CELLULAR WIRELESS NETWORK COMMUNICATION FOR SMART GRID

by

Abu Bakarr Sillah (170021165)
Coulibaly Awa (170021169)
Pamboundom Njoya Aichetou (170021175)
Mohamed Hamid (160020003)

A Thesis Submitted to the Academic Faculty in Partial Fulfillment of the Requirements for the Degree of

BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

Department of Electrical and Electronic Engineering
Islamic University of Technology (IUT)
Gazipur, Bangladesh

May 2022

DECLARATION

*We hereby declare that this thesis titled "**CELLULAR WIRELESS NETWORK COMMUNICATION FOR SMART GRID**" is an authentic report of our study carried out as requirement for the award of degree Bachelor of Science in Technical Education with Specialization in Electrical Engineering at Islamic University of Technology, Gazipur, Dhaka, under the supervision of Prof. **Dr. Rakibul Hasan Sagor**, EEE, IUT in the year 2022.*
The matter embodied in this thesis has not been submitted in part or full to any other institute for award of any degree.

17 - 05 - 2022

Abu Bakarr Sillah (170021165)

17/05/22

Coulibaly Awa (170021169)

17-May 2022

Pamboundom Njoya Aichetou (170021175)

17/05/2022

Mohamed Hamid (160020003)

CERTIFICATE OF RESEARCH

The thesis titled "CELLULAR WIRELESS NETWORK COMMUNICATION FOR SMART GRID" submitted by Abu Bakarr Sillah (170021165), Coulibaly Awa (170021169), Pamboundom Njoya Aichetou (170021175), Mohamed Hamid (160020003) *has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of Bachelor of Science in Technical Education with Specialization in Mechanical Engineering.*

Supervisor

17 MAY 2022

____

Prof. Dr. Rakibul Hasan Sagor
Department of Electrical and Electronics Engineering (EEE)
Islamic University of Technology (IUT)

Table of Contents

List of Tables

List of Figures

List of Acronyms

Acknowledgements

Firstly, we would like to thank the Almighty Allah, for giving us the strength, courage, and wisdom in making this work come to fruition.
We would also like to thank our able supervisor, Prof. Dr. Rakibul Hassan Sagor for allowing us to do what we want, and guiding us through to success. He was not only a supervisor to us, but also a father, a brother and a friend. It is a very big 'thank you" to our parents, who have been patient with us after being for months without communication.
Lastly, we say 'Thank you" to all friends, roommates, and all for their patients, love, and care.

Thank you all.

Dedication

We are dedicating this thesis to our father, who never lived to witness the completion of this great work, **Mr. Ahmadou Njoya**. We love you, we wanted you to stay and from the looks on your face, you craved to stay with us too, but Allah has something better for you. We wake up every morning with you in our thoughts, our faces clouded with grief, after some moments, a bright shadow of a smile overrides that grief because we know you are in good hands.

May Jannatul-Firdaws be your humble abode.

Abstract

Since the introduction of Long Term Evolution (LTE) networks and now 5th Generation, cellular mobile networks are turning into a great platform for universal massive data capture, communication, storage, and processing. Cellular Wireless Network will offer more acceptable services for operation and real-world applications, especially the anticipation of the upcoming Smart Grids. Throughout this article, we describe how the cellular wireless network, with its rise of Machine-Type Connectivity and the notion of Mobile Edge Computing, provides a suitable setting for dispersed monitoring and control operations in Smart Grids. In particular, we demonstrate in detail how Smart Grids could benefit from enhanced distributed State Prediction models implemented within a cellular network setting. We present an overview of highly scalable State Estimation techniques, focusing on those highly distributed optimizations and likely statistical models, and explore their inclusion as part of the Cellular Smart Grid activities. We also show the prototype utilizing both the software and the hardware implementation. As a consequence, it was evident that the integration of the newest cellular wireless technologies into the conventional power grid would boost its smartness, efficiency, security, power quality, and intelligent communications amongst the distribution substations.

Chapter 1

Introduction

Power grids are enormous, complicated systems that supply communities with crucial energy services. As a result, their dependability, security, and efficiency are critical. To improve their efficiency and assure their dependability and security, several communication and control technologies have been developed and deployed. These technologies, in particular, improve the efficiency of power systems by providing a significant volume of system data that may aid in different system activities such as system monitoring, load management, and forecasting, renewable resource integration, invoicing, dynamic pricing, and more. The high volume of data, on the other hand, has increased the communication and computing burden on these systems.

1.1 Current Power Grid Defects

The current electrical power grid is by far the most complex and important technical system of the twentieth century. The electrical power grid is a massive network based on the centralized generation and interconnected by a tangle of control systems and transmission lines. In many aspects, the current power system has performed admirably in terms of supplying users with a continuous, unidirectional supply of electricity. However, it confronts significant issues in the near future, including the depletion of basic energy supplies, generation diversification, climate change, and reliability. The traditional electricity infrastructure also lacks intelligence. The capacity to monitor and operate multiple industrial appliances or functional components to enable optimal energy generation and utilization is referred to as intelligence. Supervisory control and data acquisition (SCADA) technology, for example, provides communications infrastructure for traditional electrical power grids. This system gathers information from a variety of sensors and delivers it to a central computer for processing and storage. The SCADA system has limited control over its upstream function (from customer premises to the generating site), and the power distribution network lacks real-time control capacity. As a result, the present electrical power infrastructure is transforming into a smart grid that is more intelligent, responsive, efficient, and environmentally friendly. Increased power consumption, unstable power flow, dispersed system configuration, and emergent renewable energy sources are driving this change. The smart grid requires a dynamic design, clever algorithms, and efficient ways to handle these issues.

1.2 Overview of Cellular Networks for Smart Grid

The conversion of the present electricity distribution grid into an automated smart grid would benefit greatly from an efficient, flexible, and dependable communication system that can enable sophisticated and autonomous grid capabilities in Neighborhood Area Networks (NANs). NANs are the communication infrastructure used to manage and regulate the distribution (at medium voltage) and transmission (at high voltage) of energy from its generation to the ultimate consumer (at low voltage). At the local level, communication in the power distribution grid currently exists to facilitate basic small-scale automated processes. Large-scale activities involving long-distance deployments, such as wide-area monitoring and control systems, still require substantial human participation. Fault Location, Isolation, and Service Restoration (FLISR), for example, may need field technicians to travel on-site and undertake restoration procedures. Wireless communication solutions available today are incapable of meeting the stringent communication requirements imposed by future smart grid systems' automated and highly dynamic nature. In a summary, the smart grid framework entails developing a suitable communication architecture in which globally recognized Intelligent Electronic Devices (IEDs), including sensors, smart meters, circuit breakers and protective relaying devices, exchange status information and control instructions in an automated and distributed manner in order to proficiently operate the electrical grid. By permitting direct interaction between consumers and Power Distribution System Operators, new services and activities capable of effectively delivering instantaneous demand response might be built (DSOs). Furthermore, the extensive deployment of Distributed Energy Resources (DERs), such as solar cells, storage batteries, and wind energy producers, poses a number of issues in terms of establishing smooth and dependable communication inside the power grid. Distributed management and real-time bidirectional communication are thus required to enable basic grid tasks, which frequently include the delivery of mission-critical protective signals and/or enormous amounts of metering data.

Among the numerous available options for smart grid communications, cellular technology based on LTE-based standards has been highlighted as a potential solution to satisfy the stringent criteria of diverse distribution grid operations. The growth of LTE through global standardization via the 3GPP provides a widely deployed and future-proof technology that is designed to act as a catalyst for sophisticated - yet unattainable - functions in power distribution networks. LTE's intrinsic technological properties, such as broad coverage, low latency, high throughput, and Quality-of-Service (QoS) differentiation, open up previously unimaginable use cases and contribute greatly to the entire operation and administration of the power grid. Leaving technical considerations aside, many DSOs may be able to profit from existing public LTE infrastructure without having to build and maintain a private communication network or trust uncontrolled connections for critical applications. Furthermore, the increased competition amongst Mobile Network Operators (MNOs) as a result of LTE adoption might be used to secure competitive pricing schemes and relieve DSOs of the investment, implementation, operation, and maintenance expenses associated with a private solution.

Unfortunately, LTE was built for human-centric broadband services with a reasonable number of users per base station, not for the data traffic patterns of smart grid applications. Apart from the high amount of traffic, smart grid communications are brief and intermittent, and their related applications are based on duty-cycling methods for network access with modest mobility constraints. These fundamentally different needs for Machine-Type Communications (MTC) for the smart grid versus traditional Human Type Communications (HTC) necessitate a huge mindset shift in how cellular networks are currently developed. As a result, in recent years, the design and configuration of LTE to address these problems and allow dependable MTC for the smart grid has been a hot topic of research. Indeed, the 3GPP is approaching the suitability of future LTE releases for MTC by taking three steps: I including a User Equipment (UE) category-0 with reduced complexity (LTE-M), ii) designing a new narrow-band radio access technology for cellular Internet of Things (NB-IoT), and iii) including novel communication architectures that can better handle the specific needs of MTC. LTE network-assisted Device-to-Device (D2D) communications1 appear as a potential upgrade of LTE technology to meet the demanding needs of modern smart distribution grids, among other unique communication architectures now being suggested. Instead of broadcasting and receiving signals through a cellular base station, intelligent grid devices in close proximity can exchange information using cellular licensed resources through a direct link. When used in different distribution grid services, D2D communications may significantly reduce end-to-end latency and energy consumption, increase reliability and scalability [6] and overcome the present limits and performance constraints of LTE technology. However, communication management is still under the jurisdiction of a communications MNO that provides a Service Level Agreement (SLA).

We created a system that monitors the voltage and current entering the substation from the main power grid.

1.3 Objective of the Thesis

The existing power infrastructure is a difficult and complicated and ageing system characterized by central power generation and distribution, way power flow, and lack of user–utility interaction which leads to energy loss, overload conditions, power quality issues, poor peak load management, lack of renewable energy usage, time wastage, and manual operational processes. This together with an anticipated reduction in fossil fuel supply, increase in fuel cost, linked environmental challenges including global warming from glasshouse emissions, and growing demand for energy need re-envisioning of the old electrical Grid. Consumers throughout the world require a constant and stable energy supply in a cost-effective way. Power quality and environmental considerations are essential as well. Global customers' common worries are represented in Fig. 1 which may vary according to the geographical conditions and needs of the consumers. A smart grid is envisioned to completely handle these challenges in a sophisticated and dynamic fashion.

One of the key goals of our project to increase the dependability of the power being given by rapid identification and isolation of the issue and keeping a consistent voltage level, which will make the project maximally dependable and compatible.

As the complexity of the distribution network has risen, automation of substations has become a necessity of every utility business to raise its efficiency and improve the quality of service. One of the keys aims of this project of ours is to guarantee real-time monitoring.
Another is Remote sensing of observant parameters, while this project is aimed for all the substation kinds of equipment we built this prototype bearing in mind the transformers which are frequently put in distant places. Through this project, we seek to guarantee remote sensing of all the observable parameters. And by keeping track of the real-time characteristics, we wish to preserve the continuation of the supply.
One of the keys aims of our project is to lower the labor cost to some amount which will make the facility more cheap.
With this, we will have a highly advanced, user-friendly system that everyone may safely operate to the best of their abilities.

1.4 Our Contribution

We built this system with the aid of Arduino Uno as the primary central processor and intelligent point of contact. Processed voltage, that has been stepped down from 230 AC voltage to desired 5 DC constant voltage, that may be changed using potentiometer, is then given to the analogue input of the Arduino, since Arduino cannot accept more than 5voltage at the input. The voltage measured will then be shown on the LCD.

1.5 Chapter Distributions

Throughout the future chapters, we explored the literary component to the practical design of our model. In chapter 2, we examined the outline of the full work. Here we addressed cellular networks for the smart grids, why cellular networks, and how the introduction of the new cellular network technologies would assist t increase the smartness of the smart grid. We also reviewed the design of cellular wireless networks for smart grids and also some of the contributions made by other writers.
Following that comes the approach in chapter 3 the exact methods or strategies we utilised to find, select, process, and evaluate material regarding this thesis subject. The methodology, the selection process, and actual execution tactics. Chapter 4 is more about the actual implementation. The components involved, their specification, and their activities.
Lastly came chapter 5, which is the conclusion and the future suggestions. Our strategy was not that much efficient in effectively responding to the emerging technologies that may be incorporated into this task for improved outcomes, security, rapid reaction, and real-time data collecting.

Chapter 2

Literature Review

2.1 CELLULAR TECHNOLOGY FOR THE SMART GRID NAN

As indicated in the preceding section, standardized cellular networks operating in licensed bands are a viable approach for addressing all of the performance limitations of alternative wireless technologies for both metering and DA applications. Despite the fact that the functionality and capacity of cellular technology will continue to improve, the technological platform is mature and dependable enough to be considered a key enabler of the smart distribution grid for the foreseeable future. Cellular networks can provide wide-area connectivity for applications within the distribution grid for the following reasons(Kalalas, Thrybom et al. 2016):

1) *Use of licensed bands*: Cellular networks can better regulate interference than unlicensed bands and are more resistant to security risks that might undermine the security and privacy of sensitive energy data.

2) *Mature and ubiquitous coverage*: Smart metering implementations may span large regions and remote endpoints can be connected to the same management network thanks to a mature and widely accepted communication architecture.
Message interchange across grid entities in complicated geographical locations, such as the scenario of connecting remote DERs to the main power grid, may therefore be facilitated efficiently.

3) *Fast performance*: Cellular networks offer high data rates, low latency, and high system stability, allowing essential distribution grid automation activities that are frequently connected with strong QoS requirements, such as strict transfer time restrictions. Real-time monitoring and control can enable advanced grid applications like as inter-substation communications, outage management, and FLISR. High availability is a fundamental need for cellular networks. Multiple data pathways, quick re-routing systems, and overlapping cell coverage are examples of redundancy characteristics that assure smooth functioning in the event of a power outage.

4) *Third-party operation*: MNOs provide energy utilities with better business models and SLAs to promote cellular communication solutions within the smart grid, relieving DSOs of the burden of running and maintaining a dedicated communication infrastructure. Furthermore, the enormous number of devices creates significant commercial potential. As a result, cellular technology can help to turn an outdated distribution grid into a modernized, fully automated power distribution system.
In this paper, it described the development of an energy meter based on non-invasive current sensing. Noninvasive current sensing has the benefit of being able to be installed at any location

where power needs to be monitored. In this scenario, the energy usage information is presented on a smartphone. To transport data over the internet, an ENC28J60 Ethernet module was employed. S.H Ju et al. developed a power line communication-based automated meter reading device (AMR) (PLCC). Data is sent through electrical wire cables in PLCC. This potential necessitates proper changes to a house's domestic wiring. Furthermore, it employs an intrusive approach to detect mains current. The downside of this type of system is that the user cannot measure the amount of power utilized by each gadget(Kalalas, Thrybom et al. 2016).

(Loganathan, Prasanth et al. 2021) demonstrates the development of a wireless automatic meter reading system (WAMRS) that uses the widely utilized GSM/GPRS network. The system contains a microcontroller that sends energy usage values estimated from observed voltage and current values to a central controller on a regular basis through an established GSM/GPRS network. The biggest drawback of this technique is the problem of distance. Long-distance GPRS or GSM network coverage may not be accessible, and another drawback may be the speed of operation.

This project intends to provide a system that can monitor and operate substations using IoT technology, as well as a communication interface for IoT modules. Using the IoT module, we may update data on the webserver. Substation characteristics, voltage and current, frequency, and temperature are all considered in our project. The project will be built in such a way that a sensor will interfere with the controller, specifically the ADC input voltage for analog values and current. The microcontroller is serially connected to the IoT module in this project. The microcontroller senses voltage and current frequencies by altering these two pots and delivers specific values that fluctuate in temperature and webserver. The substation light will switch off depending on voltage and current fluctuations, during which time the relay must be triggered to protect it. The system status is also displayed on a 16 x 2 LCD. A controlled 5V, 500mA power source is used in this project. Unregulated 12V DC relay is used. For voltage regulation, 7805 three-terminal voltage regulators are utilized. The AC output of a 230 / 12V step down transformer is modified using a bridge type full wave rectifier (Sangolkar 2020).

(Narejo, Bharucha et al. 2015)The purpose of this project is to obtain remote electrical characteristics such as voltage, and current, and provide these real-time data via GSM networks using GSM modems/phones. Users can submit commands in the form of SMS texts to read electrical parameters remotely. This system can send SMS messages that include electrical parameter phases in real time (depending on time settings). This system can be set up to send SMS alerts if the relay moves or the voltage or current exceeds a certain threshold. A microcontroller is used in this project. The controller can communicate successfully with the numerous sensors in use. The controller code is stored in internal memory. This is used to program the memory controller with some assembly instruction sets. The controller's functionality is programmed in the Embedded C language, which is based on these assembly instructions.

(Thakare, Shriyan et al. 2016) As the distribution network's complexity has risen, substation automation has become a must for every utility business seeking to maximize efficiency and improve the quality of power provided. The proposed project would assist a GSM cellular network-based substation control utility firm in ensuring that local-substation problems are instantly recognized and reported to their appropriate departments through GSM, therefore reducing the duration of power outages. SMS messages will be issued with the measured parameters. The microcontroller communicates with the sensors installed at the local substation and executes the duties that have been assigned to it. To assist distribute and safeguard power transformers from burning due to overload, short circuit faults, overvoltage, and surge, electrical characteristics such as current and voltage will be continually compared to their rated values. In such cases, the entire unit is closed via the control section, which detects the relay and instantly switches off the circuit breaker. This can be sent through SMS notifications. The use of GSM makes substations sentient in the sense that they can communicate alarms and data as well as accept orders. This reduces labor expenses at substations and saves time, resulting in increased monitoring and substation job efficiency.

It is feasible to follow natural or unintentional deterioration over time by encouraging current and competitive procedures and instruments for online monitoring and diagnostics. When time is noted and corrected, significant occurrences do not occur, which may be highly costly damage sources for electric power suppliers and users. Simultaneously, it is feasible to extend the equipment's life, improve the maintenance schedule, and decrease outages and expenditures for planned repairs. paper MV provides a study of important metrics and an LV transformer substation, as well as a mechanism for monitoring their operational status. The primary goal of this study is to offer a modular system for monitoring transformer substations in order to improve electrical power supply quality for consumers while reducing equipment page changes and maintenance expenditures. The study proposes to establish such a monitoring system, which may be incorporated into SCADA, based on the consideration of the status monitoring of the transition substation.

This study presents a revolutionary integrated monitoring system for a high-voltage electric power substation system. A substation is essential for ensuring the reliability and quality of an electric power transmission system. Human health may be jeopardized by exposure to a high-voltage environment. As a result, integrating a monitoring system for convenient substation monitoring and control while eliminating human interaction with substation components is vital. The graphical user interface (GUI) designed with LabVIEW software displays and integrates all substation device conditions. The sophisticated display features many windows as well as its own displays. As a result, attributes such as frequency, voltage, load impedance, reluctance, oil level, temperature, cooling condition, power, and safety measures are efficiently shown and monitored on the substation device.

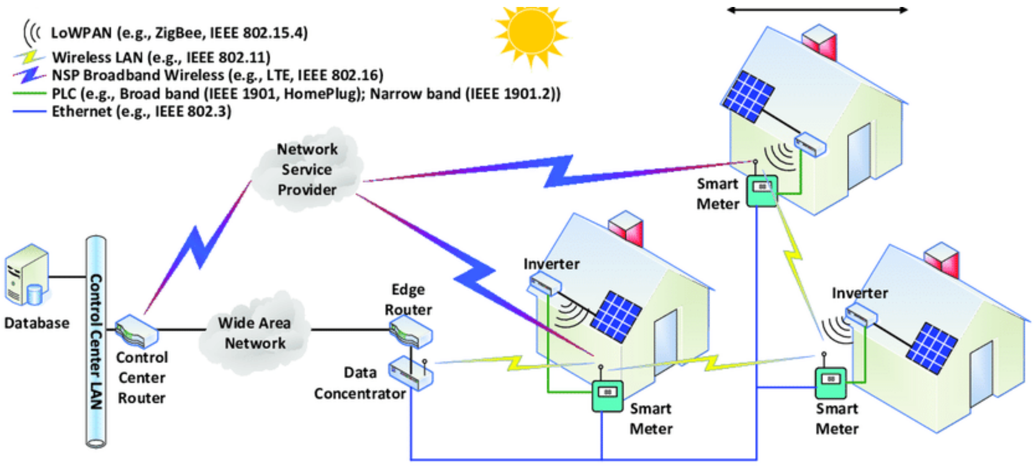

Figure 1: Cellular Wireless Network for Smart Grid(Cosovic, Tsitsimelis et al. 2017).

2.2 Architecture

In this study, we also discuss some of the components at the heart of the proposed smart grid design. They are as follows:

1) ***Smart meter:*** At the heart of smart grid applications, the smart meter is a resource-constrained device (in terms of storage capacity, computational power, and bandwidth). Regulatory authorities such as the Federal Communications Commission (FCC) and the American National Standards Institute (ANSI) on meter size (form factor), cost implications, heat dissipation, and smart meter operational performance impose the foregoing restrictions. The energy meter (EM), which measures, records, and communicates energy use, and the energy services interface (ESI), which serves as a data management gateway, make up the smart meter. The ESI is in charge of all of the network's smart meters. Customers use ESI for Demand Response (DR) programs, two-way advanced metering infrastructure (AMI), and energy data transmission to the Home Energy Management System (HEMS). Smart meters, on the other hand, are grid management instruments that are used to periodically assess the grid's power quality and support plug-in electric vehicle (PEV) charging. Smart meters provide various gateways and serve as relay nodes or forwarders to communicate with the data aggregator unit in the design, which also demonstrates mesh and peer-to-peer topologies (DAU). By generating redundant channels and decreasing congestion, the mesh topology ensures easy scalability, self-healing, and stability for excellent network performance during peak periods. SUN devices have a hop-to-hop range of 100 meters (no line-of-sight) and up to 1 kilometer for line-of-sight connections(Cosovic, Tsitsimelis et al. 2017).

2) ***Concentrator or Data Aggregator Unit (DAU):*** A data aggregator equipment (DAU) or concentrator is a multi-interface device that collects data from smart meters throughout the network and feeds it to the utility for billing and grid management. The concentrator also functions as the NAN gateway, receiving and sending control messages from service providers to customers, according to the design. Depending on the technology employed, such as RF mesh or PLC, it can divide the NAN into smaller autonomous networks. The DAU also organizes, directs, and prioritizes traffic. Cellular (3G/4G/LTE), WiMAX, and fiber optics are

potential technologies because to the utility's high bandwidth needs, whereas RF mesh or PLC alternatives are employed for the last mile network. In addition, the design shows a mesh architecture for durability, scalability, and optimal network performance in many DAU deployment situations. To relieve network congestion, a large-scale deployment of smart meters in metropolitan areas requires multiple DAU units.

3) The FAN connects intelligent electronic devices (IEDs) in the HV/MV SCADA substation domain that regulate and measure transformers and circuit breakers. In today's electrical systems, IED devices are quickly replacing older Remote Terminal Units (RTUs), current and voltage transformers. They can now support operations previously only available from the aforementioned traditional devices, reducing the complexity of substation device architecture. However, as the use of variable DER, microgrids, and energy storage systems grows in the low-voltage distribution system, IEDs will be deployed in the non-SCADA zone near customers' homes on a huge scale. This will increase the automation of the dynamic low-voltage distribution system. An IED should be positioned close to the equipment being monitored, according to IEEE Std 1815-2012. The IED currently connects with SCADA systems using the distributed network protocol (DNP3), although utility companies have begun to use the IEC 61850 standard to build IED devices(Cosovic, Tsitsimelis et al. 2017).

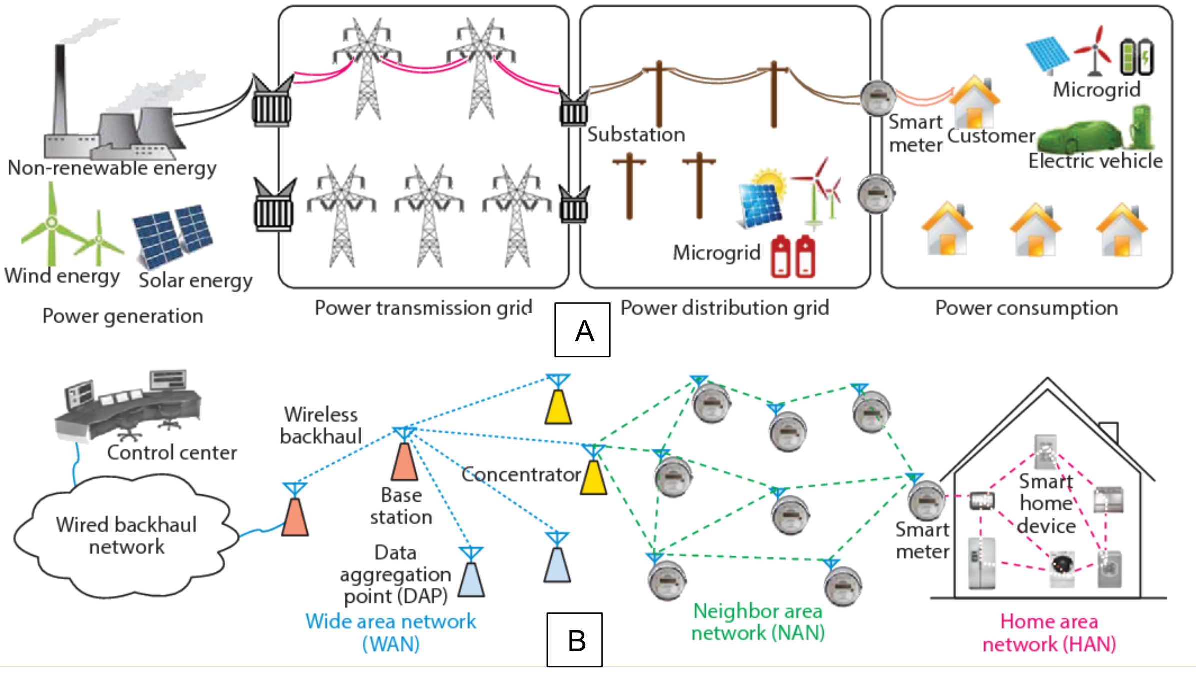

Figure 2: Wireless Network Architecture for Smart Grid." A" is the Power Grid and "B" is the Wireless Architecture (Cosovic, Tsitsimelis et al. 2017).

Chapter 3

Methodology

As the distribution network has gotten more complicated, automation of substations has become a need for every utility operator in order to maximize efficiency and improve the quality of electricity distribution. Because of the lack of automated analysis and the utility's inadequate access over the grid, there are still power failures and blackouts today. It is vital to understand what type of constraint has happened in order to improve the quality of power with a suitable solution. Furthermore, if a power system's safety, monitoring, and control are ineffective, it’s possible that the system will become unstable. As a result, a monitoring system that can automatically discover, monitor, and categorize existing electrical line obstacles is required. The goal of this project is to collect distant electrical parameters such as voltage and current and communicate them over the network in real-time using a GSM module at the power plant. This project also includes a relay that will safeguard the electrical circuits. When the electrical parameters surpass the specified limits, this relay is actuated. This technology can update the real-time electrical parameters on a regular basis (based on time settings). This system may be set up to transmit warnings whenever the relay trips or the voltage or current exceeds predetermined limitations. This project uses an Arduino microcontroller; however, because this is a prototype of the planned concept, we have utilized an Arduino Uno for demonstration reasons. The controller is able to communicate effectively with the many sensors in use.

- The project has 3 main components:
- Voltage measuring
- Communication
- Monitoring and controlling

3.1 Voltage measuring

The transformer, bridge rectifier, Zener diode, Arduino Uno, LCD, and a few more components such as resistors and capacitors make up the circuit, which is quite basic and easy to understand. The input AC voltage to be measured is applied to the primary side of transformer X1, which in this case converts a high input voltage (say 220V AC) to a low input voltage (say 12V AC). We must either clip or alter the negative half cycle to the positive half cycle since Arduino cannot measure the negative half cycle as input. We're deploying a bridge rectifier to put on the performance.

Four diodes are used to rectify the step-down AC voltage (12V AC) (1N4001). The rectified output is sent into a voltage divider network with variable resistor VR1 as the input. As indicated in the circuit design, the positive and negative terminals of the variable resistor are connected to the positive and negative terminals of the rectified output. The variable wiper of variable resistor VR1 provides the output. Capacitors C1 and C2 are now used to filter the output. A Zener diode is deployed here to safeguard the circuit, which can be damaged if the input voltage is higher than 3.7V. This output voltage is now connected to analog pin A0 on the Arduino Uno. This voltage was measured by Arduino and presented on the LCD. The LCD is linked to the Arduino using higher-order data bits, which means that only higher-order data pins (D4 to D7) are used to communicate with the LCD. As illustrated in the circuit diagram, data pins D4 to D7 are linked to Arduino D10 to D7, respectively. Where the EN and RS pins are wired to D11 and D12 on the Arduino, respectively. The LCD's Vss, RW, and LED- pins are linked to GND, whereas the VDD pin is wired to +5V. The VEE pin controls contrast, and the supply voltage must be between VDD and VSS, thus the VR2 wiper pin is attached to it. As indicated in the circuit design, the LED+ pin of the LCD is linked to +5V through a current limiting resistor. Since the voltage required at the input of the Arduino is 5 voltage, we have to make some calibrations to make the input voltage compatible with the input voltage at the primary part of the Arduino (Atay).

Procedure for calibration

- Using a multimeter, determine the voltage of the AC mains (in the context of Bangladesh it is 230V ideally but practically it shows 227V AC).
- Adjust the variable resistor such that the Zener diode's output voltage is constant and less than 3.7V. (Say 2.66V DC).
- Open Serial Monitor and upload the calibration software to your Arduino.
- It demonstrates some worth (say 545). We'll need the value for a later computation, so save it. To get this value, adjust the variable resistor (545)
- Now figure out the multiplier.

Similarly, we can use the unitary technique to determine voltage for 1 division for a 5V DC Arduino and get 1023. 1023 = 5V; 1 = 5/1023 V

Thus, the voltage for 545 division is equal to (5/1023) *545 = 2.66V.

When the mains voltage is 227V AC, the unitary method Multiplier = 227V / 2,66V = 85.30

As a result, Multiplier = 85. 30 (Atay).

3.2 Communication

Three transformers are used to scale down the voltage in three phases. The incoming phase wire is used for one connection, while the neutral wire is used for the other. We chose a working voltage range of 210V to 250V for our project. A three-phase variac is used to change the voltage. The limit may simply be changed to suit your needs. If the voltage stays within the limitations, the circuit works fine. If the voltage falls outside the stated parameters, the relay activates and isolates the circuit. A GSM message is delivered indicating whether the measured situation is under or overvoltage. When the voltage falls below the set point, the relay reconnects the load to the supply.

Figure 3: Sim 900A GSM Module.

3.3 Monitoring and controlling

When we turn on the power to our prototype, the display displays a welcome greeting, and all of the sensors begin sensing current, voltage, frequency, and temperature, sending all of the data to the server and displaying it on the display. It compares all real-time values to specified values and sends a fault alarm to the relay and buzzer as well as updating the display if any of the values exceed the predefined values. The relay separates the loads from the rest of the system if the problem persists for the pre-set time. Meanwhile, the comparison continues as before, and if the problem is resolved, the loads are reconnected to the rest of the system through relays.

Chapter 4

Implementation

In this chapter, we discussed the implementation of the experiment, the components involved, and their specifications. The mains sections are as follows: Voltage Measuring Section, Power Supply Section, Current Measuring Section, Protection Part, Display Section, Primary Microcontroller Section

4.1 Voltage measuring

One 230 V to 12 V Step-down Transformer, one Bridge Rectifier unit made up of four 1N4007 rectifier diodes, one 470 F Capacitor, one IC7805 Voltage-regulator, and two 0.1 F Film-capacitors make up the Power Supply Processing Unit (PSPU). The 230 Volt, 50 Hz single-phase AC supply is first converted to 12 Volt, 50 Hz AC, which is then fed to the bridge-rectifier unit, which converts it to 12 Volt DC, which is pulsating in nature; to make it smooth DC, we then pass it through the filter circuit, which is a 470F capacitor, which smoothed out the pulsating DC. The rectified output is sent into a voltage divider using VR1 as the input variable resistor. The positive and negative ends of the variable resistor are linked to the positive and negative terminals of the rectified output, as shown in the circuit diagram. The output is provided by the variable wiper of the variable resistor VR1. The output is now filtered by capacitors C1 and C2. The circuit is protected by a Zener diode, which can be broken down if the input voltage is higher than 3.7V(Loganathan, Prasanth et al. 2021).

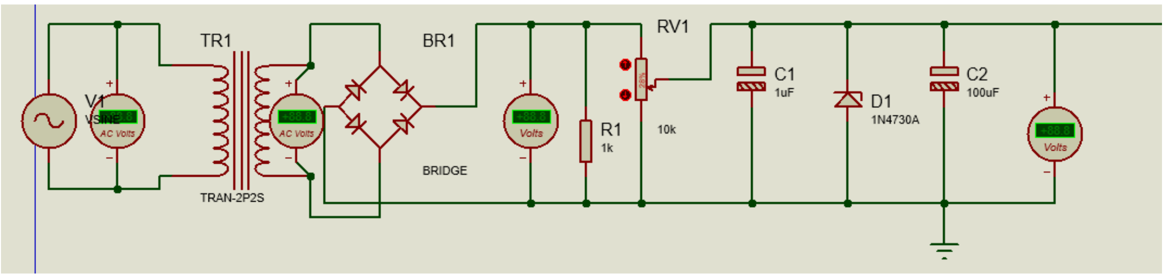

Figure 4: Voltage Measuring Section.

4.1.1 Transformer

A transformer is a passive electrical device that transmits electrical energy from one circuit to another using electromagnetic induction. It's frequently used to'step-up' or'step-down' voltage levels between circuits. Faraday's Law of Electromagnetic Induction states that "the magnitude of voltage is directly proportional to the rate of change of flux. The primary coil of a transformer receives voltage that is alternating in nature. The flux created by the alternating current that follows the coil is continually changing and alternating around the primary winding. The secondary coil, which is close to the primary coil and becomes linked to it owing to alternating flux, is the other coil. The flux fluctuates continuously, causing an EMF to be formed in the secondary coil, according to Faraday's law of electromagnetic induction. When the secondary side circuit is closed, current flows, and this is the transformer's most basic operation.

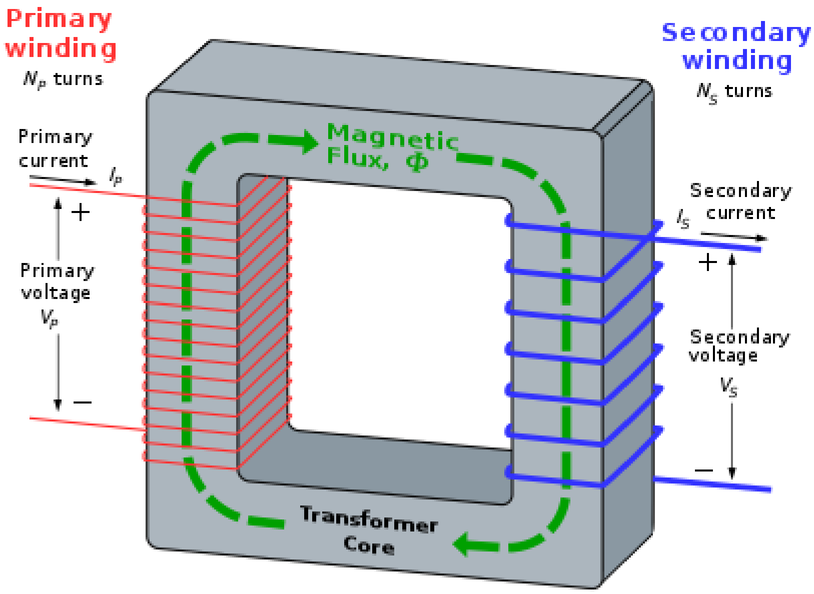

Figure 5: Step-down Transformer.(Ganguly, Poddar et al. 2016)

4.1.2 Rectifier

This is made up of four diodes in a bridge circuit. Individual diodes or bridge rectifiers sold as a single electrical component can be used. In comparison to the full-wave rectifier, which uses two diodes, the bridge rectifier accomplishes full-wave rectification and does not require a central tap in the transformer. This means that a single winding is used for both sections of the cycle. Due to its performance and capabilities, the full-wave bridge rectifier is used in many linear power supplies, switch-mode power supplies, and other electronic circuits where rectification is required.

4.1.2.1 Filtering

All rectifier circuits have a ripple factor in their outputs. The presence of an AC component is indicated by the ripple in the signal. To attain pure dc output, this ac component must be eliminated altogether. A filter circuit is a circuit that smooths the rectified output into a pure dc signal. The functioning of a filter circuit is depicted in the diagram below.
The following are some examples of simple filters: -
• Pi () Filter • Series Inductor Filter • Shunt Capacitor Filter • L-C Filter

We've only utilized the Shunt Capacitor Filter here, so we'll only talk about that.
Filter using a Shunt Capacitor
Because a capacitor enables ac to pass through while blocking dc, a Shunt Capacitor Filter may be built using a capacitor linked to the shunt, as illustrated in the diagram.

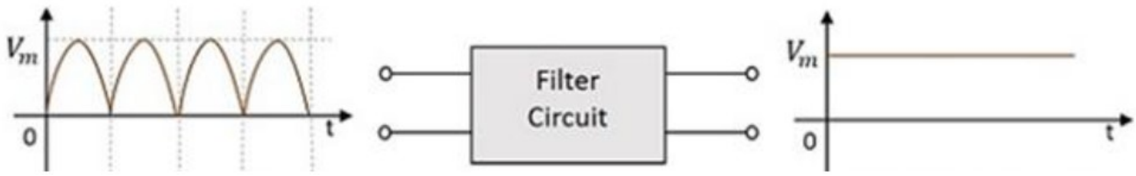

Figure 6: Filtering Process(Narejo, Bharucha et al. 2015)

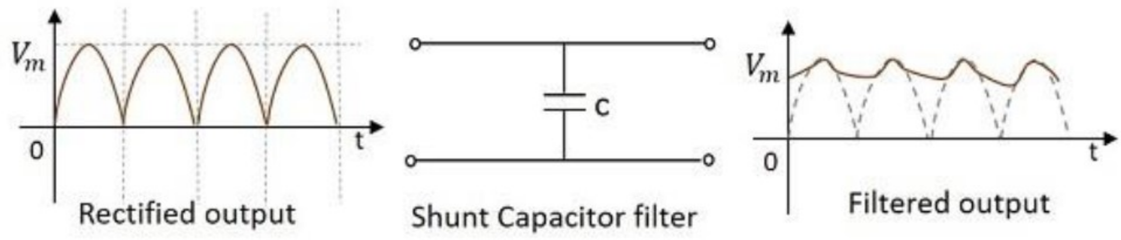

Figure 7: Functionality of the Shunt Capacitor(Narejo, Bharucha et al. 2015)

4.1.3 Variable resistor

Variable Resistor, also known as potentiometer is the kind of resistor which adjusts the flow of electrical current in a regulated way by delivering a broad range of resistance values. As the resistivity rises in the potentiometer the current across the circuit lowers and vice versa. They may also be used to adjust the voltage between circuit components also. Thus, in situations where current control or voltage control is essential, these kinds of resistors are beneficial. Figure 1 displays various real-life variable resistors.

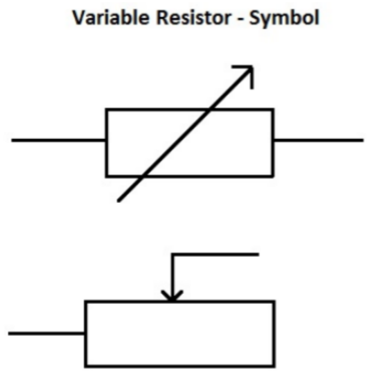

Figure 8: Symbol of Variable Resistor

As we use the phrase variable resistor, it indicates that we are talking about linear resistors by default. Linear resistors, as we know are those resistors whose resistance stays constant, even though the current and voltage through it varies. The current and voltage obey ohm's law and are proportional to each other.

A common potentiometer has 3 terminals. Out of the three, two are fixed terminals at the ends of a resistive track. The terminals are composed of conduction metal. The other terminal is a movable terminal, commonly known as the wiper. It is the location of this terminal on the resistive track that determines the resistance of the potentiometer.

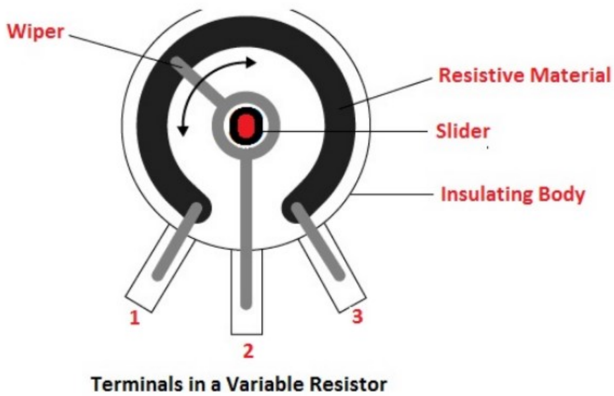

Figure 9: Terminal Configuration in Variable Resistor

These resistors provide varied resistance values, which means their resistance values may be modified to different levels so as to give the required control of current and/or voltage.

To accomplish so, a resistive strip is inserted in between two fixed terminals of the device, and a third terminal which is a moveable one is created to glide over this strip.

Recall the fundamentals of resistance; the resistance of a substance is exactly proportional to the length of the material. Yes, that's precisely what is employed here.

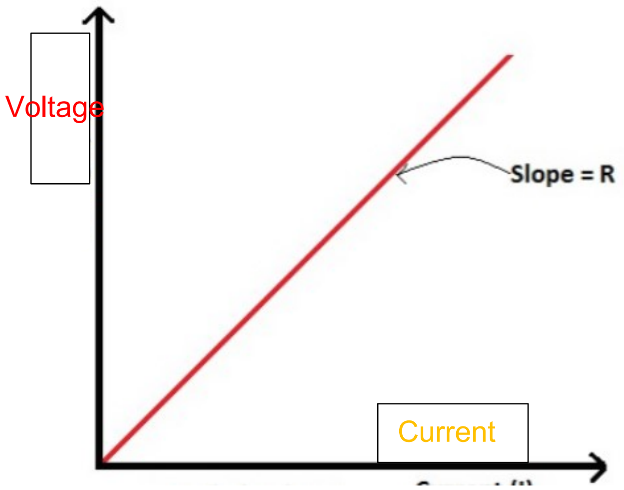

Figure 10: Ohm's Law in pertaining Variable Resistor Mechanism.

The arrow put on the resistive strip (arc-shaped track), shows the present location of the wiper terminal. Let's imagine the wiper is set at position "a", we can say that it separates the resistive track into two tracks of differing lengths, from terminal 1 to point a and the other track being from point a to terminal 3. Our point of interest is the second length, since it is what determines the output of the resistor. As we move the wiper towards terminal 3, we find that the effective length reduces. So, what will happen to the resistance supplied by the pot? It will reduce.

The resistive strip may also be put down in a straight fashion and the wiper in this instance is termed a slider. Its location cannot be observed or validated, hence a stopping mechanism is required to be included to avoid over-rotation.

Therefore, the major portion of a conventional variable resistor is the resistance material. The resistive substance might be one of the following types:

Carbon Content: One of the most prevalent forms, this substance is manufactured from carbon granules. Its inexpensive cost, fairly low noise, and fewer wear than other materials made it popular among the makers. However, their errors of functioning led to the creators exploring for alternate solutions.

Wire wound - An insulating substrate is wound using nichrome wire. They are typically employed in high power applications, have a long life, and are precise. Their sole issue is that they have low resolution.

Conducting plastic: Due to their resolution, they are commonly employed in high-end audio applications. Their usage is restricted since they are highly pricey, and can be utilised in low power applications only.

Cermet: A very stable form of material, it has a low-temperature coefficient and is extremely resistant to heat. However, it has a limited life and might burn a hole in your pocket.

4.1.4 Zener Diode

4.1.4.1 What are Zener Diodes

Zener diodes are a silicon semiconductor with a p-n junction that are particularly engineered to function in the reverse biased situation. When forwards biased, it functions like a normal signal diode, however when the reverse voltage is applied to them, the voltage stays constant over a broad variety of currents. Due to this property, it is employed as a voltage regulator in dc current. circuit. The basic purpose of the Zener diode as a voltage regulator is to maintain a consistent voltage. Let us assume if Zener voltage of 5 V is utilized then, the voltage becomes constant at 5 V, and it does not vary.

A voltage regulator is a device that controls the voltage level. It effectively lowers down the input voltage to the required level and retains it at that same level throughout the supply. This guarantees that even when a load is placed the voltage doesn't decrease. The voltage regulator is utilized for two major purposes, and they are:

- To alter or control the output voltage
- To maintain the output voltage constant at the required value in spite of changes in the input voltage.

Voltage regulators are used in computers, power generators, alternators to regulate the output of the plant.

4.1.4.2 Zener Diode as a Voltage Regulator

There is a series resistor connected to the circuit in order to restrict the current entering the diode. It is linked to the positive terminal of the d.c. It operates in such a manner the reverse-biased may also function in breakdown situations. We do not utilize conventional junction diode because the low power rating diode might be destroyed when we apply reverse bias over its breakdown voltage. When the lowest input voltage and the maximum load current is applied, the Zener diode current should always be minimal.

Since the input voltage and the needed output voltage is known, it is easy to pick a Zener diode with a voltage almost equal to the load voltage, i.e. VZ = VL

Current through the diode rises as the voltage across the diode tends to increase which results in the voltage drop across the resistor. Similarly, the current through the diode drops as the voltage across the diode tends to decrease. Here, the voltage drop across the resistor is extremely minimal, and the output voltage results properly.

Figure 11: Zenner Diode

4.2 Current Measuring Section

4.2.1 ACS712 Current Sensor

The ACS712 provides cost-effective and accurate AC or DC current sensing solutions in industrial, commercial, and communications applications. The gadget's packaging makes it simple to use for the customer. Common applications include motor control, load monitoring and management, switched-mode power supply, and over-current fault prevention. The ACS712 Module uses the Hall Effect and the well-known ACS712 IC to detect current. The ACS712 module comes with two phoenix terminal connections and mounting screws. The wire must travel through these terminals. On the other side, there are three pins. The Vcc is connected to +5V to power the module, while the ground is connected to the C's ground. The analog voltage output by the ACS712 module is then read using an analog pin on the C.

Current Sensor senses current in a wire or conductor and creates an analog voltage or digital output signal proportionate to the observed current. In addition to carrying current, a current-carrying conductor generates a magnetic field in its surroundings. The current is measured through indirect sensing by estimating the magnetic field using either Faraday's or Ampere's laws. To sense the magnetic field, either a Transformer, Hall effect sensor, or fiberoptic current sensor is utilized. The current is calculated by the ACS712 Current Sensor using the Indirect Sensing technique. This IC uses a liner, low-offset Hall sensor circuit to measure current. The device's accuracy is determined by the magnetic signal's closeness to the Hall sensor. The better the precision, the closer the magnetic signal is.

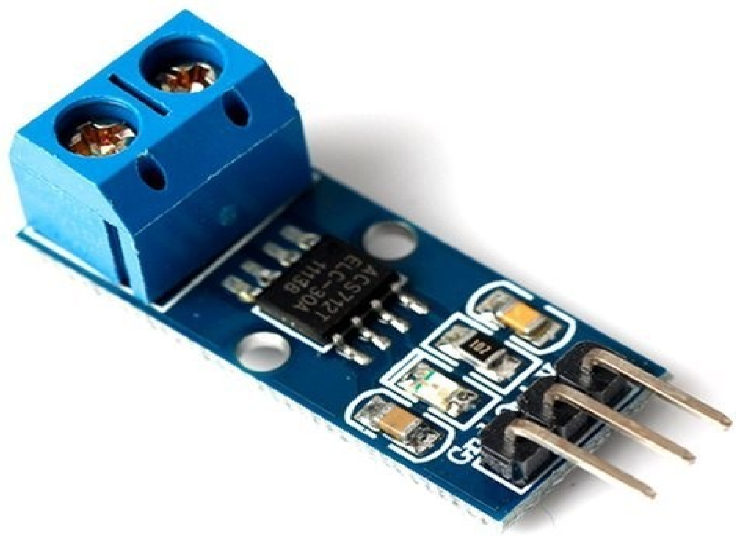

Figure 12: 4.2.1 ACS712 Current Sensor

This IC can detect both AC and DC current, which makes it helpful in a wide range of applications. ACS712 is used in a variety of industrial, commercial, and communication applications. This IC is appropriate for automotive applications. Motor control circuits, load detection and management, SMPS, and overcurrent fault prevention circuits, to name a few applications, all use this IC. This IC can measure current in 230V AC mains-powered high-voltage loads. To read the values, it can easily be connected to a microcontroller's ADC.

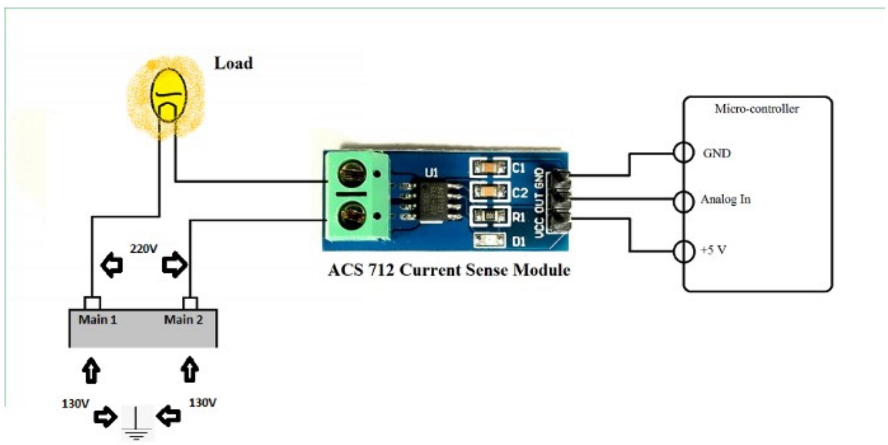

Figure 13: 4.2.1 ACS712 Current Sensor Connection(Rajnikanth).

Pin Diagram of ACS712

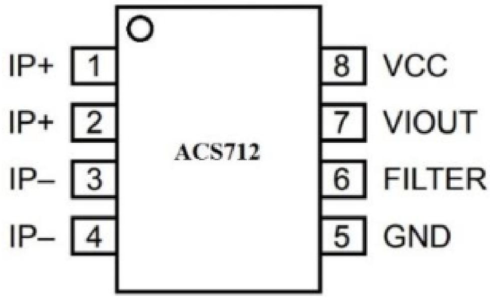

Figure 14: Pin Diagram of ACS712

IP+	Terminals for current being sensed; fused internally
IP-	Terminals for current being sensed; fused internally
GND	Signal ground terminal
FILTER	Terminal for external ground capacitor that sets bandwidth
VIOUT	Analog output terminal
VCC	Device power supply terminal

Table 1: Pin Description of ACS712

4.3 Protection Unit

4.3.1 Protective Relay

An electromagnet operates a relay, which is essentially a switch. The electromagnet requires a tiny voltage to operate, which will be provided by the Arduino, and once triggered, it will pull the contact to complete the high voltage circuit. The SRD-05VDC-SL-C is the relay module we'll be using. It works on 5 volts and can be controlled by any microcontroller, but we'll use Arduino. The relay usually has five pins, three of which are high voltage terminals (NC, COM, and NO) that connect to the device we're trying to operate. The common (COM) terminal is where the main power enters the relay. The usage of NC and NO terminals is determined by whether the gadget is to be turned on or off. A coil that functions as an electromagnet is located between the remaining two pins (coil1 and coil2). When electricity passes through the coil, the electromagnet charges up and moves the switch's internal contacts. The normally open (NO) terminal is then connected to the common (COM), while the normally closed (NC) terminal is detached. When the current in the coil stops flowing, the internal contact reverts to its original condition, with the normally closed (NC) terminal connecting to the common (COM) and the normally open (NO) terminal reopening. A single-pole, the double-throw switch is what this is called (SPDT). Two-channel relay modules will be used in this prototype demonstration. Other modules, with one, four, and eight channels, are available. This module is designed to allow your Arduino to control two high-powered devices. It features two relays, each rated for up to 10A at 250VAC or 30VDC. The location of the relay is shown by two LEDs on the relay module. The relevant LED will light up once a relay is engaged. One of the finest features of these modules is that they have two optocouplers ICs that give excellent relay-to-Arduino isolation.

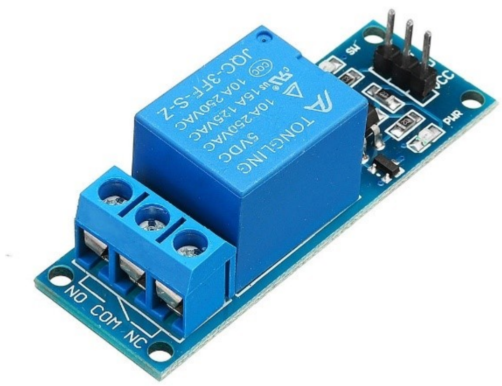

Figure 15: Protective Relay

4.3.2 Piezo Buzzer

The piezo buzzer generates sound by reversing the piezoelectric effect. The basic concept is to apply an electric voltage across a piezoelectric material to create pressure fluctuation or strain. These buzzers can be used to alert a user to a switch, counter signal, or sensor input that has initiated an event. Alarm systems also contain them. The buzzer generates the same loud sound regardless of the voltage variation delivered to it. Piezo crystals are placed between two conductors in this device. One conductor is pushed while the other is pulled when a potential is applied across these crystals. As a result of the push and pull motion, a sound wave is produced. The bulk of buzzers have a 2 to 4 kHz frequency. The +ve lead is connected to the Input, while the -ve lead is connected to the Ground. Piezo buzzers use less current, produce a louder sound, and work with a wider variety of voltages than other buzzers. In contrast, electro-magnetic buzzers can create sound at low frequencies in small, compact enclosures.

Figure 16: Piezo Buzzer.

4.4 Display Section

4.4.1 LCD

A liquid crystal display (LCD) is an electrical display module that produces a visible picture using liquid crystal. The 204 refers to a four-line display with 20 characters per line. Each character is presented at a 577-p resolution on this LCD.

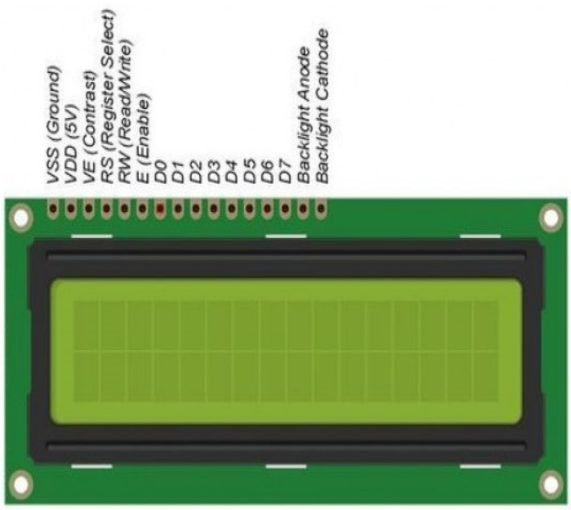

Figure 17: Liquid Crystal Display

Table 2: Liquid Crystal Display Pin Configurations(Rajnikanth)

Pin_1	GND	Source_Pin	This is the LCD's ground pin.	Connected to the MCU's ground
Pin_2	VCC	Source_Pin	This is the LCD's supply voltage pin.	The supply pin is connected.
Pin_3	V0/VEE	Control_Pin	Adjusts the LCD's contrast.	Connected to a 0-5 V variable POT
Pin_4	Register Select	Control_Pin	Switches between Command/Register mode.	When connected to an MCU pin, it receives a value of 0 for command mode or 1 for data mode.

Pin_5	Read/Write	Control_Pin	Switches the LCD between read and write mode.	Connected to an MCU pin and receives a 0 or 1 for write or read.
Pin_6	Enable Pin	Control_Pin	To perform, you must have a high IQ. Operation Read/Write	Always held high when connected to an MCU pin.
Pin_7 - 14	Data-Bits (0-7)	Data/Command Pin	This pin was used to communicate data or commands to the LCD.	The MCU is connected in four wire mode (0-3) and eight wire mode (0-7)
Pin_15	LED-Positive	LED Pin	To illuminate the LCD, use a regular LED.	Connected to +5 V
Pin_16	LED-Negative	LED Pin	Normal LED like operation to illuminate the LCD	GND is connected to

4.4.1.1 Registers of LCD

Two registers, one for data and the other for commands, are found in a 162 LCD. The RS (register select) is mostly used to change registers. The command register is referred to as the command register when it is set to '0.' It is referred to as a data register when the register set is '1'.

• Command Register

The major function of the command register is to store the instructions for commands transmitted to the display. As a result, specified tasks such as cleaning, initializing, establishing the cursor position, and controlling the display can be done. Commands can be processed within the register.

• Data Register

The major function of the data register is to store the information that will be displayed on the LCD panel. The ASCII value of the character is what will be displayed on the LCD panel. When we send data to the LCD, it is sent to the data register, where the process starts. When register set =1, the data register will be chosen.

4.5 Primary Microcontroller Section

4.5.1 Arduino Uno

The Arduino Uno is an open-source microcontroller board based on the ATmega328P microprocessor built by Arduino. Digital and analog input/output (I/O) pins on the board can be used to communicate with expansion boards (shields) and other circuits. The board features 14 digital I/O pins (six of which can be used for PWM output), 6 analog I/O pins, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power connector, an ICSP header, and a reset button, and it can be programmed using the Arduino IDE and a type B USB cable (Integrated Development Environment). It accepts voltages ranging from 7 to 20 volts and can be powered through USB or an additional 9-volt battery(Kalathil, Vaishnav et al. 2021).

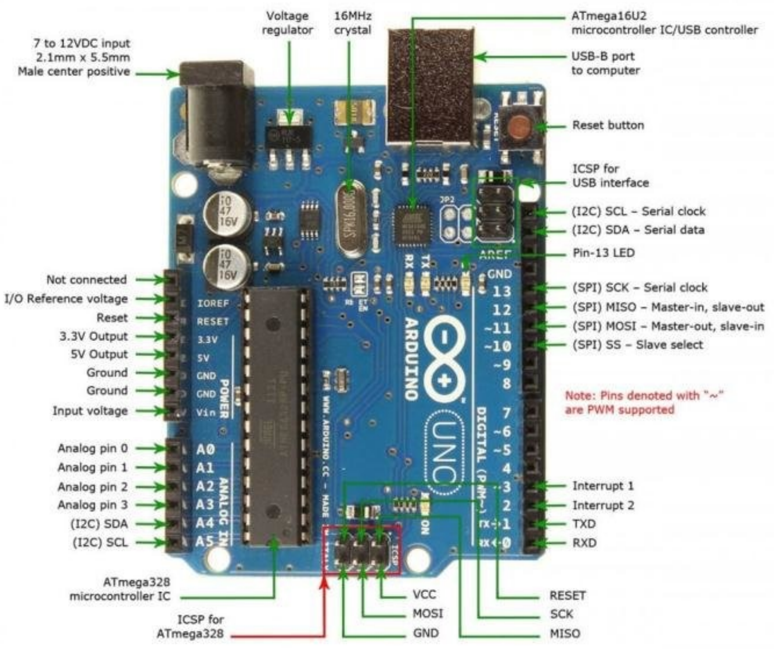

Figure 18: Arduino Uno(Thakare, Shriyan et al. 2016)

4.6 Software Prototype

Using the Proteus 8 professional, we were able to develop the prototype software component, which enable us to test the design, evaluate and determine if it would be practical to execute the hardware part. The prototype comprises of the measuring component, the primary controlling or processing part, and the protecting part.

We collect the 230 voltage AC from V.sine in proteus 8 professional, step in down to 12 voltage AC and with the help of the bridge rectifier, we convert the 12 voltage AC to 12 voltage DC and with the help of the capacitors, we were able to smooth out the ripples and obtained the constant dc voltage. We made care to utilize the Zener diode, to stabilize the output voltage at the end output end.

The output voltage from the measuring units is then supplied to one of the analogue pins of the Arduino, to measure the voltage with the assistance of calibration as was mentioned earlier. Since we are aiming to simulate a three-phase line, we have to do the same for the remainder of the two phases. The values of the measuring voltages are shown on the 20x4 LCD.
Once we provide supply to our design all the sensors start detecting the current, voltage, frequency, and temperature and update all the real-time readings to the server as well as shown\son the display. It checks all the real-time data with the pre-defined values, if any of the values exceed pre-defined values it sends a fault warning to the relay and buzzer as well as updates it on the display. If the problem persists for the pre-set time then the relay separates the loads from the rest of the system. In the interim, the comparison carries on as before, if the fault is cleared relays reconnect the loads with the rest of the system.

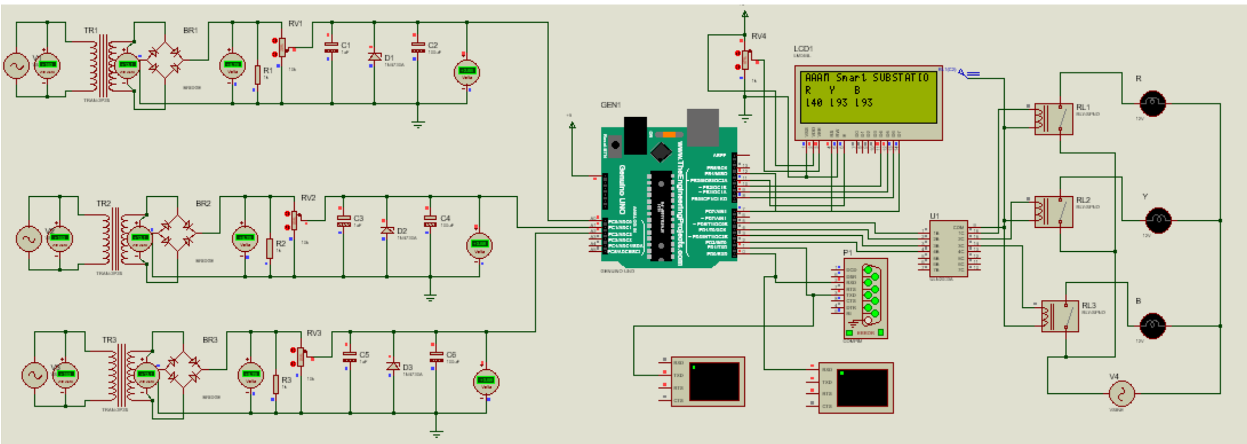

Figure 19: Software Prototype Design, using Proteus 8 Professional.

4.7 Hardware Prototype

Here in the suggested prototype, we have chosen Arduino Uno as our main microcontroller. It will operate as the heart of the system; all other measuring circuitries will be interfaced via this. Besides the microcontroller we have utilized ACS712 current sensor measurement unit, a piezo buzzer, and a 4-channel relay module; and to show the load we have used a fan and a lamp. Alongside we also have used a supply unit, consisting of a transformer, which converts 230 Volt AC to 12 Volt AC then it is passed through bridge rectifier unit which converts this 12 Volt AC to 12 Volt DC which is pulsating in nature which is then fed to the capacitor which works as a filter, makes the pulsating DC smooth DC. As a lot of our components like Arduino Uno and some of the sensors as well need 5 Volt regulated DC. In case of buzzer and relay demand a big quantity of current for operation, we have to make some measures for that. For that amplification arrangement in the case of the relay, we have used a relay driver and for the buzzer, we have utilized two BC 547 transistors in the Darlington pair configuration. For the functioning of the green and red LEDs which serve as an indication also requires a huge amount of current for their amplified current need we have utilized two BC 547 transistors one for each.
When we feed supply to our prototype the display displays a welcome message and simultaneously all the sensors start detecting the current, voltage, frequency, and temperature and update all the real-time readings to the server as well as presented on the display. It checks all the real-time data with the specified values, if any of the values surpass pre-defined values it sends a malfunction alarm to the relay

and buzzer as well as updates it on the display. If the problem persists for the pre-set time then the relay separates the loads from the rest of the system. In the interim, the comparison carries on as before, if the fault is cleared relays reconnect the loads with the rest of the system.

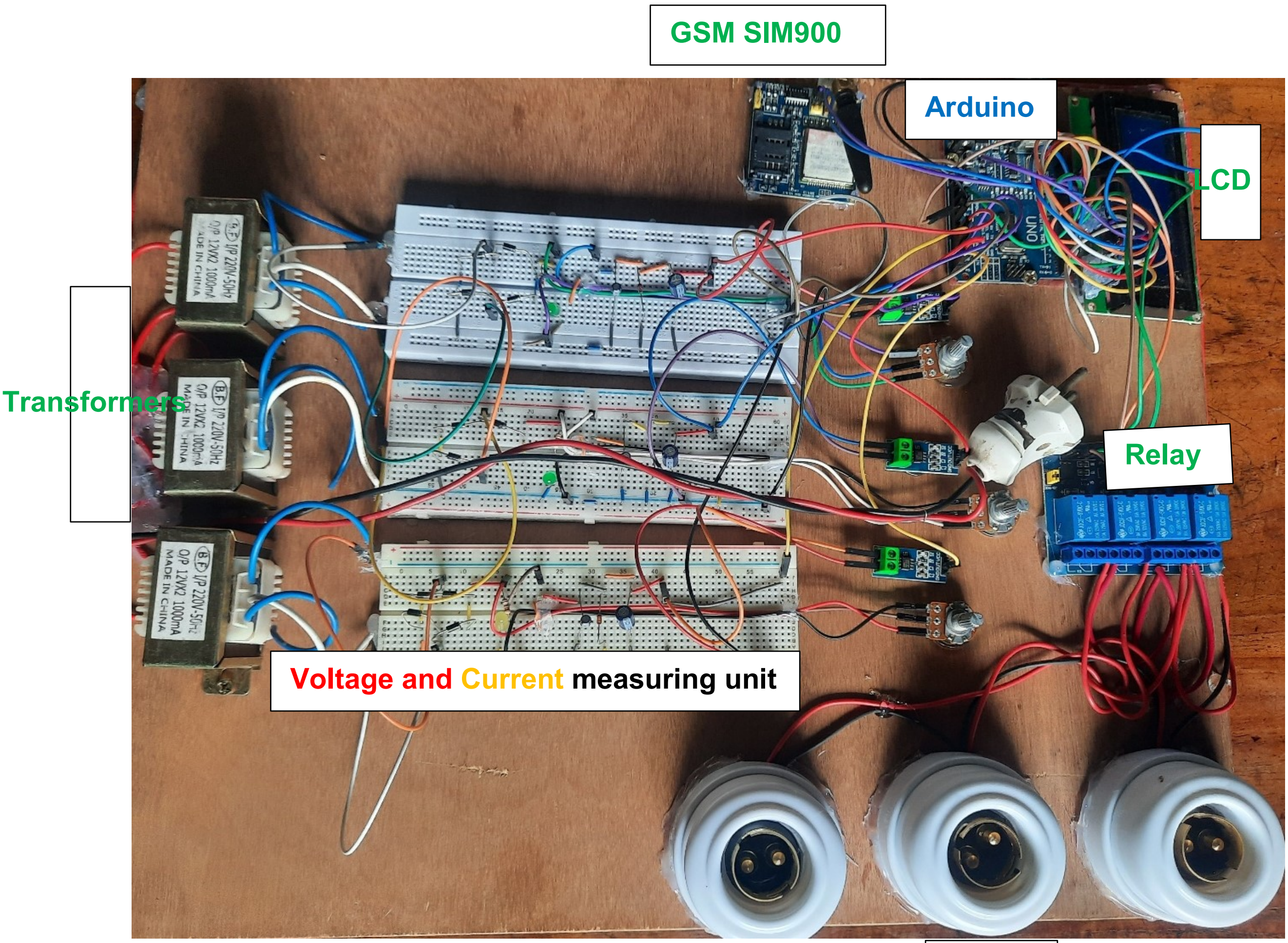

Table 3:Hardware Prototype

4.8 Arduino Generated Codes

Below is the generated Arduino code for easy measuring and monitoring. The codes are for calibration and measuring purposes as was discussed earlier in the previous chapter. The main of the calibration is to find and know your multiplier that will be multiplied by the data bit Arduino can take. This will yield the exact output you seek.

4.8.1 Calibration Code

```
int ACInput = A0; //Assigning pins for R Phase

//Start the setup function
void setup() {
```

```
  pinMode(ACInput, INPUT);
  Serial.begin(9600);
}

//Begin the Loop Function Here
void loop()
{
   int vrout = analogRead(ACInput); //At analog pin A0, read the division (0 to 1023)
   Serial.println(vrout); // Show the R-Phase voltage on the serial monitor.
   delay(500);
    }
```

Table 4: Calibration Arduino code(Atay)

4.8.2 Single phase Voltage measurement code

```
#include <LiquidCrystal.h>
LiquidCrystal lcd(12, 11, 10, 9, 8, 7); //(RS,EN,D4,D5,D6,D7)
int Volt = A0; //Ac voltage pin assignment


//Setup function Start
void setup() {
  pinMode(Volt, INPUT);
  lcd.begin(16,2);
  Serial.begin(9600);
}

//Loop Function Start Here
void loop()
{
  lcd.clear();
   int AcVolt = analogRead(Volt); //Analog pin A0 is used to read the division (0 to 1023)
   int AcVoltOut = (AcVolt * (5.0 / 1023))*93.67; // Convert the alternating current division to volts.
   Serial.println(AcVoltOut); // On the serial monitor, display the alternating current voltage.
   lcd.setCursor(0,0);
   lcd.print("AC Voltage");
   lcd.setCursor(0,1);
   lcd.print(AcVoltOut); // The AC voltage will be displayed on the LCD.
   delay(500);
    }
```

Table 5: Single phase Voltage measurement code(Atay)

4.8.3 Three Phase measurement code

```
#include <LiquidCrystal.h>
LiquidCrystal lcd(12, 11, 10, 9, 8, 7); //(RS,EN,D4,D5,D6,D7)
int RPhase = A0; //Pin assigning for R Phase
int YPhase = A1; //Pin assigning for Y Phase
int BPhase = A2; //Pin assigning for B Phase

//Setup function Start
void setup() {
  pinMode(RPhase, INPUT);
  pinMode(YPhase, INPUT);
  pinMode(BPhase, INPUT);
  lcd.begin(20,4);
  Serial.begin(9600);
```

```
}

//Loop Function Start Here
void loop()
{
 lcd.clear();
  int vrout = analogRead(RPhase); //Analog pin A0 is used to read the division. (0 to 1023)
  int vyout = analogRead(YPhase); //Analog pin A1 is used to read the division. (0 to 1023)
  int vbout = analogRead(BPhase); //Analog pin A2 is used to read the division (0 to 1023)
  int RVolt = (vrout * (5.0 / 1023))*53.12; // Convert R-Phase divison to volts
  int YVolt = (vyout * (5.0 / 1023))*53.12; // Convert the Y-Phase divide to volts.
  int BVolt = (vyout * (5.0 / 1023))*53.12; // Convert the B-Phase divide to volts.
  Serial.println(RVolt); // On the serial display, show the R-Phase voltage.
  Serial.println(YVolt);// Display the Y-Phase voltage on serial monitor
  Serial.println(BVolt); // Display the B-Phase voltage on serial monitor
  lcd.setCursor(0,0);
  lcd.print("AAAM Smart SUBSTATION");
  lcd.setCursor(0,1);
  lcd.print("R   Y   B   ");
  lcd.setCursor(0,2);
  lcd.print(RVolt); // Display the R-Phase voltage on LCD
  lcd.setCursor(4,2);
  lcd.print(YVolt); // Display the Y-Phase voltage on LCD
  lcd.setCursor(8,2);
  lcd.print(BVolt); // Display the B-Phase voltage on LCD
  delay(500);
   }
```

Table 6: Three Phase measurement code(Atay)

Chapter 5

Conclusion and Future Work

5.1 Conclusion

Cellular connectivity within NANs, for example, is an appropriate communication mechanism for putting the smart grid concept into action. Smart grid NANs define an electrical distribution system's communication facility and often include complex functions that are currently unavailable. As a result, in order to provide increased communication and control functions, the modernization of the legacy power grid demands significant advancements in current cellular technology. In this survey study, the researchers looked at the challenges and offered architectural and protocol improvements to cellular technology to suit NAN applications. A comprehensive overview of current research on the subject has been provided, as well as a classification of existing approaches, culminating in the identification of future research requirements. D2D communications have been highlighted as a feasible alternative for the future operation of NANs over public cellular networks as a potential expansion of LTE capabilities because they can unload large cellular networks and increase wireless communications performance in a variety of ways. LTE-D2D, as indicated in the literature, will enable applications that are probably not feasible with current cellular technology, such as efficient automatic control of the future distribution grid, including microgrid distributed management, and smart substation automation, and active demand-response services. We've emphasized the lessons learned and identified open research issues in cellular technology for smart grid NANs to encourage and fund future research. In order for smart energy devices to communicate autonomously and automatically, current LTE cellular networks will also need to be updated to accommodate operation applications.

5.2 Future Scope

5.2.1 GSM Module and GPS Module Addition

By adding the GSM module, we will be able to send Personalized SMS to the authorities, allowing them to stay informed about the plant even when they are not present. And the microcontroller is coded such that a certain SMS format is transmitted, which may be utilized as an input for the microcontroller to do the desired function.

5.2.2 Wireless Camera Addition

We can install wireless cameras on the premises of the substation switchyard to better visually monitor the substation. This would be especially beneficial for monitoring transformers, considering that they are usually placed in remote locations.

5.2.3 GUI development

A graphical user interface can be used to construct the window display (GUI). A displayer may be used to monitor the devices and their attributes, such as frequency, voltage, load impedance, reluctance, oil level, temperature, cooling state, and power. The operator may simply verify the status of any gadget in real-time thanks to this technology. Furthermore, if a failure happens, the operator will be notified instantly that a piece of certain equipment is having issues or is malfunctioning. Power interruptions are avoidable, and power supply continuity is ensured.

5.2.4 System for Coolant Management

In addition to the temperature sensor module, we may integrate a coolant management system for managing cooling flow and temperature. When a module's or piece of equipment's temperature reaches a specific threshold, the coolant flow can be programmed to be rapid and continuous, but when the temperature is well within range, the coolant flow can be moderate and periodic.

Reference

Atay, M. "Three Phase AC Voltage Measurement using Arduino." Retrieved 13, March 2022, from https://bestengineeringprojects.com/three-phase-ac-voltage-measurement-using-arduino.

Cosovic, M., et al. (2017). "5G mobile cellular networks: Enabling distributed state estimation for smart grids." IEEE Communications Magazine **55**(10): 62-69.

Ganguly, P., et al. (2016). Analysis of the security anomalies in the smart metering infrastructure and its impact on energy profiling and measurement. 2016 5th International Conference on Smart Cities and Green ICT Systems (SMARTGREENS), IEEE.

Kalalas, C., et al. (2016). "Cellular Communications for Smart Grid Neighborhood Area Networks: A Survey." IEEE Access **4**: 1469-1493.

Kalathil, D., et al. (2021). Microcontroller based Substation Disaster Monitoring System. 2021 Fifth International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud)(I-SMAC), IEEE.

Loganathan, N., et al. (2021). Smart Substation Monitoring and Control. 2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS), IEEE.

Narejo, G. B., et al. (2015). Remote Microcontroller Based Monitoring of Substation and Control System Through GSM Modem.

Rajnikanth, M. "Substation Equipment Monitoring And Controllig Using IoT."

Sangolkar, R. (2020). "Fault Identification and Remote Operation of Receiving Substation and Auxiliary Substation using IoT." International Journal for Research in Applied Science and Engineering Technology **8**(9): 250-254.

Thakare, S., et al. (2016). Implementation of an energy monitoring and control device based on IoT. 2016 IEEE Annual India Conference (INDICON), IEEE.