Design of a Solar Charge Controller for a 100 WP solar PV System

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Abstract

This paper presents a low cost Solar Charge Controller (SCC) using Atmel Corporation ATmega8 microcontroller to control and coordinate the functions properly. Details of design for the construction of SCC using crystal oscillator, ceramic resistors, Light Emitting Diodes (LED) and MOSFET are presented. The source code for the ATmega8 microcontroller is written in Arduino IDE to obtain accurate and efficient automatic control action. Accordingly, battery can be disconnected from solar cell when overcharging and reconnected while discharging. The loads can be disconnected according to the over current and under flow current limit for both battery and PV. The proposed charge controller is equipped with LEDs to display the battery charging /discharging status, charge level and short circuit condition via microcontroller. The construction and operation of our proposed smart solar charge controller indicates that it is cost effective and functions properly.

Key Words: *SCC, Arduino IDE, SHS, microcontroller, crystal oscillator, LED, MOSFET.*

1. Introduction

One of the best ways to get power to remote, off-grid locations, whether in developed or developing countries is through Solar Home System (SHS). The system consists of Solar PV, battery, and a solar charge controller. In most cases consumers consume solar energy at evening hours. So, solar energy is stored into batteries. A solar charge controller is similar to the voltage regulator. It regulates the voltage and current that is coming from the solar panels and going to the battery. Most of the batteries are fully charged at 14 to 14.5 volts. On the other hand, battery's life time drastically reduces due to the discharge over the level of 70%-80%; at this discharge level the battery voltage normally goes down to 11.5 volts. Each battery has a certain limit of capacity. Battery lifetime reduces drastically due to overcharging and deep discharging. As battery is a very expensive component of a Solar Home System, it is necessary to protect the batteries from being over charged or deeply discharged. In this case charge controller plays a vital role to protect the battery [1].

A series charge controller disables further current flow into batteries when they are full. A shunt charge controller diverts excess electricity to an auxiliary or "shunt" load, such as an electric water heater, when batteries are full.

Charge controllers stop charging a battery when they exceed a set high voltage level, and re-enable charging when battery voltage drops back below that level. Pulse width modulation (PWM) and maximum power point tracker (MPPT) technologies are more electronically sophisticated [2].

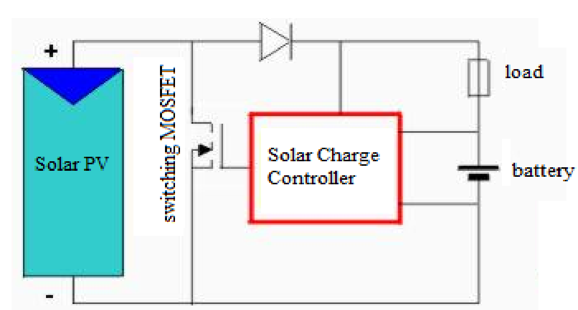

Figure 1. SHS with series controller

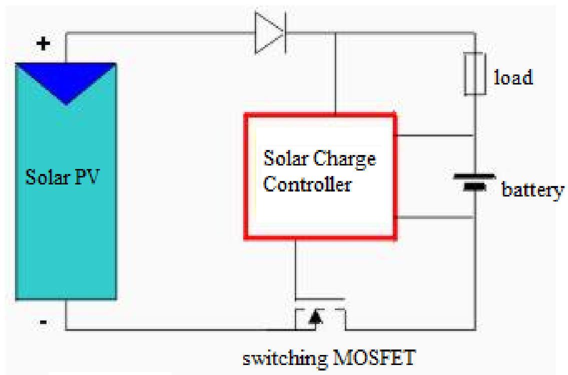

Figure 2. SHS with shunt controller

Battery condition and corresponding state of charge that we gathered from reading of formerly used batteries for solar system is used to measure the PWM states. The following chart represents a clear idea about battery condition that are generally used including charging and discharging both:

Table 1. Solar Charge Controller status set points

State of charge	12 V Battery
>13	100%
12	67%
11	34%
<10	1%

Figure 3. Charge controller and battery wiring

There are various brands manufacturing solar charge controller in the foreign markets which are developed according to the requirements of SHS. These SCC are very costly for under-developed countries like Bangladesh, especially at the rural areas. Solar Panel and battery are expensive as well. So, it is difficult for the consumers in rural areas to afford the additional costs for the expensive SCC in their solar energy system.

To make the SCCs available to the rural consumers within the affordable cost, a sophisticated solar charge controller has been developed. This SCC is very simple in construction and cost effective. The operation process is also very simple, easy to maintain and above all user friendly. The proposed SCC consists of a voltage regulator, a microcontroller, a crystal oscillator, three MOSFET and LEDs. According to the voltage level at battery terminal, which is set by the microcontroller, it controls the charging of battery from solar panel and hence improves the operational life of a battery. It also prevents the battery from complete discharging by disconnecting the load from the battery when the voltage level reaches to a critical value set by the microcontroller. It is our purpose to propose a cost effective SCC that improves the existing solar charges controller devices and the battery life of the solar system. This SCC can fulfil nearly all requirements which are needed for proper operation and protection of SHS.

2. Theoretical Background

This section covers the details regarding the importance of Battery is SHS. A battery is one or more electro-chemical cells that convert stored chemical energy into electrical energy. Since the invention batteries they have become a common power source for many household and industrial applications. There are two types of batteries: primary batteries (disposable batteries), and secondary batteries (rechargeable batteries), among them secondary batteries are more efficient and popular for its multipurpose uses. For the charging and discharging facilities the secondary batteries are exceedingly used for the solar panel power system. Despite having a very low energy-to-weight ratio and a low energy-to-volume ratio, their ability to supply high surge currents means that the cells maintain a relatively large power-to-weight ratio. These features, along with their low cost, make them ideal for using in SHS.

Because of the chemical reactions within the cells, the capacity of a battery depends on the discharge conditions such as the magnitude of the current, the allowable terminal voltage of the battery, temperature and other factors [3]. The available capacity of a battery depends upon the rate at which it is discharged. If a battery is discharged at a relatively high rate, the available capacity will be lower than expected. The speed of recharging for lead-acid batteries may be increased by manipulation [4]. The battery capacity that battery manufacturers print on a battery is usually the product of 20 hours multiplied by the maximum constant current that a new battery can supply for 20 hours at 68 F° (20 C°), down to a predetermined terminal voltage per cell i.e. a battery rated at 100Ah will deliver 5A over a 20 hour period at room temperature. However if it is instead discharged at 50A, it will have a lower apparent capacity [5].

For low values of current drawn from battery internal self-discharge must be included. In practical batteries, internal energy losses, and limited rate of diffusion of ions through the electrolyte, cause the efficiency of a battery to vary at different discharge rates. When discharging at low rate, the battery's energy is delivered more efficiently than at higher discharge rates [6], but if the rate is too low, it will self-discharge during the long time of operation, again lowering its efficiency. Rechargeable batteries self-discharge more rapidly than disposable alkaline batteries, especially LEAD-based batteries; a freshly charged $PbSO_4$ loses 10% of its charge in the first 24 hours, and thereafter discharges at a rate of about10% a month [7]. Although rechargeable batteries have their energy content restored by charging, some deterioration occurs on each charge/discharge cycle. Lead-acid batteries tend to be rated cycles before their internal resistance permanently increases beyond usable values. Day by day this resistance increases so the rated cycle rate also decreases and by that the lifespan decreases. Normally a fast charge, rather than a slow overnight charge, will shorten battery lifespan. However, if the overnight charger is not "smart" and cannot detect when the battery is fully charged, then overcharging is likely, which also damages the battery [8].

Degradation usually occurs because electrolyte migrates away from the electrodes or because active material falls off the electrodes. Lead-acid batteries suffer the drawback that they should be fully discharged before recharge. Without full discharge, crystals may build up on the electrodes, thus decreasing the active surface area and increasing internal resistance. This decreases battery capacity and causes the "memory effect". These electrode crystals can also penetrate the electrolyte separator, thereby causing shorts. Lead-acid although similar in chemistry, does not suffer from memory effect to quite this extent. When a battery reaches the end of its lifetime, it will not suddenly lose all of its capacity; rather, its capacity will gradually decrease. Lead-acid batteries should never be discharged to below 20% of their full capacity, because internal resistance will cause heat and damage when they are recharged.

Battery life can be extended by storing charge of the batteries, as in controlling the cover charge of batteries which slows the chemical reactions in the battery. Such storage can extend the life of these types of batteries by about 5%. To reach their maximum voltage, batteries must be stopped to store of charge. As a result, due to these drawbacks and lifespan improvement process of these types of batteries like lead-acid batteries if we use SCC properly then lifespan of batteries can be extended.

Basically here battery charging rate is kept normal, neither fast nor slow. The discharge limit will not go under the 50%. The microcontroller can sense according the program that when it is needed to charge and when at nearly full charged it is needed to cut off from the Solar Panel. For further operation this proposed SCC can control the movement of the load according the charge and discharge of the battery.

3. System Structure

3.1 Controlling Unit

Figure 4 shows the flowchart of Charge Controller Logic Circuit Program. All the status of solar and battery are observed by the microcontroller by the following algorithm. The whole decision is taken by the microcontroller alone. It follows the program which is burned into it. This program is written on the basis of theoretical concept to increase the battery efficiency.

The main theme of whole process and controlling can be summarized as follows:

i. If battery voltage is less than 5.5V, controller determines it a short circuit condition and load is disconnected immediately.
ii. If battery voltage is less than 10V, controller turns on the battery charging and load is disconnected from battery (for 12V load).
iii. If battery voltage is greater than 15V, controller turns off the battery charging.
iv. If battery voltage is greater than and equal 12V, load can be connected with battery normally (for 12V load).

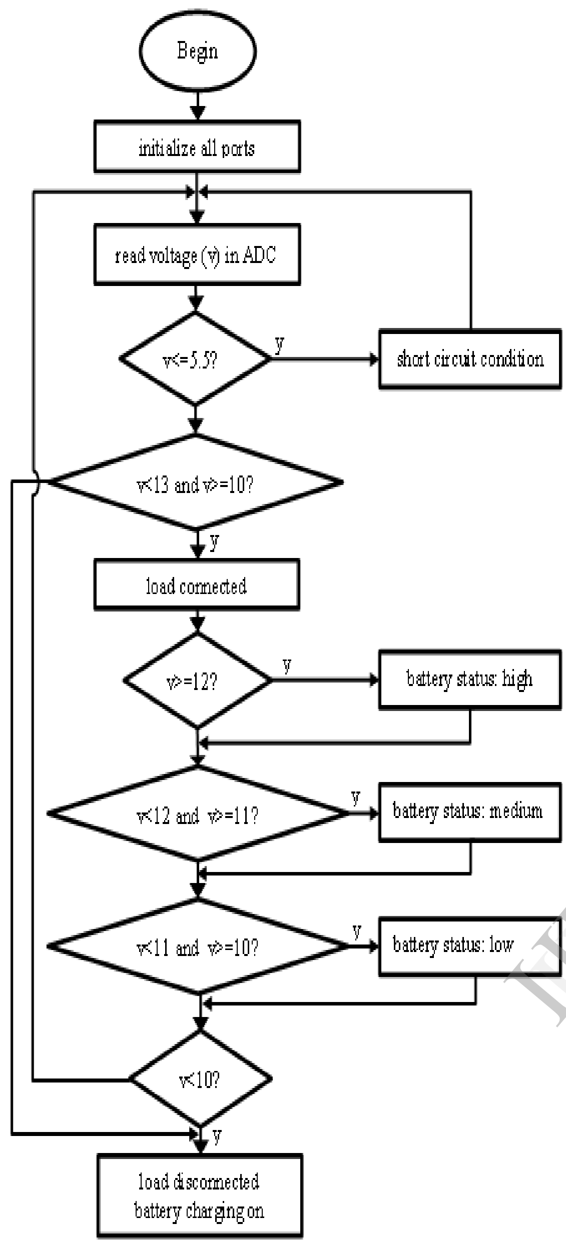

Figure 4. Flowchart of Charge Controller Logic Circuit Program

3.2 Functional Blocks of Our SCC

Figure 5 shows the whole process that can be described by using four functional blocks. In this way it is easier to understand the individual operation of step by step process of the whole system. The SCC is divided into four major blocks:

i. Power supply unit
ii. Load distribution unit
iii. Charging unit
iv. Control unit

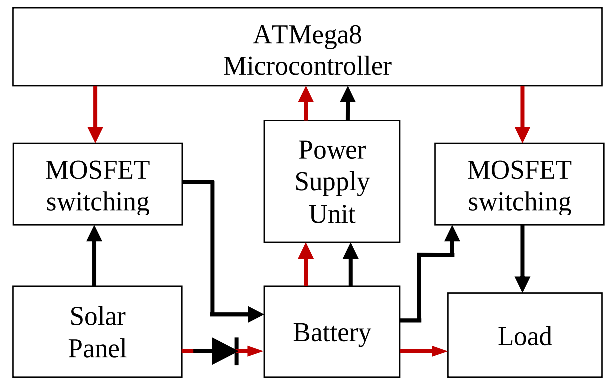

Figure 5. Functional block diagram of a SCC

(i) Power supply unit (PSU)

A PSU consists of some necessary equipment such as diodes, ceramic resistors, inductive coil, capacitors and voltage regulator. In this circuit, in Figure 5, we used Solar Panel as an input. From Solar Panel, power is delivered to battery via two Diodes. These two Diodes do not allow the flow of charge from battery to the solar panel reversely at night due to the potential difference among battery and Solar Panel. This output from the two Diodes is connected to a filter circuit which consists of a bank of capacitors and inductor. The output is fed to the voltage regulator. For our SCC circuit we needed fixed 5V supply, which is generated from voltage regulator. After the voltage regulator there are some optional filters units which may be used to prevent farther noise. This pure signal (5V) is sent to the ATMega8 microcontroller.

(ii) Load distribution unit

In a SHS all (+)ve ends of loads are connected with the (+)ve end of battery. Then the (-)ve switching is established by using MOSFETs. The positive end of battery is directly connected with the positive end of load. To control the load switching we have used microcontroller and MOSFET. The microcontroller checks the overall status of the system. If the requirement is fulfilled then microcontroller sends the signal to the MOSFETs. Thus they establish the negative switching (to reduce heat in the circuit) with the load. So the circuit is closed and load is connected with the battery.

(iii) Charging unit

Here the charging is controlled by the microcontroller and switching by the MOSFET. Here also the (-)ve switching concept is used. The (+)ve end of Solar Panel is connected to the (+)ve end of battery via two blocking Diodes. The whole voltage status of both the Solar Panel and the battery go to microcontroller analogue inputs to compare with the logic that is set inside the microcontroller. If the entire requirement is fulfilled then microcontroller sends a switching signal to the MOSFET. After that, the circuit is closed and power flows from the Solar Panel to the battery. Otherwise the microcontroller does not send any signal to the MOSFET. As a result the circuit remains open leading to no power flow from the Solar Panel to the battery. In this way battery is charged.

(iv) Control unit

In this part the status of solar and battery is sent to the microcontroller to compare with the logic which is programmed from the first in microcontroller. The crystal oscillator is used to generate stream pulse to microcontroller. The purified 5V signal comes from voltage regulator to microcontroller through filter. The decisions which are required according the logic of microcontroller are sent to LEDs for observing the whole status of the SCC. As we have described the operation of solar charge controller partly, so whole operation is combination of those four functional blocks, total work is done at a time.

When input connector gets input from solar power supply, it generates the operating voltage for the circuit, as well as to store the charge in battery. This operating voltage operates the microcontroller and LEDs after regulating this voltage using voltage regulator.

Microcontroller takes decision when battery is become over charged. This decision is given by microcontroller to MOSFET whether it has to open or not. If stored charge is available in the battery for the permitted loads according the power of battery, the whole setup is ready to operate and makes a smooth operation.

Microcontroller also performs the protection operation in this SCC. If there is any short circuit condition in the SCC or in the system it automatically detects the fault and interrupts all the power flow both from the Solar Panel to the Battery and from the battery to the load preventing further damage. A LED is then lit to make a acknowledge signal. The overall battery charge is also observed with a set of LEDs

4. Hardware Implementation

According to the flow chart a program is written in Arduino IDE and loaded to the microcontroller. Here, the microcontroller initially gets the solar panel and battery voltage through its two analogue-pins and digitizes it. If the battery voltage is less than the set value, it sends pulse to the MOSFET to charge the battery disconnecting the load. If the battery voltage is greater than the High Voltage Disconnect set point then it sends another pulse to the MOSFET to stop charging the battery and connecting to the load. The actual SCC is illustrated in Figure 6. Figure 7 illustrates a buck converter module that sets its duty cycle automatically to maintain a steady 14V power supply to the SCC. Figure 8 shows the actual wave shape during charging.

Figure 6. Actual hardware of the SCC for a 100WP SHS

Figure 7. Buck converter Module for SCC

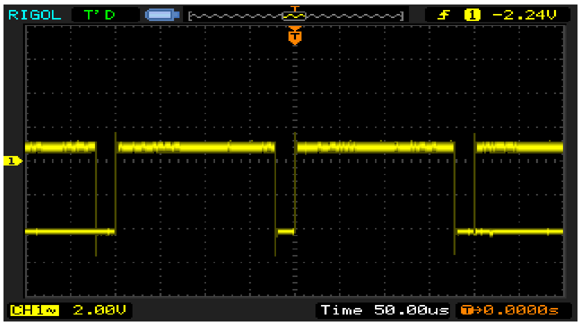

Figure 8. Charging wave shape

5. Result and Analysis

The project has been tested according its operational purposes. Maximum power rating of the experimented solar charge controller is 100W according battery capacities, so the system has been tested by both two 15W DC light and 20W DC fan, which is operated successfully.

For load distribution unit positive switching method was used. But this method was found to produce more heat. As a result, we adopted negative switching method which produced less heat than before. All (+)ve ends are connected with each other but the (-)ve ends are controlled by switching using MOSFETs.

For charging unit the instruction of the battery manufacturer has been strictly followed. The upper and lower limits are carefully set so that the battery is not damaged.

For control unit, there were some distortions of signal when it was observed into the oscilloscope. We used two times of rated LC filter circuit to reduce the noise and send the pure signal to microcontroller for its proper operation. A crystal oscillator is used to ensure a stream of clock pulse to the microcontroller.

Our SCC had to go through plenty of test runs and Short Circuit Tolerance tests before the optimum performance was achieved. The project completed successfully with all the features of operations of the solar charge control system as desired.

An over charge alarm can be added farther to protect batteries from over charging. A data logger module can also be added to the system. The system can be farther upgraded to MPPT to increase the SCC efficiency. Besides, while using in the commercial schemes the device needs to be modified and corrected. If all these modifications can be added for the further betterment a perfect and proper solar power system can be manufactured.

5. Conclusion

Cost effective solar charge controller has been designed and implemented using Atmel ATMega8 microcontroller to have efficient system and much longer battery lifetime. From the overall analysis presented, it can be concluded that our proposed SCC can be commercially used to optimize the energy crisis in the rural areas.

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