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A Novel Design Methodology for a 1.5 KW DC/DC Converter in EV and Hybrid EV Applications

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***Abstract*—**This paper presents a method for the efficient implementation of a unidirectional or bidirectional DC/DC converter. The DC/DC converter is used essentially for energy exchange between the low voltage service battery and a high voltage battery commonly found in Electric Vehicle applications. In these applications, apart from cost, efficiency of design is an important characteristic. A useful way to reduce the size of electronic equipment in the electric vehicles is proposed in this paper. The technique simplifies the mechanical complexity and maximizes the energy usage using the latest converter control techniques. Moreover a bidirectional battery charger for hybrid electric vehicles is also implemented in this paper. Several simulations on the test system have been carried out in Matlab/Simulink environment. The results exemplify the robustness of the proposed design methodology in case of a 1.5 KW DC-DC converter.

***Keywords*—**DC-DC converters, Electric Vehicles, Direct Current Control.

I. INTRODUCTION

GROWING environmental awareness has lead to a subtle shift towards electric vehicle and hybrid electric vehicle development all around the world. This activism is mainly attributed to the awareness of issues as a result of pollution from the burning of conventional sources of energy in Internal Combustion Engines of motor vehicles. Electrical propulsion technology is steadily increasing its market share by replacing the motor vehicles working on conventional internal combustion engines.

Currently in electric vehicles (EV's) and hybrid electric vehicles (HEV), a high voltage battery bank is used to supply energy to the electric traction mechanism to produce the required motion. The purpose of the high voltage bus is to feed power to the electric motor (induction motor) and the traction inverter. However, an auxiliary 12V battery supply is also present that feeds power to the other electric loads in the car such as the head-lights, audio systems, heating fans etc. Thus, transferring energy between the two voltage systems is a highly viable and a convenient option. This attribute of power exchange between the auxiliary and traction power converters is characterized by an efficient management of the battery bank. The battery pack can have a rating between 250V to 850V depending on the power rating of the electric motor.

Several non linear activators in HEV having an overload capability result in an ideal power request of the order of several kW for the auxiliary converters. The peak value of the output current is very high because of the 12V bus and is of the order of 225 Amperes. System efficiency is a regulating feature and a very important parameter for the design process. At about 60% of rated load the auxiliary 12V bus power converters have a maximum efficiency of around 80%. For such converters, an efficiency of 92% and higher is generally aimed over a wide load range.

A 1.5KW DC-DC converter that interfaces the 12V bus with the 200-450V bus system is shown in Fig. 1. In order to achieve high efficiency with values greater than 92% over a wide range of operating conditions and loads, two switching converters that are connected coherently through a transformer operating at high frequency are used [1], [2]. This strategy provides the required performance at a reasonable cost because of the use of modified Power MOSFETS, phase shifting and resonant clamping control techniques. The power devices are driven using a micro controller which generates a near optimum modulation pattern.

In order to achieve good performance characteristics it is imperative to use the new semiconductor devices and power electronic converters. For the power management between energy storage devices and energy storage elements, as well as to provide proper voltage levels, highly efficient DC-DC converters must be used. Fig. 1 shows the schematic of a hybrid power train employing two converters.

For auxiliary loads such as actuators and lighting, 12 V is maintained as the standard voltage by the service battery [3]. For the traction power train system, a voltage level of 200 to 800 V DC is used. A very high power rating converter of the order of tens or hundreds of kilowatts for the purpose of driving the electric induction motor is used as a DC/AC (Traction Inverter Module). The DC/DC power converter for the auxiliary loads is of a comparatively lower power rating of the order of hundreds of watts. The AC/DC converter connected to the mains and/or the hybrid system control can be used to charge the traction battery while as the DC/DC converter provides the energy for charging the 12V battery. In some peculiar cases it sometimes becomes necessary to use the traction battery to charge the service battery though the DC/DC converter. Thus depending on the mode of charging, a bidirectional or a unidirectional system may be required. A random fault in the system may lead to the complete discharge of the 12V battery and hence the reliability of the converter is a important factor. Energy recovery techniques like active clamping and soft switching techniques are highly useful because of the desired high efficiency.

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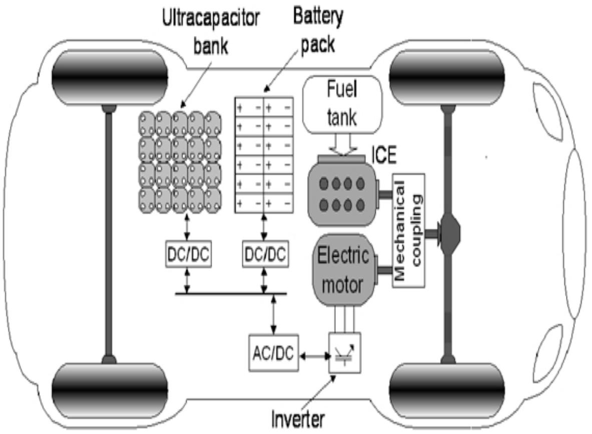

Fig. 1 Schematic of a Hybrid Power Train

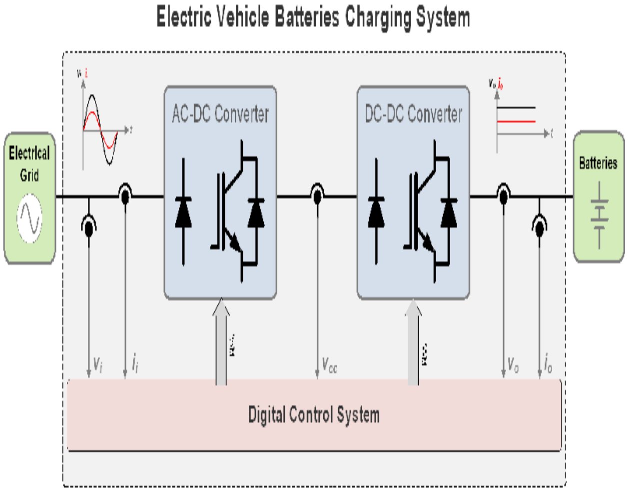

Fig. 2 Battery charging system in Electric Vehicles

The main characteristics of the DC/DC converter are:

1. Switching frequency is chosen to be 75 KHZ
2. Standard voltage of the High side voltage of the order of 290V with a range of 250V-420V
3. Standard voltage of the Low voltage side of the order of 12 V and has a range of 8V- 16 V during the charging and discharging cycles.
4. Galvanic and electrical isolation between the high voltage system and the low voltage system is necessary.

Fig. 2 elucidates the schematic of the converter. The actual converter circuitry can be seen in Fig. 3. The converter employs a full bridge orientation M3-M6 connected to a push-pull stage via a high frequency transformer. The push-pull stage employs a boost inductor. The two PWM signals which control the devices M1and M2 have a duty cycle with a value greater than 0.5 and a phase shift of 180° from one another. A resonant clamp circuit clamps the high voltage spikes across the main power devices that are quite frequently obtained because of the transformer leakage reactance. Compared to the conventional snubber, significant energy savings are observed by diverting the energy in the clamp capacitor to the main power circuit during the turn off period of the device.

II. CONTROL STRATEGY

The control strategy involves two algorithms based on a 32-bit micro-controller and an 8-bit micro-controller for bidirectional and unidirectional power flow handling capacity respectively [4]-[5].

Both of the adopted control techniques consist of gate signals that control the generation using a control signal from a closed loop based primarily on voltage regulation and output current even though at the base level both the proposed control techniques are subjectively different. The control signals for the full bridge orientation employ phase-shifting modulation for the low voltage battery.

A. Step Down Operation (Service Battery Charge)

The DC/DC converter is made to work like a step down converter during this operation which reduces the voltage to the standard 12 V from a value of 290 V. Even though for the high-voltage side, the turn-on losses are almost removed by employing a phase shift modulation strategy that achieves the ZVS operation for the Power MOSFETS, on the other hand synchronous rectification is employed to increase the converter efficiency as the switches could not be driven in principle in the low voltage side and the free-wheeling diodes tend to operate as a rectification stage. For the phase-shift modulation strategy, the signals are phase shifted by an angle fed through the feedback loop between the two legs, while as two complimentary signals with a specified fixed dead time setting and having a constant duty cycle of .5 are used to drive the two devices for devices belonging to the same leg. Core saturation is subsequently prevented in this proposed method as it utilizes a symmetrical usage of the transformer. Fig. 4 shows the described control signals. The output voltage is regulated by the overlap introduced by the phase shift which sets up the duty cycle [6], [7].

Fig. 3 1.5 KW Converter used for the design

Fig. 5 shows how the MOSFET can be turned on at zero voltage by carefully adjusting the dead times for the complementary pairs (M3, M5), (M4, M6) that drive the full bridge converter/ inverter. This may be attributed to the fact that the MOSFET such as M5 remains OFF because of the dead time even when the complementary MOSFET that was ON before M3 goes to the OFF state leading to the engendering of a natural oscillation as the center point of the half bridge will float. The oscillations rise because of the presence of a resonant circuit that includes the parasitic cap present at the center point of the half bridge and the transformer leakage reactance. M4 can be turned ON at zero voltage by properly setting the dead time while V_{DS4} is oscillating at a constant frequency.

In Fig. 6 M1 and M2 are controlled to improve the efficiency of the converter by reducing the voltage drops during the supposed conduction of the freewheeling diodes.

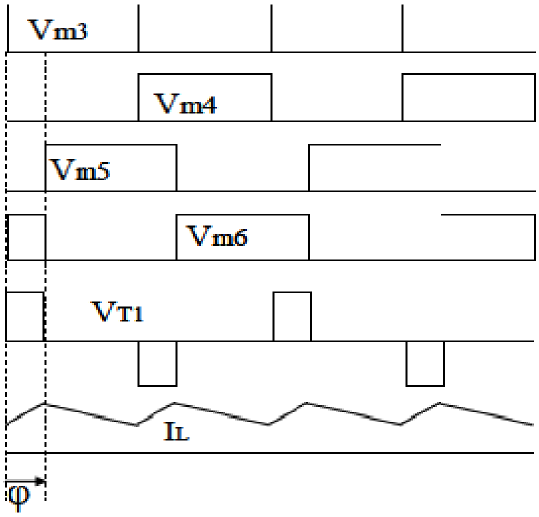

Fig. 4 Phase Shift Modulation

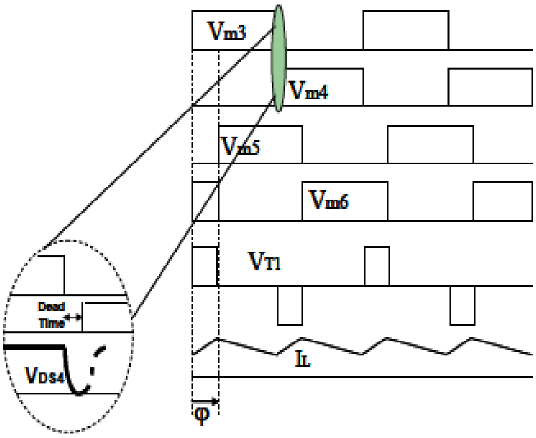

Fig. 5 ZVS operation in Phase Shift Modulation

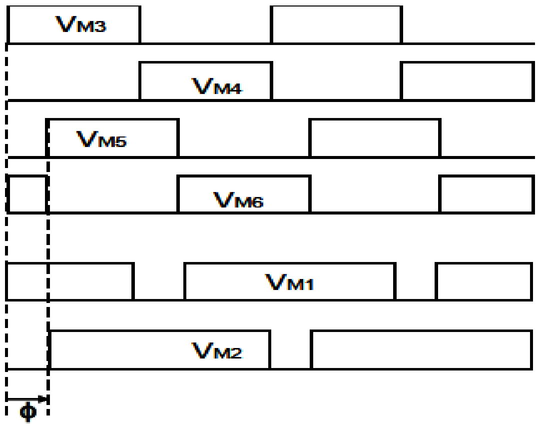

Fig. 6 Phase Shift Modulation and Synchronous Rectification

B. Step Up Operation (High Voltage Battery Charge)

The voltage of the battery pack is raised to about 290 V from 12 V by transferring the energy back to the high voltage battery pack by the DC/DC converter. Voltage rectification is performed by the free-wheeling diodes and the high voltage side bridge's switches are not driven. In order to drive the high frequency transformer to perform as a push pull stage, a boost stage operation for the inductance is performed by controlling the switches M1 and M2 as seen in Fig. 7.

A duty cycle higher than 0.5 is always maintained for the 180° shifted PWM signals. This is done mainly to avoid the over voltage across the devices by avoiding a situation in which both the switches are simultaneously open thus avoiding the generation of an unclamped situation. It is imperative to have an overlapping period which involves the simultaneous closing of both the switches in order to charge the inductance.

A clamp circuit needs to be used nevertheless, mainly because during the device turn-off the transformer leakage reactance causes an over-voltage spike. The energy is contained in the active clamp which needs to be essentially controlled by an auxiliary signal.

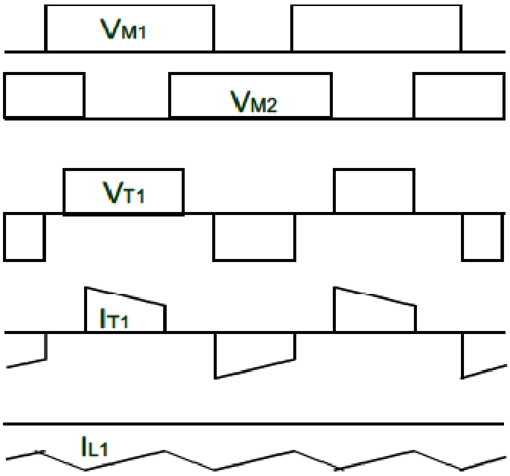

Fig. 7 PWM operation

C. *Efficiency*

The efficiency curves for the step-up and the step-down operation are shown in Figs. 8 and 9 respectively. Efficiency is comparatively higher for the electrically isolated topology as in Fig. 8 as the control methodologies listed before lead to a highly efficient process and thus in such a case there is no need of using a liquid cooling agent for the converter in the 1.5KW to 2.5 KW range.

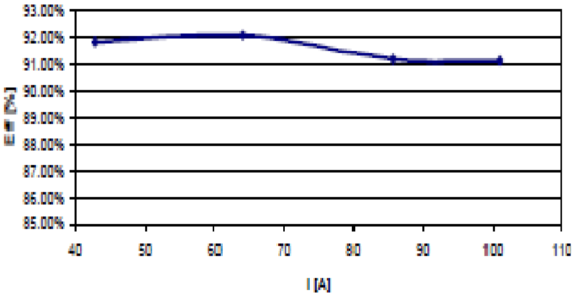

Fig. 8 Efficiency v/s output current during Step-Down operation

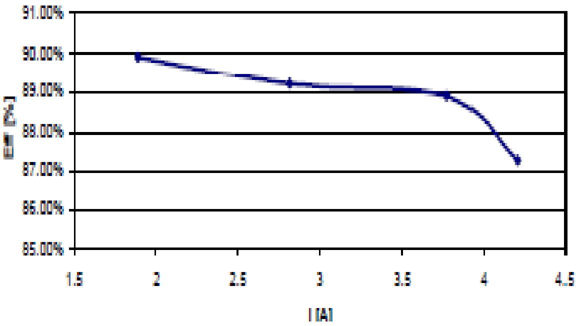

Fig. 9 Efficiency v/s output current for Step Up operation

III. KEY COMPONENTS

A. *Control Stage*

A 32-bit microcontroller with a 512 Kbyte Flash *SPC560P* has been used to develop the algorithm for the bi-directional operation. The micro-controller has a VLE instruction set and is based on the scalable PowerPC core. The 1.5KW DC/DC converter can be easily connected to the SPC560P board.

An 8 bit MCU *STM8A* having 8- 256 kB Flash is used for the uni-directional operation. The MCU has the characteristic features of LIN, USART, CAN and also qualifies to the AEC-Q100 spec.

B. *Power Stage*

TABLE I
POWER STAGE COMPONENTS

Component Name	Component Type
STV240N75F3	STripFET Power MOSFET
A5970AD	Step Down Switching Regulator
TS9541D	OPAMP High speed (3MHZ,1V/μs)
STPS340U	Schottky Diode
STTH108	High voltage ultrafast rectifier

IV. CONCLUSION

This paper elucidates the implementation of an efficient unidirectional or bi-directional DC/DC converter. The main aim of such an implementation is related to the energy exchange associated between the low voltage battery and the high voltage system bus present in HEV applications. One of the most critical design factor is related to efficiency in addition to cost as higher efficiency will also result in lower costs e.g., with better efficiency the presence of a cooling system based on liquids for the converter is no longer required.

The implementation of 1.5 KW DC/DC converter was taken up as a design example which exemplifies the control strategies involved for standard converters and provides a good platform for the evaluation and implementation of new silicon devices dedicated to the electric vehicle industry.

REFERENCES

[1] Chiu, Huang-Jen, and Li-Wei Lin. "A bidirectional DC-DC converter for fuel cell electric vehicle driving system." *Power Electronics, IEEE Transactions on* 21.4 (2006): 950-958.Hairong, C., & Zheng, X. (2007). Transient model and controller design for VSC-HVDC based on synchronous reference frame. *Transactions of China Electrotechnical Society*, *22*(2), 121-126.

[2] Al Sakka, Monzer, Joeri Van Mierlo, and Hamid Gualous. "DC/DC Converters for Electric Vehicles." *Electric Vehicles–Modelling and Simulations* (2011): 309.Qian, Chen, Tang Guoqing, and Hu Ming. "Steady-state model and controller design of a VSC-HVDC converter based on dq0-axis

[3] Clement-Nyns, Kristien, Edwin Haesen, and Johan Driesen. "The impact of charging plug-in hybrid electric vehicles on a residential distribution grid." *Power Systems, IEEE Transactions on* 25.1 (2010): 371-380.

[4] Na, Woonki, et al. "Control design of DSP based a bi-directional converter for electric vehicles applications." *Electro/Information Technology (EIT), 2014 IEEE International Conference on*. IEEE, 2014.

[5] Zhu, Lizhi. "A novel soft-commutating isolated boost full-bridge ZVS-PWM DC–DC converter for bidirectional high power applications." *Power Electronics, IEEE Transactions on* 21.2 (2006): 422-429.

[6] Tan, Kang Miao, Vigna K. Ramachandaramurthy, and Jia Ying Yong. "Bidirectional battery charger for electric vehicle." *Innovative Smart Grid Technologies-Asia (ISGT Asia), 2014 IEEE*. IEEE, 2014.

[7] Richardson, David B. "Electric vehicles and the electric grid: A review of modeling approaches, Impacts, and renewable energy integration." *Renewable and Sustainable Energy Reviews* 19 (2013): 247-254.