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Design and Analysis of Bidirectional Dc-Dc Converter for Electric Vehicle Application

STUDENT NAME: M. RANAPRATHAP

Department of Electrical and Electronics Engineering
St. John's College of Engineering and Technology

GUIDE NAME: Mr. B. GURURAJ, M.TECH, AMIE
Assistant Professor in Department of E.E.E
Department of Electrical and Electronics Engineering
St. John's College of Engineering and Technology

ABSTRACT

This project presents design and analysis of a bidirectional DC-DC converter it is suitable for power electronic interface between the main energy storage system and the electric traction drive in hybrid electric vehicles. A hybrid energy storage system composed of a battery unit and an ultra-capacitor pack is considered. A parallel dc-linked multi input converter with a half-bridge bidirectional DC-DC cell topology is chosen to link the battery/ultra capacitor storage unit with the dc-link. The paper focuses on modeling the proposed converter for both dynamic and steady state analysis. Averaging and linearization techniques are applied to obtain the averaged state space models and small signal models of the converter in both boost and buck operation modes. A criterion for sizing the converter passive components based on the imposed design specifications and constraints is illustrated. Simulation results of the buck-boost converter during normal functioning and under faulty conditions are presented. In particular, short-circuit faults and open-circuit faults of diodes and transistors are analyzed.

INTRODUCTION

Now-a-days the use of DC-DC converters playing a vital role in Hybrid Electric vehicles. Mainly, there are two types of DC-DC converters are used in Hybrid Electric Vehicle (HEV). The first is a low voltage battery which connects the bidirectional DC-DC converter with the high voltage dc-link is used to supply low power loads. The second is a high power bidirectional DC-DC Converter is used to connect the main energy storage unit with the electric traction drive system. Developing technology to store electrical energy and to supply to meet demand is a major breakthrough in electricity distribution. These devices can also help us make renewable energy, because the grid operators cannot control the electrical power output to smooth and dispatch able. An energy storage system is usually based on batteries. Such components store a big amount of energy, but with limited instantaneous power.

Compared to batteries, super capacitors are emerging as one of the most interesting new developments in the field of energy storage. Super capacitors can be used for electrical storage because of their high energy storage density, even if their energy density is 10 times lower than a battery. They exhibit a promising set of features such as high power density, fast rates of charge-discharge, reliable cycling life, and safe operation, such outstanding properties make them promising candidates for energy storage devices in a wide range of applications, such as hybrid electric vehicles, mobile electronic devices, large industrial equipment's, memory backup systems, military devices and energy harvesting applications, where high power density and long cycle-life are highly desirable.

However, the key factor limiting the widespread deployment of super capacitors in everyday technology is their moderate energy density. Energy density has long been limited to values will below 10 Wh/kg. When used in conjunction with batteries and fuel cells, by virtue of their high power densities and rapid charge–discharge characteristics shown in Fig 1.1, it finds a range of applications including in portable power sources and in electric vehicles.

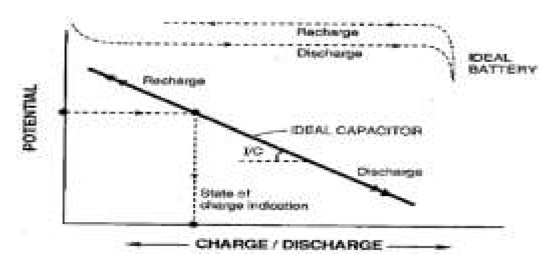

Fig 1.1 Charge-discharge characteristics of batteries and super capacitors

They have found it economically necessary to develop energy usage patterns that incorporate alternative sources of energy to reduce the

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dependence on primary fuels, and on other nations for energy producing fuels. On the other hand, industrial and commercial organizations have established energy management systems whose primary objectives are to reduce energy demands through the installation of energy conservation measures. The energy demand pattern in the commercial, industrial and utility sectors varies on a daily, weekly and seasonal basis. Energy storage units can be used with energy management systems to reduce energy consumption in commercial and industrial establishments, by using the available waste heat or alternate energy sources. Energy storage device is used along with a bidirectional DC–DC converter (BDC) in order to match the voltage level and efficient charging and discharging operation. Fig 1.1 shows an automotive engine/battery hybrid power generation system. The BDC is located between the high-voltage dc bus and the low-voltage battery which is also connected to the dc loads such as antilock brakes, electric power steering, heated seats, electronic ignition and HVAC in the vehicle.

The DC–AC inverter converts the DC power to ac power to supply the critical AC load in the vehicle such as broadcasting equipment of outside broadcast van and communications equipment of electrical vehicle. The AC–DC converter converts the ac power from the engine generator to the dc power, regulating the high-voltage DC bus. If the engine generator is capable of supplying the total demanded power of ac and DC loads, the AC–DC converter will be able to regulate the high-voltage DC bus, and the BDC will deliver the power from the engine generator to the low-voltage side. If the engine generator is shut down or the total demanded power of the AC and DC loads is greater than the maximum power of the engine generator, high side bus voltage will drop off to a voltage depending on the capacitances of the DC bus capacitor.

Then, the BDC is required to take over the regulation duty of the high-voltage dc bus by changing over from V_L control (battery charging) to V_H control (battery discharging) so that it should be able to deliver power from the battery to the ac load. Therefore, in order to provide uninterrupted power to the critical ac loads and reduce the size and cost of the dc bus capacitor, the transition from V_L control to V_H control of the BDC should be seamless and as short as possible. This is a crucial performance of the BDC, especially, in the automotive application where electrolytic capacitors cannot be used due to limited lifespan and bulky nature. The main goal of this project is to model, design and analysis of a bidirectional half-bridge DC-DC converter which acts as a power electronic interface between the main energy storage system and the electric traction drive in hybrid electric vehicles.

A hybrid energy storage system is considered as a pack of battery unit and an ultra-capacitor. The half-bridge bidirectional DC-DC cell topology with parallel DC-linked multi input converter is used to link the battery-ultra capacitor storage unit with the dc-link. The proposed converter is used to study both dynamic and steady state analysis of bidirectional half-bridge DC-DC converter. Averaging and Linearization techniques are used to obtain the averaged state space models and small signal models of the converter during boost and buck operation modes. Buck-boost converter under normal functioning and faulty conditions are presented. Short-circuit and open-circuit faults of diodes and transistors are analyzed.

DC-DC CONVERTERS

Switch mode dc-to-dc converters are used to convert the unregulated dc input into a controlled dc output at a desired voltage level. Buck (step down) converter and the Boost (step up) converters are basic converter topologies. In following description, the converters are analyzed in steady state. The switches are treated being ideal, and the losses in the inductive and capacitive elements are neglected. The dc input voltage to the converters is assumed as zero internal impedance.

BUCK CONVERTER

PRINCIPLE OF OPERATION

Fig 2.1 shows the buck converter is a step down dc-dc converter which produces a lower average output voltage than the DC input voltage.

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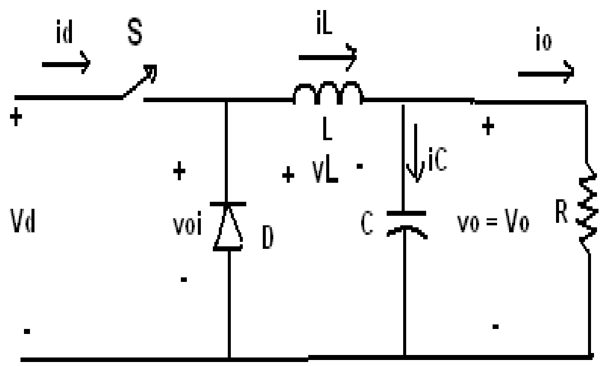


Fig 2.1 Circuit diagram for Buck converter

It consists of dc input voltage source V_d, controlled switch S, diode D, filter inductor L, filter capacitor C, and load resistance R. Assuming an ideal switch, a constant input voltage V_d, a purely resistive load, the instantaneous output voltage, v_o waveform is shown in fig 2.2 as a function of switch voltage.

The average output voltage in terms of switch duty ratio:

$$V_o = \frac{1}{T_s}\int_0^{T_s} V_O\,(t)dt = \frac{1}{T_s}\left(\int_0^{t_{on}} V_d\,(t)dt + \int_{t_{on}}^{T_s} 0\,dt\right) = \frac{t_{on}}{T_s}\,V_d = D\,V_d \qquad (2.1)$$

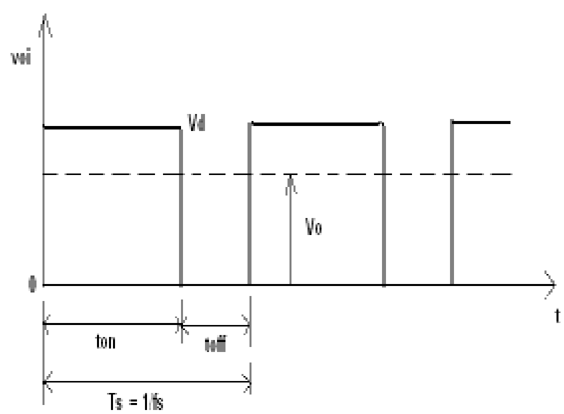


Fig 2.2 V_{oi} voltage waveform

By varying duty ratio D (= t_{on}/T_s) of switch, V_o can be controlled.

In this buck converter average inductor current is equal to average output current Io, since the average capacitor current in steady state is zero.

Buck converter operates in two modes:

- Continuous Conduction Mode (CCM), where inductor current flows continuously [$i_L(t)>0$].

Discontinuous Conduction Mode (DCM), where inductor current falls to zero after some time in OFF period. In V_R-BESS, only continuous conduction mode of operation is considered.

MATLAB/SIMULINK RESULTS AND DISCUSSION

MATLAB INTRODUCTION

Mat lab is a high-level programming language and interactive environment for numerical computation, visualization and programming. By using MATLAB we can analyze data, we can create algorithms and create model and applications.

Mat lab is special-purpose language that is an excellent choice for writing small programs (we'll define "small" to be having fewer than a thousand lines) that solve problems involving the manipulation of numbers. The design of the language makes it possible to write a powerful program in a few lines. The problems may be relatively complex, while the Mat lab programs that solve them are relatively simple: relative that is, to the equivalent program written in a general-purpose language, such as C++ or Java. For many applications in engineering and science, they are not wonderful at all. For these applications, they are an extremely poor choice when compared with Mat lab. MATLAB enables us to solve many advanced numerical problems fast and efficiently. Simulink is a block diagram tool used for modeling and simulating dynamic systems such as controls, signal processing, and communications.

The name MATLAB stands for MATRIX LABORATORY. MATLAB is primarily a tool for matrix computations. It was developed by John little and Cleve Moller of Math Works, Inc. MATLAB was originally written to provide easy access to the matrix computation software packages LINPACK and EISPACK. MATLAB is a high-level language whose basic data type is a matrix that does not require dimensioning. There is no compilation and linking as is done in high-level languages, such as C or FORTRAN. Computer solutions in MATLAB seem to be much quicker than those of a high-level language such as C or FORTRAN. All computations are performed in complex-valued double precision arithmetic to guarantee high accuracy. MATLAB has a rich set of plotting capabilities.

MATLAB has a large collection of toolboxes in a variety of domains. Some examples of MATLAB toolboxes are control system, signal processing, neural network, image processing, and system identification. The toolboxes consist of functions that can be used to perform computations in a specific domain.

MATLAB is a general purpose commercial simulation package used to perform numerical and symbolic computation. Generally, it is used to solve differential equations quickly and easily in an effective manner. It also leads to a visual plot of the results. Engineering simulation using graphical programming tool Simulink plays a vital role in understanding and assessing the operation of a system. Simulink, built upon MATLAB, is a powerful interactive tool for modeling, simulating and analyzing dynamical system; thus, forming an ideal tool for qualitative and quantitative analysis of electrical and electronic network study. It has been identified as an ideal tool for laboratory projects, and has hence been adopted for teaching a variety of courses in electrical and electronics engineering. The benefits of MATLAB and Simulink have been well documented by several workers.

The present work is an implementation of MATLAB text based description m. file, graphical programming Simulink model and data driven modeling using MATLAB and Simulink together. The MATLAB script implementation is a text based m. file description of system under reference that can be written in any text editor. The graphical approach uses Simulink model in terms of block diagram realization for visualizing system dynamics. A Simulink model for a given problem can also be constructed using building blocks from the Simulink library. The model consists of various blocks from Simulink libraries arranged in a desired fashion, offering solution to various problems without having to write any codes.

The MATLAB script implementation and Simulink model presented in this study can be used in numerous diverse engineering applications. These equations occur in numerous settings ranging from mathematics itself to its applications to computing, electric circuit analysis, dynamics systems, biological fields etc. An approach similar to the one presented in this work can be used to model various engineering applications. Some of the applications for study may include:

- Biological process modeling
- Bacteria growth in a jar
- Tumor growth in body
- Insect population modeling
- Fish growth modeling
- Water discharge modeling from hole in a tank
- Radioactive decay of material

5.2. SIMULINK RESULTS

BIDIRECTIONAL DC – DC CONVERTER

The below Fig.5.1 shows Simulink diagrams the bidirectional dc-dc converter

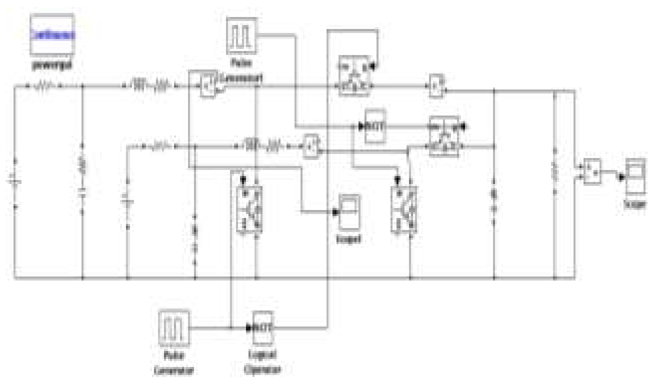
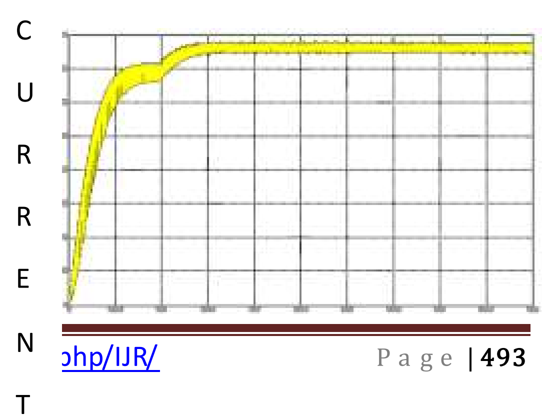


Fig 5.1 bidirectional dc – dc converter

OUTPUT OF BIDIRECTIONAL DC-DC CONVERTER:

The below Fig.5.2 the output waveform of bidirectional dc-dc converter



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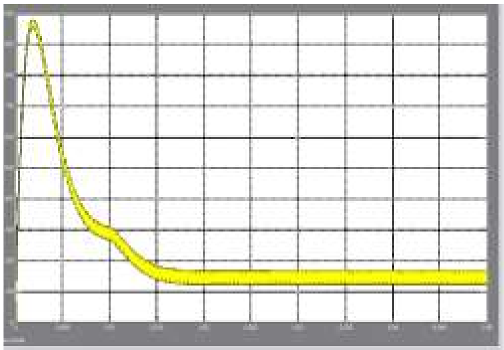
C U R R E N T

TIME (sec)

V O L T A G E



TIME (sec)

Fig 5.2 output of bidirectional dc-dc converter current and voltage
Wave forms

FAULT 1

The below Fig.5.3 shows Simulink diagrams the Fault 1 mode boost converter

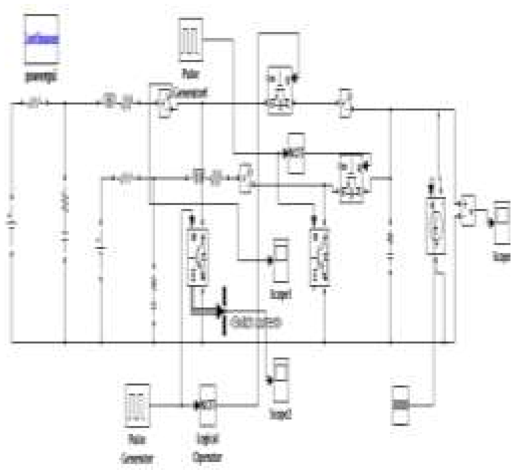
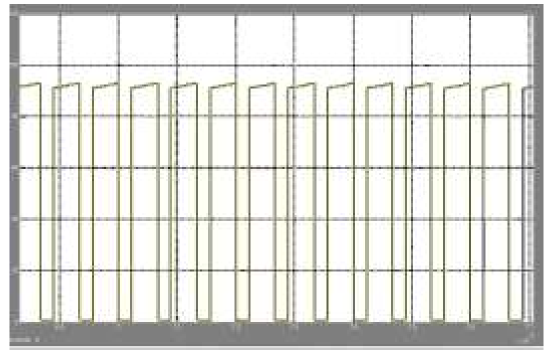


Fig 5.3 fault 1 mode

FAULT 1 OUTPUTS:

The below Fig.5.4 shows Simulink diagrams the Fault 1 out put boost converter T1 voltage waveforms

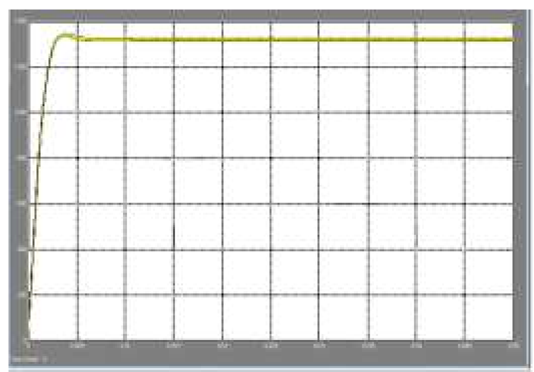


TIME (sec)

Fig.5.4 the Fault 1 output boost converter T1 voltage waveforms

The below Fig.5.5 the Fault 1 output boost converter T1 current waveforms

C U R R E N T



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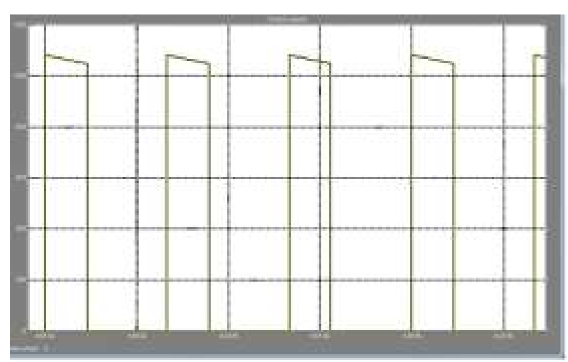

TIME (sec)

Fig 5.5 fault 1 mode outputs

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FAULT 2:

The below Fig.5.6 shows Simulink diagrams the Fault 2 mode buck converter

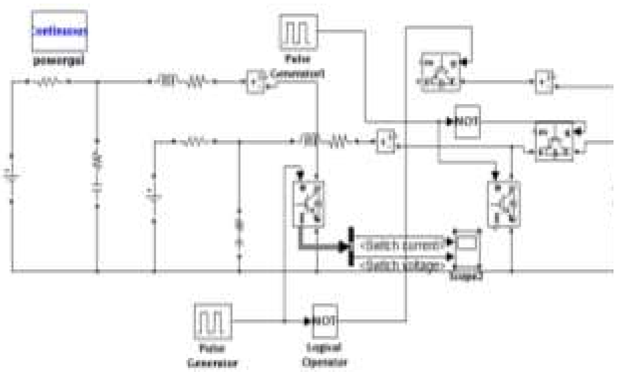
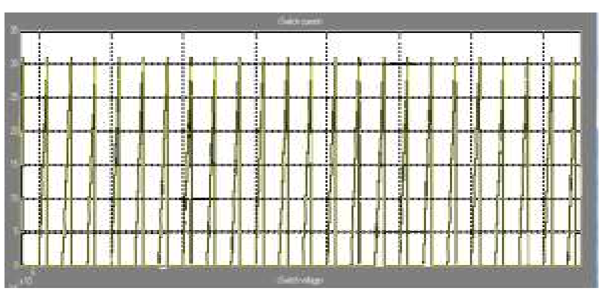


Fig 5.6 fault 2 mode

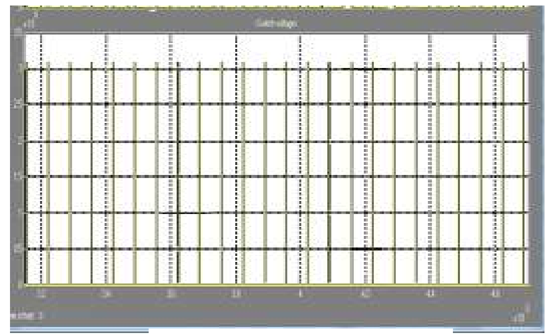
FAULT 2 OUTPUT:

The below Fig.5.7 shows Simulink diagrams the Fault 1 output boost converter T2 current waveforms



TIME (sec)

Fig.5.7 shows Fault2 output boost converter T2 current waveform



TIME (sec)

Fig 5.8 Fault2 output boost converter T2 voltage waveform

CONCLUSION

This project presents modeling, design and analysis of a half-bridge bidirectional DC/DC converter as a PEI between a HESS and the main DC bus in HEVs. The converter components are sized based on the design requirements of a full HEV. The proposed converter is modeled simulated using Mat lab/Simulink to verify the operation of converter. Table V summarizes the converter simulation results under normal and faulty conditions for boost and buck operations. The effect of the SC and OC faults of power switching devices is analyzed. By analysis the fault modes 1, 2, 3, 5, 6, and 7 of the power converter can damage the switching device; whereas, OC transistor faults do not damage the power converter.

When T2 is OC, the energy storage unit is directly to the dc-link; the PEI continues operation but not as a boost converter. When T1 is OC, the energy storage unit is completely disconnected from the dc-link; the converter behaves as if it is shut down. On the other hand, OC diode faults result in high voltage spikes across the converter power switching components which could damage the power device. Whereas, SC diodes and transistors give rise to large bursts of current flowing through the converter components. In conclusion, the parameters measured for control purposes, such as the converter output voltage/current and the inductor voltage and current, can be used as key parameters in detecting and identifying the fault mode where techniques such as residual redundancy and higher-order moments are recommended with such types of faults.

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