglecting the fluctuation in RMS voltage hence a potential transformer being induced.

The first step in energy saving approach is the awareness of energy consumption. This applies in different settings not limited to homes or traditional factories. The integration of pervasive technologies for monitoring and controlling energy consumption is a powerful tool for reducing energy demand. In this work there is use of digital instrumentation and crosscutting open edge embedded system technologies has enabled the ecological overview of energy and its related parameters.

Traditional factories having effective feedback of energy consumption, RMS current, RMS voltage, power factor, real and apparent power can help change the behavior on energy usage which can significantly direct to energy savings. The deployment of a smart energy monitoring system with the ability to acquire real time data is a vehicle for improving energy efficiency operations for manufacturing industries.

### **6.2 Recommendation**

The smart energy monitoring system if employed in traditional factory setting can improve the performance of the traditional factories and can help them migrate to smart factories. This induces energy efficiency and helps the factory to have an energy profile and the types of loads to utilize to maximize profits.

Deploying the system in traditional factories it can measure and monitor electric energy usage in real time which is the apparent way to aid in decision making in utilizing the equipment when to



turn it on or off and also it may help to know when to replace older appliances to enhance improvement of energy efficiency.

This work can be deployed not only in factories but also auditoriums, farms and apartments anywhere where there is a need to monitor energy and its power related parameters.

The deployment of smart of smart energy monitoring system based on embedded technology does not only have a bigger role in unified scheduling, optimization of energy enterprise and reduction of energy consumption. It is recommended as it helps in energy demand and supply adjustment.

The availability of real time energy sensor data and power quality enables the energy saving algorithms to be operational.

### **6.3 Future works**

The further work to be done on this research study is to employ machine learning algorithms which make use of real time energy sensor data to ensure prediction of machine failure in traditional factories using power quality data to improve the energy efficient process. The other part to be improved include the automatic load detection for efficient energy monitoring system to provide an insight on energy usage profile.

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