Design of 1 kW Buck-Boost Chopper with PI Control for Photovoltaic Power Conversion

Suroso¹,², Winasis¹, Priswanto¹, and Ignatius Daniel Purnama¹
¹Electrical Engineering Department, Jenderal Soedirman University, Indonesia
²suroso.te@unsoed.ac.id

Abstract. The design of a 1 kW buck-boost chopper with proportional-integral (PI) control is presented and discussed in this paper. The buck-boost chopper was proposed as a photovoltaic power converter to achieve a stable dc output voltage. In the design, the circuits employed IGBT power switch to function the PWM control signals to adjust the chopper’s output voltage. The circuits were tested to investigate the output waveform set at 24 V from various dc input voltage values. The chopper circuits were connected to ten solar PV modules with a total capacity of 1 kW. Simulation test results confirmed that the system was able to output 24 dc voltage with output current about 41 A. Furthermore, a prototype of the buck-boost chopper was set up and tested. The circuits worked well to output a stable 24 V DC voltage from PV output voltage varied 15 V-32 V.

1. INTRODUCTION

The development of new renewable energy technologies has been able to produce controllable DC power that can be stored in batteries or work as DC power supplies. One of the most popular is the photovoltaic (PV) or solar panel systems [1-3]. The working principle of the solar panel is that if sunlight hits the panel, electrons in the solar cell will flow from negative to positive region. As a result, the output terminal of the solar panel will generate electrical potential. The generated electrical energy of solar panels changes depending on the count of solar cells combined in the solar panel. Inherently, they work producing DC power with unstable voltage because of the fluctuated solar radiation. To utilize this energy source, the PV voltage should be kept stable. So, the generated energy can be delivered to the load or to be stored in the battery systems well. In some applications, the photovoltaic system is connected via power inverter to the power grid to supply AC power [4-6].

Along with this, the development of power electronics, control algorithms, and circuit technologies has been able to produce a high performance of DC power supply, which is generated through the conversion of DC input voltage to a higher or lower DC voltage. This DC voltage conversion is commonly referred to as DC-DC converter or specifically called as buck-boost Chopper. In its development, the application of DC-DC converter has enabled an electronic device to function in a small size using a small battery energy source where the output voltage can be changed according to application requirements [7, 8].

The buck-boost chopper system is a non-isolated switching type DC regulator that can answer the need for a voltage source in the form of a variable output voltage. With the buck-boost chopper system, the output voltage value can be set to be greater or smaller than the input voltage value by controlling the pulse width or duty cycle of the PWM (pulse width modulation) control signal [9-12]. The design of a 1 kW buck-boost chopper prototype for photovoltaic power conversion is discussed in this paper.
2. CIRCUIT DESIGN

Fig. 1 shows the developed buck-boost chopper circuits in this project. The main components of these circuits are dc voltage source, power inductor, capacitor, power IGBT, power diodes, power resistor as load, and dc voltage sensor. Two dc voltage sources are connected to the circuits to investigate the work of chopper circuits for multi-sources with different dc input voltage values. This condition will be found in a real situation such as in photovoltaic power systems.

![Fig. 1 Buck-boost converter with two inputs](image)

Table 1 presents the parameters of chopper circuits that will be developed. The dc output voltage value is predetermined at 24 V with a ripple value of about 1%. While the output current value is set at a maximum of 42 A to achieve 1 kW output power. To minimize the size of the inductor and capacitor, the IGBT switch is operated at 31 kHz switching frequency.

To obtain the desired circuits, the circuit parameters are calculated as follows. The inductance value of power inductor \( L_{\text{min}} \) of circuits can be determined as:

\[
L_{\text{min}} = \frac{(1 - D)^2 R}{2f}
\]  

(1)

The capacitance of the capacitor \( C \) is:

\[
\text{Capacitance} > \frac{I_{\text{out}}}{V_{\text{ripple}} \times f}
\]  

(2)

The duty cycle \( D \) of IGBT gating signal is:

\[
D = \frac{V_o}{V_o + i}
\]  

(3)

Where \( f \) is the switching frequency, \( V_o \) is the output voltage, and \( I_{\text{out}} \) is the output current.

To regulate the output voltage of chopper circuits, a proportional-integral (PI) controller was applied as in Fig. 2. The output voltage is sensed by the voltage sensor, and its value is fed back and compared with the reference value. The errors will be modulated by a triangular carrier signal to create a control signal of IGBT switch.

| Table 1. Parameters design of chopper |
|--------------------------------------|
| Input voltage, \( V_{\text{in}} \) | 20 V |
| Output voltage, \( V_{\text{out}} \) | 24 V |
| Voltage ripple | 1% |
| Output current, \( I_{\text{out}} \) | 42 A |
Fig. 2 PI controller

Fig. 3 Chopper circuits connected to PV systems

Fig. 3 depicts the buck-boost converter connected to two photovoltaic system PV1 and PV2 each constructed by ten PV modules. PV modules used in this research are Kyocera KD 140 series.

Moreover, a prototype of the buck-boost chopper was built in the laboratory using power IGBT as a controlled power switch. The circuit parameters are the same as in Table 1. The voltage sensor was implemented using the resistive voltage divider. The PI controller was implemented by using ARDUINO UNO as shown in Fig. 4. The gate drive circuits of IGBT is realized using optocoupler TLP 250.
3. TEST RESULTS

To examine the proposed system, some computer simulation and experimental tests were carried out for both “boost mode” and “buck mode” of chopper circuits as follow:

3.1. Boost Mode Test

Fig. 5 presents the computer simulation test results of the chopper circuits connected to photovoltaic systems, i.e. PV1 and PV2. The figure presents the output power of photovoltaic \( P_{PV1} \) and \( P_{PV2} \), output voltage of photovoltaics \( V_{PV1} \) and \( V_{PV2} \), input and output voltage of chopper \( V_{in} \) and \( V_{out} \), and current of photovoltaic systems \( I_{PV1} \) and \( I_{PV2} \). The chopper circuits changed the output voltage of PV system from 20 V to become 24 V which is the boost operation mode of the chopper circuits.

![Fig. 5 Simulation test waveforms of boost operation mode](image)

3.2. Buck Mode Test

Test results of the system during buck mode operation is shown in Fig. 6. Similarly, the output power of photovoltaic \( P_{PV1} \) and \( P_{PV2} \), output voltage of photovoltaics \( V_{PV1} \) and \( V_{PV2} \), input and output voltage of chopper \( V_{in} \) and \( V_{out} \), and current of photovoltaic systems \( I_{PV1} \) and \( I_{PV2} \) can be observed in this figure. However, in this operation the voltage of photovoltaics was reduced from 40 V to be 24 V. It is the buck operation mode of chopper circuits. Hence, the two operation modes of chopper circuits have been confirmed by computer simulations.

Moreover, the chopper prototype was tested experimentally. Fig. 7 is the gating signal of chopper circuits at duty cycle 0.5. Fig. 8 presents the measured waveform of the dc input voltage during boost operation. The voltage was boosted up from 10 V to be 23.2 V. Fig. 9 depicts the input and output voltage of chopper circuits at buck operation mode. The voltage was decreased from 32.6 V to become 23.8 V. The error value of the output voltage during open circuits condition is presented in table 2.
Fig. 6 Simulation test waveforms of buck operation mode

Fig. 7 Gating signal of IGBT with duty cycle 50%

Fig. 8 Test results of boost operation: (1) input, and (2) output voltage
Fig. 9 Test results of buck operation: input and output voltage

Table 2. The error of the output voltage at open circuit

| $V_{in}$ (V) | Setpoint | $V_{out}$ (V) | Error (%) | Mode |
|--------------|----------|---------------|-----------|------|
| 9            | 24 V     | 23.2          | 3.3%      | Boost|
| 15           | 24 V     | 23.6          | 1.6%      | Boost|
| 18           | 24 V     | 23.7          | 1.25%     | Boost|
| 28           | 24 V     | 23.5          | 2.1%      | Buck |
| 32           | 24 V     | 23.8          | 0.83%     | Buck |

4. CONCLUSION
The design of Buck-Boost Chopper is influenced by the value of the duty cycle and the value of components that complete the system. Buck-Boost Chopper circuit with PI-based Arduino Uno microcontroller control can balance the output voltage with a 24-volt setpoint value. In the Buck-Boost Chopper test with PI control and loaded with 1 resistor (10 Ω), 2 resistors are installed in series (20 Ω), and 2 resistors are installed parallel (5 Ω) with an input voltage of 15V - 32V already working properly. Because it can produce an output voltage with a 24 Volt setpoint value, with a maximum error percentage of 3.3%.

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