DESIGN OF SECLUDED ENERGY METER FOR TAMPERING AND UNAUTHORIZED ACCESS DETECTION IN SMART GRID

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Abstract

This paper deals with an energy metering system for electricity monitoring for each and every household that is different from the conventional energy meter. This proposed design is meant to be a better alternative for an efficient and more secure line for energy usage by the consumer without any illegal access to their connections so that they don't have to pay for something they aren't accountable for in the first place and protect the supplier/provider, which is the government, from incurring any losses from the theftas well as from customers who tamper with the meter values. These things are vital in today's world. So,we are taking this into account and designing a smart meter with the IoT technology for monitoring data values at thetip of our fingers, readily available at any moment. It serves many purposes, from the monitoring of energy consumption to easily using mobile phones to work on managing the energy usage according to their budget. It is also easy for the supplier to monitor without manually inspecting the location. The WiFi module ESP8266 is used for the purpose of transmitting the energy data to the server. This paper also deals with a smart grid system in which energy meters are used as a two-way communication system as opposed to conventional meters with one-way communication, which will be a more efficient system. This IoT is good in termsof its development towards an easy and advanced metering infrastructure, which also needs securecommunication between the supplier and consumer to protect that data.

Keywords: IoT, MODBUS, Smart Energy Meter, Smart Grid, Tampering detection

Introduction

This is an era of advanced technologies that is ever-growing, with loads and loads of different inventions carried around that make everyone's life easier. Automation and the Internet of Things are also sectors that are very helpful towards making many tasks easy and less time-consuming. The proposed system in this paper is an energy metering system that can carry out the electricity monitoring and store those usage details on the server through an IoT application that can be used to monitor

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the electricity consumption details and the amount one has to pay. This means the supplier, which is the government in India, doesn't need to manually reach the particular meter to take note of readings. It takes away that time-consuming process. Programming the micro-controller will use those electricity stats for electricity billing, which simplifies the whole task. This type of working model have been proposed by many authors over the years. Aswin *et al.* (2019) proposed a system interchanges conventional meter reading techniques and facilitates the energy provider to access the energy meter remotely. Just like that, Barua and Goswami (2017) proposed a system of Smart metering deployment scenarios in India and implementation using RF mesh network. This is also good news on the consumer side, who can, with these statistics, monitor and maintain their energy usage accordingly. This secluded energy metering system is designed for the prevention of electricity theft as well as tampering measures by consumers, which incurs losses for the government. Orlando *et al.* (2022). proposed a paper on A Smart Meter Infrastructure for Smart Grid IoT Applications," in IEEE Internet of Things. The AT&C losses are a combination of technical losses, theft, and inefficiency in billing, as well as commercial losses due to default in payment or inefficiency in collection. India's average AT&C losses in the sector rose from 20.73% in 2019-20 to 22.32% in 2021, as per a report revealed by Power Finance Corporation in 2022. In this country, 99% of the households have electricity. Considering these statistics, the losses cost the government a lot of money. The availability of smart grids is a much more efficient technology needed in India to recover those losses. The inclusion of smart energy metering systems with the ability of two-way communication This grid, compared to the prior grid, transports the electricity usage statistics from households to suppliers, which can help them with efficient energy generation and distribution measures. This leads to the limitation of unwanted energy generation, which is a cost-saving measure, and increases power reliability. India has already installed many smart meters and is planning to expand, and it is in need of a smart grid to replace its archaic grid. This IoT usage is very good in terms of data transfer, and this also means security in transfer. There are multiple Internet protocols for transferring data, and MODBUS is an established protocol for data transmission that is way more efficient and secure. This system design is useful in many aspects to battle the disadvantages in the electricity sector.

Literature survey

Varpe *et al.* (2020) proposed a paper with an experiment on constructing a basic smart meter that will update the values of energy consumption directly on the server using IoT Gecko without anybody having to manually collect the data. This marked the start of our research into the field and how we can improve upon it. The use of IoT means a potential data breach or vulnerability to data manipulation. This sparked the research for another paper proposed by Lee and Bahn (2014) which dives into the importance of security in smart meters while using IoT. It mandates the need for a strong, secure system in place for today's digital world. They proposed a smart grid implementation with the help of a genetic algorithm, which is a cryptography technique. So, this helped us look for a data encapsulation technique and mode of communication technologies for the safe and secure transfer of this data. So, it can't be manipulated. Then, we studied the techniques for improving the accuracy of calculating the energy consumption by looking into various parameters and mathematical calculations for the processing unit. The paper proposed by Zheng *et al.* (2020) simulated a smart meter for a smart grid that takes the values of multiple parameters ranging from energy consumption details, power factor, and instantaneous reactive power (VAR). Dineshkumar *et al.* (2015) proposed a paper on an ARM processor-based theft control system to prevent manipulating the energy meter so as to reduce non-technical losses. This is setup with a GSM module for sending SMS with the status of that meter and alerts if any theft is detected, providing insight towards constructing a system with a high tolerance for tampering. The papers mentioned above all provided a good system for addressing one or two issues at a time. Here, we have attempted to provide a more complete system, addressing many issues to provide a better, more efficient, and more affordable system.

Existing system design

This setup consists of an ESP8266 microcontroller used as the digital energy meter, which is connected to the load. You can see the setup in Figure 1. This micro- controller measures the energy consumption value in the presence of a current transformer, which is used for the measurement of the current value, which varies according to the load consumption. The current transformer is an instrument that measures the current value approximately. In Figure 2 and Figure

3, you can see the tampering methods utilised.This value is fed to the microcontroller, and the algorithm is used to calculate the rate using the formula to calculate the energy rate with the reference voltage. There are two C.T.'s present in the system, with one to be placed on the phase line and one for the neutral line, which is used as an anti-tampering measure. The system design also has a potential transformer.

placement on the circuit also for protection against tampering

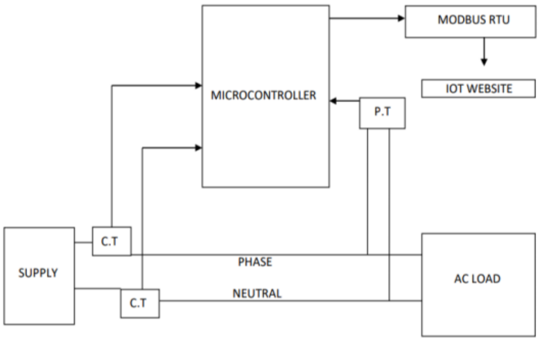

Figure 1. Block diagram of the proposed system

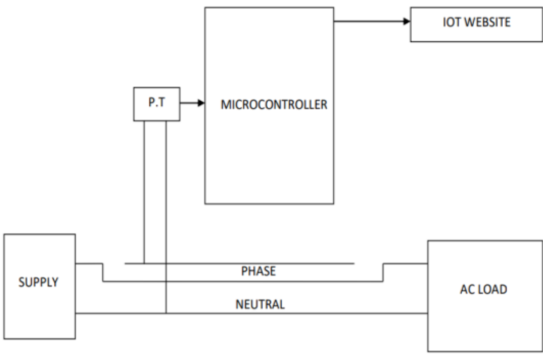

Figure 2. Block diagram for energy meter bypass

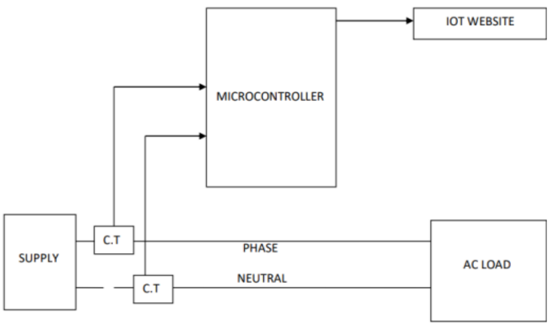

Figure 3. Block diagram for neutral disconnection

The above setup shows the neutral line being disconnected, which is a common method to avoid paying the bills for their electricity consumption. But this will be prevented in this setup as the current transformers take the current values from the phase and neutral lines. They will be compared, and the valueswon't be equal, or In will be zero, which will be captured by the meter, and the system will send a signal to alert about the tampering.

Proposed system design

This system is proposed to the existing system, as the old one was used for tampering detection with two current transformers placed, one on the phase line and the other on the neutral line. The system design can be viewed in Figure 4. Thetransformer placed on the neutral line is of no use when it comes to tampering detection in real life, and it is only useful in the sense of ground fault detection. This system has an individual CT assigned to each household to monitor each house load along with a main CT connected, which is for the entire user, and the main CT value is also taken along with individual values of power consumption.If the CT main's value varies from the addition of every household CT connected, then we can assumethere is a deviation, meaning that some unauthorized personnel are using the power.

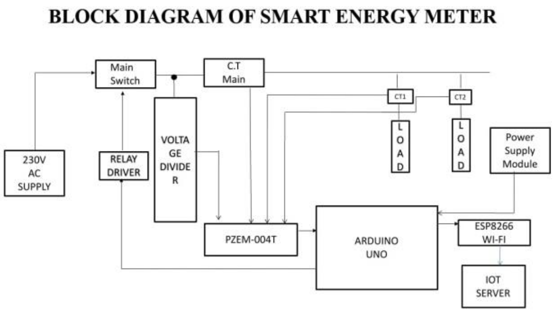

Figure 4. Block diagram of proposed system

Methodology

Modes of Operation

Prepaid Mode

Figure 5 shows Prepaid mode which is a mode of recharge under which the customer can be billed in real time. In this mode, thecustomer first pays a certain amount, which will be reduced as consumption occurs, and the amount will be redacted based on the tariff entered. This will provide a certain advantage to the user by making them consciously aware of their electricity bill and their energy spending and letting them manage their energy consumption according to their needs in a proper and efficient manner. When the recharged amount is close to zero, they will get a remainder to recharge the meter, like a phone bill. This will be updated in the system, and the power consumption will continue to be supplied to that user.

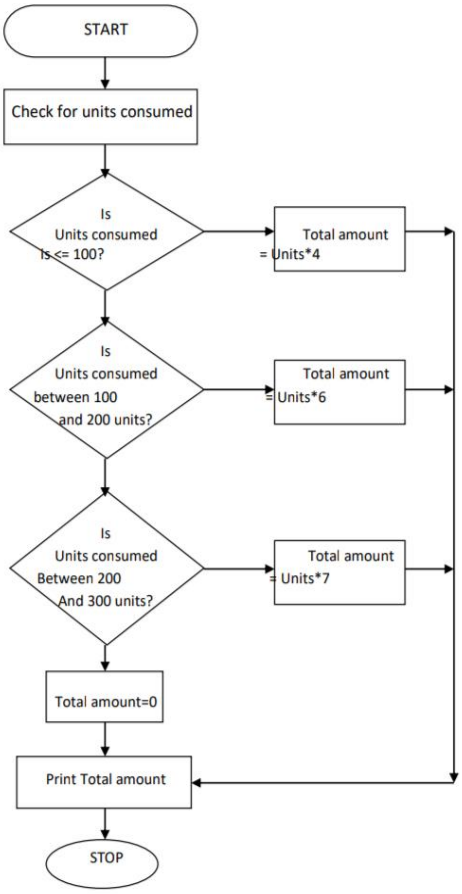

Figure 5. Flowchart for Electricity consumption bill

Postpaid Mode

This is a mode of recharge under which all the present systems are working, this mode is viewed in Figure 6. in which consumers utilize the electricity, and after a certain period, the units are measured and the billing is done accordingto the tariff that is set by each distributor organization. This mode can also be useful as it prevents a huge upfront fee and allows you to constantly monitor the amount. The electricity consumption is always available to the consumer intheir account on the website. So, even in postpaid mode, they can still monitor their bill and planaccordingly to use it in an efficient manner.

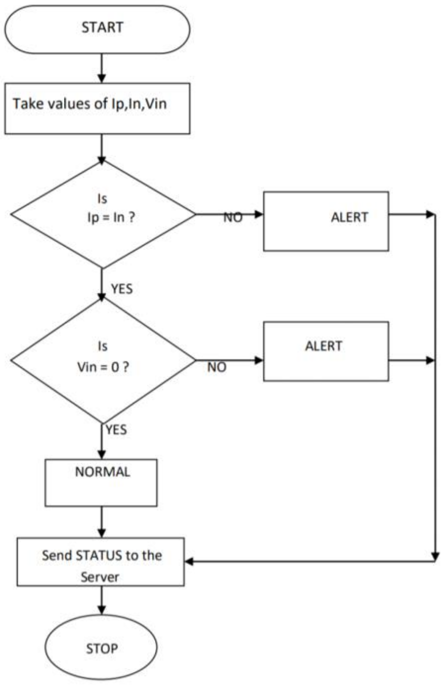

Figure 6. Block diagram for neutral disconnection

Electricity Bill Calculation

First, it notes the electricity consumption using the current sensor to measure the current value and calculate the energy consumption value, which will be used to calculate the electricity bill. The billing of energy consumption is based on the tariff set for the number of units consumed. 1 unit equals 1 KWh of energy, i.e., 1000 watts consumed in an hour-long time period. Let's assume the tariff is set at 4 rupees per unit if 100 units are consumed, and between 100 and 200 units, the amount is 6 rupees per unit; between 200 and 300 units, the amount is 7 rupees per unit; and for units consumed between 300 and 400 units, the amount is 8 rupees per unit.

Features

Power Theft detection/ Tampering Protection

This is implemented in order to prevent the customer from paying for unnecessary consumption that wasn't their usage or the distributor from facing non-technical losses due to the theft or missing out on their actual payment that was not measured due to the fact that some people tamper with the meter. This end-to-end private and secure meter contains devices to measure the current and voltage levels to keep the consumption details on file. This meter is programmed to detect anomalies in value. Two current sensors are used. One is on the phase line, and another is on the neutral line, which measures and compares them to detect any bypassed connection or neutral disconnection. This will ensure that all the electricity lines are in check. The voltage sensor is present, and the phase line bypassing can be detected easily as there will be no voltage in the line connected to the meter. This will ensure alarms are triggered by the communication triggered by the microcontroller.

Magnetic Tampering

Magnetic tampering is the usual and basic method of tampering, which manipulates the meter by saturating the core present in it. In smart meters, the microcontroller generally uses an ADC converter for converting the analog values to digital values. Since there is no coil to saturate, the magnetic tampering is void in this case.

Electricity Billing

The meter is designed not only as a device for noting the energy consumption value. It will also indicate the price of the energy used. This will, in turn, reduce a lot of work into something simple, as each meter can perform its own calculation based on the formula in-built with the code. This calculated value is updated on the server and can be displayed in the specific customer profile.

Secure and Reliable Communication

The advancement of IoT, as good as it seems, is also prone to certain vulnerabilities, like the availability of data transferring from the metering system to the server. The Smart Grid is a very helpful system if the data's that are communicated between the consumer side and supplier side can be more secure and reliable, as these data's cannot be manipulated by anyone and the reaching of these data's to the generator site without any disturbance. There are many communication protocols present, and MODBUS is a well-recognized protocol that is efficient and secure for communication between the meter and the main server in a smart grid. MODBUS is a communication protocol that provides a common language for devices to communicate with one another. MODBUS consists of 5 layers, which is less complex than the TCP/IP protocol.

Materials Required

Arduino UNO

Arduino UNO works as the brain behind this operation, acting as a central processing unit (CPU). It performs the operation of the software code that was implemented in it. This is an open-source microcontroller board. This board is equipped with many digital and analog I/0 pins that can be extended with various expansion boards and sensors to pursue its operation. This microcontroller operates at a voltage of 5 volts and a clock speed of 16 MHz. In this operation, it is coded to take measurements from the current and potential sensors and use them to calculate the energy consumption and the bill. It is also programmed to monitor the current and voltage values and store them in its memory. Figure 7 shows the Arduino module.

Figure 7. Arduino UNO

Esp8266 WiFi Module

This is a microcontroller chipset that is a very compact module built at a low cost that is used as a communicating channel to the server from the device and sends data back and forth. It is used in this model prototype to show the demonstration of data transfer between the energy meter and the server, which logs all that data. This microcontroller uses the TCP/IP communication protocol for communication. This also operates at 5 volts.In this model, these do not act as a data transfer module for communication from the meter to the server. It enables two-way communication from the server side to the meter too. The code can be accessed from the server station, which is a real advantage in controlling the power supply when anomalies are detected. This is used in the prototype to mimic real-time MODBUS communication, which is less complex than the TCP/IP protocol. Figure 8 shows the ESP Module.

Figure 8. **WiFi Module**

Current Sensor ACS712

This sensor is used to measure and calculate the value of the current applied to the system without affecting its performance. It is a fully integrated linear sensor IC chip that is based on the Hall effect. It detects the level of current in a conductor and sends a signal value directly proportional to the current in either analog or digital form. The current sensing can be done by either direct sensing, in which Ohm’s law is used to measure the voltage drop, or indirect sensing, in which the current value is measured by calculating the magnetic field surrounding it by applying Faraday’s law. Figure 9 shows the current sensor.

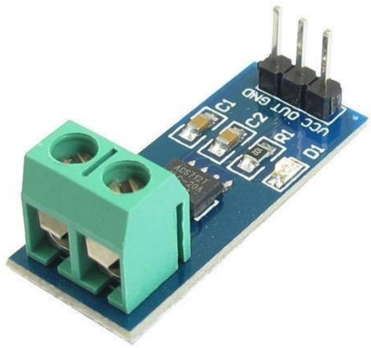

Figure 9. **ACS712 Current Sensor**

Current Transformer

Current transformers (CT) are a type of instrument transformer that are used to step down or step up the alternating current (AC). It produces a secondary current, which is directly proportional to the primary side current value. The instrument used here is for stepping down the current value to a less standardized value scale to handle measuring instruments and protective relays that operate under a small operating voltage and current. The device used here is a 5A center-tapped transformer, which is a general-purpose chassis mounting mains transformer. These have 220 volts on their primary winding side and a secondary winding center tapped, which steps down the voltage to 9 volts AC. They are used here to operate the devices with a small operating voltage to prevent them from getting damaged. It can also be used as a device to measure the current value, as it measures it accurately. Figure 10 shows the Current Transformer.

Figure 10. **Current Transformer**

Voltage Transformer

Figure 11 shows the voltage transformer. This is a device used as a voltage-sensingdevice for the measurement of voltage in a circuit. The device designed for this system is ZMPT101B voltage sensing device. This is a high-precision voltage transformer, and it makes it easy for AC mains to voltage up to high levels, well enough to monitor regular households and industries. Its primary purpose in this system is to detect the voltage levels in each phase to ensure that there is not phase or whole meter bypassing due to the fact that main lines have voltage sensor connected and if the line is bypassed for tampering with the electricity consumption. Then, it will show no voltage and the value to the microcontroller, which is coded to send an alert to take necessary action in the situation.

Figure 11. **ZMPT 101B Voltage sensor**

Simulation

This setup is designed to simulate the operation of an energy meter for its theft detection module, which detects the change in current levels as an indicator of theft. As the load varies, the power value increases. This just hints at the increase in the current value in the system. The simulation for current measurement is shown in Figure 12. This simulation is usedas a base to setup the real-world implementation with two current sensors to detect the phase line andneutral line values and compare them to actually detect the tampering issue, as well as with a drastic increase in values to suspect hooking leads. Arduinois given an analog signal as an input, converts it intoa digital signal, and supplies it to the LCD display and buzzer. This design consists of an Arduinomicrocontroller board with digital data transmissionlines connected to an LCD display for sending the digital signal of the values of voltage and current. Another digital pin is connected to the buzzer through a motor driver circuit, which assists in operating the buzzer. The buzzer's task is to indicatethrough sound when an anomaly in value is detected. This code contains a block wherea maximum threshold value for current is set. The analog pin of the Arduino is connected to a battery through a potentiometer, where we simulate thechange in current value by operating the potentiometer and sliding through different positions. When the current levels are below threshold, the circuit works normally. The crossing of the threshold value sets up the buzzer alarm.

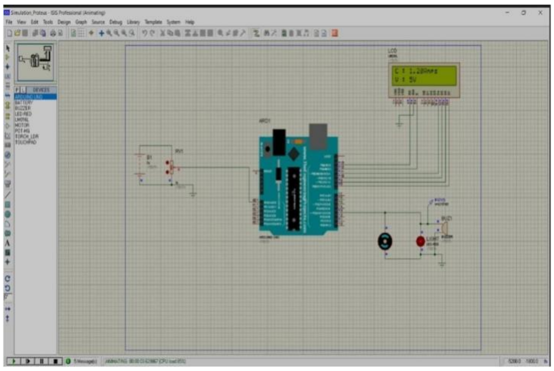

Figure 12.Simulation setup of Current measurement

This simulation uses LED arrays as the end load, and there's three of them connected, of which the third one is connected through a switch, as to how the oscilloscope responds to load managementin a power system. Two mosfet input switches are given to the two terminals, and one terminal isconnected from the load side to monitor the usage ofthe load. Here, the mosfet is used instead of the voltage divider, which divides the voltage equally among the load due to varying voltage levels due tofault. When the third load is connected, there will bea spike in the oscilloscope total power consumption line, indicating there is an extra load apart from the two loads. This is because we are separately monitoring the voltage levels of those two loads. This is just a basic idea of what we will be implementing in the hardware. The load management simulation is shown below in Figure 13.

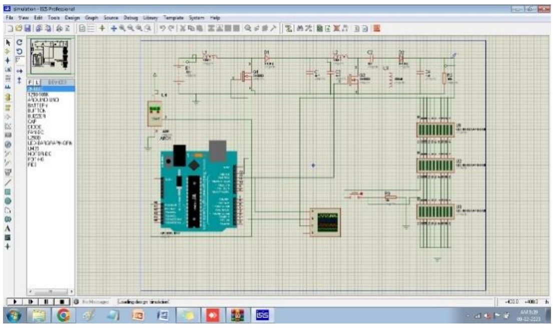

Figure 13. Simulation of Load management

Hardware Output

This is a basic hardware setup designed for the implementation of an energy monitoring and control system that uses a microcontroller paired with a current transformer for the measurement of the current value and reference voltage. V Ref is set for the voltage applied through the line, which will stay constant, and the variation in current variation. This is a setup that only consists of a current transformer for the experimental purpose of this model. The Hardware setup is shown in Figure 14.

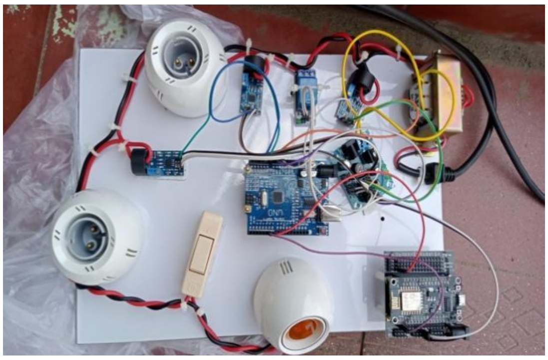

Figure 14. Hardware Prototype

Results And Discussions

This provides data on current consumption measured using the current transformer and is mapped. This is the output from the software side, which is the measured value of current sensed by the current sensor placed in the prototype. We can configure any microcontroller device logged into this application. This application is called Things view and is used to track and monitor the measurements sensed by the sensors configured with the microcontroller circuit. Since the voltage supply is constant, the need for monitoring the voltage is not required here. But these values can also be monitored, and any sensors can be configured with them. There are many applications, each tailored with many monitoring and calculating procedures that They can be utilized as per need. The power consumption is calculated to calculate the electricity bill. This setup has an ESP8266 Wi-Fi module, which transfers the meter data through the TCP/IP protocol to the server. This prototype can be developed in real time. a secluded energy metering system with studied design features to be implemented in a smart grid with the tendency to reduce energy tampering and secure communication between the supplier and end user. This inclusion will bring us another step closer to proper, secure connections. The above graph shows the individual current consumption values of each user, and a main current sensor is used to track the two users. It is shown that the main sensor value does not equal the sum of individual households. This means that there is a current theft occurring, it will be detected, and the authorities can stop the illegal consumption. Over a period of time, with enough data, we can train machine learning models to show load forecasting and bill forecasting to help consumers manage their bills and utilities to generate energy in a cost-efficient manner. The Consumption of two users and total current consumption is shown in Figures 15,16 and 17 Respectively.

Figure 15. Total current consumption value

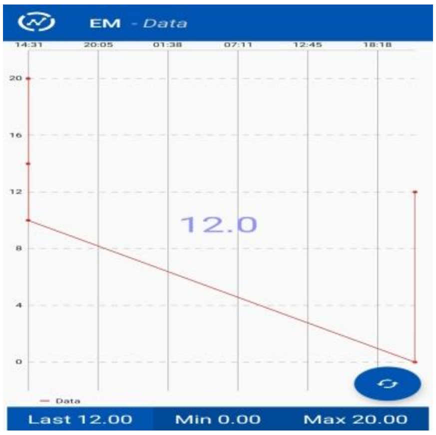

Figure 16. Current consumption of user 1

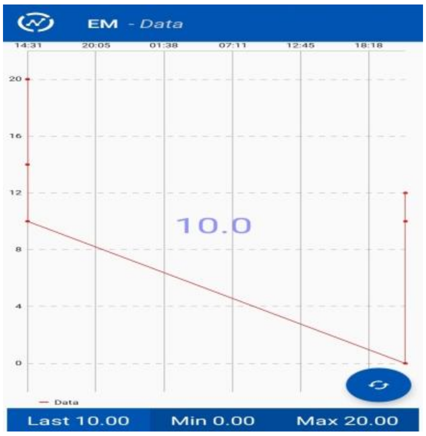

Figure 17. Current consumption of User 2

Conclusions

A smart meter is an important tool in the modern tech world that is utilized in a more systematic method of calculating the consumption of energy. Here, we have taken a keen interest in the subject matter, studied previous findings, and attempted to formulate a more accurate and systematic system for energy consumption. For the experiment, standard instruments and equipment are utilized for constructing the circuit to improve the accuracy and durability of the system within an affordable budget, considering financial constraints. The system designed is not only an efficient tool for the provider side. It is also a valuable tool for consumers because it not only calculates the consumption of energy but also ensures that they are responsible for only their usage of energy. The system does this through the ease of communication between the main CT and individual CT, presenting each consumer in the system for an accurate calculation. This study also included a convenient mode of energy bill payment, just like a mobile network system. This study concludes by improving every aspect of energy metering infrastructure.

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