AC 2010-355: DESIGN AND IMPLEMENTATION OF A SOLAR BATTERY CHARGER

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Development of a Solar Battery Charger for Lithium-ion Batteries

Abstract

Recent technological developments in thin-film photovoltaics (PVs), such as amorphous silicon and hybrid dye sensitized/PV cells, are leading to new generations of portable solar arrays. These new arrays are lightweight, durable, flexible, and have been reported to achieve power efficiencies of up to 10%. Since the emergence of these flexible and foldable solar arrays, there has become a need to develop solar battery chargers for more portable batteries, such as Nickel metal hydride (NiMH) and Lithium-ion (Li-ion) batteries for military and consumer applications. This paper describes the development of a solar battery charger for Li-ion batteries. Two electrical engineering technology undergraduate students formed a senior design project team to design and implement a solar battery charger. A senior design project is an integral part of the undergraduate engineering technology degree program requirements at Northern Illinois University. All students are required to complete a two-semester long (4 credit hours) senior design project.

Charging a battery requires a regulated dc voltage. However, the voltage supplied by a solar panel can vary significantly depending upon the day, time, weather condition and irradiation from the sun. In order to charge the battery with a regulated voltage, a dc-dc converter is connected between the solar panel and the battery. The main components in the solar battery charger are standard Photovoltaic solar panels (PV), a deep cycle rechargeable battery, a Single-Ended Primary Inductance Converter (SEPIC) converter and a controller.

Different types of rechargeable battery were considered including lead acid, Nickel Cadmium (NiCd), Nickel metal hydride (NiMH) and Lithium ion (Li-ion) batteries. Among these batteries, Li-ion batteries have the highest energy density and relatively low self-discharge rates and no memory effect. A BB2588 Li-ion battery from Bren-Tronics, Inc is used for this project.

The SEPIC converter is a type of dc-dc converter that is able to convert unregulated input voltage into either a higher or lower output voltage. This allows the solar panel to charge the battery with a wider range of output voltage, thus flexibility is increased. Experimental results of the solar battery charger are evaluated.

Introduction

Solar energy conversion is one of the most addressed topics in the field of renewable energy. Solar radiation is usually converted into two forms of energy: thermal and electrical energy. The solar electricity has applications in many systems such as rural electricity, water pumping and satellite communications.

In the past, solar power was usually used for large-scale grid connected system and small remote photovoltaic plants or stand-alone systems [1]. Recent technological development in thin-film photovoltaics (PVs) is leading to new generations of consumer portable solar panels. These new solar panels are light weight, durable, flexible, and have been reported to achieve power efficiencies of up to 10% [2]. The portable solar panels make solar power readily available for

mobile power needs such as outdoor enthusiast, expeditions and campers. It also provides portable solar power for the military to extend the run time of military devices including satellite communications, two-way radios, laptop computers, thermal imaging cameras, GPS, and etc. Therefore, solar power is expanding beyond its traditional applications.
Solar power is harvested and stored by charging rechargeable batteries. Older solar battery chargers were mainly developed for stationary situations such as solar house and RVs. Lead acid batteries are usually used because light weight is not a major factor to consider. However, since the appearance of the foldable and light weight solar panels, the need to develop solar battery chargers for more portable batteries such as Nickel metal hydrid (NiMH) and Lithium-ion (Li-ion) batteries becomes essential.

Previous work has been done to compare battery charging algorithms for stand alone photovoltaic systems [3]. Peak power from the solar panels was tracked for photovoltaic systems using various methods [4]. To increase conversion efficiency, maximum power point tracking techniques as well as optimal control were studied and implemented [5, 6].

Presented in this paper is the development of a solar battery charger for Li-ion batteries. A senior design project team works on the solar battery charger under close guidance of faculty members. To charge the battery with a regulated voltage, a dc-dc converter is designed and implemented. The dc-dc converter is connected between the solar panel and the battery. The main components in the solar battery charger are standard Photovoltaic solar panels (PV), a deep cycle rechargeable battery, a Single-Ended Primary Inductance Converter (SEPIC) and a controller.

Solar Panel

Solar panels are made of many photovoltaic (PV) cells connected in series or parallel. The PV cell is a large area p-n diode with the junction positioned close to the top surface [7]. When the cell is illuminated, electron-hole pairs are generated by the interaction of the incident photons with the atoms of the cell. The electric field created by the cell junction causes the photon-generated electron-hole pairs to separate. The electrons drift into the n-region of the cell and the holes drift into the p-region [8].

The conversion efficiency of PV cells is defined as the ratio between the electrical power output and the solar power impinging the cell. The efficiency of the PV cells generally is less than 30%. This means that when a cell is illuminated, it will generally convert less than 30% of the irradiance into electricity. The continuing effort to produce more efficient and low cost PV cells results in different types of PV technologies [7]. Major types of PV cells are single-crystalline silicon, polycrystalline, semicrystalline, thin films and amorphous silicon.

In this project, a PV-SC020J12 solar panel from Solar Cynergy is used. It has a nominal output voltage of 17 V and a nominal output current of 1.16 A, with maximum output voltage of 21.6 V and current of 1.31 A. The solar panel weighs only 2.27 Kg. Due to its small dimension and light weight, it can be moved very easily. Furthermore, it is waterproof and easy to install. The solar panel is tested by connecting an external resistor across the output. When the value of the load resistor changes, output voltage and output power of the solar panel changes. The test result is shown in Table 1. The output voltage of the solar panel can vary from 5.8 V to 19.6 V, and output power can vary from 3.92 W to 15.857 W.

Table 1. Test of solar panel with changing load resistance

Load Resistance (Ω)	Output Voltage (V)	Current (A)	Power (W)
5	5.8	1.16	6.728
10	11.7	1.17	13.689
15	15.7	1.01	15.857
25	17.3	0.68	11.764
30	17.8	0.58	10.324
35	17.8	0.49	8.722
50	18.6	0.36	6.696
90	19.6	0.2	3.92

Rechargeable Battery

Older solar battery chargers were mainly developed to charge lead acid batteries. In order to reduce the weight of the solar power system for portable needs, there has become a need to develop more portable batteries including Li-ion and NiMH batteries.

Different types of rechargeable battery were considered including lead acid, Nickel Cadmium (NiCd), Nickel metal hydride (NiMH) and Lithium ion (Li-ion) batteries. Among these batteries, Li-ion batteries have the highest energy density and relatively low self-discharge rates and no memory effect. A BB2588 Li-ion battery from Bren-Tronics, Inc is used for this project. The dimension of the battery is 89.7 mm (length) × 30.9 mm (width) × 90.2 mm (height). The weight of the battery is 0.36 Kg. Nominal and maximum voltage is 14.4 V and 16.8 V respectively. Capacity of the battery is 2.2 Ah. Operating temperature range is –20 ^{o}C to +55 ^{o}C.

The battery requires to charge at 16.5 V constant voltage, and 1A maximum current. Charge is complete when current drops to 50 mA. To allow charging to proceed, 5V dc needs to applied through a 470 Ohm, 1/4 W resistor between the "charge enable" contact (+) and the negative contact of the main connector (-).

SEPIC Converter

DC-DC converters converts unregulated DC input voltage into regulated DC output voltage. In a DC-DC converter, a transistor or MOSFET operates as an electronic switch: either completely on or completely off. Power absorbed by an ideal switch should be zero. In practice, losses will occur in a real switch due to switching and conduction losses. Efficiency of a DC-DC converter is quite high compared to a linear regulator. Several types of DC-DC converters are: buck converter, boost converter, buck-boost converter and single ended primary inductance (SEPIC) converter.

To charge the battery, a constant voltage of 16.5 V is required. However, the output voltage of the solar panel will vary depending on the time of the day, weather condition and light illumination. Testing of the solar panel shows that the output voltage of the solar panel can vary from 5.8 V up to 19.6 V with different load current. To obtain a constant voltage of 16.5 V, a DC-DC converter is inserted between the solar panel and the battery to regulate the voltage. A

SEPIC converter is chosen because it can convert the input voltage into either a higher or lower output voltage. The output voltage of SEPIC converter is non-inverted, while the output voltage of a buck-boost converter is inverted. Circuit schematics diagram of a SEPIC converter is shown in Figure 1. The Circuit parameters of the prototype SEPIC converter are listed in Table 2.

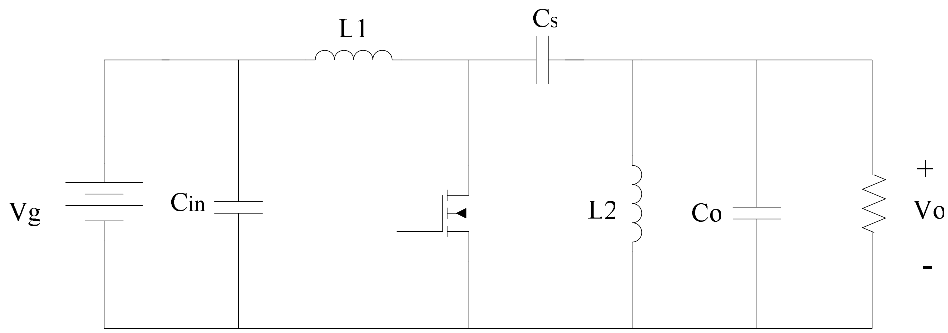

Figure 1. Schematics of a SEPIC converter

Table 2. Circuit parameters of the prototype SEPIC converter

Parameter	Value	Units
Input capacitor, C_{in}	100	µF
Filter capacitor, C_s	200	µF
Output capacitor, C_o	200	µF
Filter inductance, L_1	2	mH
Filter inductance, L_1	2	mH
Load resistance, R	75	Ω

Experimental result

The solar battery charger is developed and tested in the laboratory. Experimental setup is shown in Figure 2. Efficiency of the SEPIC converter is tested with different input voltage from the solar panel. The efficiency η is determined by (1). Test result of the efficiency is shown in Table 3.

$$\eta = \frac{P_{out}}{P_{in}} \tag{1}$$

In the students' final project report, students state that "The design challenges presented an outstanding learning experience to help add knowledge in troubleshooting and circuit design on a practical level as opposed to a simulation level. The final circuit is the result of lots of hard work, with much knowledge gained along the way." This shows students gained valuable real engineering experiences through this project, which will benefit their future careers.

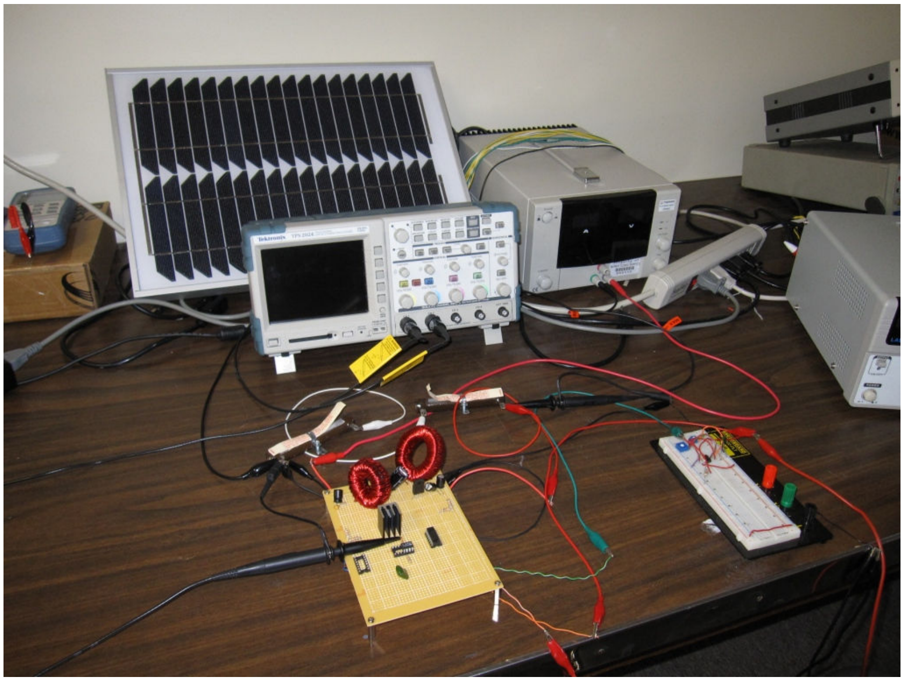

Figure 2. Experimental setup of the solar battery charger

Table 3. Efficiency of the SEPIC converter with different input voltage

V_{in} (Volts)	Duty cycle D	I_{in} (Amps)	I_{out} (Amps)	P_{in} (Watts)	P_{out} (Watts)	efficiency
6	74.5%	0.72	0.2	4.32	3.28	75.93%
10	63.4%	0.43	0.2	4.3	3.28	76.28%
14	54.3%	0.34	0.2	4.76	3.28	68.91%
20	45.3%	0.25	0.2	5	3.28	65.60%

Conclusion

A solar battery charger for an Li-ion battery is developed and tested. In this senior design project, the first semester is mainly focused on the design of the system. Students start from doing literature search and review theories related to the project. Next, simulation of the system was performed. In the second semester, students built the prototype solar battery charger. Through several iterations the system was constructed and tested. The solar battery charger allows more portable usage for solar panels, such as outdoor enthusiast and soldiers on the move. The solar battery charger includes the following components: solar panel, Li-ion battery, SEPIC converter and controller. The SEPIC converter regulates the output voltage from the solar panels into a constant voltage, which is used to charge the battery. Efficiency of the SEPIC converter is tested and reported in the paper.

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