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Design of a Bi-directional DC-DC 4 phase Interleave converter for PV applications

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Abstract

This paper presents a design of a bidirectional 4 phase interleave converter specifically for PV applications. The proposed model has rated capacity of 60 to 120 VDC, 1KW. The Design of this DC-DC bidirectional 4 phase interleave converter to investigate the behavior of the system used MATLAB/SIMULINK. The simulation results are observed to determine the output voltage value. The design used FIO controller to decision battery charge or discharge status. The first step is boost converter to transfer power from battery into 120Vdc bus and the second step is working as buck converter to store energy into the battery 60Vdc when no load required. Mathematical models for boost and buck modes are being derived and the Simulink model is constructed in order to simulate the system of both step designs. The results of simulation found that the designed converter is able to charge battery and discharge battery and deliver power to load as designed. The output current is 12A (2.3A per phase) battery capacity of selected Lead-Acid battery per designed is 12Ah.

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1. Introduction

Nowadays, renewable energy from solar energy is a world-wide implementation because solar energy is clean and no pollution. However, there is limited capacity because solar has in the daytime only. Therefore, the energy reserves in the battery when no electricity demand is so essential. When the voltage stored in the battery is still low, it is not possible to bring these energies to the load directly. Then this paper proposes the design a Bi-Directional DC-DC converter with the principle of the transfer of energy from the battery to continuously supply to the load with interleave technique to a higher power. The advantages of the interleave technique are reduce losses across high switching device and help to reduce current ripple in DC load**.**

2. Principle of DC Bidirectional Converter

The circuit for DC Bidirectional Converter using the principle of Buck and Boost converter circuit is designed using IGBT to be switching devices to reduce the voltage across the component. The operation for this converter will transfer energy to be two directions as show in Fig 1.

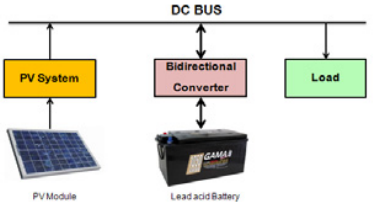

Fig.1. Digram of DC-Bidirectional Converter.

There are 2 steps to be considered, Step 1 is to charge battery with buck converter mode when no electricity demand (measuring from current sensor) but still have power output from solar cells, Step 2 is to discharge battery with boost converter mode. The power circuit is buck converter mode to drop voltage from DC BUS 120V to 60V. The battery is Lead-acid type 12V. To discharge battery when no power output from solar cell, the power circuit is boost converter mode to transfer energy from battery to load and increase voltage from 60V to 120 VDC. The main equipment for this circuit is inductance because it is responsible for the collected and discharged energy to the output voltage higher than the input.

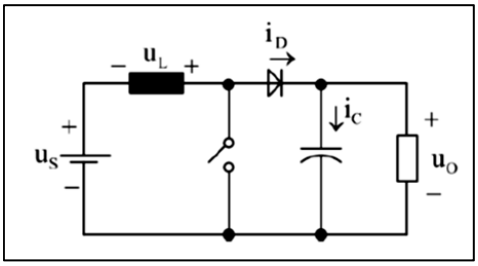

Fig.2. Equivalent circuit of boost converter.

To calculate the inductance from equation as below.

$$L = \frac{\mathrm{Vs}.\mathrm{D}}{\Delta \mathrm{I}_{\mathrm{L}} . f_s} \tag{1}$$

Duty cycle is equal to 0.5, and the frequency of the switching frequency is 25 kHz, which activates the device can operate. Duty cycle is equal to 0.5, and the frequency of the switching frequency is 25 kHz, which activates the device can operate.

The input ripple current is 13 percent of the input current. The principles of interleaved with the introduction of boost converter N circuit to connect in parallel. And phase of the signal driving the switch to working time overlap, which can be calculated from equation as below (2).

$$\text{Switch Angle} = 360 / N \tag{2}$$

N is number of circuit in parallel, this circuit used 4 phase parallel. Then switch angle for this circuit of each phase will be 90 degree. Then size of the inductor must be at least 92 µH. Cause of high load 1kW, so it can be designed by adding interleaved technique used for reduce the size of current ripple while transfer power energy.

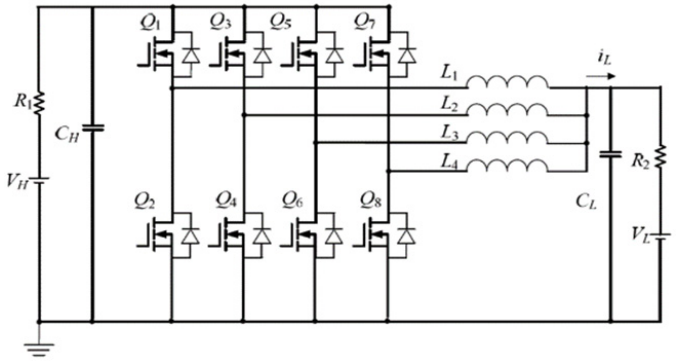

Fig.3. Circuits of the Bi-directional 4 Phase Interleave Converter.

This parallel phase current flowing through each phase is ¼ of all flows as shown in Fig 3, so the voltage across and the total loss in the switching devices was reduced. The size of the inductor in the circuit is smaller and the power to the system was increased.

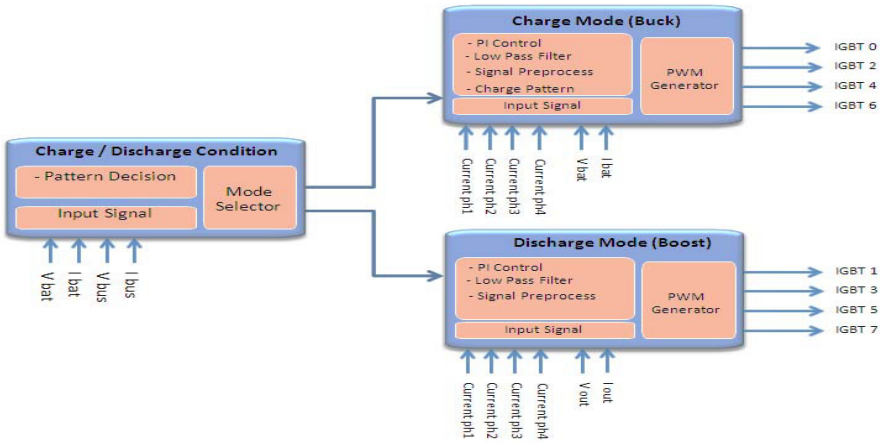

Fig.4. Control mode of Bidirectional 4 Phase Interleave Converter

Firstly, to create the conditions that apply to PI controller to control the charge / discharge of the battery the received the input signal from I bus, V bus, I bat, V bat are used then system sent PWM signal to control switch on/off power circuit of each mode to charge and discharge mode. Volume I, V BUS and the SOC of the battery is the main variable to control these converters, with condition as following.

Buck Mode when the battery is 0.4 <SOC< 0.9 and P Bus must be greater than P Bat. Boost Mode on battery SOC> 0.9 and P Bat must be greater than P Bus.

3. Experiment results.

To simulate a 4 Phase interleave bidirectional converter using MATLAB / SIMULINK by dividing the work into two parts of the circuit and the control circuit.

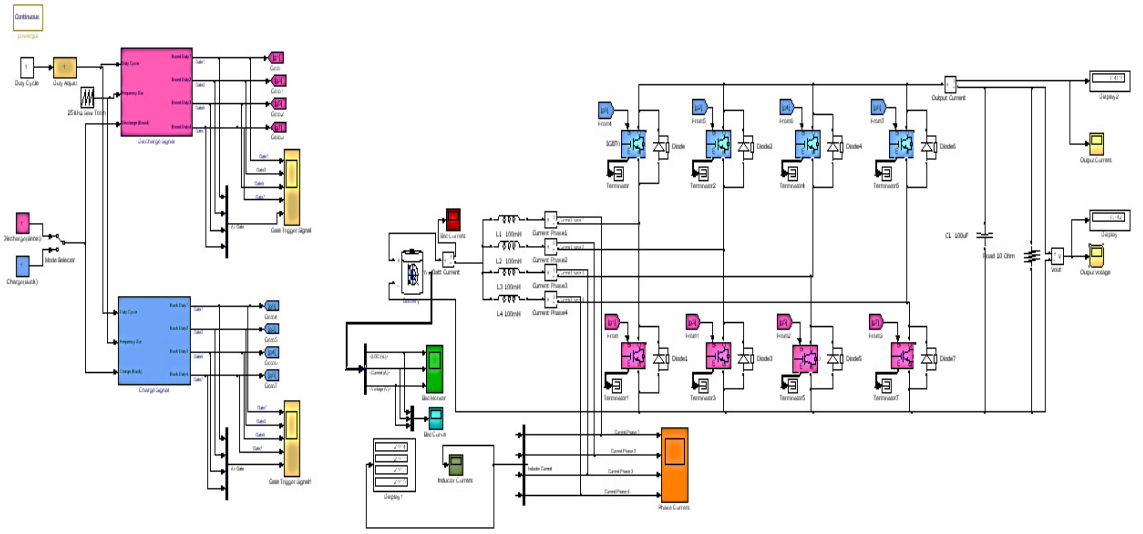

Fig.5. MATLAB/ SIMULINK model.

The control signal portion was create a reference PWM signal to drive the switch in each set. Simulation of the circuit while the circuit being Buck /Boost mode.

Test Discharge mode condition by send the PWM signal to drive the switches G1, G3, G5, G7 converter circuit works as boost converter. From battery 60V to 120V DC.

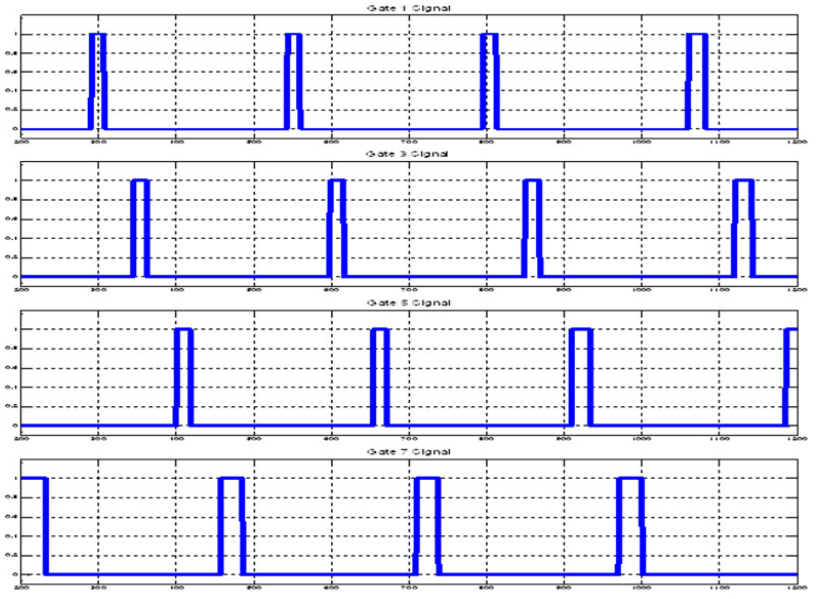

Fig.6. PWM Signal to drive switch G1, G3, G5, G7.

The switch G1, G3, G5, G7 is overlap phase shift 90 degrees in 1 period, as shown in figure 6, and each switch is running at 90, 180, 270, 360 degree in respectively.

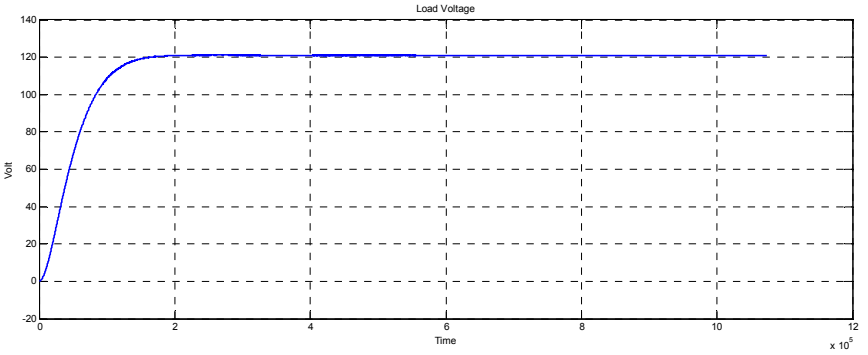

Fig.7.Voltage value at DC load.

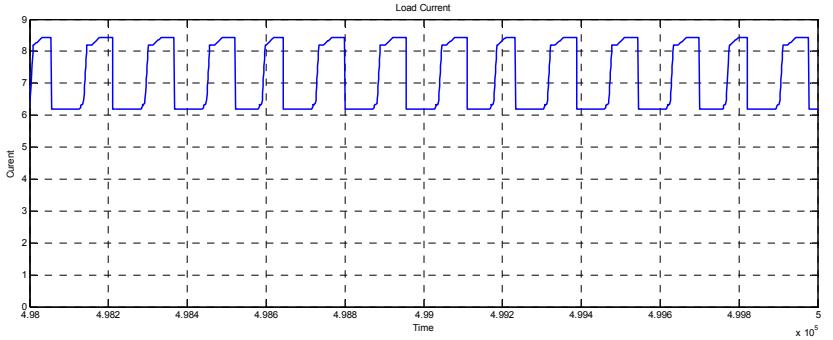

Fig.8. Current value at DC load.

Results of the Simulation on converter works as a boost converter, voltage of battery was increases to 120V by Figure 7, and the amount of electricity at current load equal to 8.3 Amp by Figure 8.

These values of current and voltage were matched with defined scope 120 V 1 kW. Battery cans supplies power to the load continuously.

Test Charge Mode condition started by generate the PWM signal to drive the switch G0, G2, G4, G6 converter circuit works as buck converter to drop voltage of DC BUS 120V into the batteries size 60V.

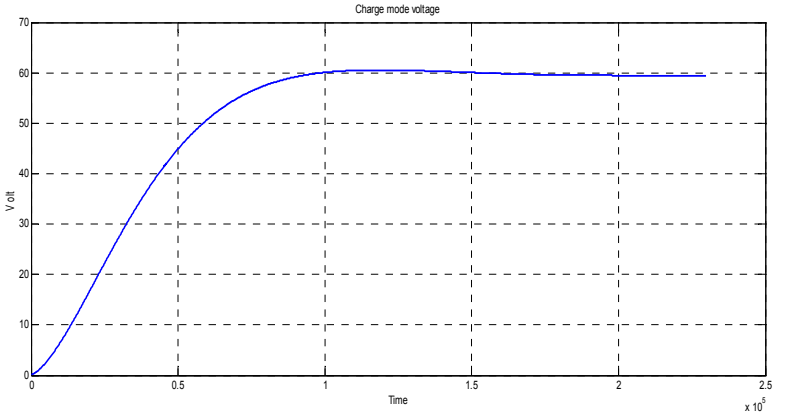

Fig.9. Voltage value at Battery 60V.

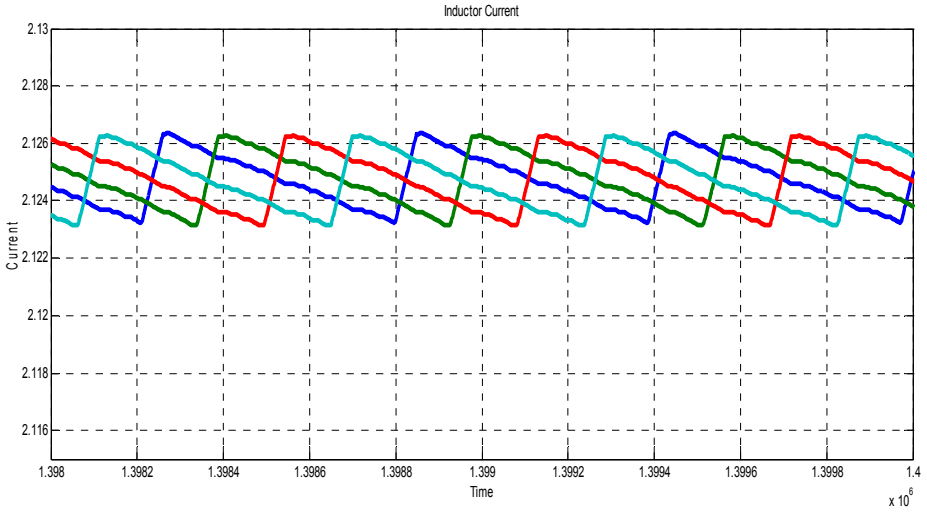

Fig.10. Current value at inductor of each phase.

Simulation results on a converter circuit work as a buck converter. It can be seen that the voltage at the battery voltage was increases to 60V as show in Figure 9, and the flow of electric current through the inductor is same in each phase as shown in Figure 10, totally the output current is 12A battery volume all the coordinates of Lead-Acid batteries per researchers have designed 12Ah /12V.

4. Conclusion

From the simulation results with MATLAB/ SIMULINK, the designed Bi-directional 4 phase interleave circuit can be able to charge battery when no load demand and can transferred power energy to load 1kW 120VDC that used controller to control charge /discharge condition by received the input signal from I bus, V bus, I bat, V bat. The total energy can be continuously transferred to system. The technique of parallel 4 phase interleave shows that power losses of the switches was reduced. Inductance in the circuit is smaller and power energy was increased.

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