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Development of Standalone PV Led Light System using Adruino

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ABSTRACT

This paper presents a simple and smart standalone PV system for LED light by using Arduino. The charging, discharging of battery and on-off LED was control by an algorithm. The proposed control algorithm has 3 modes to cater the switching between LED (load) and battery (energy storage). First mode (default mode) connected directly to the LED light, second mode focus on charging of battery where the LED is shut off and the third mode represent discharging of battery which the LED is now supplied by battery directly and PV is in off conditions. MATLAB/Simulink was used for simulation studies. Hardware or lab prototype was done to validate the standalone PV system for LED in real time operations. 2 analyses were done including steady state and dynamic operations. Dynamic operations represent by changing of modes or switching between LED and battery. From both simulation and hardware results, the proposed algorithms with 3 different modes works well in real time with 1.5 V and 0.4 A overshoot with respond time of 3 ms.

Key words : Photovoltaic, DC/DC Converter, Arduino Microcontroller, Battery, LED light.

1. INTRODUCTION

Solar energy is very useful since the non-renewable energy such coal, natural gas and oil are reducing rapidly due to increasing demand from manufacturing and automotive sectors. Due to Malaysia weather conditions, solar energy is suitable to be as a back-up energy supply due to the concern about the pollutions, global warming and greenhouse effect [1]-[3]. Solar PV system was divided in to three type systems, grid connected, standalone and hybrid system. Among these 3 types, standalone PV system is the most popular as compare to other which this type mostly used in rural or isolated areas and for certain loads. Standalone PV system is a system which operates independently and it is off grid [4]. It could assist for conserving the environment by using solar energy in locations without access to electricity and act as an indispensable electricity source for remote areas [5]. There are several advantages of the standalone PV system such as useful in the place with no grid access, self-sufficient for own energy demand and unaffected to grid failures [6]. While the disadvantages are the cost to implement the PV cell is high and it is variable energy source which is dependent on the sun and PV modules efficiency [7].

Basically, standalone PV system is implement with converter to supply DC and/or implement an inverter to supply AC required by the loads [8]. The types of DC/DC converter used in this paper is a step-up converter or called as boost converter. Thus, increase the voltage level by using boost converter can overcome power losses, support a higher load and decrease number of PV modules array in a system [9]. Usually in a typical standalone PV system, battery act as energy storage to provide back-up or second energy sources to the load during night and PV incapability to sustain energy demand by the loads. Control algorithm act as the 'brain' of the system that implemented using a microcontroller device such as Arduino. Arduino basically a simple microcontroller that contain a processor, memory and input and output pin that can be control by user (often called GPIO - General Purpose Input Output Pins) [10]. The switching between loads and energy storage elements done by using proper control algorithm. The algorithm will make sure the system work properly and efficiently depends on the user demand either to charge battery or directly used the loads.

Therefore, this paper basically aims to design a simple control algorithm for standalone PV LED light system using Arduino, and to analyses the performance of the system. Section II covers literature reviews of solar PV technology, DC/DC Boost Converter, Arduino, Lead Acid Battery, and LED light. Sections III meanwhile focus on methodology of building the smart standalone PV LED light system using Arduino. Section IV discuss more on the experimental and simulations results and Section VI concludes the overall paper.

2. LITERATURE REVIEW

2.1 Solar PV Technology

In general, a PV system consists of a PV array module which converts sunlight to direct-current (DC) electricity, a control system which regulates battery charging, converters and the loads. Sizing of the PV array, inverter, converter and battery bank for a stand-alone PV system is another important part of system design [11],[12]. Solar PV technology growing in rapid pace as it is very important to meet the demand of the energy industries. There are 3 generations of PV modules technology starting from first generation which focus on crystalline silicon modules continue to the second generation which focus on Thin Film modules and lastly the third generation that focus on the organic technologies [13]-[16]. Table 1 show the classification of solar PV modules technology.

Table 1: Types of PV module technology

Generation	Type	Advantages	Disadvantages
First Generation (Crystalline Silicon Cells)	1. Monocrystalline 2. Polycrystalline Amorphous Silicon Cell	High efficiency	Expensive
Second Generation (Thin-Film Solar Cells)	1. Amorphous Silicon 2. Cadmium Telluride Copper-Indium-Selenide(CIS) and Copper-Indium-Gallium(GIS)	Flexible solar panel	Less efficient
Third Generation	1. Dye Sensitised 2. Perovskite(cell) Organic(OPV)	Higher efficiency Less expensive	Not widely used Still on developing

2.2 DC/DC Boost Converter

DC/DC boost converter is a converter where it is function to step up the input voltage to higher output voltage [17],[18].In a typical standalone PV system, boost converter act as the main bridge between loads/battery and PV modules. This converter basically effect the efficiency of the overall PV systems. Figure 1 show the circuit diagram of PV boost converter.

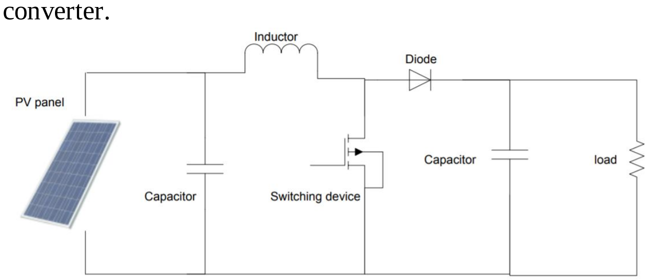

Figure 1: Circuit Diagram of PV Boost Converter

2.3 Arduino

The Arduino is an open-source microcontroller board based on the Microchip ATmega328P microcontroller [19]-[20]. The board has 14 digital pins, 6 analog pins, and programmable with the Arduino IDE (Integrated Development Environment) via a type B USB cable [10]. It can be powered by a USB cable or by an external 9V battery, though it accepts voltages between 7 and 20 volts.

2.4 Lead Acid Rechargeable Battery

Lead acid battery is very popular because of its advantages such as cheaper, convenient and can be applied to many applications especially PV. It is widely used in the automotive sector and navigation system [21],[22]. It has the effect of the self-discharge phenomenon. It is caused by the electrochemical reactions between the active plate, the electrolyte, the separator, the current collector and other components in the cell and by leakage of the ohmic current [23].

2.5 LED Light

LED light are suitable to be applied to a lighting system powered by the renewable energy such as solar energy [24]. It is becoming a highly demand in the market because many fields or sectors are applied LED light on their devices and tools. Traffic light and signalling are examples of application of LED light [25].

3. METHODOLOGY

3.1 Control Algorithm

The control algorithm was built with 3 modes. Figure 2 below shows the overall flowchart of the algorithm. Output voltage from boost converter was noted as V_b, V_1 was for the first voltage sensor and V_2 for second voltage sensor. To switch from one mode to another mode, relay switches was used and to control the LED light. The system was divided into three modes. The modes of the system were listed below:

- Mode 1 (LED light up/default): This mode was default mode of the system. LED will get the voltage supply directly from the PV source through boost converter. User only need to turn on the switch in order to light up the LED.
- Mode 2 (Charging battery): In this mode, the source from PV through boost converter will charge the lead acid battery. This happened when user turn off the switch (turn off LED). Voltage sensor V_2 will sense a voltage reading which is lower than the value set. So, it will send signal to microcontroller to trigger the relay switch to connect battery bank with the PV source. Then the lead acid battery will be in charging mode.
- Mode 3 (Discharging battery): This mode focus on lead acid battery to light up the LED. When there was no sunlight, at bad weather or at night. Voltage sensor V_1 will sense the voltage reading at the output of boost converter. If the reading was lower than the set value, it will give the signal to microcontroller to trigger relay switch for the battery turn to discharge mode.

3.2 Simulation and hardware development

In the software development, this part was divided by two which are the circuitary part and programming part. Circuitary and simulation was done by using Matlab/Simulink. Figure 3 show the circuit diagram of the overall system. The duty cycle of the boost converter was controlled by using Proportional-Integral (PI) controller. It is popular due to ability to maintain exact set point. The input voltage of the PV is about 18 V with duty cycle of the boost converter set around 0.25 with switching frequency of 20 kHz. Table 2 show the characteristics of the Solar PV SPM050-P. The second part of software development was the coding for microcontroller. A C programming language was used. Figure 4 show the program algorithm for measuring the voltage value from voltage sensor. It was important to know the value of the voltage because it will determine which mode will work. Figure 5, 6, and 7 show the program algorithm for Mode1, Mode2 and Mode 3 of the system respectively. Figure 8 show the circuit diagram of connected hardware part of overall system.

Table 2: PV characteristic SPM050-P

Specification	Values
Maximum Power	50 W
Maximum Voltage	18 V
Maximum Current	2.78A
Open Circuit Voltage	21.80 V
Short Circuit Current	2.97 A

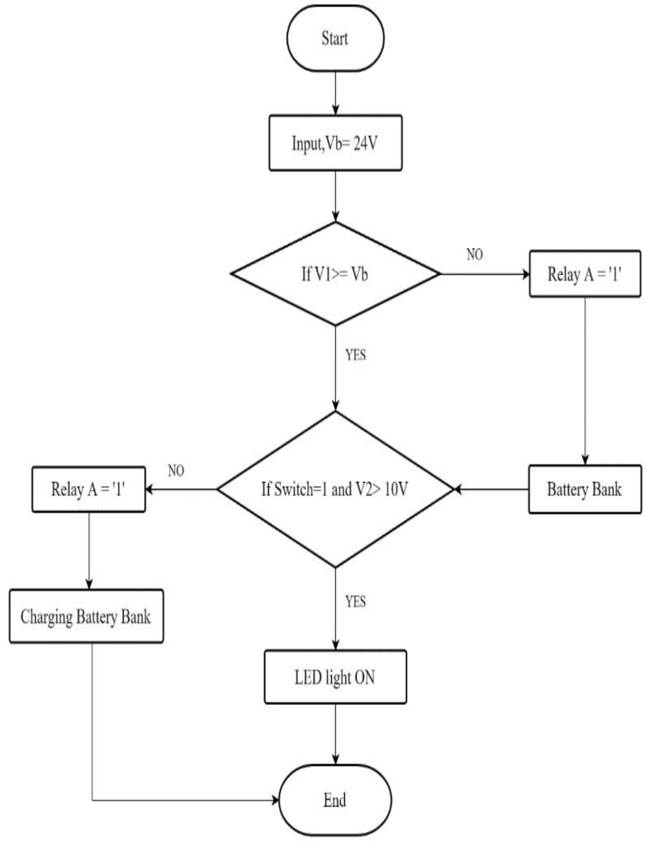

Figure 2: Flowchart of Standalone PV LED light System

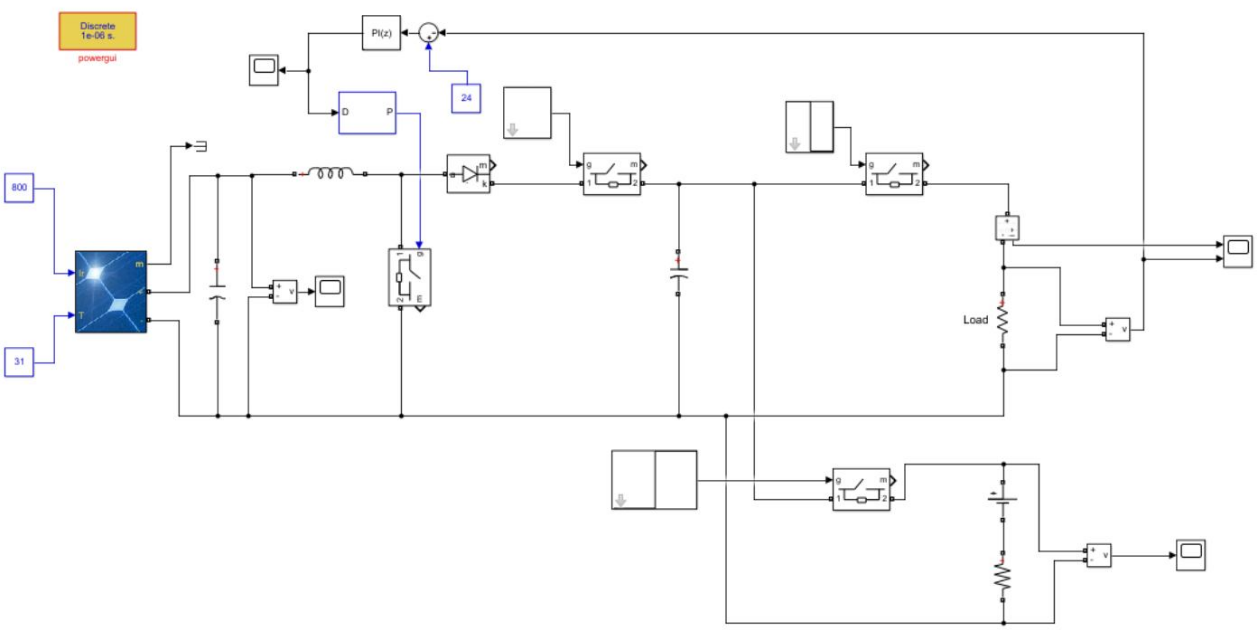

Figure 3: Simulation of the proposed standalone PV system

```
// measure voltage at voltage sensor 1
value1 = analogRead(analogInput1);
vout1 = (value1 * 25.0) / 1024.0;
vin1 = vout1;
Serial.print("INPUT V1= ");
Serial.println(v1,2);
delay(500);

// measure voltage at voltage sensor 2
value2 = analogRead(analogInput2);
vout2 = (value2 * 25.0) / 1024.0;
vin2 = vout2;
Serial.print("INPUT V2= ");
Serial.println(v2,2);
```

Figure 4: Program algorithm for measuring the voltage

```
if (v1 >= 24.00 && v2 >= 10.00 )
{
 digitalWrite(12,HIGH);                         // Relay OFF
 Serial.println("Mode 1 : LOAD ON");

}
```

Figure 5: program algorithm for Mode 1

```
{
 digitalWrite(12,LOW);                                      // Relay ON
 Serial.println("MODE 2: CHARGING BATTERY");
}
```

Figure 6: program algorithm for Mode 2

```
else if (v1 < 24.00)
{
 digitalWrite(12,LOW);                                   // Relay ON
 Serial.println("Mode 3 : BATTERY SUPPLY");

}
```

Figure 7: program algorithm for Mode 3

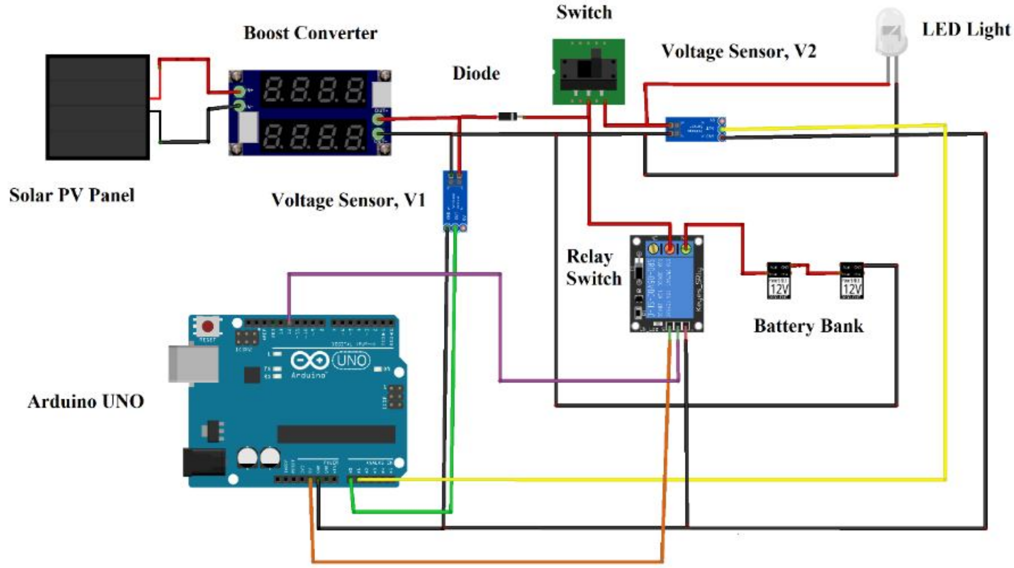

Figure 8: Circuit diagram of connected hardware part of overall system

4. RESULTS AND DISCUSSION

Simulation results done through Matlab/Simulink. Figure 9 below show the waveform of the load voltage, V_L of overall operation of the system. The time taken for overall operation of the system is set to 10 second and each mode is run for three second as for analysis of the waveform. Mode 1 represent the LED source are from PV (24 V), mode 2 represent the LED is at OFF condition and mode 3 meanwhile represent the LED is supply by battery (24 V). Figure 10 show the time response before the voltage reading at steady state. The dotted line in the figure is intersect with the point where load voltage, V_L start to be in steady state. The time response is 0.003 second. There are slight overshoot at the beginning around 1.5 V. This is normal as the system is on start-up mode.

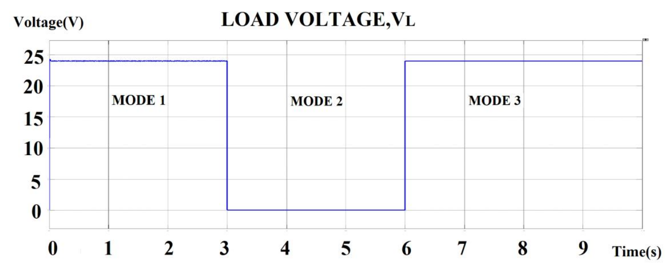

Figure 9: Load voltage V_L of overall system

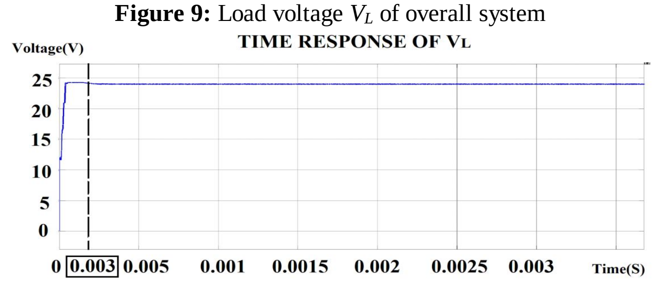

Figure 10: Response time of load voltage V_L

Load current, I_L also been analysed to measure the performance of the overall system. Figure 11 show the waveform of load current, I_L of overall operation of the system. Same as figure 9 where each mode represents different operations. Figure 12 show the time response of the overshoot. The dotted line in the figure is intersect with the point where the load current, I_L start to be in steady state. The time response is 0.003 second. After 0.003 second, the load current, I_L of Mode 1 is constant with the value of current obtained is 0.2870A.

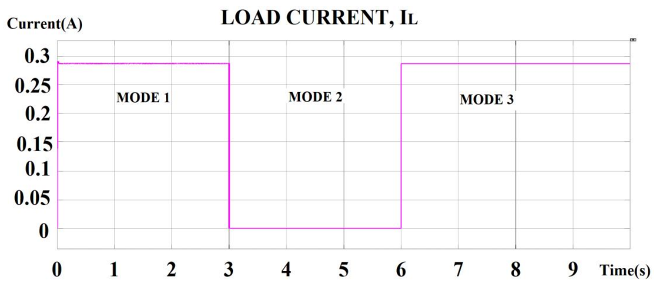

Figure 11: Load current I_L of overall system

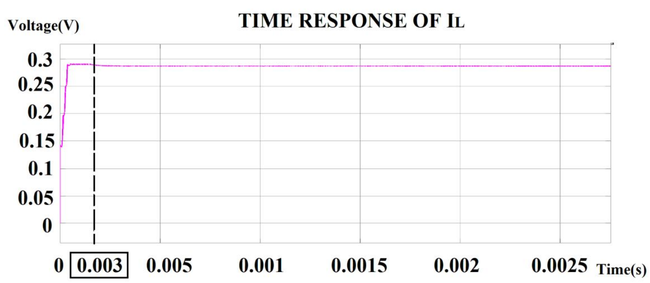

Figure 12: Response time of load current I_L

The voltage of the battery also been analysed in order to measure its characteristic and behaviour. Figure 13 show the waveform of battery voltage, V_{BATT} of the overall operation. For the Mode 1, the waveform is constant at 24 V. It is shown the voltage capacity of the battery bank. In this mode, the battery bank is not use as the source. After 3 second, the system was changed to Mode 2. From the waveform, it is shown that there was no time lagging and the system is said to be ideal when changing mode. The voltage reading for Mode 2 was constant at 24V. There was a voltage drop occurred after 6 second which is the mode is changed from Mode 2 to Mode 3. This drop because of battery now act as main supply to the LED (discharging mode). Figure 14 show the voltage drop at 6 second. There was no time lagging when changing mode. Thus, the system is ideal when changing mode. The reading of the voltage was constant at 23.9V. The reading of the battery voltage, V_{BATT} is lower than its rated voltage because the battery bank was discharged to light up the LED light.

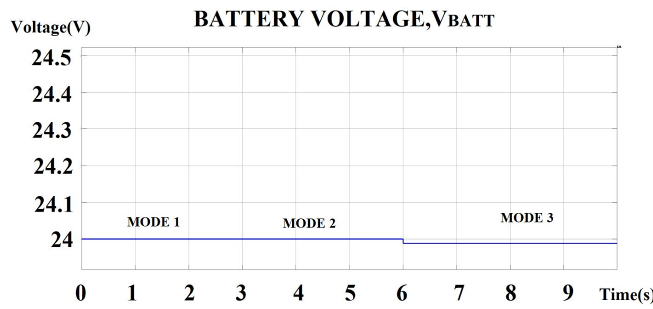

Figure 13: Battery voltage V_L of overall system

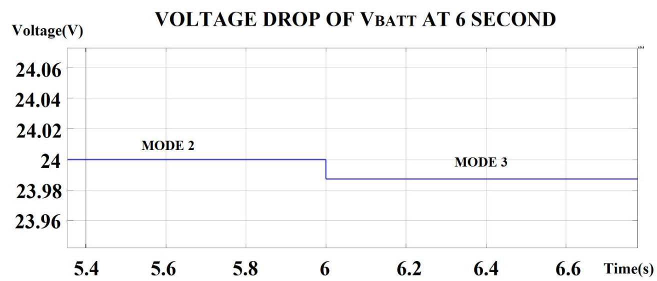

Figure 14: Voltage drop of V_{BATT} at 6 second

The experimental result is obtained by using oscilloscope. First, the steady state value and waveform of the load voltage, V_L and load current, I_L supplied by PV source were measured as in figure 15. It is shown that the value of the load voltage, V_L is about 23.7V and the load current I_L is about 0.281A. It is notice that there are some drop voltage as compare to the voltage set around 24 V due to are power losses happen in real time system.

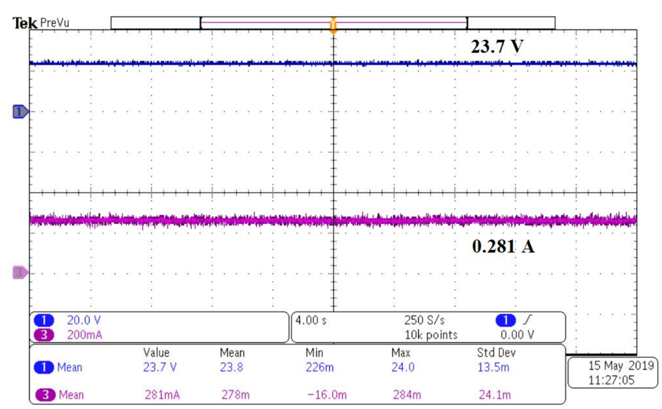

Figure 15: Waveform of steady state of V_L and I_L from PV source

Figure 16 show waveform of the steady state of the LED supply by battery. It is shown the load voltage, VL is about 23.3V and the load current, IL is about 0.255A. The voltage and current have dropped a little bit due to discharging process of the battery in supplying energy to the LED.

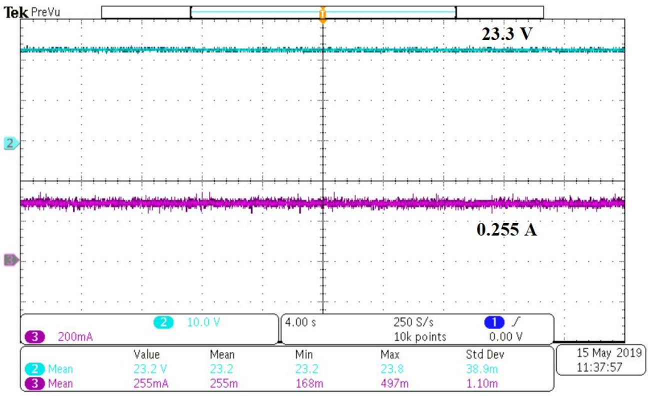

Figure 16: Waveform of steady state of V_L and I_L from battery

Next, the dynamic performance was observed. Figure 17 show the waveform of load voltage, V_L load current, I_L when Mode 1 was activated by user. The time response of V_L and I_L is about 0.004 second. The initial start-up overshoot is around 0.5 V and 0.4 A. This is normal condition for any start up characteristics of a system. Then, the performance when Mode 1 changed to Mode 2 also been measured. Figure 18 show the waveform of battery voltage, V_{BATT} when load is off. The output voltage of the PV was used to charge battery bank in this mode. During charging mode of battery, load current I_L is dropped to zero and the time response of the system is about 0.4 millisecond.

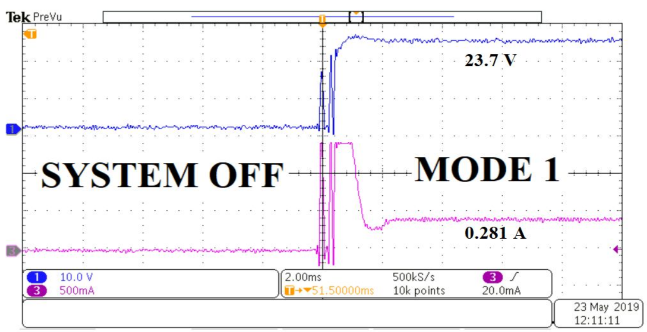

Figure 17: Waveform of load voltage, V_L and I_L when activated

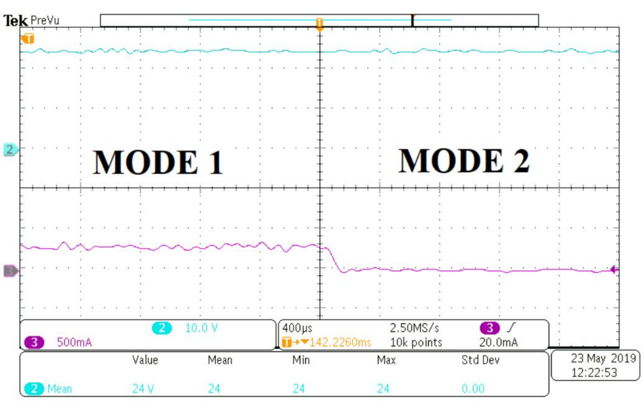

Figure 18: Waveform of battery voltage, V_{BATT} when load is off

Next, the performance when the system changed to Mode 3 is measured and observed. In this mode, battery voltage, VBATT was discharged to supply the voltage to the load. Figure 19 show the waveform of the discharged of battery voltage, V_{BATT}. The value of the battery voltage, V_{BATT} is about 23.1V because the voltage of the battery is used to supplied voltage to the load. The time response when the mode changed is about 400 microseconds. Figure 20 show the waveform of the load current, I_L when the load is supplied by the battery bank. It is shown there was an overshoot around 0.4 A at the start of Mode 3. The time response is about 3 milliseconds.

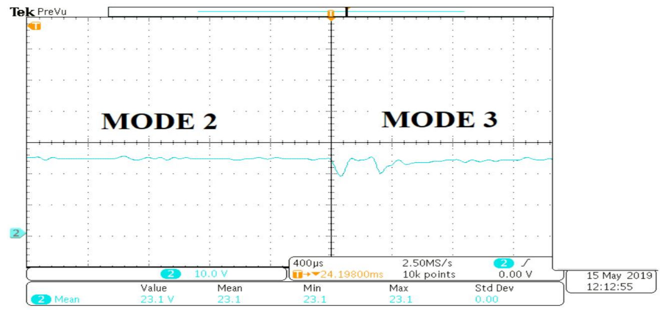

Figure 19: Waveform of the discharged of battery voltage, V_{BATT}

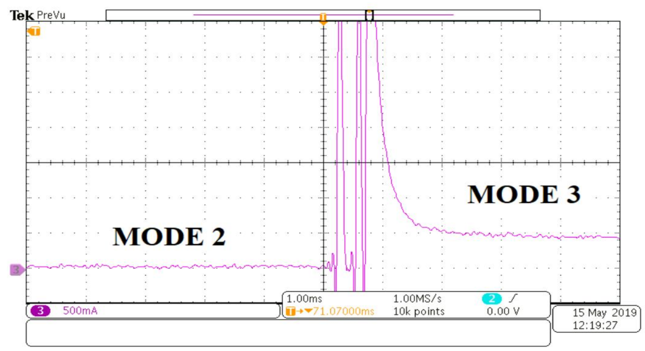

Figure 20: Waveform of the load current, I_L when the load is supplied by the battery

5. CONCLUSION

The standalone PV LED system with simple and smart control using Arduino was successfully developed. The system manages to control both LED and energy storage element (battery). Simple control algorithm was proposed with three modes which is to light up LED, charge and discharge battery. Simulation and hardware were done to test the PV system with steady state and dynamic operation analysis to justify the efficiency of the PV system to control LED and battery. The system works well using Arduino for real time operations. The system works properly with minimum overshoot around 1.5 V and 0.4 A. Overall response time recorded around 3 ms.

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