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

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Abstract. A design of 1 kW buck-boost chopper with proportional integral (PI) control is presented and discussed in this paper. The buck-boost chopper was proposed as 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 was simulated by PSIM software to investigate the output waveform set at 24 V from various dc input voltage values. The chopper circuits was connected to ten solar PV modules with total capacity 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 setup and tested. The circuits worked well to output a stable 24 V DC voltage from PV output voltage varied 15 V-32 V.

Keywords: dc-dc converter, solar energy, efficiency.

1. INTRODUCTION

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 results, 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 radiations. In order 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, photovoltaic system is connected via power inverter to 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 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]. A design of 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 this 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 real situation such as in photovoltaic power systems.

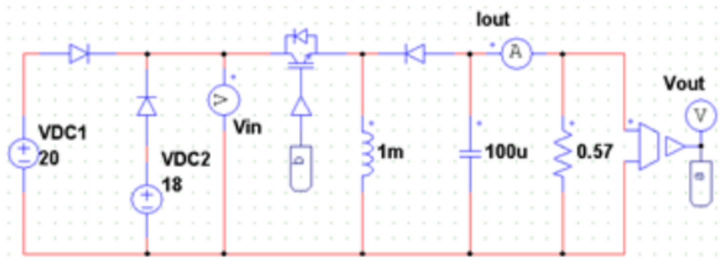

Fig. 1 Buck-boost converter with two inputs

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

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

$$L_{min} = \frac{(1-D)^2 R}{2f} \qquad (1)$$

The capacitance of the capacitor (C) is:

$$Capacitance > \frac{Iout}{V_{ripple} \times f} \qquad (2)$$

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

$$D = \frac{Vo}{Vo + i} \qquad (3)$$

Where f is the switching frequency, V_o is the output voltage, and I_{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 voltage sensor, and its value is fed back and compared with reference value. The errors will be modulated by triangular carrier signal to create control signal of IGBT switch.

Table 1. Parameters design of chopper

Input voltage, V_{in}	20V
Output voltage, V_{out}	24V
Voltage ripple	1%
Output current, I_{out}	42A
Switching frequency	31 KHz

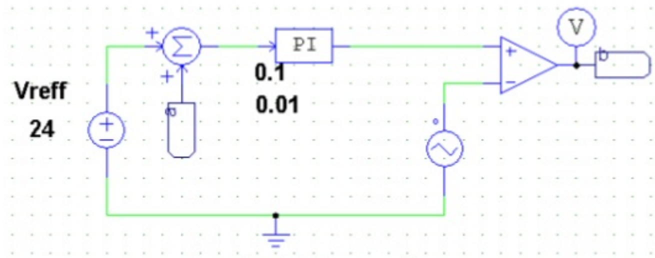

Fig. 2 PI controller

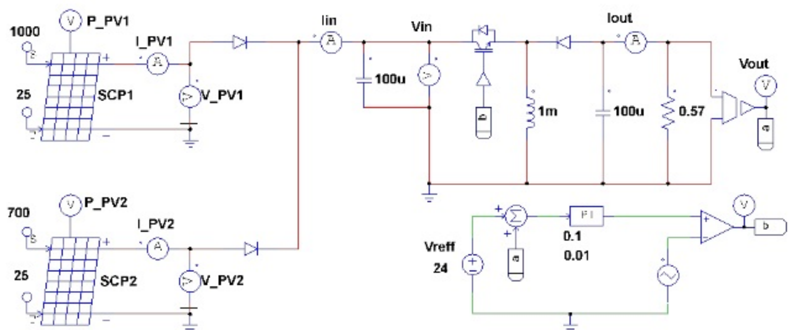

Fig. 3 Chopper circuits connected to PV systems

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 laboratory using power IGBT as controlled power switch. The circuit parameters are the same as in Table 1. Voltage sensor was implemented using 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 opto-coupler TLP 250.

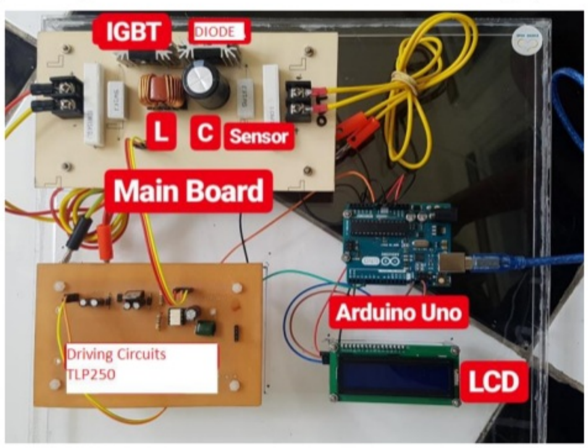

Fig. 4 Prototype of buck-boost chopper

3. TEST RESULTS

In order 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 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.

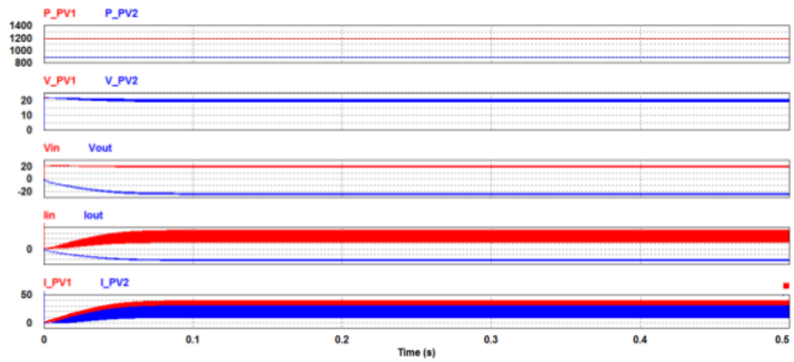

Fig. 5 Simulation test waveforms at boost operation mode

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 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.

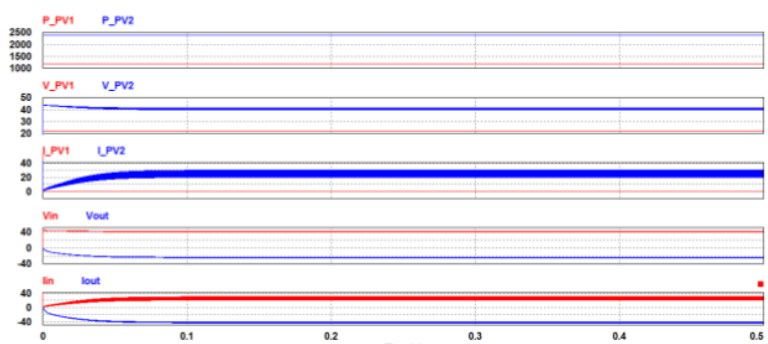

Fig. 6 Simulation test waveforms at buck operation mode

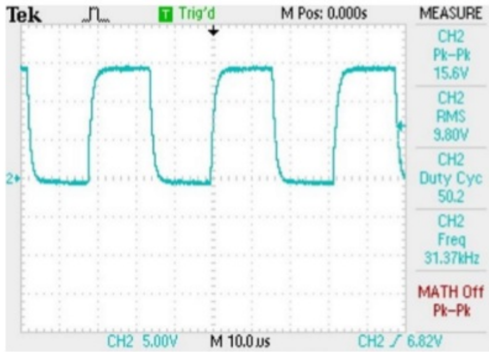

Fig. 7 Gating signal of IGBT with duty cycle 50%

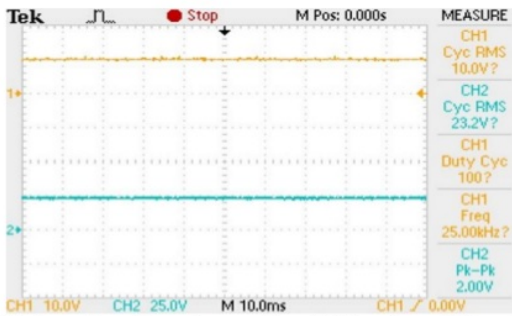

Fig. 8 Test results of boost operation: (1) input, and (2) output voltage

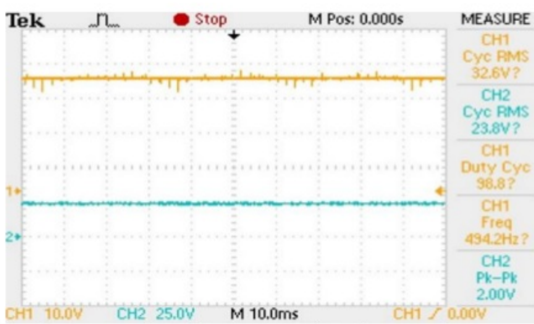

Fig. 9 Test results of buck operation: input and output voltage

Table 2. Error of the output voltage at open circuit

V_{in} (V)	Set point	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 set point 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 input voltage of 15V - 32V already working properly. Because it can produce an output voltage with a 24 Volt set point value, with a maximum error percentage of 3.3%.

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