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Design and Voltage Analysis of Power Converter Using Digital Controllers

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Abstract:
Power converter is an electronic device that converts a source of direct current from one voltage level to another voltage level. It is a type of electric power converter. Power levels range from very low to very high voltage power transmission. With the development of the electronics in car and automatic parts the capacity of the current 14 volt voltage no longer meets the demand of the on board devices in the automobile. A dual 14v/42v system is developed as a solution to this problem. This paper proposes a bi-directional DC/DC converter Using digital controllers. This converter will work in both Buck and Boost mode. Extensive study on compatibility and stability, it indicates that under changing power direction, this new converter is able to perform a closed loop control depending upon the value of current and direction.

Keywords: DC/DC Converter, Dual Voltage System, Buck Converter, Boost Converter, Closed loop Control.

1. INTRODUCTION

I. OVERVIEW

Switching power supplies offer higher efficiency than traditional linear power supplies. They can step-up, step-down, and invert. DC/ DC power converters are employed in a variety of applications, including power supplies for personal computers, office equipment, spacecraft power systems, laptop computers, and telecommunications equipment, as well as dc motor drives. The main aim of this paper is to study different types of power converters and Design a Bi- directional DC/ DC converter**.** Bi- directional DC/ DC converter has gained interest in both the industries as well as in academic field of power electronics, which can act as a platform for transaction of different DC voltage values and make management of power at the two level of power system. The demand to improve the performance, fuel economy and passenger convenience and safety has grown drastically in recent times. The standard 14 Volt electrical power systems can no longer meet the demand of the modern day automobiles. The present in car voltage level from 14 volt to 42 volts can be boosted which in turn increases the power capacity to 8 KW. Here we are introduce a Bi- Directional DC/DC converter, It contains control circuit which is able to determine the operating mode based on the direction of inductance current, after that it stabilizes the closed loop without changing the present parameters of the system. The DC/DC converter which is used for automobiles has a strict requirement for cost, volume and efficiency. A Buck/ Boost converter is used for this requirement. Switching power supplies offer higher efficiency than traditional linear power supplies. They can step-up, step-down, and invert. Some designs can isolate output voltage from the input. This article outlines the different types of switching regulators used in DC-DC conversion. It also reviews and compares the various control techniques for these converters. DC/DC converter has gained interest in both the industry and in the academic world of the power electronics field, which can perform as a platform for the transaction between different voltage values and make management of power at the two level of power system. Some designs can isolate output voltage from the input. This article outlines the different types of switching regulators used in DC-DC conversion. It also reviews and compares the various control techniques for these converters. DC/DC converter has gained interest in both the industry and in the academic world of the power electronics field, which can perform as a platform for the transaction between different voltage values and make management of power at the two level of power system. It has a promising prospect in application of automation electronics, photo voltaic cell, solar energy generation and wind power generation, etc. The power switch was the key to practical switching regulators. A switching regulator is a circuit that uses a power switch, an inductor, and a diode to transfer energy from input to output. The basic components of the switching circuit can be rearranged to form a step-down (Buck) converter, a step-up (Boost) converter, or a Buck-Boost converter. The design of these converters will be discussed later in this article. In this article we study different types of DC/DC converter, so that they can be used properly for further research on system designed using DC/DC converters. The DC/DC converter is used in automotive environment which has strict requirement for cost, volume and efficiency. The control circuit which is able to determine the operating mode depending on the inductance current direction is then stabilizes the closed loop system stable without changing the parameters. A Buck/Boost converter is used for this purpose.

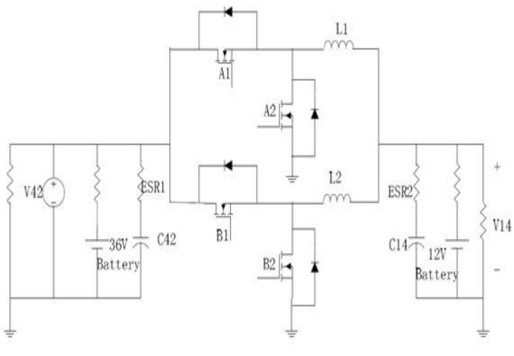

Figure.1. Bidirectional DC/ DC Converter block diagram

In the figure control method which is used is the current control method instead of the voltage control method, since the mode of operation is detected by the change in the inductor current, rather not by inductor voltage and more over current control method has a faster response than voltage control method. A current control loop is much more stable than a voltage control loop.

The working mode is determined by the loads and the voltage of two, but it is unnecessary to design two buck and boost converter separately. The purpose of this project is to design a single control action for both the buck and boost converter and hence to make it work as a bi-directional DC/DC converter.

II. DC/DC CONVERTER

There different kinds of DC-DC converters. A variety of the converter names are given below. The Buck converter, Boost converter, Buck-Boost, CUK converter, Fly-back converter, Forward Converter, Push-pull Converter, Full Bridge converter, Half Bridge Converter, Current Fed converter, Multiple output converters.

There are a variety of DC-DC converters are possible. But from the list of the converters only the first four of the converters are to be described which have basically non isolated input output terminals. It is worth noticing that any converters work in two distinct modes with respect to the inductor current: the continuous conduction mode and discontinuous conduction mode.

When the inductor current is always greater than zero, it is in. When the average inductor current is too low due to the high-load resistance or low-switching frequency, then the converter is in DCM.

The CCM is preferable for high efficiency and efficient use of semiconductor switches and passive components. The Discontinuous conduction mode requires a special control since the dynamic order of the converter is reduced. Thus, it is required to find out the minimum value of the inductor to maintain the Continuous conduction mode. Assume that the inductor and capacitor are pure (i.e. no resistive component). However, there is still what we call a small-ripple approximation. In an efficient converter, the output voltage ripple is small. So,

$$\Delta V_O = 0 \text{ and } V_O = V$$

Buck Converter:

The Buck converter is commonly used in circuits that steps down the voltage level from the input voltage according to the requirement. It has the advantages of simplicity and low cost. Figure 2 shows a buck converter the operation of the Buck converters start with a switch that is open.

When the switch is closed the current flows through the inductor, slowly at first, but building up over time. When the switch is closed the inductor pulls current through the diode, and this means the voltage at the inductors output is lower than it first was.

This is the very basic principle of operation of buck circuit. The buck converter consists of a DC supply or a rectified AC output, two switches i.e. D (diode) and S (can be semi-controlled or fully-controlled power electronics switches), two-pole low-pass filter (L and C) and a load.

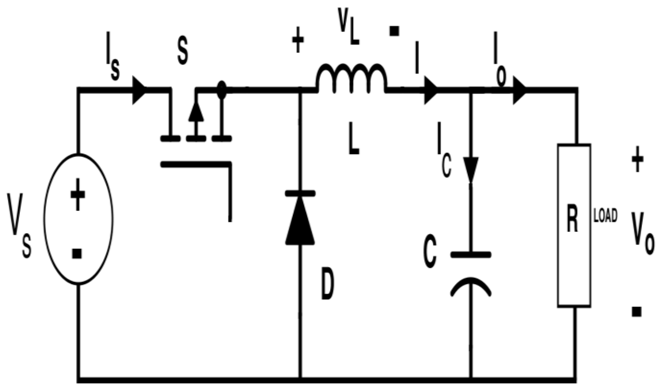

Figure. 2. Buck Converter

Let the duty ratio of switch S be

$$D=T_{ON}/ T$$

where

$$T=T_{ON}+T_{OFF}.$$

Buck converter is mostly used for DC drives systems e.g. electric vehicles, electric traction and machine tools. This circuit can be studied in two different modes. The first mode is when the switch S is on while the second mode is when the switch S is off. The circuit diagrams when the switch S is on and off are given in Fig. 3 and Fig. 4 respectively.

Voltage across the Inductor: VL=L.dI/dt

Where $I=I_C+I_O$.

Load Current: $I_O = V_{OR}$

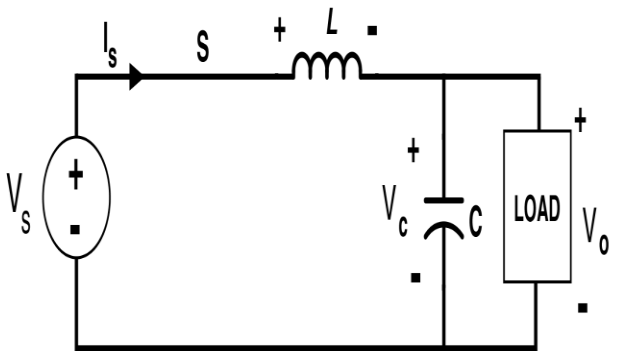

Figure.3. Buck Converter Circuit when Switch S is On (Mode-I)

When the switch S is on and applying the Kirchhoff‘s voltage law (KVL), we can get,

$VS= V_L+V_O$

$VS= L. di/dt + V_O$

And $V_O=V_C$.

When the switch S is off, the KVL in Fig.4 gives,

$V_L+V_O=0$

$V_O= -L. di/dt$.

As the output voltage is assumed constant by the small-ripple approximation,

L.di/dt = constant

Slope of the inductor currents constant. Waveforms of the voltage and current during the one-cycle period are shown in Fig. 5

switch. If the voltage is high enough it opens the diode, and one through the diode, the current can't flow back. The equivalent circuit during switch on and off condition of the switch S is shown in Fig. 7 and Fig. 8 respectively.

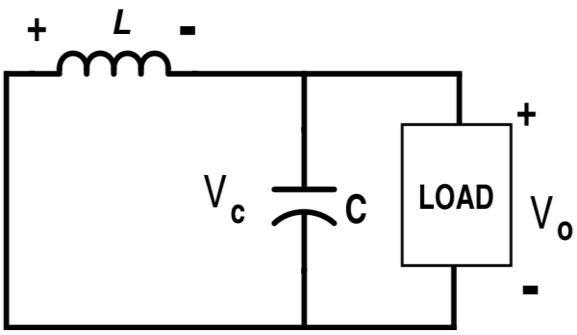

Figure.4. Buck Converter Circuit when Switch S is Off (Mode-II)

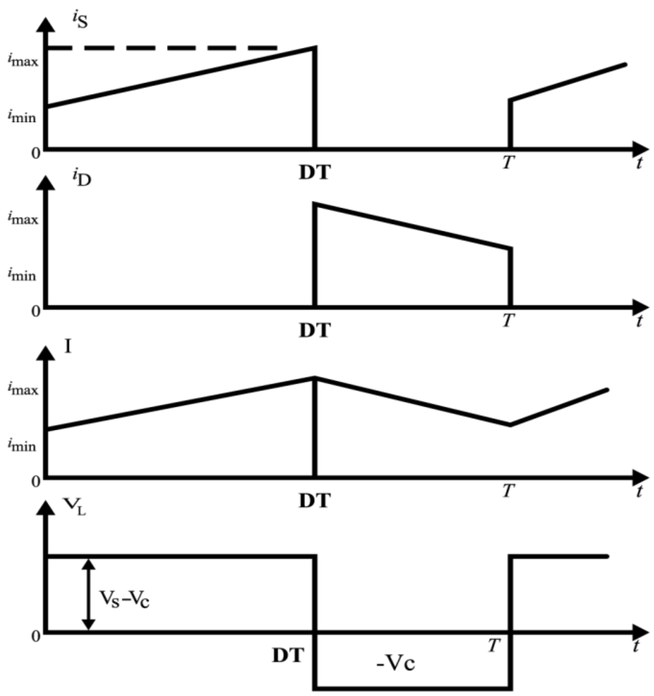

Figure.5. Waveforms of Supply Current Is, Diode Current ID, Inductor Current I, and Inductor Voltage VL.

Boost Converter:

A boost converter (step-up converter) is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching mode power supply (SMPS) containing at least two semi-conductors switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

A boost converter is sometimes called a step-up converter since it steps up the source voltage. Since power (P = VI) must be conserved, the output current is lower than the source current. The boost converter has the same components as the buck converter, but this converter produces an output voltage greater than the source.

Boost converters start their voltage conversion with a current flowing through the inductor (switch is closed). Then they close the switch leaving the current no other path to go than through a diode (functions as one way valve) The current then wants to slow really fast and the only way it can do this is by increasing its voltage at the end that connects to the diode, and

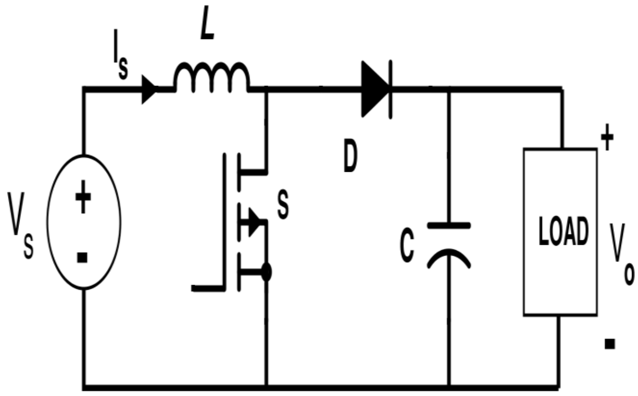

Figure. 6. Boost Converter Circuit Diagram

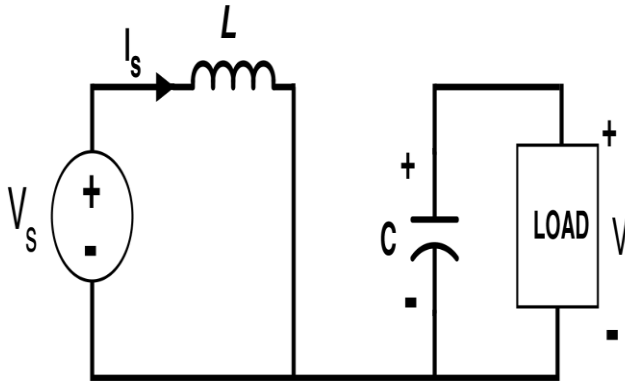

Figure.7. Boost Converter Circuit when Switch S is On (Mode-I)

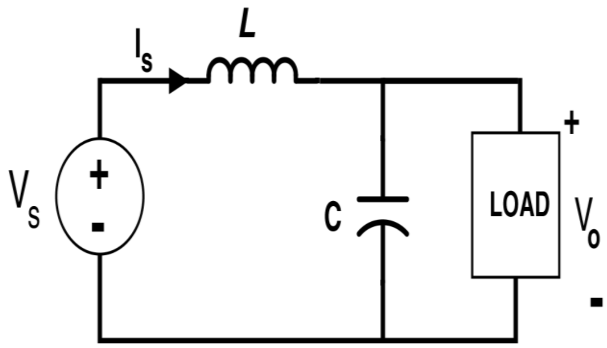

Figure.8. Boost Converter Circuit when Switch S is Off (Mode-II)

When the switch S is on,

$V_S=V_L$

L.di/dt =VS =Constant supply voltage

di/dt = constant

Current increases with constant slope. When the switch S is off,

VS = VL+VC

L.di/dt = VS−VC

Now, current decreases and must reach at a value equal to the value of the current at the initial stage when switch S is just switched on according to steady-state stability.

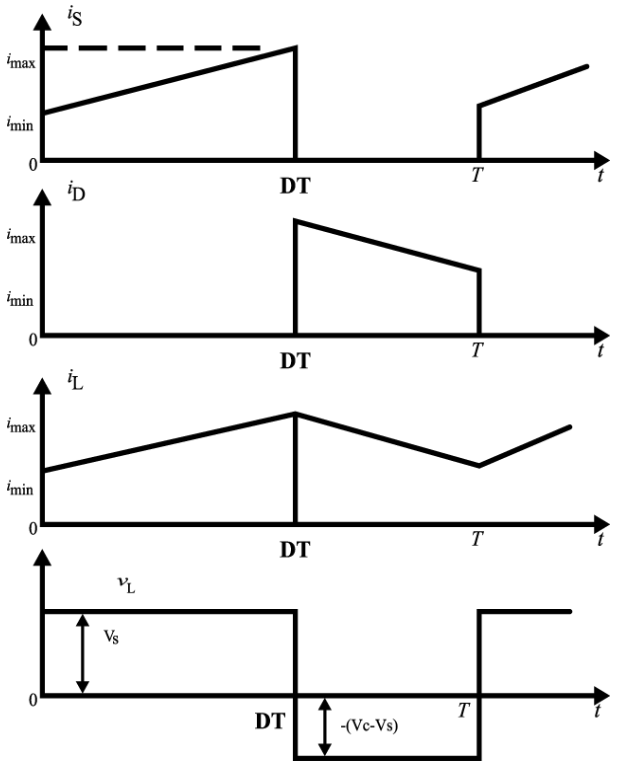

Figure.9. Waveforms of Supply Current Is, Diode Current I_D,Inductor Current I, and Inductor Voltage V_L. (Buck Converter)

Buck – Boost Converter:

A Buck-Boost converter is a type of switched mode power supply that combines the principles of the Buck Converter and the Boost converter in a single circuit. Like other SMPS designs, it provides a regulated DC output voltage from either an AC or a DC input. This converter is an inverting DC/ DC converter i.e. polarity of the output voltage is reversed compared to the input supply. Thus, it is a negative-output buck-boost converter. With respect to buck and boost converters, the operation of the buck-boost is best understood in terms of the inductor's "reluctance" to allow rapid change in current. From the initial state in which nothing is charged and the switch is open, the current through the inductor is zero.

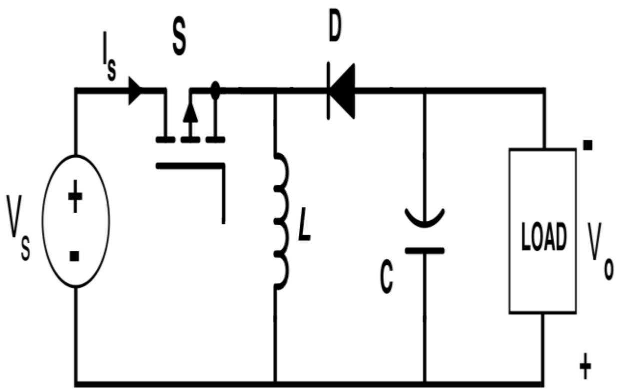

Figure.10. Buck-Boost Converter Circuit Diagram

When the switch is first closed, the blocking diode prevents current from flowing into the right hand side of the circuit, so it must all flow through the inductor. However, since the inductor doesn't like rapid current change, it will initially keep the current low by dropping most of the voltage provided by the source. Over time, the inductor will allow the current to slowly increase by decreasing its voltage drop. Also during this time, the inductor will store energy in the form of a magnetic field.

Let the capacitor be totally charged up before switching on the switch S. When the switch S is closed as shown in Fig. 11.

$-V_S + V_L = 0$

$V_S = V_L = L.\ di/dt$

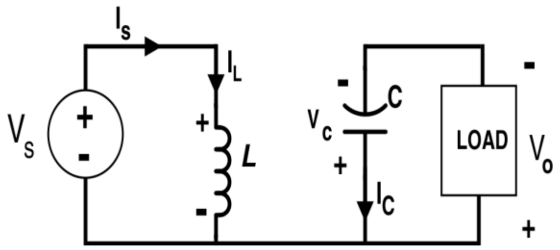

Figure.11. Buck-Boost Converter Circuit when Switch S is On (Mode-I)

Also,

$-V_C + V_O = 0$, $V_O = V_C$

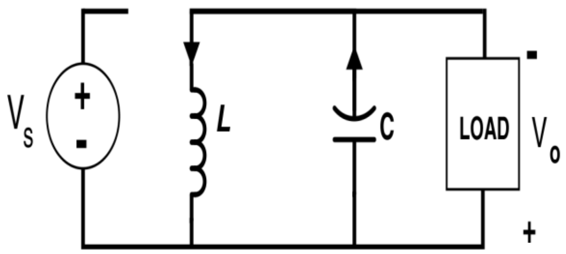

Figure.12. Boost Converter Circuit when Switch S is Off (Mode-II)

In above figure, when the switch S is opened,

$+V_L + V_C = 0$

$L.\ di/\ dt + V_C = 0$

$di/\ dt = -V_C / L$

Waveforms for the voltage and current for buck-boost converter are shown in Fig. 13

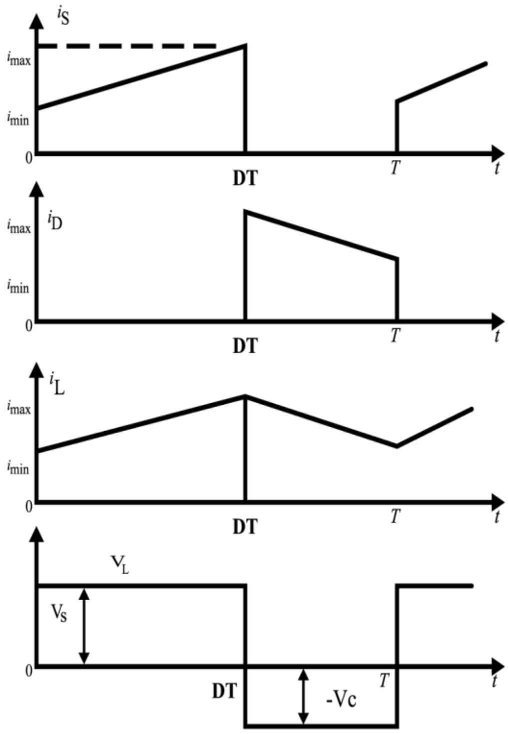

Figure.13. Supply Current, Diode Current, Inductor Current and Inductor Voltage respectively (Buck-Boost Converter)

III. OPERATING PRINCIPLE OF BI-DIRECTIONAL DC/DC CONVERTER

The implementation of 14v/42v converter with a buck- boost topology using an active switch instead of a diode is more desirable. As bi-directional operation is possible without any additional requirement of components and efficiency is very high than a typical buck-boost converter using a diode. The two active switches turn on and off alternatively through the main switches or the freewheeling diodes as per the mode of operation. The DC/DC converter is connected parallel with the batteries with 42 volt and 14 volt loads on either side of the circuit. The control method which is used is the current control method instead of a voltage control method, since the mode of operation is detected by the change in the inductor current, not by inductor voltage and more over current control method has a faster response than voltage control method. The further advantage is stability as current control loop is more stable than a voltage control loop. The three modes of converter operation can be listed as follows, (i) when the inductor current is above zero, the converter works in the buck mode and the 42 volt energy bus provides energy to the sides, 42 Volt loads as well as charge the batteries also. The second mode of operation involves (ii) when the inductor current is above zero; the converter operates in the boost mode. The 14 volt bus provides energy to the both sides of the load and charge the battery, (iii) when the inductor current repeats working through the zero, the converter operates in the alternating mode.

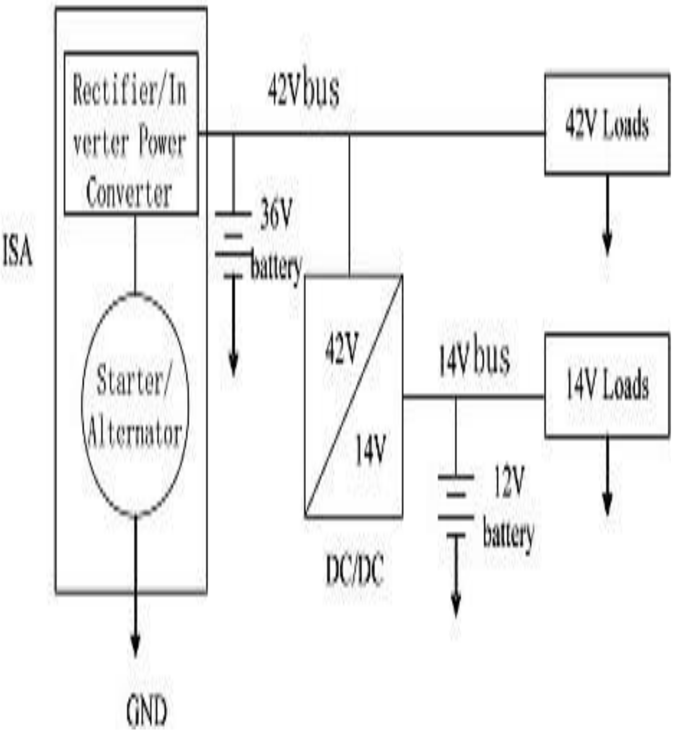

Figure.14. Fundamental Block diagram of 14/ 42V System.

The working is determined by the loads and the voltage of buck and boost converter, but it is un necessary to design two separate buck and boost converter, so the main aim of this article is to design a single converter implemented with both boost and buck action.

IV. METHODOLOGY

The experimental design and analysis of the bi-directional DC/DC converter circuit is implemented using the MATLAB (SIMULINK) software. The simulation of the circuit is needed in order to design the real time prototype circuit with the exact design parameter. The details about the software and the simulation procedure are given in detail in the next paragraph.

Simulink SIM POWER SYSTEM is a package that comes under the MATLAB software. Simulink software is a simulation tool kit, which can be used to design as well as to simulate the operation and output of a circuit with the given required parameters. The blocks of the Simulink software are pick and place types, which can be picked and place in the front panel and can be worked. The most common types of blocks to be used in the SIM POWER SYSTEM of the Simulink software are: Power electronic elements, Measurement, Sources, Power guided user interface, etc. The circuit of the bi-directional DC/DC converter is first simulated using the Simulink software. Before realizing the closed loop response of the converter circuit, the open loop response of the circuit is obtained and then as per the required parameters the controller is design and then with the combine response of the open loop circuit and as well as the controller the closed loop response is obtained. The Buck Boost Converter is used in the self regulating power supplies, consumer electronics, Battery power systems, Adaptive control applications, Power amplifier applications.

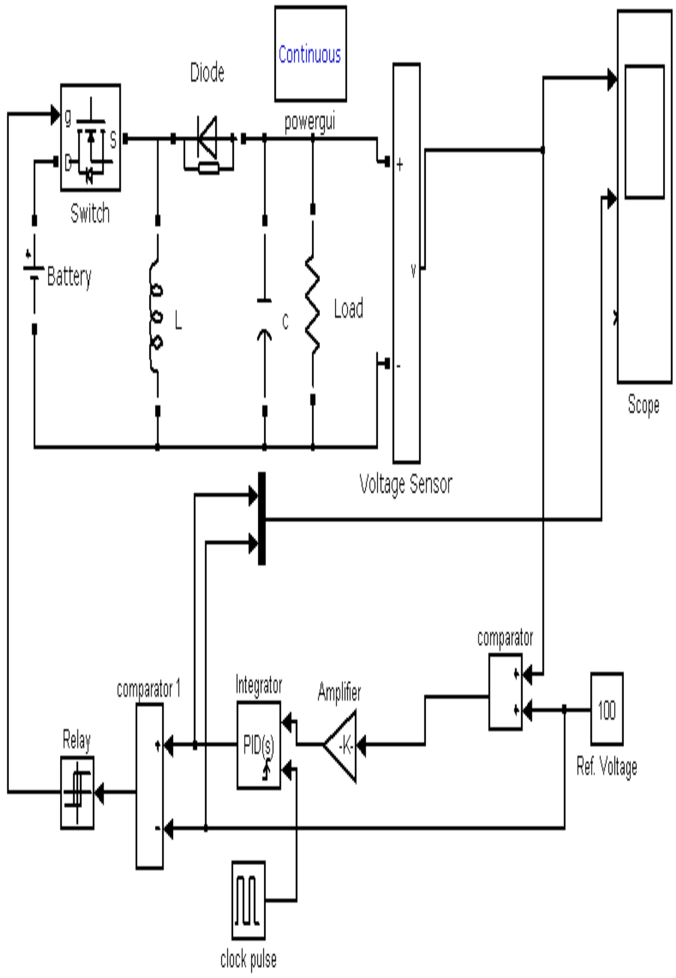

Figure.15. Shows the closed control loop of Bi- Directional DC/ DC converter Using PID Controller.

The simulation of the buck converter and the boost converter circuit is done by using the MATLAB (SIM POWER SYSTEM) software. The response or the output of the converters is obtained in the form of a response graph

(1) Buck converter: - for the buck converter the input voltage is given as 12 volt and the output is obtained at 4 volt.

There is a step down of voltage from a higher level to that of the lower level in case of a buck converter.

(2) Boost converter: - for the boost converter the input voltage is given as 4 volt and the output voltage is obtained as 12 volt. It works just the opposite of the boost converter. It boosts up the voltages from a lower value to a higher value.

V. EXPERIMENTAL RESULTS

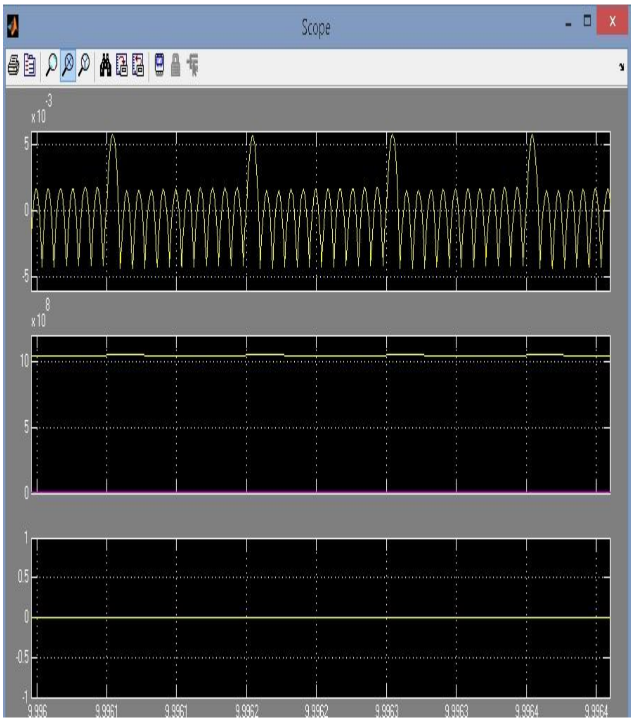

Figure.16.Buck Controller waveform Using PID Controller

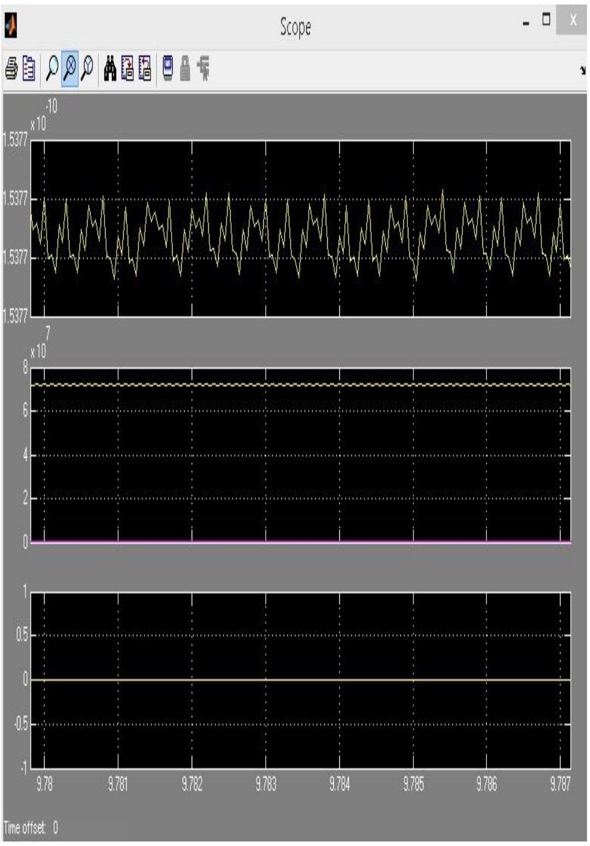

Figure.17. Boost Controller waveform Using PID Controller

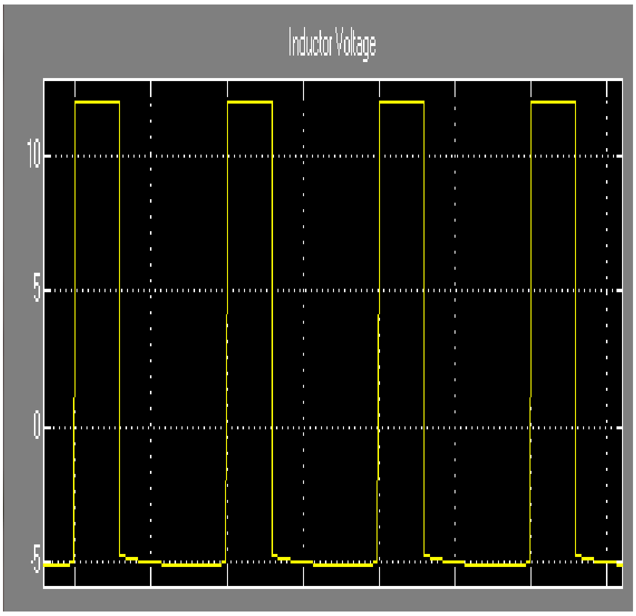

Figure.18. Simulated Output Inductor Voltage for a Boost Converter

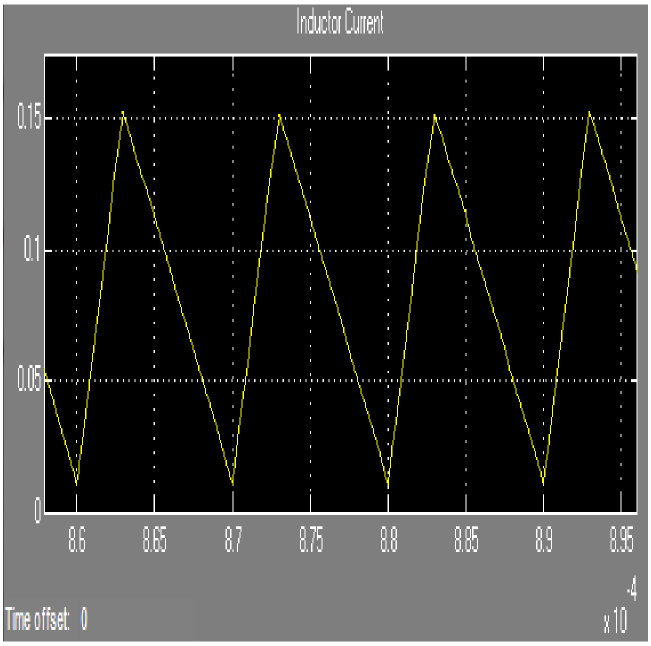

Figure.19. Simulated Output Inductor Current for a Boost Converter

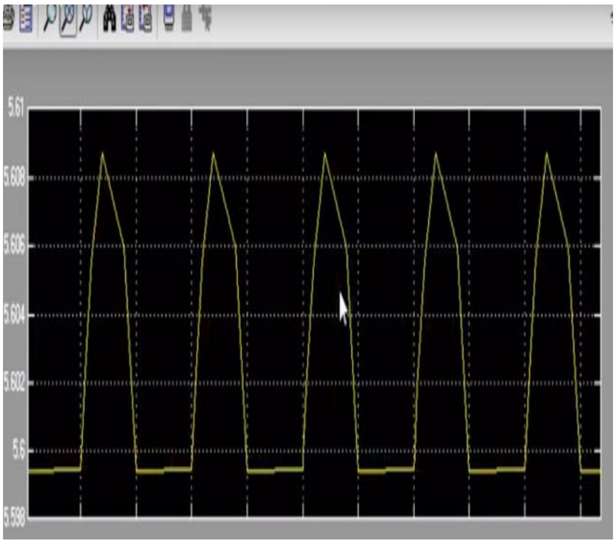

Figure.20. Simulated Output Inductor Voltage for a Buck Converter

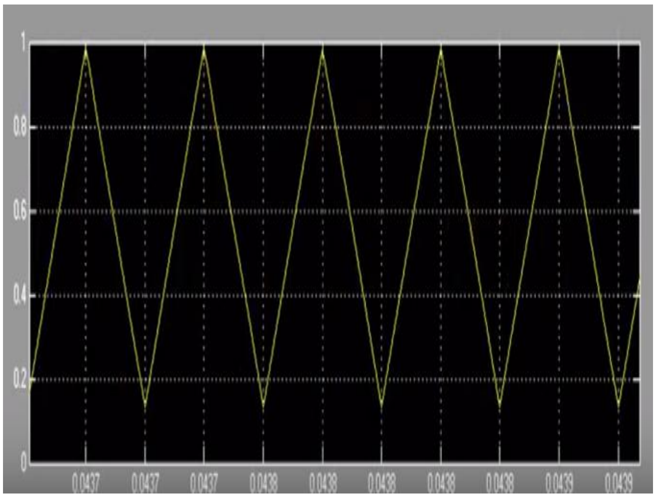

Figure.21. Simulated Output Inductor Voltage for a Buck Converter

Shows the simulated output wave form for buck and boost converter. The inductor voltages and inductor current for both buck mode and boost mode are also shown in waveforms. Both the input and output voltages are DC voltages.

VI. CONCLUSION

The Bi- Directional DC/DC converter has a promising prospect in the automation electronic area. This article proposes a bi-directional DC/ DC converter, which can work in both step up and step down mode. Current control method instead of a voltage control method, stability of current control loop is more stable than a voltage control loop. This proposed circuit can further be reinforced by extensive experimentation and future research.

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