Evolution in Electrical and Electronic Engineering Vol. 3 No. 1 (2022) 477-489

EEEE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Development of UPS for Pedestrian Traffic Light Using Solar- Piezo and Grid Power Supplies

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DOI: https://doi.org/10.30880/eeee.2022.03.01.054
Received 15 February 2022; Accepted 25 May 2022; Available online 30 June 2022

Abstract: Operating the traffic light for pedestrian crossing consume lots of electricity. As non-renewable energy is run out of sources, and the conventional method of generating electricity causes an impact on climate change, the idea of harvesting the energy from environmental sources has become significant. Therefore, this study aims to develop the uninterruptable power supply for the pedestrian crossing using the harvesting method of the solar photovoltaic and piezoelectric transducer. Specifically, it collects the energy from sunlight and vibration at the crossing road and turns it into electricity. In context, the photovoltaic technique converts the photons into electricity when there is enough sunlight while the piezoelectric technique is converting the presence of vibration on the road into electricity. To develop the UPS for the pedestrian traffic lights, the backup supply from the grid is combined. A charge controller for the UPS unit is designed to control the integrated supply of the harvested energy and grid. For the purpose of the store and supplying energy to the battery and load, the charge controller was designed using DC to DC converter which controls by the PWM technique. The simulation result showed a small difference in the output voltage and current of the converter compared to the calculation. The measurement result showed the PV module successfully charge the battery that half in target capacity while the piezoelectric transducer only pushes half of the generated charge into the battery. On that basis, the factor of weather and the mechanical vibration should be considered when determining the sizing of the harvester equipment

Keywords: UPS, Pedestrian traffic Light, Photovoltaic, Piezoelectric Transducer

1. Introduction

Electrical energy has always been a crucial part of a country's industrialization and socio-economic growth. But, generating electricity by burning fossil fuels such as natural gas, oil and coal cause the greenhouse gas emissions, environmental degradation, climate change and depletes the reserves of

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fossil fuel which could put the county at risk of market volatility and supply disruption in the future [1, 2]. For over the past few years, energy harvesting using solar photovoltaics increasingly become a popular option among Malaysians as the irradiation level of the sunlight in this country are quite high compared to other countries with an average of 1000W/m [3]. Another promising method for creating electricity that also gets a lot of attention from many researchers is the use of piezoelectric material to convert mechanical energy directly into electrical energy [4]. Even though this technology is still young, it offers some prospects for the future. When placed the piezoelectric transducer in an area where vibration frequently exists, it has the potential to produce enough electrical energy [5].

The ability of solar photovoltaic and piezoelectric technology in producing electricity can guarantee the cleanliness and sustainability of power generation. However, it could be an unreliable source when used alone due to the intermittent presence of vibration and solar irradiance [6]. After all, when these two sources are combined, they might compensate for the differences. And electricity from these two sources seems able to accommodate our electrical need usage. Thus, this study aims to develop a power supply for pedestrian traffic lights using piezoelectric, and solar photovoltaic technology and the excess energy generated will be stored in the battery for later use. As the application of this study is at a crucial and dangerous area, a backup supply from electric grid will also be integrated so the fluctuation of the energy or power outage can be avoided.

1.1 Problem Statement

Pedestrian traffic light get supply from electrical power grid to operate its system. The electrical power required to light up this traffic light is around 2.4kWh to 3.6kWh per day for incandescent lamp and around 288Wh to 480Wh per day for the LED array [7]. Even worst, the power consumption increases with increasing number of pedestrian traffic lights. As the non-renewable energy resources is running out and their climate impact has become major scientific issues, the importance of harvesting waste energy from surrounding to generate electricity should be concern by mankind. Hence, development of supply unit for pedestrian traffic light from environment energy like sunlight and vibrations on the crossing road can help in reducing dependency toward the used of electricity from the conventional method. However, in the events of power outage due to limited power generations cause by intermittent vibration and absence of sunlight will jeopardized the safety of the road user. So, for tackle this problem, excess energy harvested by this system will store in battery for later use and this system will be integrated with backup supply form electrical grid.

1.2 Objective of the Study

The objective of this project are to design a controller for controlling the integrated supply from power grid and hybrid of piezoelectric and photovoltaic; to develop a prototype of a UPS system that enable to powering up the pedestrian traffic light using a hybrid photovoltaic, piezoelectric, and grid power supplies; and to test the working condition of the prototype based on the functionality in generating, storing, and supplying electrical energy to pedestrian traffic light for the targeted period.

1.3 Scope Project

The scope to be covered in this project are energy from hybrid photovoltaic and piezoelectric use as supply for the pedestrian traffic light and backup supply is from electric grid; the charge controller is design to step down the input of 18V from solar to 13V, step up the input of 3V DC from piezoelectric transducer to 13V, and to control the sources of traffic light energy supply; and this project only develops a small-scale prototype of the UPS system. Piezoelectric transducer is design for 1 wooden board that are 1sq ft in size, the load use for the prototype is halogen lamp with 55W power, and the solar panel power is 50Wp. Arduino UNO is used as MCU of the charge controller and the biomorph ceramic piezoelectric with 35mm diameter will be used.

2. Materials and Methods

This section discusses about method and process of design and development of uninterruptable power supply for pedestrian traffic lights using hybrid piezoelectric and photovoltaic. The simulation software, hardware component and relevant calculation are also explained in this section.

2.1 Process of the UPS

The main supply of the pedestrian traffic lights is coming from harvested energy (photovoltaic and piezoelectric transducer). The voltage produced by the piezoelectric transducer and photovoltaic will be modified to 13V DC using DC to DC converter before supplying to the load and battery. Due to the variable value of the generated voltage, the duty cycle of the converter also changes. So, to obtain the fixed voltage output, the MCU unit will be used to measure the generated voltage and send the corresponding PWM signal to the switching device of the converter. During peak hours, the generated energy from the PV and PT will be handling the load and charging the battery over its maximum capacity. But if the harvested energy is detected below than the acceptable range, the battery will take over to maintain the load. In a situation where the SOC of the battery is below 20%, the MCU unit will be connecting the load to the power grid and disconnecting the harvested energy system simultaneously. During this time, the harvested energy will only charge the battery until the SOC of the battery reach 50%. Then it will resume handling the load. Figure 1 shows the block diagram of the UPS system.

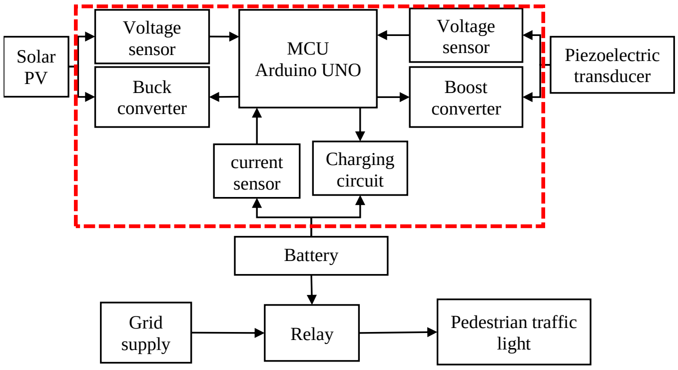

Figure 1: Block diagram of the UPS system

2.1 Power & energy consumption of the pedestrian traffic light

Whenever the pedestrian traffic light operates, it took 90 second to complete its operating sequence. This traffic light is estimated to be use by the pedestrian 8 times an hour and it is assumed to be out of operation from 12 am to 6 am. So, the total, this traffic light will operate about 4 hours a day. The total energy consumed by the pedestrian traffic light is calculated in Table 1.

Table 1: Total energy consume by pedestrian traffic light for a day

No.	Item	Operating voltage (V)	Operating power (W)	Qty	Total connected load (W)
1.	300mm Static Pedestrian LED Traffic Light:	DC 12	3	2	6
2.	200mm RYG Cobweb Lens LED Traffic Light	DC 12	7	2	14
3.	300mm Full Ball LED Traffic Light	DC 12	15	2	30
		Total power consumes (W)			50
		Total Energy use per day (Wh)			200

2.2 Battery Sizing

Energy produced by hybrid PT and PV will be supply directly to the pedestrian traffic light and the excess energy will be stored in battery for later use. To ensure the availability supply, the battery capacity should be at least the same as the total energy consumed by the load. It needs to be noted here, by avoiding the battery from over-discharge can be extended the lifespan of the battery. So, the battery capacity for this pedestrian traffic light will have 20% extra capacity. Voltage rating of all LED lamp are 12V hence 12V battery is a perfect match to be used. Therefore, the battery capacity should be 240Wh or equivalent to 20Ah. This project used SLA battery as it has the ability to operate in a low to a maximum temperature of 50 degree Celsius, which make it compatible to be used and placed at the traffic light area.

2.3 Photovoltaic Module Sizing

A monocrystalline solar photovoltaic module has been used in this project. The highest efficiency energy conversion is the reason for this panel being chosen over the other type. Besides, the size of the panel module that is placed on the traffic light poles was so considered. Other type of panel requires large space in producing the same amount of electrical energy. For this project, the PV module will be placed on the traffic light pole, and it's expected to accommodate 100% of the energy needed by battery capacity. The average peak hours of sunlight in Malaysia is 6 hours a day. The size of the module can calculate using Equation (1).

$$P_{pv} = \frac{E}{\eta * h_p} \qquad \textit{Eq. 1}$$

Therefore, the suitable size of the PV module for producing sufficient energy to the load system in this study is 50W.

2.4 Piezoelectric Array Design

The piezoelectric is placed under the asphalt layer of the crossing road so it can produce electricity whenever a vehicle or human passing on that road. To do that, a preliminary experiment needs to be conducted to find out the ability of a single disc piezoelectric in producing electrical energy, further deciding the piezoelectric arrangement and design for this project

2.4.1 Single Disc Test

The relationship between force and energy produced by a single disc of piezoelectric can be determined by dropping the different weights of an object from any height on the piezoelectric disc. The generated AC signal is then will be rectified useful-bridged rectifier before storing in the capacitor. The voltage difference measured on the capacitor due to the different weights applied is then used to calculate the produced energy. The energy produced can be calculated using Equation 2.

$$E = \frac{1}{2} C \Delta V^2 \qquad \textit{Eq. 2}$$

This experiment used three different weights of the coin, PZT biomorph piezoelectric with 35mm diameter and 220µF capacitor. The results of this experiment are recorded in Table 2.

Table 2: Single disc test result

Coin	Weight (g)	Force (N)	Initial Voltage	Final voltage	ΔV	Energy (nJ)
10¢	2.82	0.0277	26.9mV	42.3mV	15.4mV	26.09
20¢	4.18	0.0410	69.0mV	93.2mV	24.2mV	64.42
50¢	5.66	0.0555	91.0mV	163.1mV	72.1mV	571.53

The result shows that the heavier object gives higher force to the piezoelectric surface further producing the higher the voltage and energy. A previous study shows that connecting piezoelectric in series produces a higher amplitude of the AC voltage. However, if one of the discs is not pressed, the series will not produce any voltage. According to [8], the highest the force applied, the highest the voltage generated but the increment of the voltage becomes less steep as the force applied is increased. Due to the average generated voltage of 5V being sufficient to push charge into the 3.7V battery, thus this study has decided to connect all transducer discs in parallel.

2.5 Charge Controller Design

The aim of this project is to develop a UPS for pedestrian traffic lights using hybrid PV & PT. Therefore, the constant voltage technique of battery charging is presented in this work to prevent the battery from being overcharged. Also, the defined voltage management in the battery charging techniques is required to keep the expected battery lifespan. As the battery is the main supply for this project, so the charging voltage for cycle use is set at 13V. To obtain the constant voltage of 13V, this project used the DC-to-Dc converter. By measuring the voltage produced by the photovoltaic and piezoelectric, the duty ratio of the converter can be controlled. The design part of the charge controller is explained further below.

2.5.1 Voltage Measurement

Measurement of generated voltage from the solar panel is using Arduino Uno microcontroller. Build in of Analog Digital converter (ADC) in this microcontroller make it suitable to use in this project. The ADC is a component that accepts an analog input and produces a digital output. However, the maximum input voltage that can feed into Arduino UNO is 5Volt maximum. Measuring the maximum voltage of 18V from the PV module can be impractical. To overcome this, the voltage divider can be used. A simple circuit construction using two resistors increases the input impedance which means that the measurement device with load down the circuit it trying to measure and distort the reading. One end of the series connection is connected to the analog pin of the Arduino and the other end to the ground. A voltage proportional to the measured voltage will appear at the junction of two resistors. The output voltage can be found using this formula.

$$V_{out} = V_{in} \cdot \frac{R_2}{(R_1 + R_2)} \qquad \text{Eq. 3}$$

2.5.2 Buck Converter

Buck converters have the ability to reduce DC voltage by altering the duty cycle using a semiconductor switching process which makes it useful for lowering the output voltage of a solar photovoltaic system during peak hours. Figure 2 depicts the buck converter circuit.

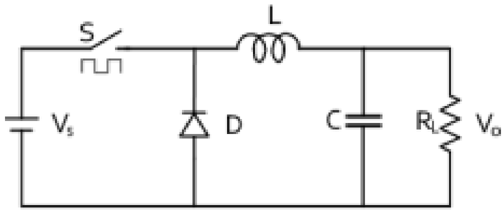

Figure 2: Buck converter circuit

When the switch is open, the capacitor and inductor provide energy to the output.

$$V_L = -V_o \quad \textit{Eq. 4}$$

$$V_L = L\frac{di_L}{dt} \quad \textit{Eq. 5}$$

$$\frac{di_L}{dt} = \frac{-V_o}{L} \quad \textit{Eq. 6}$$

The changes inductor current is:

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} \quad \textit{Eq. 7}$$

$$\Delta i_L(open) = \frac{(-V_O).(1-D)T}{L} \quad \textit{Eq. 8}$$

When the switch is closed, the diode is biased in the other direction. The output is isolated, and the input gives energy to the inductor. The inductor voltage is

$$V_L = V_s - V_o \quad \textit{Eq. 9}$$

$$\frac{di_L}{dt} = \frac{V_s - V_o}{L} \quad \textit{Eq. 10}$$

The changes inductor current is:

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} \quad \textit{Eq. 11}$$

$$\Delta i_L(closed) = \frac{(V_s - V_o)DT}{L} \quad \textit{Eq. 12}$$

The inductor value, average current and maximum current of the inductor can be determine using equation below:

$$L = \frac{(1-D).R}{2f} \quad \textit{Eq. 13}$$

$$I_L(avg) = I_o = \frac{V_O}{R} \quad \textit{Eq. 14}$$

$$I_L(max) = I_l + \frac{\Delta i_L}{2} \quad \textit{Eq. 15}$$

2.5.3 Boost Converter

The component of boost component is same as buck converter but having a different arrangement. This converter is used to step up DC voltage from one level to another level. Voltage produces by piezoelectric is proportional to the applied force. So, this convertor is suitable to be used in this project to step up the generated voltage before charge the battery. Circuit of the boost converter is as illustrated in Figure 3.

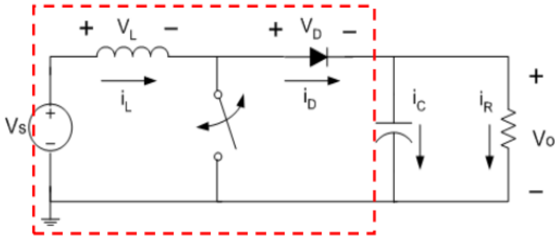

Figure 3: Boost converter circuit

When the switch is open, the diode is forward biased which allow inductor provide energy to the output.

$$V_L = V_S - V_O \qquad \textit{Eq. 16}$$

$$\frac{di_L}{dt} = \frac{V_S - V_O}{L} \qquad \textit{Eq. 17}$$

The changes inductor current is:

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} \qquad \textit{Eq. 18}$$

$$\Delta i_L(open) = \frac{(V_S - V_O)}{L}.(1-D)T \qquad \textit{Eq. 19}$$

When the switch is closed, the output is isolated, and the input gives energy to the inductor while the output get energy from the capacitor. The inductor voltage is

$$V_L = V_s \qquad \textit{Eq. 20}$$

$$\frac{di_L}{dt} = \frac{V_s}{L} \qquad \textit{Eq. 21}$$

The changes inductor current is:

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} \qquad \textit{Eq. 22}$$

$$\Delta i_L(closed) = \frac{V_s.DT}{L} \qquad \textit{Eq. 23}$$

The inductor value, average current and maximum current of the inductor can be determine using equation below:

$$L = \frac{D(1-D)^2.R}{2f} \qquad \textit{Eq. 24}$$

$$I_L(avg) = \frac{V_S}{(1-D)^2.R} \qquad \textit{Eq. 25}$$

$$I_L(max) = I_L + \frac{\Delta i_L}{2} \qquad \textit{Eq. 26}$$

3. Results and Discussion

The circuit of the charge controller for this project has been designed and simulated using Proteus software. The circuit has been simulated under three condition which are: load is being handled by the hybrid energy and the battery; the load is transfer from the battery to the grid supply; and the battery handle the load back after it being charged up to 50% capacity.

3.1 Design of Charge Controller

The circuit of charge controller for this project as shown in Figure 4. The circuit consisting of several part. Description of the circuit block is shown in Table 3.

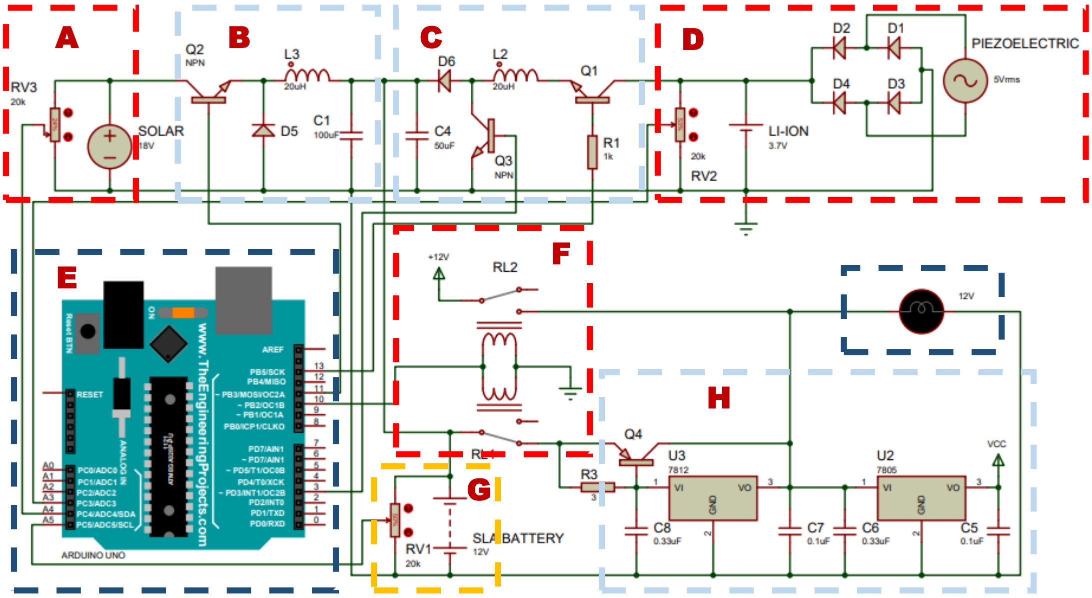

Figure 4: Charge controller circuit

Table 3: Description of the block

A	Solar Photovoltaic	F	Transfer switch
B	Buck converter circuit	G	Battery
C	Boost converter circuit	H	Regulator for output voltage
D	Piezoelectric transducer	I	Load
E	Microcontroller unit		

A battery SOC was estimated using coulomb counting method. This method estimates the charge stored in the battery by monitoring the flow of the current. To determine the SOC of the battery using this method, variable resistor is used to measure voltage at the difference point. The voltage difference between two points are then is converted into the current. During off condition of the lamp, the RES only charge the battery. When the lamp is on, it will draw 4.58A current. Since the current produced from the RES is around 2A is small than the load current, the RES and battery will supply power to the load. Mathematically, the current from RES, and the drawn current to the load will be compare and calculate by the Arduino, further estimate the SoC of the battery. When the SoC of the battery is detected below than 20% from its capacity, the Arduino will transfer the load to the grid (label as +12V) by sending the signal to the Relay.

12V Voltage regulator circuit is connected between the battery and the load. Since the load requires 4.58A each time it operates and the IC regulator can only draws an output current of 1.5A maximum, the P-type transistor Q4 is used to increase the current output without distort the circuit. The output 5V from the LM7805 (+VCC) is for supplying power to Arduino.

The buck converter and boost converter in the controller circuit is designed depending on the constant voltage charging technique. The PWM signal from Arduino that correspond to the voltage from piezoelectric and PV module will be send to the gate pin of MOSFET to control the switching frequency. The pilot parameter and the calculated value of the component in these two converters is the list in Table 4 and Table 5.

Table 4: Pilot parameter of the DC-DC converter

Parameter	Value (Buck)	Value (Boost)
Max. Input Voltage, V_S	18V	3V
Max. Input current, I_S	2.78A	2A
Output Voltage, V_o	13V	13V
Switching frequency	31kHz	31kHz
Max input power	50W	6W
Voltage ripple	1.5%	1.5%

Table 5: Calculated value of the component and output signal

Parameter	Value (Buck)	Value (Boost)
R	3.38Ω	28.17 Ω
L	10µH, 7A	10µH, 4A
C	220µF, 16V	100µF, 16V
Io	3.85A	0.46A
I_L (max)	6.58A	3.88A
I_L (avg)	3.85A	2A

3.2 Development of a UPS

The total power of the LED traffic light is 50W. For the prototype purpose, the load is substitute with one unit of 55W halogen bulb. 12V, 12 AH SLA battery used to supply stored energy and supply electricity to the bulb. When MCU detect the SOC of the battery is below that 20%, it operates the relay module and transfer the load to the Grid, and let the battery charged by the photovoltaic and piezoelectric. When the battery SOC has reached 50%, the MCU turn off the relay module and transfer back the load to the battery. Figure 5 depict the prototype of the UPS system.

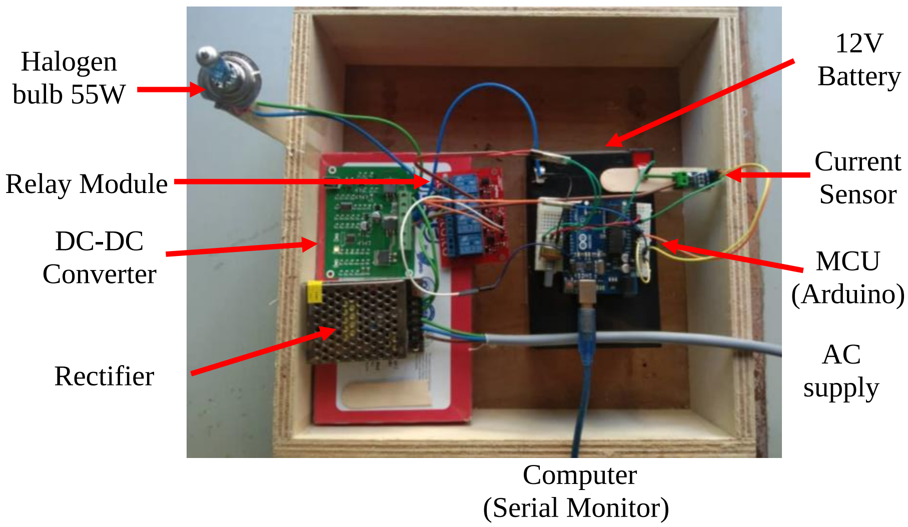

Figure 5: Hardware connection of the UPS

3.3 Prototype Functionality Test

3.3.1 Discharge of The Battery

Discharge characteristics graph of battery for 90 second with drawn current of 3.72A is depicted in Figure 6. When the battery is connected to the halogen bulb, the terminal voltage drops from 12.45V to 12.3V and fluctuate in that level. However, when the load is disconnected, the terminal voltage increases and return to original level after 5 minutes. Measuring the SoC of the battery by direct measured to the terminal battery during unload condition is not practical because voltage of the battery take a long time to stable.

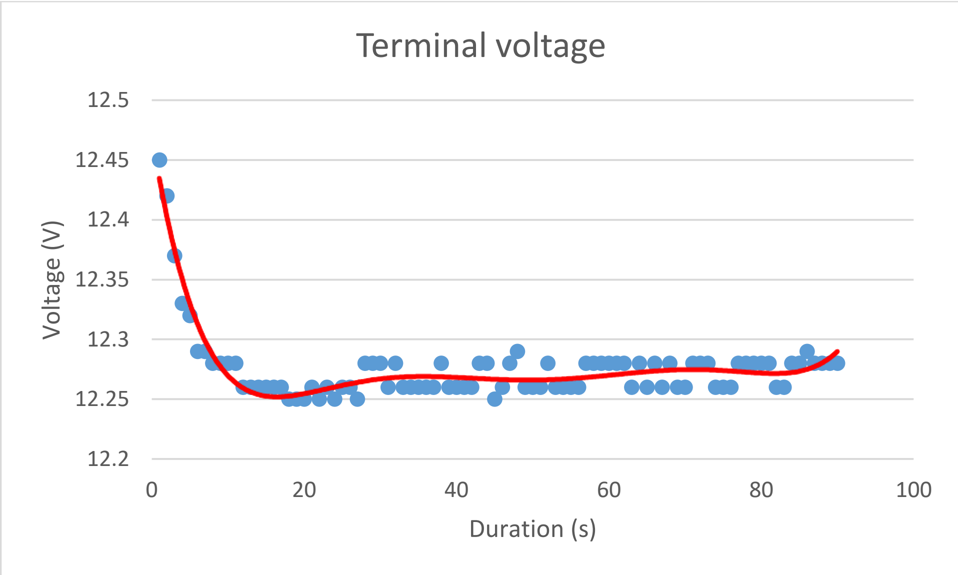

Figure 6: Discharge Characteristics for 0.31C Over 90 second

3.3.2 Harvesting energy from solar PV

The measurement of photovoltaic module under short circuit condition has been taken from 10.00am until 5.00pm with the average temperature of the day is 36 °C. The reading has been taken using digital Multimeter for every 15 minutes. The graph of the average measured data of the photovoltaic module per hour is as shown in Figure 7.

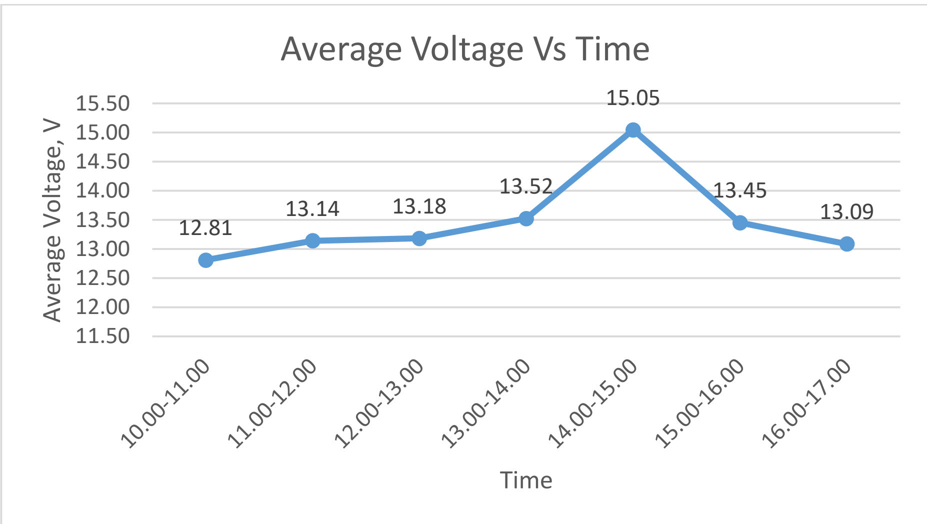

Figure 7: Average short circuit voltage, V_{sc} of photovoltaic versus time

The graph shows that the highest average voltage produced is from 2.00pm to 3.00pm with the reading of 15.05V. The result also shows that the generated voltage throughout the measured period is above 12V. Meaning that the PV module can push charge into the battery.

The current produced by the PV module is also measured. ACS712 current sensor has been used for measuring the produced current. The sensor is connected in between the PV module and the battery. Measurement of the current that flow from the module to the battery has been measured for every second, the reading is recorded and display in Serial Monitor of Arduino IDE software. Figure 8 shows the graph of the average current per minutes from 10.15am to 3.06pm and charging graph of the battery.

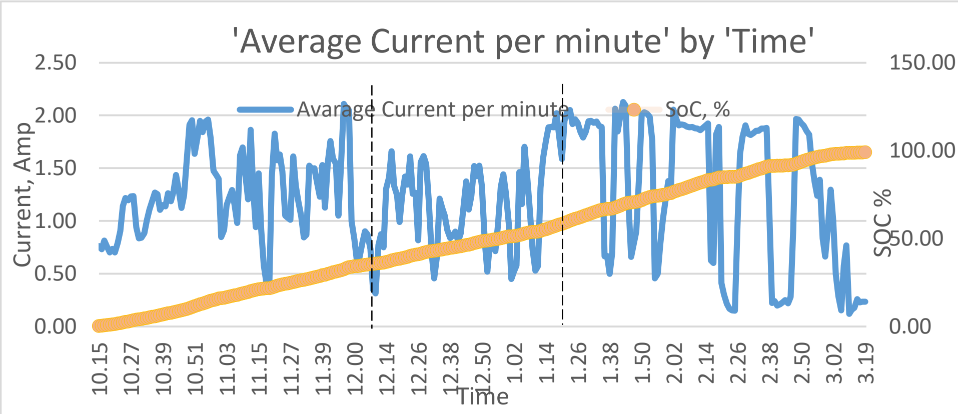

Figure 8: Average current from PV module & SOC of the battery

The average current produce by the PV module is 1.16Amp. The up and down of the current reading is influence by the dim or hot of the sunlight on the measurement day. Graph in figure 8 shows the current measured is low from 12.04noon to 1.16pm. In response, the rate of charging become slow and the SoC graph during that period is show less steep. Battery that being charge by the PV module during measurement is 12V, 12AH SLA. And this battery took about 5 hours to reach SoC of 100%. The capacity of the battery that should be charge by the same size of PV module is 20AH. But for reduce the cost of this study, 12Ah battery is used instead. However, the obtained result has driven to new hypothesis where the size of PV module used in this study is not sufficient to charge the 20Ah battery to it full capacity

3.3.3 piezoelectric transducer testing

Measurement of piezoelectric has been conducted. The voltage signal when the array is trampled few times with time interval of 1 second by a person that having a weight of 49kg is shown in Figure 9.

Figure 9: Voltage Signal of Piezoelectric Transducer

When the force is applied on the piezoelectric, it produces AC signal. Result of compression and expansion on the transducer surface, the positive and negative half cycle is produced respectively. The result also shows the peak voltage due to expansion is higher than the peak voltage of compression in AC.

To enable the generated energy to be stored in the battery, the transducer is then rectify using full bridge rectifier. The voltage signal after rectification is shown in Figure 10.

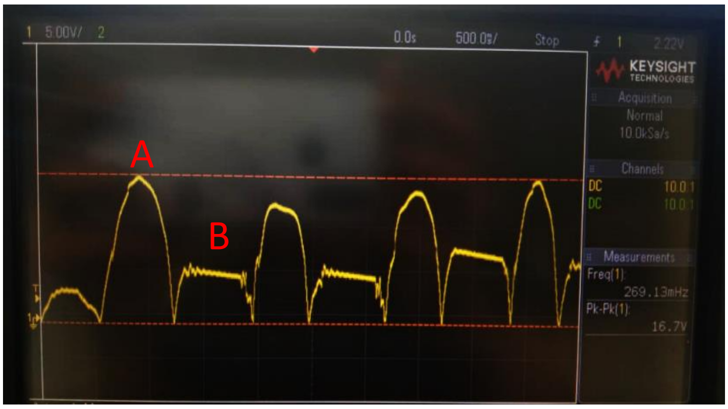

Figure 10: Voltage Signal After Rectification

Half cycle with label "A" is the result of compression and label "B" is the opposite. The compression produces 16.7V while the expansion produce half of it. But due to the volt/div of the oscilloscope is 5Vvolt/Div, so the actual voltage produced is only 3.34V for compression and 1.67V when the force is lifted. Since the lowest terminal voltage of the li-ion battery during zero capacity is 3V, so only the charge that produced due to compression will store in the battery. Since this test is not conduct with weight of the vehicle, the hypothesis that can be made is that the array will produce higher voltage amplitude if the force due to vehicle movement is apply. To conclude, when the rectified piezoelectric voltage is higher than the open circuit voltage of the battery cell, it will charge the battery.

4. Conclusion

The objective to design and develop the prototype of a UPS system for the pedestrian traffic lights using piezoelectric and photovoltaic with grid integrated has been achieved. The simulation result has validated the design. The difference of the design and the simulation result shows not much different. Besides, the testing on the working condition of the prototype is also has been completed. Apparently, the combination of hybrid photovoltaic and piezoelectric with the grid supply have successfully provide an uninterruptable power supply to the pedestrian traffic lights.

Acknowledgement

The authors would like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

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