



# Real-Time Monitoring of a Solar Charge Controller for Stand-Alone Photovoltaic Systems

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**Abstract:** Solar charge controllers are devices that handle battery charging from solar cells and control the flow current to batteries and loads. The technology to implement such controllers mostly involves microcontrollers. However, the design of integrated advanced monitoring and control mechanisms is required so that users can enhance the energy consumption performance. This work aims to develop a standalone solar charge controller that allows real-time monitoring of the battery status and is included with an automatic circuit breaker for increasing the battery lifetime. The implementation is completed in four phases which involves the design and development of the hardware, software as well as prototype for testing. The results have shown that a solar charge controller with real-time online monitoring of the battery status can be implemented successfully through Things Net platform.

**Keywords:** Solar charge controller, Stand-alone PV and Microcontroller.

## I. INTRODUCTION

Malaysia has carried out various efforts to find and generate renewable energy as a future power source. Among the efforts undertaken by the government were the establishment of the Malaysian Energy Centre (PTM) in 1998 to co-ordinate and manage research and development programs on energy and promote renewable energy use in Malaysia [1]. One of the renowned renewable energy sources in Malaysia is solar energy.

Solar power has several advantages, among which are low maintenance and pollution-free, but the main disadvantages of solar energy are high fabrication costs and lower energy conversion efficiency. Since solar panels have relatively low conversion efficiency, the overall system costs can be reduced by using an efficient solar charge controller that can produce maximum power from solar panels. In solar energy systems, charge controllers are the heart of the system designed to protect the rechargeable batteries [2].

The charge controller limits the rate at which the electric current is added or withdrawn from the battery. It prevents overcharging and prevents excessive overheads being used by loads where it reduces battery performance or lifespan and may pose a security risk. In a simple definition, solar charge controllers are devices that handle battery charging from solar cells and control the flow current to batteries and loads. Solar charge controllers like the one shown in Figure 1 inspect the battery whether they require charging and if so, it checks the availability of solar power and starts charging the battery. When the controller finds that the battery is fully charged, it then cuts off the power supply to the battery [3].



Fig. 1 solar charge controller [4] Photonic Universe

Two commonly used solar charge controllers are Pulse Width Modulation (PWM) and Maximum Power Point Tracker (MPPT) based controllers. The PWM-based controllers control the switching duty ratio as input changes to produce a fixed output voltage. The DC voltage is converted to square wave signal, alternating between zero and zero. By controlling digital analog circuits, system costs and power consumption can be drastically reduced [5].

Manuscript published on November 30, 2019.

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PWM control can be used in two modes i.e. voltage mode and current mode. In the voltage mode, the output voltage can be controlled increasingly or decreased when the ratio of the task increases or decreases. Perceived output voltage will be used as feedback.

If the system has two levels of regulation, the system will withstand the voltage until the maximum voltage is safe for the battery to fully charge. Then it will lower the voltage to maintain the completed charge [6]. In a PWM charge controller, the current from the solar panel follows the battery condition and recharging requirements. When the battery voltage reaches the set point, the PWM algorithm slowly reduces the charge current to prevent battery heating but charging continues to return the maximum amount of energy to the battery in a short time. The array voltage will be pulled to the battery [2]. PWM can extend battery life and save costs by reducing battery size [7].

MPPT based controller is a more recently introduced charge control and is the latest trend in the market. It is more expensive and more suitable for large systems. Investment in the MPPT controller can provide faster returns. The MPPT controller can charge the battery with full power to maintain the efficiency of 90% to 93% [7]. An MPPT charge control is based on a uniform buck converter circuit. It steps the solar panel voltage higher and into the battery charging voltage. It will also adjust the input voltage to collect the maximum power from the solar panel and then change this power to supply different voltage requirements to the battery and load. It is generally accepted that MPPT will overcome PWM in cold temperate climates, but both controllers will perform similarly in subtropical climate to tropical climate. The MPPT charge controller is a DC transformer to DC which allows the power conversion from higher voltage to power at lower voltage. The total power is unchanged and if the output voltage is lower than the input voltage, the output current will be higher than the input current so that the equation  $P = VI$  remains constant [2].

If the maximum charging capacity is the only factor to consider when determining charge controllers, the MPPT controller will be the preferred comparison to the PWM controller, but these two technologies are different, each having its own advantages. The results depend on temperature conditions, array voltage, battery voltage, system size and the cost of a specific solar panel system [2].

Many studies have looked at the technology used to implement the solar charge controllers. According to [8], if an analog circuit is designed, it has many disadvantages such as cost & development problems. The circuit needs to reset if there is a low current through the FET driving circuit. There are also special circuits requirements that can overcome the weaknesses of an analog circuit and should provide a high accuracy with very low size and cost. In addition, the charge controller for a photovoltaic system can be controlled separately through writing specific program codes in a multi-function microcontroller such as PIC16F73. The main purpose is to make the charge controller as low cost as possible so it is affordable, compared to an MPPT based charge controller which can be very expensive [9]. Another research, [10], have expanded their analysis and proven that the solar battery charger can be designed based on the microcontroller. Solar energy is used as a power

source for charging the battery. The battery is used to store energy from solar panels. Saved energy will be used in various applications. Microprocessor is used to measure voltage and turn off the battery.

The design of integrated advanced monitoring and control mechanisms with the capability to better monitor and control power consumption of a solar energy system is required so that users can easily measure the power consumption of electronic devices and optimize their usage to enhance their energy consumption performance [11]. For the micro grid, the monitoring and control of the microgrid is usually supported by a digital communication system integrated in the architecture of the micro grid system [12]. Variables like voltages, power, and weather parameter can be logged and made available for remote applications such as SCADA, utilizing TCP/IP capable communication infrastructure [13].

With the support of the expanding Internet of Things (IoT) and cloud computing technology, these tasks can be implemented remotely [13]. From practical aspects point of view, wireless communication network offers the best choice for ease of deployment, cost and maintainability. Examples of this are applications developed using cloud-based service for monitoring of photovoltaic system [14], and domestic small-scale renewable energy systems [15]. Within these systems, real time data monitoring and displaying are possible, as well as report generation, data history and communication status display.

This research focuses on the monitoring and control of the solar charge controller. Although the solar charge controller circuit uses basic and commonly available components in the market the main aim of this work is on the monitoring of the parameters. Thus, results of the work highlight the monitoring aspect as well as experimental readings based on what has been obtained from the monitoring system built on Things Net platform.

## II. DESIGN OF EXPERIMENT SETUP

In this research, there are four phases involved which are the design and hardware development, software development, prototype development, and final product testing. Figure 2 is the block diagram of the solar charge controller.

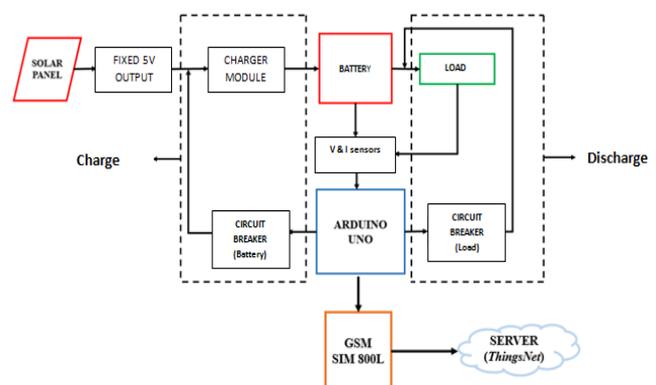


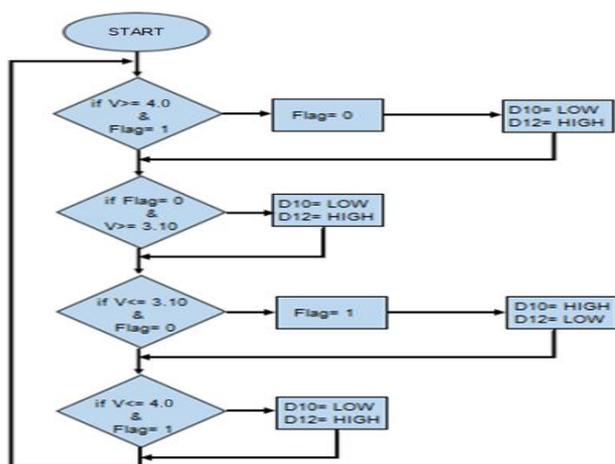
Fig. 2 Block diagram of the solar charge controller

In the first phase several parameters and hardware devices are chosen (Table 1). An automatic circuit breaker is also included to prevent excessive charging and overload of the battery.

**Table. 1 Selected variable parameters and levels.**

Hardware	Parameters and Levels
Solar panel	12V, 0.8A
Lithium ion battery	4.2V max charge
Max471	Battery voltage and current monitor
GSM SIM800L	Liaison for data to be transferred to the cloud (Things Net web server

For the second phase, the software is developed based on Arduino microcontroller. There are two sources of software code to be developed and encoded. The first source of the code is to control the battery charge and discharge the battery to the load so that the charging and discharging of the voltage can meet the specified specifications. The programming flow is shown in Figure 3. The second source code is to send voltage data information to Things Net web server to ensure that monitoring work can be done more efficiently.



**Fig. 3 Flow of the software code for charging and discharging of the battery**

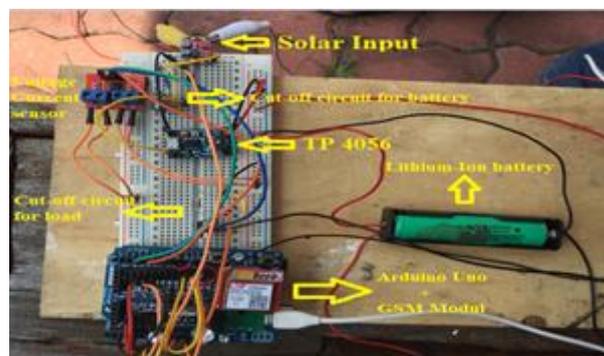
Phase 3 is the hardware prototype development. The hardware prototype of the solar charge controller is designed to protect the rechargeable battery. For these prototypes, it will be divided into three parts where the first part is a component that will be used to detect the lithium ion battery voltage and the current tuning from the load. The second part is the automatic circuit breaker for the battery and the load, and the third part is the use of the GSM module for sending solar charge controller status to a web server, ThingsNet. The ThingsNet platform used for storage of the data is a platform developed by the CAISER™ lab at UKM. It enables identified sensor data to be stored in the web server and can be accessed as required. The data is available instantaneously and allows real-time remote monitoring of the solar charge controller voltages.

The heart to this solar charge controller is the Arduino Uno board. This Arduino Uno board will store voltage from the battery by using the MAX 471 sensor and it will decide

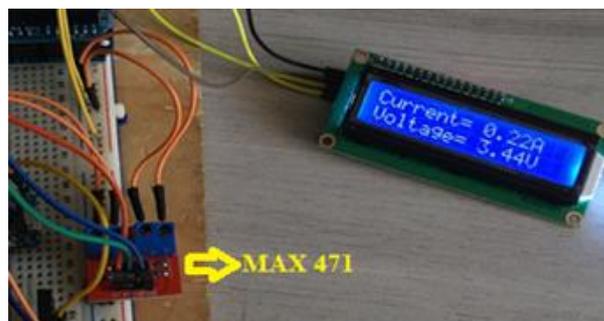
how to charge the battery and control the load according to the predefined conditions. Subsequently, the solar charge controller is included with an automatic circuit breaker using the IRF540N mosfet component as the mosfet gate is connected to the Arduino Uno to adjust charging as well as discharging according to battery status. For example, if the battery status is approaching full, Arduino Uno will send a low signal to the mosfet to break the charge circuit and connect the discharge circuit to the load and vice versa. This approach will lower the battery stresses during charging and discharging. Finally, all data from the battery will be sent and displayed to the web server using the GSM module responsible for sending data to the server.

**III. RESULTS AND DISCUSSIONS**

Figure 4 shows the experimental hardware built where the solar panel is connected to the battery and the load. An LCD display which shows the voltage and current levels is included. The voltage and current measurements are obtained using the MAX471 sensor module as shown in Figure 5.



**Fig. 4 The hardware experimental setup**



**Fig. 5 Voltage and current sensor module**

The Arduino analog input can be used to measure the DC voltage between 0 and 5V when using the 5V analogue standard as the reference voltage. The analogRead () function in the software reads the measured voltage and convert it to a number between 0 and 1023. The output of the function will produce a value between 0 (0V as input reference) and 1023 (5V as input reference) and 0.0048828V for each voltage increase. Therefore, this sensor requires a formula to be used in the software to be encoded inside the Arduino. The formula for voltage and current is as shown below:

$$5V = analogReadcount \ 1024$$

$$1 \ analogReadcount = \left(\frac{5}{1024}\right)V = 0.0048828V$$

$$Voltage = analogRead * \left(\frac{5}{1024}\right) * 5 \tag{1}$$

$$Current = analogRead * \left(\frac{5}{1024}\right) \tag{2}$$

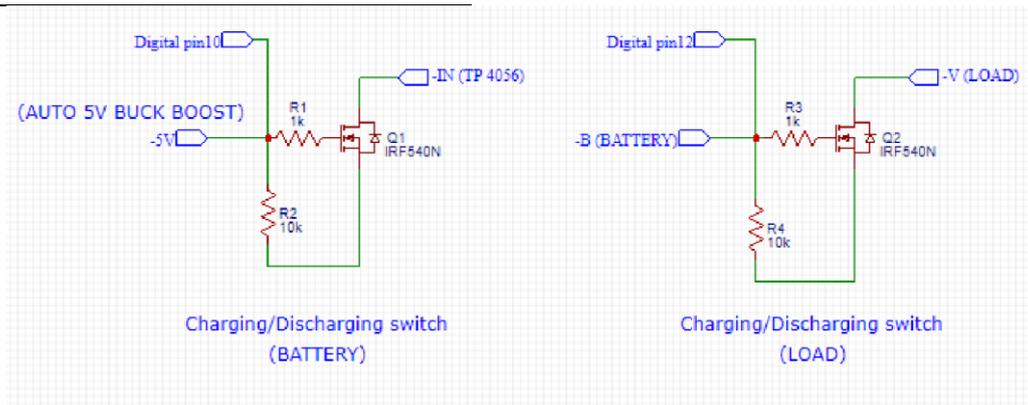
The automatic circuit breaker function allows up to 23A load and peak current of 110A. The settings for the battery and load are depicted in Table 2 below:

**Table. 2 Selected variable parameters and levels**

Battery voltage setting	Load status	Battery status
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Less than 3.10V	Close	Charging
More than 4.00V	Open	Discharging

Two automatic switching circuits are included in the charge controller as shown in Figure 6 in order to control charge or discharge of the battery and the load. The automatic switching circuit uses n-channel MOSFET (IRF540N). The combination of microcontroller and MOSFET is used to control the load operation of the charge controller. The Arduino Uno gives HIGH digital signal or LOW digital signal to the gate terminal of a MOSFET to indicate whether to operate or stop according to the charge set point voltage of the battery defined earlier.



**Fig. 6 Automatic switching circuit**

The monitoring is done through a server called Things Net by using the GSM SIM800L modules. The web server is developed by the CAISER™ laboratory under the Centre for Integrated Systems Engineering and Advanced Technologies (INTEGRA), UKM. Things Net is developed and located at a Virtual Private Server. Things Net platform enables four types of users or clients which are Arduino, raspberry Pi, AT Mega as well as mobile phone sensors. The sending of data can be done through radio frequency, internet TCP/IP and UDP, and Bluetooth technology. Things Net not only functions as remote database storage, it also enables data to be displayed through its web portal and enables users to download the data in the text or .csv format. Figure 7 shows the interface of Things Net and the source ID menu options.



(b)

**Fig. 7 (a) Things Net display and (b) source ID menu options**



(a)

Another aspect of the monitoring system is the inclusion of an LCD for DC load and battery voltage display that helps the user to analyse the behavior of the battery and load conditions.

Based on the data, the battery requires two hours and 40 minutes to fully charge and two hours to fully discharge (total time from 11:40AM to 4:20PM). A 10W solar panel was used to provide charging voltage. Battery voltage was noted and recorded at the beginning of the charging and discharging experiment. All the values are tabulated for an interval of 30 minutes until the battery is fully charged. The results obtained are tabulated in Table 3 for charging and discharging tests.

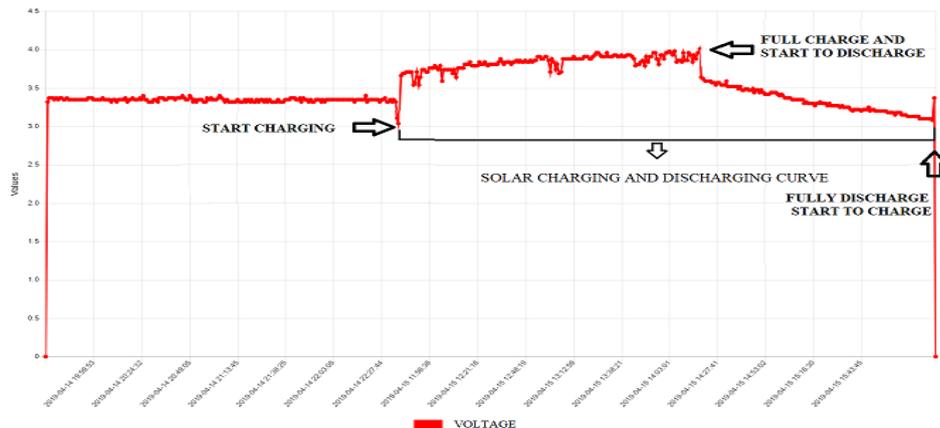
The results also show that the automatic switching circuits managed to operate without failure by starting to charge when battery voltage is below 3.10 V and stop charging when the battery voltage reaches 4.00 V.

**Table. 3 Charging and discharging test result**

TEST	TIME	BATTERY VOLTAGE (V)	LOAD STATUS	BATTERY STATUS
CHARGING TEST	11:40 AM	3.08	OFF	Charging
	12:10 PM	3.64	OFF	Charging
	12:40	3.84	OFF	Charging
	1:10	3.88	OFF	Charging
	1:40	3.91	OFF	Charging
	2:10	3.96	OFF	Charging
	2:20	4.01	ON	Discharge begins
DISCHARGING TEST	2:50	3.44	ON	Discharge
	3:20	3.30	ON	Discharge
	3:50	3.22	ON	Discharge
	4:20	3.08	OFF	Charging begins

Figure 8 shows the charging and discharging data as obtained from Things Net display showing the battery charging status as labelled. As the solar panel charges the battery, voltage data obtained will be sent to Things Net to facilitate monitoring work. The graph can be analysed where the voltage boosts up at the beginning of charging and gradually increases until full charging and the circuit will

automatically start discharging the battery through the load until the minimum set voltage is achieved and the cycle repeats. The figure shows some fluctuations during charging of the battery. The main reason for this is because of the effects of cloud on a solar panel where when there is cloud cover, the amount of sunlight received by the solar panel is reduced.



**Fig. 8 Output voltage of the charge controller showing charging and discharging**

**IV. CONCLUSION**

In this paper, hardware implementation of Arduino Uno based solar charge controller is developed and has been proven to provide charging of the battery using the solar energy. The battery is also prevented from overcharging because of the provision of cutting down the supply thus extending the battery life. The system used solar panel as the input and DC load as the output. The algorithm used here is efficient for the charge and discharge operation. Lastly, a smart monitoring had been developed effectively by using the Arduino Uno and GSM SIM800L connected to the Things Net server.

The capability of remote monitoring of the real-time status of the battery is a required to enable users to monitor and control a photovoltaic system. The availability of the IoT and cloud computing technology also allows tasks like data logging and report generation to be possible.

**ACKNOWLEDGMENTS**

The authors acknowledge the grant LRGS/2018/UNITEN-UKM/EWS/04 and DIP-2018-020 for providing the funding to this research.

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