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OPERATION OF HYBRID ELECTRIC VEHICLE USING BIDIRECTIONAL DC-DC CONVERTER

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Abstract

An HEV/EV unlike conventional vehicle, which depends solely on the IC engine for the traction power, utilizes electrical energy storage in combination with or without the ICE to provide the required traction power. Thus it facilitates the improvement in the energy conversion of the vehicle thereby increasing the efficiency and drivability and at the same time reducing the emissions. Furthermore the integration of the electrical storage system also makes the provision for the regeneration during braking which can further boost up the efficiency of the overall system. Electric vehicle drive train mainly consists of Electrical storage system (ESS, Bidirectional DC-DC Converters, Inverter, Electric motor and vehicle controller. One of the main considerations for the EV drive train is to improve the efficiency of the motor drive. This can be done by increasing the voltage level of the ESS and thereby reducing the high currents and thus the associated losses. The increase in voltage level of the ESS can be done by the addition of the more number of cells in the battery back of the ESS of EV. Although it increases the voltage level but at the voltage level but at the same time it also increases the weight, size and cost of the system which is obviously not a desirable option for a vehicular application having constraints on its size and weight. The other option is to use a bidirectional DC-DC converter. Bidirectional DC-DC converters boost up the voltage level and thereby reducing the current level and hence the losses. Also Bidirectional DC-DC converter facilitates the provision for backward power flow into the ESS during regenerative braking and hence further increasing the efficiency. These two features of the bidirectional DC-DC converter makes it a better option for power conversion in the EV drive train.

Keywords: DC-DC Converters, Electric Vehicles, PSSM, FOC, Hybrid Electric Vehicles, Bidirectional DC-DC Converter.

1. INTRODUCTION

With ever increasing concerns on energy crisis and Environmental protection, the electric vehicles (EVs) are attracted more and more attention in recent years. The use of DC/DC converters is essential in hybrid Vehicles. Mainly, there exist two types of DC/DC converters onboard of a Hybrid Electric Vehicle (HEV). The first is a low power bidirectional DC/DC converter which connects the high voltage dc-link with a low voltage battery used to supply low power loads. The second is a high power bidirectional DC/DC converter used to connect the main energy storage unit with the electric traction drive system.

The purpose of this paper is to present a Bidirectional DC-DC Converter for HEVs.

2. DC-DC CONVERTERS FOR ELECTRIC VEHICLES

DC-DC Converters in an electric vehicle may be classified into unidirectional and bidirectional converters Fig. 2 shows the applications of DC-DC converters in electric vehicles. Unidirectional DC-DC converters cater to various onboard loads such as sensors, controls, entertainment, utility, and safety equipments. They are also used in DC motor drives electric traction. Bidirectional DC-DC converters find applications in places where battery charging, regenerative braking, and backup power are required. The power flow in a bidirectional converter is usually from a low voltage end such as battery or a super capacitor to a high voltage side and is referred to as boost operation. During regenerative braking, the power flows back to the low voltage bus to recharge the battery (buck mode). As a backup power system, the bidirectional DC-DC converter facilitates the safe operation of the vehicle when ICEs or electric drives fail to drive the motor. Due to the aforementioned reasons, high power bidirectional DC-DC converters have gained a lot of importance in the recent past. Electric motors used for propulsion can be categorized as DC and AC motors. Earlier, even though DC motors were less efficient, they were preferred for electric propulsions as they were simpler to control. However, with the development of control techniques for AC motors, hybrid vehicles make use of AC motors. DC motor drives are usually used in steep trolleys, ropeways, and locomotives, whereas AC motors are used in EVs and HEVs. The latest hybrid vehicles such as Toyota Prius and Honda Civic/Accord use permanent magnet synchronous motor (PMSM). PMSM have high power density, high efficiency, and are usually controlled by field-oriented control (FOC). AC motors in EVs and HEVs are fed by inverters which in-turn is fed by a high voltage DC-DC converter. This arrangement is shown in Fig. 3. The output of the battery (a stack of number of Nickel-Metal Hydride cells) is connected to the input of a customized integrated DC-DC converter, which converts the low voltage to a high voltage to feed the inverter and later the high power PMSM For example, in the latest 2007 version of Toyota Prius, the low voltage bus is at 201.6 V (Ni-MH 288 battery output), which is converted into 500 V by a simple boost converter to feed a 50 kW (1200-1540 rpm) PMSM.

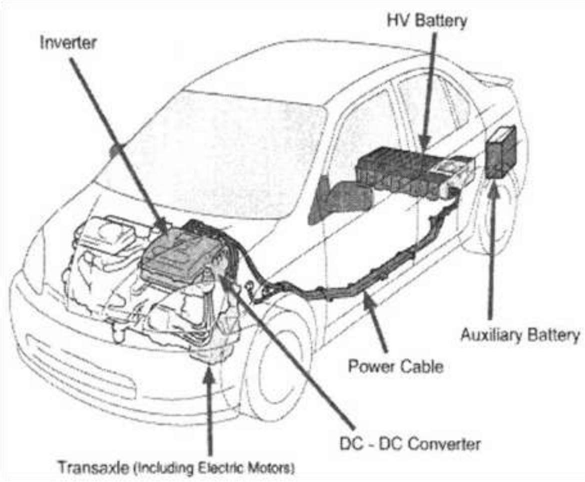

Figure 1. Power electronic components in a Toyota Prius hybrid car.

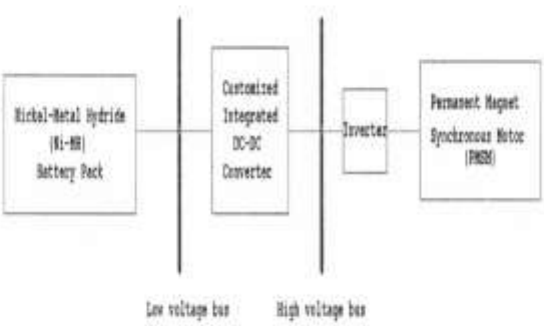

Figure 2. Applications of DC-DC converters in Electric vehicles

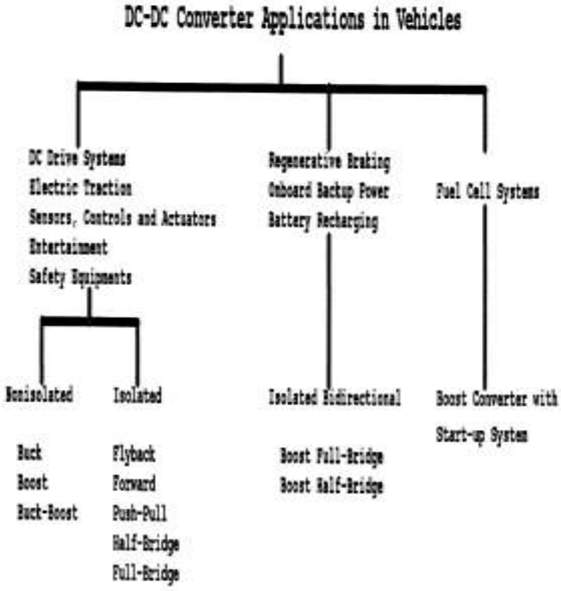

Figure 3. Power electronic circuit arrangement in HEVs .

Both unidirectional and bidirectional DC-DC converters are preferred to be isolated to provide safety for the loading devices. In this view, most of the DC-DC converters incorporate a high frequency transformer.

Inclusion of a transformer leads to the following problems:

1. Leakage inductance of the transformer leads to high voltage stresses across the converter switches and diodes due to ringing caused by the leakage inductance and the transistor/diode output capacitance.

2. Increases converter area, volume, weight, and cost.

3. Increases EMI.

Most of the DC-DC converter designs are aimed to overcome these problems to yield highly efficient, cost effective converters. Since power in full-bridge Converters can flow in both directions, development of bidirectional full-bridge based converters are in demand. To reduce the number of components and still maintain the benefits of full-bridge versions, many half-bridge based topologies are also developed. In addition to these, to overcome the high

Voltage/ current stresses due to energy stored in the transformer leakage inductance, passive snubbers, active-clamping, active commutation, soft commutation, and soft-switching solutions have been incorporated. In the following section, examples of such converters proposed and designed for utilization in electric vehicles are presented.

3. BIDIRECTIONAL DC~DC CONVERTERS

A bidirectional DC-DC converter can be divided into three main blocks, as shown in Fig. 4. The primary side (low voltage side) usually consists of a buck or boost type half or full-bridge converter and the secondary side is usually half or full-bridge arrangement.

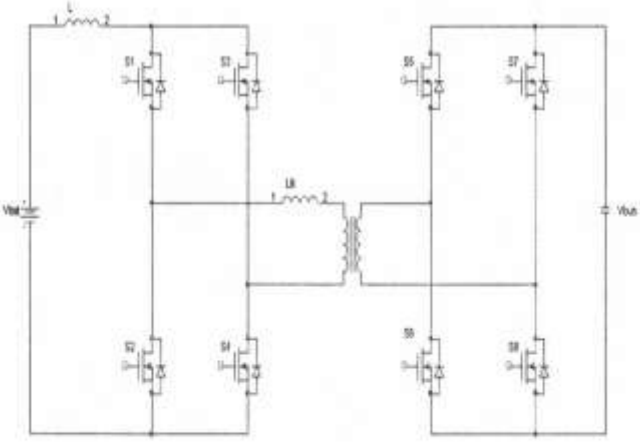

Figure 4. Conventional bidirectional full-bridge isolated boost DC-DC converter

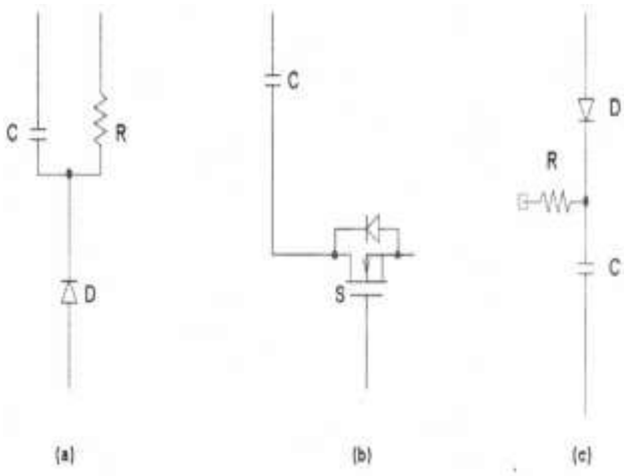

Figure 5. Voltage clamping solutions. (a) Passive snubber. (b) Active-clamp. (c) Active/accelerated/soft commutation

Based on the application, power level, and frequency range, power MOSFETs or IGBTs are used as switches. The mode of operation may be categorized as energy storing and energy transferring modes. Due to the presence of transformer leakage inductance *Llk* shown in Fig. 5, during the transfer of energy from primary to secondary, high turn-off voltage spikes are produced across the switches on the primary side (hard-switching). This leakage energy cannot be dumped into a passive resistor capacitor- diode snubber *(RCD* snubber) shown in Fig. 5(a) due to high dissipative losses caused by high primary charging current. Active-clamp solutions shown in Fig. 5(b) consisting of a clamp capacitor and an additional switch may be used to achieve soft switching (ZVS) of the switches. However, these circuits need very high voltage clamp capacitor and a complex drive circuits. Active commutation control scheme is used to clamp the primary side switch using a passive *RCD* clamp arranged differently, as shown in Fig. 5(c). A few other converters utilize coupled inductors to cancel the ripple in the primary current. This type of arrangement is particularly useful in providing ripple free dc current to the battery on the primary side. A multi-stage (four-level, 12 MOSFETs) non-isolated bidirectional DC-DC converter is developed for dual voltage architecture. Large number of components and oscillator based gate control scheme is needed for this circuit. A hybrid of current-fed full-bridge on the primary and the current fed half-bridge on the secondary along with self-driven synchronous rectification using coupled inductors is recently published. This converter is three times smaller in size when compared to current-fed full-bridge counterpart. A few examples of DC-DC converters used in hybrid vehicles are shown in Fig. 6. In a 12-V output DC-DC converter incorporating soft-switching was designed and implemented for a four-door sedan Honda Civic hybrid (Fig. 6(a)). It is reported that incorporation of soft-switching resulted in 22% size reduction, weight reduction, and had higher efficiency compared to the hard-switched converter previously used in Honda Insight. This enabled the manufacturers to utilize a cooler, which consumed lesser power and space thus increasing the fuel efficiency. Fig. 6(b) shows a DC-DC converter, which automatically senses temperature and limits the currents and voltages such that the cut-off temperature is not exceeded. Note that the converters shown in Fig. 6 are based on isolated full-bridge topologies.

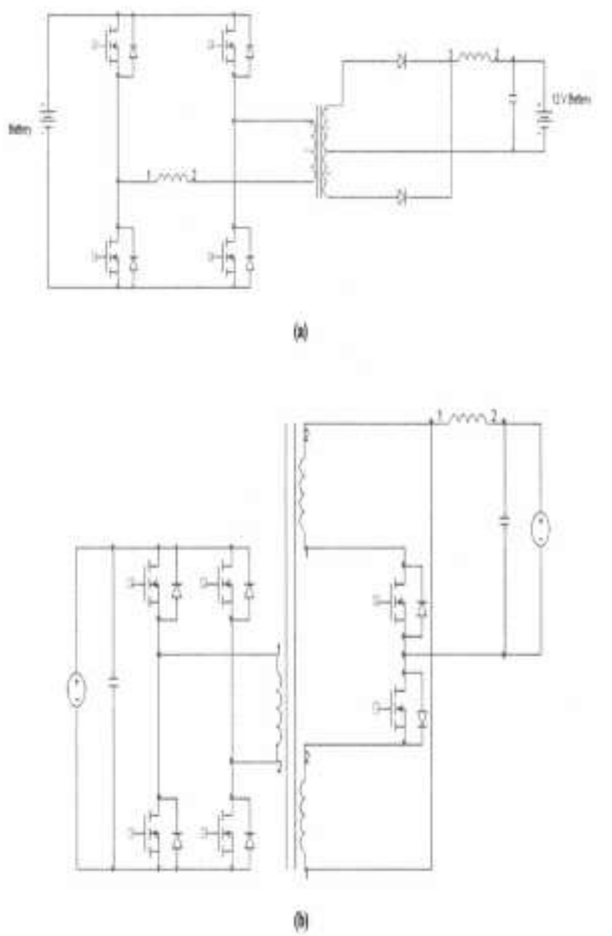

Figure 6. DC-DC converters used in vehicles. (a) 12-V DC-DC converter circuit. (b) Battery recharging DC-DC converter circuit with automatic temperature control.

4. CONCLUSION

Apart from finding solutions to reduce device stresses and to improve .the converter efficiency, many other challenges are posed for a power electronic circuit designer. DC-DC converters in EVs must be precisely controlled for safety of the passengers. Almost all of the DC-DC converters presented in this Section have complex drive control. Moreover, the dynamics of each circuit must be studied and rigorously tested before selecting a DC-DC converter topology, the efficiency of the converter must be evaluated in comparison with the Overall efficiency of the EV. Based on this evaluation, hard-switched or soft-switched topology must be chosen. Thorough investigation of DC-DC converters regarding EMI Must be carried out to satisfy the standard regulations. Temperature effects must be considered to ensure a safe and reliable operation.

DC-DC converters play an important role in efficiently distributing electric power in vehicles. With increasing demand for power electronics in electric vehicles, it may be concluded that DC-DC converters will continue to play a major role in the technological advancement of vehicles in the future.

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