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Analysis of Power Converters: A Review

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Abstract:
Power converters are electronic devices 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. 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.

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

I. OVERVIEW

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. 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.

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.

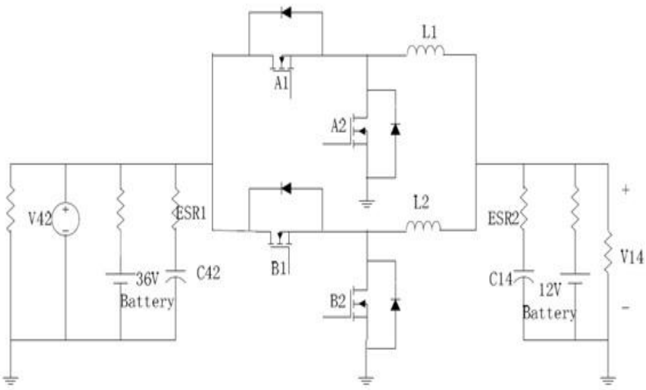

Fig1: Bidirectional DC/ DC Converter block diagram

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. TYPES OF 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

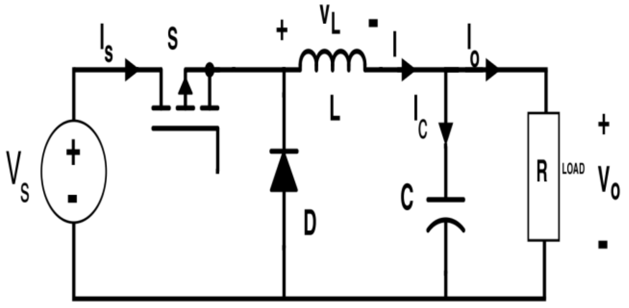

Fig 2: Buck Converter

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. 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: $I_O = V_{OR}$

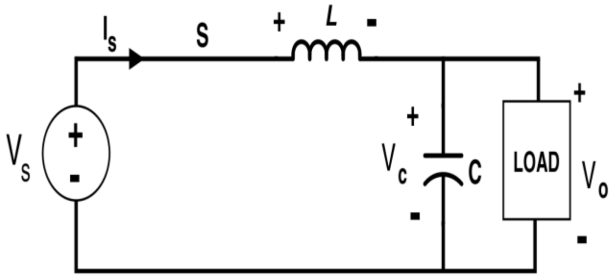

Fig 3: Buck Converter Circuit when Switch S is On (Mode-I)

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

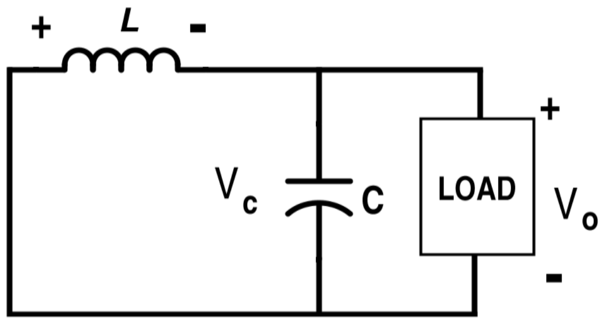

Fig 4: Buck Converter Circuit when Switch S is Off (Mode-II)

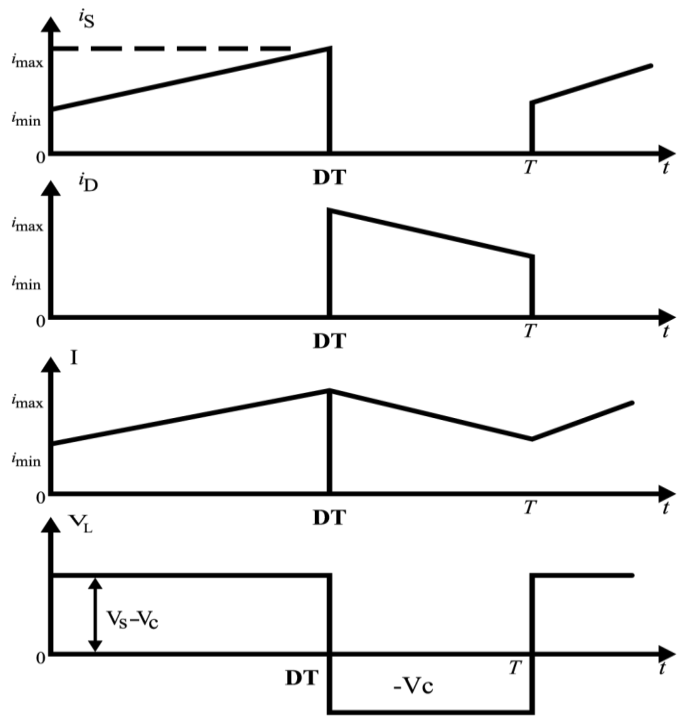

Fig 5: Waveforms of Supply Current Is, Diode Current ID, Inductor Current I, and Inductor Voltage VL.

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 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.

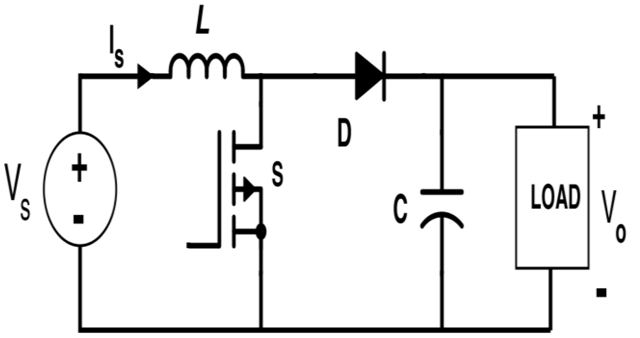

Fig 6: Boost Converter Circuit Diagram

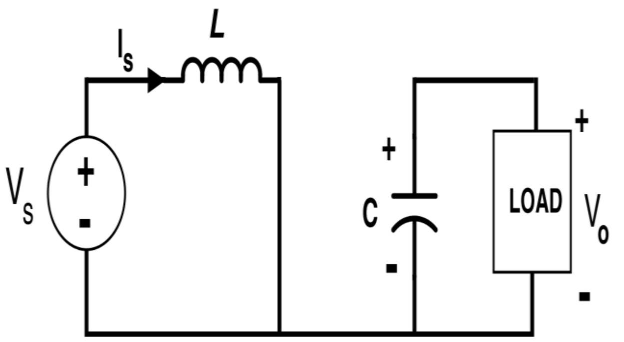

Fig 7: Boost Converter Circuit when Switch S is On (Mode-I)

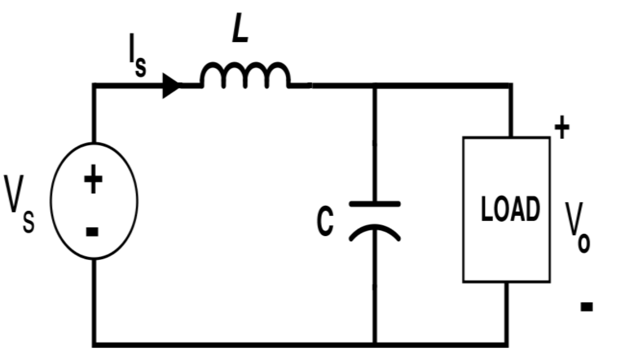

Fig 8: Boost Converter Circuit when Switch S is Off (Mode-II)

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.

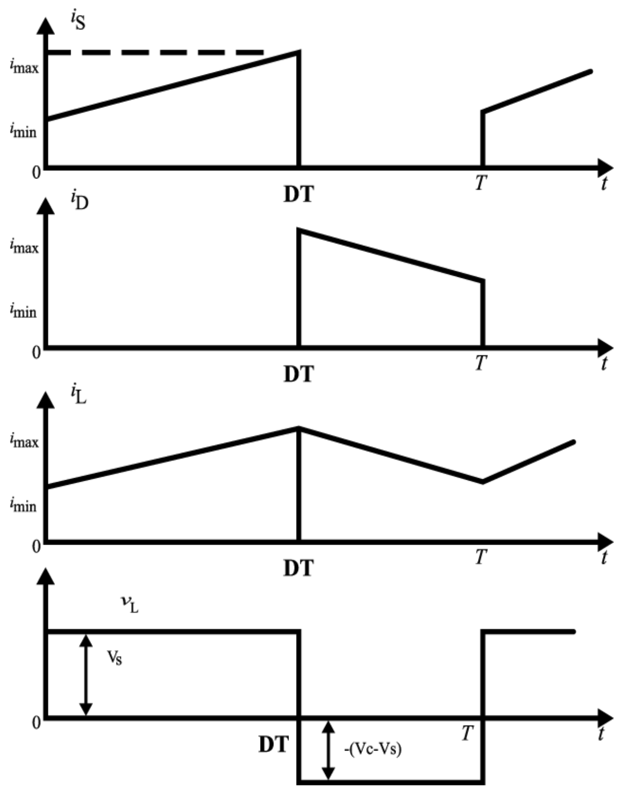

Fig 9: Waveforms of Supply Current Is, Diode Current I_D, Inductor Current I, and Inductor Voltage V_L. (Buck Converter)

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.

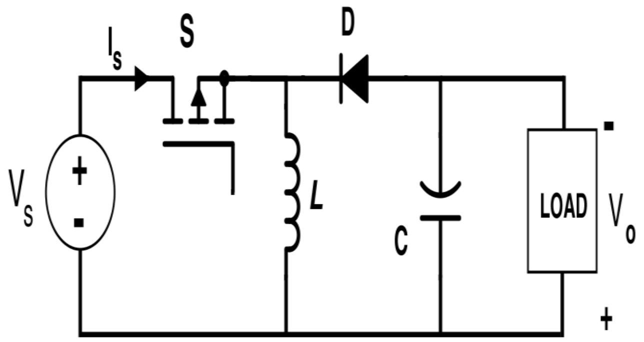

Fig 10: Buck-Boost Converter Circuit Diagram

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.

$-V_S + V_L = 0$

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

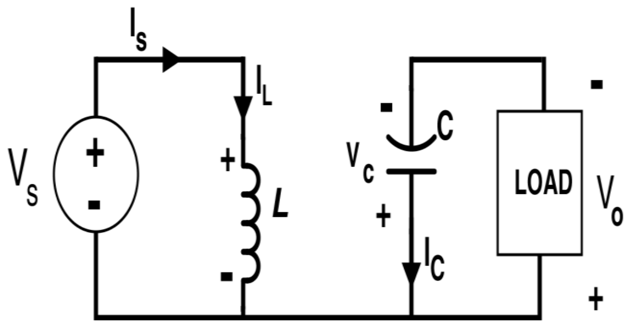

Fig 11: Buck-Boost Converter Circuit when Switch S is On (Mode-I)

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

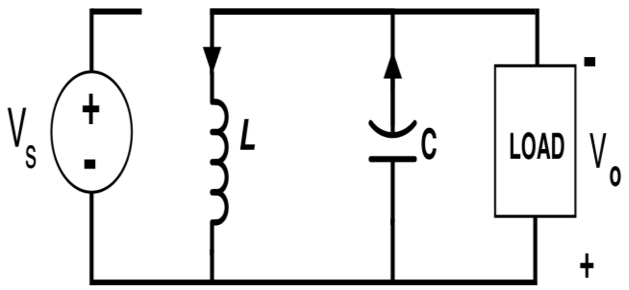

Fig 12: Boost Converter Circuit when Switch S is Off (Mode-II)

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

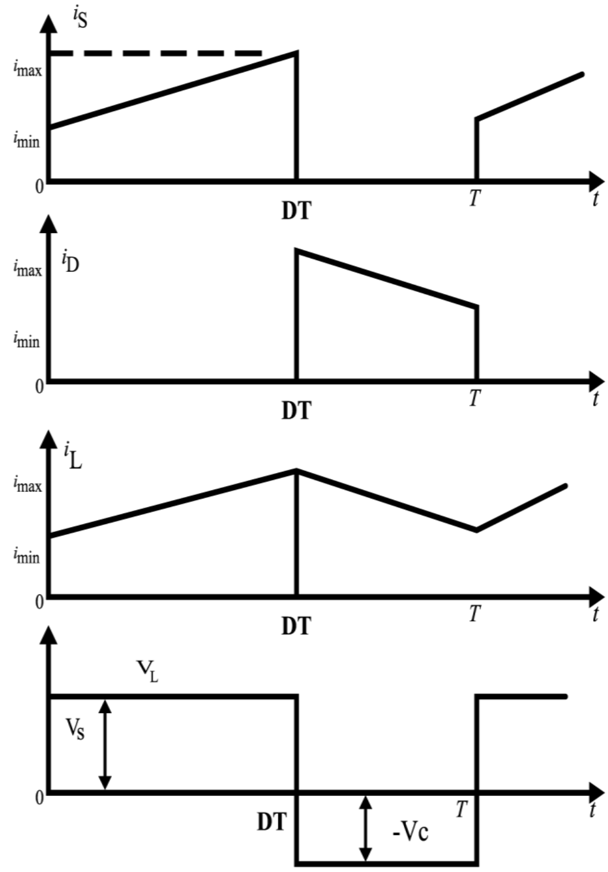

Fig 13: Supply Current, Diode Current, Inductor Current and Inductor Voltage respectively (Buck-Boost Converter)

CUK Converter:

A CUK converter can be implemented by cascading the boost converter followed by the buck converter. It also has a negative-output polarity as in the case of the simple buck-boost converter. But we have assumed here that the polarity of the output is positive. The CUK converter is a type of DC/DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is essentially a boost converter followed by a buck converter with a capacitor to couple the energy.

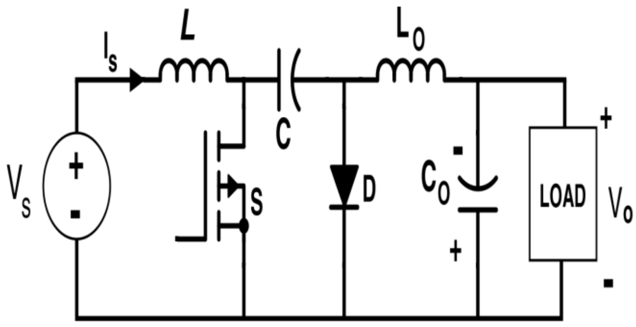

Fig 14: CUK Converter Circuit Diagram

Similar to the buck–boost converter with inverting topology, the output voltage of non-isolated CUK is typically also inverting, and can be lower or higher than the input. It uses a capacitor as its main energy-storage component, unlike most other types of converters which use an inductor.

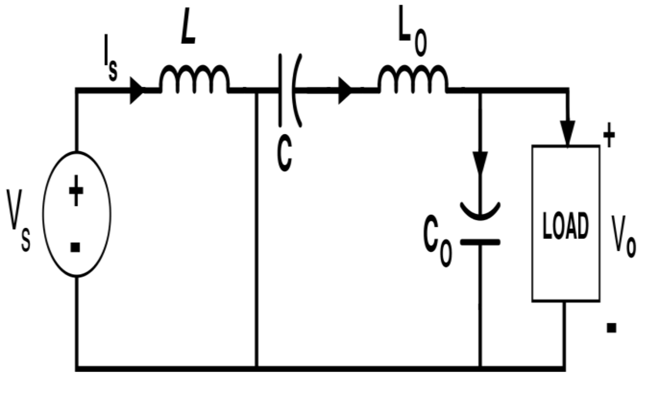

Fig 15: CUK Converter Circuit when Switch S is On (Mode-I)

When switch S is on, the circuit will be reduced as shown in Fig. 12.,

$V_S=V_L$

$di/dt = V_S / L$ (Current Increases)

$\Delta IL=V_S. DT / L$

For inductor L_O,

$V_C + V_{Lo} + V_O = 0$

$dI_{Lo} / dt = -1 / L\ (VC+VO)$ (Current Increases)

If the VC and VCO polarities are in the reverse direction of the loop considered and the current must increase, the current must actually increase in the opposite direction of the assumed direction.

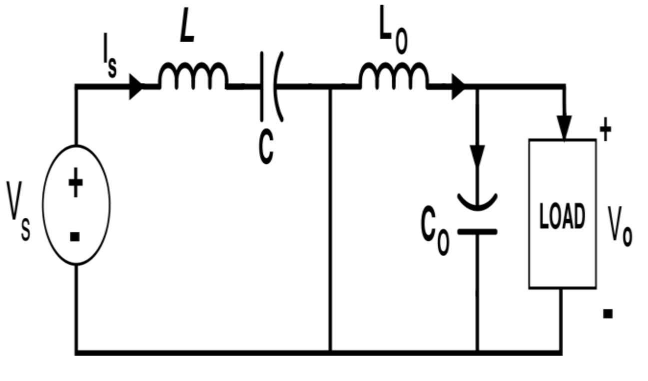

Fig 16: CUK Converter Circuit when Switch S is Off (Mode-II)

When switch S is off, the circuit will reduced to the configuration shown in Fig.16.

$-V_S+V_L+V_C=0$

$di / dt = -(V_C - V_S) / L$ (Current decreases)

For inductor Lo,

$V_{Lo} - V_{Co} = 0$, $dILo / dt = VCo / L$ (Current decreases)

Note that the current actually decreases in the opposite direction. So, di / dt must be positive.

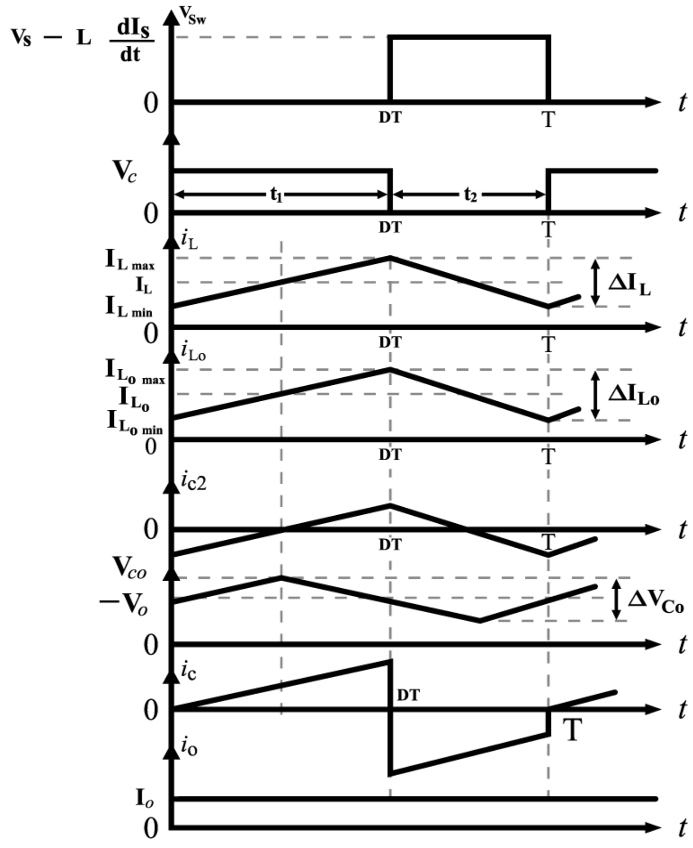

Fig 17: Switch (S) Voltage, Capacitor (C) Voltage, Inductor (L) Current, Inductor (L_O) Current, Capacitor (C_O) Voltage, Capacitor (C) Current and Load Current respectively for the Cuk Converter

III. CONCLUSION

Buck-Boost converter requires input filter to reduce current ripple and to meet electromagnetic interference requirements as input current is pulsating due to switching of power switch. Also output current is discontinuous and hence large output capacitor is required to reduce ripple voltage. Even though buck-boost converter is able to step up or step down input voltage it gives negative output voltage with respect to ground. Moreover, presence of right half zero in continuous conduction mode makes feedback loop compensation difficult.

IV. FUTURE SCOPE

The Buck Boost Converter is used in the self regulating power supplies, consumer electronics, Battery power systems, Adaptive control applications, Power amplifier applications. In our future research we will design different types of DC/DC converters in MAT Lab (Simulink). In Further research a Bidirectional DC/ DC converter can be designed.

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