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Design and Implementation of Iot Based Smart Meter

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Abstract
The increasing demand for efficient and sustainable energy consumption has led to the development of smart metering technology. Smart meters have advanced features such as real-time monitoring of electricity consumption, remote meter reading, and two-way communication between the utility company and customers. However, most smart meters in use are single-phase meters, which can limit their use in commercial and industrial settings that require high power demands. Three-phase electricity is commonly used in industrial and commercial settings, and a three-phase smart meter can provide more accurate energy usage data than a single-phase meter. This project aims to design and construct a three-phase IoT-based smart meter with load shedding, that can measure and transmit energy consumption data in real-time. The smart meter will be designed to provide accurate readings of each phase of electricity consumption separately, using Internet of Things (IoT) technology to transmit data to utility companies and customers. The project will explore the potential benefits of using a three-phase smart meter in industrial and commercial settings, including more accurate energy usage data, the ability to optimize energy consumption, and reduce costs.
Keyword: IoT, Smart Meter, Electricity,

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I. Introduction

The worldwide energy demand is increasing as a result of the growth in population or by the use of new equipment has brought big challenges to the energy security as well as the environment and hence necessity measures need to be taken to reduce the energy wastage with proper metering infrastructure in the buildings [1].The traditional electricity meters initially used by utility companies to measure customers' electricity consumption are being replaced with smart meters that offer advanced features and capabilities. Smart meters are designed to provide accurate real-time readings of electricity usage, allowing utilities to better manage their distribution networks and customers to monitor their energy usage and costs.

A **smart meter** is an electronic device that records information such as consumption of electric energy, voltage levels, current, and power factor. Smart meters communicate the information to the consumer for greater clarity of consumption behavior, and electricity suppliers for system monitoring and customer billing. Smart meters typically record energy near real-time, and report regularly, short intervals throughout the day. Smart meters enable two-way communication between the meter and the central system. Such an advanced metering infrastructure (AMI) differs from automatic meter reading (AMR) in that it enables two-way communication between the meter and the supplier. Communications from the meter to the network may be wireless, or via fixed wired connections such as power line carrier (PLC) [2].

An IoT-based smart meter is an advanced type of energy meter that is capable of measuring and transmitting energy consumption data in real-time. Unlike traditional energy meters, smart meters are equipped with internet of things (IoT) technology that enables them to communicate with other devices over the internet [3]. IoT-based smart meters can transmit energy consumption data to both utility companies and customers, allowing for better energy management and cost-saving strategies. Customers can view their energy consumption data in real-time and make adjustments to their energy usage accordingly. Utility companies can use the data to balance energy demand and supply, which can help reduce the likelihood of blackouts and brownouts.

This project aims to design and construct a three-phase IoT-based smart meter. The project will involve the development of a hardware and software system that can measure and transmit energy consumption data in real-time. The smart meter will be designed to be user-friendly and easy to install, with the ability to connect to the internet and transmit data securely. The project will also explore the potential benefits of using a three-phase smart meter in industrial and commercial settings, including more accurate energy usage data and the ability to optimize energy consumption and reduce costs.

II. Methodology

IoT-based smart meters are digital devices that measure and record energy consumption in real-time and transmit that data to a central system using the internet. They are part of the larger concept of the Internet of Things (IoT), where everyday objects are connected to the internet and can communicate with each other [22].

Smart meters are designed to provide a more accurate and efficient way of tracking energy usage and can help consumers and energy providers better understand and manage energy consumption. With IoT-based smart meters, the energy provider can remotely monitor the energy usage and bill the customer accurately based on actual consumption. This eliminates the need for manual meter readings, which can be time-consuming and prone to errors.

Smart meters can also provide consumers with access to real-time energy usage data through a web portal or mobile app, allowing them to make informed decisions about how to conserve energy and save money on their bills.

IoT based energy meter system mainly consists of three major parts i.e. Controller, Wi-Fi and Theft detection part. Whenever there is any fault or theft, the theft detection sensor senses the error and circuit response according to the information it receives. The controller plays a major role in the system making sure all the components are working fine.

Therefore, IoT can improve the performance and efficiency of the smart grid mostly in the three phases. Firstly, it increases the reliability and durability. Secondly, it focuses on enablement i.e. collection and analyzation of data to manage active devices within the smart grid. Lastly, controlling can be done by analyzing the result obtained from the second phase which helps the grid department to make fine decision for future upliftment. The energy meter available till now can only control and monitor the energy consumption of customers. Smart energy meter developed using power line communication (PLC) helps in power loss [23].

A. Block Diagram of IoT Based Smart Meter

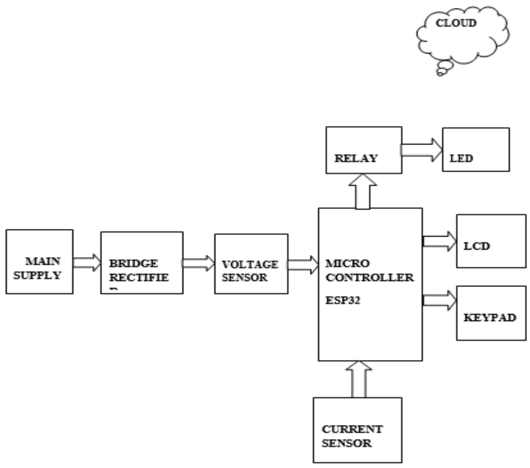

Fig 1: Block diagram of IoT Based Smart Meter

B. Principle of Operation

The principle of operation of a three-phase IoT-based smart meter with load shedding involves measuring the energy consumption of a three-phase electrical system and transmitting the data to a cloud-based server for analysis and management. The server then analyzes the data and determines when to shed load during peak demand periods to prevent blackouts or brownouts. Load shedding can be done on a priority basis, with less critical loads being shed first. The smart meter consists of a Microcontroller, Voltage Sensor, Potential Transformer, Current Sensor, Relays, and LCD display, e.t.c to measure the energy consumption of each phase and display the data to the user. The smart meter may also use a smart industrial power sensor and a BLYNK App to monitor energy consumption patterns in equipment and buildings and transmit real-time energy consumption data to a cloud-based server for better management of energy consumption and industrial equipment. The smart meter may also provide hourly, daily, weekly, and monthly consumption reports on the BLYNK App and notifications on the user's smartphone when usage goes beyond defined thresholds. The smart meter may also reconcile the energy consumed and the energy bill to analyze key consumption areas.

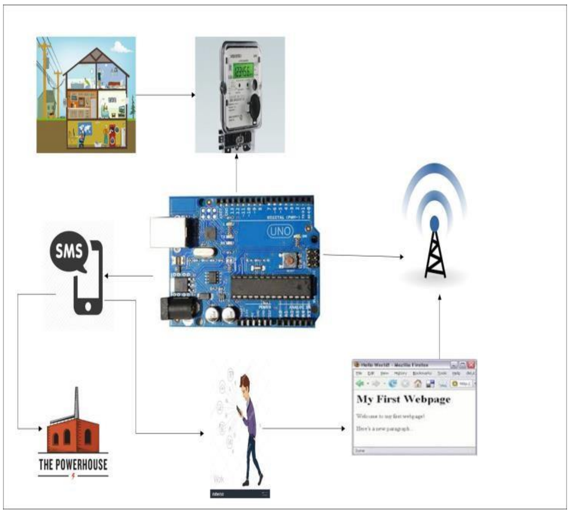

Fig 2: Architectural view of the proposed system [21]

C. BLYNK IoT

The proposed work is connected through BLYNK IoT server for control applications. The status of the connected hardware pins, are continuously transmitted to the BLYNK server and the smartphone installed with the BLYNK App gets the ability to read the saved data from the IoT server. The hardware is also controllable from the smartphone through wireless connections with the help of BLYNK hardware. In order to connect an IoT hardware with BLYNK server, it is a must to install the respective BLYNK library to the IoT hardware unit [24].

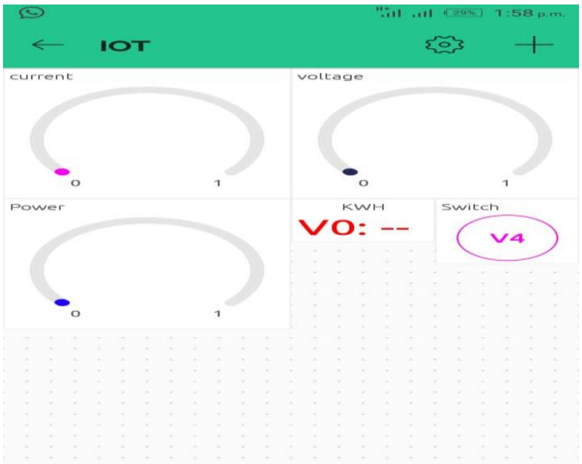

Fig 3 BLYNK IoT Server

D. Description of Components
List of Components Used

- ESP32 Microcontroller
- Current sensor (ZMCT103C)
- Voltage Sensor
- Relay 12V 30A
- LCD Display
- I2C (Inter- Integrated Circuit)
- Transformer (220V-12V-220V)
- Resistors (100KΩ and 10KΩ)
- Bridge rectifier
- 8×8 keypad

E. ESP32 Microcontroller

The ESP32 is a low-cost and low-power microcontroller developed by Espressif that includes Wi-Fi and Bluetooth wireless capabilities and a dual-core processor. It is the successor to the ESP8266 and has many new features. It is also designed for mobile, wearable electronics, and Internet-of-Things (IoT) applications. The ESP32 is a complete standalone system that comes in a range of low-cost modules. It has a powerful processor, such as a Xtensa LX6 (~240 MHz) with 512 KiB memory, and an ultra-low coprocessor (ULP) with only 8 KiB memory designed to run when ESP32 is in low-power mode. The ESP32 is power-packed with hardware features, including numerous built-in peripherals, making it a great choice to build anything connected. The ESP32 is well-suited for IoT projects due to its low cost, power, and ability to connect to other electronic devices

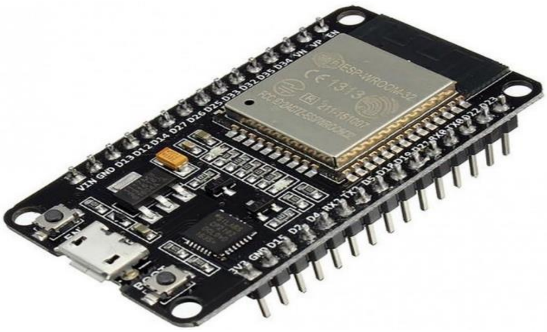

Fig 4 ESP32 Microcontroller[19]

F. ESP 32 Interfacing

The ESP32 module is interfaced with the following components: ZMCT103C, the LCD, and relay as depicted. It receives inputs from these components and then generates the desired output to the connected components. It performs the following functions:

- Converts the Analog output voltage from the ZMCT103C to an equivalent DC current value ranging from 0-15A with the aid of an onboard Analog to digital converter.
- Scans the keypad for input. This input is the pin code for subscription specific to a customer.
- Controls the relay via a transistor.
- Sends and receives messages while monitoring the output displayed by the LCD.

**G. Current Sensor (ZM
CT103C):**

This is the transducer used for sensing and monitoring of current flow. In essence, ZMCT103C current sensor was used owing to its high accuracy. It senses AC and DC currents based on Hall-effect principle. The ZMCT103C Current Sensor is a Hall Effect current sensor that accurately measure current when induced. The magnetic field around the AC wire is detected which gives the equivalent analog output voltage. The current sensor detects current up-to 5A of AC current. Since, the actual current reading is needed, the analog voltage is sent to the microcontroller for processing. The sensor has four pins which are:

Pin 1 and 2 [Ground]: These pins are used for common ground connection.

Pin 3 [Analog Signal]: These pins are used to generate analog output signal proportional to the current flowing through the wire

Pin 4 [+5V]: This is the positive power supply of +5V.

Fig 5 A DC/AC Current Sensor [19].

H. Current Sensor Interfacing

To determine the amount of current that is drawn by the load or heating element, a 5A-15A Hall Effect current sensor was used. This Hall Effect sensor isolates the current that is supplied by the main supply from damaging the microcontroller, since it can allow only 5V input voltage. The ZMCT103C was interfaced with the microcontroller and the main supply. For the ZMCT103C the pin 5 or GND, pin 7 or Vout, and pin 8 or Vcc were considered in developing of the system. Therefore, for the connection configuration, the ZMCT103C output pin was connected to the analog pin A0 of the Arduino, the GND pin also was connected to the GND of the microcontroller, and then the Vcc to the 5V pin on the controller board. The sensor outputs an analog output voltage that corresponds to the current flow which ranges from 0-5V [25].

I. Voltage Sensor

The voltage sensor module is a small size 0-25 DC voltage sensing device. The design of the module is based on a resistive voltage divider circuit. It is a voltage sensor module that reduces the input voltage signal by the factor of 5 and generates a corresponding analog output voltage with respect to step down voltage factor. This voltage measurement circuit is small and portable and can be used to detect under and over-voltage faults in electrical circuits.

The voltage sensor module is embedded with two header blocks. One with the screws is connected to the power source whose voltage to be measured while the other connector is used to interface microcontrollers such as Arduino, Pic microcontroller, Raspberry Pi, Beagle bone, etc. The schematic diagram of the voltage Sensor module which is a resistive voltage divider is shown below:

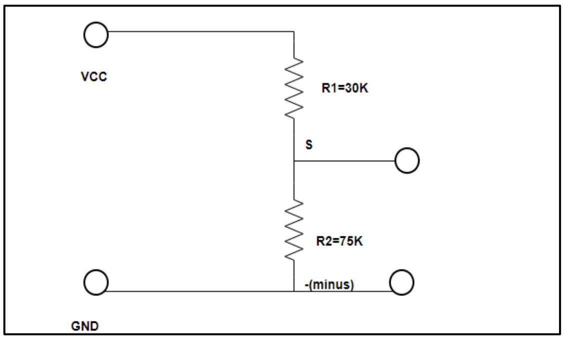

Fig 6 Circuitry of the Voltage Sensor

The voltage sensor module works on the voltage divider principle. A voltage divider is a circuit made of two resistors connected in series. An input voltage is connected to the circuit. The applied voltage is then passed on between the two resistances and division takes place in direct accordance with the resistances. The output analog voltage is taken from the second resistor and measured. The general equation of the output voltage is:

$$\text{Vout} = \text{Vin} \times \frac{\text{R2}}{\text{R1+R2}} \qquad 3.$$

The equation shows that the output voltage is directly proportional to the input voltage and the ratio of the R_2 resistor to the sum of R_1 and R_2 resistors.

J. Relay

A relay is an electromagnetic switch. The switching on/off of relay is based on flow of current through its coil. A relay is used for switching on/off various high voltage circuits. In Electric smart load meter, relays are used to allow and disallow the flow of current to the load when it needs current and when it does not respectively.

Fig.7 Relay [19].

K. Liquid Crystal Display (20X4)

A 20x 4-character LCD display with white text on a vivid blue backlit LCD, standard Hitachi HD44780 compatible interface for easy connection to microcontrollers, LCD20×4 Display is 20 characterswide,4 rows character LCD module, HDD44780 controller (Industry-standard HD44780 compatible controller),6800 4/8-bit parallel interface, single led backlight with white color included can be dimmed easily with a resistor or PWM, STN- blue LCD negative, white text on the blue color, wide operating temperature range, robs compliant. It's optional for pin header connection,5V or 3.3V power supply and I2C adapter board for Arduino. It can be used in any embedded systems, industrial device, and security, medical and hand-held equipment. LCD20X4 is a dot-matrix liquid crystal display module specially used for displaying letters, numbers, and symbols, etc. 20×4 LCD Display can display 4 rows with 20 characters in each line. Divided into 4-bit and 8-bit data transmission methods. 1604 Green Character LCD provides rich command settings: clear display; cursor return to origin; display on/o; cursor on/o; display character ashes; cursor shift; display shift, etc.

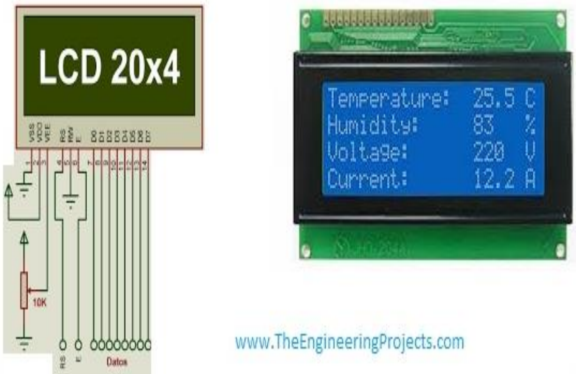

Fig. 8 Liquid Crystal Display[19].

L. I2C (Inter-Integrated Circuit)

I2C (Inter-Integrated Circuit) is a communication protocol used to establish communication between multiple digital devices in a system. I2C uses a two-wire interface consisting of a serial data line (SDA) and a serial clock line (SCL) to transfer data between devices. It supports multiple masters and multiple slaves, and each device on the bus is identified by a unique 7-bit or 10-bit address.

The I2C protocol is designed for short-distance, low-speed communication between devices on the same printed circuit board (PCB) or within the same system. It is commonly used in applications such as sensors, real-time clocks, and other low-speed peripherals.

Overall, I2C is a simple and flexible communication protocol that has become a standard in many embedded systems and is widely supported by microcontrollers, sensors, and other digital devices.

M. LCD Interfacing with I2C

Interfacing an LCD with I2C is a simple process that involves connecting the LCD to an I2C module and then connecting the I2C module to the microcontroller. The I2C module communicates with the microcontroller using only two pins, SDA (data) and SCL (clock), which simplifies the wiring process. The LCD I2C module typically has four pins: GND, VCC, SDA, and SCL. The GND and VCC pins are connected to the ground and power supply, respectively, while the SDA and SCL pins are connected to the SDA and SCL pins of the microcontroller. Once the LCD is connected to the I2C module and the module is connected to the microcontroller, the appropriate library for the LCD display should be installed in the microcontroller's IDE, and the code should be written to display the desired text or characters on the LCD [25].

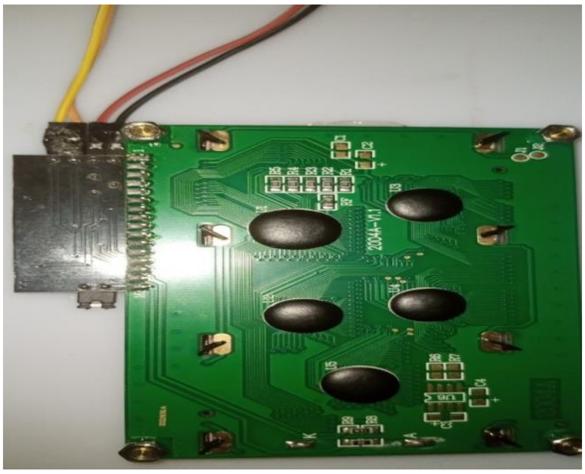

Fig 9: LCD with I2C interfacing

N. Buzzer

Buzzer is an electrical device, which is similar to a bell that makes a buzzing noise and is used for signaling or alarming. The buzzer is integrated into this design as to alarm when the meter is being tempered with or when the units on the energy meter is low. The buzzer is connected to PIN 12 of the microcontroller.

O. Power Supply Rectified Circuit

A **regulated power supply** converts unregulated AC (Alternating Current) to a constant DC (Direct Current). A regulated power supply is used to ensure that the output remains constant even if the input changes.

A regulated DC power supply is also known as a linear power supply, it is an embedded circuit and consists of various blocks.

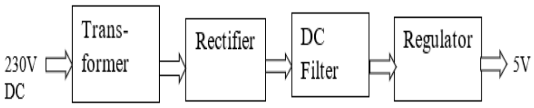

Fig 10 Block Diagram of a regulated power supply

P. Rectified Circuit Diagram

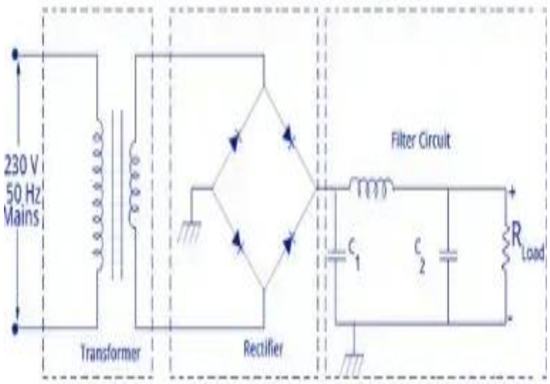

Fig 11: A Rectified Circuit Diagram [26].

The basic building blocks of a regulated DC power supply are as follows:

- A step-down transformer
- A rectifier
- A DC filter
- A regulator

Step-Down Transformer: A step down transformer will step down the voltagefrom the ac mains to the required voltage level. The turn's ratio of the transformer is so adjusted such as to obtain the required voltage value. The output of thetransformer is given as an input to the rectifier circuit.
Rectifier: Rectifier is an electronic circuit consisting ofdiodes which carries out the rectification process. Therefore, Rectification is the process of converting an alternating voltage or current into corresponding direct (DC) quantity. The input to a rectifier is AC whereas its output is unidirectional pulsating DC.
Half wave rectifier can be used because its power losses are significant compared to a full wave rectifier. As such, a full wave rectifier or a bridge rectifier is used to rectify both the half cycles of the ac supply [26].

$\mathrm{Vout} = \mathrm{Vin}\ \times \frac{\mathrm{R2}}{\mathrm{R1+R2}}$ 3.2

DC Filter: The rectified voltage from the rectifier is a pulsating DC voltage having very high ripple content. Since the circuit requires a pure ripple free DC waveform. Hence a filter is used. Different types of filters are used such as capacitor filter, LC filter, Choke input filter, π type filter. As the instantaneous voltage starts increasing the capacitor charges, it charges until the waveform reaches its peak value. When the instantaneous value starts reducing thecapacitorstarts discharging exponentially and slowly through the load (input of the regulator in this case). Hence, an almost constant DC value having very less ripple content is obtained.
The capacitance value can be obtained from the current formula of the capacitor given as;

$\mathrm{ic} = \frac{\mathrm{dq}}{\mathrm{dt}}$ 3.3

q = charge in coulomb
q = CV 3.4

Regulator: This is the last block in a regulated DC power supply. The output voltage or current will change or fluctuate when there is a change in the input from ac mains or due to change in load current at the output of the regulated power supply or due to other factors like temperature changes. This problem can be eliminated by using a regulator. A regulator will maintain the output constant even when changes at the input or any other changes occur. Transistor series regulator, Fixed and variable IC regulators or a zener diodeoperated in the zener region can be used depending on their applications [26].

$$\mathrm{Vout} = \mathrm{Vin}\ \times \frac{\mathrm{R2}}{\mathrm{R1 + R2}}$$
$$\mathrm{Vout} = 12\mathrm{V}\ \times \frac{10\mathrm{K}}{100\mathrm{K} + 10\mathrm{K}}$$
$$\mathrm{Vout} = 12\mathrm{V}\ \times \frac{10\mathrm{K}}{110\mathrm{K}}$$
$$\mathrm{Vout} = 12\mathrm{V}\ \times\ 0.090$$
$$\mathrm{Vout} = 1.09\mathrm{V}$$

Q. Interfacing the Power Supply Unit
The Alternating Current (AC) and voltages supplied to the consumer end by the main supply was stepped down to a minimum voltage via the power supply unit which in this case is in a form of a rectified circuit. The rectified circuit is being stepped down from 220V supplied from the mains to a minimum of 12V. The voltage regulator was used to further step down the 12V to a minimum of 5V [25].

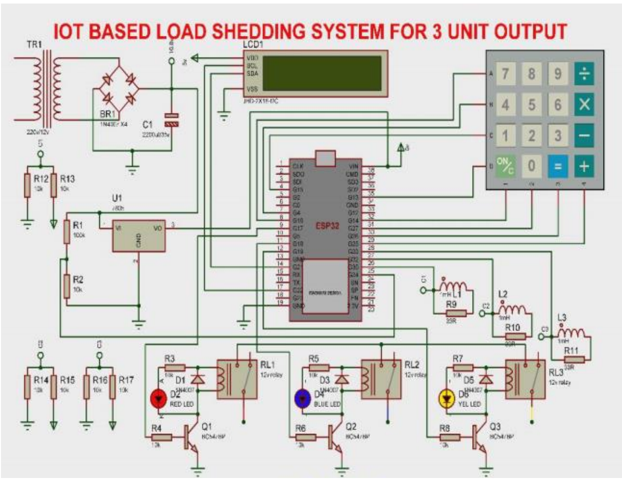

Fig 11 Schematic Circuit diagram of an IoT Smart Meter

III. Result and Analysis

This section presents the actual results obtained from the completed design. The results from design have been summarized under four stages:

A. Programming of the Microcontroller

The ESP32 which is the heart of the system i.e. the meter controller was programmed using C++ on the Arduino IDE.

The program was properly tested and debugged in order to ensure that the communication between the ESP32 and other components was achieved.

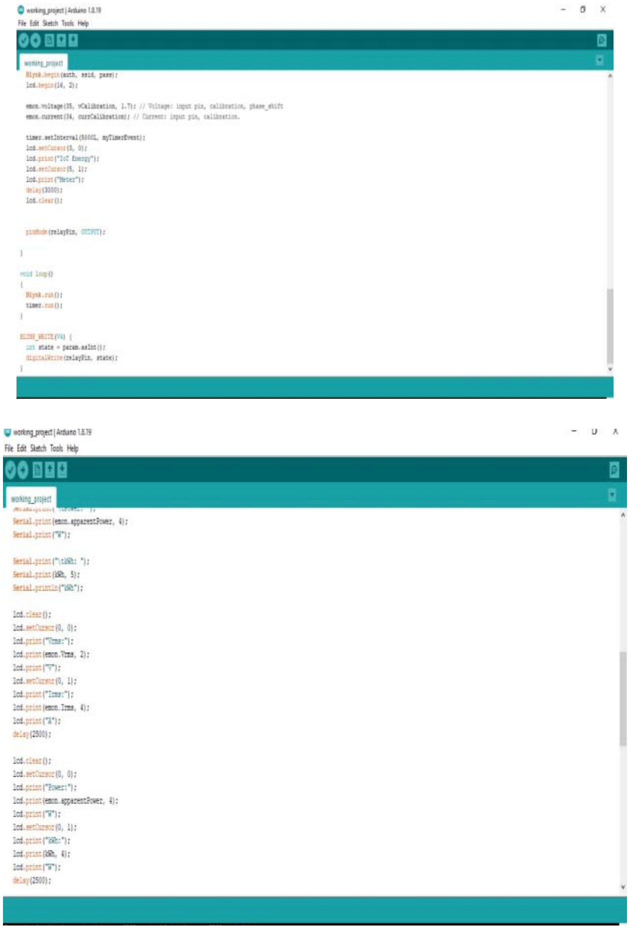

Fig 12: ESP32 Microcontroller using C++ Programming Language

B. Component Testing

The components that were used were individually tested to ensure that they were working as required.

Each major component that was supposed to be interfaced with the microcontroller was connected and tested to ensure proper communication.

C. ZMCT103C Current Sensor Test

Here are the steps followed to test the ZMCT103C current sensor:

ZMCT103C was connected to the microcontroller (ESp32 nodeMCU). The sensor Connected has four pins: VCC(pin 4), GND(pin 1 and 2), and ANALOGUE(pin 3). So, the VCC was connected to a 5V power supply, GND to ground, and OUT to an analog input pin on the microcontroller board.

The program was written in Arduino IDE to read the analogue voltage output of the sensor.

The program was uploaded to the ESP board in order to view the voltage and current readings through the serial monitor.

Took note of the current reading on the serial monitor when on no load and when on load.

D. Voltage Sensor Test Using Voltage Divider Network

The voltage divider network consists of two series resistors connected to the transformer primary. Although, 10kΩ and above resistor can be used for this measurement. but in this case, I used 100kΩ and 10kΩ. also note that the resistor connected the ground in relative to the analogue pin is one tenth of the other. Hence, the use of 10kΩ with respect to 100kΩ in this scenario.

The transformer used in this project is a 220v to 12v step down transformer. Therefore, the input voltage is 220v at the primary and the output voltage is 12v at the secondary.

Voltage ratio = $\frac{\text{Primaryvoltage}}{\text{Secondaryvoltage}} = \frac{V1}{V2} = \frac{N1}{N2}$

For our transformer,

$\frac{220v}{12v} = 18.3v$

Therefore, the voltage ratio of the transformer is 18.3.

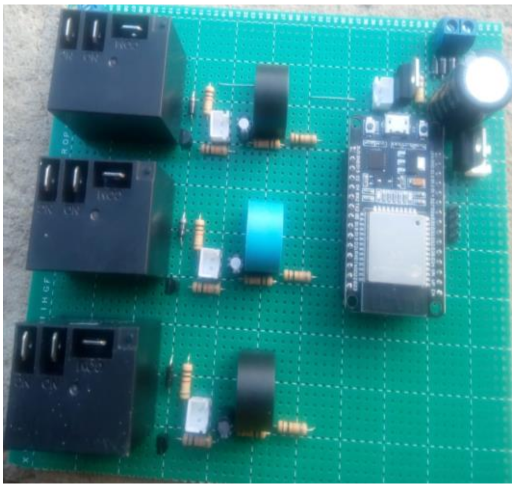

Fig 13: Cloud Script/Web Application Design

The web application was designed using C++ programming language.It was then tested to ensure that there was communication between the smart meter and the web server.

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