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Bidirectional of DC-DC Converter Topologies for Electric Vehicle Application

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ABSTRACT

Electric vehicles that use a bidirectional DC-DC converter between the electric supply and the traction motor can more easily regenerate energy when braking and moving downhill. The addition of this feature can increase traction drive efficiency by up to 25%, enhancing the entire operating range. Now that the design performance has been optimized, a suitable bidirectional DC-DC converter topology should be chosen in order to lower the system's weight, size, and cost. The basic bidirectional DC-DC converter topology is examined in this research, along with its comparative benefits and drawbacks for making the best design choice for an electric vehicle traction application.

Keywords: Regenerative braking, traction energy, Electric Vehicle.

1. INTRODUCTION

A bidirectional DC-DC converter has the capacity to move power in both directions while performing voltage level stepping up and down. Bidirectional DC-DC converters are presently employed in many different applications, including fuel cells, renewable energy sources, electric vehicle energy storage systems and uninterruptible power supplies. They were only ever utilized in the past for motor drive regenerative braking and speed regulation. Utilizing a bidirectional DC-DC converter is primarily done to achieve DC bus voltage management and allow power to flow both ways. As an illustration, the energy produced by wind and solar power plants has significant ups and downs since the energy supply from the primary source to the conversion unit (wind turbines and PV panels) is unpredictable. Due to its significant ups and downs, it cannot be used as a sole source of power and must always be supplemented by secondary sources like super capacitors or rechargeable batteries. When there is an energy shortage, these auxiliary sources provide power, and when there is an energy surplus, they recharge. Power can now flow in both directions thanks to the bidirectional DC-DC converter capability. Similar to this, in electric vehicles (EVs), a bidirectional DC-DC converter is employed to connect the DC bus and energy storage system (battery or fuel cell with super capacitor), as shown in Figure 1. Here, they are utilized to adjust the power supply to the motor drive in accordance with the need for traction power. The following factors make the usage of a bidirectional DC-DC converter in EVs necessary:

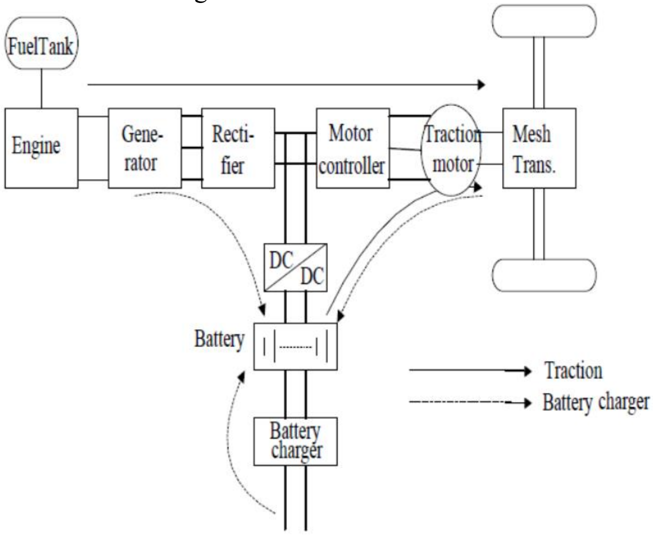

Figure 1: Drivetrain for a series hybrid using a bidirectional DC-DC converter.

1. Since the system uses a lot of power, low voltage causes current to rise to high values, putting both the active and passive parts of the system under stress. This generates significant ohmic losses, which lowers efficiency.
2. Wide input voltage variations stress devices with voltage and current, and input voltage variation affects component ratings that are employed in devices.

3. EMI emissions are brought on by parasitic components, which also generate parasitic ringing. Therefore, appropriate steps must be made to combat this.
4. Regenerative braking produces power loss that should be used to replenish electrical energy sources, which calls for bidirectional power flow. The aforementioned factors make the device expensive and cumbersome. Thus, a bidirectional DC-DC converter is required.

The following are some benefits of employing a bidirectional DC-DC converter in an EV:

- High efficiency.
- Compact size and less bulky.
- Lower EMI (electromagnetic interference).
- Lower input and output current ripple.
- Instead of input voltage variation-controlled power flow.

2. BIDIRECTIONAL DC–DC CONVERTER CLASSIFICATION

There are two types of bidirectional DC-DC converters, depending on the isolation between the input and output sides:

- Non-Isolated Bidirectional DC-DC converters
- Isolated Bidirectional DC-DC converters

3. BIDIRECTIONAL DC-DC CONVERTER WITHOUT ISOLATION

For constructing an isolated bidirectional DC-DC converter, a basic unidirectional DC-DC converter with bidirectional conducting switches is used. The basic circuit of a buck and boost converter (Figure. 2) contains a diode that prevents the flow of power in both directions. When a MOSFET or an IGBT with an anti-parallel diode between them creates a bidirectional switch and permits bidirectional conduction, the problem will be solved.

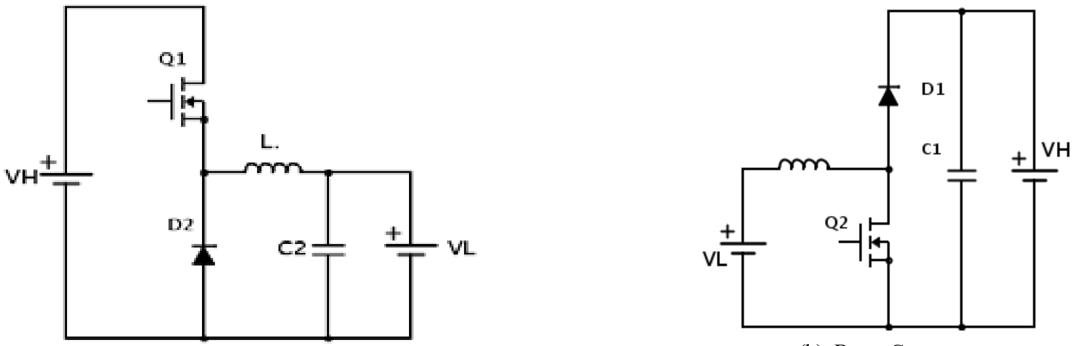

Figure 2: (a): Buck Converter. (b): Boost Converter.

A) Buck Boost Converter

As shown in Figure. 3, the first bidirectional topology is created by deriving a typical buck boost topology and implementing bidirectional conducting switches. During step-up operation, Q2 is always off while Q1 is kept on for the specified duty cycle. Similar to this, Q1 is switched off at all times while Q2 remains switched on at the required duty cycle during step down operation. Small dead time is supplied during mode transitions to prevent cross conduction across switches and converter output capacitance.

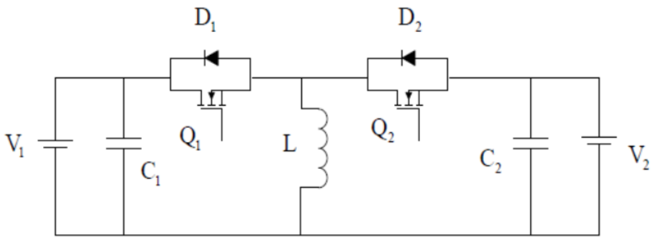

Figure 3: Bidirectional Buck and Boost Converter.

B) Cascade Buck Boost Converter

Bidirectional boost converters and bidirectional buck converters can be cascaded to make a buck boost cascade converter, as shown in Figure 4. In this system, the output voltage can be greater or lower than the input voltage depending on the switch configuration and current flow.

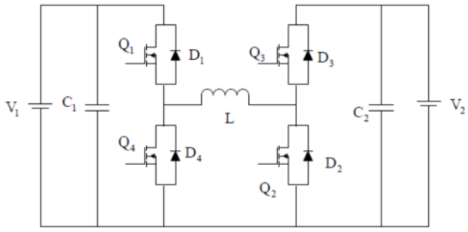

Figure 4: Bidirectional Buck Boost Cascade Convert.

switches S2 and S4 are always off during forward steps, whereas S1 is always on, with S2 conducting depending on duty cycle. Switches S2, S3 and S4 are always off while S1 is operated at the required duty cycle during forward step-down operation. While diodes D2 and D3 are always reverse biased, diode D3 always maintains a forward bias. As a freewheeling diode, diode D4 is used. When moving backward, S4 is operated with the required duty cycle, S3 is constantly on, and D1 serves as a freewheeling diode.

C) Cuk Converter

Cuk converter can be developed by replacing unidirectional switches in a traditional cuk converter with bidirectional switches. According to Figure 5, the capacitors C1 and C2 serve as coupling capacitors and capacitor C serves as an energy storage component. Similar to a buck boost converter, but with the opposite polarity, it can step up or decrease the input voltage.

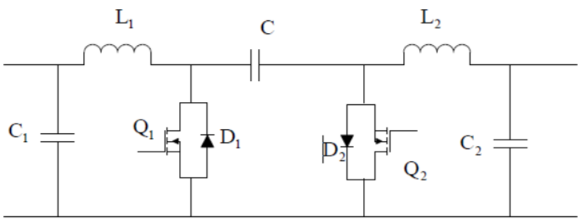

Figure 5: Bidirectional Cuk Converter.

D) Half Bridge Converter

The circuit formed by connecting the buck and boost converters in opposition to one another has the same basic design as the buck and boost construction but also includes bidirectional power flow, as seen in Figure 6. Depending on how MOSFET Q1 and Q2 are switched, the circuit will either run in buck mode or boost mode. The voltage across the switches Q1 or Q2 is changed in one of two ways: up or down, depending on the combination of diode D1 or D2 (a freewheeling diode). The mentioned circuit's bidirectional operation is described below.

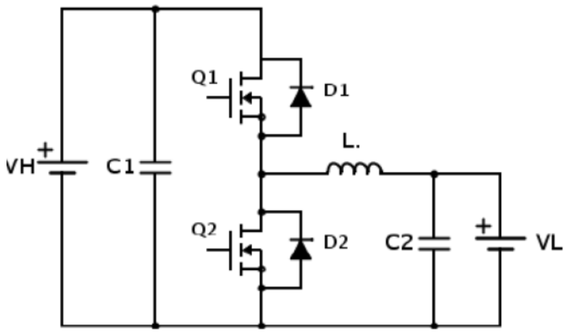

Figure 6: Non-Isolated Half-Bridge Bidirectional DC-DC Converter resulting out of the anti- parallel connection of the Buck and Boost converters.

Mode 1 (Boost Mode)

Switch Q1 and diode D2 are always off in this mode, while switch Q2 and diode D1 conduct based on the duty cycle. Based on the conductivity of switch Q1 and diode D2, this mode is split into two intervals.

Interval 1 (Q2 on, D2 off; Q1 off, D1 off)

When Q2 is turned on during this time, the inductor is charged by the lower battery and its current keeps rising until Q2 is turned off. Switch Q1 is not being used because it is off and diode D1 is reverse biased.

Interval 2 (Q1 off, D1 on; Q2 off, D2 off)

Since the current flowing through the inductor cannot change instantly in this mode, both Q1 and Q2 are off. As a result, the voltage's polarity is flipped and it begins to function in series with the input circuit. Since diode D1 is forward biased, the output capacitance is charged by the inductor current, increasing the output voltage.

Mode 2 (Buck Mode)
switch Q1 and the diode D2 conduct according to duty cycle. This mode is divided into two intervals based on how well switch Q2 and diode D1 conduct.
Interval 1 (Q2 off, D2 off; Q1 on, D2 off)
Since Q2 is off and Q1 is active during this time, the battery charges both the output capacitor and the inductor.
Interval 2 (Q1 off, D1 off; Q2 off, D2 on)
Switches Q1 and Q2 are not operating at this time, which causes the inductor current to discharge through the freewheeling diode D2 and step down the voltage across the load.

4. ANALYSIS OF VARIOUS NON-ISOLATED BIDIRECTIONAL CONVERTER TOPOLOGIES & FEATURES

1. In step up mode, the RMS value of current through the inductor and switches in the buck-boost bidirectional converter is greater by an amount equal to output current, and the RMS value of current through the capacitor also increases by a factor of 1/3 of output current in the buck-boost cascade converter. Therefore, in buck-boost bidirectional converters, inductor, capacitor and power switches operate under thermal and electrical stress, causing more power loss and inductor core saturation than in buck-boost cascade converters. Additionally, high RMS current causes high conduction losses and lowers overall efficiency, necessitating the usage of power devices with greater ratings due to the increased stress on the diode and MOSFET in the buck-boost cascade converter.
2.Although buck-boost cascade converters require twice as many devices as buck-boost bidirectional converters, this issue can be solved by employing half-bridge bidirectional DC-DC converters. It can be used when a boost operation in one direction and a buck operation in another is necessary.
3. The fundamental advantage of a half-bridge bidirectional converter over a cuk converter is that it only needs one inductor as opposed to two. It also uses a power device with a much lower rating than a cuk converter. In addition, half-bridge bidirectional converters have higher efficiency and lower conduction losses than cuk converters.

5. BIDIRECTIONAL ISOLATED DC- DC CONVERTERS

A converter of this kind can be used to regulate power ranging from a few watts to hundreds of kilowatts. The necessity for a transformer arises because it is typically utilized for this purpose when a system demands galvanic isolation and voltage matching. A Clink is required for energy transfer when utilizing a transformer. These many features make the system big and complicated. The isolated bidirectional DC-DC converter's most typical structure shown below.

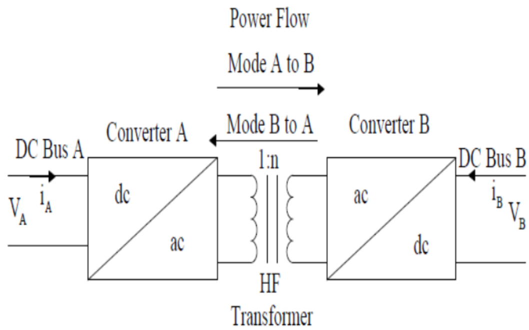

Figure 7: Isolated Bidirectional DC-DC Converter Basic Structure
To convert dc input to ac quantity, this system uses two switching DC to AC converters. Transformers provide galvanic isolation and voltage matching; however, because they can only operate with ac current, a dc to ac converter is needed on both the source and load sides. The converter must accommodate the bidirectional power flow because the system is bidirectional. Isolated bidirectional DC-DC converters can be divided into two groups based on configuration: The current fed isolated bidirectional DCDC converter has an inductor at its terminal that functions similarly to a typical boost converter's inductor at its input terminal. The voltage fed isolated bidirectional DCDC converter has a capacitor at its terminal that functions as a voltage source, just like a typical buck converter does at its input terminal.

6. CONCLUSION

Due to the isolated bidirectional DC-DC converter's less efficient overall operation and more complex, expensive and bulky structure compared to non-isolated bidirectional DC-DC converters, it is not suitable for use in electric vehicle applications. For EV drive train applications, Non-Isolated Half Bridge Bidirectional DC-DC converter may be the best choice.

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