Development of smart energy meter to measure energy saving of dimmable LED panel light

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Abstract. Conserving energy is important now more than ever. Dimming lamps to the required illuminance is one way to reduce the energy usage. Technological advancement in the form of new materials, sensors, and apparatus allows us to reduce the energy usage of an equipment. To obtain a clear understanding of consumer energy usage, a smart meter which is able to monitor and store energy usage characteristics can be a useful tool to have. This paper discusses the development of multi-points smart energy meter using ESP32, ZMPT101B voltage sensor, and SCT-013 current sensor. The measurements result of the meter developed has been validated using commercial energy meter. A 35 W dimmable LED panel light benefitting dimming function in QH7938 chip has also been constructed. The dimming characteristics were obtained, with the output luminous flux of 5644 to 950 lumen, and power input of 35 to 5.32 watt. Subsequently, the energy saving case scenario in 2.5 x 2.8 x 3 meters home office with various natural lighting condition were also presented.

1. Introduction
Climate change is becoming a more and more critical issue, and many belief that efficient use of energy is an essential approach in greenhouse gas emission reduction [1]. In attempt to reduce fossil energy, households are responsible for 15-20% of energy usage. The use of electricity in household could be reduced by changing the behaviour of the user. This might be done by promoting the energy-efficient products and services [2]. Lighting is one of the main loads in household, and the study in making power reduction is interesting topic.

Several previous studies have discussed energy saving aspects of lighting loads. Study in Khan [3] compares techno-economic performance of different light sources, which concluded to propose a widespread use of LED lamps. LED lights are electrical devices that produce light using one or more light-emitting diodes (LEDs). LED lights have a life span several times longer than equivalent incandescent lamps, and are significantly more efficient than most fluorescent lamps. In addition, LEDs are considered as flicker-free when compared to their predecessor, fluorescent lamps [4].

In its development, many LEDs are implemented as smart lighting systems because of the flexibility of their control. Smart lighting is a lighting technology designed for energy efficiency. This concept includes equipment with high efficiency and automatic controls that make adjustments based on room conditions or lighting requirements. In that matter, this study focusses on the development of dimmable LED panel light in attempt to save lighting energy consumption. Effects of LED control to the reduction of power needed, lumen output, and its power factor will be investigated. Finally, an experiment in home
office setup were conducted to exhibit the possibility of dimmable LED panel to further be developed into a smart lighting system.

2. Methods
The study starts with the development of multi-point smart meter. The meter was validated using commercial energy meter, as well as utility energy meter. A dimmable LED panel lamp were also developed. The LED panel dimming characteristics will be measured. The device then will be installed at home office with various natural lighting condition to simulate power reduction scenario. Fig 1 shows the flowchart of methodology of this study.

![Flowchart of methodology of the study](image1)

**Figure 1.** Flowchart of methodology of the study.

2.1. Smart energy meter design
Several other studies has developed devices to monitor energy meter [5–9]. This project is using two sensors such as ZMPT101B for AC voltage measurement and SCT-013 10A/1V for current measurement. The data from this sensor is sent to smartphone over Wi-Fi features on board from ESP32 that connected to internet. The platform used to make this monitoring application is Blynk which can be used for free. Fig 2 shows the block diagram of this project.

![Block diagram of smart energy meter proposed](image2)

**Figure 2.** Block diagram of smart energy meter proposed.

Fig 3 is a schematic of signal conditioning for SCT-013 10A/1V current sensor. This schematic explains the installation of the sensor to ESP32. This sensor require a burden resistor which can be read below, and it is needed to use resistor value for R1 and R2 between 10k-470k. The ceramic capacitor 104 is
used to filter noise from input. The sensor is CT clamp with 2000 turns and should be calibrated with formula to calculate the calibration value for emonlib library used.

\[
\text{Calibration number} = \frac{\text{number of turns of CT Clamp}}{\text{Burden Resistor}}
\]  

(1)

An output from CT clamp need to be used with a burden resistor. The burden resistor completes or closes the CT secondary circuit. The burden resistor value is chosen to provide a voltage proportional to the secondary current. The burden resistor value needs to be low enough to prevent CT core saturation. The system voltage is getting from the supply using 3.3 VDC.

\[
\text{Burden resistor} = \frac{\text{system voltage}}{2.0} \div \left(\frac{I_{RMS} \times 1.414}{\text{CT Turns}}\right)
\]  

(2)

2.2. Dimmable LED panel light design

A 35-watt LED panel light has been constructed from 35 high power LED connected in series. The dimmer was constructed from QH7938 chip. Fig 4 shows the schematic of QH7938 obtained from the datasheet. The characteristics of the developed LED panel will be measured, such as lumen, power usage, and also power factor. The constructed LED lamp were then be installed in a home office with the natural light available. An experiment will be conducted to maintain illuminance in workspace to be within the limit, regarding various natural light condition.

Fig 5 is a schematic of home office. The LED panel was installed in 2.5 x 2.8 x 3 m home office setup. The workspace is situated 1.75 m above the floor, and 2.55 m to the LED panel. There is a window where the natural light comes into the room. The illuminance is to be kept within the limit. Table 1 shows the residential building minimum illuminance and colour rendering recommendation. A value of 250 lux is used as limit in home office experiment.
Figure 5. Schematic of home office dimmable LED panel installation and measurement.

Table 1. Residential building minimum illuminance and colour rendering recommendation [11].

| Room Function                                | Illuminance (lux) | Colour Rendering |
|----------------------------------------------|-------------------|-----------------|
| Terrace                                      | 60                | 1 or 2          |
| Living Room, dining room, bed room           | 120-250           | 1 or 2          |
| **Office**                                   | **120-250**       | **1**           |
| Bath room                                    | 250               | 1 or 2          |
| Kitchen                                      | 250               | 1 or 2          |
| Garage                                       | 60                | 3 or 4          |

3. Results and discussion
Smart energy meter and LED dimmable panel has been developed. This section presents the results and discussion of the proposed system.

3.1. Smart energy meter
Fig 6 shows the proposed energy meter device, which constructed from ESP32, ZMPT101B AC voltage sensor, SCT-013 10A/1V current sensor. The measurement of AC voltage is done by ZMPT101B and the current flow from SCT-013 10A/1V. The values of power factor, apparent power, real power, and energy in Watt-hour is obtained from calculations through the code from library of the program.

Figure 6. The developed smart energy meter.
Fig 7 shows the measurement value that was sent to the Blynk App, and can be monitored via a smartphone with some add-ons like to set the set point of the maximum energy value, and the notification can be sent to the smartphone that the energy has reached the maximum value. The energy value should be reset if the maximum value is reached.

![Figure 7. Current, Power Factor, Energy with load graph.](image)

Fig 8 shows the measurement of the energy meter (including AC voltage, current, energy in Watt-hours, power factor, power and frequency) and the Blynk App with no load, with load, and when the energy threshold passed. The commercial energy meter can measure very low current with no issues. The Blynk App shows the small tolerable difference in error values between the power analyzer and the hardware on the AC voltage value. Table 2 shows the comparison of commercial energy meter and the proposed smart energy meter. It shows some differences in measurements.

![Figure 8. Current, Power Factor, Energy with load graph.](image)

**Table 2.** Measurement comparisons of different loads.

| No | Load | Commercial Energy Meter | Proposed Smart Energy Meter |
|----|------|--------------------------|-----------------------------|
|    |      | V | I | PFa | Fq (Hz) | Pwr | V | I | PFa | Apparent Power | Real Power |
| 1  | Kettle | 220 | 2.68 | 1 | 50 | 586 | 220 | 2.68 | 1.0 | 589 | 543 |
| 2  | Drill | 221 | 1.2 | 0.9 | 50 | 260 | 219 | 1.23 | 1.0 | 292 | 223 |
| 3  | Blower | 222 | 2.7 | 0.9 | 50 | 300 | 220 | 2.7 | 1.0 | 516 | 504 |
| 4  | Solder | 219 | 0.118 | 0.93 | 50 | 23,9 | 220 | 0.15 | 0.8 | 33 | 21 |
3.2. Dimmable LED panel light

After development of smart meter, a dimmable LED panel light were constructed. Fig 9a shows the dimming characteristics of LED panel constructed. The maximum power consumption is 35.6 watt, with the measured output of 5644 lumen. The minimum power of the dimmable LED panel is 5.35 watt, with measured output of 950 lumen. The output shows linear relationship between power consumption with lighting output.

![Figure 9a](image1.png)

![Figure 9b](image2.png)

**Figure 9.** a) LED panel power input versus centre spot lumen output dimming characteristics; b) LED panel power factor versus power input dimming characteristics.

Fig 9b shows the power factor characteristics versus power consumption. The power factor of LED panel in brightest setting is 0.98. The power factor decreases when the lamp is dimmed. The lowest setting of the LED panel causes the power factor to be drop to as much as 0.82.

After obtaining the characteristics, the LED panel lamp was installed to the home office setup. The ceiling and wall paint white with a window act as natural light source. The lux meter is placed on worksurface, and the natural light is varied. The LED was kept to light the work surface at the predefined illuminance, 250 lux. Fig 5 shows the home office experimental setup.

Fig 10 shows the power needed for LED panel to maintain illuminance at the work surface to be at 250 lux. The natural light is varied from 115 to 200. The experiment resulted in the variance of LED panel light needed to maintain the 250 lux as shown by Fig 10. A linear relationship can be obtained, with the correlation coefficient $R^2 = 0.9903$. This result is interesting to be used in future study, to develop self-dimming smart LED panel.

![Figure 10](image3.png)

**Figure 10.** LED power needed to reach 250 lux in various natural lighting condition

4. Conclusion

From the research experiment that has been done, it can be concluded that the dimmable LED panel in attempt to save electrical power has been successfully implemented. A 35 W dimmable LED panel light...
benefiting dimming function in QH7938 chip has been constructed. The dimming characteristics were obtained, with the output luminous flux of 5644 to 950 lumen, and power input of 35 to 5.32 watt. Subsequently, the power reduction case scenario in 2.5 x 2.8 x 3 meters home office with various natural lighting condition were presented. A dimming curve with high correlation coefficient of 0.99 were obtained. This result shows the ability of the system to be used in the future study, to develop self-dimming smart LED panel.

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