



Design and Modeling of PV Charge Controller for Low Power Applications

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ABSTRACT –

Photovoltaic charge controllers are the essential part of a standalone and battery based PV system. In this paper a PWM based dc-dc closed loop buck converter as PV charge controller for low power application is presented. The mathematical model is developed and simulation is carried out using MATLAB/Simulink for both open loop and closed loop system. Proteus platform is used with other components to test the prototype with microcontroller. The simulated charge controller hardware is realized and presented in this paper.

Key words - Buck converter, PV charge controller. Arduino-Nano

1. INTRODUCTION

The demand of energy is increasing particularly in developing countries like India and China. Unfortunately the existing fossil reserves that fuel the conventional power is depleting at high rate. The unavailability of fossil fuel and increased demand for energy has pushed us towards finding alternative sources of energy. There are many alternative sources of energy such as solar, wind, ocean thermal, tidal, biomass, geo-thermal, nuclear energy etc [1]. The abundance of solar energy present everywhere makes it readily available than any other source of energy that can be feasibly extracted and utilized. This solar energy can be converted into electricity with the help of solar panels that are made up of silicon photovoltaic cells. This readily available energy can be utilized for portable applications. Since designing low cost high efficiency solution to generate power in rural areas is easier with PV system than most of the other systems available. This paper is aimed at developing charge controllers for low power PV applications such as mobile charging, solar lamps, etc. for use in rural areas [2, 3].

2. PV CHARGE CONTROLLER

The block diagram of the closed loop PV charge controller is shown in Fig. 2. The input power is from PV array that traps the solar incident energy and converts it into the dc voltage. The intermediate section which is a PV charge controller process the solar PV power and delivers the processed power to the battery connected at the output section. The controller unit which is an Arduino-Nano senses and monitors the panel voltage V_{pv} and the panel current I_{pv} . At the output side it senses and monitors the feedback voltage V_b and feedback current I_b . The sensed feedback voltage is then compared with a reference value by the Arduino-Nano microcontroller and the error in the voltage is reduced by adjusting the switching pulse [4]. The objective of the control unit is, if the error value is positive duty ratio of the drive signal is reduced and if the error is negative the duty ratio of the drive signal is increased continuously. The adjustment of the duty ratio of the drive signal is termed as pulse width modulation. Thus the output voltage is maintained at the set reference value.

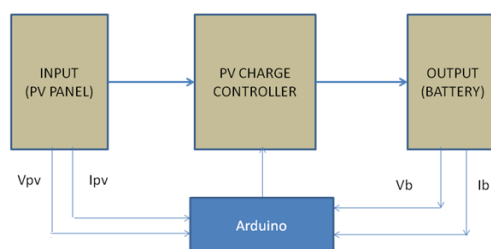


Fig. 1. General block diagram of proposed PV charge controller

2.1 DESIGN OF BUCK CONVERTER

The equivalent circuit of dc-dc buck converter is shown in Fig. 2. The output voltage in this topology is always less than the input voltage and thus it is considered as buck converter [5,6]. The general equation for design of inductor and capacitor is derived and presented in equation (1) to (18).

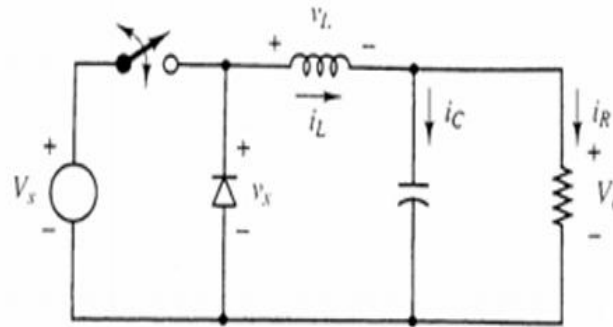


Fig 2. Equivalent circuit of Buck Converter [6]

2.1.1 Inductor Design

The notations used are, Δi_L is ripple current, i_L is inductor current, V_s input voltage of buck converter and V_o is output voltage, D is duty cycle, R is resistance, f is frequency and T is time period. In this case the voltage ripple is taken as 7.5% [3].

$$\Delta i_{L(\text{closed})} + \Delta i_{L(\text{open})} = 0 \quad (1)$$

$$\left(\frac{V_s - V_o}{L}\right)(DT) - \left(\frac{V_o}{L}\right)(1 - D)T = 0 \quad (2)$$

$$V_o = V_s D \quad (3)$$

$$VL = (V_s - V_o)DT + (-V_o)(1 - D)T = 0 \quad (4)$$

$$I_{\max} = i_L + \frac{\Delta i_L}{2} = V_o \left(\frac{1}{R} + \frac{1 - D}{2Lf}\right) \quad (5)$$

$$I_{\min} = i_L - \frac{\Delta i_L}{2} = V_o \left(\frac{1}{R} + \frac{1 - D}{2Lf}\right) \quad (6)$$

Where $f=1/T$ is the switching frequency,

$$L_{f\min} = \frac{(1 - D)R}{2} \quad (7)$$

$$L_{\min} = \frac{(1 - D)R}{2} \quad (8)$$

For continuous current,

$$\Delta i_L = V_o \frac{(1 - D)}{Lf} \quad (9)$$

Therefore,

$$L = V_o \frac{(1 - D)}{\Delta i_L f} \quad (10)$$

2.1.2 Capacitor Design

$$i_C = i_L - i_R \quad (11)$$

$$Q = CV_o \quad (12)$$

$$\Delta Q = C\Delta V_o \quad (13)$$

$$\Delta V_o = \frac{\Delta Q}{C} \quad (14)$$

$$\Delta Q = \frac{T\Delta i_L}{8} \quad (15)$$

$$\Delta V_o = \frac{T\Delta i_L}{8} \tag{16}$$

$$\frac{\Delta V_o}{V_o} = \frac{1-D}{8LCf^2} \tag{17}$$

Therefore,

$$C = \frac{1-D}{8L\left(\frac{\Delta V_o}{V_o}\right)f^2} \tag{18}$$

For the proposed converter, designed values are obtained using equation (9) and (18), and are shown in Table 1.

Table 1 Designed values

Sl No	Component	Values
1	Inductance	100μH
2	Capacitance	100μF
3	Resistance	100Ω
4	Switching Frequency	10kHz

3. Simulations

Figure 3 and 4 shows the Simulink diagram of the open and closed loop charge controller. The Equation (1) to (18) is used to obtain the desired value of inductor and capacitor for the input DC voltage of 12 V. Fig. 4 shows the flow chart of PWM pulse generation.



Fig 3. Simulink diagram of open loop system

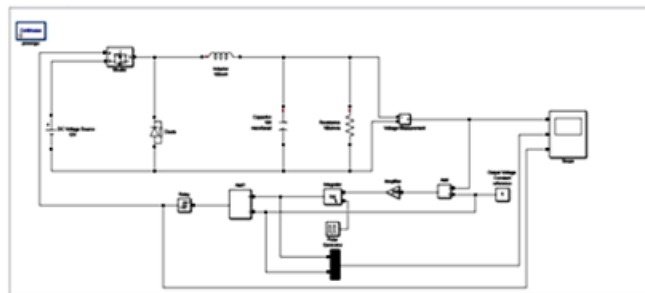


Fig 4. Simulink diagram of closed loop system

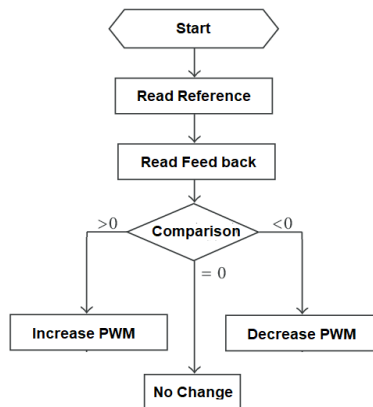


Fig .5. Flow chart of generation of PWM pulses

4. Hardware Implementation

The open loop and closed loop schematic is tested with Proteus software and the schematic diagrams are shown in Fig. 6 and 7 respectively. The details of Arduino board consist of 14 digital I/O pins. To generate the PWM pulses we use six pins of the Arduino which is built already inside the Arduino to perform the PWM function. According to Fig. 4, the potentiometer connected to the analog input A0. With this potentiometer, choose the output value between 1 and 12 volts since the maximum input voltage in this case is 12V. With the help of Arduino's ADC a value between 0 and 1024 is chosen, next, in the code, map that value from 1 to 244 which are the values used with the analog Write function of the Arduino. With this a PWM signal on pin D3 where 1 is the lowest duty cycle and 244 the maximum is applied. Since the Arduino digital voltage is 5V we add a small BJT driver using one S8050 NPN and two resistors of 10k and 1k. The output of this driver is connected to the gate of the IRF9540 P-MOSFET. The Fig. 5 shows the closed loop schematic with Arduino board. Depending on the code the output will be either high (5V) or low (0V). In PWM signal generation, the output voltage and the reference voltage are compared and accordingly the on or off period of the PWM signal is varied to maintain the output at constant value.

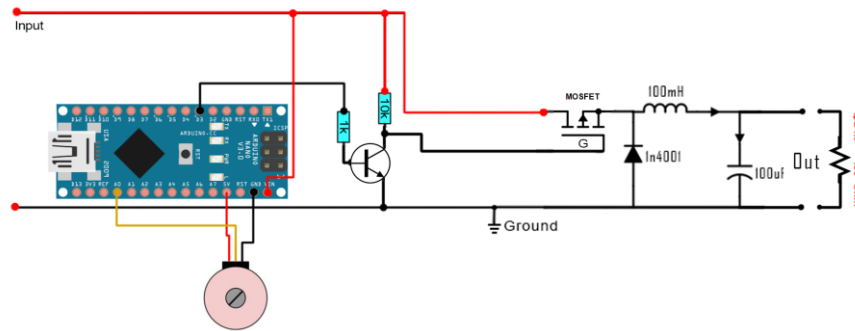


Fig.6. Proteus diagram of open loop PV Charge Controller

The flowchart of the PWM signal generation is shown in Fig. 4. The code for generating PWM signal is given below.

4.1 Program Code

```
int pot = A0;
int fb = A1;
int PWM_PIN = 3;
int pwm = 0;
void setup()
{
pinMode(pot, INPUT);
pinMode(fb, INPUT);
pinMode(PWM_PIN, OUTPUT);
TCCR2B = TCCR2B & B11111000 | B00000001;
}
void loop()
{
floatPotValue = analogRead(pot);
floatFbValue = analogRead(fb);
if (PotValue>FbValue)
{
pwm = pwm+1; pwm = constrain(pwm, 1, 254);
}
if (PotValue<FbValue)
```

```

{
pwm = pwm-1;
pwm = constrain(pwm, 1, 254);
}
analogWrite(PWM_PIN,pwm );
}

```

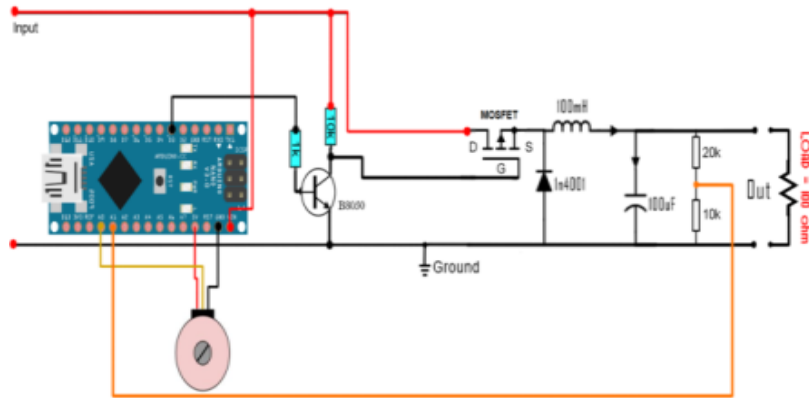


Fig. 7. Schematic diagram of closed loop PV charge controller

Similar to open loop configuration, a potentiometer is connected to the analog input pin A0 of the Arduino. Again this potentiometer is used to select the desired output voltage level that can range in between 1 and 12 volts. A voltage divider circuit is added at the output side to reduce the voltage from 12 volt to 5 volts. This voltage scaling is done because the maximum input voltage which Arduino ADC can handle is 5 volts. When the voltage higher than the 12 V is required to be applied to the input, the values of R_1 and R_2 should be selected in such a fashion that always a voltage below 5V should be available to the Arduino. The closed loop charge controller hardware setup is shown in Fig. 5 and the components used are shown in Table 2.

Table 2 List of major components used

SI No	Name of the component	Specification
1	P-MOSFET	IRF9540
2	Diode	IN4007
3	Inductor (air core)	100µH
4	Capacitor	100µF
5.	Potentiometer	10 K
6	BJT	BC547
7.	Arduino NANO	V 3.0

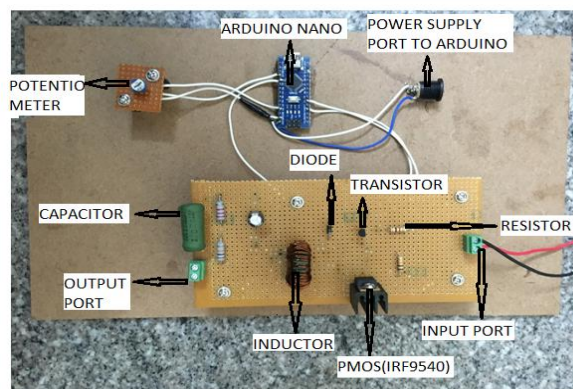


Fig. 8.: Hardware setup showing buck converter based closed loop PV charge controller

Fig. 8 shows the hardware model of proposed PV charge controller. For the sake of simplicity input panel or battery is not shown in the diagram. The individual components are labeled and the specification is given in table 2. The pulse generator output, wave is shown in Fig. 9 and the closed loop output voltage of Simulink model is presented in the Fig. 10.

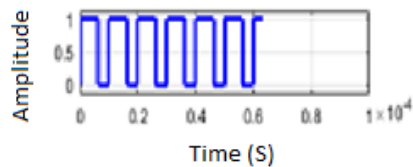


Fig.9. Pulse generator output

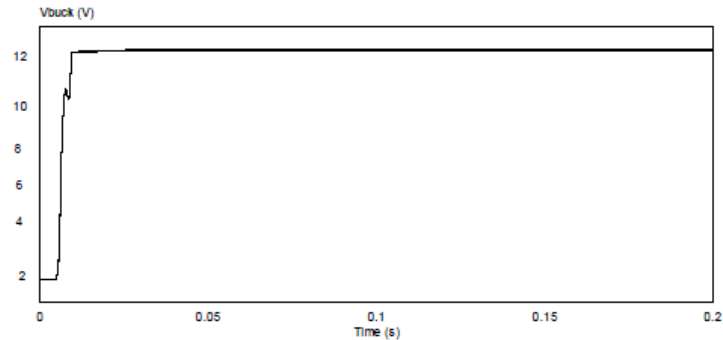


Fig. 10. Output voltage of closed loop Controller

5. Conclusion

Design and hardware implementation of PV charge controller using dc-dc buck converter in conjunction with Arduino-Nano is presented. The open loop and closed loop hardware model is tested with variable dc input of 12 V. The simulation results showing the behavior of the controller is presented. The features of the proposed converter are easy to use and less maintenance and low cost. The proposed charge controller is having better efficiency and best suited for low power applications.

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