Research Article

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Bidirectional Buck-Boost Controller for Electric Vehicle Using FPGA Board

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ABSTRACT

Due to increasing of fuel price, a new vehicle without using fuel is required to reduce dependent on fuel consumption. Electric vehicle used battery as an energy source and electric motor as propulsion components. A converter is required to control the power flows between battery and electric motor. In the current century, DC motors plays a vital role in industrial areas. It is an efficient motor that be able to control the speed. This project focuses on power converter controller for DC motor application. Buck-boost converter is used to control power flows between battery and DC motor. FPGA is used to generate the output signal. An FPGA schematic diagram is designed using Quartus-II and ModelSim-ALTERA. In addition, hardware prototype has been developed based on the circuit designed. The system performance are evaluated and analyzed in comparison with a simulation results. At the end of this project, FPGA board is satisfied with the desired controller design.

INTRODUCTION

Nowadays, electric vehicle (EV) is cutting-edge technology in automobile industry. In advanced country their government taking seriously in developing green vehicle, in order to protect the environment especially air pollution. The concept of EV is use a charged battery to energize and converts from electric energy to mechanical energy. So basically EV are propelled by Direct-Current (DC) motor and powered by electricity from fuel cell in the car itself. Due to its soft characteristics, the output voltage of fuel cells cannot be directly connected to an inverter [1]. So a buck-boost converter is inserted between them to make a match and improve the performance of traction motors [1]. Buck-Boost converters are also known as DC-DC converter, which have so many applications to use it such as controlled DC motor or battery charging. To control the buck boost converter, the controller circuit will be added at the converter. At the same time, because of their intrinsic nonlinearity, these systems represent a challenging field for control algorithms [2]. Using Field Programmable Gate Array (FPGA) also known as logic circuit is the way to control the converter. FPGA consist of hundreds or thousands of transistors, maybe it goes to millions. The complexity that comes with large size of logic circuit can be handled by using highly organizing design techniques. Logic circuits are made from digital hardware. It derives the information in electronic signals that carries digits of information. In the beginning of this technology, the logic circuits only use a few of transistor, but when the technologies goes advance, it become improved and larger. The designer of digital hardware may be faced with designing logic circuit that can be implemented on a single chip or designing circuit that placed chips on a Printed Circuit Board (PCB). But some logic circuit can be realized with existing chip that are readily available and this situation can shorten the time needed to develop the final product. More large variety of chip can do various functions that are useful in the design of digital hardware.

LITERATURE REVIEW

A. Buck-Boost Converter

A bidirectional buck-boost converter for electric motor with battery as supply is shown in Fig. 1. It consist of two switching device, one inductor, and two electrolyte capacitors. The power flows can be control according to the operation of the electric motor whether in forward motoring or regenerative braking. It also operates like a two-quadrant chopper [4]. Buck-boost converter is simple configuration, fewer components, and higher reliability [1].

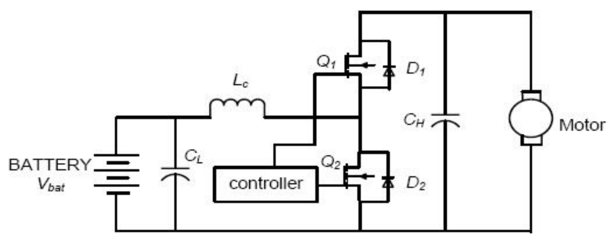

Fig. 1 Bidirectional Buck-Boost Converter [3]

B. Buck-Boost Control Method

The speed of DC motor can be control by controlling the output voltage. When the load changed, the output voltage will change accordingly. PI controller will compares the output voltage with reference voltage and minimize the error. Then it is fed to PWM generator to obtained PWM waves to control the switching devices. Fig. 2 shows the Buck-Boost control system applying PI controller and PWM generator in the design.

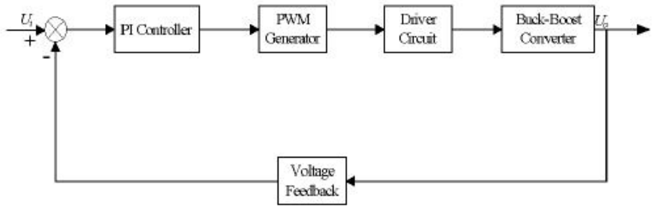

Fig. 2 Buck-Boost Control System [1]

The duty cycle for this converter is shown in Equation 1 [5].

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D} \tag{1}$$

The duty cycle is linearized through PI controller with characteristic as shown in Equation 2 before fed to the gate driver [5].

$$D_L = \frac{D_{NL}}{D_{NL}+1} \tag{2}$$

Where,

D_{NL} = non-linearized duty cycle

D_L = linearized duty cycle

C. DE0-Nano Board

Altera and collaboration with Terasic developed a compact-sized FPGA development platform suited for a wide range of portable design project i.e. robotics and mobile projects. Fig. 3 and 4 shows the DE0-Nanao board and component diagram respectively. It uses Altera Cyclone IV FPGA that has 22320 logic elements. It also has other features as shown in Table 1. It comes together with DE0-Nano system builder and Quartus II for easy creating an FPGA design.

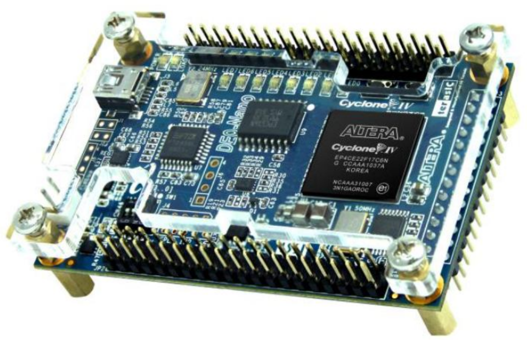

Fig. 3 DE0-Nano Board [6]

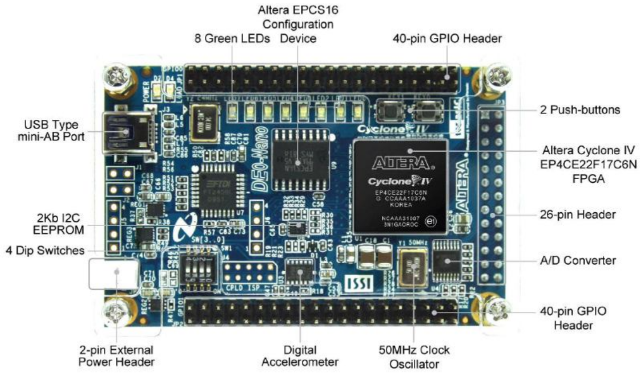

Fig. 4 DE0-Nano Board Component Diagram (Top View) [6]

TABLE I

DE0-NANO FEATURES

Features	Device
FPGA	Cyclone IV EP4CE22F17C6NN
Configuration and Set-up elements	On-board USB Blaster, Serial configuration device EPC16
Expansion header	40-pin Headers (GPIOs)
Memory	32MB SDRAM 2Kb I2C EEPROM
General user input/output	8 green LED, 2 debounced pushbuttons, 4-position DIP switch
G-Sensor	ADI ADXL345, 3-axis accelerometer (13-bit)
A/D Converter	8-Channel 12-Bit
Clock	Onboard 50MHz clock oscillator
Power Supply	USB type mini-AB port, 2 DC 5V pins, 2-pin external power header

METHODOLOGY

The block diagram of the overall system is shown in Fig. 5. A 12V lead-acid battery is used as a DC supply. A 12V DC motor is used a load. A buck-boost converter is used to control the power transfer bidirectional i.e. from battery to DC motor during forward motoring mode and from DC motor to battery during regenerative braking mode. The buck-boost converter consists of two MOSFETs, inductor and capacitor. A driver circuit is required and connected from FPGA board outputs to the buck-boost converter.

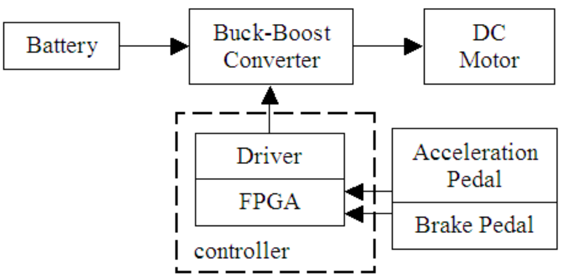

Fig. 5 Buck-Boost Control System

This is due to FPGA board only able to supply low voltage and current output. FPGA board can be program by software tools and develop digital signal that carries information for specific application. The acceleration and brake pedal are connected directly to the FPGA board to control accelerating and braking. It is because the output from the acceleration and brake pedal is in digital form. A DE0-Nano board consist of Cyclone IV EP4CE22F17C6 FPGA is used in the project. The schematic diagram of the buck-boost converter is shown at Fig. 6. This buck-boost converter consists of two MOSFETs i.e. Q1 and Q2. When Q1 is turn-on, the boost mode will operate in this converter. In boost mode, the power is transferred from battery to DC motor. The DC motor will moved in forward direction. When Q2 is turn-on, the buck mode will operate and the power is transferred from DC motor to battery. The DC motor acts as a generator and start charging the battery. This is happened when the DC motor speed is reduced due to braking. However, these two switches are forbidden to be turn-on at the same time. Table 2 shows the operation mode for the buck-boost converter. Operation principle for the controller system of buck-boost converter is shown in Table 3. Q1 is functioning as switch 1 and Q2 is functioning as switch 2. When the brake pedal is pressed (ON), automatically Q2 is (ON) and Q1 is (OFF). In this condition the converter will operate in buck mode. When the acceleration pedal is pressed (ON), automatically Q1 is (ON) and Q2 is (OFF). In condition the converter will operate in boost mode. Both Q1 and Q2 are (OFF) if the acceleration and brake pedal are pressed (ON) or leave (OFF) simultaneously.

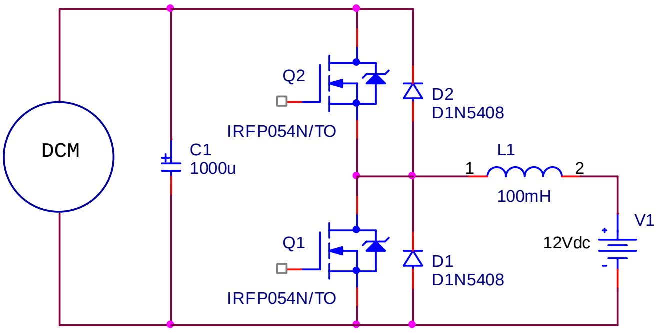

Fig. 6 H-Bridge Bidirectional Buck-Boost Converter

TABLE 2

BUCK-BOOST MODE OF OPERATION

Mode Operation	Device Activated
Buck	Q2, D1
Boost	Q1, D2

TABLE 3

BUCK-BOOST OPERATION PRINCIPLE

Acceleration Pedal	Brake Pedal	Q1	Q2
OFF	OFF	OFF	OFF
OFF	ON	OFF	ON
ON	OFF	ON	OFF
ON	ON	OFF	OFF

Table 3 is simplified into truth table as shown in Table 4. Digital numbers 1's and 0's are used as digital input for the FPGA board. (ON) is represent as 1 and (OFF) is represents 0. Karnaugh map for Q1 and Q2 are shown in Fig. 7 respectively. K-map is applied to obtain the Boolean expression for this converter as shown in Equation 3 and 4.

TABLE 4

BUCK-BOOST TRUTH TABLE

A	B	X	Y
0	0	0	0
0	1	0	1
1	0	1	0
1	1	0	0

Where,

A = Acceleration Pedal

B = Brake Pedal

X = Q1

Y = Q2

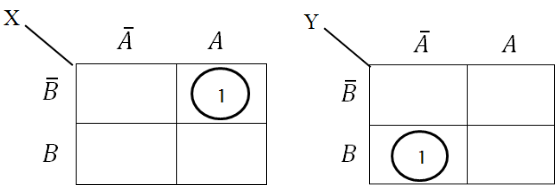

Fig. 7 K-Map for X and Y

$$X = A\bar{B} \tag{3}$$

$$Y = \bar{A}B \tag{4}$$

The logic diagram for buck-boost controller is shown in Fig. 8. The DE0-Nano board is configured according to the pin assignment as shown in Table 5. KEY_0 is for A, KEY_1 is for B, and LED is used as an indicator.

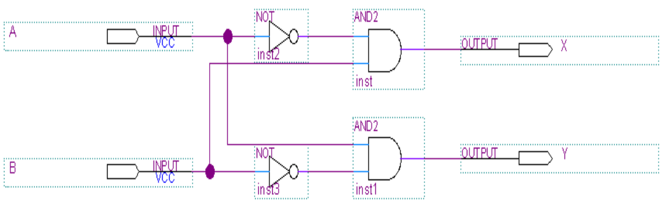

Fig. 8 Logic Diagram for Buck-Boost Controller

Table 5

PIN ASSIGNMENT FOR DE0-NANO BOARD

Input and Output	Pin
KEY_0	J15
KEY_1	E1
Output X	D3
Output Y	C3
LED_0	A15
LED_1	A13

RESULT AND DISCUSSION

Fig. 9 shows the hardware part for this project. The signal generated is tested inside the Quartus platform and Fig. 10 shows the results. Fig. 11 and 12 shows the results obtained from hardware part. The controller correctly operated when KEY_0 is high, the output X is high and vice versa. The controller is in boost mode. Whereas when KEY_1 is high, the output Y is high and vice versa. The controller is in buck mode. Both output X and Y is low when both KEY_0 and KEY_1 is high or low.

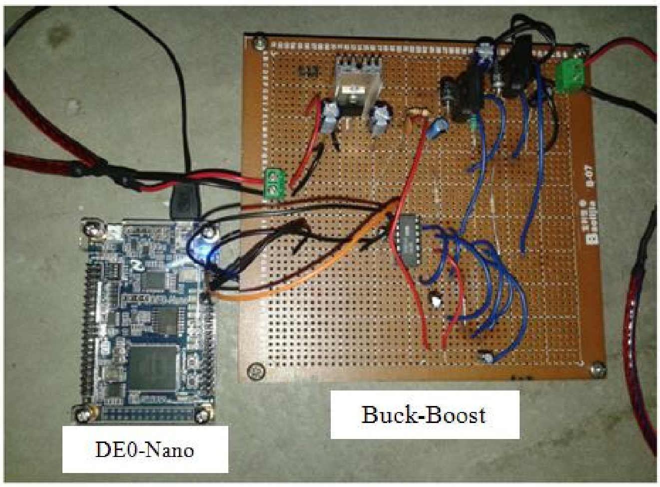

Fig. 9 Hardware of Buck-Boost Controller System

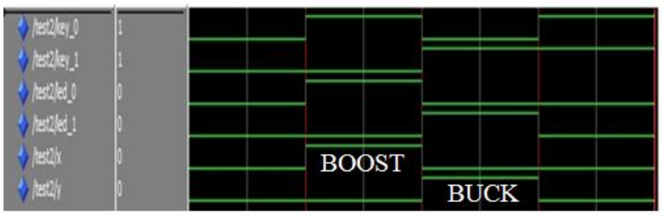

Fig. 10 Output Signal Generated by Quartus

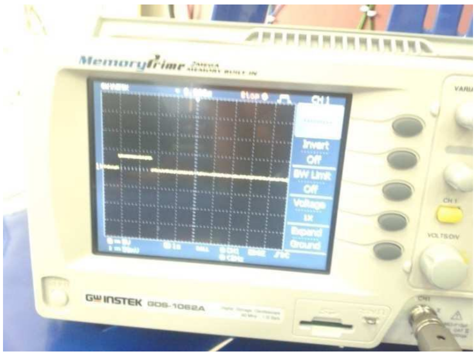

Fig. 11 Output Signal Generated by FPGA for output X

Fig. 12 Output Signal Generated by FPGA for output Y

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