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Development of real-time energy metering bypass and remote reporting system for registered consumers

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ABSTRACT

Every economy is driven by energy supply, the quantity of energy produced, transmitted, and distributed needs to be paid for by consumers. This leads to a pay-as-you-go metering system. Paying for every energy unit used helps the energy company to improve its quality delivery. Most developing countries around the globe have not attended to their profit margin even with the introduction of the pay-as-you-go metering system. Given that some local energy users seem to bypass the metering system, thereby accessing energy without passing through the metering system, this usually hampers the productivity of the distribution companies and results in a huge revenue loss. To address this issue, this research presents a real-time energy bypass and remote reporting model to detect metering bypass from registered consumers. An inspectorate metering system was incorporated in the energy supply line to compare the amount of current-voltage supplied to consumers against the amount being utilized by the consumers to achieve the detection and reporting of the metering bypass incident by registered consumers. As a result, a signal is sent to the energy company through a remote server and the incident of the metering bypass would be displayed on a monitoring dashboard in case of disparity between the inspectorate and consumer metering system.

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1. INTRODUCTION

The world is geared towards achieving sustainability across every sector. In the energy distribution sector, optimal energy utilization must be implemented to achieve the goal of sustainability in the sector, hence, the need for metering systems. Energy metering provides a means to measure or quantify the energy consumption of consumers and using this measure, a bill is prepared for the consumer. This method of energy metering helps in the efficient, effective, and accurate utilization of energy by consumers hence, supporting energy management. However, in the course of managing energy supply, distribution companies encounter lots of challenges among which the major challenge was the problem of electricity thieving [1]. The analysis of [2] brings to mind the fact that metering bypass is one of the most widely explored options for electricity thieving. In developing countries, this occurs when a consumer taps energy from the service cable just before the energy meter instead of tapping from the load wire after the energy meter. This implies that the consumption of the consumer is not metered. This usually causes an overload on the electricity grid and a loss of revenue to distribution companies. With this in mind, the aim of this research is poised towards the development of a real-time energy metering bypass and remote reporting system for registered consumers. The system provides a real-time metering bypass detection model with a remote controlling option and reporting system with a location identification scheme.

The importance of energy metering systems cannot be overstated, given that these systems are in charge of energy management in any grid system, since they are the backbone of energy consumption measurement, invoicing and pilferage detection, among other things. Typically, the energy board dispatch meter readers to certain areas to record and compute user consumption, this technique of billing has shown to be inconvenient and may contain too many mistakes owing to meter reading irregularities and corrupt nature of the inspectorate. To solve this problem, a device that calculates and reports each user's usage has to be implemented.

In [3], a system which uses Arduino Uno as the main controller together with ESP8266 and GSM module for communication was developed as a subsystem attached to an already existing energy meter. Hence, it takes the reading of the energy meter through a signal conditioning device and feeds it to the ATmega328p microcontroller, while the GSM and Wi-Fi module communicate with the Arduino Uno through a Max232. The system then uploads information of the meter to a webserver or the consumer using the ESP8266 and SIM900 respectively. A similar approach was seen in the work of Sahani [4] which adopted the use of microcontroller to develop a metering system which has the ability to detect meter bypass. The benefit of the approach was integrated to an existing system instead of developing a new electric meter which may relatively increase the cost of the system. Also, the system has the ability to remotely report cases of meter bypass to the electricity company.

Syed *et al.* [5] adopted a machine learning methodology to implement the bypass detection. The system was broken down into three sections which are data description, data processing and data classification. In the first stage, data was acquired from consumers for two years and the amount of data collected was 42,372 of which 3,615 have committed metering bypass. In the second stage, the data collected in the first stage was processed and classified in the third stage hence, determining the honest and fraudulent users.

Saikiran and Hariharan [6] showed that there are various ways in which electricity pilferage could be executed, this includes but are not limited to the following ways: direct tapping from power lines, injecting foreign materials into meters, drilling holes into electromechanical energy meters, inserting film, depositing a highly viscous fluid, using strong magnets like neodymium magnets, changing the incoming and outgoing terminals of the meter, damaging the pressure coil of the meter, resetting energy meter reading, exposing the meter to mechanical shock, and improper or illegal calibration of energy meters. Although majority of these electricity pilferage techniques have been eliminated since the introduction of smart electric meters [7]. The kind of energy pilferage that smart electric meters encounter are in three categories; customer end pilferage, feeder line pilferage and utility service pilferage, with meter bypassing being one of the techniques used in customer end pilferage.

Illegal usage of electricity is a crime and is punishable by law to ensure that consumers stay away from this act. To detect those who indulge in this act, a system that detects the use of electricity by illegal users was developed [8], the system used two current sensors for the detection of theft in the distribution lines so as to mitigate the challenge of meter bypass or direct hooking on distribution lines. One of the current sensors was installed on the pole while the other was installed on the meter. The current sensor reads the value of current passing through the distribution lines on the pole and with the help of an analog-to-digital converter (ADC), the value is converted into a digital signal. The microcontroller monitors these values and any difference between the two sensors was recognized as energy theft. The architecture suggests having one current sensor on the pole and another on the meter, this undoubtedly helped to mitigate the energy meter bypass from consumers. It also uses an external ADC which helps to reduce the work done by the microcontroller thereby increasing the microcontroller efficiency and a GSM communication was used to remotely communicate to the distribution company. The architecture was limited in the sense that the communication line between the current sensor mounted on the pole and the microcontroller in the meter could be disconnected by the consumer and this will allow the consumer to carry out their fraudulent activity [9]. Control measure was successfully implemented using a relay to disconnect the power in any case of bypass. Unlike the problem solved by [9], [10] focused on solving the problem of meter tampering, using two current transformers, one voltage transformer, and the ARM-cortex microcontroller. The current transformers were responsible for reading the value of current flowing through the phase and neutral power line. These values were compared by the microcontroller and in any case where a disparity occurs between both values an interrupt signal is sent to the GSM module to send a message to the electricity board that reports the suspected case of electricity thieving for an adequate follow up for disconnection. Given the fact that the system was relatively cost-effective, was integrated into existing energy meters, and it also supports remote reporting, it cannot remotely disconnect the fraudulent user hence still making it hectic for the distribution company to disconnect the energy supply to the user.

Bose *et al*. [11] was able to simulate a system that suggests using an inductor-capacitor (LC) trap which is called Traps; these traps are installed at the source and home meter respectively and the service line between this trap was used for the detection of electricity stealing. A non-interfering low amplitude high-frequency signal was injected into the distribution line between these traps. Two ammeters were installed before and after the injection point. These ammeters were used to compute the power spectral density (PSD), the PSD coefficient was then used to perform logical computation which was further used to detect energy stealing of either meter bypassing or direct hooking. The system was cost-effective and simple to implement. Although in any case of bypass, the system damages the consumer's appliance as a result of high frequency from the signal generator, and was unable to remotely report any case of meter bypassing.

In contrast to [11], Mohammad *et al*. [12] suggests that it wouldn't be fair to damage consumers' appliances using high-frequency signals to mitigate meter bypassing. Rather, encoding and decoding the AC signal would be a methodology to explore. On the distribution transformer, a signal encoder was installed to convert the secondary output of the transformer to binary signal and it was transmitted through the electrical conductor. On the meter side, a signal decoder was installed to convert the binary signal into AC signal. This system was complex to implement, highly expensive, the authors were not able to implement a prototype of the system but only a simulation was carried out, and most of the literatures reviewed in this work are susceptible to the issue of false detection. In a bid to be sensitive to anomalies in the configuration and classification of these anomalies in meter bypass, this system does not give considerations for simple conditions which are normal, but falsely seen as a meter bypass scenario. The design template presented in this work clearly solves the aforementioned drawbacks, with a working prototype to justify the workability and scalability.

The distribution system, being the electricity network that is responsible for connecting all homeowners and offices into a particular grid has to be monitored to maintain its reliability and effectiveness. Monitoring can be done manually or it can be automated to remove the human labor involved in manual monitoring. In automating energy monitoring, the system would have to work in real-time to produce an efficient result [13]. In conventional meters, there are various limitations with respect to meter reading, energy pilferage and many more, but the introduction of smart meters has largely eliminated the challenge related to electricity pilferage which seems to have attracted other challenges. Therefore, the need to continuously monitor the meter. Energy monitoring is the process of observing the utilization of energy by consumers [14]. Energy monitoring helps to save cost and bring sustainability to the electric grid [15].

Deepthi *et al.* [16] used two current sensors to monitor the energy consumption of consumer. This was to ensure that the amount of energy supplied to the user was what the user consumed. If the user tampers with the meter in any way, the current measured by both current sensors would be different and, in each case, the integrated buzzer in the meter would be activated. Similarly, Somefun *et al*. [17] concurred with the work of [16], and hence used the same approach to ensure effective monitoring of the electric meter to protect it from any form of tampering.

Bandim *et al*. [18] employed the use of a central observer meter based on some mathematical formulae. The central observer meter monitors the consumption of all the meters connected to its distribution network and with the data collected from the meters, it executes a mathematical computation to determine where a tampering of the meter or meter bypass occurred. This approach was inexpensive because only one observer meter can cover a huge number of consumer meters but due to the limitation of the central observer meter to determine some parameters such as the finite resolution of energy meter and non-zero resistance of energy cable, the meter was unable to determine the total technical loss and hence could not effectively determine the amount of non-technical loss which is where meter bypassing was categorized.

To solve the prevailing problem of the central observer meter, Souza *et al*. [19] and Supriya *et al*. [20] used an approach that monitors energy consumption when supplying and the amount consumed by consumers. Remote server was developed to compute the difference between the energy supplied and the amount utilized and if in any case, the supply was greater than the amount recorded as the amount being utilized then signal sent to the distribution board. But this approach also has its limitation although it was able to solve the computation inability faced using the central observer meter of [18].

The challenge of the system was its inability to work in real-time and to compensate for the problem, Jeffin *et al*. [21] adopted a model that has three aspects which included a client layer (Android app), server layer (cloud platform), and device layer (energy meter). Now, in this system, the client layer and device layer directly communicate to the server layer using web API and an ESP8266 respectively. All the devices in the device layer communicate the energy meter data to the web server and the server uses a linear regression model, to compute the energy deficit to identify electricity stealing. This means that energy monitoring in this instance was done by data computation and it was also executed in real-time.

In every system, it is imperative to have an effective communication channel through which information could be procured. In so doing, the management of resources could be effectively achieved. Over the years, the mode of communication has greatly evolved from wired to wireless communication of various kinds such as Zig-bee, Bluetooth, RF, and GSM. Concerning energy metering bypass and reporting such cases, different schools of thought have tried different types of communication protocols to achieve remote communication.

In the work of [22], Bluetooth was used to achieve remote reporting such that when any meter bypass case was detected, the system sends a signal over the Bluetooth communication protocol to the distribution company. Although the system prototype was implemented successfully, it was unable to work effectively in real-world implementation due to the limitation of the Bluetooth which sterns from its short-range distance coverage and slow speed of communication. Due to all these limitations, Singh *et al*. [23] suggested using RF technology to solve the problems of the Bluetooth communication protocol. Another approach for remote energy reporting was implemented and GSM modem-max232 was used. PIC microcontroller and the GSM module make this work strong by measuring and remotely communicating meter bypass cases to the electricity board [24]. Also, Okokpujie *et al*. [25] adopted the same approach of remote reporting thereby establishing two-way communication between the electricity board and the consumer meter. Establishing two-way communication and a remote reporting system was not enough, it was also important to provide a platform where reports were presented in a friendly, readable, and easy to understand manner. To this effect, Sathyapriya and Jeyalakshmi [26] adopted another approach of remote reporting they suggested that the approach Loren-wan was used to upload data to the web server, and therefore, the system will be cost-effective and reporting were executed in real-time. Also, a web application was developed to enable real-time monitoring of energy utilization by the electricity board and a mobile application was also developed. These applications aid in the readability and easy understanding of energy reports. In the digital world, cloud computing has upgraded how information are manipulated or controlled because it has given humans the ability to monitor information remotely. In the area of electricity distribution, energy metering was used to measure the consumption rate of consumers.

Leveraging on internet of things (IoT)/cloud-based technology, it was possible to measure the consumption of energy by consumers and at the same time determine if the consumer has indulged in meter bypass practice and report the case remotely. To achieve this, Uddanti *et al*. [27] stated that an Arduino Uno controller was used to monitor the data from the meter readings and remotely send it onto the cloud where the electricity board could monitor the consumption and bill of consumers. A relay was installed before the load of the consumer to connect or disconnect the energy supply when the consumer is unable to pay for the energy they consume. Thus, the need for development of real-time energy metering bypass and remote reporting system for registered consumers to monitor energy metering system bypass in a view of reporting and automatically disconnecting.

2. RESEARCH METHODOLOGY

This section discusses the work done in more detail, clearly stating the materials and methods used, which includes functional block diagram, circuit design and flow chart of the metering bypass detection model. This research utilizes Proteus design suite for circuit design and simulation, EasyEDA for web-based schematic and PCB design, Arduino IDE for programming, and Blynk as an IoT platform. Hardware components includes voltage and current sensors, a relay, thin film transistor (TFT) liquid crystal display screen, ESP-32 and Arduino Uno microcontrollers, connectors, and wires. These materials are used to achieve the prototype of the system. The ESP microcontroller was used for the design hardware implementation whereas the Arduino Uno was use to achieve the simulation.

2.1. Design of metering bypass detection model and remote controlling option

Figure 1 shows the architecture of the metering bypass detection model. It is classified into the inspectorate metering system and the consumer metering system. The data acquisition unit was used to collate the real time current and voltage data. It is represented by the I-sensor and C-sensor in Figure 1. The data acquisition unit provides relevant information for the bypass detection unit to make prompt and real time decision. As shown in the circuit diagram in Figure 2, the current and voltage sensor was connected to the energy input cable in series and parallel respectively. These sensors convert the analog readings into a measure compactible to the controller. In Figures 1 and 2, the design system has both the inspectorate and consumer metering functionality, the first determines when the consumer has bypassed the measuring system whereas the later automatically disconnects and reports the incident of energy bypass.

The bypass detection unit uses a differential technique to identify the case of metering bypass. An automation process was carried out between the controller of the inspectorate metering system and the consumer metering system using data streams. The inspectorate metering system sends real time data of its data acquisition unit to the consumer metering system through the Blynk server. On the consumer metering system, a subtraction equation was carried out as shown in the flowchart in Figure 3. If there is a disparity of 0.15 amps, the bypass signal was activated and a report was sent to the mobile client through the Blynk server.

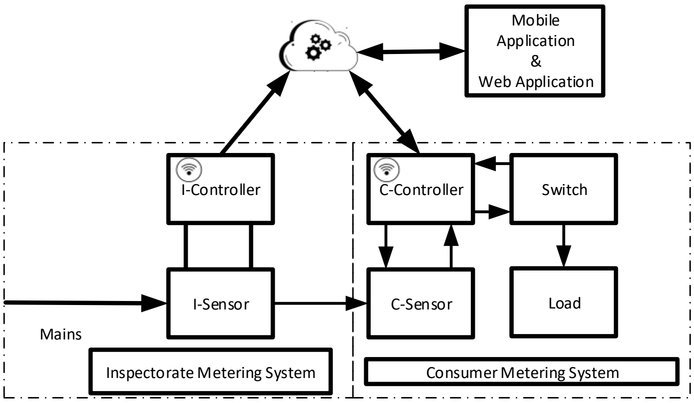


Figure 1. Functional block diagram of energy metering bypass detection system

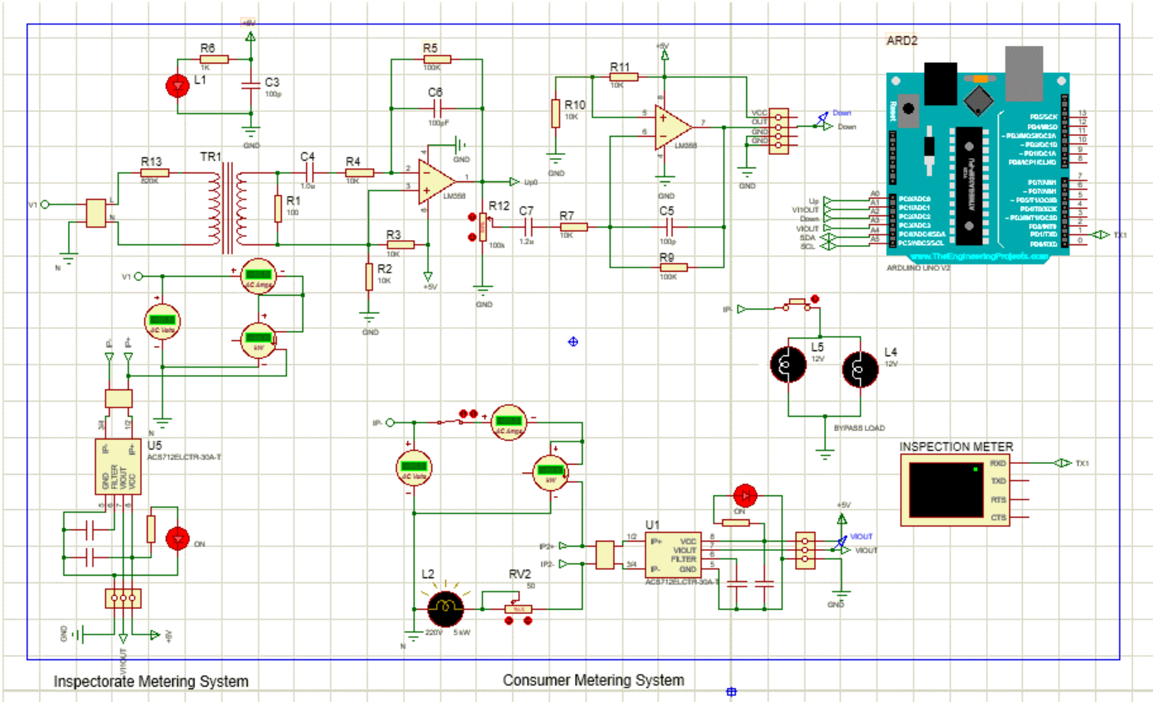


Figure 2. Circuit diagram of energy metering bypass and remote reporting system

The automatic switching unit as a crucial component of the system, enables remote control and automation of the meter disconnection process. With the use of a relay module, the unit was able to automatically deactivate a consumer in the event of a metering bypass signal being detected. Additionally, the unit provides the ability for an administrator to remotely disconnect a meter through the use of the remote reporting dashboard, thus providing a convenient and efficient method of managing and monitoring the system. This feature offers flexibility and convenience to the user and makes it possible to control the system remotely. The remote reporting and communication unit as a vital component of the system, enables remote monitoring and management. This unit uses Wi-Fi communication protocol and Blynk server as the platform to send and receive data in real-time. The ESP-32 microcontroller as the heart of this unit equipped with an integrated Wi-Fi, transmits the data stream to the Blynk server and the Blynk server then process the data, and provide a user-friendly interface to access the data on mobile and web platforms. This feature allows the administrator to keep track of the system's status and performance remotely, and make informed decisions accordingly. Also, this feature could enable the user to set up notifications, alarms or triggers based on certain parameters. The power supply unit ensures that all components in the circuit, including the controller, sensors and relay, have the necessary voltage for proper operation. The controller and sensors require a 5 V DC power supply, while the relay requires a 5 V DC supply with a minimum of 2 amps. This power supply unit provides the necessary power to all the components in the circuit, allowing them to function effectively and efficiently.

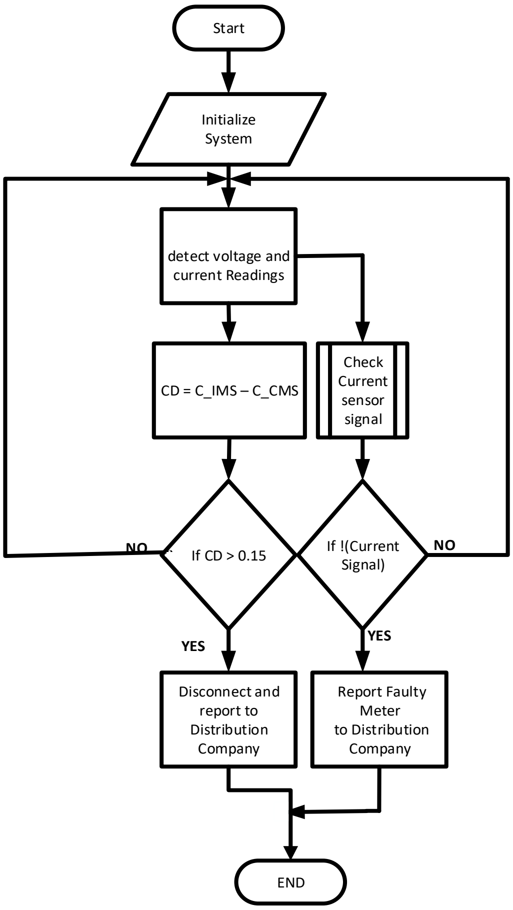


Figure 3. Flow chart of real-time energy metering bypass and remote reporting system

2.2. Design of remote reporting system

The remote reporting system utilizes Blynk IoT to securely transmit sensor data, such as current and voltage measurements, from remote locations to a central location for monitoring and analysis and this was achieved using Wi-Fi communication technology. The system also processes and presents the data in a user-friendly format through the use of graphical interfaces and dashboards. The design of the system prioritizes flexibility and scalability to accommodate a range of sensors and devices, and handle increasing amounts of data over time.

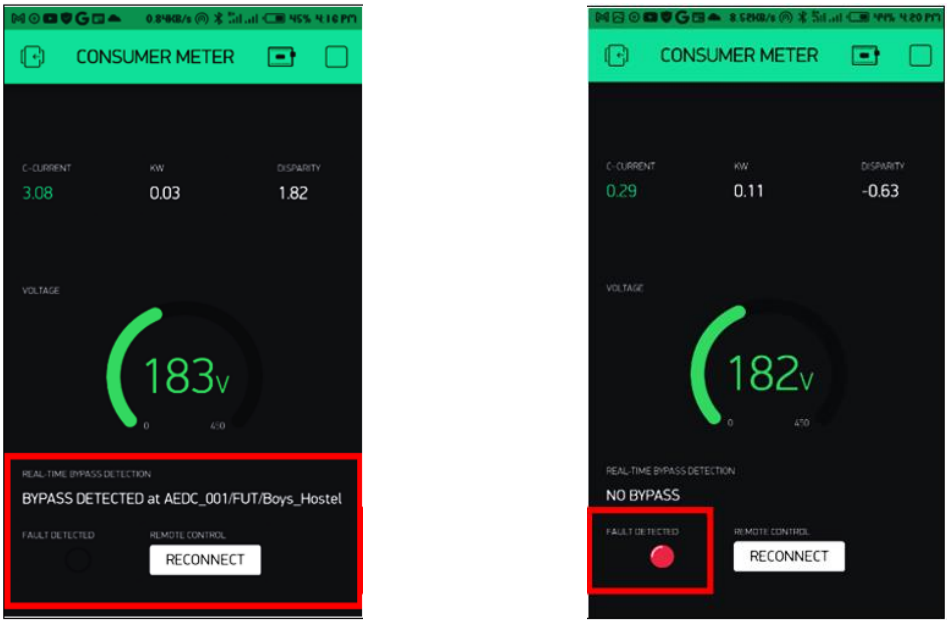
3. RESULTS AND DISCUSSION

This section gives insight on how the results were obtained. It shows the Android interface of the energy metering bypass detection, automatic and remote-control feature. Additionally, it presents a means of detecting fault in the metering system and the hardware prototype of the bypass detection system. This section also shows how the system was tested efficiently to monitored energy bypass from registered consumers.

3.1. Energy metering bypass detection testing

The energy metering bypass detection was tested using a 200 W bulb which serves as a bypass load and it was connected before the consumer metering system and after the inspectorate metering system. When the bypass load was connected, the current sensor of the inspectorate metering system measured a high a value of 0.75 amps while the consumer metering system measured a value of 0.1 amp. The application interface in Figure 4 shows the features available in the remote metering bypass detection and reporting platform. The model was capable of detecting when there was bypass or not.

The remote reporting system communicates to the electric distribution company on the status of the meter that was being monitored. In Figure 4(a), it was shown that bypass was detected in the metering system from the test location whereas, Figure 4(b) shows the reporting platform where there was no bypass in the metering system.



(a) (b)

Figure 4. Android interface of the bypass detection system (a) bypass detection and (b) no bypass detection

3.2. Automatic and remote-control interface

The automatic and remote-control feature makes connection and disconnection of consumers metering system easy. This feature aids the energy company by automatically disconnecting a consumer who attempts to bypass the energy metering system in a bid to steal energy. Additionally, it gives the energy company the power to control a metering system with the click of a button. The automatic and remote-control features of this model was tested through the monitoring dashboard and was initialized by a virtual pin responsible for sending a virtual command to the device from a remote location. This was tested using the button shown in Figure 5.

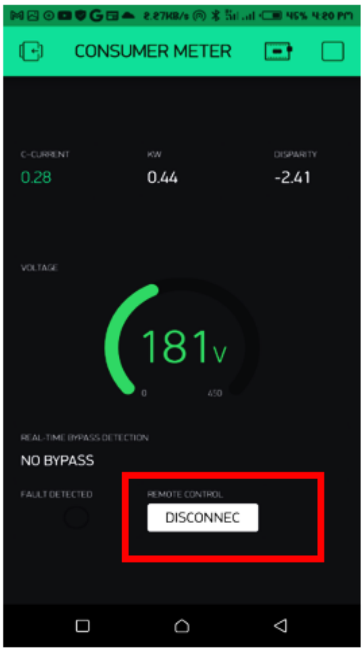
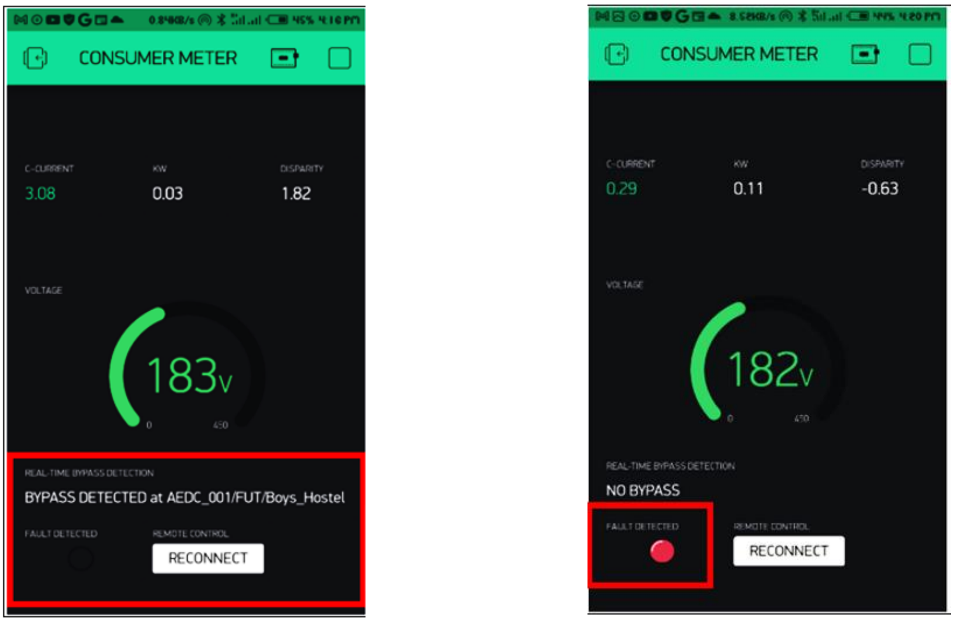


Figure 5. Remote energy connection and reconnection interface

3.3. Location and fault detection

The real time remote reporting system feature makes it possible for the energy company to detect the incidence of metering bypass alongside the location where incidence occurred. Figure 6(a) shows the designed metering bypass scenario by registered consumer within the test location and Figure 6(b) show that the meter was faulty and needs to be worked upon without bypass attempt. The prototype of the real time energy metering bypass and remote reporting system was implemented as shown in Figure 7.

The systems as designed with inspectorate and consumer metering model adopts the use of current sensing mechanism to compare the differences that exist between the two-metering system. The compares was such that the difference between the inspectorate and consumer metering system in Figure 5 reveals whether or not there has been an attempt to bypass the meter. The disparity between the two-metering system in a bypass scenario leads to the automatic disconnection of the consumer as displayed remote control application interface in Figure 6(a) similarly, in the event of no bypass but fault detection in the energy metering system the remote-control application interface appears as in Figure 6(b). This engendered prompt response from the maintenance team of the energy distribution company without on-site assessment of the metering system.



(a) (b)

Figure 6. Android interface of bypass detection system (a) location of bypass and (b) detection of meter fault

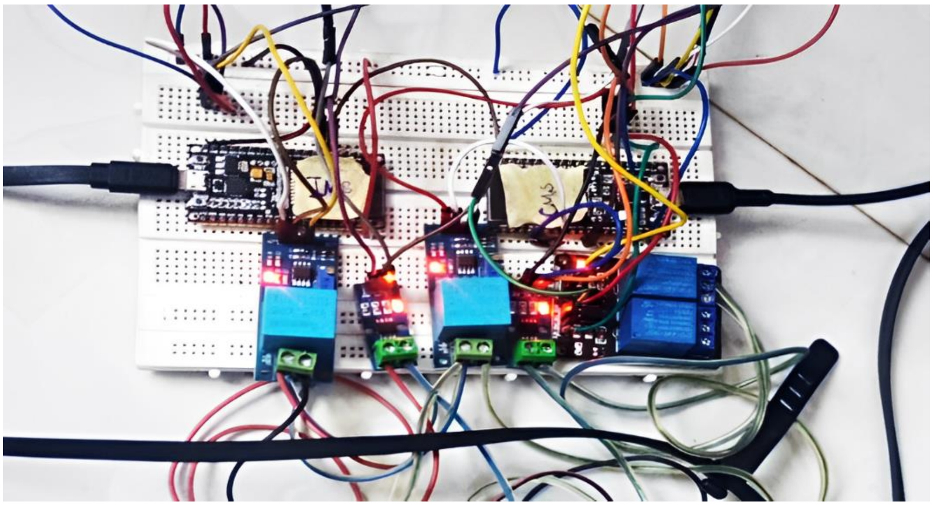


Figure 7. Prototype of real-time metering bypass detection model

4. CONCLUSION

The development of real-time energy metering bypass and remote reporting system revolutionizes the way energy consumption was monitored and managed. The designed systems allow energy companies to accurately track and measure energy usage in real-time, providing valuable insights into consumer behavior and energy efficiency. One key advantage of this developed real-time energy metering bypass detection system was its ability to detect, disconnect and alert energy companies of metering bypass. By continuously monitoring energy usage, the designed system detects disparity between the inspectorate and consumer metering devices, by indicating that the energy metering system is being bypassed by illegal energy consumers. On an account of faulty metering system, the designed system aids energy companies to identify and address the problem quickly, reducing the risk of lost revenue and improving overall efficiency. Remote reporting capabilities have also played a significant role in this developed real-time energy metering bypass detection system, the system as designed reveals its ability to remotely access and analyze energy usage data. This helps energy companies to make more informed decisions about energy management and conservation. Similarly, the designed system helps to reduce energy waste and lower costs for both energy companies and consumers. The development of real-time energy metering bypass and remote reporting system has greatly improved the way energy was monitored and managed. This system provides valuable insights into consumer behavior and energy efficiency, helping to reduce energy waste and improve overall efficiency. It is recommended that this work be implemented in metropolitan cities where bulk energy consumers are populated with global position system (GPS) functionality.

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