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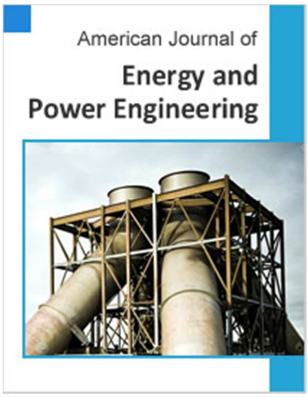

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Adjustable Power Monitoring System (APMS) for Daily Usage

Siti Amaniah Mohd Chachuli, Mohammad Zulkhairi Badrulhisham

Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia

Email address
sitiamaniah@utem.edu.my (S. A. M. Chachuli),
zulkhairibadrulhisham@gmail.com (M. Z. Badrulhisham)

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Abstract
With the increasing of new tariff of electricity, peoples try to find a method to minimize their electricity usage in a home or working places. The pattern of their electricity consumption should be understood to minimize the energy usage. A device that able to monitor the power usage in daily usage should be developed to help user in understanding electricity consumption at their home. In order to increase the awareness of electricity usage among the residential consumers, this project has been developed. This project consists of microcontroller, current sensor, LCD panel, LEDs and switches. The current sensor will be clamped at the live cable in the main distribution board to sense the current flow. Then, the target value will be compared with the actual usage of electricity. If the actual usage is exceeding the target value, a notification by LED will turn on. The prototype of power meter was designed with the ability to read the overall power usage in a house or at individual appliance and display the amount of electric bill. This meter is suitable for the residential buildings as the current sensor can measure RMS current up to 100A and measure power up to 240kW. From the experiment conducted, the average error is between 3.72% - 9.05%. Thus, this design of power meter is still reliable and robust to use.

1. Introduction

Nowadays, many users are focused in reducing electricity consumption due to the increasing of electricity bill. As the cost of electricity and energy used increases, alternative solution to reduce or optimize the energy usage should be carried out. While household appliances are increasingly more energy efficient, a household has a plethora of personal electronic devices (gadgets) for each member of the dwelling. The typical end-result is a monthly electric bill that leaves the question of where all the kilowatt-hours have gone [1]. Currently, user does not know how much electricity usage used by household appliances and they only know total usage of KWh and amount of electricity bill in a month.

With recent technologies, a lot of methods were introduced in order to minimize the usage of electricity and consequently reduce the electricity bill. One of the most practice methods is the introduction of energy saver device such as Power Tune Power Saver [2]. This device is used to reduce the current used in electrical appliances. However, this method will only save some amount of electricity bill, not raising the awareness towards consumers on how important to save electricity usage. In order to raise the awareness of energy usage, consumers need to know how much the energy used by them every day. In order to know the pattern of electricity usage, usage of electrical appliances should be measured. Thus, usage of electrical appliances that contributed to the high energy consumptions can be reduced.

Currently, many researchers have developed power monitoring system that able to help consumer in monitoring their electricity usage in daily lives. The most common methods are Power Line Communication Concept [3], Client Server Concept [4], Current and Voltage Sensor Concept [5], [6], and energy metering IC [7], [8]. As smart home concept getting world-wide popularity, monitoring power by real-time monitoring has attract incredible interest by researchers [9]. It can be implemented using current technology such as zigbee [10], [11], [12], [13], wireless sensor network (WSN) [14] and Wi-Fi network [9], [15], [16].

In this work, current sensor concept will be applied to measure the power in electrical appliances. This concept has been chosen due to it offers a simple solution to the growing power needs by raising the awareness of homeowners regarding how much individual household devices are consuming electricity [1]. With the aim to reduce the energy usage of the domestic devices, this power meter can display the total power, total electricity bill and it also able to alert user when the electricity usage has exceeded the target usage by giving the light indication on the power meter. Thus, this power meter will help consumers in understanding amount of energy used in term of kWh and Ringgit Malaysia.

2. Methodology

Figure 1 shows methodology flow of this project. At first, a suitable circuit to sense the power in the circuit should be selected. This project is divided into hardware development and software development. Hardware parts consist of microcontroller, measuring circuit and notification circuit. In the software part, algorithm is developed to read the current from the current sensor, then converted to power and display the data on liquid crystal display (LCD) panel. Next, the program will calculate the total power consumption and total bill in Ringgit Malaysia. It also will compare the measurement value with the target measurement value. If the measured value is exceeding the target value, a notification by LED will light on. Lastly, the performance of the system will be analysed. All the analysed data will be discuss further in the result and discussion section.

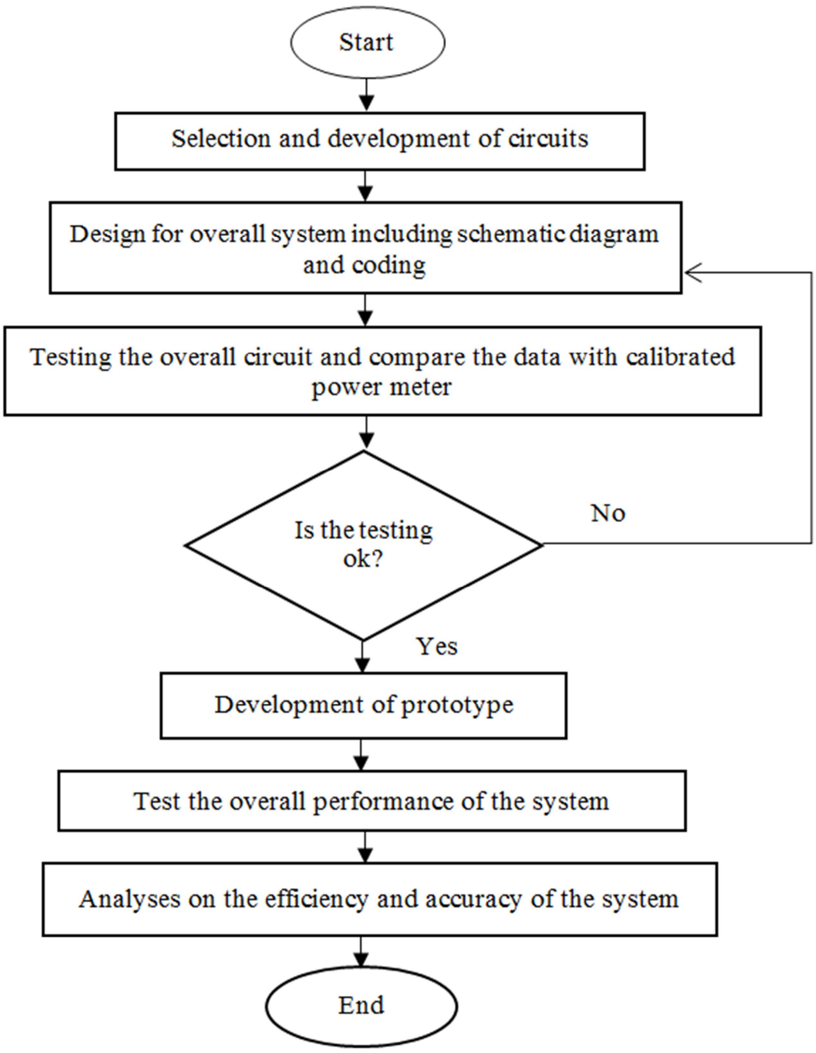

Figure 1. *The methodology flow of APMS.*

2.1. Overview of Overall Circuit

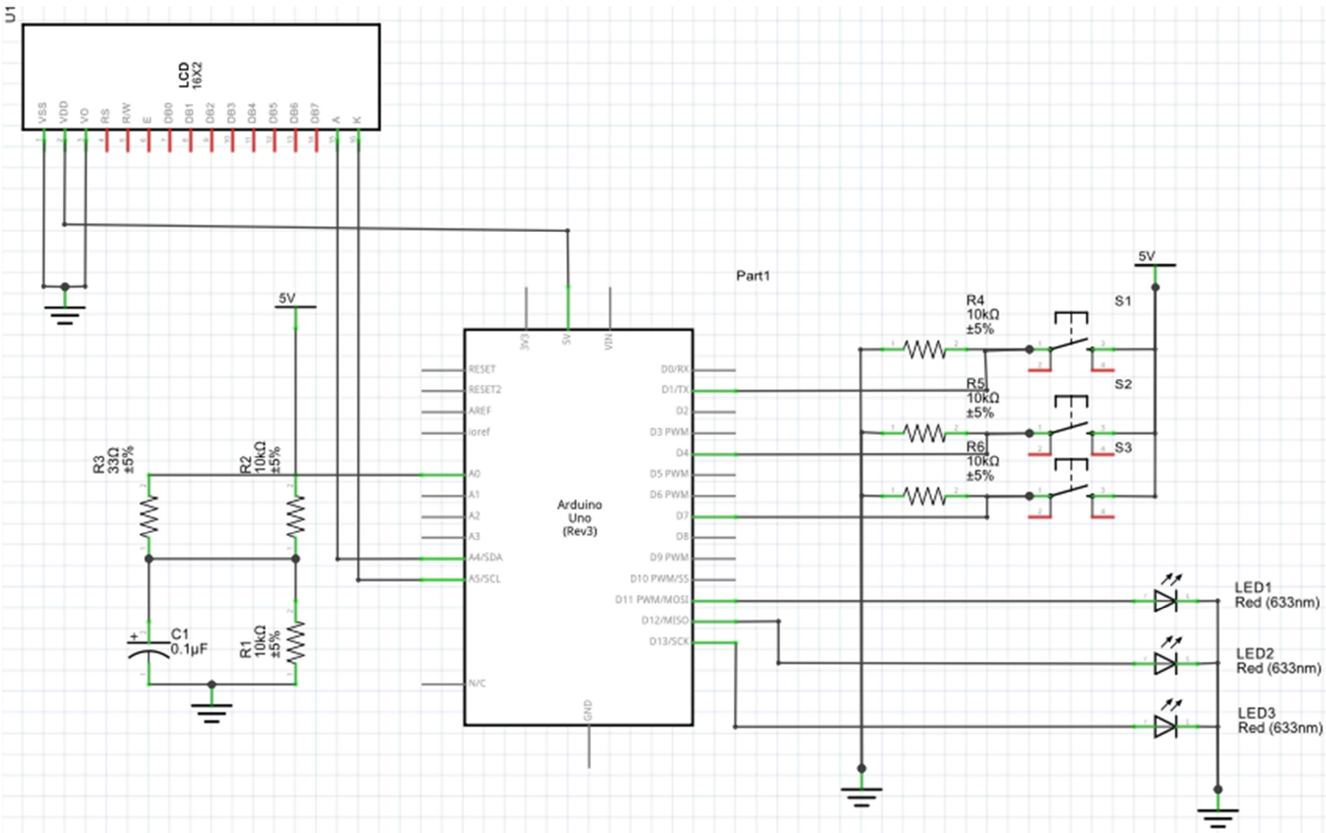

Figure 2. *Schematic diagram of overall circuit.*

Figure 2 shows a schematic diagram of the overall circuit. Firstly, the SCT 013-000 was connected with the Arduino Uno microcontroller. The programs were written, verified and uploaded in the 1.6.2 Arduino software. The output current that appear at the serial monitor were observed. This SCT 013-000 current sensor is current output type. Thus, the current signals need to be converted to voltage with a burden resistor. The push-button will be used as a medium for user to select their target electricity consumption. The LCD panel will display the total usage of electricity and total bill. The Arduino also will be used to compare the target input value with the actual usage of electricity. If the usage is exceeding the target value, the LED will be turn on. Three switches have been selected based on three amounts of target bill in a month.

2.2. Specification of Designed Power Meter

The specification of proposed power meter is tabulated in Table 1. The specification is based on the selected component used in this project.

Table 1. *Specification of Designed Proposed Power Meter.*

Parameter	Value
Voltage	240 Vrms
Current	0 A – 100 A
Power	0 kW – 240 kW

2.3. Prototype of Power Meter

The prototype of power meter was designed to measure the power consumption of daily usage with 100A maximum RMS current can be measured. This meter needs to be clamped at the live wire of an electrical appliance in order to measure the current flow of the appliance used as shown in Figure 3. The measurement will be carried out on a single phase system because only one current sensor is used in this project. The current sensor used in this project is SCT 013 000. For three phase system, three current sensors are needed to measure the current flow.

Figure 4 shows the prototype of power meter. It is equipped with three push-buttons and LEDs. Each of the push-button will set a different limit of electricity usage. It will be powered by 5V DC supply, which in this project we used a power bank. Before this meter can be used to measure the power consumption, it needs to be calibrated to get more accurate current and power measurement values. Besides, this meter needs to calibrate to ensure that the meter is safe before it can be clamped at the live cable on the individual appliance or in the distribution board.

Figure 3. *Setup of the current sensor with live wire.*

Figure 4. *The prototype of power meter.*

3. Results and Analysis

After the prototype has been developed, experimental test and analysis should be carried out to ensure the prototype able to successfully operate with minimum error. Firstly, the experimental test is carried out based on the inductive load and resistive load. The test is chosen to recognize the pattern of power consumption in the electrical appliances. Next, analysis will be carried out to calculate the minimum and maximum error produced by the developed power meter.

3.1. Experimental Test on Electrical Appliances

To measure the power used by domestic devices, the power meter was clamped to the live cable where it supplied current to the domestic devices which are fan and laptop. By clamping the current sensor to the live cable, the power in kilo watt hour (kWh) and the total price will be displayed on the LCD display. Also, additional measurements such as instantaneous current, instantaneous power and total operation time of the power meter will be displayed through the serial monitor of Arduino IDE Software as shown in Figure 5.

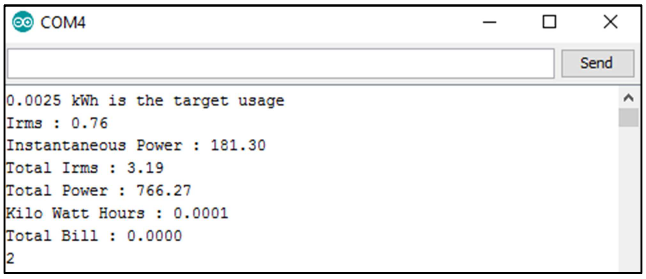

Figure 5. *Display on serial monitor or Arduino IDE.*

The test is carried out based on inductive load and resistive load. In the experimental test, fan and laptop have been used as the inductive load. While for the resistive load, water heater is used. The value of power is recorded between intervals of 1 second. The measurements are tabulated in Table 2. From Table 2, it can be seen that the value of usage power is increasing when the number of used device is increased. From the table also, it can be observed that the resistive load drew more power compared to the inductive load. The power consumption by resistive load is increases up to seven times greater than the inductive load. Hence, it can be concluded that less resistive load should be used in daily lives in order to minimize the electricity usage.

Table 2. *Measurement power from inductive and resistive load.*

Appliance	Fan	Fan + Laptop	Water Heater
Time (second)	**Power (W)**	**Power (W)**	**Power (W)**
1	114.75	171.03	1473.11
2	115.09	178.28	1458.56
3	111.53	170.67	1465.28
4	110.65	168.63	1460.50
5	113.57	171.68	1495.19
6	112.55	168.79	1447.92
7	113.72	169.72	1456.06
8	114.69	173.07	1463.39
9	111.85	165.96	1444.87
10	114.12	173.65	1452.87
Average	113.25	171.15	1461.78

Starting operation of power meter is shown in Figure 6. LED will light on if the value of the measured power is exceeded the target limit. Table 3 shows the limitation value of electricity usage for each different switch. 3.033 kWh is chosen because of user will get exceptions for paying their electricity bill, 10 kWh is moderate bill and 16.667 kWh is electricity usage more than 300 kWh in a month. For demonstration purpose, the limit usage is set at 0.0025 kWh. Figure 7 shows a LED will light on when the electricity consumption has exceeded the target usage for that day.

Table 3. *Limitation value of electricity for each push-button.*

Switch	Limitation Daily Usage (kWh)	Total Bill in 30 days (RM)
1	3.033	20.00
2	10.000	65.40
3	16.667	109.00

Figure 6. *Starting operation of power meter.*

Figure 7. *Total usage is exceeding the target usage.*

3.2. Accuracy Analysis for Power Meter

In order to analyze the accuracy of power meter, the measurement from power meter is compared with the reference meter which is Energy Monitor model D02A. Several experiments were conducted in order to measure the accuracy of designed power meter. Different loads were used in each experiment. The absolute error and error are tabulated in Table 4, Table 5 and Table 6. The average error produced by three different experiments are calculated and tabulated in Table 7.

From the tabulated data, it can be seen that the average of highest error produced by APMS is 9.05% while the average of lowest error is 3.72%. Both errors from conducted experiment are lower than 10%. Thus, this error still can be accepted and the APMS can be considered to deliver 90% performance of accuracy. In the experiment, voltage used is 240V. This is one of the factors that lead APMS readings have some error. In order to minimize the error, real value of voltage should be measured by using voltage sensor. Another factor that leads to the error is the sensitivity of current sensor. From the experiment that has been conducted, it is found that the sensor is less sensitive towards the lower current value. Thus, this will cause an error in measurement of power for low current appliances such as mobile phone charger.

Table 4. *Comparison between measurements of reference meter with APMS (Load: laptop).*

Reference Meter (W)	APMS (W)	|Absolute Error| (W)	Error (%)
113.4	120.23	6.83	6.02
113.3	121.94	8.64	7.63
113.4	121.54	8.14	7.18
113.3	116.79	3.49	3.08
113.4	122.37	8.97	7.91
113.3	123.42	10.12	8.93
113.3	120.54	7.24	6.39
113.2	123.54	10.34	9.13
113.2	119.23	6.03	5.33
113.4	124.47	11.07	9.76

Table 5. *Comparison between measurements of reference meter with APMS (Load: laptop and fan).*

Reference Meter (W)	APMS (W)	|Absolute Error| (W)	Error (%)
161.6	174.01	12.41	7.68
162.0	173.62	11.62	7.17
161.6	168.65	7.05	4.36
161.1	160.44	0.66	0.41
161.2	167.26	6.06	3.75
162.3	169.29	6.99	4.31
162.7	170.72	8.02	4.93
161.3	172.06	10.76	6.67
161.7	168.63	6.93	4.29
162.4	163.88	1.48	0.91

Table 6. *Comparison between measurements of reference meter with APMS. (Load: laptop and water heater).*

Reference Meter (W)	APMS (W)	|Absolute Error| (W)	Error (%)
1605	1460.91	144.09	8.98
1603	1454.60	148.40	9.26
1602	1459.78	142.25	8.88
1605	1458.73	146.27	9.11
1606	1483.31	122.69	7.66
1604	1449.85	154.15	9.61
1605	1461.39	143.61	8.95
1604	1461.65	142.35	8.87
1602	1446.38	155.62	9.71
1603	1448.63	154.37	9.63

Table 7. *Average of highest and lowest error.*

Load	Highest Error (%)	Lowest Error (%)
Fan	9.76	3.08
Fan and Laptop	7.68	0.41
Water Heater	9.71	7.66
Average Error	9.05	3.72

4. Conclusion

A system that can help user to understand their electricity usage by giving additional information such as instantaneous power, instantaneous current, total power used and total bill have been developed. User can set a limit usage of electricity in a day by selecting one of the push-button. The advantage of this meter is easily handled by the consumers. From the experiment conducted, it is found that the highest percentage error of this system is 9.05% while the lowest error is 3.72%. In order to improve this project, some recommendations can be implemented in the future work as follows:

1) To measure more accurate power, voltage sensor also needs to install. This will give a real time voltage value. When the real voltage value is known, the error can be reduced. The voltage taken in consideration is from 220V to 240V which it will cause the power meter to give the power slightly different in accuracy. If the voltage was also measured, the value of the power also can be more accurate.
2) In order to give the consumers clear understanding on the pattern of electricity usage, a data logger can be used to collect the data from the sensors, analyse and save the output. This result can be shown to the consumers in graphical form for the monthly electricity usage. So that the consumers can easily compared their electricity usage from the previous months and try to reduce their electricity usage for the next becoming months.
3) Implement an Ethernet module to monitor power consumption through online.

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