Bi directional DC-DC converters for electric vehicles

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Abstract: *The present thesis deals with the analysis, design and control of a DC/DC converter for the powertrain of an electric vehicle. The objective is to develop an integral solution of DC/DC converter and control that supports bidirectional operation, in order to recover energy during regenerative braking. The proposed DC/DC converter topology is a bidirectional boost converter with output filter. The stability of this topology is analysed considering the electric vehicle application. A motor drive can behave as a constant power load, which has negative incremental impedance, and thus holds unstable effects. An RC snubber is presented to avoid the instability, and a 1.5-kW prototype is designed. Sliding-mode control is the chosen control method for the current loop of the bidirectional boost converter with output filter, due to its robustness and disturbances rejection capability. The stability of the converter under sliding mode control is corroborated according to the Routh-Hurwitz criterion. Then, the voltage PI control is designed by means of the small-signal transfer functions of the bidirectional boost converter with output filter. As the Middlebrook criterion is accomplished, the stable DC/DC converter will remain stable when the load is connected. An analogue implementation of both the current sliding-mode and the voltage PI controller for the designed converter is presented, and validated by simulation and experimental test.*

Keywords: *Electric vehicle traction system, Energy requirement*

INTRODUCTION

Recently the use of renewable energy resources has been increased to save the environment and remaining fossil fuel and the requirement of storing the energy is also increased. In many applications like electric vehicles the need of interfacing of energy storage with load and source is increased for a reliable and efficient system. Bidirectional dc to dc converter is the main device used to interface the energy storage devices and system. Moreover, as in electric vehicles bidirectional dc to dc converters are used for capturing the kinetic energy of the motor and charging the battery during regenerative breaking by reverse flow of energy. Similarly, the output of the wind energy, solar energy etc., are environment dependent so fluctuations of output power and sudden change in load demand makes this hybrid system unreliable so, the solution for this issue is use of storage system like battery,super capacitor etc. with the help of bidirectional dc to dc converter for power conditioning and smooth flow of power to the load .In industrial application also, bidirectional dc-dc converters are used in many applications because devices are switch on and off at high frequency so DAB(Dual active bride)-IBDC (isolated bidirectional dc to dc converter) provide both galvanic isolation, storage of surplus energy and efficient flow of power without wasting the energy. For proper understanding of hybrid energy systems and electric vehicles, it is necessary to have knowledge of the working principle of dc-to-dc converter.

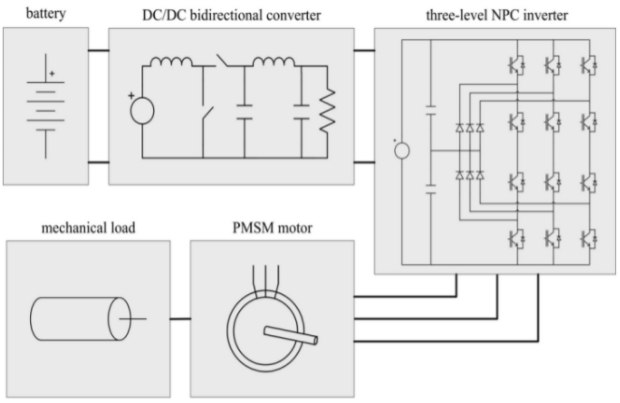
LITERATURE REVIEW

Power electronic devices, especially inverters have been extending their range of use in industry because they provide reduced energy consumption, better system efficiency, improved quality of product, good maintenance, and so on. Inverter can convert dc input voltage to a symmetric ac output voltage of required magnitude and frequency. The Magnitude of the inverter output voltage to be fixed or variable at a fixed or Variable frequency at variable output voltage of the inverter can be obtained by varying the Bidirectional Isolated DC-to-DC Converter 2 dc voltage and maintaining the gain of the inverter, if the dc input voltage is fixed and is controllable, a variable output voltage can be obtained by varying the gain of the inverter is normally accomplished by PWM control within the inverter. The inverter gain is defined as the ratio of the ac output voltage to the dc input voltage of the inverter. The output voltage of ideal inverters is to be sinusoidal. But the practical inverters are non-sinusoidal and contain definite harmonics. For low and medium-power applications, square wave or quasi square wave voltages may be suitable and for high power applications, low warped sinusoidal wave forms are required. By using high speed power semiconductor devices, the harmonic content can be minimized or reduced significantly by switching techniques.

BACKGROUND:

Successive EV were developed with electromagnet-based motors and using electrochemical cells as a source of energy. Although quite limited, their features overcame those of the internal combustion engine (ICE) vehicles, first invented in 1826 by the American inventor Samuel Morey. Further development was achieved with the use of a lead-acid rechargeable battery, by Gaston Planté in 1859. Moreover, the efficiency of the DC electric motors was improved thanks to the improvements introduced by Zénobe Gramme in 1873. The first commercial EV vehicle dates from 1893. This design from Paul Pouchain was able to carry six passengers at 16 km/h. Until 1910s, EV outnumbered ICE vehicles. However, the mass production of ICE vehicles introduced by Henry Ford in 1910 and the invention of the automobile starter in 1920 by Charles Kettering finished the prevalence of the EV over ICE vehicles. Moreover, the large-scale oil production that started in 1920 offered extended driving range to the ICE vehicles, with a lower production cost. This combination of factors made EVs less attractive , and after the 1920s their use became very restricted
A conventional buck-boost converter can manage the power flow in one direction only but power flow in both the directions in a bidirectional converter. Bidirectional dc-dc converters are the devices for the purpose of step-up or step -down the voltage level with the capability of flow power in either forward directions or in backward direction. In the power generation by windmills and solar power systems, output fluctuates because of the changing environment condition. These energy systems are not reliable to feed the power as a standalone system because of the large fluctuations in output and hence these energy systems are always connected with energy storage devices such as batteries and supercapacitors.

Block Diagram



TYPES OF BIDIRECTIONAL CONVERTER:

There are two types of Bidirectional dc/dc converter based on galvanic isolation provided between input and output.

- NIBDC
- IBDC Bidirectional Isolated DC-to-DC Converter

Non-Isolated Bidirectional DC to DC Converter (NIBDC)

NIBDC is a converter which does not use high frequency transformer to provide any electrical isolation between source and load. Hence these converters are not used in high power applications due to safety reasons but in low power application these converters are more efficient because these are easy to control and light weight due to absence of transformer.

Types of NIBDC are:

➔ Bidirectional Buck-boost Converter

➔ Cascaded Bidirectional Buck-boost Converter

➔ Bidirectional CUK Converter

➔ Bidirectional SEPIC-ZETA dc to dc Converter

➔ Switched Capacitor Bidirectional dc to dc Converter

➔ Interleaved Non-isolated Bidirectional dc to dc Converter 1.

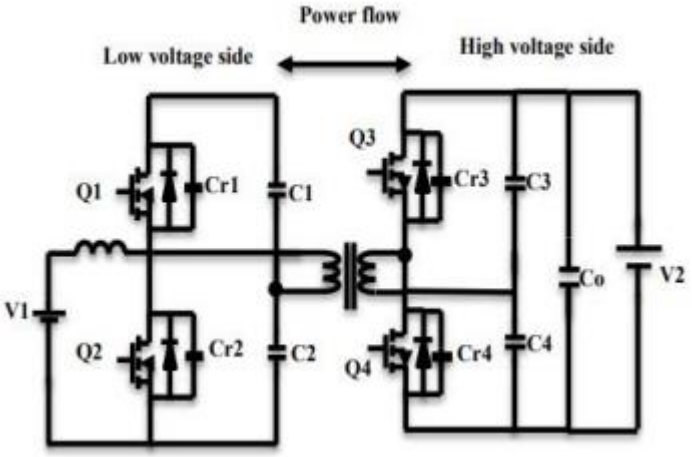
2-phase interleaved Non-isolated Bidirectional dc to dc converter.

Isolated Bidirectional dc to dc Converter:

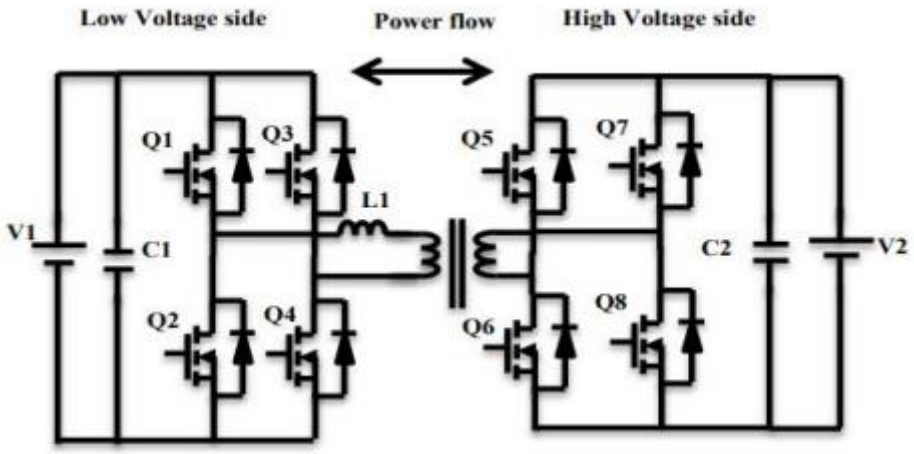
NBIDC are not capable to provide the safety standards of galvanic isolation. Hence in many applications, IBDC is used in place of NIBDC. In IBDC, high frequency transformer is used to provide galvanic isolation. Galvanic isolation is necessary in many applications for safety of source in overload condition, for noise reduction for voltage matching between conditions. This converter works in two stages. In first stage dc is converted to ac and second stage ac is converted into dc and both the stages are connected through high frequency transformer. The basic circuit of isolated bidirectional dc-dc converter. Since transformer can work only at there are many topologies of isolated converters such as

forward flyback IBDC, dual push pull IBDC and Dual active full bridge IBDC. But half bridge and full bridge are widely used because of their high efficiency

a) **Dual Half Bridge (DHB)-Isolated Bidirectional DC to DC Converter (IBDC**): Dual Half Bridge (DHB) isolated ZVS bidirectional dc-dc converters achieve high power Bidirectional Isolated DC-to-DC Converter 5 density, soft switching and easy control hence are used in EV applications. Its efficiency is 92% to 94%.



b) **Dual Active Full Bridge (DAFB)-Isolated Bidirectional DC to DC Converter:** Full bridge isolated bidirectional dc-dc converters are more suitable choice in hybrid energy system because of the high-power density and high efficiency. The power capacity with the switches so the above discussed DAFB-IBDC has higher power capacity than another. Its efficiency is 95%.Hence in high power application like Hybrid energy system,this converter is most suitable.



Working of Bidirectional DC to DC Converters:

Half bidirectional bridge topology combines the unidirectional buck and boost converters. The basic topology of the bidirectional DC/DC converter is shown in Fig. For the high-voltage side of the power supply, the power input voltage, diode, switch tube, and capacitor are represented by U1, D1, Q1 and Cf 1, respectively. For the low-voltage side of the power supply, the power output voltage, switch tube, diode, and capacitor are represented by U2, Q2, D2 and Cf 2, respectively. The diode is added in the position of the switch tube in the basic one-way buck converter, and the switch tube is placed in the original position of the diode, which is composed of a buck-boost type of bidirectional DC/DC converter circuit to control the state of the two switch tubes and further control the direction of the current and the values of the voltage and current. When Q1 is switched on and Q2 is switched off, the forward current flows through Q1 and D2. At this point, the energy is transmitted through the high-voltage side of the DC power supply to the low-voltage side of the lithium battery, and the depressurization process is completed. Hence, the buck-boost bidirectional DC/DC converter is equivalent to the unidirectional buck converter circuit at this point. The energy in the system is transmitted to the low-voltage side of the lithium battery through the high-voltage side of the DC power supply. When Q2 is switched on, Q1 is switched off, Q2 and D1 are in parallel, which Bidirectional Isolated DC-to-DC Converter 7 constitutes a unidirectional boost circuit, and the value of voltage rises; the energy is then boosted from the low-voltage side of the lithium battery. This combined design not only achieves bidirectional flow of energy but also retains the equivalent circuit of basic buck and boost topologies. To prevent the power circuit from working in a switch-off state that may damage the equipment, the two switch tubes Q1 and Q2 are restrained from being connected simultaneously. The proper dead time Td should be set between the driving signals, i.e., Q2 can be switched on after experiencing delay time Td and Q1 switches off. Moreover, after switching off Q2 and experiencing delay time Td, Q1 switches on to prevent the short circuit from damaging the system. The main reason is the energy storage inductance in the main circuit. However, to achieve switch-on of the switch in zero voltage, the Schottky diode is needed at both ends of the switch tube, which is used for the current freewheeling after the switch tube is switched off. When the circuit works in buck mode, the energy is transmitted forward, and the current in the inductor flows from the high-voltage side to the low-voltage side. When the circuit operates in boost mode, the current in the inductor flows from the low-voltage side to the high-voltage side. The polarity of the voltage U1 and U2 is the same at both ends of the circuit because the circuit works in forward or reverse direction. Hence, in this situation, this type of bidirectional DC/DC converter is called the current bidirectional DC/DC converter.Structure of Blockchain

A blockchain consists of blocks that are linked using a hash function. A hash function is a complex mathematical expression for the encryption of data. The block is timely stamped so it cannot be backdated. It also contains a special type of number which ranges from 0 to 4 billion called nonce. A block consists of a bundle of transactions. In the case of bitcoin, a transaction is a change of ownership of money. In the case of smart grids, it is a transaction of electricity. A node is an entity that connects to a blockchain network and performs various actions such as joining and leaving the network. There are two types of nodes full nodes, which hold a complete copy of the blockchain ledger that records and verifies all transactions. Light nodes are small limited resource-based blockchains that are used for smaller amounts of data verification and do not hold a complete copy of the blockchain.

Working Principle of Boost Circuit:

The boost structure is also divided into three states, namely, continuous, discontinuous, and critical. In the bidirectional DC/DC system, the inductor current is in continuous state. When the inductor current is continuous, the buck circuit also has two working states in one working period. Fig. 4 shows the equivalent circuit in the first mode of operation when Q2 is switched on and Q1 is switched off. The voltage of the lithium battery is directly connected with the inductor, the inductor Bidirectional Isolated DC-to-DC Converter 11 current continues to increase, and the storage energy also increases. The inductor current cannot be produced because Q1 is switched off, and the voltage is generated by the capacitor discharge. When the DC power supply is switched off, the bidirectional DC/DC alters to boost mode, and the voltage output is stable. The duty ratio of Q1 is D, and Equation (10) is expressed as the mathematical model of the boost converter. Figure 2.6 shows the equivalent circuit of Q2 and the Q1 is switch off . Equation (11) is obtained according to the circuit analysis.

Vo (S)/ Vi (S) at d(S)=0, = D/ LCS 2+ (L /R) S+D2 (10)

Vo (S)/ d(S) at Vi(S)=0 , = Vo(D 2− (L/ R) S) /D(LCS 2+ (L/Req)S+D2) (11)

Vbat = L diL/ dt (12)

The increment of inductance current can be obtained as:

ΔiL+ = Vbat/ L DT (13) In the second mode of operation, when Q2 is switched off, the lithium battery and the inductive current are discharged through the diode. Given that the inductor current is inertial, the current is produced together with the supply current, and the capacitor is charged. The output voltage is stable, and the polarity remains unchanged. The inductance current decreases linearly. Fig. 2.7. shows the equivalent circuit of the boost mode when Q2 works in the switch off state, and Equation (14) is derived from the circuit analysis.

L di /dt = Vbat − Vdc (14)

When Q2 switches off, energy is released by inductance as shown in Equation (15) below. ΔiL+ = Vbat − Vdc /L[(1 − D)T] (15)

Bidirectional Isolated DC-to-DC Converter 12 When the boost circuit is stable, the energy of changes in the inductance (when Q2 is switched on) is equal to the energy of release of inductance (when Q1 is switched off), and Equation (15) is obtained as follow. ΔiL+ = |ΔiL−| (16) Equation (15) can be rewritten to Equation (16).

Vbat /L [DT] = (Vbat − Vdc) /L [(1 − D) T] (17)

To sum up, Equation (17) shows the relationship between input and output voltages of the boost circuit.

$$\mathbf{Vdc = Vbat / (1 - D)}$$

CONCLUSION:

The design and analysis of bidirectional converter is discussed, and the simulated bidirectional converter can share the power with the supply and with the battery. The proposed Bidirectional converter can be used in many applications like in domestic, industrial, commercial areas and we can adopt this converter at remote areas too because it is able to operate especially with renewable energy systems. Some of the applications like uninterrupted power supplies, integration of renewable energy with the grid and dc motor drives and in electric vehicles too. The simulation is carried out in MATLAB/Simulink. Components that we use in this project are energy storage device such as Li-ion Battery and Isolations transformer for voltage matching, able to act as buck or boost mode and galvanic isolation between the source and the grid so we can achieve high degree of safety as compared with the other existing converters. This paper has presented the experimental results from the combination of a 60.8 V Li-ion battery bank with a single-phase full-bridge bidirectional isolated dc–dc converter. The results have verified the proper operation of the Li-ion battery energy storage system. In this project we mainly focus on the design of a Bidirectional converter which is suitable for various sources either it is renewable source or non-renewable source. The input of the supply is a DC which is taken from various sources like Solar PV, Wind Turbine followed by DC generator or simply DC supply source. Based upon the availability of the source and requirement of application we can adopt this converter. The simulation results during charging and discharging operation are included in the paper

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