Modelling of Bidirectional D.C. to D.C. Power Converters

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October 3, 2021

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***Abstract*—Bidirectional DC to DC converters are increasingly implemented in varying applications because of their ability to flow power in both directions, forward as well as reverse. It also plays a great role in handling load coming from renewable resources as they are fluctuating and the dc power converter help in maintaining a constant load at the other end. This paper aims to present all the topologies of Bidirectional DC to DC converters available in the literature. Buck-Boost and CUK converter models are simulated by using a voltage control algorithm which controls the flow of voltage by triggering the switches and the outputs of both the model is compared.**

Keywords— Alternating current (AC), Direct current (DC), Power switch, single-ended primary inductance converter (SEPIC), current ripples.

1. Introduction

Global climate alternate and depleting fossil fuel reserves are navigating societies for sustainable energy infrastructure. Renewable energy has many limitations. Therefore, it is necessary to use an energy storage system to compensate for source variations. Thus, the study of the bidirectional power converters has become an important area of research in power electronics. It is the opposite of unidirectional converters. These converters are more versatile and are widely used in smart grids [1], hybrid electric vehicles [2]-[6], uninterruptable power supplies [7]-[8], aerospace applications [9],

and renewable energy systems such as photovoltaic arrays [10]-[13], fuel cells [14]-[16], and wind turbines [17]. It is used as a key device for interfacing the storage devices between source and load, the bidirectional configuration reduces the size and improves the efficiency and performance of the system.

Bidirectional DC / DC converters operate in both buck and boost modes and can control power in the direction between the DC source and the load using a specific switching circuit and control strategy, so the generated excess power can be stored in the battery.

These converters are split mainly into two classes, non-isolated and isolated configuration. The features of each topology are discussed to to find the appropriate converter for a specific application. This paper is arranged as follows: Section 2 contains the classification of bidirectional dc to dc converters from a topology perspective. Section 3 contains the simulation part in which Different models are constructed like Buck-Boost and Cuk converter with outputs and component Tables. The voltage Control algorithm was used to control the models.

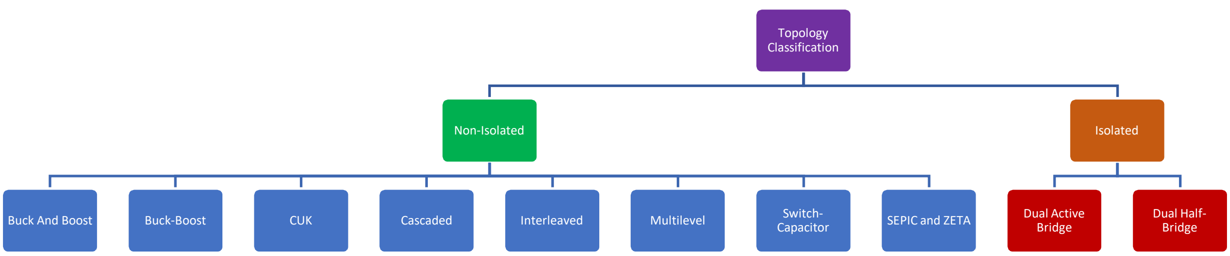

Fig. 1. Flowchart of the Topology.

2. Classification:

These converters can be divided into two main groups: isolated and non-isolated. Non-isolated converters transmit power without magnetic isolation.

The non-isolated converters transfer the power without magnetic isolation. These converters do not use a transformer [18] which makes them small in size, less weight, and do not suffer from magnetic interference. These factors make them appropriate in situation where area and weight are critical factors in specific applications.

On the alternative hand, the isolated converters transform DC voltage to Ac voltage waveform which passes via a high-frequency transformer after which is rectified to DC waveform. The voltage gain of non-isolated converters is less than isolated converters. However, the design of the transformer and the influence of leakage inductance is a crucial factor in this converter.

A. *Non-Isolated Topologies*

The non-isolated configurations are divided into eight groups shown in figure: 1.

1. Non-Isolated Buck and Boost Derived Bidirectional converter.

This bidirectional topology can be realized by the unidirectional buck and boost converter, If the switches of unidirectional buck and boost converter are substituted with the power switches, that will drive bidirectional buck and boost converter.

2. Non-Isolated Buck-Boost Bidirectional Converter.

The identical technique was used to expand a unidirectional to a bidirectional converter, by changing the switches of the unidirectional buck-boost converter with the power switches to obtain a bidirectional converter. The characteristics of a traditional buck-boost converter, such as the ability to increase or decrease voltage levels, bidirectional buck- boost converters provide this characteristic in each direction of power flow with a negative output voltage.

3. Non-Isolated CUK Bidirectional DC to DC converter.

This converter can be obtained by substituting the power switches and diode of the unidirectional converter with power switches to obtain a bidirectional Cuk Converter.

The Cuk converter is known for its characteristics like input and output current continuity. To eliminates the input/output current ripples [19] the unidirectional Cuk converter has coupled inductor, this technique has also been applied to the bidirectional Cuk converter.

4. Non-Isolated SEPIC and ZETA Bidirectional DC to DC Converter.

ZETA and Single Ended Primary Inductor (SEPIC are two other types of DC / DC converters obtained by rearranging the elements of the Cuk converter. This Converter act as a Zeta converter when power flow from High to Low Voltage and act as SEPIC when power flow from Low to High Voltage.

5. Cascaded Bidirectional DC-DC Converter.

This converter is the result of cascading of two bidirectional converters. This converter uses a higher number of elements than the basic bidirectional buck-boost converter, thereby improving the voltage boosting capability of the converter and lowering the current stress. To operate the converter at high rated power, the current stress of the inductor, switches, diodes and capacitors were reduced.

A supporting capacitor has been added to reduce the ripple of the output current. [20].

6. Switched-Capacitor Bidirectional DC-DC Converter.

Similar to cascaded bidirectional converter Switched-Capacitor Cell converter also can boost the voltage. The converter cells are made by expanding a unidirectional switched capacitor cell to a bidirectional configuration [21].

The weight and the magnetic utilization required because of neither inductor nor converter can maintain a continuous input by connecting two related strings of cells in parallel and operating them in phase opposition.

7. Multilevel Bidirectional DC to DC converter.

A switching module is used as a repeating source in each level to provide large voltage gain in Multilevel Bidirectional DC to DC converter. The weight and size of this converter are low because of the No inductor. These converters are preferred to use in the Automotive system.

8. Interleaved Bidirectional DC to DC converter.

The interleaved converter is the parallel combination of two or more than two converters with a relative phase shift of 360 degrees. The advantages of using interleaved converter are current ripple cancelation, more excellent thermal performance, high efficiency, current splitting, and high-power density. It Split's the current into numerous paths which reduces the conduction losses. This configuration is more cost-effective than conventional Bidirectional DC-DC converters, because of no inductor and a smaller number of capacitor and having high voltage gain, high efficiency, and low input current ripple.

delivery is proportional to the number of switches [28] that's why this topology is appropriate for high power applications [29]. Using a large number of switches there will be losses too, which can be overcome by using low power loss switches made of silicon carbide (SiC) or gallium nitride (GaN).

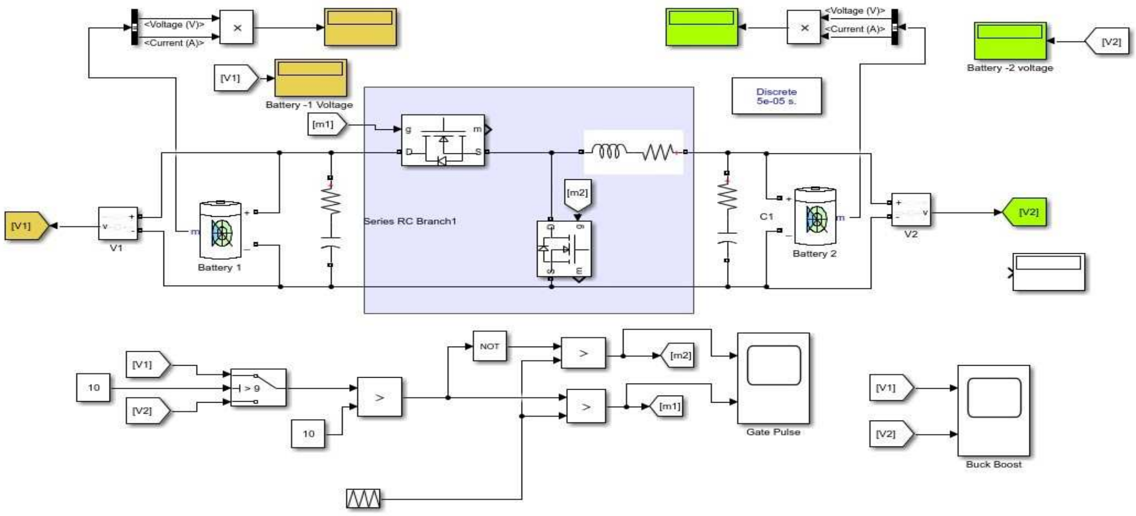

Fig. 2. Buck-Boost Bidirectional DC to DC Converter Model

B. Isolated Topologies.

In an Isolated DC-DC converter, a transformer which operates at high-frequency is used to give galvanic isolation. The isolation protects in overload conditions, noise attenuation, high voltage gain ratio. The isolated converters which operate in both directions are predominantly used in aircraft industry, electric vehicles, solar energy industries, etc. There are several configurations of isolated converters such as Forward-flyback IDBC, Dual-Cuk IBDC, Dual flyback IBDC, Dual half-bridge and full bridge IBDC, Dual push-pull IBDC [22]-[27]. The Full bridge and half-bridge IDBC are generally used owing to their high efficiencies.

1. Dual-Active Bridge (DAB) Bidirectional DC to DC converter.

The basic topology of the DAB converter shown in Figure: 1. Two full bridge converters are used on both sides of the transformer. with a high voltage gain ratio such as automotive systems. This topology is mostly used in automotive systems where voltage gain and power requirements are high. It has eight power switches in this configuration with galvanic isolation, power

This converter works in three stages:

1. In the first stage, the full-bridge performs the DC to AC conversion.
2. In the Second Stage, the High-frequency transformer step-up the AC voltage and provide isolation. To accomplish Zero voltage switching or Zero current Switching (ZVS/ZCS) and to intensify efficiency, a resonant tank may be used [30].
3. In the third stage, the full-bridge performs the AC-DC rectification.

2. Dual Half-bridge Bidirectional DC to DC converter.

This converter has less amount of power switches as compared to Dual Active Bridge (DAB) and we know power is directly related to the number of switches, hence this converter is used in low power application, with voltage-fed half-bridge in both side of the transformer. It provides high power density, soft switching, and easy control therefore, these are accepted in Electric-vehicles implementations.

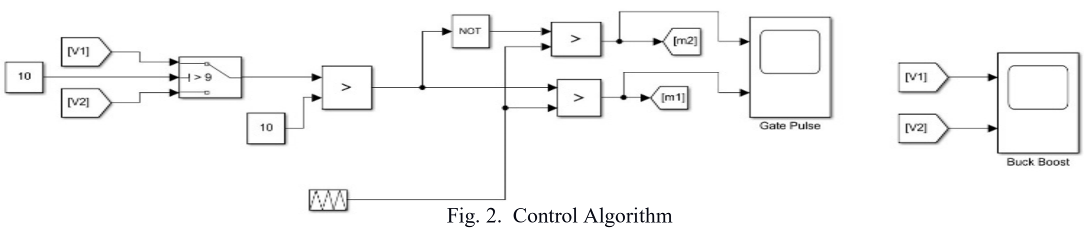

Fig. 2. Control Algorithm

3. Simulation.

In this section, numerical simulations were performed in MATLAB, and were based on the control-oriented model and its controllers. Different models have been constructed and tested like Cascaded Bidirectional DC to DC, converter buck-boost, Cuk. Voltage Control algorithm has been used and modelled as shown in figure: 3. First, the algorithm detects the voltages of batteries 1 & 2 and finds out which is at higher potential, and compares them against the base 10volts.

This algorithm in turn and sends the signal m1 and m2 to the corresponding MOSFETs for triggering through gate signal.

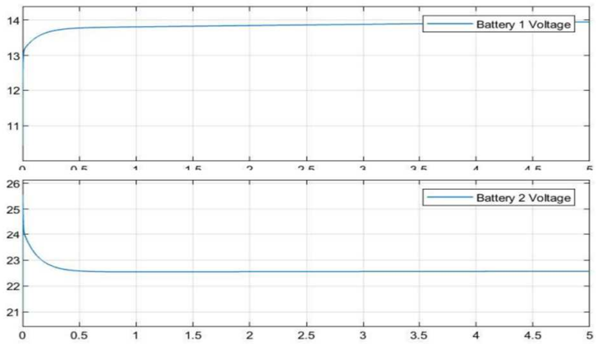

Fig.4. Battery1 Charging and Battery2 Discharging.

Test 1: When Battery1 has lower voltage than Battery2.

When v1 voltage is less than v2 voltage then it works as a boost converter. Battery1 has 12volts at around 10% initial charge and Battery2 at 24volts around 8% initial charge, battery2 is having more voltage in comparison to battery1. So, power needs to be transferred from right side battery2 to left side battery1. This results in battery1 power to be shown as -ve as in the power gauge, i.e. it is in charging mode.

The simulation outcomes are shown in Figure: 4 that battery2 is discharging and battery1 is

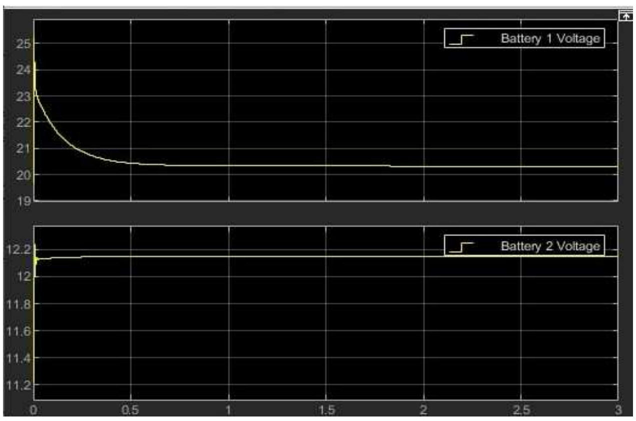

Fig. 5. Charging and Discharging of Battery.

charging. Under boost condition, m2 (MOSFET2) needs to turn ON and m1 (MOSFET1) needs to turn OFF.

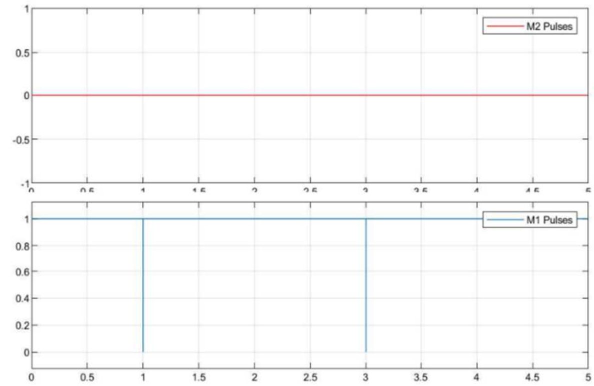

Fig.6. M2 OFF and M1 ON.

Test 2: When Battery1 has higher voltage than Battery2.

In this case, the v1 is at higher potential than v2 and it works as a buck converter. Now power has to shift from the left side to the right side of the circuit, m1 (MOSFET1) will have gate pulses and m2 (MOSFET2) will not be triggered shown in figure: 6 and so battey2 power is displayed in negative as it is receiving from battery1 shown in figure: 7.

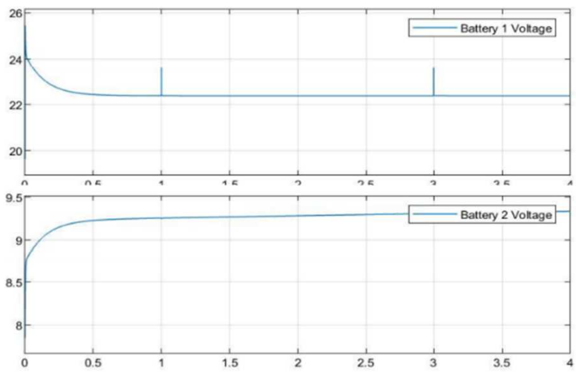

Fig.7. Battery2 Charging and Battery1 Discharging

1. Result

The complete analysis of the discussed converters from the point of topological structure and simulation of a couple of Bidirectional DC-DC converter has been modelled and tested in MATLAB. The non-isolated converters are simply originated by substituting the switches of the basic converters with that which are bidirectional in nature.

Figure: 5 and 8 shows the Cuk Bidirectional converter Model with the battery status and status of switches, from that we conclude that the CUK converter has high charging and discharging rate as compare to the Buck-Boost converter.

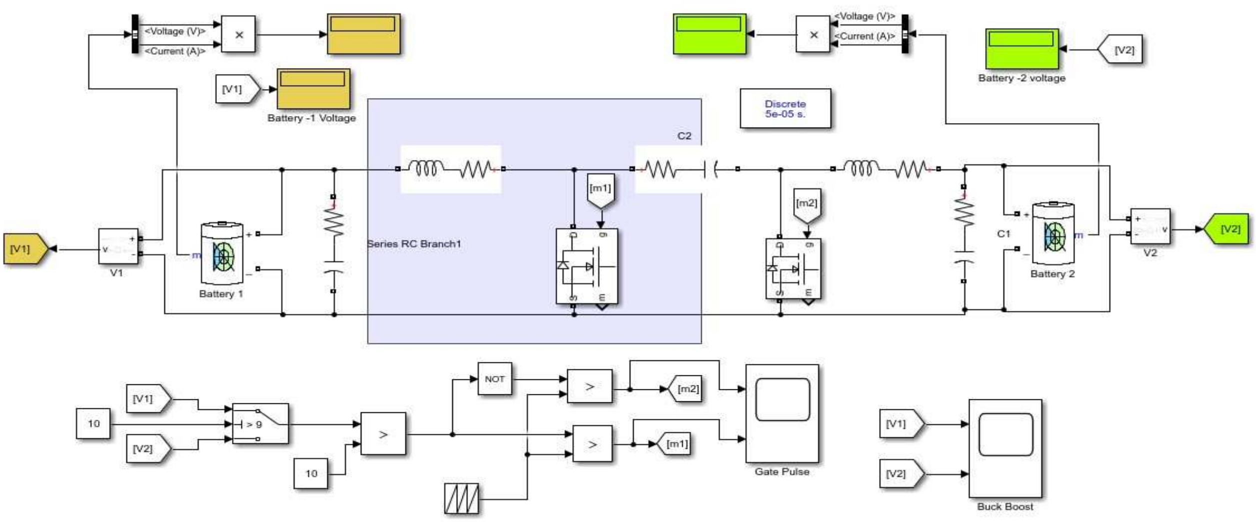

Fig.8. CUK Bidirectional DC to DC Converter Model

Table 1: Component Values of Buck-Boost Model

Properties	**Battery 1**	**Battery 2**	**Components**	**Values**
Composition	Nickel-Metal-Hydride	Nickel-Metal-Hydride	**Resistance (Ohms)**	0.1
Nominal Voltage(V)	24	8	**Capacitor(F)**	2000e-6
Rated Capacity(aH)	6.5	6.5	**Inductance(H)**	1e-3
Initial state of charge (%)	80	10	**Switching frequency (Khz)**	25
Battery response time(s)	0.5	0.5		

Table 2: Component Values of CUK Model

Properties	**Battery 1**	**Battery 2**	**Components**	**Values**
Composition	Nickel-Metal-Hydride	Nickel-Metal-Hydride	**Resistance (Ohms)**	0.1
Nominal Voltage(V)	12	24	**Capacitor(F)**	2000e-6
Rated Capacity(aH)	6.5	6.5	**Inductance(H)**	1e-3
Initial state of charge (%)	10	80	**Switching frequency (Khz)**	25
Battery response time(s)	0.5	0.5		

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