Development of a Microcontroller-based Battery Charge Controller for an Off-grid Photovoltaic System

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Abstract. A development of a microcontroller-based charge controller for a 12V battery has been explained in this paper. The system is designed based on a novel algorithm to couple existing solar photovoltaic (PV) charging and main grid supply charging power source. One of the main purposes of the hybrid charge controller is to supply a continuous charging power source to the battery. Furthermore, the hybrid charge controller was developed to shorten the battery charging time taken. The algorithm is programmed in an Arduino Uno R3 microcontroller that monitors the battery voltage and generates appropriate commands for the charging power source selection. The solar energy is utilized whenever the solar irradiation is high. The main grid supply will be only consumed whenever the solar irradiation is low. This system ensures continuous charging power supply and faster charging of the battery.

1. Introduction

In an isolated system, excessive electricity is usually stored in batteries during the day and the batteries are used to power the appliances in times when PV panels do not absorb enough energy. Solar regulator (also known as electronic charge controller) plays an important part in an isolated solar system. The goal is to ensure the battery charging cycle is working at optimal conditions, mainly to prevent overcharging and deep discharge.

Nevertheless, the conventional electronic charge controller only utilizes a single power source to charge the batteries, either the renewable source or non-renewable source [1-3]. To overcome the limitation, some hybrid electronic charge controllers have been developed to incorporate multiple charging sources such as main grid and PV panel [4-6]. Nonetheless, the controllers are still lack of appropriate techniques for proper utilization of multiple charging sources. Some charge controllers were used a timer to switch-on or cut-off the power supply. Besides, the charging time taken was longer [7-9].

In this paper, a development of a hybrid charge controller for the battery and its implementation are discussed. One of the main purposes of the hybrid charge controller is to supply a continuous charging power source to the battery. Furthermore, the hybrid charge controller was developed to shorten the battery charging time taken. The solar energy is utilized whenever the solar irradiation is high. The main grid supply will be only consumed whenever the solar irradiation is low. The hybrid charge
controller is equipped with an Arduino UNO R3. The Arduino UNO R3 is embedded with an algorithm which selecting the power charging source. The proposed method focuses on the implementation of two predefined voltage thresholds. When the battery status reaches the upper voltage threshold, the charging process is stopped. The battery voltage is monitored until it drops to the lower voltage threshold, in which the charging process begins.

2. Control system
The control system can be divided into two components which are the schematic diagram and system cycle.

2.1. Schematic diagram
Figure 1 shows the schematic diagram of the proposed hybrid battery charge controller system. As can be seen, there are two power sources that will charge the battery which are PV panels and main grid supply. The charging power sources selection was controlled by the hybrid battery charge controller. For this system, solar energy gets the priority to charge the battery rather than the main grid supply which may save hundreds of kilowatts power per day.

![Schematic diagram of battery charge controller](image)

**Figure 1.** Schematic diagram of battery charge controller.

2.2. System cycle
The principal aim of this study is to develop a hybrid charge controller that can auto-select the best power source for the purpose of battery charging system. The system is realized by monitoring the battery voltage, $V_{bat}$ and solar voltage, $V_{sol}$ status. To connect or disconnect the battery with the charging power source, two predefined battery voltage thresholds, which are upper voltage threshold, $V_{UV}$ and lower voltage threshold, $V_{LV}$ have been determined. The $V_{UV}$ is defined as the maximum value of battery voltage in which the charging power source will be cut-off. Meanwhile, the $V_{LV}$ is defined as the minimum value of battery voltage in which the charging power source will be connected.

2.2.1. Battery voltage thresholds. The determination of $V_{UV}$ and $V_{LV}$ is depends on the battery instantaneous state of charge (SOC) (will be discussed in Section 3.2). The SOC is described as the
ratio of battery current capacity, \( Q_t \) to the nominal capacity, \( Q_n \) [10]. The nominal capacity is given by the battery’s manufacturer and represents the maximum amount of charge that can be stored in the battery. For this study, the \( V_{UV} \) and \( V_{LV} \) are 13.5V and 10.8V, respectively. When the \( V_{bat} \) is lower than the \( V_{LV} \), the battery will start to be charged. The battery also will be charged continuously if the \( V_{bat} \) is lower or equal to the \( V_{UV} \). The charging process is disconnected only if the \( V_{bat} \) is higher than the \( V_{UV} \).

2.2.2. Charging power source selection. To select the charging power source, \( V_{sol} \) status is observed. If the \( V_{sol} \) is higher than the main grid supply (already stepped down to 12V DC), the solar source is utilized to charge the battery. Otherwise, the main grid supply will be selected to charge the battery. These cycles are presented as in Figure 2.

![Flowchart of the battery charge controller](image.png)

**Figure 2.** Flowchart of the battery charge controller.
3. System components
The hybrid charge controller design requires the estimation of solar PV array, battery model and the charge controller circuit. In order to estimate the components, there are some calculations applied.

3.1 Solar PV array
For the modeling of PV array, it is important to configure the power supplied by a set of PV panels, \( P_{pv} \) at hour, \( t \). The \( P_{pv} \) can be calculated using the PV module specifications provided by the manufacturer and it can expressed by Equation (1) [11].

\[
P_{pv}(t, \beta) = N_s \cdot N_p \cdot V_{OC}(t, \beta) \cdot I_{SC}(t, \beta) \cdot FF(t)
\]  

(1)

where \( N_s \) and \( N_p \) are the number of PV modules connected in series and parallel, respectively. \( V_{OC}(t, \beta) \) is the PV module open circuit voltage (V) at hour \( t \), \( I_{SC}(t, \beta) \) is the PV module short circuit current (A) and \( FF(t) \) is the fill factor of hour \( t \). Thus, from the Equation (1), the total power output from a PV array is can be calculated by Equation (2). Note that the \( \eta_{pv} \) is the PV module’s and corresponding converters efficiency [12].

\[
P_{array}(t, \beta) = \eta_{pv} \cdot N_s \cdot N_p \cdot P_{pv}(t, \beta)
\]  

(2)

3.2 Battery model
The modeling of battery has very important role for the simulation of the standalone PV system to maintain power balance between generation and demand. In this work, a generic battery model of lead-acid battery is used as it is more convenient for renewable energy system because of its low cost and availability in large sizes. The instantaneous SOC is usually used to determine the battery charging and discharging state. The instantaneous SOC can be expressed by Equation (3) [13].

\[
SOC(t) = SOC(t-1) \times \left(1 - \frac{\sigma \times \Delta t}{24}\right) + \frac{I_{bat}(t) \times \Delta t \times \eta_{bat}}{C_{bat}}
\]  

(3)

where \( SOC(t) \) and \( SOC(t-1) \) are the SOC at the current (t(h)) and previous (t-1) hour respectively, \( \sigma \) is the self-discharge rate (assumed to be 0.2% per day) and \( C_{bat} \) is the capacity of a battery. The battery charge efficiency \( \eta_{bat} \) is taken to be 0.8 and the discharge efficiency is taken to be 1 as suggested in [13].

3.3 Charge controller circuit
For reliability and stability features, Arduino Uno R3 was used to programme the algorithm that controls the system of the charging cycle. The Arduino Uno R3 has been chosen over other microcontrollers for the reason of easily configurable and faster to prototype. Furthermore, it is very easy to code and interface with other sensors [14]. Voltage sensor is used to replace the conventional voltage divider components. Its input pin is connected with the battery terminals and it compares the \( V_{bat} \) with the \( V_{LV} \) and \( V_{UV} \), respectively. Another voltage sensor also used to monitor the \( V_{sol} \). Its input pin is connected with the solar panel terminals and the measured \( V_{sol} \) will be compared with the main grid supply voltage. The voltage sensors pin for battery and solar panel are connected with the analog pin A0 and A1 of the Arduino Uno R3 board, respectively. Next, the control system algorithm assembled in the microcontroller board will process the input from the analog pin and producing the output on the digital output pin.
It is important to note that the Arduino digital output pins are connected with the input pins of 2-channel relay module and a liquid crystal display (LCD). The relay module is connected with the solar source and main grid supply. It is triggered by the digital output produced from the Arduino digital pin and switching to which power source is selected. The voltage readings for both battery and solar source are displayed on the 20x4 liquid crystal display (LCD) connected on the digital output pin. The battery charging status and charging source also can be observed on the LCD. The fabricated control circuit and LCD interface are shown as in Figures 3 and 4, separately.

![Figure 3. The fabricated control circuit.](image1)

![Figure 4. LCD display.](image2)
4. Experimental setup
The hybrid charge controller system performance is carried out following the flowcharts of Figure 2. The system design and input data for each component is outlined in Table 1. An experimental setup was prepared at a small cabin container located in School of Mechatronic, Universiti Malaysia Perlis showed in Figure 5. The 100W solar panel is placed according to the optimal tilt angle for location of Perlis, Malaysia which is 6.840° [15]. The battery charge controller box is placed in the panel box (installed in the cabin container). Figure 6 shows the panel box, equipped with the battery and charge controller box. The charge controller box needs to be connected to the solar panel, 12V battery, 12V DC power supply and a central processing unit. The experimental is running from 7 a.m. to 7 p.m.. The data collected were two sets of data which are $V_{bat}$ and $V_{sol}$.

Table 1. System’s components specifications.

| No. | Components | Specifications                  |
|-----|------------|---------------------------------|
| 1.  | Solar PV   | Model GSMG-100M                 |
|     |            | Maximum power($P_{max}$) 100W   |
|     |            | Power tolerance ±3%             |
|     |            | Maximum power voltage ($V_{mp}$)17.1V |
|     |            | Maximum power current ($I_{mp}$)5.85A |
| 2.  | Battery    | Type Lead-acid                  |
|     |            | Nominal voltage 12V             |
|     |            | Capacity 7.2Ah                  |
|     |            | Float charging voltage 13.5V    |

Figure 5. The cabin container (testing site).

Figure 6. Panel box.

5. Result and discussion
Several experiments were conducted to determine the time taken for the battery to be fully charged. Figure 7 represents the average daily voltage-time characteristics of the battery during charging periods. The solar irradiation also presented in the figure. From the graph, it can be seen that the initial $V_{bat}$ is 10.8V. The charging power source is connected automatically. The $V_{bat}$ reached maximum voltage capacity at 1 p.m. and starts to constant at 2 p.m.. At that time, the power source has been cut-off due to the battery capacity has reached the $V_{UV}$. Note that the battery capacity is dropped due to the battery behaviour of float mode.
Compared to the other charge controllers [7-9], the battery connected to the developed hybrid charge controller is only took about six hours to be charged from 10.8V to 13.5V. From the graph, there was a significant relationship between charging time and $V_{bat}$. It is observed that the battery is rapidly charged from 10 a.m. to 1 p.m.

![Figure 7. Solar charging test.](image)

6. Conclusion
In this study, a hybrid charge controller for a battery of a PV system has been discussed to observe the battery charging time characteristic. The charge controller is combined two power sources, solar energy and main grid supply electric, to charge the battery in a continuous manner. The results obtained from the experiments showed that the charge controller can be implemented in a PV system as the battery charging time can be shortened compared to the conventional charge controller.

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