行政院國家科學委員會專題研究計畫　成果報告

太陽能電力電源系統設計與驗證

計畫類別：個別型計畫
計畫編號：NSC94-2212-E-032-005-
執行期間：94 年 08 月 01 日至 95 年 07 月 31 日
執行單位：淡江大學航空太空工程學系

計畫主持人：蕭照焜

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報告類型：精簡報告

處理方式：本計畫可公開查詢

中　華　民　國 95 年 10 月 25 日

Design of a Solar Power Management System for an Experimental UAV

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NSC Project No: NSC94-2212-E-032-005

Abstract

This paper summarized the design of a solar power management system for an experimental UAV. The system will provide power required for the on-board electronic systems on the UAV. The power management system mainly consists of the maximum power point tracking, the battery management, and the power conversion stages. The maximum power point tracking stage attempts to obtain the maximum power available from the solar cell panels. The battery management stage monitors and controls the charge and discharge processes of the Li-Ion polymer battery modules. The last stage is for power conversion that consists of DC/DC synchronous buck converters to generate +5V and ± 12 V powers for the on-board computers and other electronic circuitries.

Keyword: solar power management system, battery management, synchronous power converter, UAV.

1. Introduction

Solar power, without a doubt, is the cleanest energy in the world. Usages of solar energy are widespread in industry, commercial, and military applications [1-5]. It will gradually become one of the primary energy supply resources in the future. This paper discusses the design of a solar power management system for an experimental uninhabited aerial vehicle (UAV). Solar-powered UAV possesses broad research value for technology development and commercial applications. A solar-powered UAV could in principle stay overhead indefinitely as long as it had a proper energy-storage system to keep it flying at night. The design of the power management system for such aircraft is challenging.

The experimental UAV considered in this power management system design is shown in Figure 1. Design and function validation of a solar power management system (SPMS) are the primary purpose of this research. Therefore, the obtained solar power will be used to power some certain on-board computers only. Power required for the propulsion and control systems is not included in the design. A much larger solar cell panel will be needed to power the complete system. The SPMS considered in this research consists of three stages. The first stage is the solar cell panel and the maximum power tracker [6,7]. The purpose is to increase the efficiency of the solar cells so that we can draw as much power as we can from the solar cells. The second stage is the battery management system that monitors and controls the energy storage and delivery of the solar power drew from the solar cell panel. The last stage is the power conversion stage that includes DC/DC synchronous buck power converters [8,9] to provide reliable $+5\,V$ and $\pm 12\,V$ power sources for on-board electronic systems.

Figure 1. Picture of the experimental UAV

The solar power management system (SPMS) is designed to obtain electric energy from the solar system and to make the required power available for the on-board computers and other electronic circuitries for an experimental UAV. The overall system structure is depicted in Figure 2. In this research, we use mono-crystalline solar cells as the power source. To accommodate the aircraft configuration, the solar cell panels are divided into three panels, namely left wing, right wing and fuselage panels. Pictures of these solar cell panels are shown in Figure 3. Under a standard test condition, the solar panels will generate a maximum power of up to around 57.2W. The maximum power point voltage and current are around 30V and 1.91A respectively. The electric characteristics of each panel are list in Tables 1 to 3.

2. System Overview

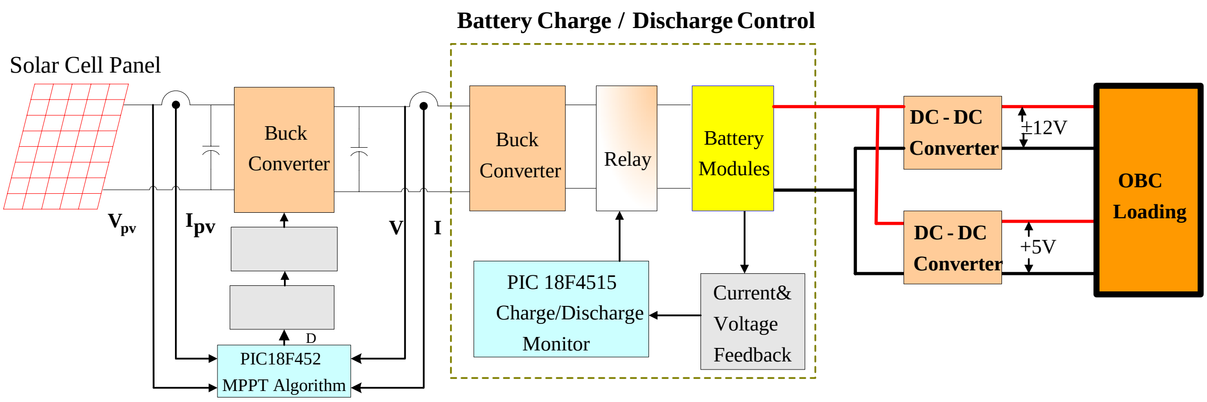

Figure 2. Configuration of the solar power management system

Figure 3. Left wing panel (top), fuselage panel (central), right wing panel (bottom)

Table 1. Left wing panel

Typical peak power	23.23 W
Voltage at peak power	30.08 V
Current at peak power	0.772 A
Short-circuit current	0.839 A
Open-circuit voltage	37.66 V

Table 2. Right wing panel

Typical peak power	24.29 W
Voltage at peak power	30.10 V
Current at peak power	0.807 A
Short-circuit current	0.872 A
Open-circuit voltage	37.78 V

Table 3. Fuselage panel

Typical peak power	9.686 W
Voltage at peak power	29.95 V
Current at peak power	0.323 A
Short-circuit current	0.341 A
Open-circuit voltage	37.84 V

As shown in Figure 2, the SPMS system is divided into three stages. The first stage, maximum power point tracking, attempts to obtain the maximum power available from the solar cell panels. The second stage, battery management, controls the charge and discharge processes of the Li-Ion polymer battery modules. The third stage, power conversion, converts input voltage to $+5\text{V}$ and $\pm 12\text{V}$ for the on-board electronics. The functional considerations and designs for each stage are discussed in the following sections.

3. Maximum Power Point Tracking

The electric power generated from the solar cells depends on the temperature and the solar radiation conditions and the load electric characteristics. Output power at different insolations and different temperatures are shown in Figures 4 and 5.

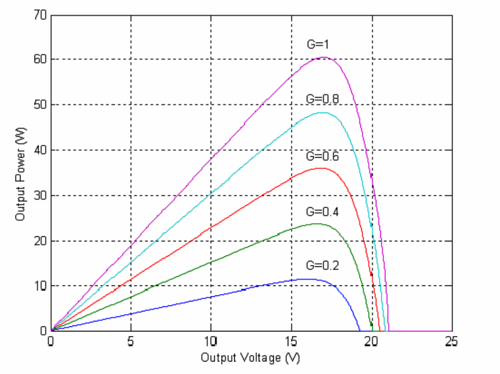

Figure 4. Power characteristics at $25^{\circ}C$ and insolation G varies from 0.2 to 1 kW/m^2

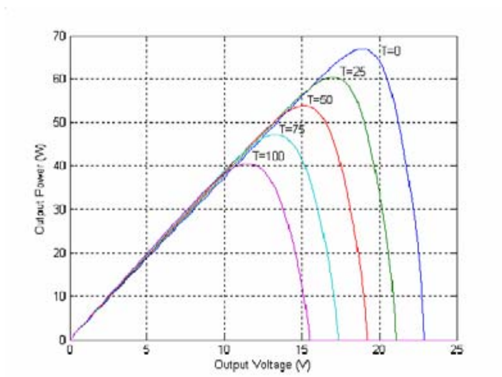

Figure 5. Power characteristics at insolation $G = 1$ kW/m and temperature varies from $T = 0^{\circ}C$ to $T = 100^{\circ}C$

Each curve has a maximum power point [10], which is the optimal operating point for the efficient use of the solar cells at that particular operating condition. In order to efficiently use the solar cells, we attempt to force the solar cells to operate at the maximum power point through some mechanism called the maximum power point tracking (MPPT).

The MPPT system consists of a pulse-width-modulated (PWM), a DC/DC buck power converter, and a micro-controller (PIC18F452 in this design). The block diagram of the MPPT system is shown in Figure 6. The main idea is to continuously adjust the voltage at the load terminal by controlling the duty cycle of the PWM regulator. Commonly used MPPT algorithm includes perturbation and observation method [11], incremental conductance technique [12], and fuzzy logics [13,14].

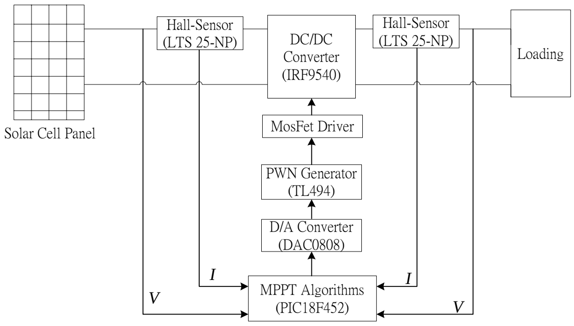

Figure 6. Maximum power point tracking system

4. Battery Management

The battery management system monitors and controls the storage and delivery of the energy drew from the solar panels. The system block diagram of the battery management system is shown in Figure 7. The system consists of three major subsystems, namely the lithium battery modules, an auto-ranging power converter, and a charge controller. The input power of the battery management system comes from the output of the MPPT system. The output of the battery management system supplies the required power to the power conversion system (the last stage of the power management system) to provide all the required power for the on-board computers and all other electronic circuitries.

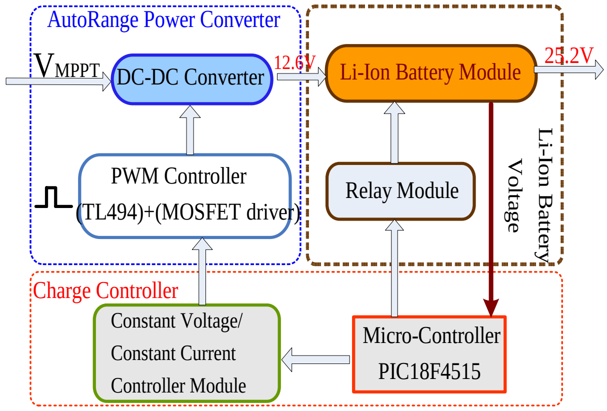

Figure 7. Functional block diagram of the battery management system.

The battery modules selected in this system are Lithium ion (Li-Ion) polymer rechargeable battery (HECELL company, battery model: H6849D5-4800mAh). A battery sub-module consists of three battery cells, the nominal voltage is 12.6V and the nominal current is 4800mA. The battery management system contains two battery modules. Each module consists of four sub-modules, arranged as shown in Figure 8. Its nominal current is 9600mA and nominal voltage is 25.2V.

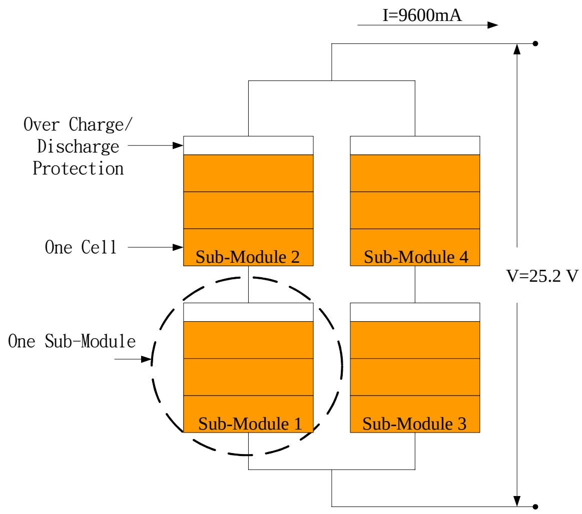

Figure 8. Construction of the battery module.

Figure 9 is the charging and discharging control circuitry for the Li-ion batteries. In charging the Li-ion battery, the battery is charged at a constant current until the battery voltage reaches the maximum voltage limit. The circuit then switches to voltage regulation, allowing the current to taper to lower values. Accurate voltage regulation is necessary to put the maximum safe charge into the battery. The constant current/constant voltage charging waveform is shown in Figure 10 [15]. In constant current mode, we keep the voltage drop between V_1 and V_2 at a constant voltage through controlling the pulse width of the PWM regulator in the auto-ranging power converter. We will adjust the pulse width of the PWM regulator to maintain V_3 at a constant level while in constant voltage mode. To charge sub-module 1, we will close the relay S_1 with relays S_2, S_3 and S_4 open. On the other hand, we need to close the relays S_2 and S_4 and open the relays S_1 and S_3 to charge the battery sub-module 2. While in discharging mode, we will close the relays S_2 and S_3, and open the relays S_1 and S_4.

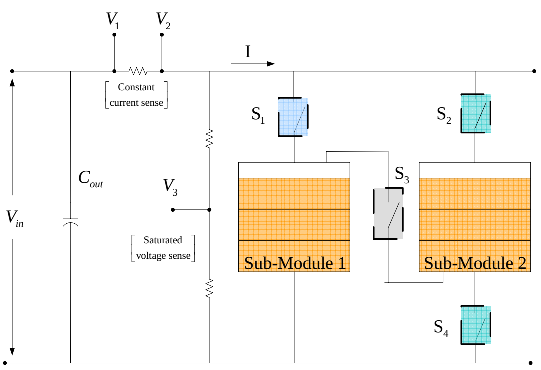

Figure 9. Charging/discharging circuitry for Li-ion battery.

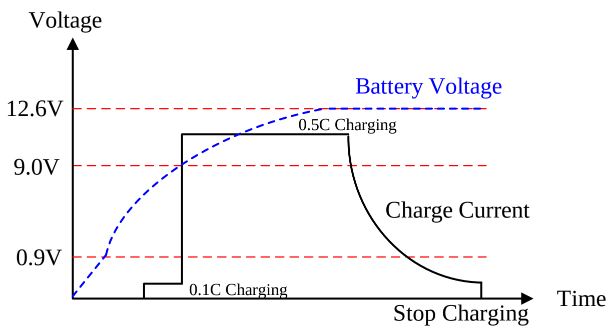

Figure 10.Constant current/constant voltage charging waveform.

5. Power Conversion

The power conversion system converts the voltage level from 25.2V at the battery end or the voltage from the MPPT output to +5V and ±12V for providing the required power to the OBCs and all other electronic circuitries. The power conversion system consists of two synchronous buck converters and a negative voltage conversion unit. The simplified functional block diagram of the synchronous buck converter is shown in Figure 12. It uses two N-type MOSFETs Q_1 and Q_2 to control the energy flow from source to the load. Synchronous buck controller used in this design is TPS40055 [16].

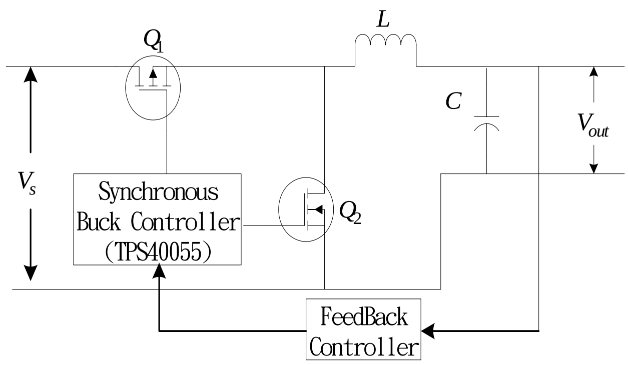

Figure 11. Synchronous buck power converter

6. Experiments and Results

The physical setup for the MPPT experiment is shown in Figure 12. The results are shown in Figure 13. The experiment was conducted at about 12:15 on 22 April 2006 at Tamkang University. Voltages and currents at both input and output of the MPPT system are recorded as shown in Figure 13. Temperature measured on the solar cell panel is about 50^{o} C. Powers obtained from the solar cell panels and transferred to the load are also shown in Figure 13. .The efficiency shown in the figure is the efficiency of the MPPT circuitry not the efficiency of the solar cell panels. The results also show the rapid changes of the power when it suddenly became clouded.

Figure 12. MPPT experiment set up

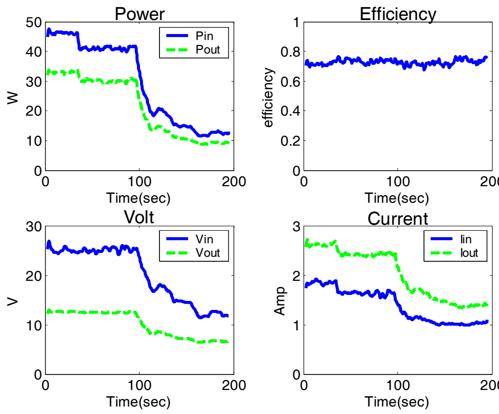

Figure 13. MPPT test results on 04/22/2006

Figure 14 shows the experimental results that was conducted on September 1, 2006. The temperature measured on the solar cell panel is about 70^{o} C. The power we obtained is lower than we got at the previous experiment due to obvious panel temperature changes.

Figure 15 shows the results for varying the incident angle of the sunlight. We rotate the solar cell panel for up to ±45 degrees with a incremental of 5 degrees. This is essential for aircraft maneuver considerations. Attitude changes directly affect the power drew from the solar system. This in turn will limit the pitch angle of the aircraft maneuver and must be taken into consideration for optimal flight path design. The results show that pitch angle may be limited to 20 degrees.

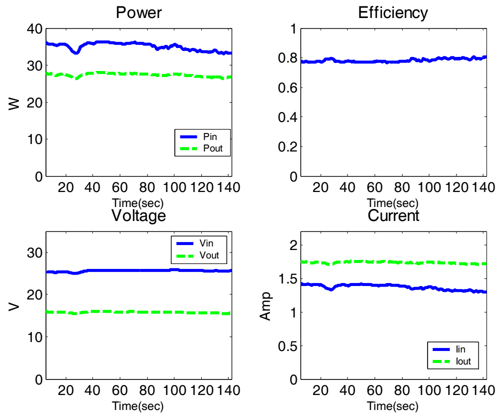

Figure 14. MPPT test results on 09/01/2006

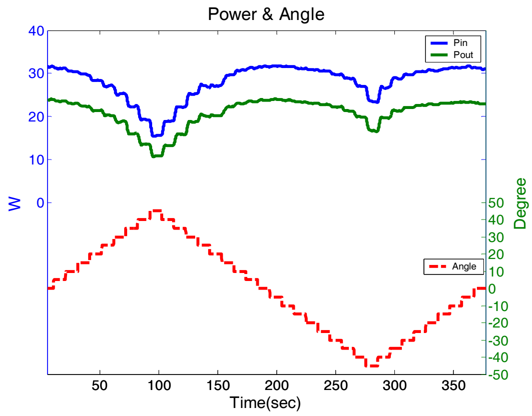

Figure 15. Power variations due to changes of the sunlight incident angles.

7. Conclusions

This paper discusses the design of a solar power management system. The system mainly consists of solar power panels shaped to accommodate aircraft configuration, a maximum power point tracking system to increase operating efficiency of the solar cells, a battery management system to monitor and control the energy storage and delivery, and a power conversion system to convert the power drew from the solar system to the using systems. An experiment system for MPPT evaluation is also developed to support the system design. The results will be used to improve the solar powered UAV configuration, propulsion and performance designs.

8. Acknowledgement

This research was supposed by National Science Council, Taiwan, Republic of China, under grant NSC94-2212-E-032-005.

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太陽能電力電源管理系統設計與驗證

國科會計畫編號：NSC94-2212-E-032-005

摘要

本文探討無人飛行載具太陽能電力電源管理系統之設計，目的為提供機載電腦系統之電力需求。此電源管理系統主要分為三級：第一級為太陽能電池與最大功率追蹤，其主要目地是用來收集太陽能，並且追蹤太陽能板隨著溫度與照度而改變的最大功率點，以得到最佳效率。第二級是電池充/放電管理，使用鋰高分子聚合物電池為充/放電管理之蓄電池，共分為二個電池模組，其一為放電模組，用來做電力轉換之供電電源，另一為充電模組，不斷攫取從太陽能板經最大功率追蹤後之電力，並用來當備份電池，適時與放電模組交換使用。第三級為電力轉換，將供電電壓轉換為 +5V與 ±12V，以提供系統及機載電腦之所需。

關鍵詞: 太陽能電源管理系統、電池管理、同步式電力轉換器、無人飛行載具。