國立清華大學 電機工程學系

實作專題研究成果摘要

Development of Solar-Powered Energy and Wind Power Converters for the Application in Green Energy House Storage Systems

太陽能及風力發電之電能轉換器研製對於綠能屋儲能系統之應用

專題領域：電力領域

組　　別：B452

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Abstract

This project aims to develop a power converter for solar and wind power generation, specifically for the application and development of a green energy house storage system. The power converter designed in the project consists of a DC voltage source flowing into the gate driver and half-bridge circuit, which is composed of components such as capacitors, inductors, and loads. Additionally, the system is controlled by a digital signal processing microcontrollers with programming, providing signals and forming a complete closed-loop control for the power converter.

The first stage of the system simulates wind power generation through a DC motor and generates a 110V DC via a rectifier. This voltage is then reduced to 48V through a buck converter, which can charge the 48V battery of the green energy house. In the second stage, the 48V is further reduced to 24V by another buck converter, allowing it to charge a 24V battery suited for the green energy house. Furthermore, when the first stage's power supply is unstable, the system can boost the voltage from the 24V battery back to 48V for use by the 48V power devices. This architecture achieves the structure of a microgrid, aiming to reduce energy waste and reach the goal of sustainable operation through this microgrid setup.

Keywords：DC-DC converter, DSP, wind power generation, voltage feedback control, current feedback control, microgrid, pulse width modulation.

摘要

本專題旨在太陽能及風力發電之電能轉換器研製對於綠能屋儲能系統之應用研發。專題所架構的電能轉換器透過直流電壓源流入閘極驅動器和半橋電路並透過電容、電感和負載等元件所組成，此外透過程式操作數位信號處理微控制器提供訊號和閉迴路控制形成完整的閉迴路電能轉換器。

架構的第一級透過由直流馬達模擬風力發電，利用整流器產生直流電壓110V，並經降壓轉換器降至 48V，並可對 48V綠能屋電池進行充電，第二級由48V經降壓轉換器降至 24V，並可對適合 24V的綠能屋進行充電，另外當第一級的供電不穩時，也可以由 24V的綠能屋電池升壓回充給 48V的用電端做使用，並以此架構達到微電網的架構，並希望透過此微電網減少能源浪費，達成永續經營的目標。

關鍵詞：直流-直流轉換器、DSP、風力發電、電壓回授控制、電流回授控制、微電網、脈波寬度調變。

I. INTRODUCTION

Due to the increasingly severe issue of global warming, the impact of thermal power generation has attracted attention worldwide. Many countries are now beginning to develop new green energy industries in an effort to provide alternative energy sources. However, research in green energy is various, and integrating these energy sources is a challenge. Therefore, we aim to design an energy system that integrates electricity generated from wind power and solar energy into a stable and reliable green energy house storage system, providing these energy sources for users.

In this two semesters' research project, we divided our work into three major categories: software simulation, DSP (Digital Signal Processing) programming, and hardware circuit experimentation. Our team collaborated closely, like resoldering components to assemble circuits, PI control design and hardware testing. We complete each step progressively.

Our main focus includes wind power generation system testing, DC to DC buck converters, and DC to DC boost converters. We use the TMS320F28379D microcontroller as the main controller, combining a sensor board and gate driver to control the converters. By programming the TMS320F28379D and using the sensor board to give feedback to the actual values, we employ the PI control method to achieve closed-loop control.

II. RESEARCH METHODOLOGY

System design

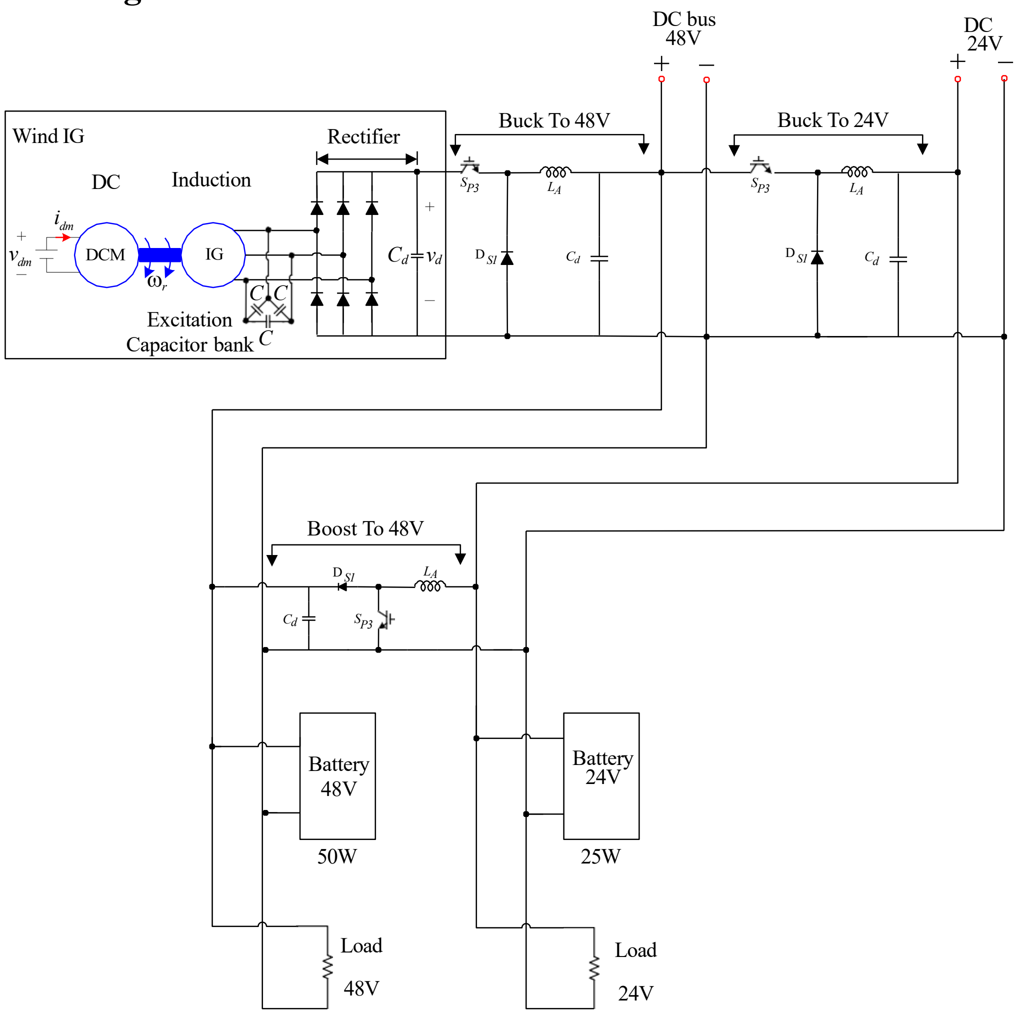

Fig. 1. System Design Diagram.

Fig. 1, shows the system design diagram of this project, there is a wind power generator in the first stage that produces 110V DC. This voltage is then reduced to 48V through a buck converter to charge the green energy house's battery and supply the power to the load. In the second stage, the voltage is further reduced from 48V to 24V using another buck converter, which charges the green energy house's battery and powers the load. When the wind power supply becomes unstable, the 24V battery can charge to 48V through a boost converter, ensuring that the 48V load continues to be powered. This structure helps achieve the purpose of a microgrid system.

Gate Driver

The main function is to access the EPWM signal and let the signal drive the converter. The main IC in the gate driver is an isolated dual-channel gate driver, so it can avoid danger when using higher voltage.

Sensor Board

The function of this sensor board is to convert the current or voltage that we want to measure into an ADC signal. This signal can be converted into a digital signal for measurement using DSP programming.

Programming Process

In the project, we use TMS28379D Dual-Core Microcontrollers and use CCS code to write programs. We focus on writing programs about signal generation and PI controller.

Producing Switching Signal

We use a code to generate a 20kHz square wave through DSP, with a duty cycle of 50%, and generate two complementary signals (PWMA and PWMB) for the gate driver. Afterwards, we connect the gate driver and half bridge, and measure whether the two signals obtained from the half bridge are complementary.

Control Methods

We employ the PI control method as our feedback control approach. PI control can eliminate steady-state errors and optimize the settling time by adjusting the two parameters Kp and Ki of the PI controller. Voltage and current values are returned to the computer, and the PI control processes can achieve a voltage-current dual-loop feedback control. The processed EPWM signals generated by the PI controller are transmitted to the gate driver, completing a closed-loop control system.

III. EXPERIMENTAL RESULTS

Wind Power Generation

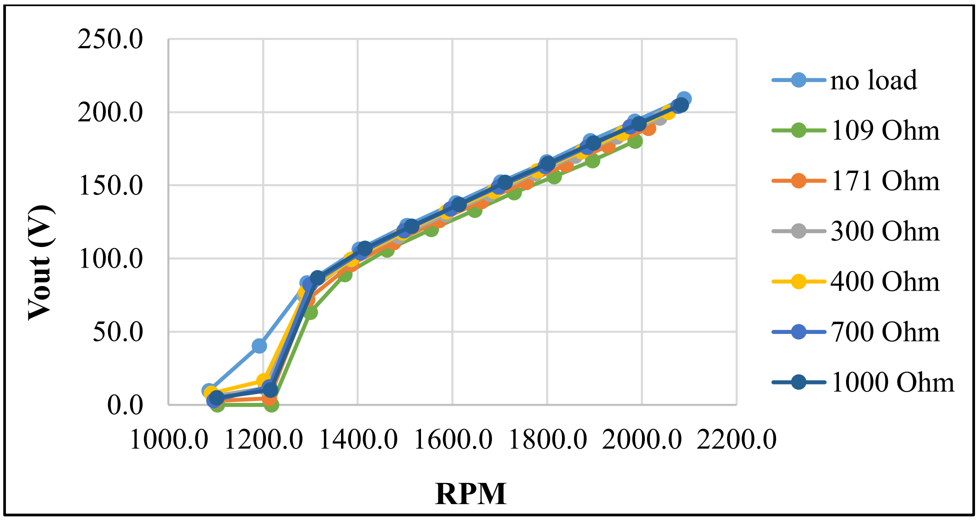

Fig. 2. Situation of Motor Speed and Output Voltage under Different Loads.

It can be observed that at low output voltages, there is a sharp change in speed. This situation should be due to the motor needing to increase to a certain voltage to provide a certain speed. We can find that if the resistance is larger, this situation is less obvious. We know the power formula is $P = V^2/R$。When the voltage is fixed, a smaller resistance (R) results in greater power. In addition, $P = I \times V$, when the voltage is fixed, a greater power results in the greater current, which also means the load is greater. From the Fig. 14f, it can also be found that when the load is lighter, compared to the heavy load, it is easier to generate electricity and produce speed.

From the results, we can observe the motor under different loads can all produce the DC 120V. As a result, we can use the DC 110V to be the input voltage in the first stage.

Open-loop Converter

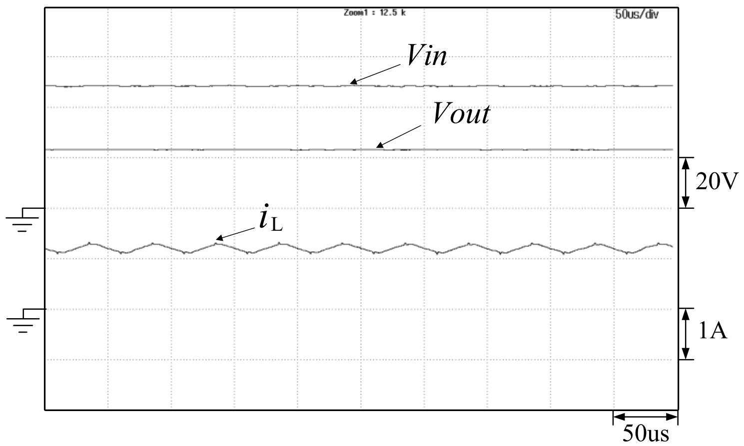

Fig. 3. Measured Steady-state Waveform of Buck Converter (48V to 24V).

It can be observed that Vout stabilizes at 23V, and the current does not enter to Discontinuous Conduction Mode (DCM), indicating that the buck converter works properly. However, due to the power losses and other factors in the actual components, the output cannot perfectly reach 24V. Therefore, we need closed-loop control to adjust the output voltage, ensuring it reaches the ideal value.

Closed-loop Converter

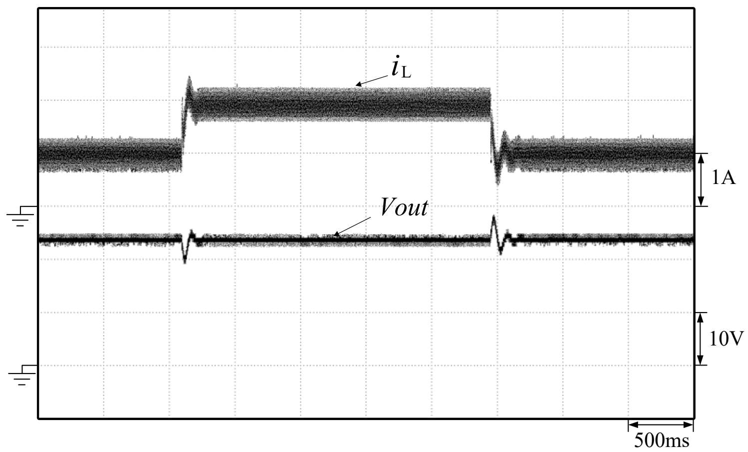

Fig. 4. Measured 48V to 24V Buck Converter Waveforms at Loads Changed.

Changing the load from 24Ω to 12 Ω to 24 Ω, so the power was changed from 25W to 50W to 25W. In the figure, Vout represents the output voltage at load and i_L means the inductor current. When the load switch, V_{out} is easily and fast to stabilize at 24V under PI control. Also, i_L was controlled easily and the current spike did not exceed 4A.

Physical Circuit

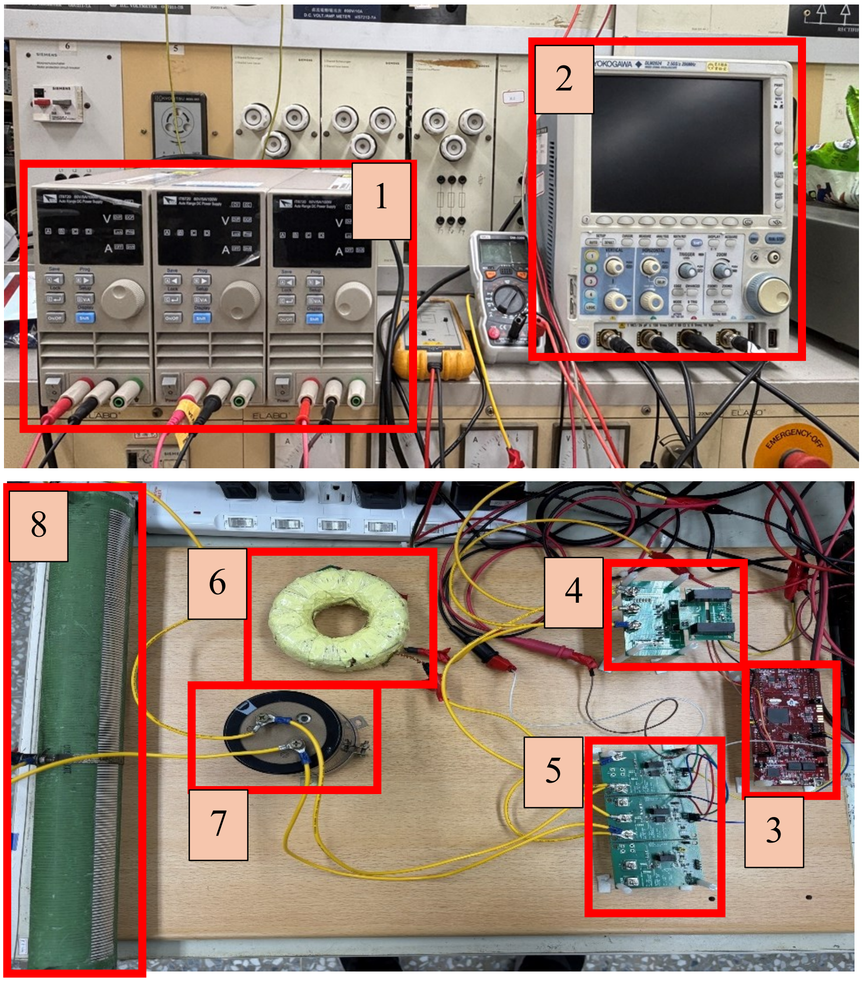

Fig. 5. Photos of the Practical Circuit.

1. **DC Power Supply**：Simulation of rectified wind power generation and the supply of operating voltages to circuit.
2. **Oscilloscope**：Observing the waveforms of voltages and currents.
3. **DSP Microcontroller**：Generating the EPWM signal and access the feedback values from sensorboard.
4. **Gate Driver and Half Bridge**：Receiving EPWM signal to drive the converter.
5. **Sensorboard**：Returning the values of current/voltage from closed loop.
6. **Inductor**、**7. Capacitor**、**8. Load**：Constructing the converter.

IV. CONCLUSION

The project combines the converter with green energy generation and achieves PI control through a DSP microcontroller, allowing the system to stably output voltage and current under different load conditions.

The system architecture includes a wind power generator simulated by DC motor and an induction generator, DC to DC converters, and closed-loop control systems with using a DSP microcontroller. We have completed the project including wind power generation tests, 24V to 48V boost converter and 48V to 24V buck converter.

Through the DSP PI control system, the project's system can stabilize fast and precisely. This can let the system raise the energy efficiency. In addition, the green energy is important to protect the environment. As a result, we believe that the system's design can be widely applied in more areas.

V. FEEDBACK AND THOUGHTS

吳竑逸：

從今年寒假開始就著手進行模擬電路，再到這學期的實作電路專題，這將近一年的時間讓我從模擬到實際成果的展現，讓我收穫真的很多，非常謝謝教授和學長的指導，讓我們能在實作專題課程中能不斷地學習和進步，也非常謝謝組員的幫忙，在遇到的問題後，可以互相討論，能一起完成這份專題，是件非常快樂的事。

謝東烜：

參與專題論使我獲益良多，除了讓我學到了更多電力組的相關知識，做中學也使我對於電路的運行有了更深入的了解，過程中經歷的失敗及電路成功運行時的成就感都使我難以忘懷。學長們和教授的指導及組員間彼此分工、互相扶持都為我的大學生涯增添了許多光彩。

黃博洋：

從今年一月進入實驗室開始，我們陸續學會了焊接電路板、跑程式驅動等。藉由連接電路板與用程式驅動產生訊號，雖然過程中有遇到許多大大小小的挫折，但我非常感謝組員們的一起努力以及教授和學長姐們的耐性指導，為我們做專題的過程增添了許多的溫暖、欣慰與成就。也讓我們的這一年成為了我大學生涯中一個難忘的部分。