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Design of Resonant Converter Topologies in Electric Vehicles

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ABSTRACT

The world climate and environment are facing serious threats due to the carbon emission caused by diesel-based vehicles. The increased use of fossil fuels in diesel based vehicles is one of the main reasons for global warming and climate change issues. A recent report suggests that transportation is responsible for contributing 24% of global carbon emissions. Another study by the European Union mentions that carbon dioxide (CO2) emissions by the transport sector are approximately 27%, while 70% of emissions are directly emitted by vehicle transport.

To address these concerns, electric vehicles (EVs) have received massive attention around the world due to their zero carbon emissions, low noise, light weight, improved performance and efficiency.

Keywords: Power convertors, Electric Powertrain, Power Sim, Resonant, Boost, Bidirectional, DC-DC convertors.

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INTRODUCTION

EVs are facing challenges with regard to battery cost, recharge time and driving range, as well as the proper functionality of various types of converters in the EV drivetrain.

The efficient functionality of EVs requires appropriate interfacing between energy storage systems (ESSs) and power converters as well as advanced driver assistance systems, acceleration lip regulation, active control systems and anti-lock brake systems.

Figure 1. Electric Vehicle Auto-Rickshaw

In the electric power aspect, the design of power electronics converters plays a very important role inan efficient conversion of power as per the ratings of the original power source and the ratings of the equipment used. Till recently, the use of power electronics was avoided in the architecture of electric vehicles owing to the huge cost involved. But presently, the power electronics gain immense importance and the reasons are the following. Firstly, the modern architecture which included the integrated switching and fusing functions into a single component with increased reliability. The power convertors can be used for different control methods Secondly; the conversion of power is realized by using adjustable speed drives. Lastly, the conversion of voltage as per the demand of the application can be efficiently realized by using power electronics. The different components used in the power electronics of an electric vehicle are rectifiers, inverters dc-dc converters etc.

Background

The dc-dc power converters are used to condition the level of the voltage and to deliver a stable dc busvoltage. The input DC voltage is converted to a regulated output DC voltage. This process of conversion is highly efficient with an efficiency percentage of almost 90%. These converters operate at high frequencies of the order of 10 kHz - 1MHz. The high frequency ensures that size of the hardware components involved in the converter is small which in turn helps in the EV applications.

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The various types of types of DC-DC convertors which are not isolated are: Buck converter, Boost converter and Bidirectional converters.

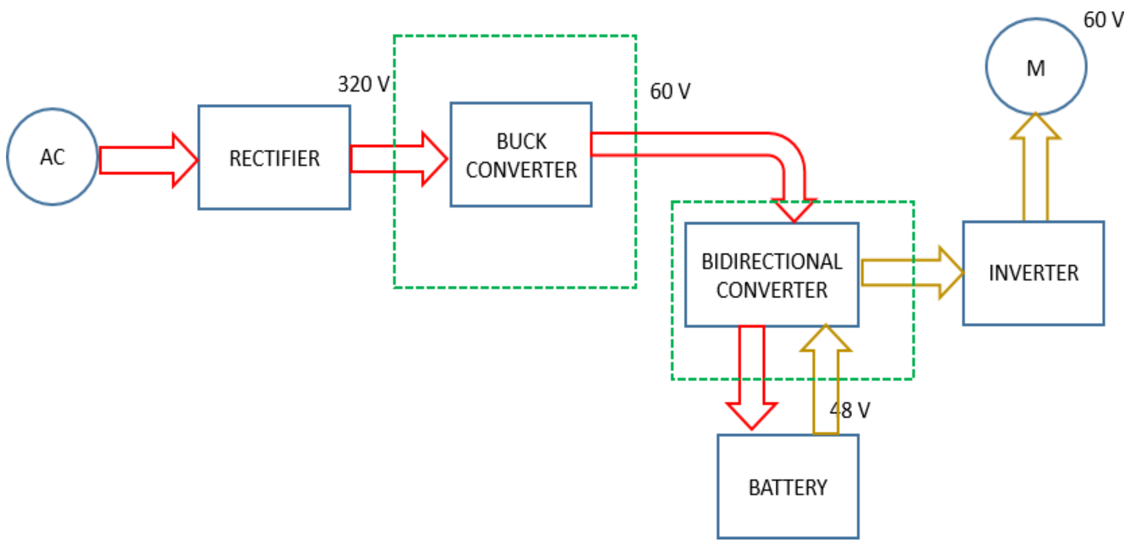

Figure 2. Power train diagram of Electric Vehicle

METHODOLOGY

THEORY OF BOOST CONVERTER

The Boost converter is capable of providing as output voltagethat is greater than the input voltage. It is also known as a step-up converter. A boost converter using a MOSFET transistor asthe switching transistor is shown in Figure 3.

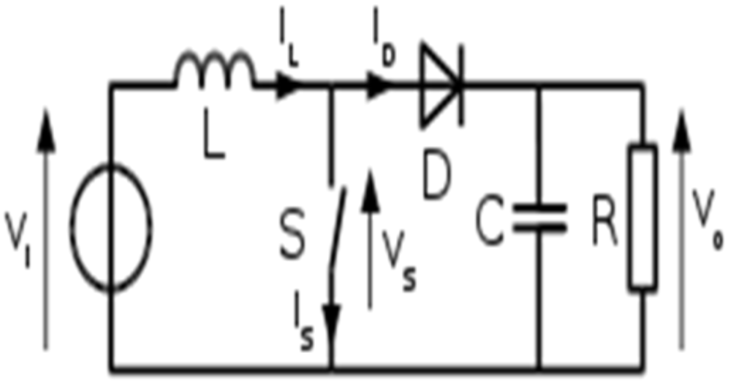

Figure 3. Circuit diagram of Boost converter

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The operation of the boost converter can be divided into two modes:

Mode 1 ($0 < t < ton$)

Mode 1 begins when the switching mosfet, M1, is switched onat a time $t = 0$ and it terminates at $t = ton$. The equivalent circuit for mode 1 is shown in Fig-2. The diode D is reverse biased since the voltage drop across the drain-source junction of the switching transistor is smaller than the output voltage.

The output current during this interval is supplied entirelyfrom the output capacitor, C, which is choose large enough to supply the load current during ton with a minimum specified drop in output current.

The equations for boost converter are given as below:

$di_L / dt = V_S / L$.. (1)

$dV_O / dt = (I_L – V_O / R) / C$.................................. (2)

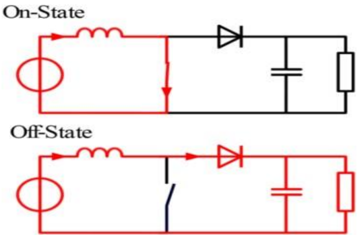

Figure 4. Operating statesMode 2 ($ton < t \leq T$)

Mode 2 begins when the switching transistor, M1, is switchingoff at $t = ton$. The equivalent circuit for this mode is shown in Fig-2. Since the current in the inductor cannot change instantaneously, the voltage in the inductor reverses its polarity in an attempt to maintain a constant current. The current which was flowing through the switching transistorwill now flow through L, C, diode D and load. The inductor current decreases until the switching transistor is turned on again during the next cycle. The inductor delivers its stored energy to the output capacitor, C, and charges it up via D to a higher voltage than input voltage, V_S. This energy supplies thecurrent and replenishes the charge drained away during the on time.

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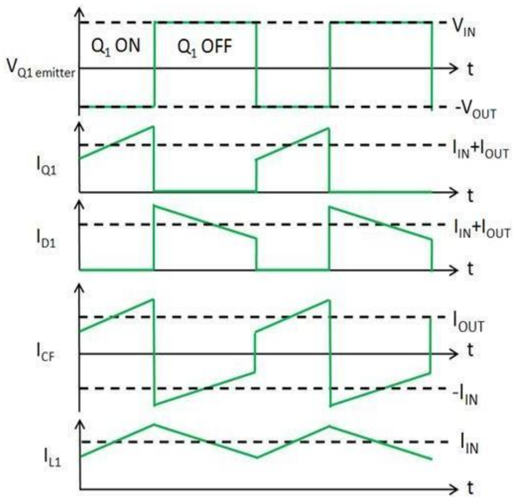

Figure 5. Waveforms of converter

The equations for boost converter are given as below:

$di_L / dt = (V_O – V_S) / L$ ....(3)

$dV_O/ dt = (I_L – V_O / R) / C$ .... (4)

If the current flowing through the inductor falls to zero before the next turn-on of the switching transistor, M1, the Boost converter is said to be operating in the discontinuous mode. To ensure that the Boost converter is operates in continues mode the inductor L must be less than critical inductor, L_C, which given by:

$L_C = RD (1-D)2 / 2 f_S$...(5)

Where R= load resistanceD= duty cycle

fs= switching frequency

Analysis and Design Boost Converter

The design of the converter is performed to step-up the inputvoltage of 12V to an output voltage of 24V.

The followingparameters are required for the design of the Boost converter:

Input voltage (V_S) = 12V,

Output voltage (V_O) = 24V,

Switching frequency (f_S) = 20 KHz,

Maximum load current (I_{Omax}) = 2A,

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Maximum inductor current (I_{Lmax}) = 4.25A,

Minimum inductor current (I_{Lmin}) = 0.5A,

Ripple in the output voltage (dV_O) = 1.2V,

Ripple in the output current (dI_O) = 0.03A,

Load resistance (R) = 20 ohm.

We get the value of parameters from equation (1) and (2) as: L=80µH C=42µF L_C=62.5µH

Also the converter operates in continuous conduction mode as $L < L_C$

Bidirectional Converter

The bidirectional converter consists of two MOSFET switches i.e. the switch1 operates the voltage source to the battery whereas as switch2 operates the motor through the battery. It is known as bidirectional converter. In this operation when the switch1 is turned ON the buck mode will operate and supplies the voltage from source to battery whereas switch2 is turned ON the boost mode will operate and supplies the voltage from battery to the motor to run the wheels by keeping the power asconstant throughout the circuit.

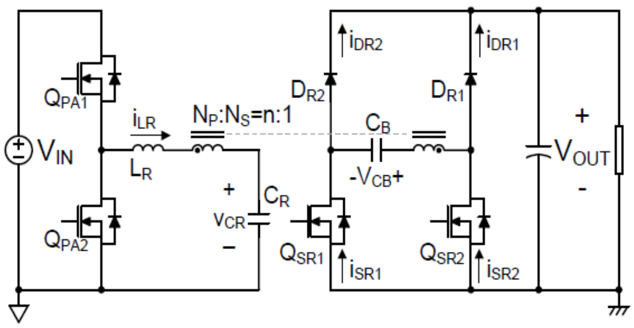
Table 1. Analysis calculation values of Bidirectional Converter

PARAMETER	ALYTICAL (BUCK)	ANALYTICAL(BOOST)
RESISTANCE	1.152 Ω	1.8 Ω
INDUCTOR CURRENT	41.19 A	41.19
INDUCTANCE	0.4607 mH	0.4607 mH
CAPACITANCE	2.17 µF	0.2 mF
OUTPUT VOLTAGE	46.08 V	64.23 V

The resultant of the voltage obtained from the buck converter is applied to the bidirectional converterwhich will charge the battery in the buck action. Consequently, the battery powers the motor in the boost action of the bidirectional converter and thereby discharges itself.

Simulation Results

LTspice IV version 4.23i 2016 simulation programs are used to simulate the considered Boost switching converter. Fig-4 shows the Spice models of the Boost switching converter.



The following waveforms shows the results obtained in simulation using PSIM

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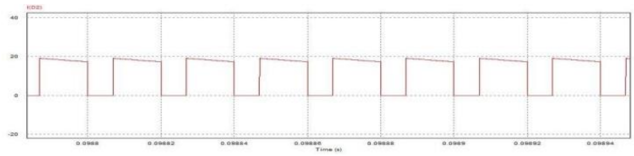
DATA ANALYSIS AND RESULTS

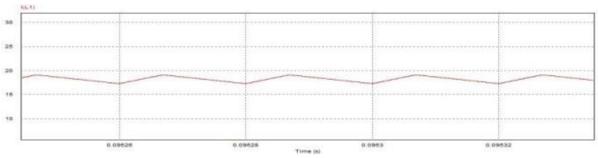
Bidirectional Buck and Boost Converter Waveforms

The following table shows the results obtained in simulation using PSIM.

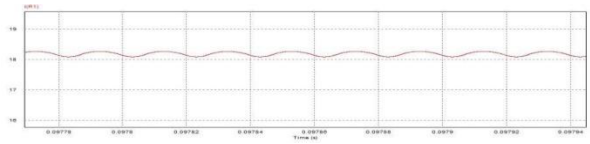
CAPACITOR CURRENT PEAK VALUE: 0.5788A



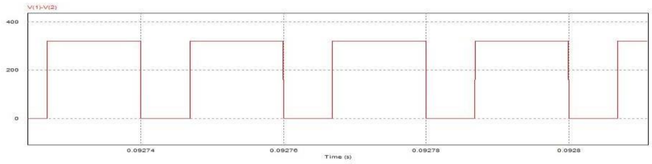
DIODE CURRENT PEAK VALUE: 3.38A



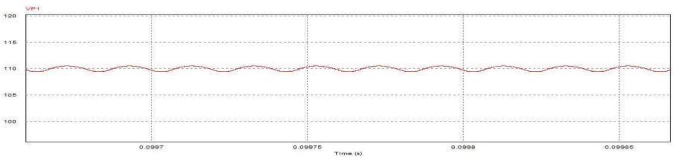
INDUCTOR CURRENT PEAK VALUE: 3.38A



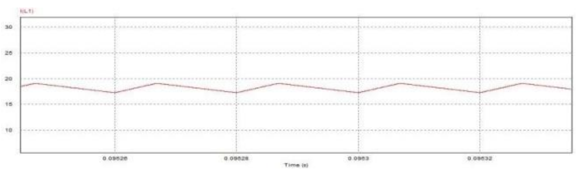
RESISTANCE CURRENTPEAK VALUE: 3.34A



SWITCH CURRENT PEAK VALUE: 3.38A



OUTPUT VOLTAGE PEAK VALUE: 60.224V



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CONCLUSION AND RECOMMENDATIONS

The DC-DC converters for the electrical powertrain applications is successfully designed. The results of simulation are in close agreement with the analytical solutions. This validates the credibility of the software. The designed converters consider the AC power grid as the primary source of power. This investigation can further be carried out by the solar source and the converters can be designed as an extension of the same work.

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