

Comparison of DC-DC Converter Topologies for Electric Vehicular Application

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Abstract

In this paper comparison of various topologies of dc-dc converter for electric vehicular application are presented. Non-isolated converter is the first one and the second one is isolated dc-dc converter. Non-isolated dc-dc converter have low cost and simple, but there is one drawback in it that input and output are not isolated each other. To overcome this drawback, an isolated dc-dc converter is used. An isolated dc-dc converter consist of transformer, which is used to step-down and step-up the voltage as well as it isolate the input and output. To trigger the converter switches, Sinusoidal-Pulse-Width- modulation technique is preferred. Comparison of proposed model of various dc-dc converter are simulated in MATLAB Simulink. The simulation results helps to select the best converter for electric vehicle.

Keywords

Li-ion Battery, DC-DC Converter, SiC MOSFET, Transformer, DC Motor.

Introduction

The electrification of the transportation has importantly augmented in past ten years. This is mainly to drop down the utilization of greenhouse emissions and fossil fuels. Battery operated vehicles are deliberately giving place of the vehicle based on internal combustion engine as one of the key for future transport, which offers better petroleum economy and lower emissions. Though, the increasing exploitation of these vehicles could have a great impact on the grid. Lately, the contamination problems with fast populace growth are turn out to be world problems. Due to the least amount of air contamination and small or zero greenhouse gas emissions, hybrid electric vehicle (HEV) and electric vehicle (EV) technology is growing interest as an alternate solution in most of the countries around the world. Cars and trucks are liable to produce 25% of CO₂ emission and other transportation methods account for another 12% of CO₂ emission. Electric trucks and electric cars are often cleaner than the engine operated vehicles. Thus a number of developments conceded to turn down of electric vehicles. Electric vehicles are different from fossil fuel power-driven vehicles. In electric vehicles power is consumed, which is generated from sources like including nuclear power, fossil fuels and renewable sources such as wind power, solar power and tidal power. The extensive adoption of the electric vehicle fetch considerable changes for society in terms of technologies which we utilize for own transportation. It also does our economies away from fuel [1]-[4].



Figure 1: Block Diagram of an Electric Vehicle Power Train.

The block diagram of electric vehicle power train is shown in Figure 1. This paper is prepared as follows: In Section 1, the introduction of electric vehicle is discussed. Section 2 described the different proposed replica of the whole system. Simulation results of isolated dc- dc converter and non-isolated converter i.e boost converter, buck converter and buck-boost converter are shown in section 3. Conclusion and future scope are given in section 4.

Electric Vehicle

In electric vehicles (EVs) at the place where they are operated has no exhaust tube air pollutant. They also normally less noise production than an internal ignition engine vehicle, whether at in running condition or in rest. EVs dispense silent and downy operation thus have less noise and trembling than internal ignition engines. In EV cars previously used Nickel Metal Hydride batteries. These types of battery are considered obsolete due to their self-discharge tendency in the heat. Therefore now a day's lithium- ion batteries are the most popular battery for EVs. Lithium ion batteries have long life, higher power density and higher energy density than most other empirical batteries. EVs have minor direct emissions, each and every one rely on electrical energy produced through electrical power generation system and will generally effuse contamination and produce waste material, unless energy is generated by non- conventional power plants. EVs utilize electrical energy from electrical utility/grid operator. By some modification in the electrical power plants, EVs can be more capable, a lesser amount of pollution and less costly to run. In general, the electric vehicle is energy competent, cleaner and environment friendly than the vehicle which is depend on fossil fuels [5]-[8].

Description of Proposed Model

One of the type of power converter in electrical engineering is the DC to DC converter. It converts dc power from one voltage to another voltage. It delivers the electrical energy to the output at different voltage level just by storing the input energy momentarily. Storing of energy is done by the component of electric field (capacitors) or by the component of magnetic field (inductors, transformers). To transfer power from the input to the output in only one direction, DC-DC converters can be constructed. Still, entire topologies of DC-DC converter can be built of bi-directional converter. To transfer power in either direction, a bi-directional converter can be used. It is helpful in regenerative braking applications. There are two types of dc-dc converter are discussed in this paper, non-isolated converter and isolated converter.

(i) Non- Isolated Converter:- As there is no issue of dielectric isolation between input and output and to stepped up and stepped down by a moderately small ratio, a non-isolated converter is generally used. In this paper boost converter, buck converter and buck-boost types of non-isolated converters are discussed. For step-down voltage and step-up voltage, the buck converter and the boost converter are used respectively. To step-up or step-down the voltage, the buck-boost type converters are used.

A. Buck Converter:

To step down the voltage, buck converter is generally used. The basic topology of buck converter is shown in figure 2. Buck converter takes a higher voltage and its output will be lesser than the input voltage. Switch S_1 is close at $t = 0$ in mode 1. The current flows from input to output through switch, filter inductor L , filter capacitor C . Switch S_1 is open at $t = t_1$ in mode 2. The diode D_m will conducts due to stored energy of the inductor, and current flows in the inductor through inductor, capacitor, diode D_m and load [9].

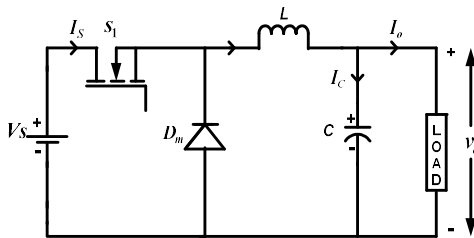


Figure 2: Buck Converter

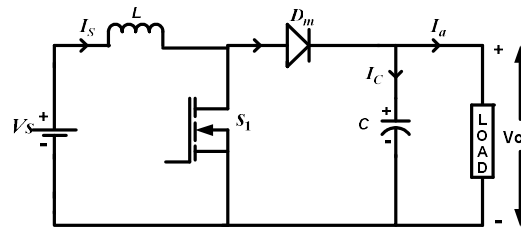


Figure 3: Boost Converter

B. Boost Converter

Boost converter takes the input voltage and boost that voltage at the output side. Figure 3 shows the basic topology of boost converter using a power MOSFET. Switch S_1 is switched on at $t = 0$ in mode 1. The input current rises flows through inductor L and switch S_1 . Switch S_1 is switched off at $t = t_1$ in mode 2. In mode 2, the current that was flowing through the switch would now flow through inductor L , capacitor C , load and diode D_m . The inductor current decreases as far as switch S_1 is turned on again in the next cycle and the energy stored in inductor L is transferred to the load [9].

C. Buck-Boost Converter

Buck-Boost Converter is shown in figure 4. To decrease and increase the voltage level relative to the input voltage, buck-boost converter is used. The operation of this converter are split into two modes. When switch S_1 is closed during mode 1, diode D_m is reversed biased. The input current flows through switch and inductor. By opening the switch S_1 in mode 2 and the current in inductor would flows through inductor L , diode D_m , capacitor C , and the load. Inductor L delivers its energy to the load and the current flows through inductor would drop till switch S_1 is closed anew in the next half cycle. [9].

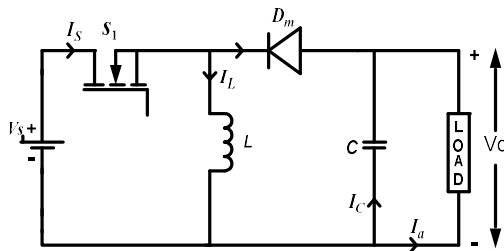


Figure 4: Buck-Boost Converter.

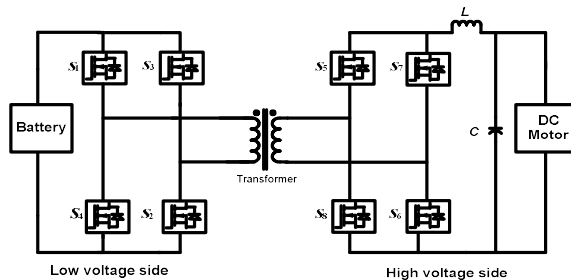


Figure 5: Isolated DC-DC Converter

(ii) Isolated DC-DC Converter:-

For the application of electric vehicles where isolation is required between input and output, isolated dc-dc converter are also used. It is shown in figure 5. Various types of converter comes under this group, for example push-pull, full bridge etc. By making some modification in these converters, bi-directional converter (reversal of power) can be possible.

In isolated converter, two converters are used. One is full-bridge rectifier and other is full-bridge inverter are the parts of isolated dc-dc converter. An ac output is amalgamate from a dc input by switching on and off the switches in an proper order. To convert dc input voltage into ac output voltage at suitable magnitude, full bridge inverter is used. In medium and low power applications inverter gives quasi-square or square wave value of output which is tolerable but sinusoidal waveform is requisite in high-power applications.

To convert ac output voltage of transformer into dc voltage, full-bridge rectifier is used which is further fed to dc motor.

Methodology

To get low distortion in sinusoidal output, inverters are designed carefully.[9]. There are different techniques to vary the inverter gain. Single- pulse-width modulation(single PWM), Multiple-pulse width modulation(Multiple PWM), Phase-displacement control and Sinusoidal pulse-width modulation (SPWM) are the commonly used techniques. SPWM control technique has been used in this paper. The SPWM technique produces a sinusoidal waveform by filtering an output pulse waveform with varying width. A high switching frequency leads to a better filtered sinusoidal output waveform. The desired output voltage is achieved by varying the frequency and amplitude of a reference or modulating voltage. The variations in the amplitude and frequency of the reference voltage change the pulse width patterns of the output voltage but keep the sinusoidal modulation. A low-frequency sinusoidal modulating signal is compared with a high frequency triangular signal, which is called the carrier signal. The switching state is changed when the sine waveform intersects the triangular waveform. The crossing positions determine the variable switching times between states.

1. Non-Isolated Converter

(a) Buck Converter

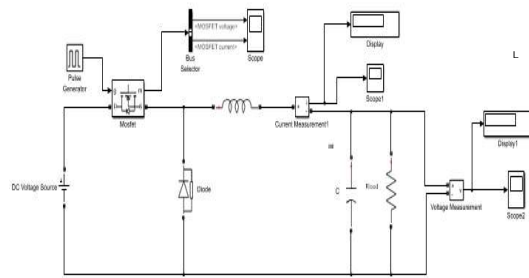


Figure 6(a): Simulation Model of Buck Converter

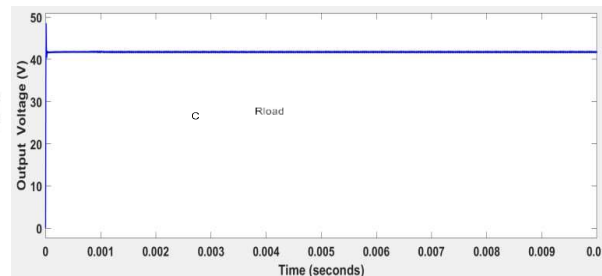


Figure 6(b): Simulated Result of Buck Converter

(b) Boost Converter

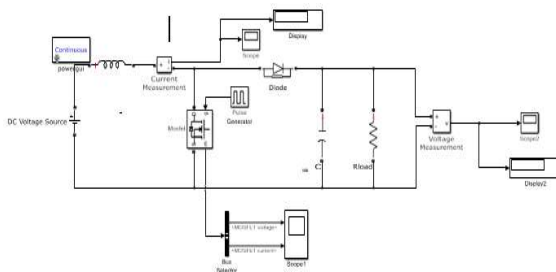


Figure 7(a): Simulation Model of Boost Converter

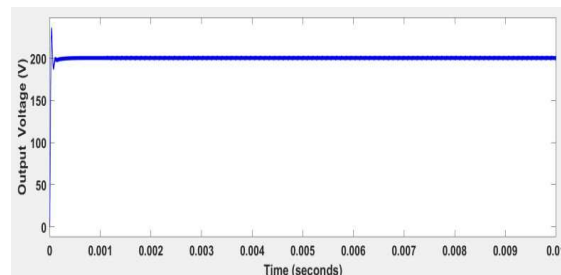


Figure 7(b): Simulated Result of Boost Converter

(c) Buck- Boost Converter

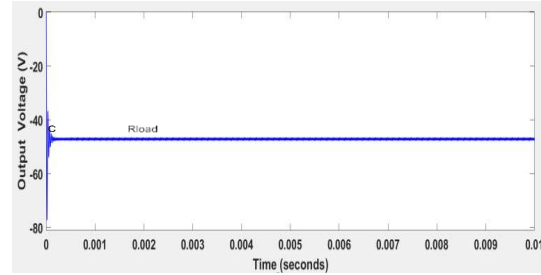
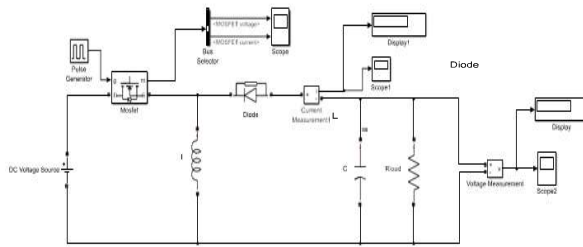


Figure 8(a): Simulation Model of Buck-Boost Converter

Figure 8(b): Simulated Result of Buck Converter

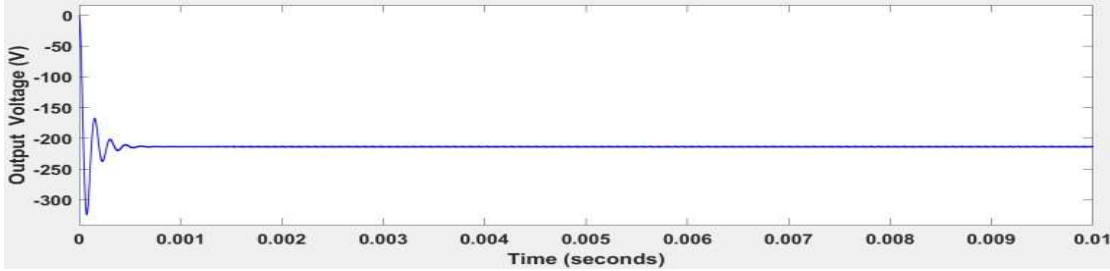


Figure 8(c): Simulated Result of Boost Converter

2. Isolated DC-DC Converter

In steady state condition of an isolated dc-dc converter, lithium-ion battery has taken as a source and separately excited DC motor is acting as a load. In Fig. 9(a), DC input is provided by battery to the inverter. Inverter helps to convert this dc value of voltage into the ac value of voltage. SPWM technique is used with **0.95** modulation index for triggering the switches. To step - up this voltage level, transformer is used. It also offer segregation between output and input of this type of converter. Conversion of transformer ac output voltage into dc voltage was done by rectifier. To reduce the harmonic contains, C and L filter is constructed and to charge the battery at desired voltage. From figure 9(b) to figure 9(e), the simulated results are shown.

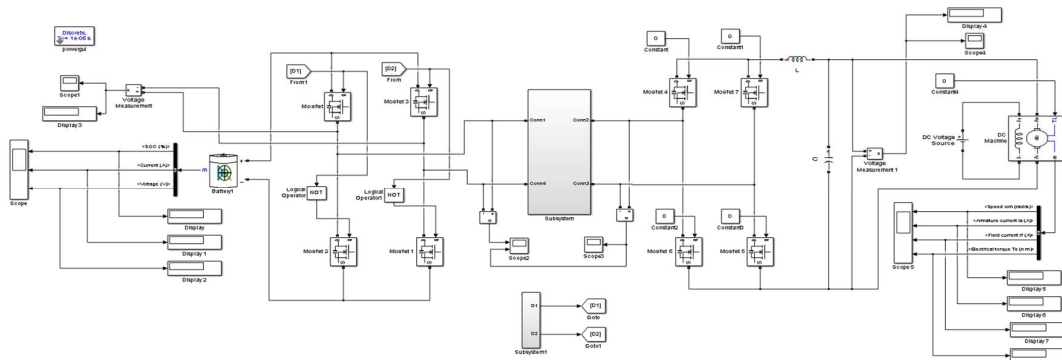


Figure 9(a): Simulation Diagram of Isolated DC-DC Converter

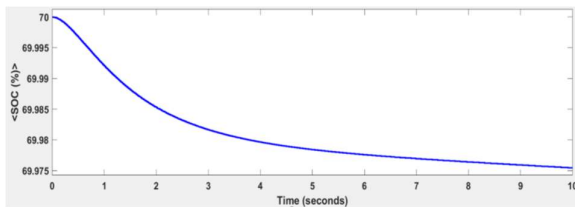


Figure 9 (b): State of Charge of Battery

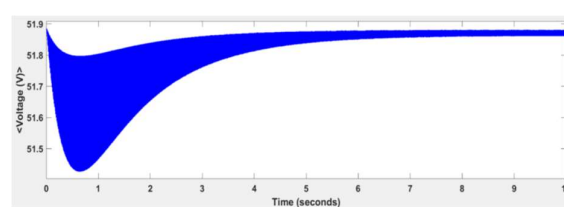


Figure 9(c): Simulated Result of Battery Voltage

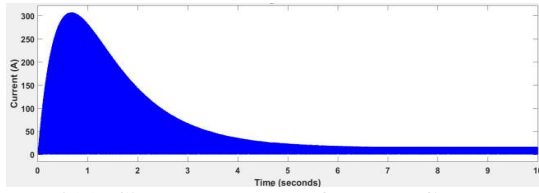


Figure 9(d): Simulated Result of Battery Current

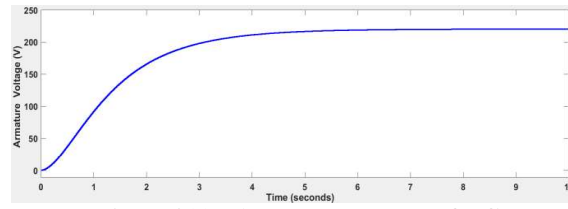


Figure 9(e): Armature Voltage of DC Motor

Battery Parameters	Values	Transformer Parameters	Values	DC Motor Parameters	Values
Nominal Voltage	48 V	Nominal Power	1000 VA	Armature Voltage	221.7 V
Rated Capacity	500 Ah	Nominal Frequency	50 Hz	Armature Current	1.823 A
SOC	69.97 %	Primary Voltage	51.867 V	Speed of motor	2715 rpm
Internal Resistance	0.00096 Ω	Primary Current	15.5 A	Field Current	0.7509 A
Battery Voltage	51.862 V	Secondary Voltage	368.5 V	Field Voltage	120 V
Battery Current	15 A	Secondary Current	2 A	Electrical torque	1.41 Nm

Table 1: Input and Output Values of Battery, Transformer and DC Motor

Conclusion

In conclusion, this paper distinguished two dc-dc converter for electric vehicular application. The first converter are a buck, boost, buck/boost non-isolated and the second converter is an isolated. The input and output values of isolated converter (battery, transformer and dc motor) are given in table no. 1. Simulation of non-isolated and isolated dc-dc converter has studied and simulated using MATLAB/Simulink. The non-isolated Buck/Boost converter seems to have lot of merits over the filters size and simple control, the dual active bridge stick out when isolation is necessary between input and output. Analyzing the requisite of the segregation, the Buck/Boost needs an supplementary isolation circuit to assure that it respects the charging and discharging level and standards, while in isolated converter consist of a transformer that acquiesce it to comprehend a propulsive isolation between the input circuit and output circuit and assure the users safety. Future scope of this proposed system is that, bidirectional non-isolated and isolated dc-dc converter can be introduced and performance of this converters can be figure out in MATLAB/Simulink for Battery Fed Electric Vehicle.

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