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Smart Lighting System for a Classroom using Solar PV and Internet of Things (IoT)

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Abstract: Nowadays, all schools around Malaysia still rely upon the continuity of power supply from Tenaga Nasional Berhad (TNB) to operate the lighting system in the classroom. Therefore, when power outages occur, the school's lighting system is unable to operate since the power outages usually happen without prior notified in advance by TNB. This main issue should be prioritised with utmost importance to ensure the learning and teaching session can be conducted effectively. Therefore, the development of a smart lighting system for a classroom using solar PV and the Internet of Things (IoT) is designed to tackle this issue. The project was composed of a stand-alone off-grid photovoltaic system, which used a battery to power up the lighting system and integrated with the implementation of IoT system. The IoT system comprised two features: controlled the lighting system and monitored the illuminance level from the emitted light wirelessly. Hence, the project intended to design and simulate a power converter inverter circuit output voltage from 12V DC to 220V AC, to control the lighting system as well as monitor the illuminance level by accessing through the Blynk application. A mini-scale classroom prototype consisting of the solar PV system and integration of IoT system also being developed. The prototype development involves a monocrystalline solar panel, sealed lead-acid battery, solar charge controller, LED bulbs, ESP8266, 4-relay channel module, digital BH1750 light sensor, and digital lux meter. The results accuracy of the measurement apparatus is 87.30% for the digital BH1750 light sensor and 83.57% for the digital lux meter interpreted that the system effectively monitored the illuminance level of the LED bulbs in the classroom.

Keywords: Stand-Alone PV System, Internet of Things (Iot), Blynk

1. Introduction

According to Energy Commission, the electricity generated in the Malaysian Peninsula mainly depends on coal, and natural gas provides 52% and 44% of the energy generation and distribution [1]. Therefore, if coal and natural gas are used continuously and enormously, subsequently, Malaysia will

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suffer severe power shortages due to the diminishing fossil fuel reserves. In 2003 and 2005, major power shortage cases were reported across the Malaysian Peninsula, whereby most systems relied on primary power supply from Tenaga Nasional Berhad (TNB). The trend of the statistical performance show that the number of electricity supply interruption cases were gradually decreasing, but still beyond the limit par [2]. The causes of unscheduled electricity supply interruption cases such as failure in equipment, tree falls, and natural catastrophes [3]. To begin with, the specific area of work is a lighting system for the classroom at school as the power consumption for lighting system lower than ventilation system [4]. The lighting system in the classroom should maintain with utmost importance so the lecture sessions can be carried out during the day or at night. Whilst the lighting intensity in the classroom sights an essential contribution that ensures the teachers and students can carry out lecture sessions without any disturbances from the external surroundings, such as power outages [5]. Thus, this project intended to scale down the dependence on the continuity of electrical energy from TNB by designing a stand-alone lighting system that relies on renewable energy with the integration of an Internet of Things (IoT). The IoT uses the internet to yield interconnected connectivity between remote accessibility, particularly a device and lighting system in the classroom [6].

All systems implied in the schools still rely on TNB as the primary power source for electricity [7]. Therefore, any disruption, such as a school blackout, can doubtlessly occur whenever a power outage and failure happen. This issue was common without being notified in advance by TNB. Furthermore, all classrooms use a conventional switch to turn on the lighting system. It requires mandatory physical contact, which can expose the severity of electrical shock due to several circumstances, e.g., faulty outlet, improper grounding, etc., that can harm teachers and students. Hence, this project proposed implementing a stand-alone photovoltaic system with an IoT integration. This project can minimise the dependency and reliability of the power grid from TNB and imposes electrical safety by controlling the switches wirelessly using an only smartphone.

2. Materials and Methods

This section specified the approach used to determine, designate, and analyse the workflow process towards software and hardware implementation inquiries, which will systematise a work-specific in designing a smart lighting system for the classroom using solar PV and IoT.

2.1 Project Block Diagram

A block diagram is graphical of a system that demonstrates its operationality and functioning. Figure 1 illustrates the block diagram for the computation of the primary structure to manifest the relationships between the working principle of the summation blocks for the smart lighting system for the classroom using solar PV and IoT. The electricity generated from solar PV panels behaved as the main supply for the lighting system in the classroom. The conversion of energy principle for the solar PV panels is a sun's light energy to electrical energy. The solar PV panels incorporate photovoltaic cells that absorbed the sun's rays directly to produce electricity [8]. The solar charge controller connected the solar PV panel and the battery bank. The solar charge controller is a voltage and current regulator to prevent the batteries from overcharging and under-charging [9]. The solar charge controller used to block and obstruct any reverse current flows returned through the solar PV panels at night [10]. The inverter circuit in the system used to convert the conversion of V DC load to a V AC load. The step-up transformer used to step-up the rated voltage of 12V AC to the 240V AC to lighten up the classroom as the specifications of the load requires a voltage rating of 220-240 V AC. The 4-channel relay module utilised as the electrical switch to turn the LED bulbs and a digital BH1750 ambient light sensor utilised to measure the luminous flux over the classroom area wirelessly and remotely. The IoT system used a NodeMCU board as the microcontroller platform that contains an ESP8266 Wi-Fi-enabled chip to operate the lighting system by transferring data using Wi-Fi protocol. The NodeMCU ESP8266 Wi-Fi Module acquired command and receive data wirelessly from the smartphone by establishing an internet connectivity connection within the lighting system. Therefore, the lighting system in the classroom encoded by switching on and off the LED bulbs and monitor the illuminance of the lighting system in the classroom using the smartphone. The Blynk App installed on the smartphone, which used as the interface device for the operationality of the lighting system.

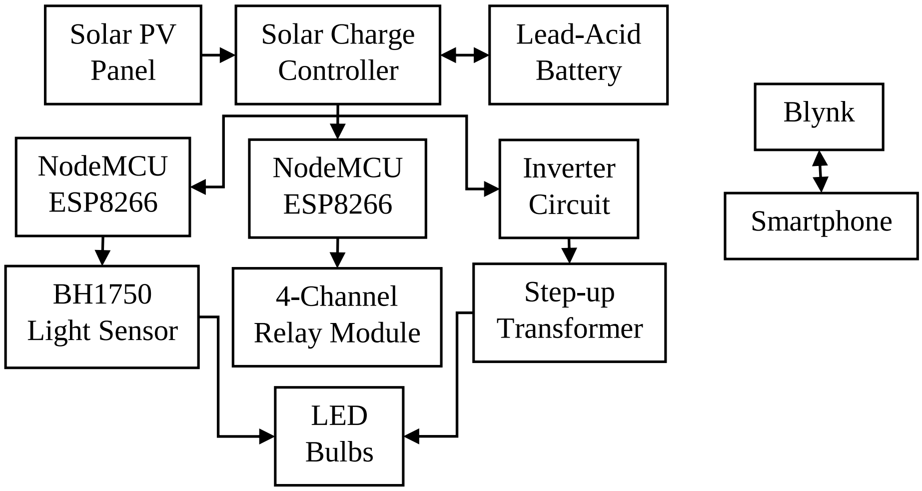


Figure 1: Block diagram of a smart lighting system for a classroom using solar PV and IoT

2.2 Project Flowchart

A flowchart is diagrammatic representation of a system that represents a workflow or process in sequential approach and order. Figure 2 illustrates the flowchart operation of a smart lighting system for the classroom using solar PV and IoT. The project was divided into two phases: the simulation of inverter circuit and the integration of IoT. To design the inverter circuit, it was necessary to produce a simulation result beforehand to construct the hardware development for the inverter circuit. It was to ensure the simulation result can achieve the outcome so the hardware development can produce close working results to the simulation. Firstly, designed and simulated the inverter circuit using Proteus 8 software. Then, simulated to ensure the output voltage met the load requirement. Supposed the simulation met the specifications to design the hardware development. In that case, it can proceed to the next stage, developed the inverter circuit using the actual components at the breadboard. The result was obtained through measurement apparatus: a multimeter to measure the voltage at the input, switching, and output of the inverter circuit. Hence, whenever the hardware result did not correspond to the simulation result, troubleshooted the connection of the components and re-tested the measurement value for each specific part. Finally, once the hardware result was obtained as similar to the simulation result, the inverter circuit merged into the mini-scale of the classroom prototype. Operating input voltage of NodeMCU ESP8266 was in a range of 4.5V-10.0V, thereafter, the NodeMCU ESP8266 commenced its functionality by receiving 5 VDC from the battery thorough the solar charge controller. Then, the NodeMCU ESP8266 transmitted coding command in accordance from the coding programme at the Arduino IDE software to the 4-channel relay module and BH1750 sensor. After that, the 4-channel relay module and BH1750 sensor operated to act as the switching mechanism to turn ON and turn OFF the LED bulbs and converts the value of an analogue illuminance to the value of a digital lux. Last but not least, the manual switching of an ON and OFF and the measurement of illuminance in lux, lx interface can be controlled wirelessly by a smartphone through the Blynk App once the Wi-Fi and personal hotspot can integrate in the IoT system

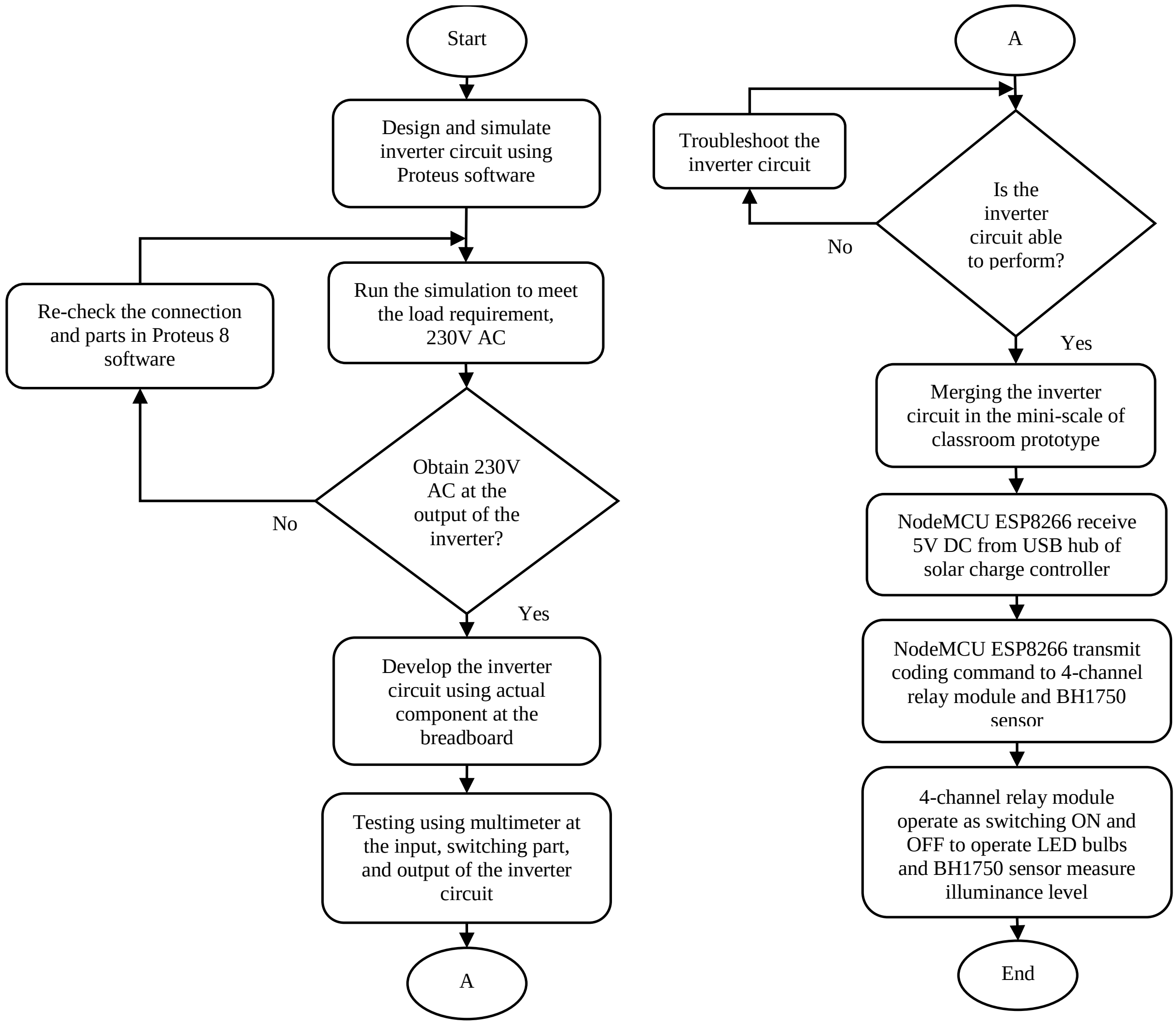


Figure 2: The flowchart operation of a smart lighting system for the classroom using solar PV and Internet of Things (IoT)

3. Results and Discussion

This section focused on the results and analysis based on the corresponded objectives. All of the testing had been carried out in different manner. The first objective was to design and simulate the power converter inverter circuit. The final testing results achieved by comparing between the simulation result from the software and hardware results from the hardware actual setup. The second objective was to control the lighting system with the assistance of the IoT system. The final testing results achieved by comparing the results for experimental hardware setup and the results for actual hardware setup. The second objective also was to monitor the illuminance level with the assistance of the IoT system. The final testing results achieved by comparing the theoretical results from the calculation method and measured results using two different measurement apparatus devices. The third objective was to develop a mini-scale of prototype consisting of solar PV and integration on IoT. The final testing results achieved by measuring the charging and discharging operation of the prototype's system design when utilised at maximum capability.

a. Power Converter Inverter Circuit

The simulation for the inverter circuit was required before proceeded to construct the actual hardware inverter circuit. To design the inverter circuit, the circuit was simulated using Proteus 8 software, in which the analysis interpreted in the form of waveform and output values.

Figure 3 shows the results obtained at the input, switching and output of the inverter circuit of AC voltmeter. The result stated the value for input of the inverter circuit was 12V DC while the value for the switching part of the inverter circuit was 23Vpeak-to-peak. Thus, to find the value of Vpeak, using the formula Vpeak, Vpeak = Vpeak-to-peak/2, the result was 11.5Vpeak AC. It is observed that the result stated the value for the output of the inverter circuit was 220Vrms AC.

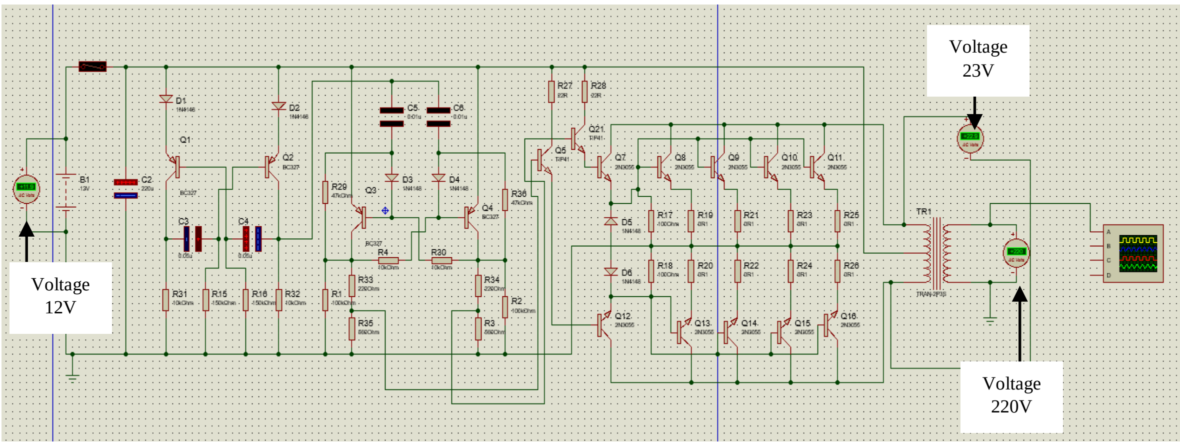


Figure 3: The results obtained at the input, switching and output of the inverter circuit (AC voltmeter)

Figure 4 shows the waveform produced at the output of the switching part of the inverter circuit. One complete cycle of the green line consisted of 10 horizontal divisions. The parameter set at the oscilloscope was 2ms of time/div. One complete peak-to-peak of the red line consisted of 5 vertical divisions. The parameter set at the oscilloscope was 5V of volt/div. Each division represented 2ms multiplied by the total of divisions concluded to 20ms. Using the frequency formula, which is frequency = 1/period, the result of the frequency signal was 50Hz. Each division represented 5V multiplied by the total of divisions concluded to 23Vpeak-to-peak. Using the formula of Vpeak, Vpeak = Vpeak-to-peak/2, the result of the inverter circuit was 11.5 Vpeak AC.

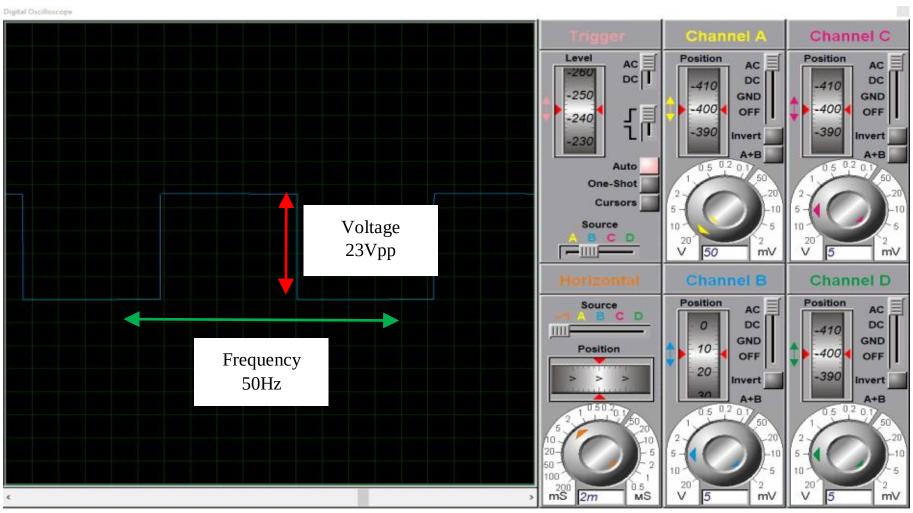


Figure 4: Waveform produced at the output of the switching part of the inverter circuit

Figure 5 illustrates the waveform produced at the output of the inverter circuit. One complete cycle of the green line consisted of 10 horizontal divisions. The parameter set at the oscilloscope was 2ms of time/div. One complete peak-to-peak of the red line consisted of 10 vertical divisions. The parameter set at the oscilloscope was 50V of volt/div. Each division represented 2ms multiplied by the total of divisions concluded to 20ms. Using the frequency formula, which is frequency = 1/period, the result of the frequency signal was 50Hz. Each division represented 50V multiplied by the total of divisions concluded to 440Vpeak-to-peak. Using the formula of Vpeak, Vpeak = Vpeak-to-peak/2, the result of the inverter circuit was 220 Vpeak AC.

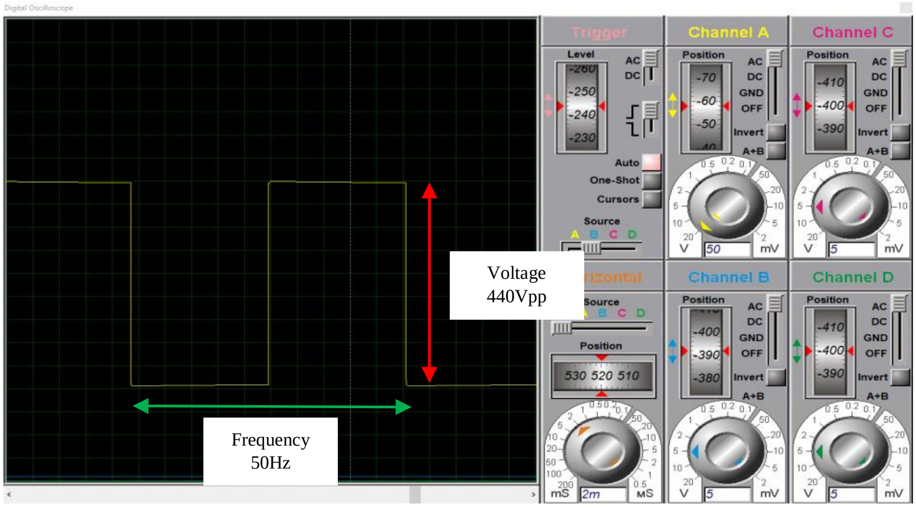
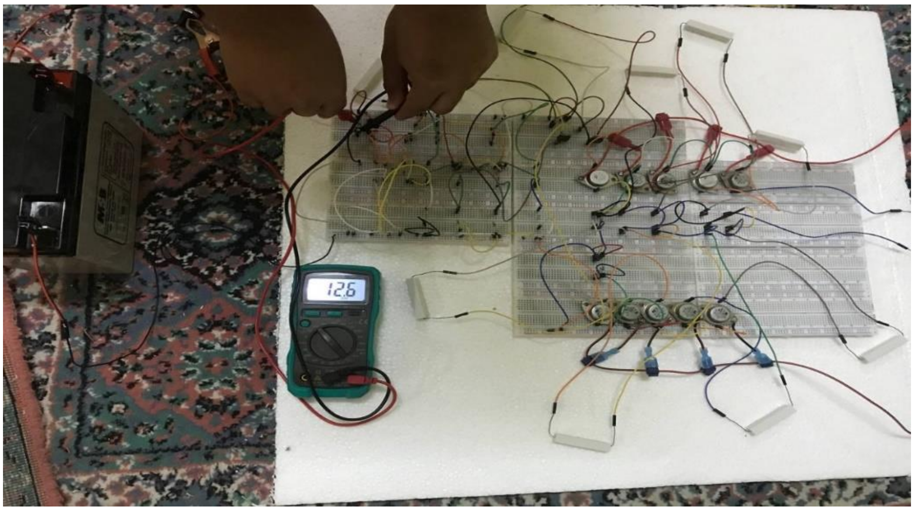
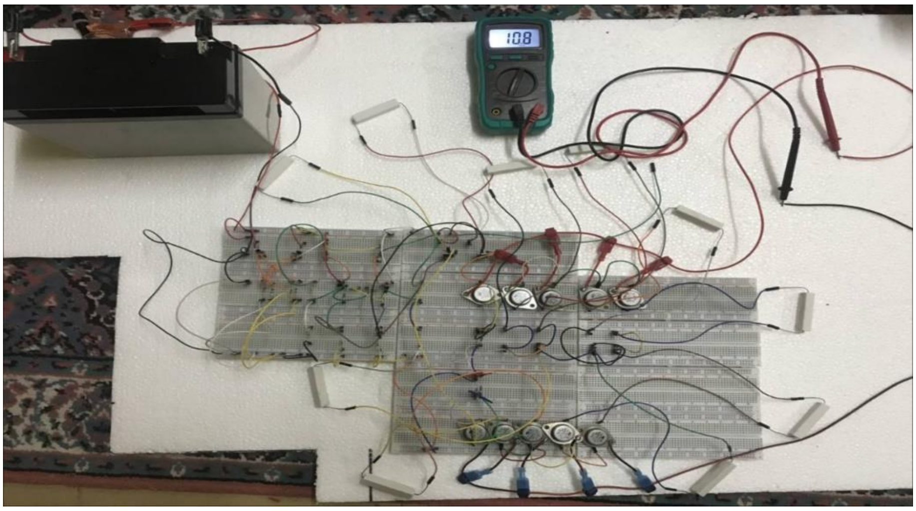


Figure 5: Waveform produced at the output of the inverter circuit

Once the simulation obtained the desired results, the actual hardware inverter circuit was constructed and assembled at the breadboards. The hardware results obtained by measuring the input, switching, and output of the inverter circuit using digital multimeter. Figure 6 illustrates the hardware results of the inverter circuit obtained from the digital multimeter. It is observed that the result value of the digital multimeter taken at the input of the actual hardware setup of the inverter circuit was 12.6V DC. Meanwhile, the result value of the digital multimeter taken at the switching part of the actual hardware setup of the inverter circuit was 10.8V AC.



(a)



(b)

Figure 6: The results obtained from the multimeter (a) at the input of the inverter circuit and (b) at the switching part of the inverter circuit

The overall results outcome of the inverter circuit deduced to determine the percentage error and the accuracy of the inverter circuit. Table 3 illustrates the overall outcome from the theoretical, simulation, and hardware results of the inverter circuit.

Table 3: Overall comparisons between simulation and hardware results of the inverter circuit

	Theoretical Result	Simulation Result	Hardware Result
Input	12.0V DC	12.0V DC	12.6V DC
Switching	12.0V AC	11.5V AC	10.8V AC
Output	220.0V AC	220.0V AC	0V

By comparing the outcome between the simulation and hardware results of the inverter circuit, the accuracy of the measurement was determined by calculated the percentage error for both measurements with the theoretical values. The calculation of the percentage error allowed was defined as an essential indicator parameter to determine the accuracy of the results measurement. Table 4 illustrates the calculation of the percentage error measurement with its accuracy for the inverter circuit.

Table 4: Results of percentage error with its accuracy for the inverter circuit

	Simulation Result		Hardware Result	
	Percentage error	Accuracy	Percentage error	Accuracy
Input	0%	100.0%	5.0%	95.0%
Switching	4.2%	95.8%	10.0%	90.0%
Output	0%	100.0%	100.0%	0%

b. Integrating with Internet of Things (IoT)

To enable the functionality and workability of the IoT to control the lighting system, the results compared with experimental hardware setup and actual hardware setup. Table 5 illustrates the summary results for the integration of IoT to control the lighting system. Based on the results in Table 5, the experimental hardware setup and the actual hardware setup succeeded in integrating the IoT system. The results showed that the number of LED bulbs turned ON depended on the number of relays switched ON. The testing was implemented in sequential order. Thereafter the sequence did not influence the number of LED bulbs turned ON. For example, 3 LED bulbs can still turned ON even though Relay 1, Relay 2, and Relay 4 are switched ON. Then, LED bulb 1, LED bulb 2, and LED bulb 4 will turn ON. The total number of LED bulbs turned ON was still 3.

Table 5: Summary results for the integration of IoT to control the lighting system

Experimental Hardware Setup					Actual Hardware Setup				
Relay 1	**Relay 2**	**Relay 3**	**Relay 4**	**Condition**	**Relay 1**	**Relay 2**	**Relay 3**	**Relay 4**	**Condition**
ON				1 LED bulb turned ON	ON				1 LED bulb turned ON
ON	ON			2 LED bulbs turned ON	ON	ON			2 LED bulbs turned ON
ON	ON	ON		3 LED bulbs turned ON	ON	ON	ON		3 LED bulbs turned ON
ON	ON	ON	ON	4 LED bulbs turned ON	ON	ON	ON	ON	4 LED bulbs turned ON

Apart from that, to enable the functionality and workability of the IoT to measure the lux for a lighting system, the results for actual hardware setup were compared with two different measurement apparatus devices. Table 6 illustrates the summary results for the integration of IoT to measure the lux for a lighting system.

Table 6: Summary results for the integration of IoT to measure lux for a lighting system

	Theory	**Digital BH1750 light sensor**	**Digital lux meter**	**Differences**
One LED bulbs	33lx	40lx	44lx	4lx
Two LED bulbs	65lx	70lx	70lx	0lx
Three LED bulbs	98lx	106lx	108lx	2lx
Four LED bulbs	131lx	149lx	150lx	1lx

By comparing the results obtained from both measurement apparatus: digital BH1750 light sensor and digital lux meter, the accuracy of the measurement was determined by calculated the percentage error for both measurements with the theoretical values. The interpretation of the results accuracy of the measurement apparatus devices deduced from the values of the percentage error. To obtain the theoretical value, the formula equation stated:

$$E = \frac{N \times F \times UF \times MF}{A} \quad \text{Eq.1}$$

where:

N : The number of luminaires
E : The illumination level in lux, lx
A : The total area of the mini-scale of classroom prototype in square meter, m^2
F : The luminous flux in lumen, lm
UF : The utilisation factors
MF : The maintenance factors

Table 7 illustrates the calculation of the percentage error measurement with its accuracy for these two measurement apparatus devices. Based on the accuracy results in Table 7, the accuracy results for each respective LED bulbs utilised to calculate the average values for the measurement accuracy of both measurement apparatus devices. Table 8 illustrates the comparisons of average accuracy for both measurement apparatus devices: digital BH1750 light sensor and digital lux meter.

Table 7: Results of percentage error with its accuracy for measurement apparatus devices

	Digital BH1750 light sensor		Digital lux meter	
	Percentage error	**Accuracy**	**Percentage error**	**Accuracy**
One LED bulb	21.21%	78.79%	33.33%	66.67%
Two LED bulbs	7.69%	92.31%	7.69%	92.31%
Three LED bulbs	8.16%	91.84%	10.20%	89.80%
Four LED bulbs	13.74%	86.26%	14.50%	85.50%

Table 8: Comparisons of average accuracy for measurement apparatus devices

	Average accuracy
Digital BH1750 light sensor	87.30%
Digital lux meter	83.57%

c. Mini-Scale of Classroom Prototype

The project's third objective was to develop a mini-scale prototype consisting of solar PV and integration on the IoT. The project was scaled down to 1:10 in form of mini-scale of prototype to operate the lighting system in the classroom. To operate the lighting system using solar PV system, the processed of charging and discharging operation of the battery played an essential role to ensure the lighting load functioned with maximise capability. To measure the charging hours and obtained the maximum capacity of the sealed-lead acid battery, the solar PV panel was placed and positioned under the sunlight. The sun's ray from the sunlight emitted to the solar PV panel, thereafter the solar PV panel charged the sealed lead-acid battery from 12:00 PM in the afternoon until 7:00 PM in the evening. The data for the charging hours voltage rating of sealed lead-acid battery was tabulated in Table 9. The analysis results shows that the charging operation increase of 0.1V per hour and up to 0.3V during peak hour which was at 12:00 PM in the afternoon until 2:00 PM in the evening.

Table 9: Voltage rating of the battery during charging condition

Time	Charging condition
	Voltage rating
12:00 PM	12.4V
1:00 PM	12.7V
2:00 PM	13.0V
3:00 PM	13.1V
4:00 PM	13.2V
5:00 PM	13.3V
6:00 PM	13.4V
7:00 PM	13.5V

To measure the discharging hours and the minimum capacity of the sealed-lead acid battery, the lighting system of the mini-scale of classroom prototype was ran continuously for 5 hours at 7:00 AM in the morning until 12:00 PM in the afternoon. All four LED bulbs in the mini-scale of classroom prototype turned ON simultaneously to operate the maximum capability of the illuminance level within the LED bulbs. The data for the discharging hours voltage rating of sealed lead-acid battery was tabulated in Table 10. The analysis results shows that the discharging operation decrease of 0.2V per hour and up to 0.3V at one certain period. Figure 7 shows the comparisons between voltage rating during charging and discharging condition against time

Table 10: Voltage rating of the battery during discharging condition

Time	Discharging condition
	Voltage rating
7:00 AM	13.5V
8:00 AM	13.3V
9:00 AM	13.1V
10:00 AM	12.9V
11:00 AM	12.7V
12:00 PM	12.4V

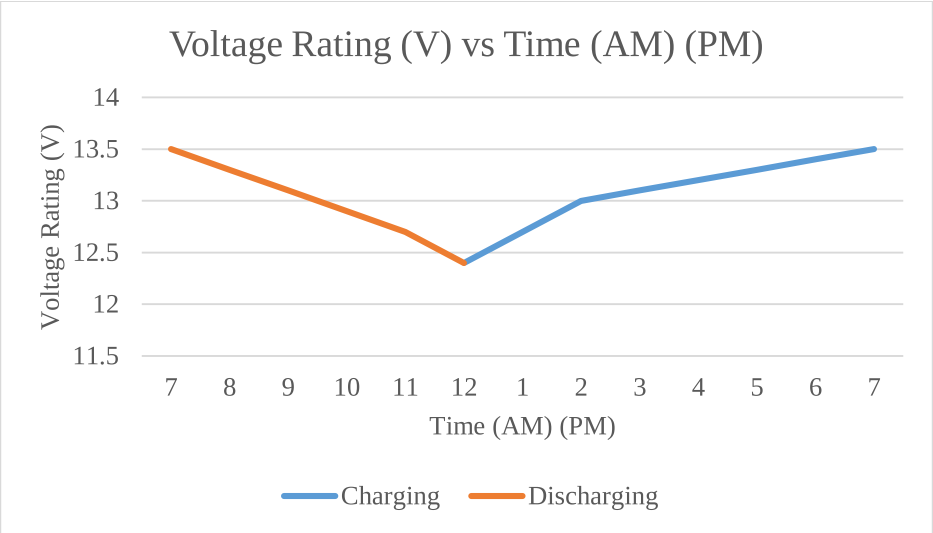


Figure 7: The comparisons between voltage rating during charging and discharging condition against time

4. Conclusion

In conclusion, the smart lighting system for a classroom using solar PV and the Internet of Things (IoT) design has been completed and operated partially per the project's objectives. The project's first objective was to simulate a power converter inverter circuit that can adjust the output voltage from 12V DC to 220V AC using Proteus 8 software. The inverter circuit was unable to accomplish and operate as simulation results because the output of the inverter was inadequate to step up from 10.8V AC to 220V AC. The power conversion mechanism succeeded as the multimeter showed the output at the switching part of the power converter inverter circuit displayed 10.8V AC from the battery supply of 12V DC. Furthermore, the second objective was to control the lighting system and monitor the illuminance level by accessing a smartphone using Blynk. The Internet of Things (IoT) system succeeded in integrating into the lighting system as the operationality can control and monitor wirelessly using a smartphone. Furthermore, the smartphone can control and switch in, encoded ON and OFF the LED bulbs in the mini-scale classroom prototype using the widget button from the interface of the Blynk App. Moreover, the smartphone also can monitor the illuminance level of the lighting system in the mini-scale classroom prototype using a level gauge from the interface of the Blynk App. Both the IoT system able to integrate into one device so the user can control the lighting system and monitor the illuminance level at the same time. Finally, the third objective was to develop a mini-scale prototype consisting of solar PV and integration on the IoT. The mini-scale of the classroom prototype can articulate within processes of the

IoT system as well as the implementation of the solar PV system. The mini-scale of the classroom prototype used solar energy to charge the sealed lead-acid battery through the solar charger controller. The integration of the IoT system also can operate successfully in the mini-scale of classroom prototype.

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