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Design and Implementation of IoT-Based Smart Meter

Ayeza Khan *, Ifra Shabbir, Shoaib Zafar, Jalal Haider, and Afifah Tahir

Electrical Engineering Department, Government College University, Lahore, 54000, Pakistan
Corresponding author: Ayeza Khan

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***Abstract*—Pushed through the call for sustainable electricity control, the clever metering era has advanced to offer real-time usage monitoring, remote reading, and bidirectional communication. However, the prevalence of single-phase meters limits software in business and commercial settings, that require greater capacity. Three-section clever meters are essential for providing accurate data in those sectors. This project proposes designing and building an IoT-enabled, 3-segment clever meter capable of measuring and transmitting time-intake statistics. The device will independently monitor every phase, utilising IoT to share data between software groups and consumers. This venture aims to illustrate the advantages of 3-section smart metering, specifically improved data accuracy, optimised energy consumption, and decreased operational costs.**

***Index Terms*—IoT, smart meter, power.**

I. Introduction

The all-encompassing strength requirement is climbing on account of the rise in people or through the use of new equipment, which has posed a generous challenge to the strength protection and the atmosphere, and therefore, skilled concession may be unavoidable conduct taken to mitigate the strength disappearance by establishing an appropriate metering foundation in the houses. The traditional power meters that utility parties used to measure power secondhand from customers are being replaced by smart meters that are more advanced and have intelligence. Smart meters will have specifications that present real absolute-occasion values of the power expended, and this will enable the service to control their distribution plans and consumers to control their energy use and expenses.

A smart rhythm refers to a photoelectric design that captures details such as custom energy strength, heat levels, current, and power determinants. The smart meters send the dossier to the services to make devouring performance clearer, and power suppliers to monitor the bureaucracy and bill the customer. Smart meters frequently capture data in real-time, and report at normal, brief periods of 24 hours. The use of smart meters admits a two-way communication between the rhythm and the principal arrangement. This is an advanced metering foundation (AMI) as opposed to a mechanical meter reading (AMR), by which two habits are established between the temporary and the beat. The beat-to-network communications may be Wi-Fi publicity or by use of established wired relations like cable clipper.

A smart meter is a complicated type of electricity meter that may measure and provide an improved type of power meter, real-time transmission of electricity consumption data. Compared to traditional energy meters, smart meters use the Internet of Things (IoT) to interact with various devices. Clever meters built on IoT can relay power consumption data to software companies and consumers, enabling them to respond with more effective energy management and cost-saving measures. clients can see their strength consumption statistics in real-time and also adjust their strength intake. The statistics could assist software companies in matching power demand and supply, and this will be a useful resource for minimising the risk of blackouts and brownouts.

The project is supposed to lay out and increase the usage of a three-phase smart meter through IoT technology. The assignment will introduce a hardware and software program intended to measure and relay real-time power consumption information. The clever meter could be made person-friendly and easy to install, and will be able to connect to the internet and send data in a secure manner. The assignment may even discuss the potential benefits of a three-section smart meter software in business and industrial settings, including more precise power usage records and the opportunity to streamline energy utilisation and reduce costs.

II. Working Principle

Smart meters are digital tools that use the Internet of Things (IoT) to track and record energy usage in real time. They send this information to a central system through the internet. As part of IoT, these meters connect with other devices, making it easier to share and manage data.

These devices make energy monitoring more accurate and efficient. Both users and utility companies benefit because they get a clearer understanding of energy consumption and can manage it better. With IoT-based smart meters, companies can check usage remotely and create bills based on actual consumption. This removes the need for manual meter readings, which can take time and may include mistakes.

Consumers can view their energy usage instantly using websites or mobile apps. This helps them make better decisions and reduce their electricity costs. An IoT energy metering system usually includes three main parts: a controller, a Wi-Fi module, and a theft detection sensor. The theft detection system spots unusual or illegal usage and responds accordingly, while the controller manages the overall operation of the system.

IoT improves smart grid systems in several ways. First, it makes them more reliable and long-lasting. Second, it allows better data collection and analysis, which helps control grid devices more effectively. Third, it supports smarter decision-making by using data to plan future improvements.

Unlike traditional meters that only measure energy use, modern smart meters use power line communication (PLC) technology. This helps reduce energy loss and improves the overall efficiency of the system, as shown in Fig. 1.

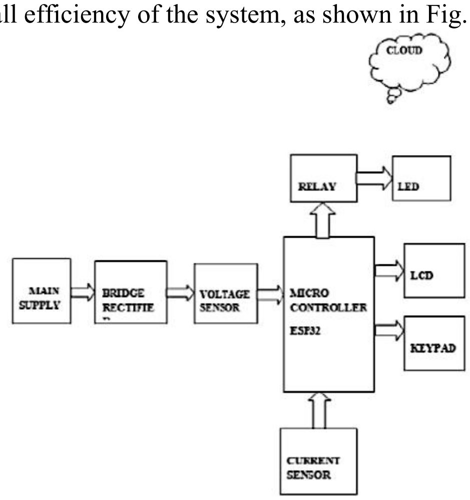

Fig 1: Block diagram of IoT Based Smart Meter

A three-phase IoT-based smart meter with load shedding works like this. It measures electricity usage in all three phases and sends the data to a cloud server through the internet. The server checks this data and decides when to reduce load during high demand to avoid power cuts.

Load shedding involves turning off less important devices first. The smart meter uses components such as a microcontroller, voltage and current sensors, relays, and an LCD screen to measure and display energy usage.

The system also tracks energy use in buildings and machines and sends real-time data to the cloud. This helps in better energy control. Users can see their energy usage hourly, daily, weekly, and monthly using the Blynk app. It also sends alerts to the user's phone when energy use exceeds the set limit. Meter readings can also match energy use and the energy bill to identify key consumption areas.

III. Blynk IoT

The proposed work utilises the BLYNK IoT server as a control application. The status of the connected hardware pins is continuously transmitted to the BLYNK server, allowing the smartphone application to access and display the stored data on the IoT server. Using wireless communication, the hardware can also be controlled via the smartphone with the aid of BLYNK hardware. To connect an IoT device to the BLYNK server, the appropriate BLYNK library must be installed on the IoT hardware unit as shown in Fig.2.

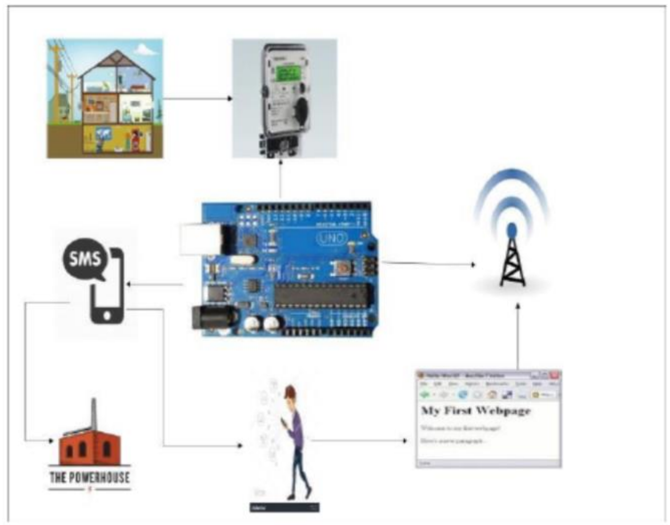

Fig 2: Architectural view of the proposed system [21]

The following components are used in the system:

ESP32 Microcontroller – controls the whole system and processes data. Current Sensor (ZMCT103C) – measures the flow of current. Voltage Sensor – measures the voltage level . 12V 30A Relay – used to switch loads on and off. LCD Display – shows readings and system information. I2C (Inter-Integrated Circuit) – helps communication between devices. Transformer (220V–12V–220V) – steps voltage up or down as needed. Resistors (100KΩ and 10KΩ) – control current and voltage in the circuit. Bridge Rectifier – converts AC into DC. 8x8 Keypad – used for user input. ESP32 Microcontroller

ESP32 is a microcontroller made by Espressif. It uses very little power, is affordable, and supports Wi-Fi and Bluetooth. It also has a dual-core processor, meaning it can handle more tasks at once. The ESP32 follows the ESP8266 and offers many improvements. It is designed for use in mobile devices, wearables, and Internet of Things (IoT) projects. ESP32 is a complete system that comes in different low-cost modules. Its main processor is strong, with an Xtensa LX6 chip that runs at about 240 MHz and has 512 KiB of memory. It also has a small ultra-low power coprocessor that uses just 8 KiB of memory and only works when the ESP32 is in low-power mode. The ESP32 has many built-in features and hardware components that can be used to create connected devices. It is perfect for IoT applications because it is affordable, uses little power.

A. *ESP 32 Interfacing*

The ESP32 module is connected to components such as the ZMCT103C sensor, an LCD, and a relay, as illustrated. It acts as the central unit, managing these components and delivering the required outputs. Its main functions include converting the analog voltage output from the ZMCT103C into a corresponding DC current value ranging from 0–15A using its built-in analog-to-digital converter. It also reads input from a keypad, where customers enter their unique PIN codes, and controls a transistor to operate the relay. Additionally, it handles communication by sending and receiving messages while updating and monitoring the LCD display.

A current sensor is a device designed to detect and monitor the flow of electrical current. In this setup, the ZMCT103C model is used for current measurement due to its high accuracy. It is capable of sensing both AC and DC currents based on the Hall-effect principle. Specifically, the ZMCT103C operates as a Hall-effect sensor, measuring current through electromagnetic induction. It identifies the magnetic field generated around an AC conductor and converts it into an analog voltage output. This sensor can measure AC currents up to 5A.

The generated analog voltage is then transmitted to the microcontroller, where it is processed to determine the actual current value. The sensor includes four pins: Pins 1 and 2 serve as ground connections, while Pin 3 provides the analog signal output corresponding to the detected current.

B. Voltage Divider

The voltage sensor module is a small device used to measure DC voltage from 0 to 25V. It works using a resistive voltage divider circuit. The module reduces the input voltage and gives an analogue output that can be read by a microcontroller. It can also increase (scale) the signal properly for measurement.

This module is small and easy to carry, and it helps detect low voltage (under-voltage) and high voltage (over-voltage) problems in electrical systems.

The voltage sensor has two connector blocks. One side is connected to the power source, where the voltage is measured. The other side is connected to microcontrollers such as Arduino, PIC, Raspberry Pi, or BeagleBone for reading the data. The internal circuit of this module is based on a simple resistive voltage divider.

C. Relay

A relay is an electromagnetic switch. It turns on or off based on the current flowing through its coil. Relays are used to switch on or off different high voltage circuits. In an electric smart load meter, relays help allow current to flow to the load when it needs power and stop the current from flowing when it doesn't.

D. Liquid Crystal Display (20X4)

I have a 20x4 LCD display with text on a blue background. This display is like the standard Hitachi LCD20x4 display. It is compatible with the HD44780 interface. It is easy to connect to microcontrollers. The display shows 20 characters wide and 4 rows of characters. It has a controller that's compatible with the HD44780 controller. It also has an interface that can be 4 bits or 8 bits. The display has a background and white text. It has a led light on the back that can be made dimmer with a resistor or something called PWM. The display can work in a range of temperatures. You can connect it to something using a pin header. It can use 5 volts or 3.3 volts of power. There is also a board that can be used to connect it to an Arduino. This display can be used in lots of things like machines, devices, for security, medical equipment and equipment that you can hold in your hand. The LCD20X4 display is special because it can show letters, numbers and symbols. It can show 20 characters in 4 rows. It can send data in 4 bits or 8 bits. There are lots of commands you can use with this display like clearing the screen moving the cursor and turning the display on and off.

A regulated power supply changes the Alternating Current to a constant Direct Current. This means the regulated power supply makes sure the output of the Direct Current is always the same, when the input of the Alternating Current is different. The regulated power supply, which is also called a power supply has many parts inside it and these parts work together to make this happen. The regulated power supply is, like a circuit that is built into things to make sure the Direct Current is always constant.

E. DC Filter

The voltage coming out of the rectifier is not a DC voltage it has a lot of ripples.We need a DC voltage without ripples in our circuit.That's why we use a filter.There are types of filters used like:

- Capacitor filter
- LC filter
- Choke input filter
- π type filter

When the voltage starts to charge the capacitor it charges fully till the voltage peak.Then as the voltage starts to decrease the capacitor starts to discharge through the load, which is the input of the regulator in this case So we get a constant DC voltage, with very little ripples.The capacitors current is based on its capacitance value.You can get the capacitance value using this formula.

$$i_c = \frac{\Delta q}{\Delta t}$$

F. Regulator

This is the part of a controlled DC power supply. The output current or voltage changes when the AC mains input changes or when the load current, at the output changes. It also changes with temperature. A regulator can fix this problem. It keeps the output steady when the input or other things change. There are types of regulators.

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

G. Interfacing Power Supply

The Alternating Current and voltages that come to our homes from the supply have been lowered by the power supply unit to the smallest possible voltage. This happens with a circuit. The rectified circuit brings it down to 12V which is much lower than the 220 V that we get from the mains. Then the 12V is brought down more to at least 5 V, with the help of the voltage regulator. The voltage regulator does this job of reducing the 12V to 5 V. The Alternating Current and the voltage regulator work together to make this happen.

IV. Implementation Challenges

Although the smart metering program has made a lot of progress over the few years it still faces many problems. These problems include technical and consumer-side issues.There was a delay because there were not enough qualified specialists to install meters in the field.

One of the issues is that people do not want smart meters and are not aware of their benefits.Another problem is that communication infrastructure is still a challenge in states.From a technology perspective communication infrastructure remains a challenge across states. We need help from regulators on key issues like prepayment requirements, time of use tariffs and demand response measures. Operationally the ability to connect, disconnect or recharge meters within given timeframes is limited by delays and coordination gaps between AMISPs, Discom field teams and IT backend systems.

V. Future Trends and Developments

This section describes major future trends and developments in the IoT-based technology.

A. Smart Grid Integration

IoT technology can be integrated into grids to create the future of energy metering.With a connection between energy meters and infrastructure to a system utilities will be able to receive real-time information regarding energy demand, supply and distribution.This combination enables management of energy minimizes risks of power outage and makes the grid stable.

B. Artificial Intelligence and Machine Learning

The development of AI and ML will augment the performance of energy meters using IoT.These technologies are capable of processing an amount of data on energy consumption detecting trends and contributing useful information on energy consumption habits.AI and ML will allow energy meters to learn and evolve, proposing energy-saving plans to customers.

C. Distributed Energy Resources (DER)

As DERs like rooftop wind turbines and battery storage become increasingly popular future smart meters will play a significant role in the decentralized operation of energy.Every element of DER outputs can be monitored.

D. Bidirectional Metering

Bidirectional smart meters can measure how much energy is consumed and provided to the grid and detect outputs of DERs.

E. Dynamic Load Balancing

Smart meters dynamically measure generators in real-time and update them to balance the loads between the main grid and localized energy sources stabilizing the grid when DER is highly penetrated.

VI. Conclusion

The IoT-based smart meter system is a modern solution for tracking electricity usage instantly and efficiently. It ensures more accurate readings and removes the need for manual meter checking. Through IoT integration, both consumers and energy providers can easily view and analyze power data. The system also plays a key role in detecting electricity theft and improving load control. Overall, it promotes better energy utilization and supports a smarter and more reliable electricity system.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest to report regarding the present study.

AUTHOR CONTRIBUTIONS

Conceptualization, I.S., S.Z., J.H., A.K. and A.T.; methodology, A.T., J.H., S.Z; software, A.K., J.H., and I.S.; validation, A.T., A.K., J.H., I.S.; writing—original draft preparation, A.K.; writing—review and editing, J.H., S.Z and A.T.

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Not applicable.

DATA AVAILABILITY STATEMENT

Data is available on reasonable request.

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