Charge Controller for Lithium-ion Battery

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Abstract

A device used for charging the Lithium-ion battery from PV panel has been designed. The circuit is built with the MEGA328 microcontroller and the P-Channel FET switch. The circuit is series connected regulator. Charging method uses two stages: 1) BULK and 2) SATURATION charging. The first BULK stage is simply connected PV panel to the Lithium-ion battery directly. The second stage, charging current is regulated by PWM method, maintaining the battery voltage at +16.8V for 1.6 Hours. Lithium-ion 4S4P battery packs, is made with spot welding using sixteen 18650 cells. The charge controller circuit accepts up to 24V_{OC}, 3A I_{SC} PV panel. The optional load control is for providing up to 30W LED lamp. Experimental results showed the charging profile, and the discharging curve. The depth of discharge was 70.3%.

Keywords: Charge controller, 4S4P Li-ion battery, PWM charger

1. Introduction

Charge controller is a device that charges the battery with Photovoltaic panel and provides over charged/discharged protection. The common type of the charge controllers have long been using for charging the lead acid battery. The disadvantages of lead-acid battery are low energy density, difficulty of maintenance. The Li-ion battery, one of the highest energy density battery [1], currently is being used for many energy storage applications. It can store and supply electrical power from a small wattage to the mega wattage. The author's previous design of charge controller [2] was for Lead-acid battery using PIC microcontroller. Such design uses 3 stages charging. The basic of power circuit was modified for the new design with Li-ion battery pack.

This paper presents the design of a small charge controller for use with the 4S4P, 18650 Li-ion battery pack. Charging state was detected with battery voltage, no charging current detection circuit. This makes the circuit to be simple hardware and use a small number of electronic parts. Details of hardware, firmware and experimental results are described.

2. Principle of Operation

2.1 Charging the Lithium-ion Battery

Charging the Li-ion battery [3] typically is charged to 4.20V per cell. Standard charging method recommended by battery manufacturer employs two stages: 1) Constant Current, CC and 2) Constant Voltage, CV.

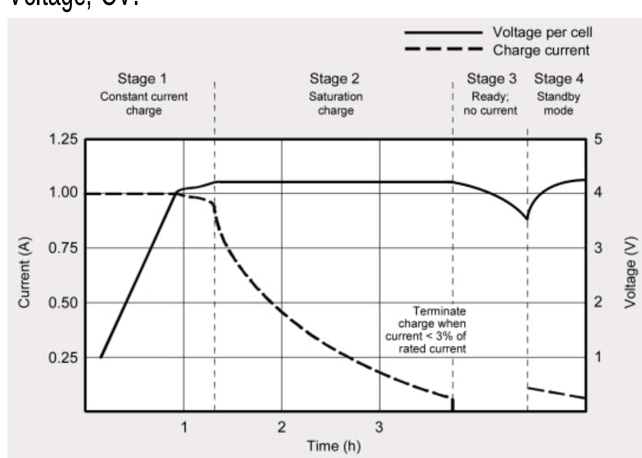

Fig. 1 Li-ion charging stages

On stage 1, with constant current charging, the voltage is rising linearly with charging time. When the voltage reaches 4.2V, it will change to Saturation charging. The battery voltage is maintained at 4.2V and the charging current will be dropped. When the charging current is less than 3% of rated current, charging will be terminated.

2.2 Charging by PV Panel

Charging the Li-ion battery by PV panel is simply done by connecting the Li-ion in series with the reversing protection diode to PV panel directly. Since, the PV panel is the current source, thus the charging current will depend on the insolation. SW1, solid-state switch is for protection the overvoltage. It will be cut off when the voltage reaches 4.2V. D1 provides one direction current flowing from PV to BT1.

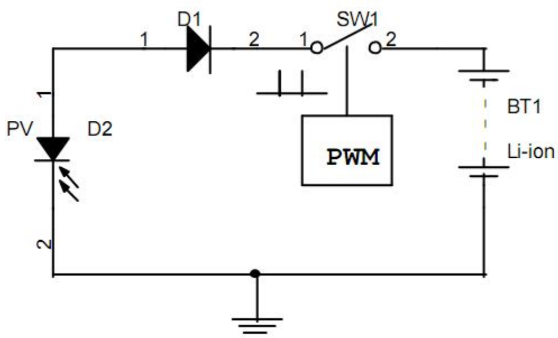

Fig. 2 Basic of charging circuit with PV panel

2.3 PWM method

The proposed charge controller conforms charging profile as shown in Fig. 1, however with adaptation for PWM method. The first stage, SW1 is connected, charging will begin when the available current from low insolation in the morning to high insolation at noon. When the battery voltage reaches 4.2V, the second stage for saturation charge will use PWM method. The PWM method controls charging current by regulating the voltage to be constant. Since charging state is detecting by battery voltage, second stage will keep constant voltage for 1.6 Hours. The features of PWM method are simple circuit and use a small number of electronic parts.

3. Hardware descriptions

3.1 Block diagram

Basic circuit of the charge controller is series regulator. The microcontroller unit, MCU detects PV (Vpv) and battery (Vbatt) voltages. The MCU controls Q1 and Q2 with PWM and LOAD signals. Q1 switch connects PV to the battery depending on charging stage. The first BULK charging stage, PWM is 100%, Q1 keeps turn on. The second stage, Saturation charging, the PWM signal will be varied 0-100% by Proportional-Integral, PI control method. Q2 is for optional load control switch, connecting the battery to the load, e.g. LED street lamp.

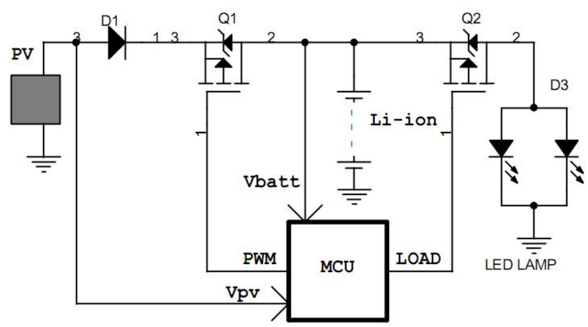

Fig. 2 Block diagram

3.2 Li-ion Battery Pack

The Battery pack is 4S4P, Panasonic NCR18650B cell. Each cell provides 3200mAh capacity. Four cells are series connected to provide +16.8V. Four rows are then paralleled connected, forming 4S4P battery pack. Total capacity is approximate 12800mAh. The battery pack was made by EVSbattery company [4] using spot welding.

Fig. 3 Panasonic NCR18650B cell

Each cell has specification shown in Fig. 4.

Specifications

Rated capacity[(1)]	Min. 3200mAh
Capacity[(2)]	Min. 3250mAh Typ. 3350mAh
Nominal voltage	3.6V
Charging	CC-CV, Std. 1625mA, 4.20V, 4.0 hrs
Weight (max.)	48.5 g
Temperature	Charge*: 0 to +45°C Discharge: -20 to +60°C Storage: -20 to +50°C
Energy density[(3)]	Volumetric: 676 Wh/l Gravimetric: 243 Wh/kg

[(1)] At 20°C [(2)] At 25°C [(3)] Energy density based on bare cell dimensions

Fig. 4 Specification of NCR18650B

The charging recommendation is Constant Current (CC) – Constant voltage (CV) method. The standard charging current is 1625mA (0.5C) and 4.2V voltage regulation for 4 Hours. Cell temperature should be 0 to +45°C while charging.

3.3 Power train

The power train is built with P-channel FET. The left-side is for connecting the PV panel to the battery. And the right-side is for Load control. D13 is reverse protection diode, MBR1645. The left-side FET is controlled by the output from microcontroller port, PWM signal. Q1 pulls GATE pin of the D11 to LOW, thus turn on the P-channel FET, connects BUS2 to BUS3.

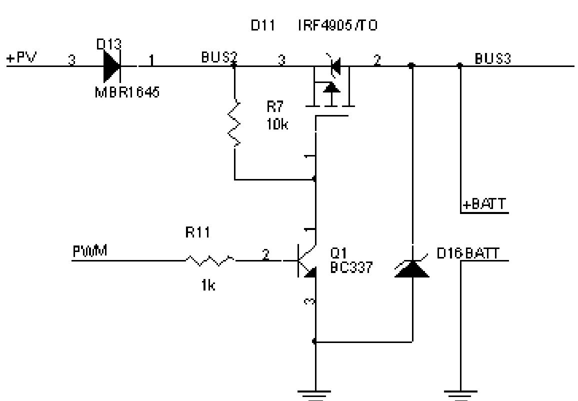

Fig. 5 Power train: Left-side

The Right-side circuit is the same as the left-side. Battery voltage on BUS3 will be connected to the BUS4 when the LOAD_CONTROL signal drives logic HIGH to the Q2. BUS4 will provide power to LED lamp. D15 indicates the load is turned on.

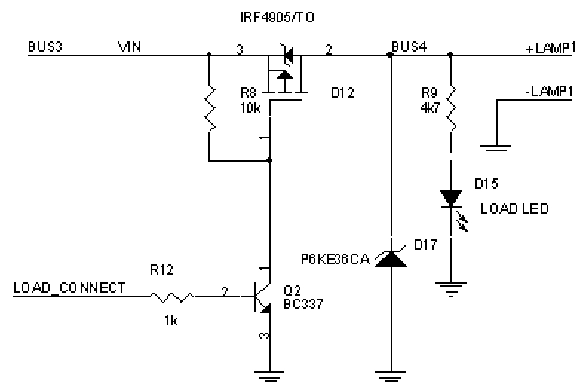

Fig. 6 Power train: Right-side

3.4 Microcontroller

The microcontroller chip is MEGA328, 32-pins TQFP package. The chip is running with 16MHz oscillator. PD6 is PWM output and PD7 is LOAD_CONNECT. ADC0 to ADC3, 10-bit analog to digital converter are for analog signals reading. The ADC will be used to read battery and PV voltages.

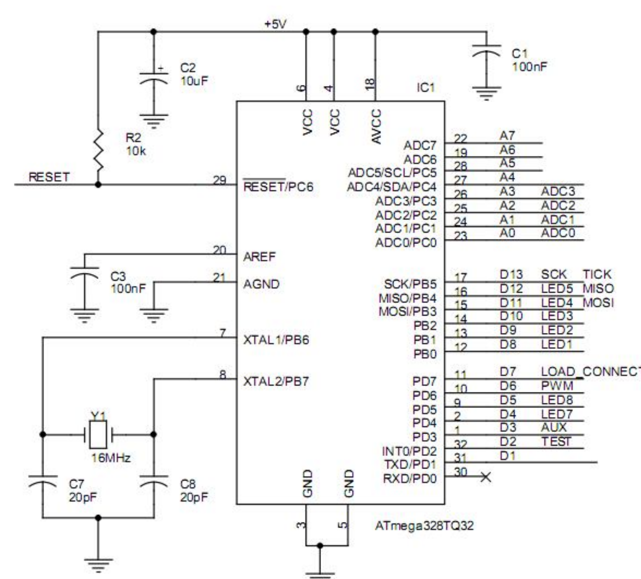

Fig. 7 MCU circuit: MEGA328 Microcontroller

3.5 PV and Battery voltage detectors

Charging/discharging state is detected with battery voltage. R4 and R5 is voltage divider 10:1. The signal is fed to ADC channel 0.

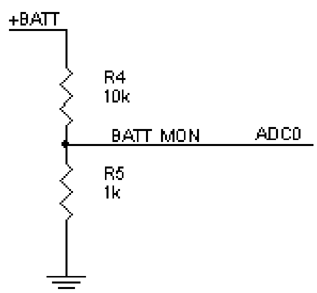

Fig. 8 Battery voltage detection circuit

PV voltage detector is also built with voltage divider circuit, R6:R10. The signal, LIGHT_SENSOR is fed to ADC channel 1.

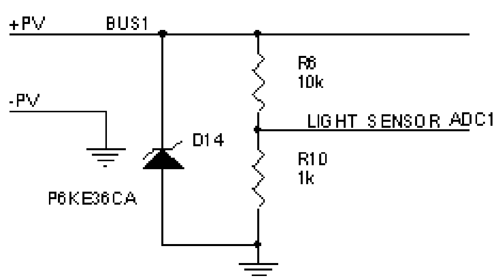

Fig. 9 PV voltage detection circuit

3.6 Battery power meter

The charger provides analog display for battery power meter. Minimum indicator is +12.5V and Maximum display is +16.5V. Fully charged LED, D2 is green color. D2 will be turned on for fully charged status. The display measures battery voltage indicating the available power of battery in real-time. D9, Tick LED blinks every 2 seconds to indicate normal functioning.

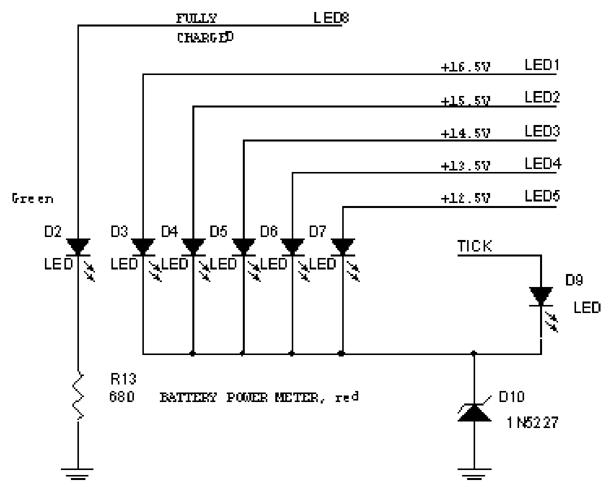

Fig. 10 Battery power meter

4. Firmware

The control program was developed with C++ coding. Tasks switching is performed by 2 seconds timer interrupt. Every two seconds, the tasks that read PV voltage, battery voltage and PI control will be executed.

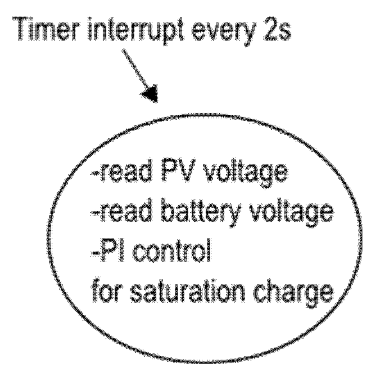

Fig. 11 Timer interrupt for tasks switching

State diagram shows sequence of the tasks. It begins with PWM initialization to 500Hz. In the morning, when PV voltage reaches +17V, BULK charging will be activated. Charging the battery is started. When the battery voltage reaches +16.8V, stage 2 will be entered. Charging state will change from BULK to Saturation charge. The battery voltage will be regulated at +16.8V for 1.6Hrs. Regulation is done by PI control method. When completed, the controller turns off charging current and enters standby mode. In the evening, when the PV voltage is less than +9V, the night mode is entered. The LOAD signal will be turned on. The load will discharge battery. When battery voltage is less than +12V, the low voltage disconnect will turn off the load to prevent over discharged.

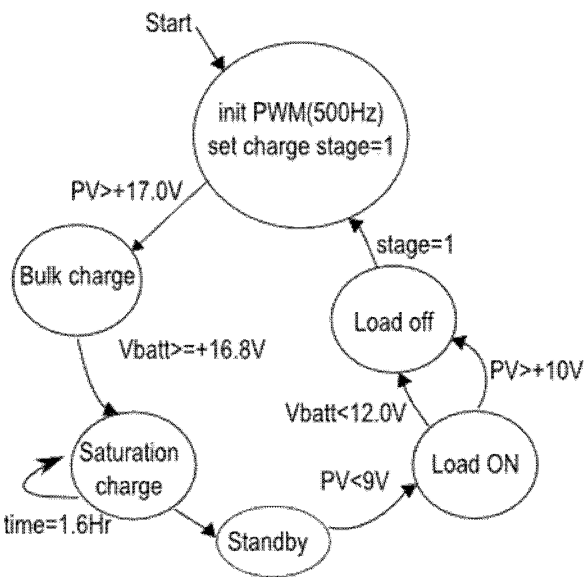

Fig. 12 State diagram

5. Prototype board

The prototype was built with double sides PCB. All surface mounted chips are placed on the TOP layer. The MCU, MEGA328 is 32-pin TQFP package. Left-hand power devices are protection diode and P-channel FET.

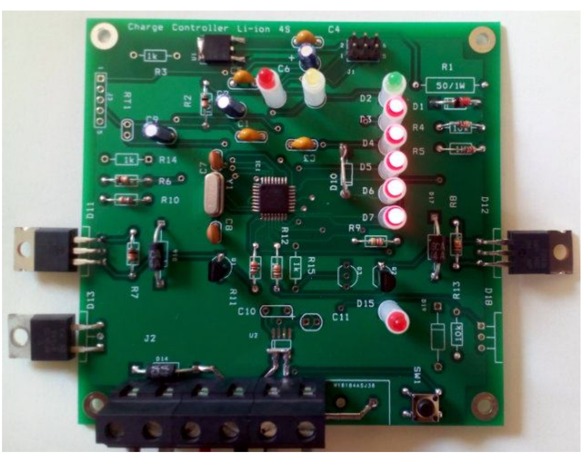

Fig. 13 Prototype of charge controller

6 Experiments

6.1 Testing

Testing the charge controller was done by setting up the solar street light system. Specification of the components being test is shown in Table 1.

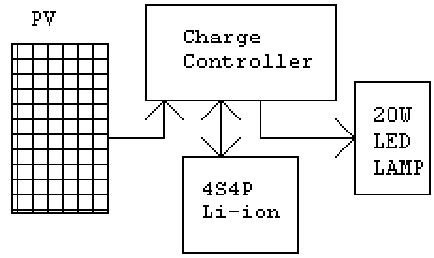

Fig. 14 Solar Street light testing system

Table. 1 Specifications of the components

Components	Specification
1. Charge controller	+16.8V Li-ion
2. PV panel	24Voc, 3A Isc
3. Lithium-ion battery	4S4P, 12800mAh
4. Super light LED lamp	20W

6.2 Experimental results and Discussion

The PV voltage, battery voltage and load control signal were recorded from 06:00 to 03:00 with 1 minute sampling rate. The plotting showed charging profile, PV voltage and load output signal.

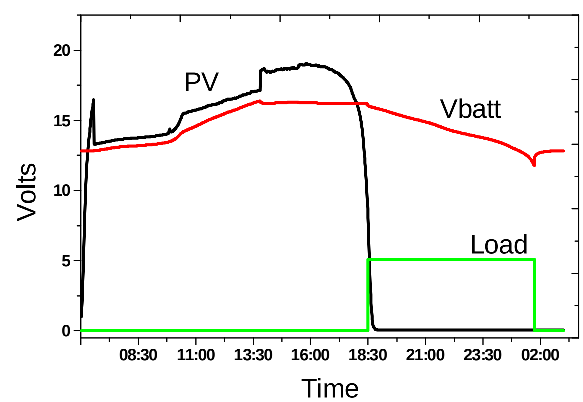

Fig. 15 Plot of PV, battery voltage and load control

Analysis of the charging profile shown in Fig. 15 will be described using Fig. 16 as follows. The charge controller begins connect the PV panel to the battery at point 1, where the PV voltage is larger than +17V. The charging stage is BULK charging from point 1 to 2. We found battery voltage was increased until it reaches +16.8V at point 2. The controller then enters the 2nd stage, SATURATION charge. In this stage, the PWM signal will regulate charging current, in order to maintain battery voltage nearly +16.8V for 1.6Hrs. When completed at point 3, the controller enters to standby mode, no charging current. We found the battery voltage is nearly constant. At point 4, in the evening, the PV voltage dropped below +9V, the controller will enter night mode, turn on the LOAD discharging the battery. We found the battery voltage was decreased linearly from point 4 to point 5. At point 5, the battery voltage is below +12V, low voltage disconnect will turn off the load. We found battery voltage swing back to the open circuit terminal voltage.

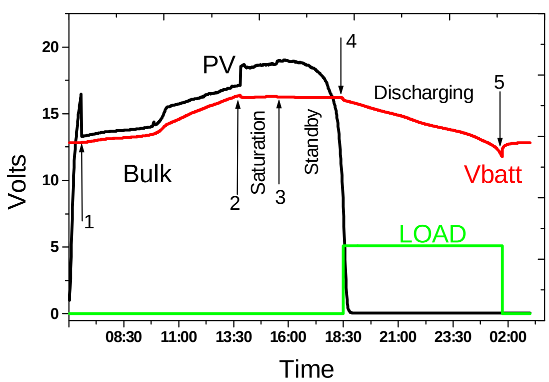

Fig. 16 Analysis of charging profile

Discussions are as follows. The charging profile for stage 1, BULK charging, without constant current mode as recommendation by manufacturer, instead the charging current will depend on the insolation. We found that the battery voltage at the half way has shown step increasing, and then linearly increase until reaches point 2. On stage 2, Saturation charge, the PWM method performs quite well to maintain battery voltage nearly constant at +16.8V. From point 3 to point 4, it is standby mode, no charging, the battery terminal voltage is very constant. Discharging begins at point 4 and ends at point 5 when the battery voltage is less than +12V.

Analysis of discharging curve when load has turned on is shown in Fig. 17. We found the dropped terminal voltage, started at point 1 was linearly decreased to point 2. At point 3, approx. 30 mins before the load was turned off, we found the dropped was slightly faster. Total load turn on period was 434 mins or approx. 7.2Hrs. The load being tested was 20W LED lamp. Thus total energy consumed was 144Whrs. Since, the battery pack provides capacity approx. 12.8Ahrs or 204.8Whrs (using nominal voltage 16V). The computed of the depth of discharge was 70.3%.

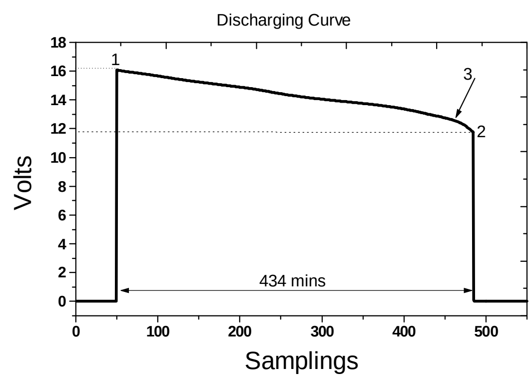

Fig. 17 Discharging curve

6. Conclusion

The charge controller has been developed for charging the +16.8V 4S4P, Lithium-ion battery pack. The circuit is simple series regulator with PWM method. Charging uses only two stages; BULK and Saturation. Test result shows the charging profile and discharging curve.

7. References

[1] Lithium Ion Battery: URL: https://www.cei.washington.edu/education/science-of-solar/battery-technology/, access on 18/03/2019.

[2] Wichit Sirichote and Kajpanya Suwansukho (2013). Photovoltaic Charge Controller, paper presented in the 9th Conference on Energy Network of Thailand 2013, Nakhon-Nayok, Thailand.
[3] Charging Lithium-ion Battery University, URL: https://batteryuniversity.com/learn/article/charging_lithium_ion_batteries, access on 18/03/2019
[4] Lithium-ion battery power bank, URL: http://www.evsbattery.com/, access on 17/03/2019