Wireless AC Appliance Energy Manager

Ili Najaa Aimi Mohd Nordin, Sh. Nurul Hidayah Wan Julihi, Muhammad Rusydi Muhammad Razif, Amar Faiz Zainal Abidin

Abstract: Manual home energy meter reading and billing had caused inconvenience to the utility companies due to lack of manpower to read the energy meter at each household especially in remote areas, which explains the increasing number of smart meter reader in the current market. Most of the smart meters in the market do not offer safety of privacy of consumers' personal information since the data of electricity usage is being transferred digitally to the utility companies for more accurate bill calculation. Plus, the smart meter system comes with its own device for monitoring and control which makes the whole system expensive. In this paper, a private ESP8266 Wi-Fi module-Arduino compatible device that is capable of measuring energy consumption and calculating the bill according to the Malaysia electricity tariff is proposed. Current is measured using ACS712 current sensor that operates based on generation of magnetic field as a result of current flows in copper conduction path being converted into a proportional voltage. The proposed system allows real-time energy consumption with bill monitoring and On-Off control of the specific electrical appliance from a smartphone via a user-friendly graphic user interface of Blynk. Results shows that energy meter device developed, named EnergySense, is able to measure current with average of 93.58 % accuracy from an air conditioner and 98.14 % accuracy from a water heater. The Blynk app is able to receive and show all the data transmitted from EnergySense, particularly the energy bill and On-Off condition of the electrical appliance connected to EnergySense at the present time, with 2 seconds delay in receiving the signal transmitted. EnergySense is proved to be suitable in providing accurate energy measurement. Plus, long distance energy monitoring and On-Off control of electrical appliances connected to EnergySense are successfully achieved.

Index Terms: ACS712 current sensor, Blynk, Home energy meter manager, NodeMCU Wi-Fi Module

I. INTRODUCTION

In the early days, meter reading for electricity consumption and billing are done manually by human operator. This would cause inconvenience to the utility companies such as need for additional manpower as a meter reader must be on-site to take readings [1]. This method contributed to delay in meter reading and was very time-consuming [2].

The process of preparing the bill by the utilities company is also affected if the house owner is absent, preventing the meter readers from the utilities company to enter the house for meter reading [1]. Consumers are unable to monitor the real-time energy and power consumption of their household whenever they need to check, which could lead to over usage of electricity as they are unable to predict the energy consumption at present time.

Electricity in Malaysia is generated from burning resources, such as natural gas, coal and petroleum products, which have a huge impact on the environment [3]. Burning natural gas produces less emission of nearly all types of air pollutants and carbon dioxide (CO_2) than burning coal or petroleum products to produce an equal amount of energy [4]. This explains why natural gas is used more than other resources. According to Malaysian Energy Commission, residential electricity consumption has steadily increased from 2010 to 2015, indicating the increasing demand of electricity generation yearly [3]. The proposed system will help consumers to reduce the burning of natural gas by managing the electricity consumption of their household.

II. LITERATURE REVIEW

Current technology that is available in Malaysia does not provide access for house owner to monitor and manage their electricity usage remotely. In late 2006, smart meters were introduced to customers. Smart meter can communicate in both directions, i.e. the meter can transmit information to the utility and the utility can also send information to the meter [5]. In 2013, researchers from National Institute of Technology, Calicut, India developed a Global System for Mobile Communications (GSM)-Based Automatic Energy Meter Reading System with Instant Billing [1]. Digital power meter was used to read energy consumed by each appliance. Energy consumption was continuously recorded and sent to the energy provider's server and user's phone through GSM network for bill generation [1]. The proposed system allows user to monitor their monthly power consumption and its rounded up billing either on a Liquid Crystal Display (LCD) display via web portal or by receiving Short Message Services (SMS). However, this system requires additional charge as every SMS received by the user is charged at standard SMS rate [1]. In addition, an interactive GUI is not provided for the users to control their appliances remotely.

Cellular network coverage now extends to remote areas and it has become a favorable monitoring method that can be done from Android application whenever the app is connected to the Internet. In recent years, this method has been used to connect a small number of devices to the relay board and the control circuit so that the status of the devices

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can be monitored on the Android application [7]. ESP8266 NodeMCU Wi-Fi shield was used to send the data received at the Arduino UNO (from its control circuit) via Internet to the Android application. Its Android application is designed so that it will shows the same switch as in the web server [7].

Another method used for the wireless monitoring of energy consumption of electrical appliances is with Bluetooth technology [6]. Controller circuit or Home Energy Management (HEM) connected to home network was used to continuously monitor the value of energy consumption [6]. Some of the energy measurements were done manually by using control circuit and some of them were done using smart meter. The energy consumption values from the smart meter is sent to the utility company's billing server to calculate the bill for the energy consumption used according to the current tariff [1]. The latter method is risky as it can be manipulated by irresponsible individuals in order to gain benefits. Therefore, to be cautious, the first option is safer because all the steps, from energy meter reading and bill calculating to sending it to the user, is done manually, without third party data invasion.

Based on the previous research related to energy consumption monitoring methods, most of the energy consumption can be known either via SMS, from LCD display [1] or from Android-based application [2], [3]. However, there is a lack regarding bill information of the total energy consumed. Therefore, a wireless home energy meter manager is proposed in this project so that users have the ability to wirelessly monitor household energy usage and estimate the bill of the total consumed energy whenever they need through Blynk app installed in their smartphones. This allows them to manage their household energy consumption and monthly electricity bill budget more efficiently.

III. METHODOLOGY

The proposed wireless energy monitoring and control system can be visualized in Figure 1. Figure 2 shows the hardware setup when measuring current consumed by AC appliance connected to the EnergySense.

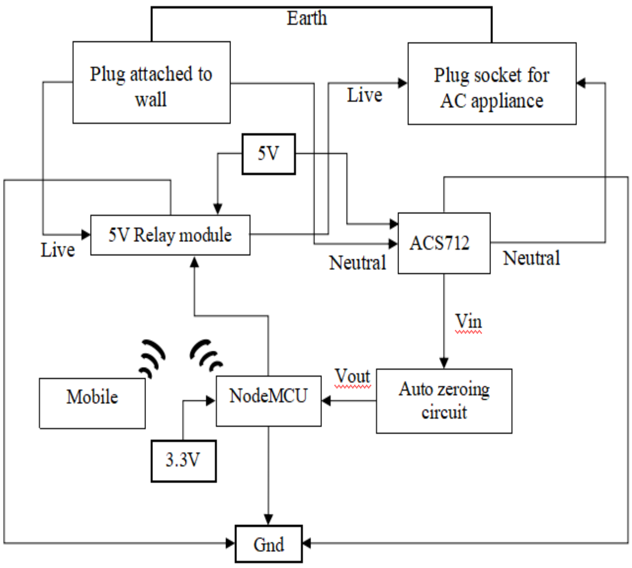

Fig. 1 Block diagram of the proposed system

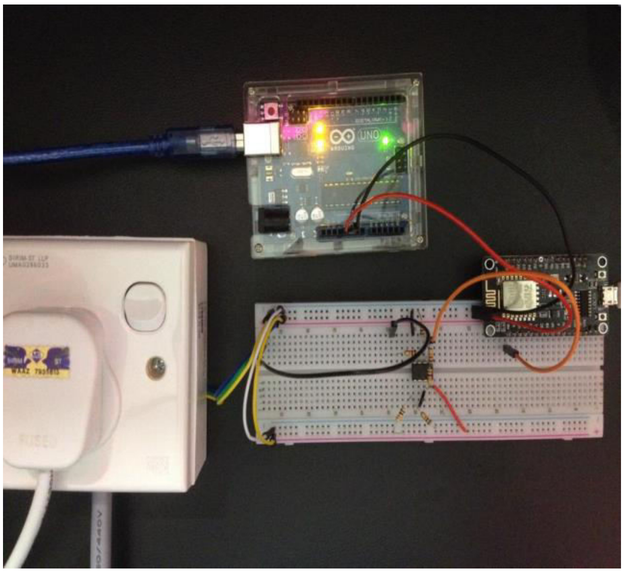

Fig. 2 Hardware setup of the AC load current measurement

The wireless communication between ESP8266 in NodeMCU board and Blynk is developed. In this proposed system, Soft Access Point (SoftAP) mode is used to connect ESP8266 to the Internet. SoftAP is actually an abbreviated term for "software enabled access point", which is when computer or smart phone is used as Wi-Fi access point without having to connect ESP8266 to a separate wireless router. NodeMCU board is used as it offers a simpler and more direct protocol of analog-to-digital converter interfacing.

A. Current Measurement

In this proposed system, current sensor ACS712 ELCTR-20A-T is used to measure the current flowing to the appliance. The current sensor used can measure current up to approximately 20 Ampere, with 100 mV per ampere of output sensitivity. The applied current flowing through the copper conduction path generates a magnetic field which is sensed by the integrated Hall IC and converted into a proportional voltage. The Hall effect is the production of a voltage difference (the Hall voltage) across an electrical conductor, transverse to an electric current in the conductor and to an applied magnetic field perpendicular to the current. This analog voltage signal output will be sent to the analog pin of NodeMCU to be converted into digital voltage. NodeMCU will then generate the current, power, energy and bill which is displayed on the Serial Monitor. The process of all electrical parameters measurement and calculation can be visualized in the flowchart shown in Figure 3.

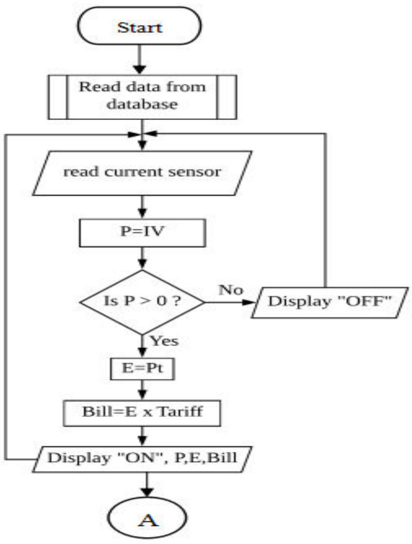

Fig. 3 Flowchart of current measurement

The offset voltage of the current sensor ACS712 when there is no current flow through the sensor as noted in the datasheet, is 2.5 V, but the maximum voltage that the ADC pin on NodeMCU can measure is not more than 1 V. Hence, auto-zeroing circuit is used in this proposed system to step down the output voltage from ACS712 current sensor ranging from 2.5 to 5 V to 0 to 1 V in order for NodeMCU to convert the analog voltage output from current sensor to digital voltage in NodeMCU accurately. The analog voltage input to the ADC pin were then sampled at discrete time intervals.

In the AC load experiment setup, the current sensor is placed in between the extended plug and the socket from the wall which connect the neutral wire in series. This connection allows current sensor to read current consumed by the appliance. Both circuits can obtain precise readings of the load.

B. Wireless Energy Monitoring

As shown in Figure 4, the Blynk app must first register for the administrative log-in of the application. The function of having administrative log-in in this system is to prevent an unauthorized person from logging in.

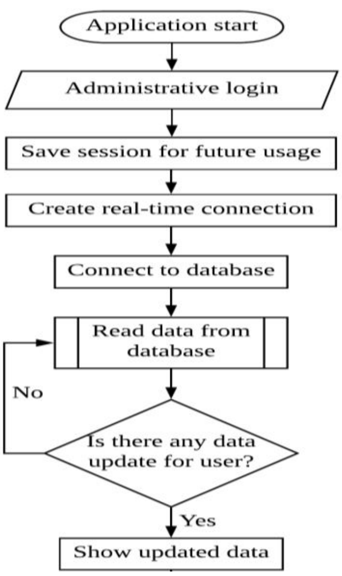

Fig. 4 Flowchart of wireless energy monitoring

The session will be saved for future usage and will be reset after a certain time. Next, the smart phone must be connected to the Internet for the application to create a real-time connection with Blynk database which will continuously update its data in Blynk app since it has real-time connection with the EnergySense. The data sent to the database came from the EnergySense current and energy measurement.

C. Wireless Energy Control

The voltage use for every household in Malaysia is 230/240 V with 50 Hz. Arduino cannot directly control high voltage and high current circuit, thus, relay is used for controlling the On and Off state of the electrical appliance from a low-voltage signal from NodeMCU. A relay can handle and switch high-voltage circuits. It works by using electromagnet that causes the switch to either open or close when there is signal received from NodeMCU. The relay used in this proposed system is single relay module, therefore it has a total of three pins which are NO (Normally Open), COM (Common) and NC (Normally Close). NO pin is not connected to the COM pin and is only connected when LOW signal is sent from NodeMCU. NC pin is opposite to NO, as the NC pin is always connected to the COM pin, even when the relay is not being powered up. For NC pin, LOW signal from NodeMCU will disconnect NC pin from COM pin. COM pin is the center terminal as the power to the load is connected to it and the pin is connected to the ground. Live wire from plug and the socket is connected to COM and NO pin of the relay module, respectively. The relay is powered up by using 5V and is grounded. Since COM and NO pin is used, LOW signal from digital pin of NodeMCU will activate the relay module and turn on the switch, thereby turning on the appliance.

Wireless energy appliance control shown in Figure 5 is a continuation of Figure 3.

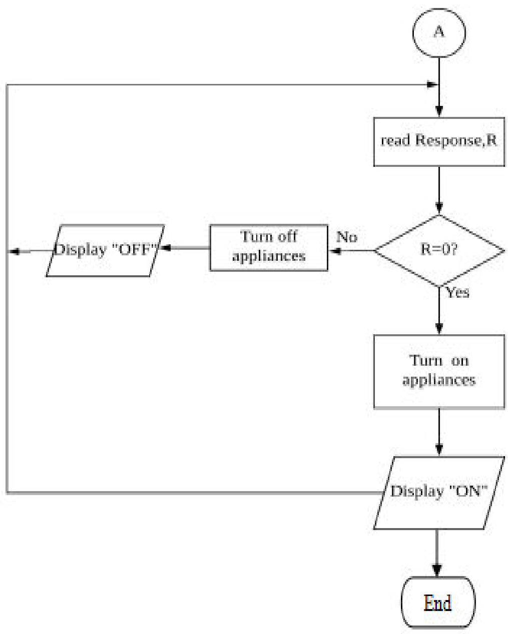

Fig. 5 Flowchart of wireless energy control

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The information in the Blynk app will be updated every second and at the same time it will send command to digital pin in NodeMCU in bit 0 or bit 1. Since the circuit is active low, whenever the user chooses to turn the load on, the application will send bit 0 to NodeMCU to turn on the load through relay module. Likewise, when user chooses to turn the load off, the application will send bit 1 to the control circuit to turn off the load. After turning the load on or off, the On/Off button in the Blynk application updates the On or Off status, respectively. The control process will keep repeating as the control circuit will keep checking if there is any response coming from the Blynk application.

IV. RESULTS AND DISCUSSION

A. Current Measurement

All of the processed data is successfully sent from NodeMCU to Blynk database. The graph of energy consumption and its bill can be viewed in Blynk app. The current values displayed on the Serial Monitor, which is measured by EnergySense, are validated with current value measured using conventional energy meter.

The accuracy of the current measurement by EnergySense can be known by comparing both results using Equation 1 and 2. It is proven that the current measured from the current sensor used in EnergySense, Imeasured, is very near to the expected value, Iexpected, measured from the conventional energy meter, resulting in 98.14 % accuracy on average.

Percentage of Error = |(Iexpected-Imeasured)/Iexpected| x 100% (1)

Percentage of Accuracy = 100% - Percentage of Error (2)

Data collection for current measured by EnergySense displayed on serial monitor and the current measured from conventional energy meter were taken three times, each data collected in one-minute duration before converting it into average current value. Energy meter serves as the true value of the current measured, whereby the data on the Serial Monitor serves as the measured value. The data obtained in the graph for water heater in Figure 6 is constant because the current use for the appliance remains the same as before as long as the water heater is still heating. The same goes for the graph of Irms vs time when measuring current for air conditioner. The accuracy of the data measured by this proposed system for high current consumed load can also be seen clearly in Figure 6 and 7.

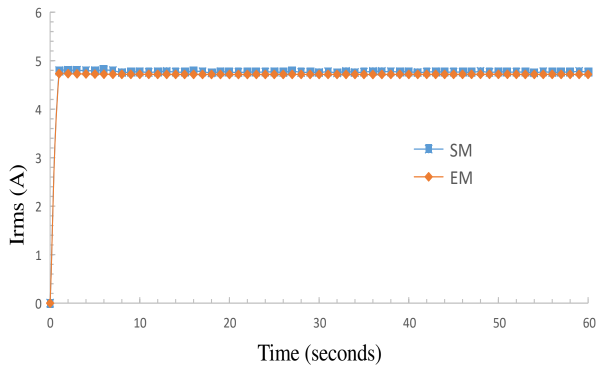

Fig. 6 Validation of water heater current measurement from EnergySense, SM with the conventional energy meter, EM

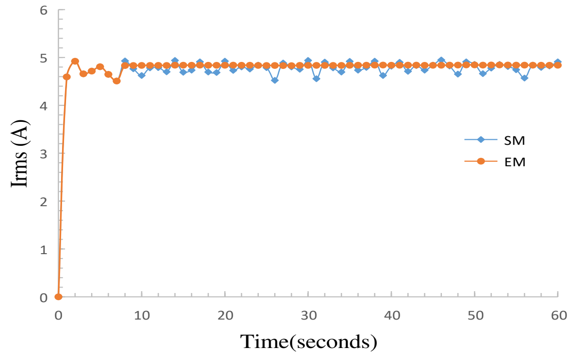

Fig. 7 Validation of air conditioner current measurement from EnergySense, SM with the conventional energy meter, EM

B. Wireless Energy Monitoring

First, the wireless connection between the current measurement device and Blynk application can be secured by connecting the NodeMCU Wi-Fi module with Wi-Fi hotspot connection. The status of Wi-Fi connection can be known from the Serial Monitor window, as shown in Figure 8. The energy data received from EnergySense, which were shown at Blynk app (BM), were validated with the energy value transmitted by EnergySense displayed on the Serial Monitor (SM). The GUI of Blynk app is as shown in Figure 9.

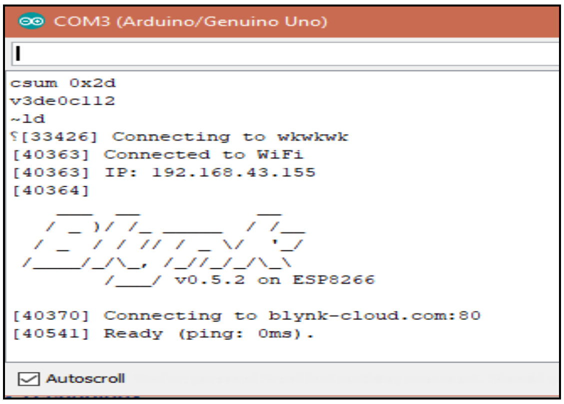

Fig. 8 Wi-Fi connection status displayed on Serial Monitor (SM) when NodeMCU is connected to Wi-Fi

Fig. 9 GUI of Blynk Energy Meter (BM)

The energy consumption data collection was taken three times in one-minute duration for both water heater and air conditioner. The average value of energy consumption in one-minute time were visualized in graph Energy versus Time as shown in Figure 10 and 11. Two second lag was observed in the energy value received at BM compared with energy value shown at SM. The graph in Figure 10 and 11 is increasing linearly because the energy is depending on the time variable of the system. Therefore, as the time increases, the value of energy increases.

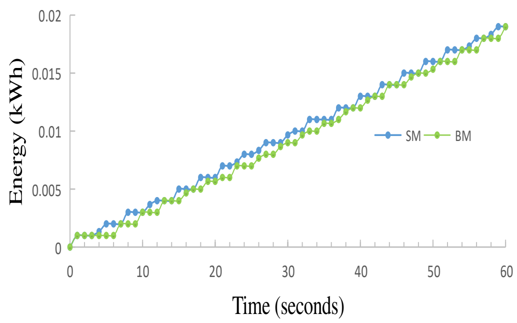

Fig. 10 Validation of water heater energy consumption from EnergySense (Transmitter), SM with the Blynk Energy Meter, BM (Receiver)

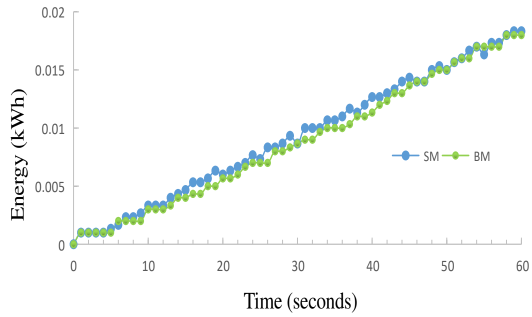

Fig. 11 Validation of air conditioner energy consumption from EnergySense (Transmitter), SM with the Blynk Energy Meter, BM (Receiver)

C. Wireless Energy Control

For wireless energy control, user can control their appliance remotely as long as the NodeMCU is connected to the Internet which allows it to send and retrieve data to and from Blynk server. Figure 12 shows that the appliance (water heater) turns off when the off button is pushed from the Blynk app, while Figure 13 shows that the appliance turns on when the on button is pushed in Blynk app.

Fig. 12 Water heater state when off Button is pushed from Blynk App

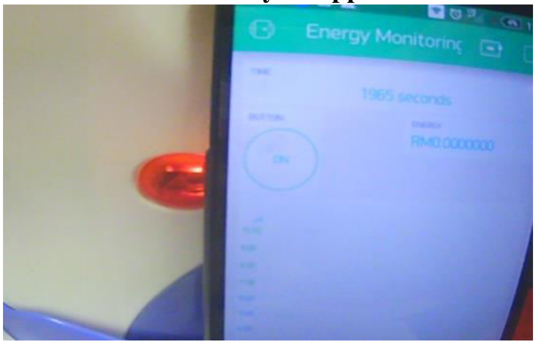

Fig. 13 Water heater state when On Button is pushed from Blynk App

V. CONCLUSION

Current measurement technique using ACS712 current sensor and auto-zeroing circuit in EnergySense shows high accuracy with maximum percentage error of 1.86 % when measuring current for water heater and 6.42 % when measuring current for air conditioner. Wireless transmission using NodeMCU is safely established with a 2 second transmission data lag. The appliance can be safely controlled wirelessly from the virtual On and Off button in GUI of the Blynk app. This does ease the energy monitoring and control process of specific AC appliance towards saving the electricity bill. For future improvement, decision making feature can be added into the proposed system so that the relay will automatically turn the appliance off if the total energy consumption is more than the amount set by the user.

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