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MAXIMUM POWER POINT TRACKING OF PHOTOVOLTAIC SYSTEM FOR TRAFFIC LIGHT APPLICATION

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Abstract

Photovoltaic traffic light system is a significant application of renewable energy source. The development of the system is an alternative effort of local authority to reduce expenditure for paying fees to power supplier which the power comes from conventional energy source. Since photovoltaic (PV) modules still have relatively low conversion efficiency, an alternative control of maximum power point tracking (MPPT) method is applied to the traffic light system. MPPT is intended to catch up the maximum power at daytime in order to charge the battery at the maximum rate in which the power from the battery is intended to be used at night time or cloudy day. MPPT is actually a DC-DC converter that can step up or down voltage in order to achieve the maximum power using Pulse Width Modulation (PWM) control. From experiment, we obtained the voltage of operation using MPPT is at 16.454 V, this value has error of 2.6%, if we compared with maximum power point voltage of PV module that is 16.9 V. Based on this result it can be said that this MPPT control works successfully to deliver the power from PV module to battery maximally.

Keywords: photovoltaic, maximum power point tracking, traffic light, voltage converter, battery charging.

I. INTRODUCTION

Photovoltaic pedestrian light system is a significant application of photovoltaic source. The development of the system is an alternative for local authority to reduce expenditure for paying fees to power supplier which the power comes from electric generator. Many research institutions around the world have developed these systems as contribution to society and thus will accelerate initiatives to adopt solar energy as an alternative source for power supply. Since the photovoltaic pedestrian light system is expensive to build, it should be operated at its maximum output power level, using a control technique in order to the system can work efficiently [1-12].

The main objective in this project is to design a traffic light system powered by photovoltaic and to obtain the maximum power from PV energy output to charge the battery and to operate the system.

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II. TRAFFIC LIGHT SYSTEM POWERED BY PHOTOVOLTAIC

A. Diagram of Overall System

Figure 1 below shows the general layout of the electrical system. This system consists of PV module, MPPT, battery, traffic light lamp, push button switch for pedestrian, relay unit, voltage regulator and Peripheral Interface Controller (PIC) microcontroller. Traffic light lamp in this experiment uses light-emitting diode (LED) type, the LED-based lamps consist of an array of LED elements, arranged in various patterns. When viewed from a distance, the array appears as a continuous light source. LED-based lamps have numerous advantages over incandescent lamps; among them are: much greater energy efficiency, much longer lifetime between replacements, brighter illumination with better contrast even in direct sunlight, the ability to display multiple colors and patterns from the same lamp. Individual LED elements can be enabled or disabled, and different color LEDs can be mixed

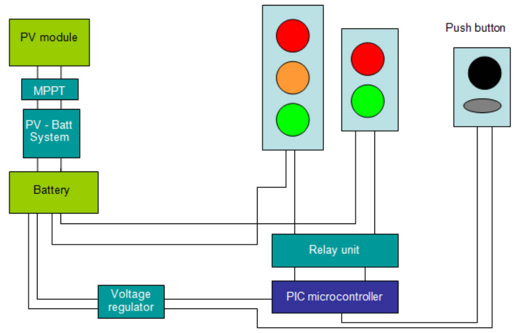

Figure 1. Schematic diagram of traffic light system powered by photovoltaic

Figure 3. Sealed lead acid battery

in the same lamp, much faster switching. Figure 2 shows LED Traffic light that is used in this experiment. The solar module selected for this prototype is polycrystalline silicon type. Table 1 shows characteristic of this PV module. To store the energy we use a battery. Battery is a device that converts chemical energy contained in active materials directly into electrical energy by means of an electrochemical reaction. Batteries used in PV lighting system must be rechargeable. Battery characteristic used in this experiment is shown in Table 2 and Figure 3.

The optimal type of battery for PV traffic light is a deep-cycle (or deep discharge) battery which most of its energy can be repeatedly drained and recharged. The maximum depth of discharge for low-maintenance (sealed) batteries is 30%. The maximum depth of discharge is a measure (in percentage) of the amount of energy that can be drained from the battery during the cycle, without damaging the battery. Batteries should generally be located in a weather resistant, non-metallic enclosure in order to prevent corrosion.

The main controller used to control the sequence of traffic light and reading battery level as well is PIC microcontroller 16F877A. In another word, we can say that it is the brain of the system. In order to give instruction to this kind of microcontroller, we need to do programming according to the sequence needed. To achieve this, we need its software (PIC C compiler) and PIC programmer kit. In this PIC, there is also a module for displaying characters in liquid-crystal display (LCD) and reading analog input.

We select PIC 16F877A as main controller in here because this microcontroller has complete peripheral and more reliable, if compared with other microcontroller [9]. Basic wiring of PIC microcontroller is shown in Figure 4. Because

Table 1.
Characteristics of PV module

Item	Specification
Manufacturer	KYOCERA (Japan)
Model	KC120-1
Standard Irradiance / Cell temperature	1000 W/m^2 (AM 1.5) 25 °C
Maximum power	120 W
Voltage at maximum power	16.9 V
Current at maximum power	7.0 A
Open circuit voltage	21.5 V
Short circuit current	7.45 A

Table 2.
Characteristics of battery

Item	Specification
Manufacturer	MSB
Model	MSL 12-40
Voltage	12 V
Capacity	40 Ah
Dimensions	195 × 165 × 170 mm
Weight	10.0 kg

Figure 2. LED traffic light (left) and LED pedestrian light (right) are under testing in lab

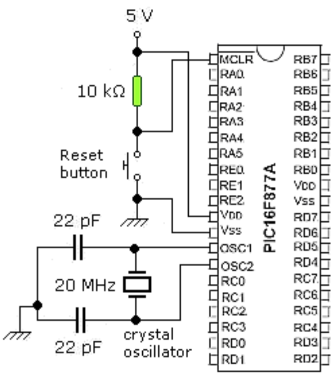

Figure 4. Basic connection of PIC microcontroller

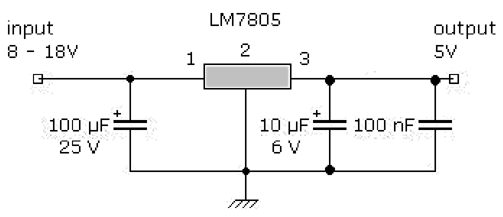

Figure 5.Basic connection of PIC microcontroller.

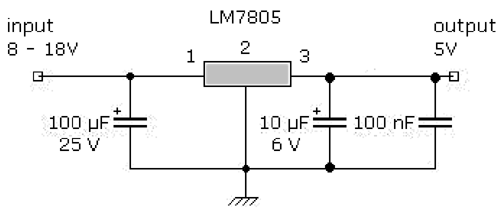

Figure 6. Basic connection of PIC microcontroller, relay and lamp

PIC microcontroller (or small scale circuit) needs only small amount of voltage, a voltage regulator is required to regulate the voltage coming from PV cell. In this system, we have chosen LM7805 which provides 5V supply. In order to have further stabilized voltage, the capacitors are required to filter high frequency (as shown in the following voltage regulator schematic diagram) because digital devices are very sensitive with small change of voltage. Basic wiring of the regulator for the PIC microcontroller shown in Figure 5.

To control voltage of traffic light lamp using PIC microcontroller we use a relay. It is very crucial to isolate one circuit electrically from another, while still allowing the first circuit to control the second. One simple method of providing electrical isolation between two circuits is to place a relay between them, as shown in the circuit diagram in Figure 6 below. A relay consists of a coil which may be energized by the low-voltage circuit and one or more sets of switch contacts which may be connected to the high-voltage circuit.

In this project, Single Pole - Double Throw (SPDT) relays with 5V-rating have been chosen because the relay voltage is supplied by output of PIC microcontroller. Even though every output pin already produces 5V (for high state), it is still insufficient to energize the relay due to the low current output. Therefore, transistors are required to amplify the current for energizing the relays.

B. Control Mechanism of Traffic Light

Flow chart of control mechanism for traffic light system is shown in Figure 7. Where we set an instruction command for PIC microcontroller 16F877A, in PIC has some I/O pin in Port D, we

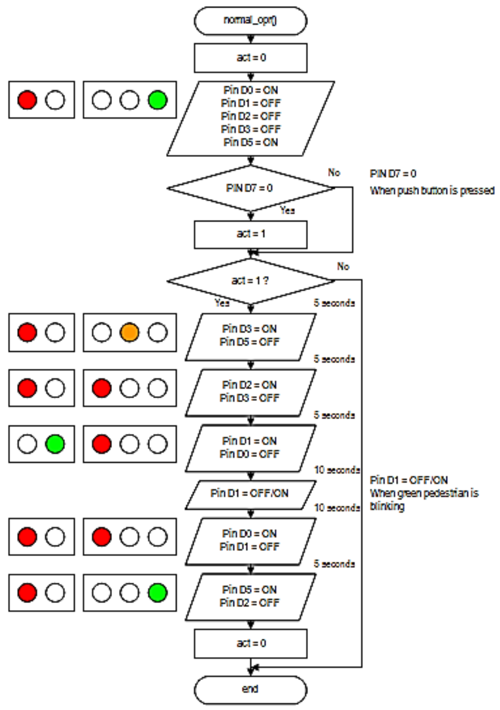

Figure 7. Control mechanism of traffic light system

can control the traffic light lamp to be ON or OFF use a set a sequence command to make Port D ON or OFF, and based on this ON or OFF sequence we can make the lamp (green, yellow or red) ON or OFF too.

C. PV-Battery Charging

This design implements a charger for a lead-acid battery as a sub-function in a microcontroller whose main function can be any more complex task. Furthermore, PIC microcontroller gets its power from the same battery. The charging process is gradual and uses so little processor time and therefore it does not disturb the PIC microcontroller primary task-controlling sequence of lighting. Diagrams of connection and charging between PV and battery are shown in Figure 8 and Figure 9.

In the case, when the battery is being charged, power switch must be on until the voltage reaches the upper limit of charging. In the second case, when the battery is being discharging, the power switch must be off until it reaches the lower limit of discharging. The lowest limit can be configured in PIC microcontroller and the state of charge can be monitored by user using LCD.

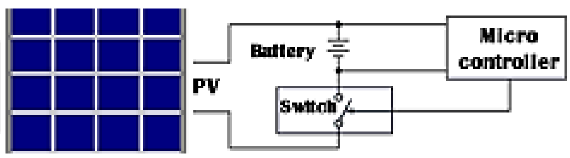

Figure 8. PV-battery charging diagram

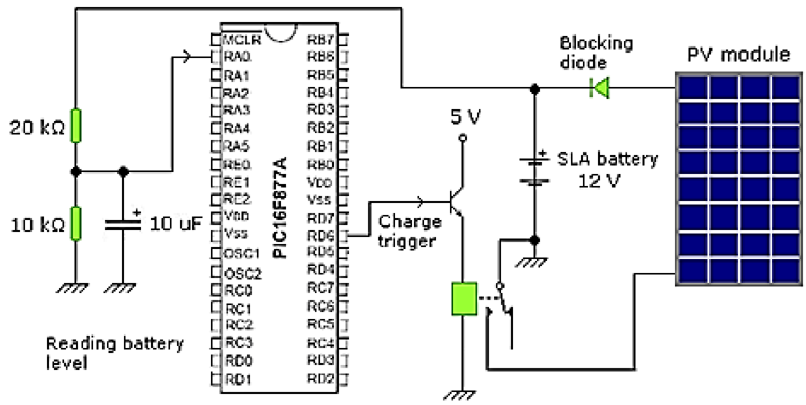

Figure 9. PV-battery charging circuit

Charging control mechanism is shown in Figure 10. Where if voltage of the battery over 14.5 V, then switch of relay will be off. And if voltage of the battery below 14.5 V this switch will be on.

III. Maximum Power Point Tracking

A. Theoretical Approach

Electrical characteristic of voltage and current of solar module can be represented by the curve experimentally and can be mathematically expressed using curve identification.

$$i(v) = I_{sc} - I_d\left(\exp\left(\frac{eV}{kT}\right) - 1\right) \quad (1)$$

where $i(v)$ is current density flowing into load (A/m^2), I_{sc} is short-circuit current density (A/m^2), I_d is dark (saturation) current density (A/m^2), V is voltage across cell (V), k is Boltzmann's constant

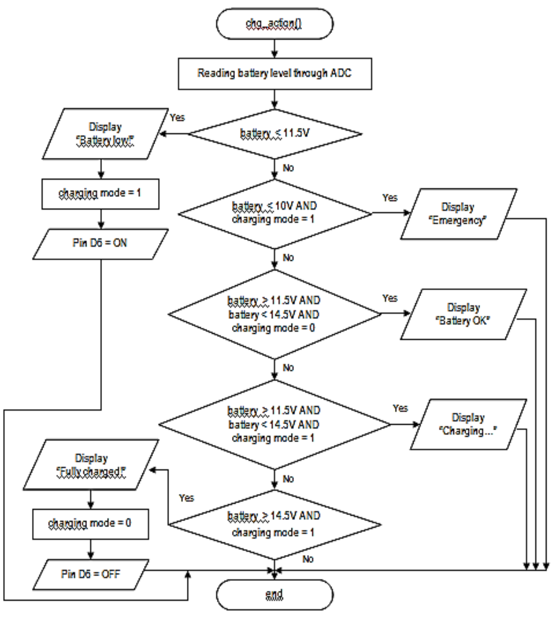

Figure 10. PV-battery charging control mechanism

(1.38 x 10^{-23} J/K), T is absolute temperature (K), and e is single electron charge (1.6 × 10^{-19} C).

The maximum voltage across PV cell is achieved under open-circuit condition, or $i(v)$=0,

$$\left.\begin{aligned} 0 &= I_{sc} - I_d\left(\exp\left(\frac{eV_{oc}}{kT}\right) - 1\right) \\ V_{oc} &= \left(\frac{kT}{e}\right)\ln\left(\frac{I_{sc}}{I_d} + 1\right) \end{aligned}\right\} \quad (2)$$

Power obtained from PV cell is:

$$\left.\begin{aligned} p &= iv \\ p(v) &= \left[I_{sc} - I_d\left(\exp\left(\frac{ev}{kT}\right) - 1\right)\right][v] \end{aligned}\right\} \quad (3)$$

The maximum power point is obtained by applying the condition dp/dt = 0.

$$\left.\begin{aligned} \frac{dp}{dv} &= v\frac{di}{dv} + i(v) \\ \frac{di}{dv} &= \frac{d}{dv}\left[I_{sc} - I_d\left(\exp\left(\frac{ev}{kT}\right) - 1\right)\right] \\ &= -\frac{d}{dv}\left[I_d\exp\left(\frac{ev}{kT}\right)\right] = -I_d\frac{d}{dv}\left[\exp\left(\frac{ev}{kT}\right)\right] \\ &= -I_d\left(\frac{e}{kT}\right)\exp\left(\frac{ev}{kT}\right) \\ \frac{dp}{dv} &= v\left[-I_d\left(\frac{e}{kT}\right)\exp\left(\frac{ev}{kT}\right)\right] + \left[I_{sc} - I_d\left(\exp\left(\frac{ev}{kT}\right) - 1\right)\right] \\ &= -\left(\frac{I_d ev}{kT}\right)\exp\left(\frac{ev}{kT}\right) + I_{sc} - I_d\left(\exp\left(\frac{ev}{kT}\right) - 1\right) \end{aligned}\right\} \quad (4)$$

$$0 = -\left(\frac{I_d ev}{kT}\right)\exp\left(\frac{ev}{kT}\right) + I_{sc} - I_d\left(\exp\left(\frac{ev}{kT}\right) - 1\right) \quad (5)$$

The maximum power is achieved at the voltage that satisfies $dp/dv = 0$ as shown in Figure 11.

In a DC-DC Converter, we can set voltage as a function of duty factor (*D*), as formulated below:

$$V_o = V_i \, D \tag{6}$$

Where V_i is voltage input of DC-DC converter, V_o is voltage output of DC-DC converter, and *D* is Duty cycle of Pulse Width Modulation (PWM) in switching MOSFET. Therefore, changing of duty cycle will increase or decrease the output voltage.

B. DC-DC Converter

Stepping-down or stepping up the voltage needs adjustment of PWM connected to MOSFET as switch. In this case, according to investigation of electrical characteristics of current-voltage, we have decided to use step-down or buck converter to implement DC-DC conversion. Actually, most of MPPTs usually use buck converter. Diagram of DC-DC converter used in this experiment is shown in Figure 12.

Switching DC-DC converter is more efficient at very high frequency. Therefore, using PIC, we can generate high frequency PWM. A very high frequency signal is generated, with amount of 2.4 kHz through pin C2.

For duty cycle adjustment, we need to know the maximum power obtained at particular voltage. This voltage can be either measured by investigating electrical characteristic or referring data sheet or specification provided by manufacturer.

According to the specification provided by the manufacturer (kindly refer to Table 1), the maximum power is obtained at 16.9 V at 1000 W/m^2 irradiance with 25°C temperature. Because the load of the system is almost constant, we can

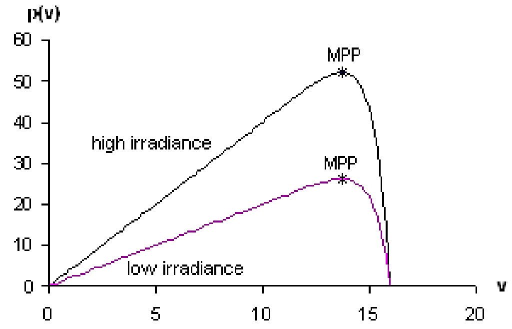

Figure 11. Characteristic of power-voltage of PV panel

only fix the duty cycle according to the input and output voltage in which depend on the load. We have output voltage from PV module at certain load, and then the maximum power point voltage has been obtained. Then, duty cycle is the ratio of maximum power point voltage (V_{MPP}) to output voltage from PV module at certain load. Mathematically, it can be expressed as follows:

$$D = \frac{V_{MPP}}{V_{output}} \tag{7}$$

For instance, the output voltage from PV module is 18 V and maximum power point voltage is 16 V. Then, duty cycle = 16/18 = 0.89. In the algorithm, the signal is generated using the following algorithm:

```
setup_ccp1(CCP_PWM);//pin C2
setup_timer_2(T2_DIV_BY_16,127,1);
  // 2.4 kHz signal
set_pwm1_duty(113);//  0.89  duty
  cycle
```

According the algorithm above, 113 is obtained based on duty cycle value obtained previously, 113/127 ≈ 16/18.

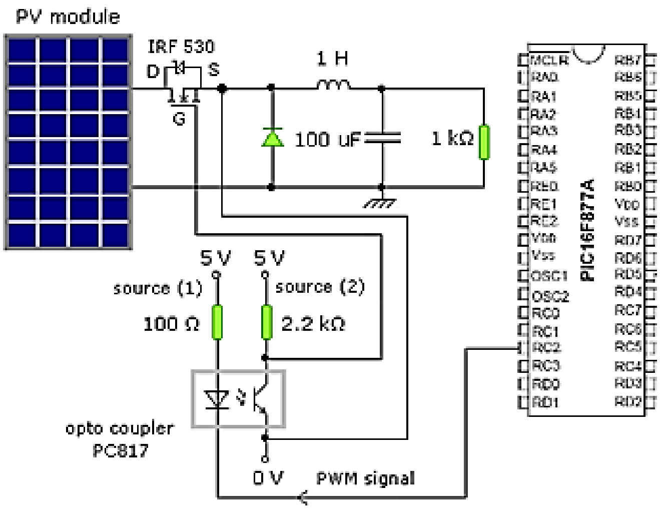

Figure 12. A DC-DC converter circuit for MPPT control

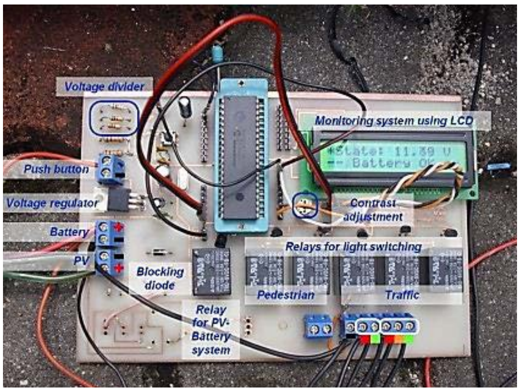

Figure 13. Experimental board

Figure 14. Traffic light lamp and PV module

IV. Result and Discussion

A. Implementation Circuit

Figure 13 shows circuit of this experiment board consits of DC-DC converter, control circuit and relay. Figure 14 shows a traffic light lamp with a mounting PV modul that is used in this experiment.

B. Measurement Technique

After completing traffic light module installation and its control, performance analysis for power consumption should be done. This involves measurement of voltage and current for both PV-Battery and Battery-Load.

For voltage and current analysis, it was suggested to take the reading for every 10 minutes for graph plotting purpose. There were two ways of measurement of these parameters; using data acquisition or multimeters. For voltage measurement, LABVIEW 7.0 is used with several hardwares:

- NI-PCI-6221 is installed inside the host computer through PCI slot with provided driver software.
- NI-SCC-68 is to be connected with to-be-measured source (attenuated source) or to be connected with direct source in between -10V and +10V.
- NC-SCC-AI01 for voltage attenuation due to the limited range of NI-SCC-68. The gain for this attenuator is 0.2. Therefore, 12V will display 12V x 0.2 = 2.4V.

For current measurement, there must have been a current to voltage converter with a determined gain prior to attenuation using NC-SCC-AI01. However, the current-to-voltage package was unavailable.

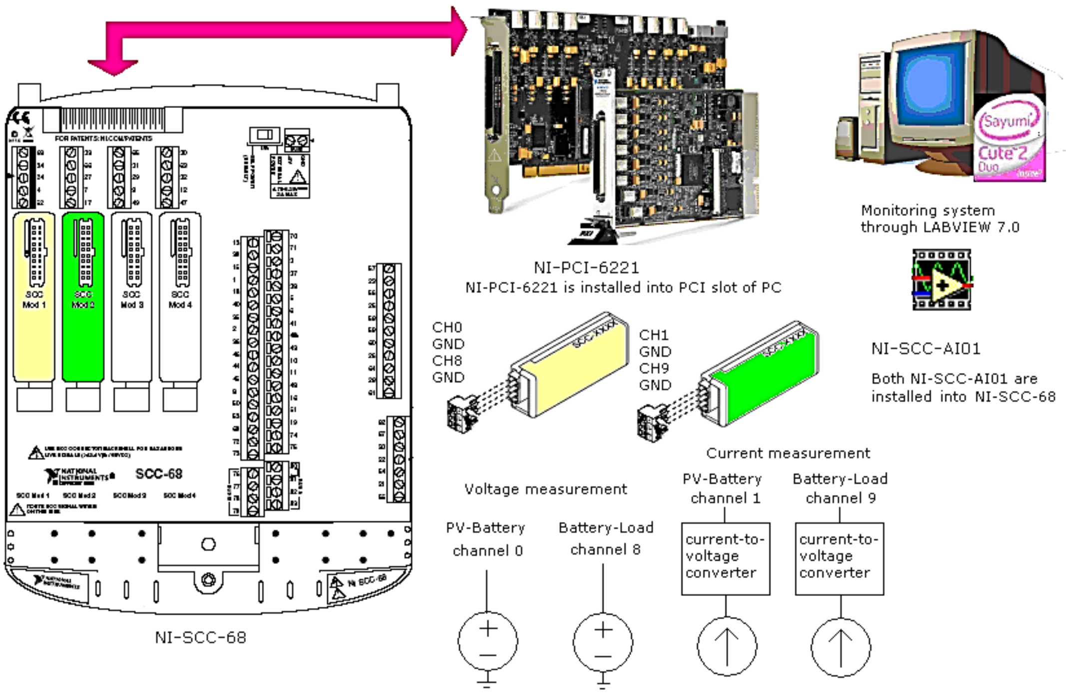

Figure 15. Measurement components using NI SCC-68

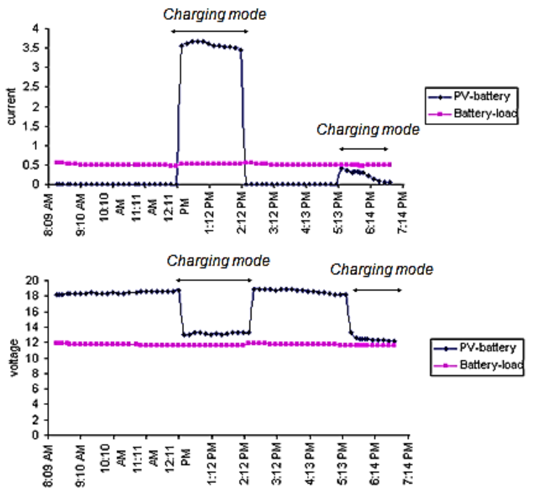

Figure 16. Performance of battery charging system

Designing the new one seemed to be difficult and required a lot of time. Hence, the manual way was suggested; using two multimeters with ammeter configuration. Then, the data containing four parameters were taken from the morning until evening and tabulated. After finishing tabulation, the data were plotted with four parameters versus time. Figure 15 shows some components that are used to measure the performance of this system.

C. Battery Charging Performance

Figure 16 shows performance graph of battery charging system. Based on Figure 16 and Figure 10, we can see that this charging system work well. Where in the beginning of this experiment the battery is in full condition (voltage of battery more than 14.5 V), this condition makes relay circuit cut off the current. When the voltage of battery below 14.5 V the relay switch will ON and charging battery occurs, at this time we can see the current 3.5 A delivered from PV modul to battery.

D. MPPT Performance

The experimental tests have been done for the MPPT. Figure 17 shows output of generated pulse from microcontroller as a feed pulse for MOSFET. This generated pulse can be programmed as we desired as duty cycle of DC-DC converter. For PWM control, the duty cycle is 0.866 with 2.4 kHz frequency. From theoretical analysis, we can obtain the expected output voltage, 0.866×19 V = 16.454 V at maximum power.

Figure 18 shows the output voltage of the DC-DC converter after being filtered, where we can keep output of the DC-DC converter oround 16.5 V. This voltage is a swing point of maximum power point of PV module. This

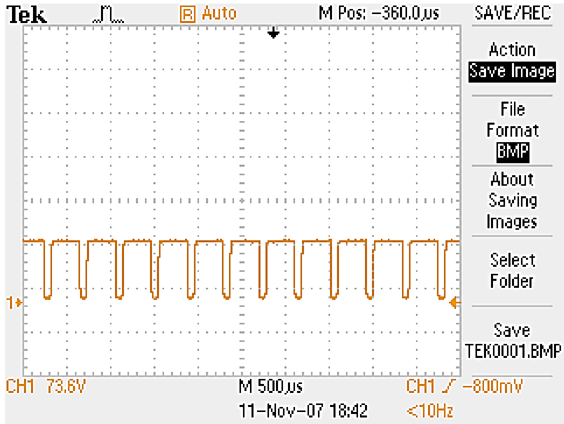

Figure 17. Generated pulse from microcontroller as a feed pulse for MOSFET

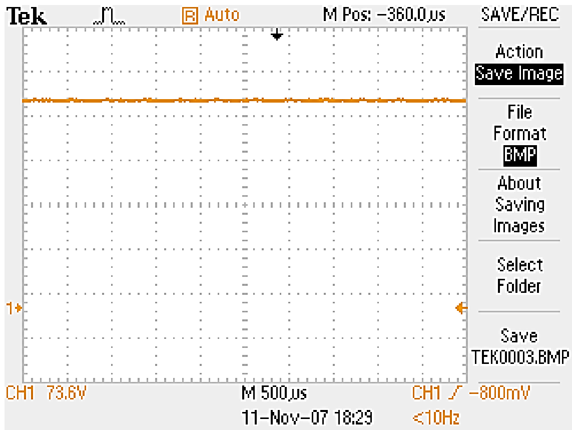

Figure 18. The output voltage output of DC-DC converter

method is known as MPPT technique uses Constant Voltage Control [13]. This value had has error of 2.6%, if we compared with maximum power point voltage of PV module in Table 1 that is 16.9 V.

E. Test of The Overall System

We have tested overall system of traffic light system powered by Photovoltaic and MPPT for one day. Based on the test, the traffic light lamp, battery charging system and MPPT work well as we designed.

V. Conclusions

In this paper we have presented the design and experimental of traffic light system powered by Photovoltaic and MPPT. Based on experiment we can conclude that the MPPT, battery charging and lamp controller worked as we desired in design process. The output voltage from DC-DC converter circuit from measurement showed value around 16.5 V, where this voltage measurement closes to MPP voltage of PV module data sheet. This shows that MPP control worked well to deliver a maximum power from PV module to battery.

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