

Smart Energy Monitoring System

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Abstract: Smart Energy Monitoring System (SEMS) aims to create a device that can monitor home power consumption remotely using mobile gadgets without disturbing the utility's power meter. By leveraging the Internet of Things (IoT), power consumption can be monitored continuously and ubiquitously. SEMS uses Wi-Fi technology to send data from sensors to the cloud. The voltage data and sensors that have been processed by the ESP32 for the calculation of power consumption is in real time. Calibration using multimeter and clamp meter has been carried out to ensure the accuracy of the readings. The system will provide push notification to user mobile application in the event of overcurrent, undervoltage and overvoltage which is very helpful in case of a circuit breaker failure or fuse. As a result, SEMS has successfully displayed electrical power usage readings at home through websites and phone applications in real-time and has been calibrated precisely.

Keywords: IoT Meter, Monitoring, Power Consumption

1. Introduction

Electricity is widely used in modern society; it boosts productivity and improves people's living conditions [1]. Electricity consumption in 2016 posted an increase of 8.9 per cent from the previous year to register at 144,024 GWh [2]. Domestic, commercial, and industrial loads all use electricity. A household or industry's power consumption is measured by an electricity energy meter. The meter, among other things, assists the consumer in generating accurate bills [3].

Power companies measure consumers' electricity usage using meters that are typically located outside the customer's premises, where the power line enters the property. Customers' electricity consumption is usually measured in kilowatt hours (kWh). One kWh is equal to one kilowatt hourly generated or consumed. Different types of energy measuring meter have shifted over time, from the electromechanical meters to the smart meter, with the goal of obtaining the greatest and most efficient solutions for energy conservation.

The electricity department assigns workers specifically to monitor monthly energy use at residential buildings, resulting in a financial loss for the government [4]. Then, automatic reader is finally available.

Automatic meter sends reading to utility monthly using electronic signal. Many countries have already started the smart meter implementation [5]. One major technique for attaining efficient energy control is to monitor the on and off statuses of electrical appliances in real time using smart devices that collect this data [6].

This current project, called the "Smart Monitoring Energy System," uses an Internet of Things (IoT) to enable consumers to monitor their home power consumption via website and mobile application. This project combined hardware and software in monitoring home electricity. An algorithm is set up so that the system will log the voltage, current and power consumption data continuously into cloud storage.

2. Methodology

A block diagram is used to represent the layout and structure of the system that is involved. The design of the project will be described. Figure 1 illustrates the block diagram for the project.

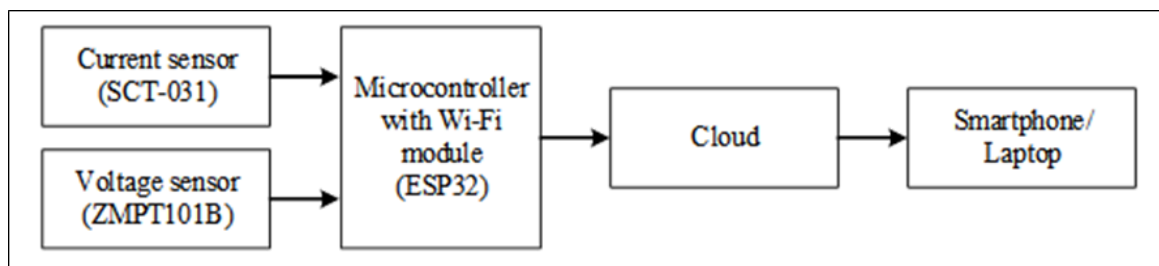


Figure 1: The block diagram of the project

The current and voltage of the 230 V AC power supply is measured by the current and voltage sensor. The sensor reproduces a lower level of signal represent the actual current and voltage. Then, the output signal from the sensor is transferred to microcontroller. The microcontroller reacts to the analog signal given by sensors and keeps on counting the supply and then calculates the power consumed. Followed by the data is sent time-to-time via Wi-Fi to the cloud. As a final process, the data from the cloud will be displayed and monitored on smartphone or laptop.

2.1 Flowchart

The entire process of this project is represented in Figure 2. Firstly, current and voltage sensor measure the AC power supply from consumer house or appliance. The output current and voltage generated from the sensor is transmitted to the microcontroller analog-digital (ADC) input and power consumption is calculated. At the same time, the program scans the Wi-Fi and internet connections. The program will loop automatically until it connects to Blynk cloud. When it is connected, the data of power consumption will be sent to cloud and can be displayed by the user on Blynk web dashboard and mobile dashboard. When the current or voltage value is out of range, the Blynk application will send notification to the user about the errors. If no error detected, the program will be looped to start again.

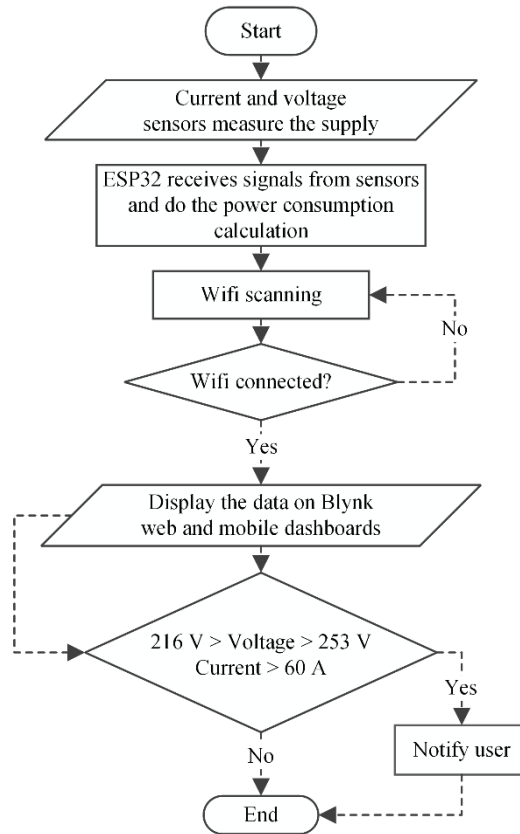


Figure 2: Flowchart of the smart energy monitoring system

2.2 Hardware Development

Table 1 shows the list of the component for smart energy monitoring system circuit.

Table 1: List of components

Component	Description	Operating supply
NodeMCU-32s ESP32 Module	Microcontroller	5 V input, 3.3 V output
ZMPT101B Module	Voltage Sensor	5 V input, 0-5 V output
SCT013-000 Module	Current Sensor	100 A input, 50 mA output
Resistor 100 Ohm	Burden resistor	0.5 Watt rated power
Resistor 10k Ohm	Voltage divider	0.5 Watt rated power
Capacitor 10 uF	Bypass resistor	16 V rated voltage
Power Supply AC-DC	Power converter	240 V AC - 5 V DC 2 A
0.91" OLED Display	Display data	3.3 V, 0.04 W

2.2.1 Circuit Diagram

Figure 3 illustrates the circuit diagram of the project. Using SCT013-000 sensor CT, the output signal of the sensor is current type output which is up to 50 mA when the measured current through it is 100 A. Before connected it to ADC input, there are some electronics parts attach to the CT output signal. The current need to be converted into voltage signal as the microcontroller’s only has analogue voltage inputs which measure 0-3.3 V AC. Thus, the current is then scaled with the voltage reference of 0 to 3.3 V range. Burden resistor or sampling resistor is connected across the across the secondary winding of the CT to complete or close the CT secondary circuit.

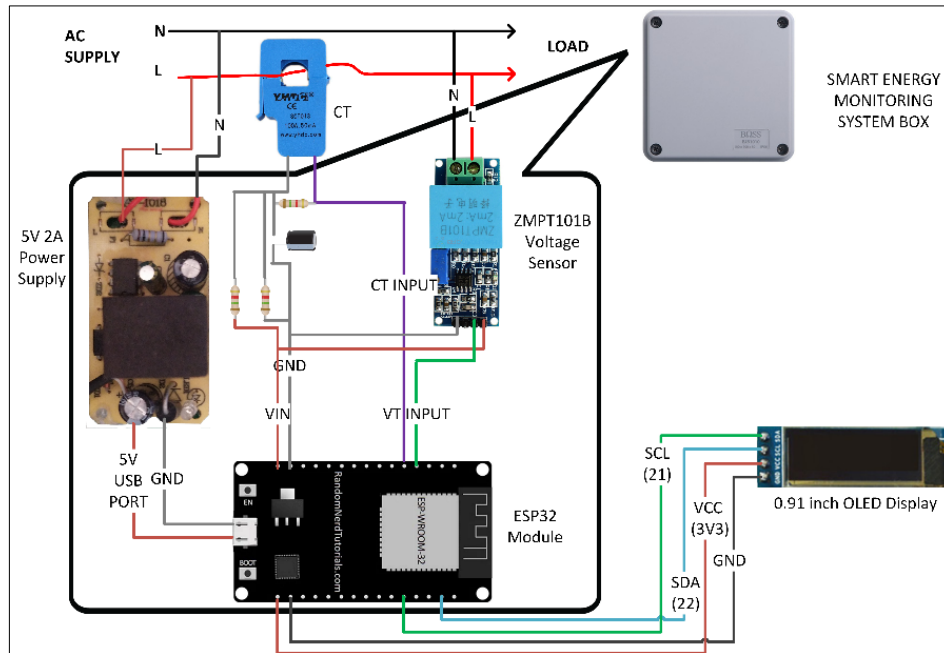


Figure 3: The illustration circuit of the project

The voltage oscillates from positive to negative if one of the CT conductors is connected to ground and the voltage of the second wire is monitored relative to ground. The ESP32 analog inputs, on the other hand, a positive voltage is needed. The CT output voltage will now swing above and below 1.65 V, remaining positive, by connecting the CT lead connected to ground to a source with half the supply voltage. This is done by connected the voltage divider resistor to the grounded CT lead. The resistor value must be equal and higher resistance to lowers quiescent energy consumption and reduce heat. A capacitor is installed as it has a low reactance and allow alternating current to bypass the resistor, enhancing accuracy.

For voltage sensor input, the ZMPT101B module must be calibrated by using the built-in potentiometer, to adjust the signal amplification. This is because the output range of the module is 5 A. Therefore, the signal must be amplified to 3.3 V. Theoretically, the 250 V AC signal should be reproduced as a signal. To power up the ESP32 and voltage sensor, 5 Vdc is needed. So, an AC to DC power converter which convert 230 V AC to 5V DC installed in the circuit. On the front cover, there is also an organic light-emitting diode (OLED) display that displays current, voltage, and power as well as a power status indication.

2.3 Software Development

Software development is a part where the Smart Energy Monitoring System program were built. The program decided the flow of work of ESP32 microcontroller in collecting data from current sensor and voltage sensor. The program also the place for calculations the power consumption output based on the data from two sensors were set up. In addition, the coding for the OLED display also created in software development.

2.3.1 Arduino IDE Software

Arduino Integrated Development Environment (IDE) was employed in the present project. Using the C++ programming language, the Arduino IDE is used to build and develop the project's program. Using the libraries available in the software, the ESP32 can be interface with the current sensor and voltage sensor to collect data and make calculations. With this software, calibration of sensors to get accurate reading are made. Besides that, the program to send to data to Blynk through Wi-Fi internet connection also coded in this software.

2.3.2 Blynk website and mobile application setup

Blynk web dashboard and mobile application is an interface between user Blynk cloud. All data send by ESP32 to the cloud can be view through Blynk website and application. Before that, some work must be done to setup the user interface called dashboard. The setup is consisting of determination microcontroller types, datastreams and dashboard widget. Without this setup, the data only send to cloud but cannot be viewed by users. Wi-Fi credentials and password used by the microcontroller also installed in this setup. Figure 4 shows the print screen during the setup in adding widget to the web dashboard.

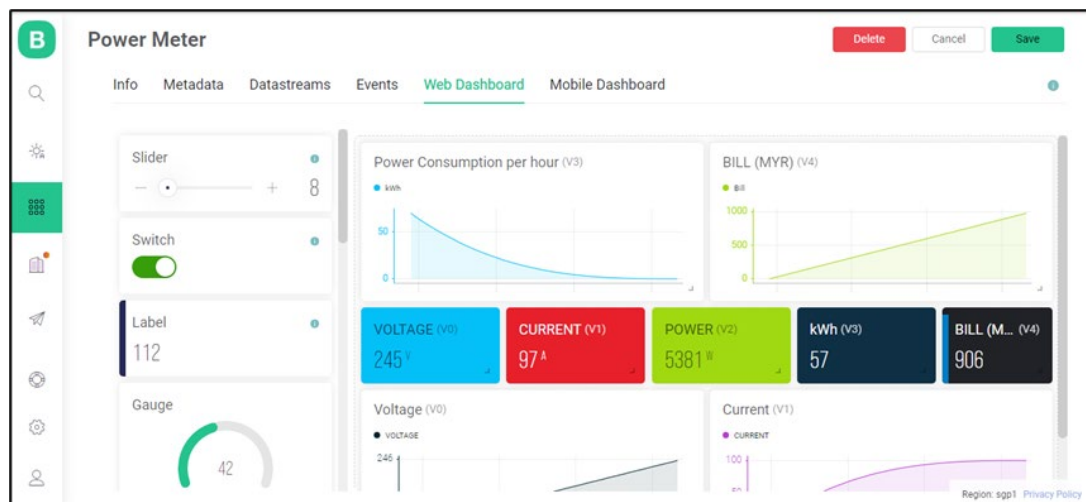


Figure 4: Widget setup for user interface for Blynk web dashboard

3. Results and Discussion

3.1 Hardware result

Figure 5 shows the final design of Smart Energy Monitoring System. On the outside, there is an ac voltage power switch. The switch controls the power supply input for the ESP32 module as well as the input signal for the ZMPT101B voltage sensor. To connect the current transformer to the circuit, an audio jack 3.5 mm is provided at the bottom edge of the box. There is also an 0.91" OLED display at front cover of the box to show the real-time voltage, current and power consumption reading. The readings displayed are synchronized with the reading appeared on Blynk dashboard. The circuit setup for the smart energy monitoring system is fitted inside the box. The circuit is build based on the circuit diagram on previous chapter. All the components are soldered on a protoboard.

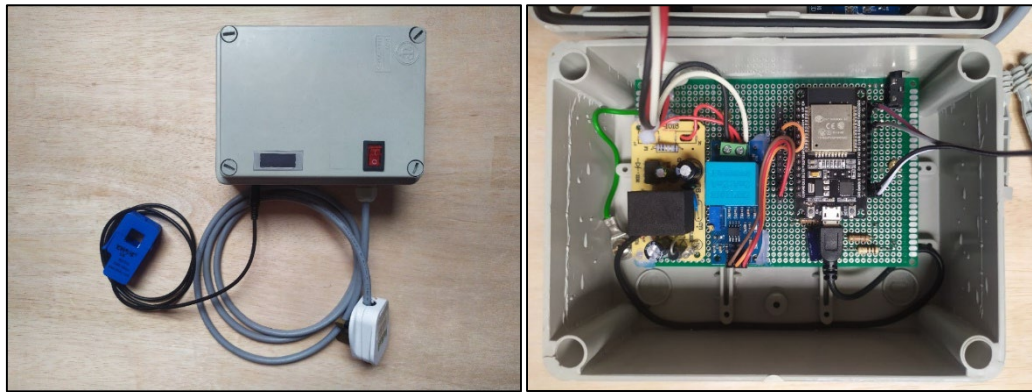


Figure 5: Final Design of the Project

3.2 Blynk application and website dashboard result

The real-time voltage sensor, current sensor, power, and kWh usage are all shown on the mobile dashboard. All readings are represented by a gauge symbol. A chart depicting the current and kWh plot depending on the user's electricity use is also included. The first display when users start the Blynk app on their phone is shown in Figure 6 (a). There is also written the status of the system internet connection either offline or online. When the first display in Figure 6 (a) is clicked, a new tab will open with the full display of the reading, as seen in Figure 6 (b). Users may also view the bill computation based on kWh power use by selecting the billing tab. Figure 6 (c) depicts real-time bill counts as well as a chart illustrating bills vs time.

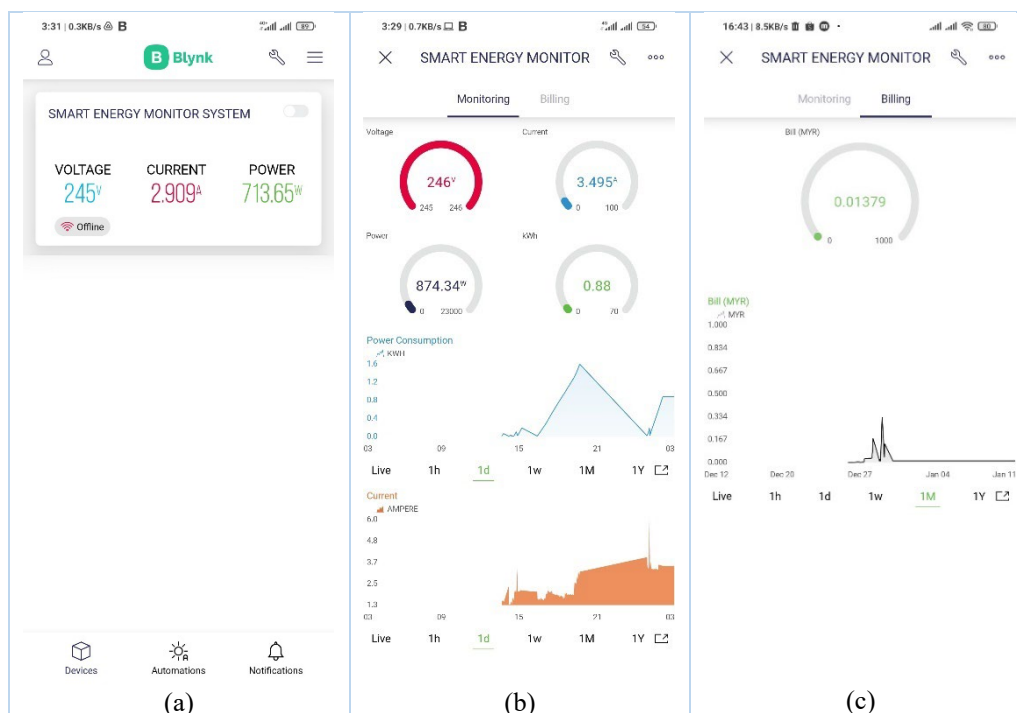


Figure 6: (a) Blynk apps initial screen, (b) Power monitoring tab, (c) Billing tab

The Blynk.cloud website also displays all readings. Users only need to enter their registered email address and password to gain access. The online dashboard's readings and plots are instantly synced to the mobile dashboard. According to the voltage and current sensors, the power consumption (kWh and Power) measurement is in real time, as illustrated in Figure 7. Additionally, real-time billing is incorporated. The billing fees are defined by Tenaga Nasional Berhad's (TNB) current tariff rates.



Figure 7: Sensors and power consumption reading in Blynk website

Blynk will detect that the system is currently offline if there is no internet connection to the ESP32. After a few minutes, Blynk will send a notification to the user informing that the Wi-Fi signal has been disconnected. This can be an indicator that the electricity supply has been cut off or something has happened to the Wi-Fi connection. Figure 8 (a) depicts the notification, which the user will receive on their phone's notification bar.

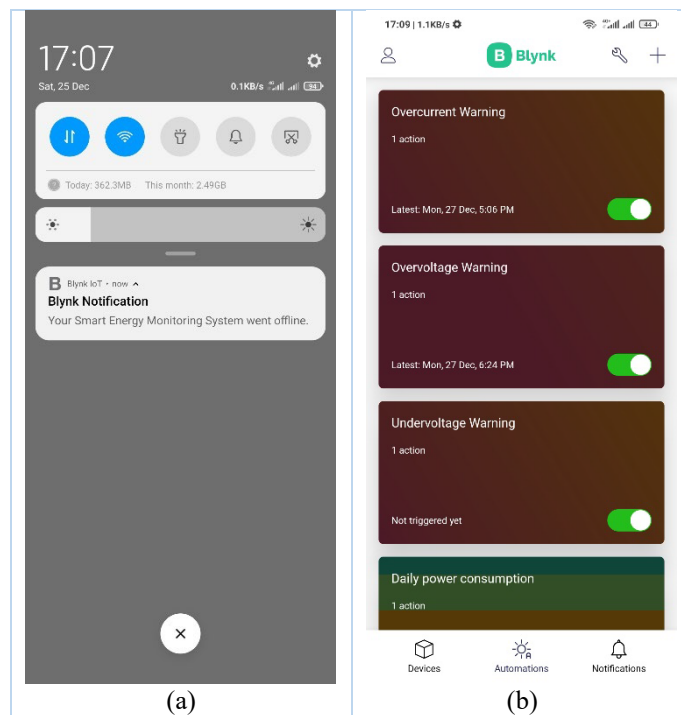


Figure 8: (a) Offline notification, (b) Notification settings for voltage and current

Figure 8(b) shows the automation tabs where user can set the notification based on certain device state. The application will send the notification when the value of the sensor is out of the ordinary or exceed the limit. In this system, developer have set the reading value to notify the user. For current reading, Blynk will send notification when the current exceeded the maximum rated current on user distribution board. While for the for the voltage, notification will be appearing when the reading is 10

percent exceed the nominal voltage for low voltage supply in Malaysia which is 230 V or 6 percent lower than that. The range is set by following the standard from MS IEC 60038.

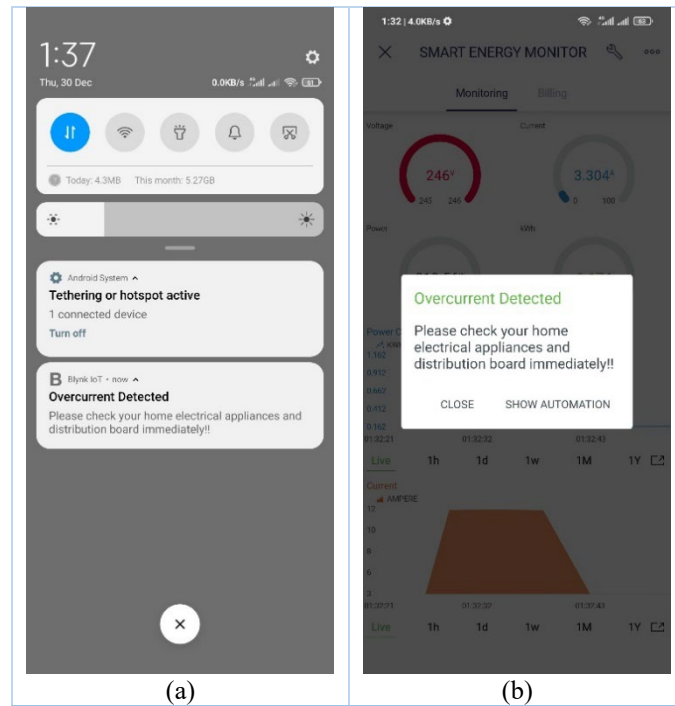


Figure 9: (a) Overcurrent notification on home screen, (b) Overcurrent notification in apps

Figure 9 shows a screenshot of a push notification sent by the Blynk app on a mobile phone. The message is about an overcurrent detection on the home's electrical system. The notification is followed by a brief message advising users to inspect their electrical appliances and distribution boards in case something undesirable occurs. This warning can prevent a fire from starting if electrical safety mechanisms in the distribution board, such as fuses and circuit breakers, fail to function correctly.

3.3 Data calibration and analysis

Some calibration has been completed to improve the accuracy of sensor readings. The voltage and current sensor readings are compared to the reading multimeter and clamp meter, respectively. Both data sets were compared by varying the load at home. The results of the calibration and comparison are shown in the Table 2. Figure 10 shows the calibration process using clamp meter.

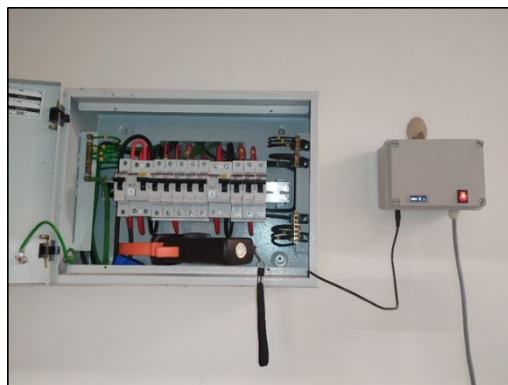


Figure 10: Calibration using clamp meter

Table 2: Comparison between sensor reading and clamp meter reading

Multimeter & Clamp Meter		Sensor		Differences, %	
Vrms (V)	Irms (A)	Vrms (V)	Irms (A)	Voltage	Current
246	3.4	243	3.44	1.22%	-1.18%
245	12.5	240	12.45	2.0%	0.40%
246	3.4	243	3.45	1.22%	-1.47%
246	3.1	245	3.12	0.41%	-0.65%
246	2.9	244	2.85	0.81%	1.72%
246	2.3	242	2.33	1.63%	-1.30%
246	1.7	244	1.72	0.81%	-1.18%
246	2.6	247	2.57	-0.41%	1.15%

Based on the data measured on both sensor and meter, there are minor differences between them. The reading of the voltage sensor is not stable as the multimeter reading. But it is still in allowed voltage range according to Malaysia voltage standard as stated in previous subchapter. While the current reading differences are still in permissible errors for electricity meter based on BS 37 which is $\pm 2.00\%$ [7]. Calibration is accomplished by modifying the code in the Arduino IDE.

Users can also review their previous power consumption using the chart widget on the Blynk website and app. The real-time power usage readings will be saved on the Blynk server and may then be viewed as historical data. Figure 11 represents kWh, voltage, current, and billing calculation data stored in the Blynk cloud as charts over an hour period for later user data interpretation.

**Figure 11: (a) kWh reading, (b) Bill reading, (c) Voltage reading, (d) Current reading**

4. Conclusion

In a conclusion, smart energy monitoring system has been successfully developed. This system was developed by using five main parts which are voltage sensor module, current transformer, ESP32 microcontroller, Blynk IoT platform, and Wi-Fi with internet connection. From data analysis in previous chapter, it has been shown that the rms voltage reading and multimeter measurement are still in allowed range. While the current signals detected by the current transformer also only have a minor error. By having accurate voltage and current data will resulting in accurate power consumption calculations. Besides that, user can display the historical data of their home appliances energy consumption in the Blynk mobile application and website that can be used to manage their electricity usage. In addition, set up notification based on the data to alert them when the voltage and current is out of range.

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