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# Bidirectional DC to DC Converter for Electric Vehicle Applications

P.A. Chougule[1] and D.A. Patil[2]
[1-2]Assistant Professor, Department of Electrical Engineering, DKTE, Ichalkaranji
Email: pachougule@dkte.ac.in, dapatil@dkte.ac.in

***Abstract*—A DC to DC Converter is an important component in electric vehicles. With new features being added in speed control methods, the converter demands are ever increasing. The latest electric vehicles come with feature of regenerative breaking which optimizes battery usage. To incorporate such features which require electric power flow in both directions i.e. from source to load and from load to source, a converter with special features is essential. This can be achieved by implementing a bidirectional DC to DC Converter. A converter which can flexibly adjust the voltage gain is very much preferred. This paper presents a bidirectional DC to DC converter which can be flexible operated in buck mode or boost mode in either direction. The details regarding hardware design and experimental results are presented in this paper.**

***Index Terms*— bidirectional converter, boost, buck, duty cycle, PWM**.

## I. INTRODUCTION

The DC to DC converters are in practice for years. Broadly these converters are categorized as buck converter and boost converter. A buck converter is used when the required output voltage is less than input voltage. A boost converter is used when the required output voltage is more than input voltage. In these converters the current flow or power flow is from source to load i.e. in one direction only. Hence these converters are referred as unidirectional converters. Few applications such as renewable energy conversion, regenerative breaking in electric vehicles etc. require power flow from source to load as well as from load to source i.e. in both directions. The converter deployed for such cases are referred as bidirectional converters. A bidirectional DC to DC Converter is build by combining buck converter and boost converter [1].

The basic purpose of using bidirectional DC-DC converter is to achieve DC bus voltage regulation with ability of power flow in both directions. The bidirectional DC to DC converters are classified as isolated and non isolated converters.

In the study of DC bus voltage stability, the key aspects are the hardware circuit and the controlling method in the bidirectional DC/DC converter, which is related to the flow of the energy through the battery storage [2]. The converters control the direction of the energy flow of the bidirectional DC/DC converter as well as the energy storage unit to maintain the voltage stability to satisfy the efficient operating conditions [3].

The bidirectional DC/DC converter outputs DC voltage by filtering the time ratio of opening and closing of the switch transistor. With the technical progress of integrated circuits, bidirectional DC/DC converters are moving toward integrated development and miniaturization [4]. The bidirectional DC/DC converter mainly uses pulse width modulation (PWM) and combines it with power electronic technology. DC/DC switching power is a

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highly efficient power supply type and it has become a focus of attention in the development of DC power supply [5].

A detailed classification of bidirectional DC to DC converter topologies is presented in [6] along with control strategies. It also gives a comparative study of these topologies which assists for choosing a proper topology for selected application. The design of bidirectional DC to DC converter involves selection of power circuit components namely MOSFET/IGBT, inductor and freewheeling diode and the control circuit components usually build with a controller of user's choice [7].

## II. Bidirectional DC to DC Converter Operation

The basic configuration of bi directional DC to DC Converter is shown in figure 1. This converter is built by combining buck converter (working from side A to B) and a boost converter (working from side B to A).

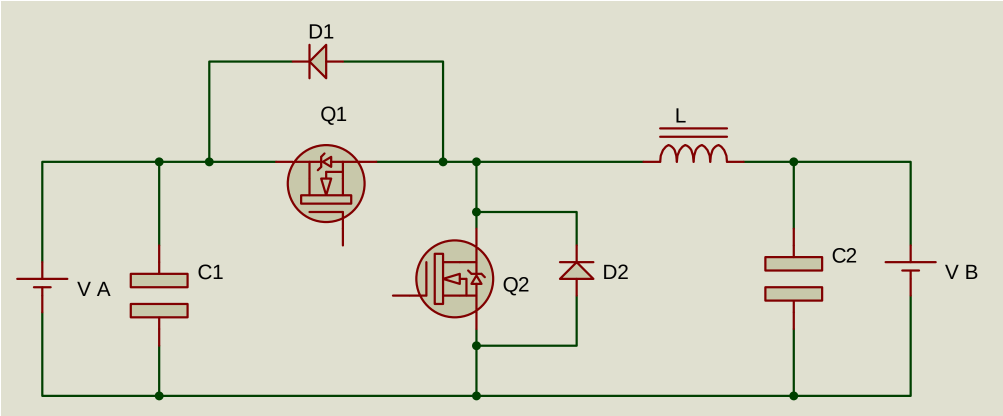


Figure 1: Bidirectional DC to DC Converter

The operation of this circuit can be understood with the help of the direction of power flow i.e. from side A to B and vice versa. The power flow from side A to B is achieved through a buck converter as shown in figure 2.

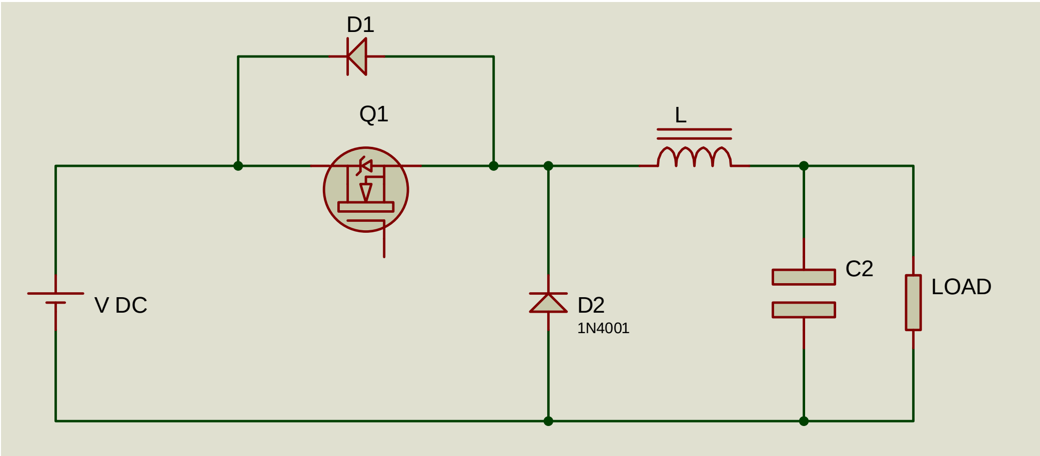


Figure 2: buck converter

The input voltage source is connected to a controllable power electronic semiconductor device (MOSFET) which operates as a switch. The MOSFET is turned on and off by using Pulse Width Modulation (PWM).

The voltage equation of buck converter is given as,

$$V_o = D.V_{in} \quad \text{.... (1)}$$

In boost converter, an inductor is connected in series with the input voltage source and a MOSFET is connected in shunt with the load. The inductor connected to input source leads to a constant input current, and thus the

Boost converter is seen as the constant current input source. And the load can be seen as a constant voltage source. The controlled switch is turned on and off by using Pulse Width Modulation (PWM).
The voltage equation of boost converter is given as,

$$V_o = \frac{1}{1-D} V_{in} \qquad \dots (2)$$

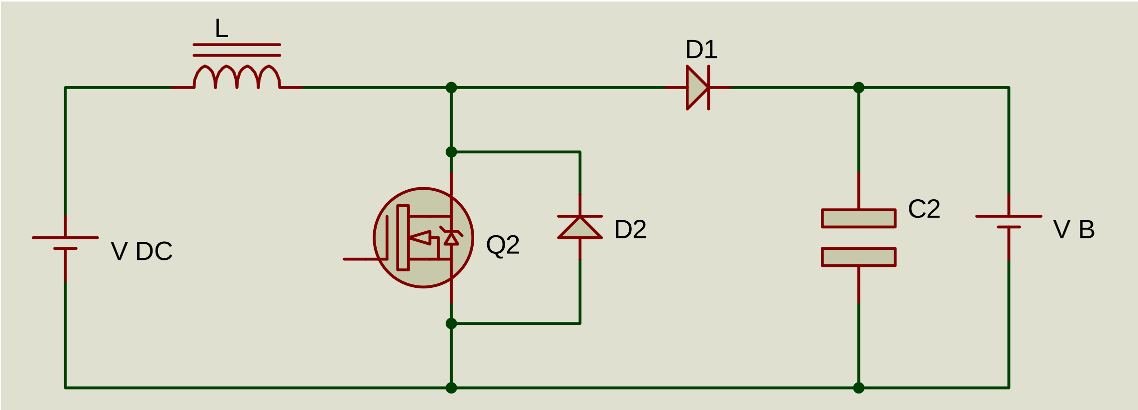


Figure 3: Boost Converter

From equation 1 and 2 it is clear that the output voltage of a buck converter or a boost converter is proportional to the duty cycle of the PWM control signal. Hence to regulate the voltage output of these converters, the duty cycle of the control device i.e. MOSFET is required to be regulated.

## III. Circuit Design and Results

TABLE I: Specifications of proposed converter

| | |
|---|---|
| Voltage on side A | 24 V |
| Voltage on side B | 36 V |
| Power | 250 W |
| Purpose | Electric vehicle |
| Switching Frequency | 10 KHz |

For design of the power circuit, specifications as mentioned in table 1 are used.

### *A. Selection of MOSFET / IGBT*

The maximum voltage in the circuit is 36V. Hence the selected MOSFET / IGBT should have voltage rating at least three times to that of working voltage.
The maximum current handled by the MOSFET is,

$$i = \frac{P}{V} = \frac{250}{24} = 10.41\ A$$

Considering factor of safety of 2, select MOSFET with at least 20A current rating.
Switching frequency is 1 KHz (Time period = 1mS). Hence the response time of MOSFET should be less than 100µS. By considering above stipulations, MOSFET IRF250 can be selected for prototype development. To eliminate the risk of thermal runaway, a bank of MOSFET can be selected with two or more devices in each branch.

### *B. Calculation of Inductor*

The inductor ripple current can be considered as 40% of the maximum load current

$$I_L = 10.41\ \text{A}$$

$$\therefore \text{di} = 0.40 * 10.41 = 4.16\ \text{A}$$

Therefore, the inductor value can be calculated as

$$L = V_L \frac{dt}{di} = V_L \frac{D}{f.di} = 36 \frac{0.6}{1000 \times 4.16} = 5.1\text{mH}$$

*C. Results*

For control circuit design a microcontroller with ADC and PWM facility is preferred since PWM is required for duty cycle control and ADC for voltage measurement. The interface between microcontroller and MOSFET is done with MOSFET driver IR 2110. The photograph of the developed circuit is shown in figure 4. The figure 5 shows PWM waveforms of the MOSFET. A summary of results for operation in buck mode i.e. power flow from side A to B is presented in table II and the summary of results for operation in boost mode i.e. power flow from side B to side A is presented in table III.

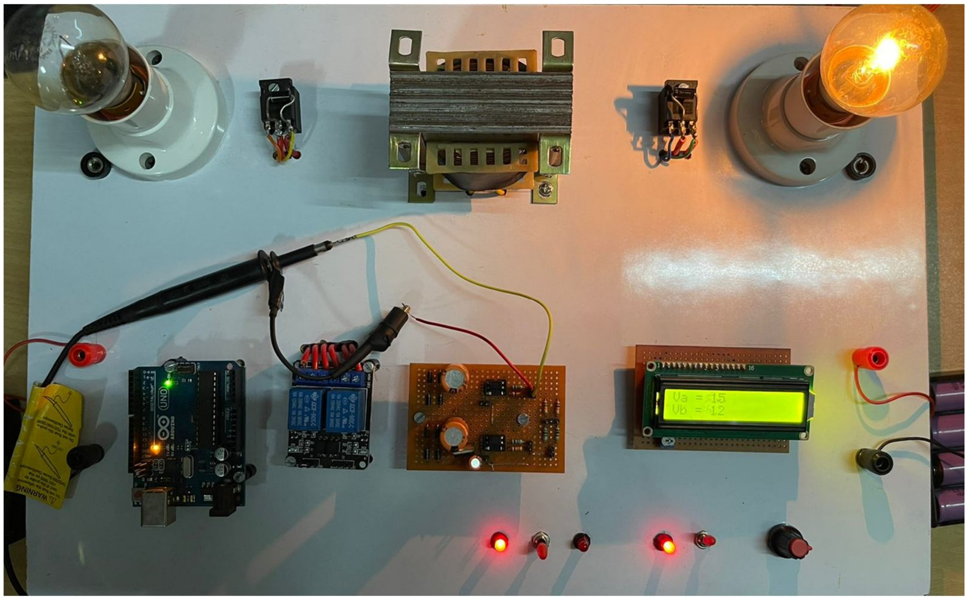

Figure 4: Photograph of the developed circuit

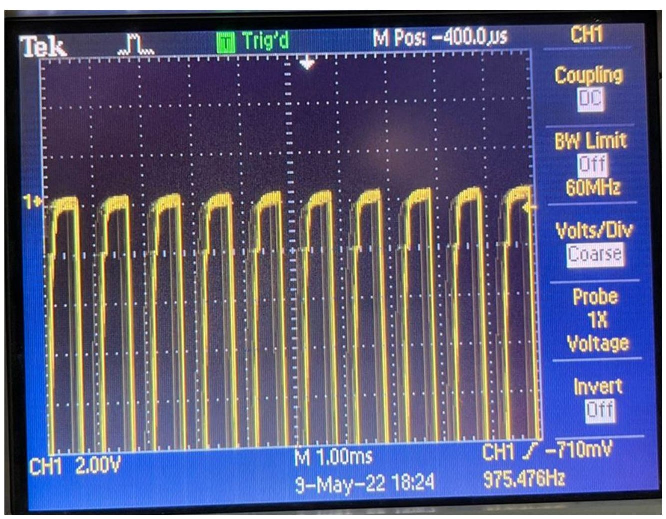


Figure 5: PWM signals of the MOSFET

TABLE II: RESULTS SUMMARY (SIDE A TO B OPERATION)

| Side A Voltage | Side B Voltage | Duty Cycle |
|---|---|---|
| 36 | 20 | 0.59 |
| 36 | 24 | 0.68 |
| 36 | 30 | 0.86 |
| 36 | 33 | 0.94 |

TABLE III: RESULTS SUMMARY (SIDE B TO A OPERATION)

| Side B Voltage | Side A Voltage | Duty Cycle |
|---|---|---|
| 20 | 36 | 0.48 |
| 24 | 37 | 0.37 |
| 28 | 37 | 0.29 |

## IV. CONCLUSION

This paper discusses operation and control requirements of the bidirectional DC to DC converter for electric vehicle application. The power conversion from battery to motor is done through buck mode such that the speed of the motor can be smoothly controlled. During regenerative braking, the voltage generated depends on speed of the motor. Hence boost mode is deployed for power flow in reverse direction. The voltage control in both modes is achieved by PWM duty cycle control.

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