Photovoltaic Charge Controller

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Abstract

A device used for controlling the charging current to the battery from a photovoltaic panel has been developed. The circuit is built with PIC18F46J11 microcontroller. The regulating charge current is series interrupting with fixed frequency PWM. The amount of charging current is determined by difference between battery voltage and preset voltages. The switching device, IRFP9540 p-channel power FET is placed in series between battery and the solar panel. The frequency of PWM signal is 500Hz. The duty cycle 0-100% is adjusted by proportional control. The controller uses three stages charging i.e. bulk, absorption and float. The charge controller has been tested with a solar street light. The test result showed the plot of charging profile, low voltage disconnect and load control.

Keywords: charge controller, PWM, three-stage charging

1. Introduction

One of the main components of the Off-grid PV system is the charge controller. The main function of charge controller is to prevent the battery from overcharge and over discharge. The battery must also be maintained at fully charged state. To provide efficient charging, the series regulator is used for most of the commercial charge controllers. The regulating power is simply done by PWM (Pulse Width Modulation) using the semiconductor switches. Some controllers have MPPT (Maximum Power Point Tracking) control circuit. For small system, e.g. a solar street light, the PWM power regulation provides a simple design and efficient at low cost. This paper describes the complete design for hardware and software of the small charge controller. The controller is microcontroller based using software generated PWM control. The charging method uses three stages with preset voltages. The controller is designed for solar street light using a 120W PV panel, a +12V battery, and a 50W maximum load.

2. Battery charging method

2.1 Three stages charging [1]

The charge controller regulates the charging current to the battery using three stages method. Fig. 1 showed the charging profile. Descriptions for each stage are as follow.

Stage 1 Bulk charge: The controller will connect the PV to the battery directly. The battery voltage will increase gradually. When the battery voltage reaches +14.5V, stage 2 will begin.

Stage 2 Absorption charge: The controller will regulate the charging current by maintaining the voltage level at +14.5 for one hour.

Stage 3 Float charge: The controller generates the trickle charge to maintain the voltage level at +13.8V. This stage keeps the battery to be fully charged. If battery voltage is less than +13.2V for 10mins, stage 1-2-3 will be repeated

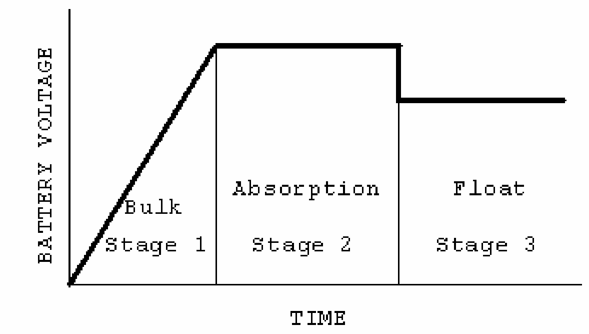

Fig. 1 Three stages charging profile

2.2 Load control

For solar street light applications, the PV itself is used as the light sensor. In the evening, when the PV voltage level falls to +8V for 5 mins, the controller will turn on the light. In the morning when the PV voltage is larger than +10V for 3 mins, the light will be turned off.

2.3 Low Voltage Disconnect, LVD [2]

When the load is supplied by the battery current, the battery voltages will decrease gradually. The charge controller will disconnect the load from the battery at LVD point, +11.5V.

3. Hardware descriptions

A simplified block diagram of the charge controller is depicted in Fig. 2. The circuit is a series regulator. Q1, a semiconductor switch is used to connect the battery to the PV panel. D1 is a fail-safe diode for disconnecting the battery to the PV panel when PV voltage less than battery voltage. Q2 provides load control for disconnecting the load from battery at LVD condition. Regulation the charging current is done by PWM control signal. The PWM signal is fixed frequency with adjustable 0-100% duty cycle. The percent of duty cycle is proportional to the difference between PV voltage and the battery voltage. The proportional control is done by software. The preset voltages for three stages charging are preprogrammed in the microcontroller.

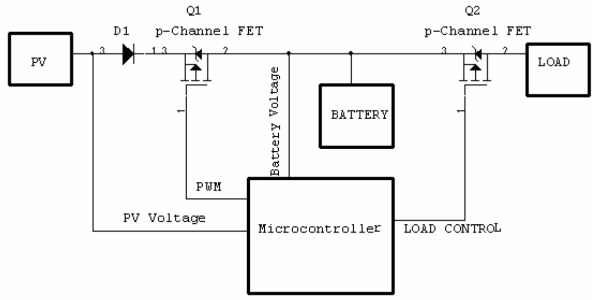

Fig. 2 Block diagram of charge controller

3.1 Microcontroller

The microcontroller circuit is shown in Fig. 3. The chip is Microchip PIC18F46J11, 44 pins TQFP package. The chip runs with 4MHz internal oscillator. Timer1 produces 32768Hz for time base functions. The analog inputs are RA0, RA1 and RA3 for battery voltage, light sensor and temperature sensors respectively. PORTB, RB0-RB4 drives five LEDs for battery voltage monitor. PORTD, RD0-RD3 drives four LEDs for functions indicators. The PWM signal is produced by the built-in PWM module and the output signal is RC2. RD7 is load control signal. The serial port RC6/RC7 is for 9600 terminal interface.

3.2 PWM Module

The PIC18F46J11 has a built-in hardware PWM module. The PWM mode uses CCPx pin as the output pin. The period and duty cycle can be programmed using timer2, period register (PRx) and duty cycle register. The PWM output pin (CCP1) is remapped to RC2 output port.

3.3 Power FET switch for battery charging

The +P terminal of PV is series connected to the battery (BUS3) through the power FET switch, D12. The circuit is high side switching which is controlled by Q1. D14 is power diode, 16A for fail-safe protection. Light sensor signal is generated by R16 and R20 voltage divider. Battery monitor signal is generated by R14 and R15 voltage divider.

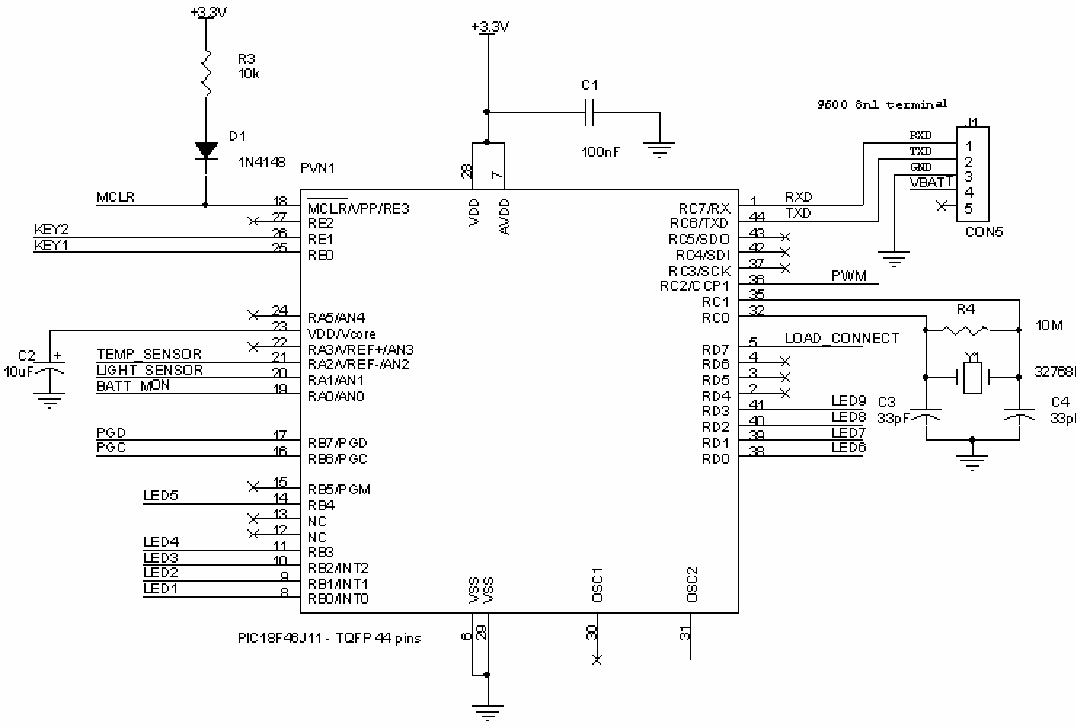

Fig. 3 Microcontroller circuit PIC18F46J11

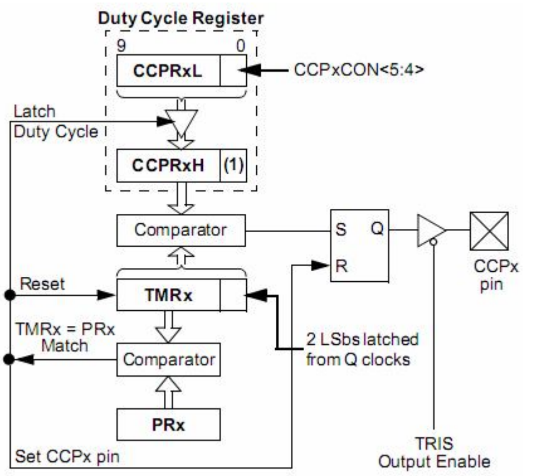

Fig. 4 Built-in PWM module

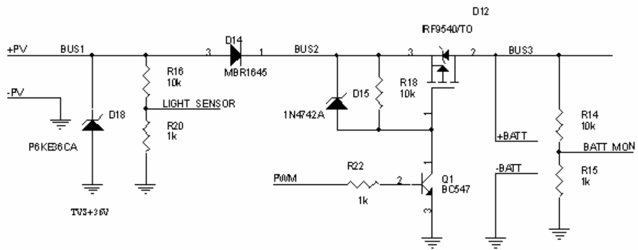

Fig. 5 Power FET at battery side

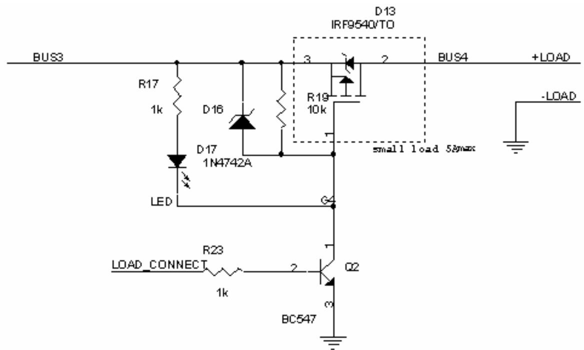

Fig. 6 Power FET at load side

3.4 Power FET switch for load control

D13, power FET is a switch between battery (BUS3) and the load (BUS4). Q2 controlled by LOAD_CONNECT signal. The maximum load power is 50W. D12 and D13 are placed with heat sinking.

3.5 LED Display for battery monitor and charging stage indicators

The battery voltage is displayed in analog level using five LEDs, D3, D4, D5, D6 and D7. The level scale is displayed from +10.5V to +14.5V with +1V/step.

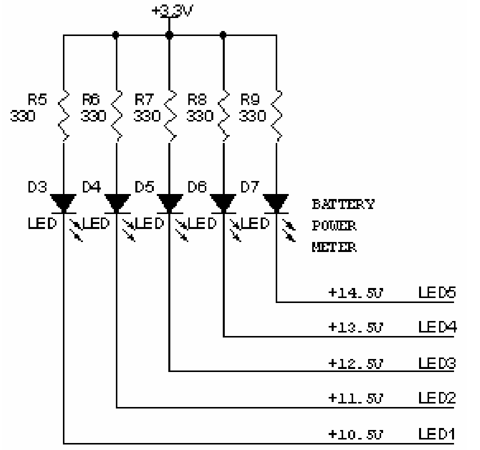

Fig. 7 Battery voltages monitor display

The LED for charging stages and tick indicator are D8, D9, D10 and D11. D9 is Yellow LED and D10 is Green LED. D8 and D11 are Red LED.

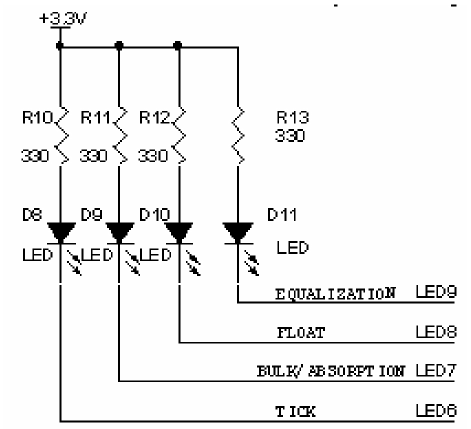

Fig. 8 Charge stages indicators

Table 2 Functions of Status LEDs

LED	Color	Functions
Tick	Red	Blink every 2s, to indicate program running
Bulk/Abs	Yello w	Lit for Bulk charge, and blink for absorption charge
Float	Green	Lit for fully charged and Float stage
Load LED	Red	Lit when load is connected.
Equalization	Red	optional for new design

3.6 Power supply circuit

The charge controller is powered from the battery being charged. The microcontroller and control logics are supplied with +3.3V from U1, LM1117 linear voltage regulator.

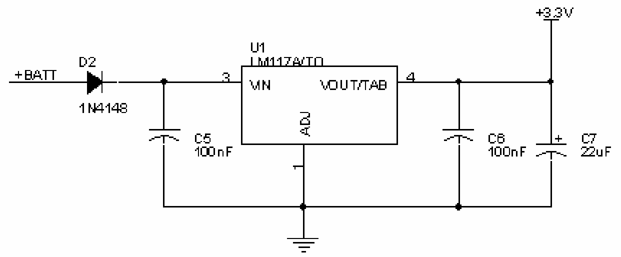

Fig. 9 Power supply circuit

4 Software descriptions

4.1 State diagram

Operation of the main loop is defined by the software control. Illustration by state diagram is shown in Fig 10. When the controller is connected to the battery, the program is start the operation. The PWM module is initialized for generating the PWM signal and charging state is set to bulk charge, stage=1.

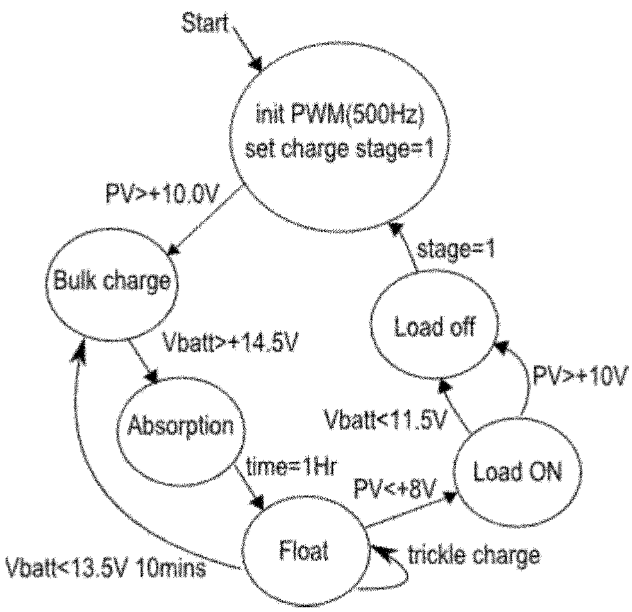

Fig. 10 State diagram of the main loop

The bulk charge begins when PV voltage is larger than +10.0V. The bulk LED (yellow) is lit. When the battery voltage reaches +14.5V, stage

2, absorption charge will be entered. The bulk LED is blinking to indicate the absorption charge. The charging current will be regulated by PWM signal to maintain the battery voltage at +14.5V for one hour. Float charge will then enter after one hour, the Bulk/absorption LED will turn off and the float LED (green) is lit. The float stage generates a trickle charge to keep the battery voltage at +13.8V. When the battery voltage falls below +13.5V for 10mins, the charging cycle will be repeated.

In the evening, when the PV voltage falls to +8V for 5 mins, the load will be turned on. In this state, the battery voltage will be monitored, if it is less than +11.5V for 3 mins the LVD condition met, the load will be turned off. The PV voltage is also monitored, if it is larger than +10.0V, the daytime met, the load will be turned off and charge stage will set to 1.

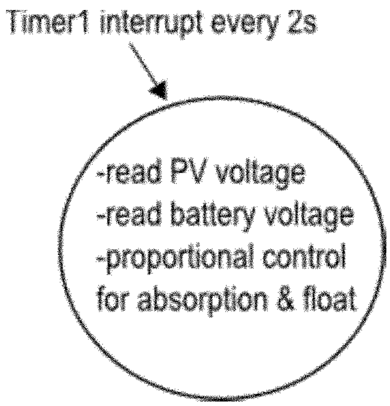

Fig. 11 Functions serviced by timer1 interrupt

4.2 Timer interrupt

The control software generates 2s tick using timer1 interrupt. The time bases for all functions are based on this tick. As shown in Fig.11, the functions for 2s tick are read the PV and battery voltage, calculating the error between PV and battery voltage for proportional control. The duty cycle of PWM thus is updating every 2s.

4.3 Proportional control coding

The example of proportion coding for absorption charge (maintaining at +14.5V) is shown below. The error value is computed by subtracting the set point for absorption voltage and sensed battery voltage (current_volt). Proportional term (pTerm) is computed by multiplying the Kp and error value. PB is proportional band.

```
error = absorption_volt-
current_volt;
  Kp=100/PB; // PB proportional band
    pTerm=Kp*error;
```

The amount of percent of output control value 0-100% is then used to set the duty cycle of the PWM signal. For example 100%, is full power and 50% is half power. If proportional term is less than zero, the output will be turned off. If it is larger than 100, the output will be 100% power.

```
    j=pTerm;

    if(j<0) j=0;
    if(j>100) j=100;

  if(j>0 && j <=100) // regulating
    {
    j= (j*255)/100;
 PWM1_Set_Duty(j); // set duty cycle
    }
```

5 Board layout and components placement

The charge controller has been fabricated using plate through-hole double sides PCB. All parts are surface mounting devices. The center chip is the PIC18F46J11 microcontroller. The power switching devices, FET and power diode (left-hand) are mounted on the aluminum plate heat sinking. The bottom terminal provides wire connecting for PV, Battery and Load. Table 2 shows the specification of the charge controller.

Fig. 12 Board layout and component placement

6 Experimental results and discussion

The charger controller was tested with a solar street light system. The system consists of a 120W PV panel, a +12V battery, a 12V/50W DC load and the charge controller. The PV voltage, battery voltage and load voltage were recorded using the Data Logger. The sampling interval is 1 min. The result of charging profile plotting with Fractional of day was depicted in Fig.14. For bulk charging, the battery voltage was increased gradually in the same direction as the PV voltage. However when absorption began, the battery voltage was dropped to +13.5V (avg) for one hour.

Table 2 Charge Controller Specification

Battery	+12V flood type
PV panel	+20V_{OC} I_{SC} 10A
Bulk Voltage	+14.5V
Absorption period	1 hour
Float Voltage	+13.8V
Low Voltage Disconnect	+11.5V
Load power max	50W

In the float charging, the controller could maintain the voltage level at +13.4V (avg) during the high insolation. In the late afternoon, when the insolation is going down, the float voltage was also dropped. The load control worked well when the PV voltage falls below +8V. LVD condition was detected at 1.00 after midnight.

Dropping of the battery voltage in the absorption and float charging could be caused by the control logic. The insolation was also the main factor for controlling the voltage level of battery. The example of solar street light that uses the charge controller is shown in Fig. 15.

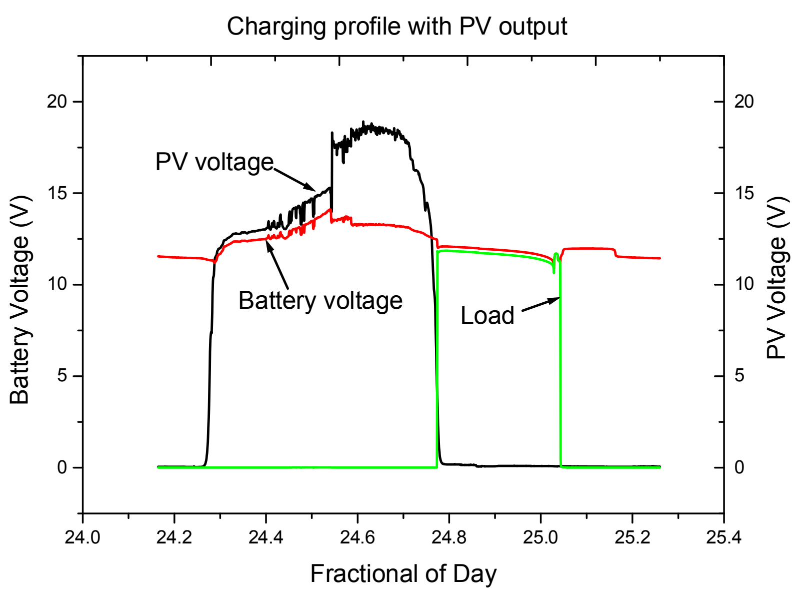

Fig. 14 Charging profile recorded on 23 January 2013

Fig. 15 Solar street light being tested

7. Conclusions

We have developed the charge controller circuit based on series regulator. The charge controller provides protection for overcharge and over discharge of the battery. The charging method employs three stages charging. The power regulation is done by PWM method. The load control is also provided for the application of automatic night light. The switches using power MOSFET enables charge controller to be developed for providing higher charging capacity easily. One of the applications being developed is the solar street light. The controller is now under tested and the control algorithms are being developed.

8. Acknowledgement

The charge controller was designed to be used in the Rural Electrification Project. The project was funded by Faculty of Science, KMITL. For the first year of the project (2012), fifteen units of solar street light and ten units for home lighting have been installed at Tambol BaanDong, Amphoe Charttrakarn, Changwat Pitsanulok.

9. References

[1] Dan Fink, “Charge Controller,” Home Power (ISSN 1050-2416), Bimonthly magazine, p. 106-111, December 2012-January 2013.

[2] Danial Welsh, Kenneth F. Gerken, “Method and Apparatus for Controlling Battery Charging Current,” United States Patent, US 5,635,816, Morningstar Corporation, June 3, 1997.