Chapter-1

INTRODUCTION

1.1 Introduction

In order to protect the natural environment on the earth, the development of clean energy without pollution has the major representative role in the last decade. By accompanying the permission of Kyoto Protocol, clean energies, such as fuel cell (FC), photovoltaic (PV), wind energy, etc., have been rapidly promoted. Due to the electric characteristics of clean energies, the generated power is critically affected by the climate or has slow transient responses, and the output voltage is easily influenced by load variations. Thus, a storage element is necessary to ensure proper operation of clean energies. Batteries or super capacitors are usually taken as storage mechanisms for smoothing output power, start-up transition, and various load conditions [1]. The corresponding installed capacity of clean energies can be further reduced to save the cost of system purchasing and power supply. For these reasons, hybrid power conversion systems (PCS) have become one of interesting research topics for engineers and scientists at present. Based on power electronics technique, the diversely developed power conditioners including dc–dc converters and dc–ac inverters are essential components for clean-energy applications. Generally, one power source needs a dc–dc converter either for raising the input voltage to a certain band or for regulating the input voltage to a constant dc-bus voltage [4]. However, conventional converter structures have the disadvantages of large size, complex topology, and expensive cost. In order to simplify circuit topology, improve system performance, and reduce manufacturing cost, multi-input converters have received more attentions in recent years [2].

In this study, a high-proficiency ZVS double include converter is examined, and this converter straightforwardly uses the current source sort applying to both information force sources. Taking into account the arrangement associated data circuits and the composed beat width regulation (PWM) driving flags, the conduction loss of the switches can be extraordinarily decreased in the double power-supply state. Lee performed zero-current-move dc–dc converters without extra present anxiety and conduction misfortune on the principle switch amid the reverberation time of the assistant cell. The assistant cell gives zero-current-exchanging turn-off for all dynamic switches and minimizes the converse recuperation issue of the principle diode. The adjusted sort of this agent assistant cell is brought into the proposed double include converter to diminish the opposite recuperation momentums of the diodes. An assistant circuit with a little inductor worked in the broken conduction mode (DCM) is used for accomplishing turn-on ZVS of every last one of switches, and the tremendous opposite recuperation present of the yield diode in the customary support converter can be evacuated through the use of a helper inductor arrangement joined with a diode. Subsequently, the proposed double include converter can productively change over two force sources with diverse voltages to a stable dc-transport voltage. As per the force dispatch, this converter could be worked at two states including a solitary force supply state and a double power-supply state.

1.2 Background

For high efficiency, the SMPS switch must turn on and off quickly and have low losses. The advent of a commercial semi-conductor switch in the 1950s represented a major milestone that made SMPSs such as the boost converter possible. The major DC to DC converters were developed in the early 1960s when semiconductor switches had become available. The aerospace industry's need for small, lightweight, and efficient power converters led to the converter's rapid development [3].

Switched systems such as SMPS are a challenge to design since its model depends on whether a switch is opened or closed. R. D. Middle brook from Caltech in 1977 published the models for DC to DC converters used today. Middle brook averaged the circuit configurations for each switch state in a technique called state-space averaging. This simplification reduced two systems into one. The new model led to insightful design equations which helped SMPS growth [3].

1.3 State of the Problem

Static power converters are used for controlled, efficient and clean use of electricity in various applications. These converters according conversion types are: AC-AC (Voltage Controllers and Cyclo-converters), AC-DC (Rectifiers), DC-DC (Choppers) and DC-AC (Inverters). Among the four static power converters mentioned, high frequency dc-dc chopper-converters are known as switch mode power supplies (SMPS). SMPS are extensively used as power supplies of computers and electronic equipment [5-6]. According to the type of voltage regulation (step-down/step-up/step-up-down) SMPS has three basic (Buck, Boost and Buck-Boost/Ĉuk/SEPIC) and many derived configurations. The voltage regulation is achieved by duty cycle (D) control of the switching signal of the semiconductor switch of the SMPS. In a practical SMPS, the efficiency and the voltage-gain are function of the duty cycle D [5]. Each type of SMPS has high value of efficiency for limited range of voltage gain (within a range of duty cycle D). In case of extreme gains (either high or low), hybrid SMPS converters may be used to maintain high conversion efficiency. Hybrid SMPS converters are combination of voltage multiplier/divider circuits with appropriate SMPS circuits. As per need, any of the conventional SMPS circuit may be modified in hybrid manner to achieve extreme duty cycle operation (for either very-low or very-high gain) [5-6].

1.4 Objective

The main objective of the thesis is to design a new type of dc-dc boost converter with double input power sources to get high voltage gain and efficiency of a boost converter. This double input dc-dc boost converter gives high voltage output at low frequency (about 10 kHz) for renewable and fuel cell application. There are different type of methods to get high voltage and efficiency of a dc-dc boost converter such as interleaving, switch capacitor based, SMPS etc. In this paper it is shown that by adding more and more power sources, it is possible to get more voltage gain and high efficiency.

1.5 Layout of Thesis

This thesis consists of five chapters. Chapter-1 deals with introduction, background and objective. Chapter-2 includes DC/DC converter, basic operation principles of DC/DC converters, review of DC/DC converters, converters comparison and application of DC/DC converters. Chapter-3 contains study of boost converter and multiple input converters. Chapter-4 represents the design of a novel boost converter and the analysis of result and simulation of this designed dual input DC/DC boost converter. Chapter-5 contains conclusion and recommendation.

Chapter-2

DC-DC CONVERTERS

2.1 **Introduction**

The DC-DC converters are widely used in industrial applications and computer hardware circuits, DC-DC conversion techniques have been developed very quickly. Modern electronic systems require high-quality, small, lightweight, reliable, and efficient power supplies. Linear power regulators, whose principle of operation is based on a voltage or current divider, are inefficient [7]. This is because they are limited to output voltages smaller than the input voltage, and also their power density is low because they require low frequency (50 or 60 Hz) line transformers and filters. Linear regulators can, however, provide a very high-quality output voltage. Their main area of application is at low power levels. Electronic devices in linear regulators operate in their active (linear) modes, but at higher power levels switching regulators are used. Switching regulators use power electronic semiconductor switches in on and off states. Because there is a small power loss in those states (low voltage across a switch in the on state, zero current through a switch in the off state), switching regulators can achieve high energy conversion efficiencies.

Modern power electronic switches can operate at high frequencies. The high frequency DC-DC chopper-converters are known as switch mode power supplies (SMPS). SMPS are extensively used as power supplies of computers and electronic equipment. According to the type of voltage regulation (step-down/step-up/step-up-down) SMPS has three basic (Buck, Boost and Buck-Boost/Ĉuk/Sepic) and many derived configurations. The voltage regulation is achieved by duty cycle (D) control of the switching signal of the semiconductor switch of the SMPS [7]. In a practical SMPS, the efficiency and the voltage-gain are function of the duty cycle D. Each type of SMPS has high value of efficiency for limited range of voltage gain (within a range of duty cycle D). In case of extreme gains (either high or low), hybrid SMPS converters may be used to maintain high conversion efficiency. Hybrid SMPS converters are combination of voltage multiplier/divider circuits with appropriate SMPS circuits [8]. In this Thesis work the boost, the hybrid boost dc-dc converter with two inductors, the hybrid proposed boost converter with two inductors and the proposed hybrid boost dc-dc converter with three inductors are studied by simulation at variable duty cycles.

2.2 DC/DC Converter

The electrical circuit which converts or transfers one electrical signal at a frequency into another electrical signal at same or different frequency is called converter and the converter circuit which converts or transfers one electrical signal (DC) at a voltage into another electrical signal (DC) at different voltage is called DC/DC converter [7].

A DC converter is equivalent to an AC transformer with a continuously variable turn's ratio. Like a transformer it can be used to step down or step up a dc voltage or a current. DC conversion is of importance in applications, starting from low power to high power. For low power levels, linear regulators can provide a quality output voltage. For medium power levels, switching regulators are used. Switching regulators use power semiconductor switches in ON and OFF states. Because there is a small power loss in these states, switching regulators ideally has high efficiency [8]. A block diagram of a general dc-dc switching regulator converter is shown in Figure-2.1

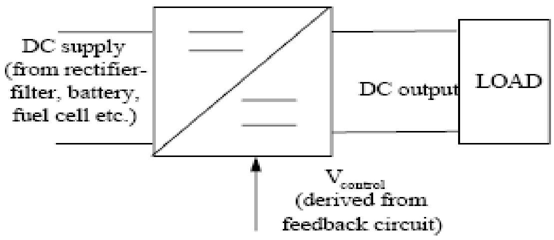


Figure-2.1: General block diagram of a dc-dc switching regulator.

2.3 Basic Operation Principle

2.3.1 Basic (one coil) type dc-dc switching regulator

With the basic type circuit, the operation is limited to either stepping up or stepping down to minimize the number of parts, and the input side and the output sides are not insulated. Figure-2.2 shows a step-up circuit and Figure-2.3 shows a step-down circuit. These circuits provide advantages such as small size, low cost and small ripples, and the demand for them is increasing in accordance with the needs for downsizing of equipment [9-12].

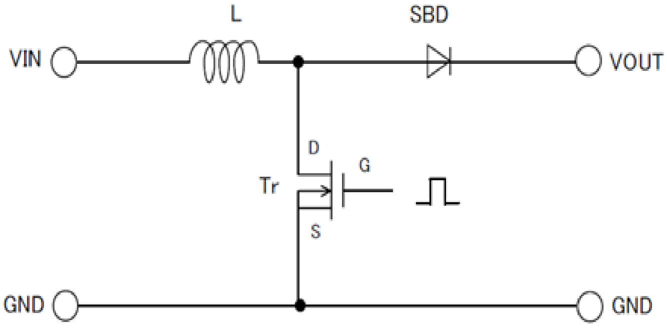


Figure-2.2: Step-up circuit

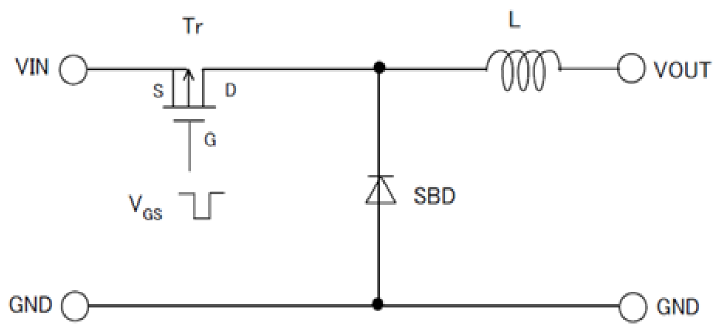


Figure-2.3: Step-down circuit

With SEPIC and Zeta, a capacitor is inserted between VIN and VOUT of the step-up circuit and the step-down circuit of the basic type, and a single coil is added. They can be configured as step-up or step-down DC/DC converters by using a step-up DC/DC controller IC and a step-down DC/DC controller IC, respectively. However, as some DC/DC controller ICs do not assume to be used with these circuit types, make sure your DC/DC controller ICs can be used with these circuit types. The capacitor coupling two-coil type has an advantage to allow insulation between VIN and VOUT. However, the increased coils and capacitors will reduce the efficiency. Especially, at the step-down time, the efficiency is substantially reduced, usually to about 70% to 80% [9-12].The charge pump type requires no coil, enabling to minimize the mounting area and height. On the other hand, this type is not liable to provide high efficiency for the applications that need a wide variety of output powers or larger currents, and is limited to applications for driving white LED or for the power supply of LCD [9-10].

The insulated type circuit is also known as the primary power supply (main power supply). This type is widely used for the AC/DC converters that generate DC power mainly from a commercially available AC source (100 to 240 VAC) or for the applications that require the insulation between the input side and the output side to eliminate noises [11-12]. With this type, the input side and the output side are separated by using a transformer, and the stepping up, stepping down, or reverse operation can be controlled by changing the turn’s ratio of the transformer and the polarity of the diode. Therefore, you can take out many power supplies from a single power circuit. If fly-back transformer is used, the circuit can be composed of a relatively small number of parts and may be used as a secondary power supply (local power supply) circuit [9-12]. Fly-back transformer, however, requires void to prevent magnetic saturation in the core, increasing its dimensions. If forward transformer is used, a large power source can be easily retrieved. This circuit, however, requires a reset circuit on the primary side to prevent magnetization of the core, increasing the number of parts. Also, the input side and the output side of the controller IC must be grounded saperately [9].

2.4 Basic Operation Principles of DC/DC Converters

The operating principles of stepping up and stepping down in DC/DC converter circuits will be described using the most basic type. Circuits of other types or those using coils may be considered composed of a combination of step-up circuit and step-down circuit or their applied circuits [13].

Figure-2.4 and Figure-2.5 illustrate the operations of a step-up circuit. Figure-2.4 shows the current flow when the FET is turned on. The broken line shows a slight leak current that will deteriorate the efficiency at the light- load time. Electric energy is accumulated in L while the FET is turned on. Figure-2.5 shows the current flow when the FET is turned off. When the FET is turned off, L tries to keep the last current value and the left edge of the coil is forcibly fixed to VIN to supply the power to increase the voltage to VOUT for step-up operation [13-15]. Therefore, if the FET is being turned on longer, much larger electric current is accumulated in L, allowing retrieval of larger power. However, if the FET is being turned on too long, the time to supply the power to the output side becomes too short, and the loss during this time is increased, deteriorating conversion efficiency [13-14]. Therefore, the maximum duty (ratio of on/off time) value is generally determined to keep an appropriate value.

With step-up operation, the current flows shown in Figure-2.4 and Figure-2.5 are repeated

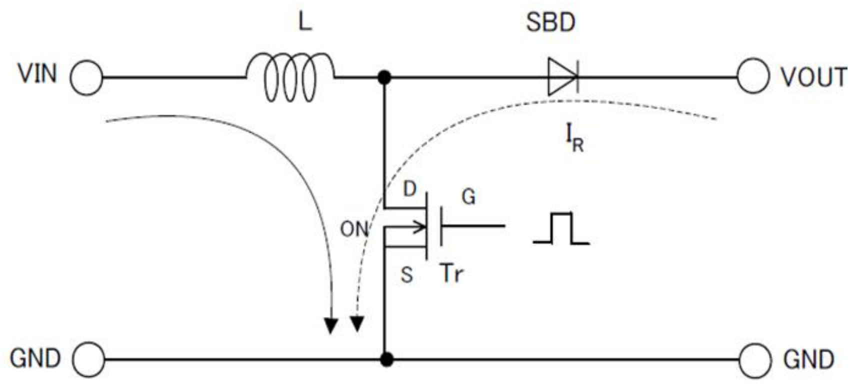


Figure-2.4: Current flow when the FET is turned ON in a Step-up circuit

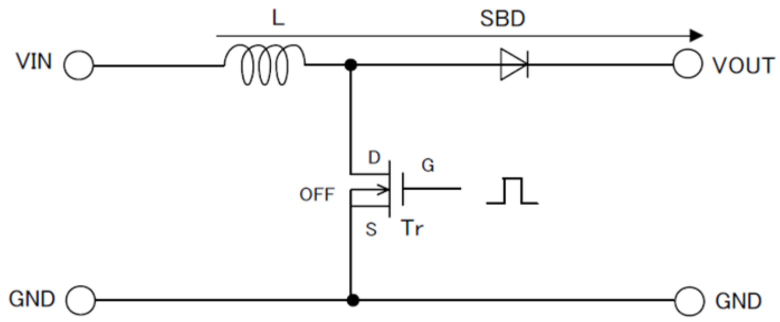


Figure-2.5: Current flow when the FET is turned OFF in a Step-up circuit

Figure-2.6 and Figure-2.7 illustrate the operations of a step-down circuit. Figure-2.6 shows the current flow when the FET is turned on. The broken line shows slight leak current that will deteriorate the efficiency at the light-load condition. Electric energy is accumulated in L while the FET is on and is supplied to the output side [13-15]. Figure-2.7 shows the current flow when the FET is turned off. When the FET is turned off, L tries to keep the last current value and turns on the SBD. At this time, the voltage at the left edge of the coil is forcibly dropped below 0V, reducing the voltage at VOUT. Therefore, if the FET is being turned on longer, much larger electric current is accumulated in L, allowing retrieval of larger power. With a step-down circuit, while the FET is being turned on, power can be supplied to the output side, and the maximum duty needs not to be determined. Therefore, if input voltage is lower than output voltage, the FET is kept on. However, as the step-up operation is disabled, the output voltage is also lowered to the input voltage level or less [13-15]

With the step-down operation, the current flows shown in Figure-2.6 and Figure-2.7 are repeated

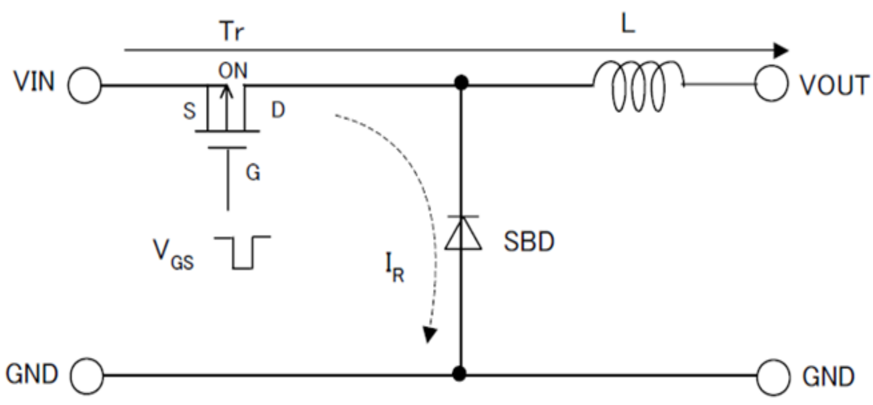


Figure-2.6: Current flow when the FET is turned ON in a Step-down circuit

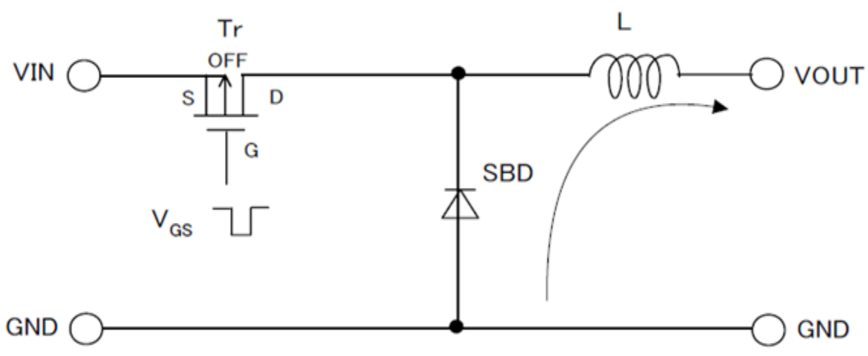


Figure-2.7: Current flow when the FET is turned OFF in a Step-down circuit

2.5 Switch Mode DC- DC Converters (SMPS)

Conventional switch mode dc-dc converters (SMPS) operate either in single quadrant or in two quadrants. A switch mode DC-DC power supply is switched at high frequency.

Conversion of both step-down and step-up dc can be accomplished with small input/output filter having facility of feedback regulation by ON/OFF switching. Usually SMPSs are used in dc-dc conversion for their light weight, high efficiency and isolated multiple outputs with or without voltage regulation. Uses of SMPS are generic in space power applications, computers, TV, biomedical equipment and industrial units etc. SMPSs have advantage of being low cost, compact, and self-regulating and self-protected [5].

A DC-DC SMPS consists of a rectifier fed dc source, a filter and a static switch. The SMPS is switched by control circuitry at a very high frequency to step-down or step-up dc voltage by ON/OFF ratio (duty cycle) control. The filter and the feedback circuit are the other components of a dc-dc SMPS. Figure-2.8 shows the block diagram of a DC-DC SMPS [5].

Main components of a dc-dc SMPS are [5]

1. Power circuit ,
2. Control circuit and
3. Magnetic circuit.

The control circuit of an SMPS generates high frequency gate pulses for the switching devices to control the dc. Switching is performed in multiple pulse width modulation (PWM) fashion according to feedback error signal from the load to serve two purposes.

1. Produce high frequency switching signal and
2. Control ON / OFF period of switching signal to maintain constant voltage across the load.

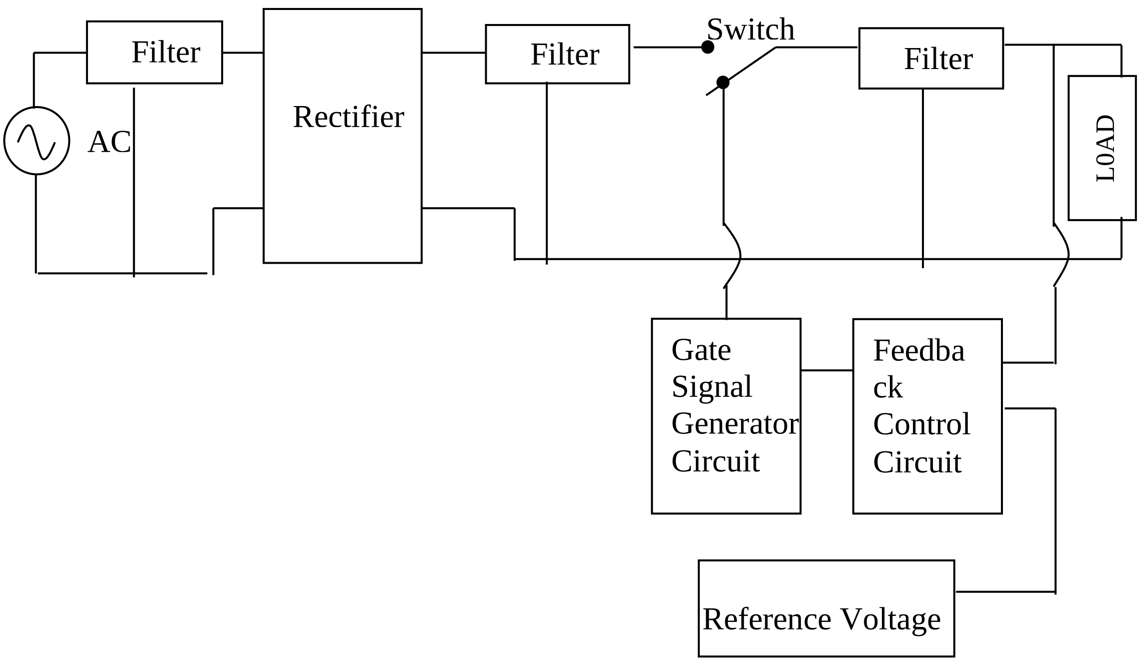


Figure-2.8: Block diagram of an SMPS

High frequency switching reduces filter requirements at the input/output sides of the converter. Simplest PWM control uses multiple pulse modulations generated by comparing a dc with a high frequency carrier triangular wave [5].

2.6 Functions of Dc-Dc Converters [16]

- Convert a DC input voltage into a DC output of same higher or lower voltage,
- Regulate the DC output voltage against load and line variations,
- Reduce the voltage ripple on the DC output voltage,
- Provide isolation between the input source and the load (if required) and
- Protect the supplied system and the input source from electromagnetic interference (EMI)

2.7 Review Of Dc-Dc Converters

There are four basic topologies of switching regulators [5]

a. Buck converter
b. Boost converter
c. Buck-Boost converter and
d. Ĉuk converter.

2.7.1 Buck Converter

In Buck converters, output voltage is regulated and is less than the input voltage, hence the name "Buck". The circuit diagram is shown in Figure-2.9, the circuit operations can be divided into two modes. Mode-1 (Figure-2.9.a) begins when transistor Q_1 is switched on at t = 0. The input current rises and flows through inductor L, capacitor C and load resistor R [5]. Mode-2 (Figure-2.9.b) begins when transistor Q_1 is switched off at t = t_1. The freewheeling diode D_m conducts due to energy stored in the inductor and the inductor current continuous to flow through L, C, load, and diode D_m. The inductor current falls until transistor is switched on again in the next cycle [7-8].

The voltage across the inductor L, is in general

$$e_L = L\frac{di}{dt} \tag{2.1}$$

Assuming that the inductor current rises linearly from I_1 to I_2 in time t_1

$$V_s - V_a = L\frac{I_2 - I_1}{t_1} = L\frac{\Delta I}{t_1} \tag{2.2}$$

or

$$t_1 = \frac{L\Delta I}{V_s - V_a} \tag{2.3}$$

And the inductor current falls linearly from I_2 to I_1 in time t_2

$$-V_a = L\frac{\Delta I}{t_2} \quad (2.4)$$

or

$$t_2 = \frac{\Delta IL}{V_a} \quad (2.5)$$

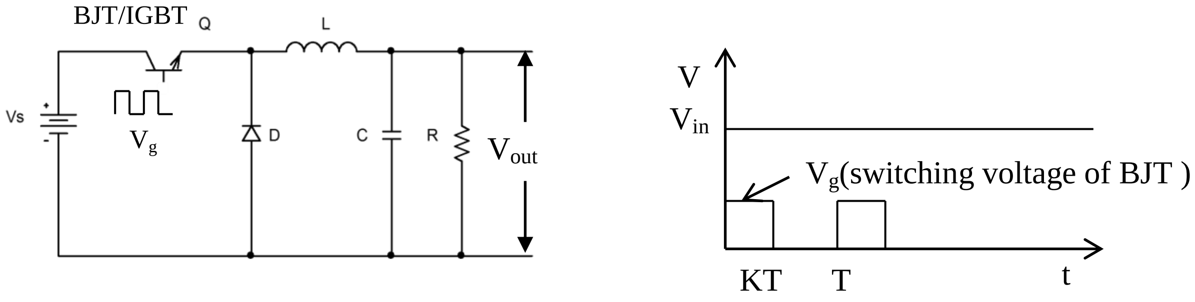


Figure-2.9: DC-DC Buck Converter

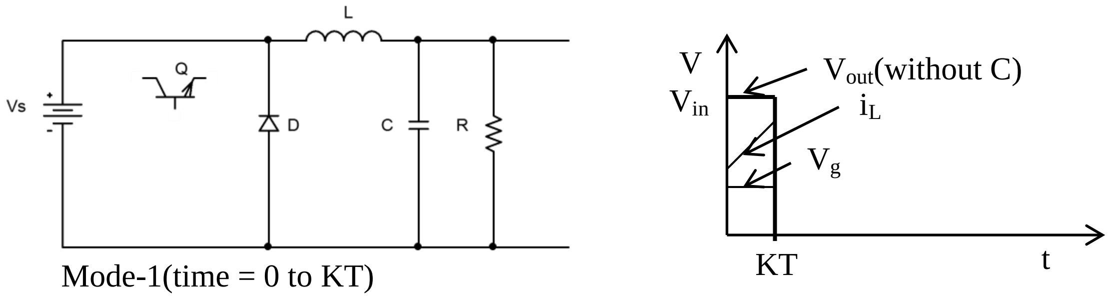


Figure-2.9.a: DC-DC Buck Converter Equivalent circuit

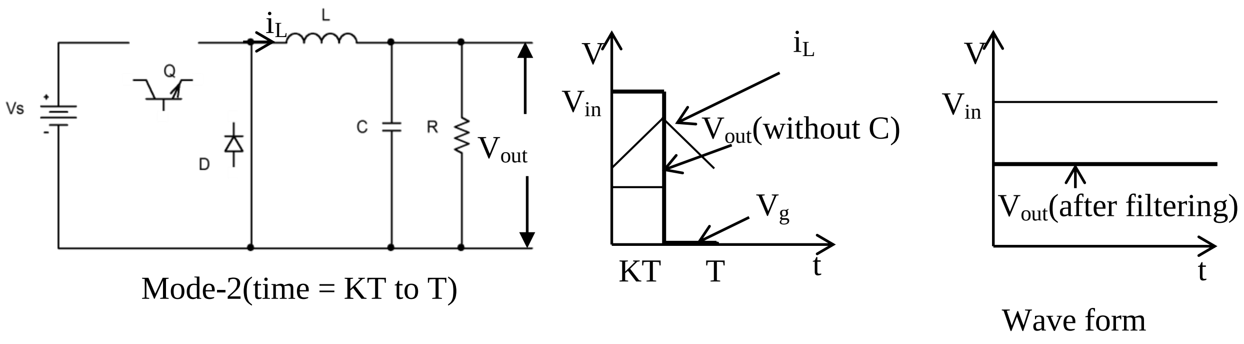


Figure-2.9.b: DC-DC Buck Converter Equivalent circuits with continuous i_L.

Where $\Delta I = I_2 - I_1$ is the peak to peak ripple current of the inductor L. Equating the value of ΔI in equations-(2.2) and (2.4) we get

$$\Delta I = \frac{(V_s - V_a)t_1}{L} = \frac{V_a t_2}{L} \quad (2.6)$$

Substituting t_1 = KT and t_2 = (1-K)T yields the average output voltage as

$$V_a=V_s\frac{t_1}{T}=KV_s \tag{2.7}$$

From equation-(2.7) it is seen that output voltage V_a is less than the input voltage V_s since K is less than 1.

The ideal voltage gain, current gain and efficiency relationships of this converter are

$$\frac{V_0}{V_{in}}=D \tag{2.8}$$

$$\frac{I_0}{I_{in}}=\frac{1}{D} \tag{2.9}$$

$$\eta=1 \tag{2.10}$$

Where, D is the duty cycle of the gate/base pulse that controls the voltage and current gain of the converter. $D=T_{on}/T$, on time to period ratio of the gate /base pulse of the switch used to the buck converter [7-8].

2.7.2 Boost Converter

In Boost converters, the output voltage is greater than the input voltage, hence the name "Boost". The circuit diagram is shown in Figure-2.10, the circuit operations can be divided into two modes. Mode-1 (Figure-2.10.a) begins when transistor Q_1 is switched on at t = 0 [8]. The input current rises and flows through inductor L and transistor Q_1. Mode-2 (Figure-2.10.b) begins when transistor Q_1 is switched off at t = t_1. The current which was flowing through the transistor would now flow through L, C, load and diode D_m. The inductor current falls until transistor Q_1 is turned on again in the next cycle. The energy stored in inductor L is transferred to the load [7].

Assuming that the inductor current rises linearly from I_1 to I_2 in time t_1

$$V_s = L\frac{I_2-I_1}{t_1} = L\frac{\Delta I}{t_1} \tag{2.11}$$

or

$$t_1 = \frac{L\Delta I}{V_s} \tag{2.12}$$

And the inductor current falls linearly from I_2 to I_1 in time t_2

$$V_s-V_a = -L\frac{\Delta I}{t_2} \tag{2.13}$$

or

$$t_2 = \frac{\Delta IL}{V_a - V_s} \quad (2.14)$$

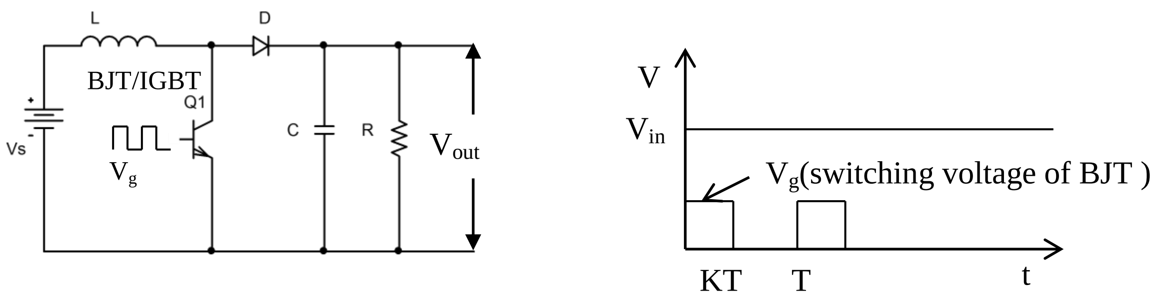


Figure-2.10: DC-DC Boost Converter Circuit diagram

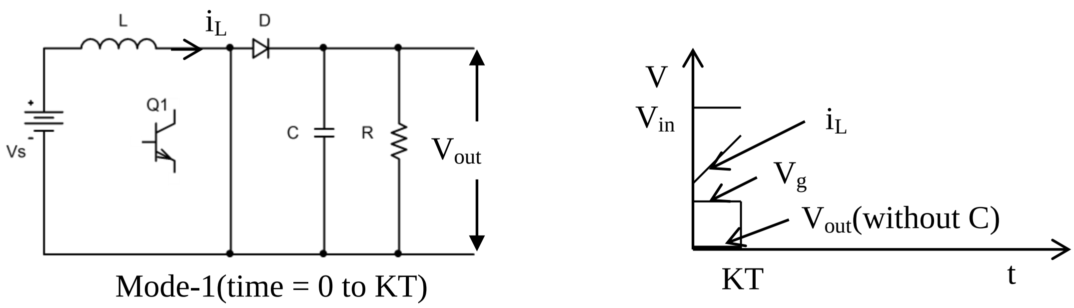


Figure-2.10.a: DC-DC Boost Converter Equivalent circuit

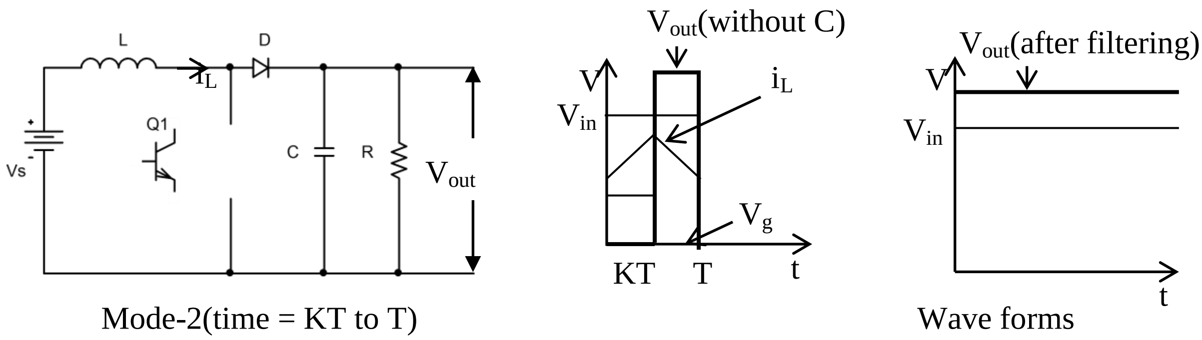


Figure-2.10.b: DC-DC Boost Converter Equivalent circuit with continuous i_L.

Where $\Delta I = I_2 - I_1$ is the peak to peak ripple current of the inductor L. From equations-(2.11) and (2.13) we get

$$\Delta I = \frac{V_s t_1}{L} = \frac{(V_a - V_s)t_2}{L} \quad (2.15)$$

Substituting t_1 = KT and t_2 = (1-K)T yields the average output voltage

$$V_a = V_s \frac{T}{t_2} = \frac{V_s}{1 - K} \quad (2.16)$$

From equation-(2.16) it is seen that output V_a is greater than the input V_s since K is less than 1. The ideal voltage gain, current gain and efficiency relationships of this converter are

$$\frac{V_0}{V_{in}} = \frac{1}{1 - D} \quad (2.17)$$

$$\frac{I_0}{I_{in}} = (1 - D) \quad (2.18)$$

$$\eta = 1 \quad (2.19)$$

Where, D is the duty cycle of the gate/base pulse that controls the voltage and current gain of the converter. $D = T_{on}/T$, on time to period ratio of the gate /base pulse of the switch used to the boost converter [5, 7-8].

2.7.3 Buck- Boost Converter

Buck converters can step-down and boost converters can step-up dc voltages individually. The Buck-Boost converter in which the inductor is grounded can perform either of these two conversions. The output voltage polarity is opposite to input voltage and as a result the converter is also known as an *inverting* converter [5, 7-8].

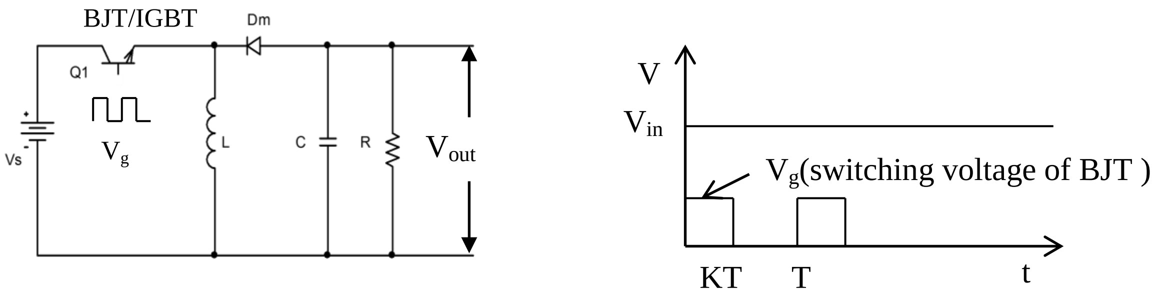
Operation of the Buck-Boost converter can be explained with the help of Figure-2.11. During mode-1 (Figure-2.11.a) transistor Q_1 is turned on and diode D_m is reversed biased. The input current which rises flows through inductor L and transistor Q_1. During mode-2 (Figure-2.11.b) transistor Q_1 is switched off and the current, which was flowing through inductor L, would flow through L, C, D_m and the load. The energy stored in inductor L would be transferred to the load and the inductor current would fall until transistor Q_1 is switched on again in the next cycle.

Assuming that the inductor current rises linearly from I_1 to I_2 in time t_1

$$V_s = L \frac{I_2 - I_1}{t_1} = L \frac{\Delta I}{t_1} \quad (2.20)$$

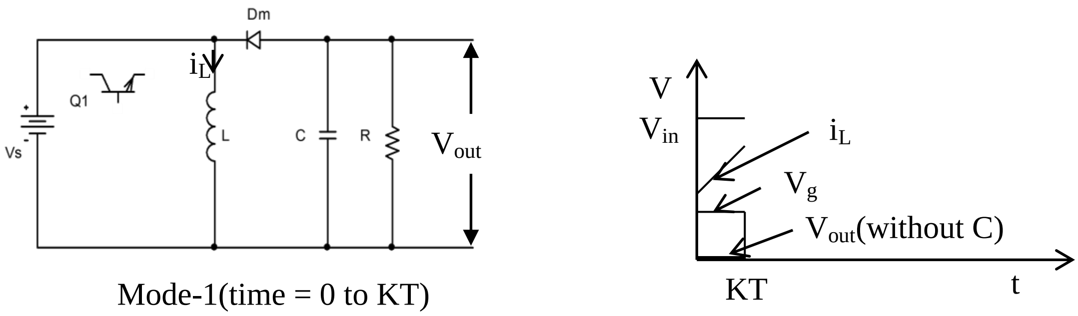
or

$$t_1 = \frac{L \Delta I}{V_s} \quad (2.22)$$



(a) Circuit diagram

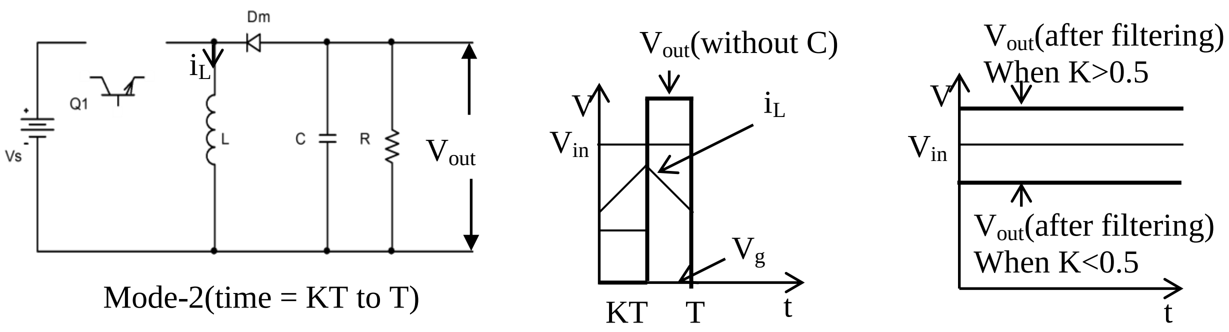
Figure-2.11: Buck-Boost Converter circuit



Mode-1(time = 0 to KT)

(b) Equivalent circuits

Figure-2.11.a: Buck-Boost Converter circuit with continuous i_L



Mode-2(time = KT to T)

(c) Equivalent circuits

(d) Wave forms

Figure-2.11.b: Buck-Boost Converter circuit with continuous i_L

And the inductor current falls linearly from I_2 to I_1 in time t_2

$$V_a = -L\frac{\Delta I}{t_2} \tag{2.22}$$

or

$$t_2 = \frac{-\Delta IL}{V_a} \tag{2.23}$$

Where $\Delta I = I_2 - I_1$ is the peak to peak ripple current of the inductor L. From equations- (2.20) and (2.22) we get

$$\Delta I = \frac{V_s t_1}{L} = \frac{-V_a t_2}{L} \tag{2.24}$$

Substituting t_1 = KT and t_2 = (1-K)T yields the average output voltage,

$$V_a = \frac{-V_s K}{1-K} \tag{2.25}$$

From equation-(2.25) it is seen that output V_a is greater than input V_s, when K is greater than 0.5 and output V_a is less than input V_s, when K is less than 0.5 [5].

The ideal voltage gain, current gain and efficiency relationships of this converter are

$$\frac{V_0}{V_{in}} = -\frac{D}{1-D} \tag{2.26}$$

$$\frac{I_0}{I_{in}} = \frac{1-D}{D} \tag{2.27}$$

$$\eta = 1 \tag{2.28}$$

Where, D is the duty cycle of the gate/base pulse that controls the voltage and current gain of the converter. $D = T_{on}/T$, on time to period ratio of the gate /base pulse of the switch used to the Buck Boost converter [7-8].

2.7.4 Ĉuk Converter

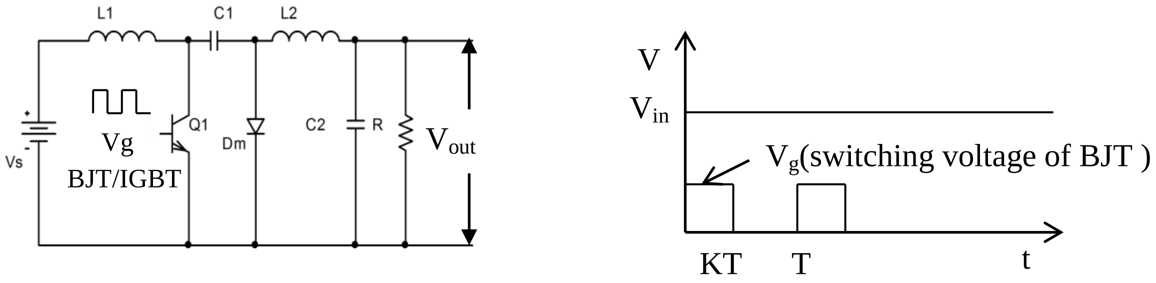
It is the modified form of Buck-Boost converter having the capability to regulate input voltage in both buck and boost way. The operation can be explained with the help of Figure-2.12. Mode-1 (Figure-2.12.a) begins when transistor Q_1 is turned on at t = 0. The current through inductor L_1 rises. At the same time, the voltage of the capacitor C_1 reverse biases diode D_m and turns it off. The capacitor discharges its energy to the circuit formed by C_1, C_2, load and L_2. Mode-2 (Figure-2.12.b) begins when transistor Q_1 is turned off at t = t_1 [5, 7-8]. The capacitor C_1 is charged from input supply and the energy stored in the inductor L_2 is transferred to the load. The diode D_m and transistor Q_1 provide a synchronous switching action. The capacitor C_1 is the media for transferring energy from the source to the load [5, 7-8].

Assuming that the current of inductor L_1 rises linearly from I_{L11} to I_{L12} in time t_1

$$V_s = L_1 \frac{I_{L12} - I_{L11}}{t_1} = L_1 \frac{\Delta I_1}{t_1} \tag{2.29}$$

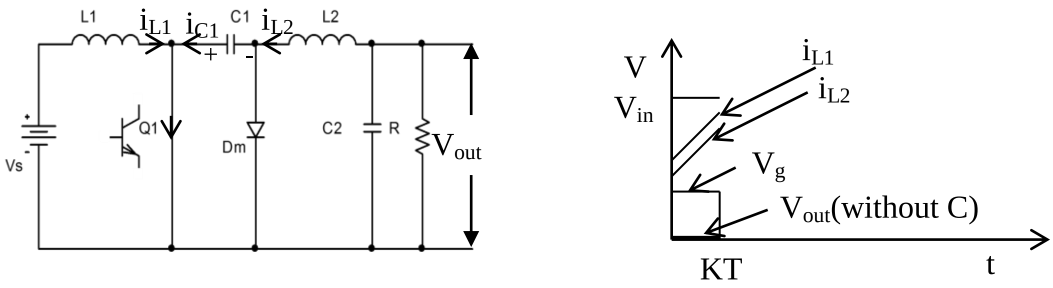
or

$$t_1 = \frac{L_1 \Delta I_1}{V_s} \tag{2.30}$$



(a) Circuit diagram

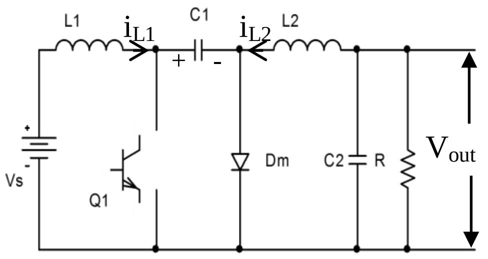
Figure-2.12: Ĉuk Converter circuit



Mode-1(time=0 to KT)

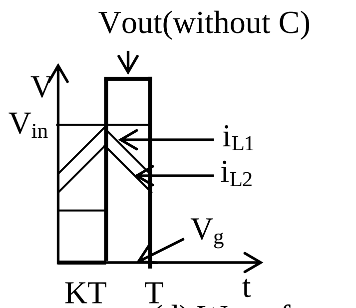
(b) Equivalent circuits

Figure-2.12.a: Ĉuk Converter circuit with continuous i_L



Mode-2(time=KT to T)

(c) Equivalent circuits



(d) Wave forms

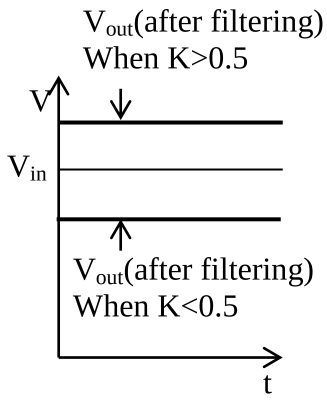


Figure-2.12.b: Ĉuk Converter circuit with continuous i_L

And due to the charged capacitor C_1, the inductor L_1 current falls linearly from I_{L12} to I_{L11} in time t_2

$$V_s - V_{c1} = -L_1 \frac{\Delta I_1}{t_2} \tag{2.31}$$

or

$$t_2 = \frac{-\Delta I_1 L_1}{V_s - V_{c1}} \tag{2.32}$$

Where V_{c1} is the average voltage of capacitor C_1 and $\Delta I_1 = I_{L12} - I_{L11}$ is the peak to peak ripple current of the inductor L_1. From equations-(2.30) and (2.31)

$$\Delta I_1 = \frac{V_s t_1}{L_1} = \frac{-(V_s - V_{c1})t_2}{L_1} \tag{2.33}$$

Substituting t_1 = KT and t_2 = (1-K)T yields the average voltage of capacitor C_1 is V_{c1}

$$V_{c1} = \frac{V_s}{1-K} \tag{2.34}$$

Assuming that the current of inductor L_2 rises linearly from I_{L21} to I_{L22} in time t_1

$$V_{c1} + V_a = L_2 \frac{I_{L22} - I_{L21}}{t_1} = L_2 \frac{\Delta I_2}{t_1} \tag{2.35}$$

or

$$t_1 = \frac{L_2 \Delta I_2}{V_{c1} + V_a} \tag{2.36}$$

And the current of inductor L_2 falls linearly from I_{L22} to I_{L21} in time t_2

$$V_a = -L_2 \frac{\Delta I_2}{t_2} \tag{2.37}$$

or

$$t_2 = \frac{-\Delta I_2 L_2}{V_a} \tag{2.38}$$

$\Delta I_2 = I_{L22} - I_{L21}$ is the peak to peak ripple current of the inductor L_2. From equations-(2.35) and (2.37)

$$\Delta I_2 = \frac{-V_a t_2}{L_2} = \frac{(V_{c1} + V_a)t_1}{L_2} \tag{2.39}$$

Substituting t_1 = KT and t_2 = (1-K)T yields the average voltage of capacitor C_1 is V_{c1}

$$V_{c1} = \frac{-V_a}{K} \tag{2.40}$$

Equating equations-(2.34) and (2.40) we can find the average output voltage as

$$V_a = \frac{-KV_S}{1-K} \tag{2.41}$$

From equation-(2.41) it is seen that output V_a is greater than input V_s, when K is greater than 0.5 and output V_a is less than input V_s, when K is less than 0.5 [5, 7-8].
The ideal voltage gain, current gain and efficiency relationships of this converter are

$$\frac{V_0}{V_{in}} = -\frac{D}{1-D} \tag{2.42}$$

$$\frac{I_0}{I_{in}} = \frac{(1-D)}{D} \tag{2.43}$$

$$\eta = 1 \tag{2.44}$$

Where, D is the duty cycle of the gate/base pulse that controls the voltage and current gain of the converter. $D=T_{ON}/T$, on time to period ratio of the gate /base pulse of the switch used to the ĈuK converter.

2.8 Converter Comparison

The voltage ratios achievable by the DC-DC converters are summarized in Figure-2.13. Notice that only the buck converter shows a linear relationship between the control (duty ratio) and output voltage. The buck-boost can reduce or increase the voltage ratio with unit gain for a duty ratio of 50% [5, 17].

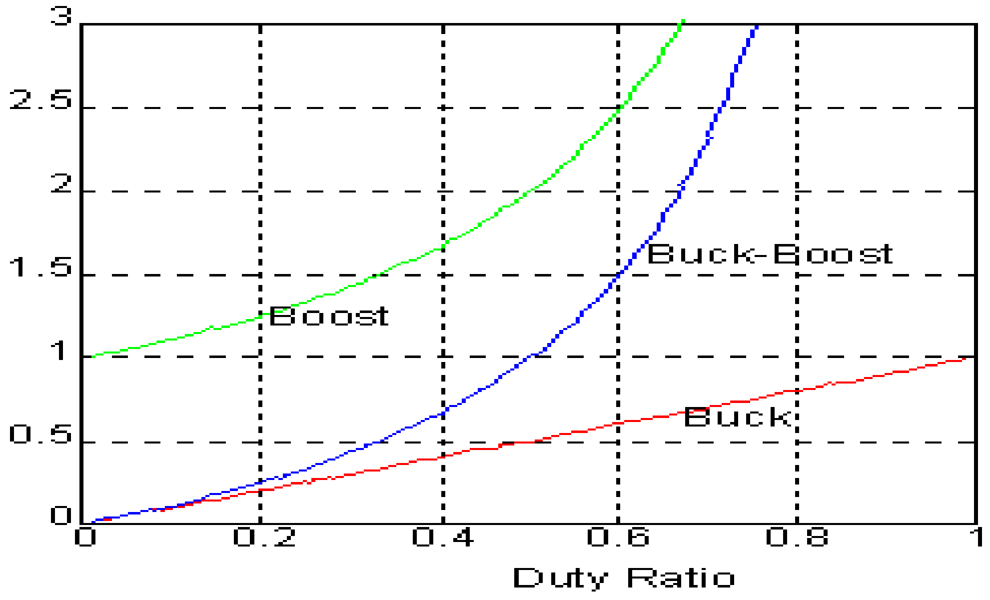


Figure-2.13: Comparison of voltage ratio

2.9 Applications of DC-DC Converters

Step-down choppers find most of their applications in high performance dc drive systems, for example, electric traction, electric vehicles, and machine tools. The dc motors with their winding inductances and mechanical inertia act as filters resulting in high-quality armature currents. The average output voltage of step-down choppers is a linear function of the switch duty ratio. Step-up choppers are used primarily in radar and ignition systems. The dc choppers can be modified for two-quadrant and four-quadrant operation [8]. Two-quadrant choppers may be a part of autonomous power supply systems that contain battery packs and such renewable dc sources as photo-voltaic arrays, fuel cells, or wind turbines. Four-quadrant choppers are applied in drives in which regenerative breaking of dc motors is desired, for example, transportation systems with frequent stops. The dc choppers with inductive outputs serve as inputs to current-driven inverters. The addition of filtering reactive components to dc choppers results in PWM dc-dc converters [8]. The dc-dc converters can be viewed as dc transformers that deliver to the load a dc voltage or current at a different level than the input source. This dc transformation is performed by electronic switching means, not by electromagnetic means such as in conventional transformers. The output voltages of dc-dc converters range from one volt for special VLSI circuits to tens of kilovolts in X-ray lamps. The most common output voltages are: 3.3 V for modern microprocessors; 5 and 12 V for logic circuits; 48 V for telecommunication equipment; and 270 V for main dc bus on airplanes. Typical input voltages include 48 V, 170 V (the peak value of a 120-V_{rms} line), and 270 V. Selection of a topology of dc-dc converters is determined not only by input=output voltages, which can be additionally adjusted with the turns ratio in isolated converters, but also by power levels, voltage and current stresses of semiconductor switches, and utilization of magnetic components [8]. The low-part-count fly-back converter is popular in low power applications (up to 200W). Its main deficiencies are a large size of the fly-back transformer core and high voltage stress on the semiconductor switch. The forward converter is also a single switch converter. Because its core size requirements are smaller, it is popular in low-medium- (up to several hundreds of watts) power applications. Disadvantages of the forward converter are the need for demagnetizing winding, and a high voltage stress on the semiconductor switch. The push-pull converter is also used at medium-power levels. Due to bidirectional excitation, the transformer size is small [8]. An advantage of the push-pull converter is also a possibility to refer driving terminals of both switches to the ground, which greatly simplifies the control circuitry. A disadvantage of the push-pull converter is potential core saturation in the case of symmetry. The half-bridge converter has a similar range of applications as the push-pull converter. There is no danger of transformer saturation in the half-bridge converter. It requires, however, two additional input capacitors to split in half input dc source. The full-bridge converter is used at high (several kilowatts) power and voltage levels. The voltage stress on power switches is limited to the input voltage source value. A disadvantage of the full-bridge converter is a high number of semiconductor devices [8]. The dc-dc converters are building blocks of distributed power supply systems in which a common dc bus voltage is converted to various other voltages according to requirements of particular loads. Such distributed dc systems are common in space stations, ships and airplanes, as well as in computer and telecommunication equipment. It is expected that modern portable wireless communication and signal processing systems will use variable supply voltages to minimize power consumption and to extend battery life. Low-output voltage converters in these applications utilize the synchronous rectification arrangement. Another major area of dc-dc converter applications is related to the utility ac grid. For critical loads, if the utility grid fails, there must be a backup source of energy, for example, a battery pack. This need for continuous power delivery gave rise to various types of uninterruptible power supplies (UPSs). Thus dc-dc converters are used in UPSs to adjust the level of a rectified grid voltage to that of the backup source. Because during normal operation the energy flows from the grid to the backup source and during emergency conditions the backup source must supply the load, bidirectional dc-dc converters are often used. Moreover dc-dc converters are also used in dedicated battery chargers. Power electronic loads, especially those with front-end rectifiers, pollute the ac grid with odd harmonics. Thus dc-dc converters are used as intermediate stages, just after a rectifier and before the load-supplying dc-dc converter, for shaping the input ac current to improve power factor and decrease the harmonic content. The boost converter is especially popular in such power factor correction (PFC) applications. Another utility grid-related application of dc-dc converters is in interfaces between ac networks and dc renewable energy sources such as fuel cells and photovoltaic arrays. In isolated dc-dc converters, multiple outputs are possible with additional secondary windings of transformers. Only one output is regulated with a feedback loop, but other outputs depend on the duty ratio of the regulated one and on their loads. A multiple-output dc-dc converter is a convenient solution in applications where there is a need for one closely regulated output voltage and for one or more other noncritical output voltage levels [8].

2.10 Application in Renewable systems

Renewable energy systems offer clean power and independence from fossil fuel, since the product of the chemical reaction in fuel cells is H_2O when H_2 is used as fuel; therefore, the fuel cells are environmentally cleaner than traditional generators. Nowadays, the main energy generation is based on concentrated high power plants; in the future, a diverse and disperse generation will become a major energy source. According to these scenarios, the increase in world energy demand will be supplied by renewable energy technologies, which will provide 30% - 50% of world energy by 2050 [18-19]. This scenario makes multilevel topologies ideal for renewable energy generation systems. Some applications have been developed; the major ones related with multilevel converters based renewable systems that use the renewable source in the optimum operating point and the DC-Link voltage balance. Renewable systems are often made by a dc-dc converter that can track the maximum power operating point, and an inverter to deliver the active power into the utility. It is known that for applications on active power transfer, such as motor drives, or renewable applications, conventional multilevel topologies require either isolated dc power sources, or a complicated voltage balancing circuit and control to support and maintain each voltage level, and they are neither operable nor complete for active power conversion because they depend on outside circuits for voltage balancing [18-19]. The multilevel configuration makes it possible to utilize low voltage MOSFETs, which have extremely low on-resistance and are low cost, because of large production volume for switching power supplies used in communications and computer industries. These low cost-size switches proportionate the possibility of integrating inverters in a small space and make renewable systems inverters compact and cheap. The challenge is to link the DC renewable energy source with a DC-AC multilevel inverter. Such links should be balanced, and is highly desirable to be self-balancing to avoid complex control strategy. It also requires a high boost ratio, which is a challenge for transformer-less DC-DC converters, although for utility connected renewable applications the boost ratio can be larger than five. For multilevel inverters based renewable applications, it is highly desirable to design a DC-DC converter to overcome such challenges, and connect an N-level multilevel inverter to the utility with a high boost ratio, self-balanced voltage, and unidirectional current. The DC-DC converters proposed in this paper overcome such difficulties. This paper proposes a new DC-DC converter, named *Multilevel Boost Converter* (MBC), based on one inductor, one switch, 2N-1 diodes and 2N-1 capacitor for N levels. It is a boost converter PWM controlled and able to maintain the same voltage in all N output levels and able to control the input current. This converter is based on the multilevel converters principle; and it is proposed to be used as DC-link in applications where several voltage levels are needed with self-balancing and unidirectional current flow, such as photovoltaic (PV) or fuel cell generation systems with multilevel inverters. Used to feed a multilevel inverter, the proposed topologies achieve a self-balanced voltage. Experimental results in a low power prototype are exhibited [18-19].

Chapter-3

Study of Boost converter

3.1 Boost converter

A boost converter (step-up converter) as shown in figure-3.1 is a DC-to-DC power converter with an output voltage greater than its input voltage. It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple [3].

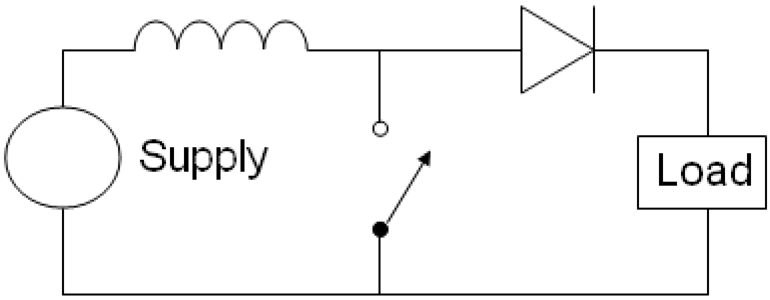


Figure-3.1: The basic schematic of a boost converter. The switch is typically a MOSFET, IGBT, or BJT.

3.1.1 Overview of Boost converter

Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. 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 [3].

3.1.2 Background of DC/DC boost converter

For high efficiency, the SMPS switch must turn on and off quickly and have low losses. The advent of a commercial semiconductor switch in the 1950s represented a major milestone that made SMPSs such as the boost converter possible. The major DC to DC converters were developed in the early 1960s when semiconductor switches had become available. The aerospace industry's need for small, lightweight, and efficient power converters led to the converter's rapid development. Switched systems such as SMPS are a challenge to design since its model depends on whether a switch is opened or closed. R. D. Middle brook from Caltech in 1977 published the models for DC to DC converters used today. Middle brook averaged the circuit configurations for each switch state in a technique called state-space averaging. This simplification reduced two systems into one. The new model led to insightful design equations which helped SMPS growth [3, 16].

3.1.3 Operating principle of boost converter

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost power stage is shown in figure-3.2 [3, 16].

(a) When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive [3].

(b) When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current flow towards the load. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result two sources will be in series causing a higher voltage to charge the capacitor through the diode D [3, 16].

If the switch is cycled fast enough, the inductor will not discharge fully in between charging stages, and the load will always see a voltage greater than that of the input source alone when the switch is opened. Also while the switch is opened, the capacitor in parallel with the load is charged to this combined voltage. When the switch is then closed and the right hand side is shorted out from the left hand side, the capacitor is therefore able to provide the voltage and energy to the load. During this time, the blocking diode prevents the capacitor from discharging through the switch [3]. The switch must of course be opened again fast enough to prevent the capacitor from discharging too much.

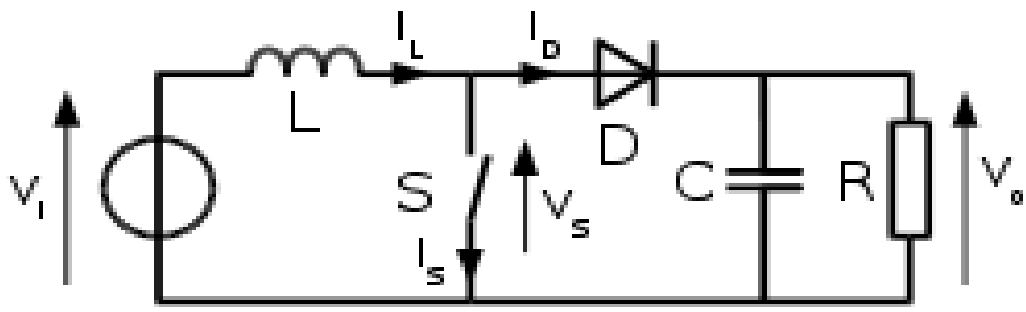


Figure-3.2: Schematic of a boost converter

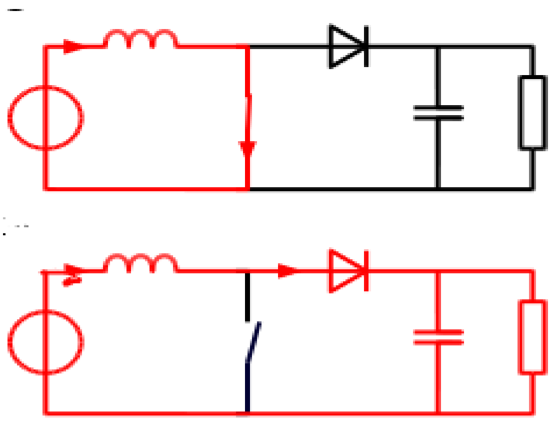


Figure-3.2.a: The two configurations of a boost converter, depending on the state of the switch S.

The basic principle of a Boost converter consists of 2 distinct states (shown in figure-3.2.a). In the On-state, the switch S (shown in figure-3.2) is closed, resulting in an increase in the inductor current; in the Off-state, the switch is open and the only path offered to inductor current is through the fly back diode D, the capacitor C and the load R. These results in transferring the energy accumulated during the On-state into the capacitor [3, 16].
The input current is the same as the inductor current as can be seen in figure-3.3. So it is not discontinuous as in the buck converter and the requirements on the input filter are relaxed compared to a buck converter [3, 16].

3.1.4 Continuous mode

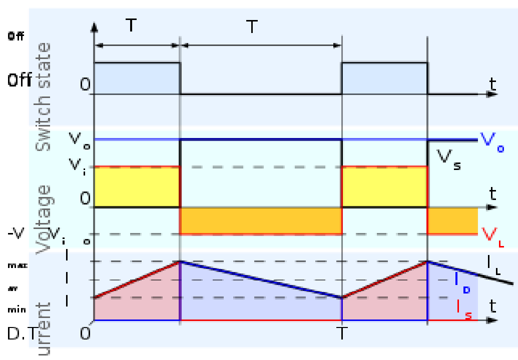


Figure-3.3: Waveforms of current and voltage in a boost converter operating in continuous mode.

When a boost converter operates in continuous mode, the current through the inductor (I_L) never falls to zero. Figure-3.3 shows the typical waveforms of currents and voltages in a converter operating in this mode. The output voltage can be calculated as follows, in the case of an ideal converter (i.e. using components with an ideal behavior) operating in steady conditions [3, 20]

During the On-state, the switch S is closed, which makes the input voltage (V_i) appear across the inductor, which causes a change in current (I_L) flowing through the inductor during a time period (t) by the formula

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L} \quad (3.1)$$

At the end of the On-state, the increase of I_L is therefore

$$\Delta I_{L_{On}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L} V_i \quad (3.2)$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is on. Therefore D ranges between 0 (S is never on) and 1 (S is always on) [3, 20].
During the Off-state, the switch S is open, so the inductor current flows through the load. If we consider zero voltage drops in the diode, and a capacitor large enough for its voltage to remain constant, the evolution of I_L i

$$V_i - V_o = L\frac{dI_L}{dt} \quad (3.3)$$

Therefore, the variation of I_L during the Off-period is

$$\Delta I_{L_{Off}} = \int_{DT}^{T} \frac{(V_i - V_o)\, dt}{L} = \frac{(V_i - V_o)(1-D)\,T}{L} \quad (3.4)$$

As we consider that the converter operates in steady-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in the inductor is given by

$$E = \frac{1}{2} L I_L^2 \quad (3.5)$$

So, the inductor current has to be the same at the start and end of the commutation cycle. This means the overall change in the current (the sum of the changes) is zero

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = 0 \quad (3.6)$$

Substituting $\Delta I_{L_{On}}$ and $\Delta I_{L_{Off}}$ by their expressions yields

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = \frac{V_i DT}{L} + \frac{(V_i - V_o)(1-D)\,T}{L} = 0 \quad (3.7)$$

This can be written as

$$\frac{V_o}{V_i} = \frac{1}{1-D} \quad (3.8)$$

Which in turn reveals the duty cycle to be

$$D = 1 - \frac{V_i}{V_o} \tag{3.9}$$

The above expression shows that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a step-up converter [3, 20].

3.1.5 Discontinuous mode

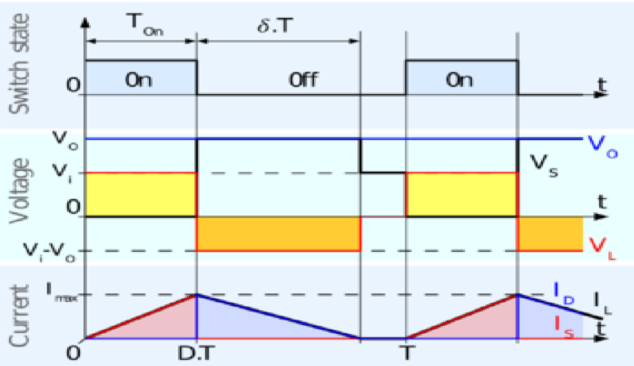


Figure-3.4: Waveforms of current and voltage in a boost converter operating in discontinuous mode

If the ripple amplitude of the current is too high, the inductor may be completely discharged before the end of a whole commutation cycle. This commonly occurs under light loads. In this case, the current through the inductor falls to zero during part of the period (waveforms shown in figure-3.4). Although slight, the difference has a strong effect on the output voltage equation. It can be calculated as follows [3, 20]

As the inductor current at the beginning of the cycle is zero, its maximum value $I_{L_{Max}}$ (at $t = DT$) is

$$I_{L_{Max}} = \frac{V_i DT}{L} \tag{3.10}$$

During the off-period, I_L falls to zero after δT

$$I_{L_{Max}} + \frac{(V_i - V_o)\,\delta T}{L} = 0 \tag{3.11}$$

Using the two previous equations, δ is

$$\delta = \frac{V_i D}{V_o - V_i} \tag{3.12}$$

The load current I_o is equal to the average diode current (I_D). As can be seen on figure 4, the diode current is equal to the inductor current during the off-state. Therefore the output current can be written as

$$I_o = \bar{I_D} = \frac{I_{L_{max}}}{2}\delta \tag{3.13}$$

Replacing I_{Lmax} and δ by their respective expressions yields

$$I_o = \frac{V_i DT}{2L} \cdot \frac{V_i D}{V_o - V_i} = \frac{V_i^2 D^2 T}{2L\,(V_o - V_i)} \tag{3.14}$$

Therefore, the output voltage gain can be written as follows

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2LI_o} \tag{3.15}$$

Compared to the expression of the output voltage for the continuous mode, this expression is much more complicated. Furthermore, in discontinuous operation, the output voltage gain not only depends on the duty cycle, but also on the inductor value, the input voltage, the switching frequency, and the output current [3, 20].

3.1.5 Advantages of Boost Converter [3, 8]

- Gives the high output voltage
- Low operating duty cycles
- Lower voltage on MOSFET
- Output voltage with low distortion
- Good quality of wave forms even the line frequency is present

3.1.6 Applications of Boost Converter [3, 8]

- Automotive applications
- Power amplifier applications
- Adaptive control applications
- Battery power systems
- Consumer Electronics
- Communication Applications Battery Charging circuits
- In heaters and welders
- DC motor drives
- Power factor correction circuits
- Distributed power architecture systems

3.2 Study of different types boost converter

3.2.1 Charge pump (charge capacitor based) DC/DC boost converter

Charge pumps, also known as inductor-less DC/DC converters, are a special class of switching DC/DC converters that use capacitors as energy storage elements. When compared to "inductive" switching DC/DC converters, which use inductors as energy storage elements, charge pumps offer unique characteristics that make them attractive for certain end-user applications[21-22].

One of the simplest and most commonly used charge-pump architectures is that of doubling. The doubling charge-pump architecture includes four switches, external energy storage and transfer capacitor commonly known as the "flying capacitor," and an external output capacitor commonly known as the "reservoir capacitor."

Figure-3.5 illustrates the doubling charge pump architecture. This architecture's operation consists of two phases-charging (energy storage) and discharging (energy transfer) [21-22].

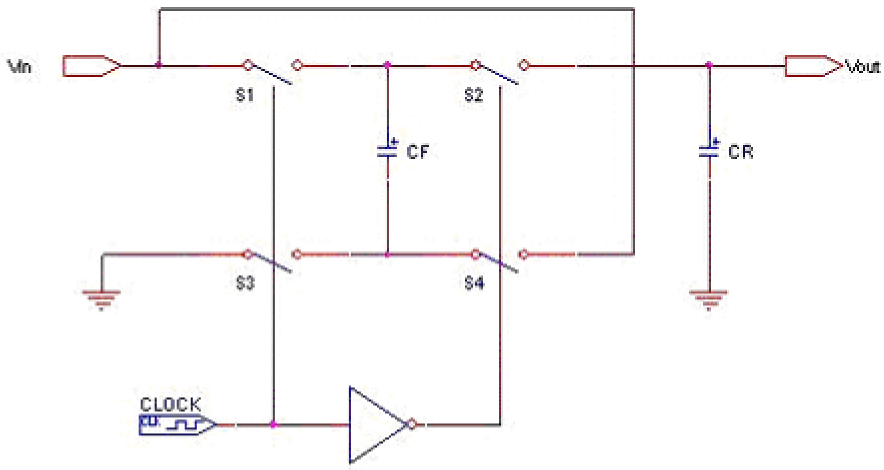


Figure-3.5: An unregulated, doubling charge pump

During the charging phase, switches S_1/S_3 are closed (switch on) and S_2/S_4 are open (switch off). The flying capacitor, C_F, charges to the input voltage, V_{IN}, and stores energy that will be transferred during the next discharging phase [21]. The reservoir capacitor, C_R, having been charged to $2V_{IN}$ with energy transferred from C_F during the previous discharging phase, supplies the load current.

During the discharge phase, switches S_1/S_3 are open and switches S_2/S_4 are closed. C_F is now level-shifted by V_{IN}, and since C_F has already been charged to V_{IN} during the previous charging phase, the total voltage across C_R is now $2V_{IN}$ (hence, the name "doubling" charge pump). C_F then discharges to transfer energy stored during the charging phase to C_R, as well as supply the load current [22].

The frequency of the charge/discharge cycle is determined by the frequency of the clock. It is a common practice to use a higher-frequency clock to reduce the capacitance, and hence the size, of both the flying and reservoir capacitors [21].

The output voltage of the simple doubling charge pump in Figure-3.5 is not regulated, as it changes according to the input voltage and load. This is not desirable for applications that require a source with regulated output voltage. However, the addition of a simple feedback loop easily overcomes this. Figure-3.6 illustrates a very simple doubling charge pump with a regulated output, frequently called a "regulated charge pump" [21-22].

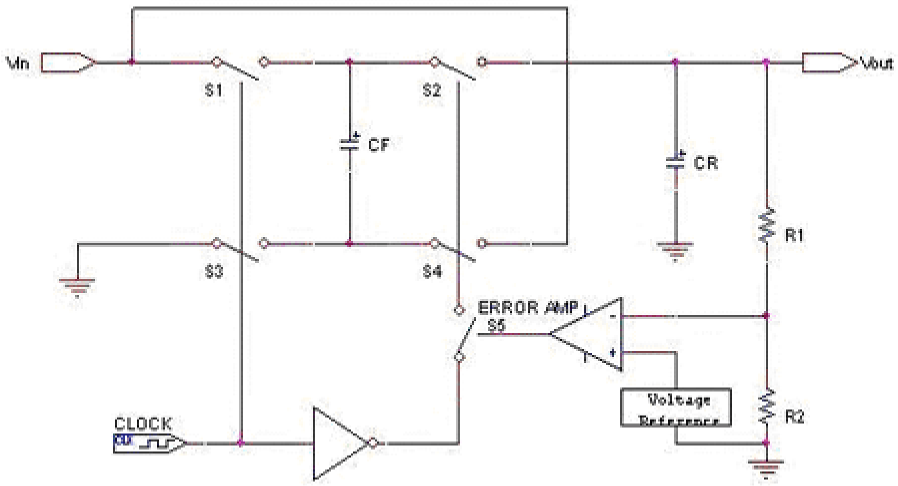


Figure-3.6: A regulated charge pump

In Figure-3.6, a switch, S_5, is added to provide additional control on switches S_2/S_4. A comparator, the output of which is determined by the differential between a fraction of V_{OUT} through a resistor divider R_1 and R_2) and a highly accurate voltage reference, controls the state of S_5. The comparator usually has built-in hysteresis to prevent oscillation. The comparator, the resistor divider, the voltage reference and the S_5 switch complete the feedback loop. The feedback loop regulates the output voltage of the charge pump by controlling the on and off states of switches S_5 and S_2/S_4 in the discharge phase [21-22].

During the discharge phase, if V_{OUT} is below the preset regulated output voltage, the comparator closes S_5, which in turn closes S_2 and S_4. This allows C_F to transfer energy to C_R and the load, in order to bring V_{OUT} up to the preset regulated voltage. When V_{OUT} is brought up to the preset regulated voltage, the comparator opens S_5, which in turn opens S_2 and S_4 to terminate the energy transfer. If V_{OUT} cannot be brought up to the preset regulated voltage during this discharging phase, S_5, S_2 and S_4 stay closed until the end of this phase.

On the other hand, if V_{OUT} rises above the present regulated voltage, the comparator opens S_5, which in turn opens S_2 and S_4. This terminates the energy transfer from C_F to C_R and the load, in order to bring V_{OUT} down to the preset regulated voltage. S_5 and S_2/S_4 stay open if V_{OUT} cannot be brought down to the preset regulated voltage during this discharging phase [21].

The regulated charge pump can output a regulated voltage that is between ground and $2V_{IN}$, by simply manipulating the values of the resistors (R_1 and R_2) in the divider. This means the regulated output voltage can be either higher or lower than the input voltage. However, this is not the case for the most commonly used DC/DC conversion topologies that utilize inductors as energy storage elements, such as buck (step down) and boost (step-up) regulators. [21-22]

3.2.2 Inductor-based DC/DC boost converter

The operation of the majority of today's inductor-based DC/DC converters is periodic, with a period of time (T) controlled by the frequency of the clock. To simplify analysis in this article, only fixed-frequency inductor-based DC/DC converters operating in continuous current mode are considered. Inductor-based DC/DC converter operation includes two phases: switch on (close) and switch off (open). The switch-on duration (t_{ON}) is controlled by the feedback loop and determined by the amount of deviation of V_{OUT} from the preset, regulated output voltage. The switch-off duration is therefore given as $T - t_{ON}$ (shown in figure-3.7) [16].

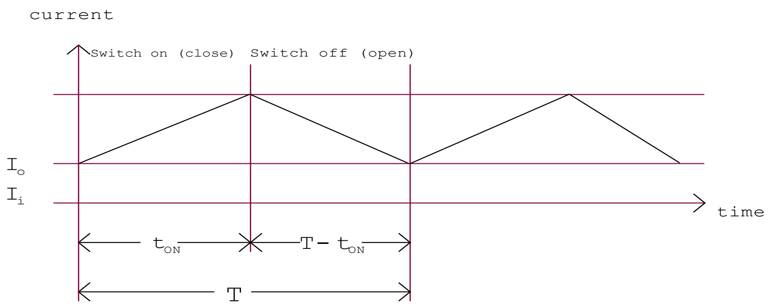


Figure-3.7: Fixed frequency, continuous mode inductor-based DC/DC boost converter timing

The operation of the buck regulator is generally well understood. Its regulated output voltage is given as

$$V_{OUT} = V_{IN} (t_{ON}/T) \qquad (3.16)$$

This equation can also be expressed as

$$V_{OUT} = V_{IN}D \qquad (3.17)$$

Where D is the Duty Cycle and is equal to t_{ON}/T

From the above equations, it is easy to see that the output voltage of a buck converter is always lower than its input voltage, as the Duty Cycle (D) is always less than 1. Figure-3.8 illustrates the architecture of a buck regulator.

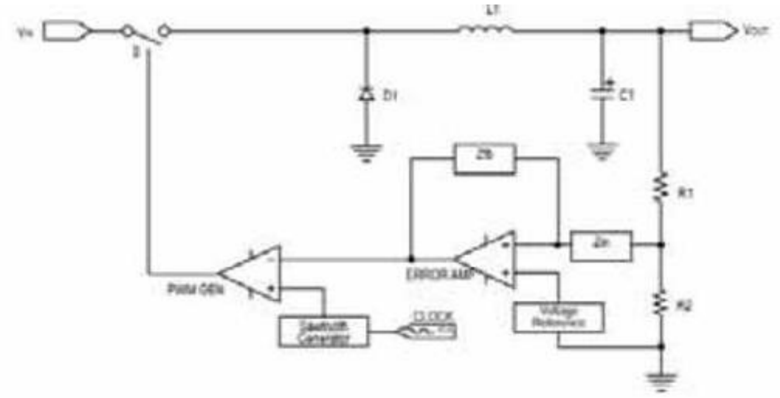


Figure-3.8: A buck converter

The operation of the boost regulator is also generally well understood, with its regulated output voltage is given as

$$V_{OUT} = V_{IN}\ T/(T\text{-}t_{ON}) \quad (3.18)$$

This equation can also be expressed as

$$V_{OUT} = V_{IN} / (1 - D) \quad (3.19)$$

Where D is the Duty Cycle and is equal to t_{ON}/T

Therefore, the output voltage of a boost converter is always higher than its input voltage, as the 1/ (1 – D) is always greater than 1. Figure-3.9 illustrates boost regulator architecture [16-17].

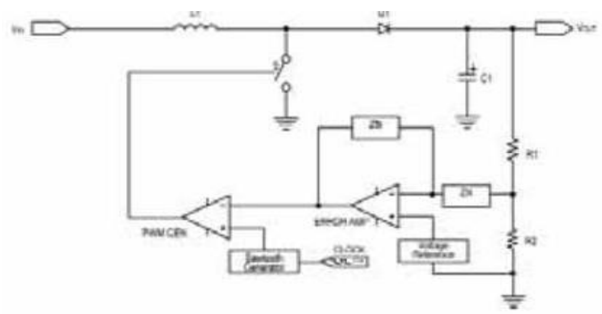


Figure-3.9: A Boost Converter

Consequently, in applications that require the regulated output voltage to be either higher or lower than the input voltage, neither the buck nor the boost regulator is suitable.

3.2.3 Single-ended primary-inductor boost converter (SEPIC)

Single-ended primary-inductor converter (SEPIC) (shown in Figure-3.10) is a type of DC-DC converter allowing the electrical potential (voltage) at its output to be greater than, less than, or equal to that at its input; the output of the SEPIC is controlled by the duty cycle of the control transistor [16]

.

A SEPIC is essentially a boost converter followed by a buck-boost converter, therefore it is similar to a traditional buck-boost converter, but has advantages of having non-inverted output (the output has the same voltage polarity as the input), using a series capacitor to couple energy from the input to the output (and thus can respond more gracefully to a short-circuit output), and being capable of true shutdown: when the switch is turned off, its output drops to 0 V, following a fairly hefty transient dump of charge [23-24]

.

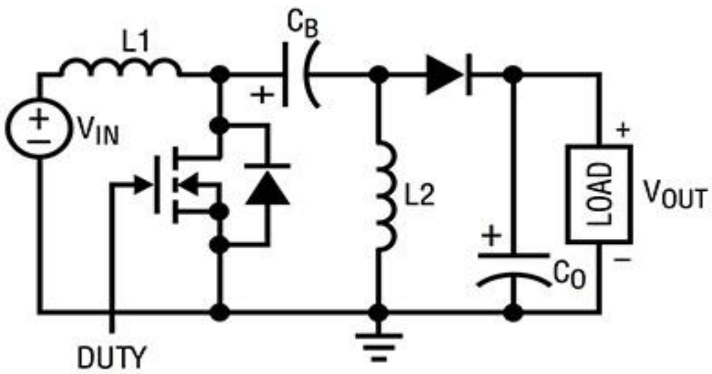


Figure-3.10: SEPIC-switching-voltage-regulator topology (Courtesy of Linear Technology).

SEPICs are useful in applications in which a battery voltage can be above and below that of the regulator's intended output. For example, a single lithium ion battery typically discharges from 4.2 volts to 3 volts; if other components require 3.3 volts, then the SEPIC would be effective [16, 23-24]

.

3.2.3.1 Circuit operation

The schematic diagram for a basic SEPIC is shown in Figure-3.10. As with other switched mode power supplies (specifically DC), the SEPIC exchanges energy between the capacitors and inductors [16, 23-24].

In order to convert from one voltage to another the amount of energy exchanged is controlled by switch S1, which is typically a transistor such as a MOSFET; MOSFETs offer much higher input impedance and lower voltage drop than bipolar junction transistors (BJTs), and do not require biasing resistors as MOSFET switching is controlled by differences in voltage rather than a current, as with BJTs) [16, 23-24].

3.2.3.2 Continuous mode

A SEPIC is said to be in continuous-conduction mode ("continuous mode") if the current through the inductor L_1 never falls to zero. During a SEPIC's steady-state operation, the average voltage across capacitor C_1 (V_{C1}) is equal to the input voltage (V_{in}). Because capacitor C_1 blocks direct current (DC), the average current across it (I_{C1}) is zero, making inductor L_2 the only source of load current. Therefore, the average current through inductor L_2 (I_{L2}) is the same as the average load current and hence independent of the input voltage [16, 23-24].

Looking at average voltages, the following can be written

$$V_{IN} = V_{L1} + V_{C1} + V_{L2} \tag{3.20}$$

Because the average voltage of V_{C1} is equal to V_{IN}, $V_{L1} = -V_{L2}$. For this reason, the two inductors can be wound on the same core. Since the voltages are the same in magnitude, their effects of the mutual inductance will be zero, assuming the polarity of the windings is correct. Also, since the voltages are the same in magnitude, the ripple currents from the two inductors will be equal in magnitude [16, 23-24].

The average currents can be summed as follows

$$I_{D1} = I_{L1} - I_{L2} \tag{3.21}$$

When switch S_1 is turned on (shown in Figure-3.11), current I_{L1} increases and the current I_{L2} increases in the negative direction. (Mathematically, it decreases due to arrow direction.) The energy to increase the current I_{L1} comes from the input source. Since S_1 is a short while closed, and the instantaneous voltage V_{C1} is approximately V_{IN}, the voltage V_{L2} is approximately $-V_{IN}$. Therefore, the capacitor C_1 supplies the energy to increase the magnitude of the current in I_{L2} and thus increase the energy stored in L_2. The easiest way to visualize this is to consider the bias voltages of the circuit in a dc state, then close S_1.

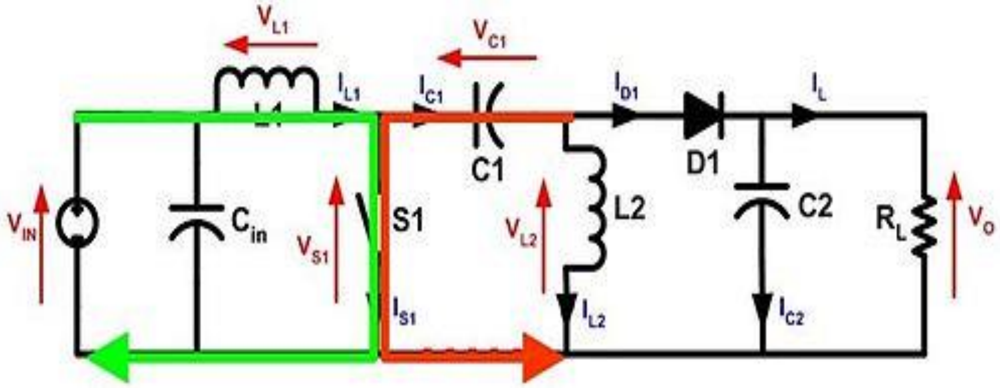


Figure-3.11: With S_1 closed current increases through L_1 (green) and C_1 discharges increasing current in L_2 (red)

When switch S_1 is turned off (shown in Figure-3.12), the current I_{C1} becomes the same as the current I_{L1}, since inductors do not allow instantaneous changes in current. The current I_{L2} will continue in the negative direction, in fact it never reverses direction. It can be seen from the diagram that a negative I_{L2} will add to the current I_{L1} to increase the current delivered to the load. Using Kirchhoff's Current Law, it can be shown that $I_{D1} = I_{C1} - I_{L2}$. It can then be concluded, that while S_1 is off, power is delivered to the load from both L_2 and L_1. C_1, however is being charged by L_1 during this off cycle, and will in turn recharge L_2 during the on cycle.

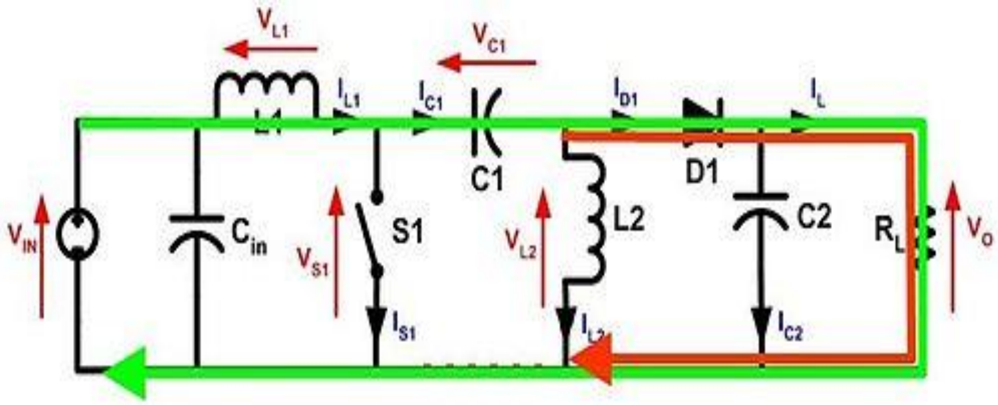


Figure-3.12: With S_1 open current through L_1 (green) and current through L_2 (red) produce current through the load

Because the potential (voltage) across capacitor C_1 may reverse direction every cycle, a non-polarized capacitor should be used. However, a polarized tantalum or electrolytic capacitor may be used in some cases, because the potential (voltage) across capacitor C_1 will not change unless the switch is closed long enough for a half cycle of resonance with inductor L_2, and by this time the current in inductor L_1 could be quite large [16, 23-24].

The capacitor C_{IN} is required to reduce the effects of the parasitic inductance and internal resistance of the power supply. The boost/buck capabilities of the SEPIC are possible because of capacitor C_1 and inductor L_2. Inductor L_1 and switch S_1 create a standard boost converter, which generates a voltage (V_{S1}) that is higher than V_{IN}, whose magnitude is determined by the duty cycle of the switch S_1. Since the average voltage across C_1 is V_{IN}, the output voltage (V_O) is V_{S1} - V_{IN}. If V_{S1} is less than double V_{IN}, then the output voltage will be less than the input voltage. If V_{S1} is greater than double V_{IN}, then the output voltage will be greater than the input voltage [16, 23].

The evolution of switched-power supplies can be seen by coupling the two inductors in a SEPIC converter together, which begins to resemble a Fly back converter, the most basic of the transformer-isolated SMPS topologies.

3.2.3.3 Discontinuous mode

A SEPIC is said to be in discontinuous-conduction mode (or, discontinuous mode) if the current through the inductor L_1 is allowed to fall to zero [23-25].

3.2.3.4 Reliability and Efficiency

The voltage drop and switching time of diode D_1 is critical to a SEPIC's reliability and efficiency. The diode's switching time needs to be extremely fast in order to not generate high voltage spikes across the inductors, which could cause damage to components. Fast conventional diodes or Schottky diodes may be used [16, 23-25].

The resistances in the inductors and the capacitors can also have large effects on the converter efficiency and ripple. Inductors with lower series resistance allow less energy to be dissipated as heat, resulting in greater efficiency (a larger portion of the input power being transferred to the load). Capacitors with low equivalent series resistance (ESR) should also be used for C_1 and C_2 to minimize ripple and prevent heat build-up, especially in C_1 where the current is changing direction frequently [16, 23-25].

3.2.3.5 Disadvantages [25]

Like buck–boost converters, SEPICs have a pulsating output current. The similar Ćuk converter does not have this disadvantage, but it can only have negative output polarity, unless the isolated Ćuk converter is used.

Since the SEPIC converter transfers all its energy via the series capacitor, a capacitor with high capacitance and current handling capability is required.

The fourth-order nature of the converter also makes the SEPIC converter difficult to control, making them only suitable for very slow varying applications.

3.2.4 Interleaved Boost DC-DC Converter

The fuel cell is drawing the attention by researchers as one of the most promising power supply in the future. Due to high efficiency, high stability, low energy consumed and friendly to environment, this technology is in the progress to commercialize. Fuel cell has higher energy storage capability thus enhancing the range of operation for automobile and is a clean energy source [1-4]. Fuel cells also have the additional advantage of using hydrogen as fuel that will reduce the world dependence on non-renewable hydrocarbon resources [26]. A Fuel Cell Electric Vehicles (FCEV) has higher efficiency and lower emissions compared with the internal combustion engine vehicles. So, FCEV is providing a much better promising performance [27].

In FCEV application, the power supply system is composed of Fuel Cell Engine (FCE), DC-DC boost converter, energy storage element, and bidirectional dc-dc converter, as shown in Figure-3.13. In this system, a high power dc-dc converter is needed to adjust the output voltage, current and power of FCE to meet the vehicle requirements. In such applications, it becomes a challenge to maintain high efficiency using conventional boost converter.

At the same time for high power application like electric vehicle, the low input voltage causes large input current to flow. Also with low duty cycle operation the rms ripple current through the boost diode and output capacitor becomes very high. These increase the losses enormously and make the conventional boost converter quite inefficient [26-28].

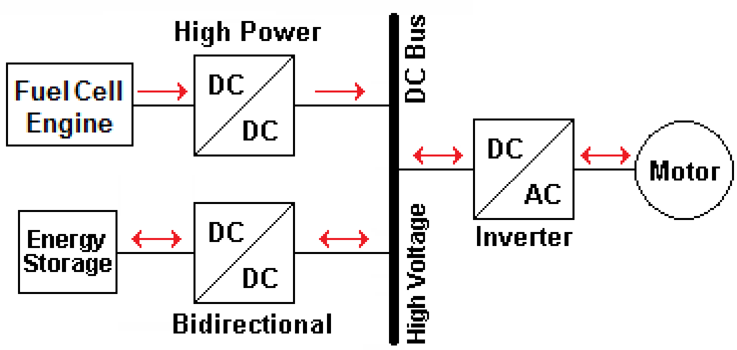


Figure-3.13: Power supply system of FCEV

The major challenge of designing a boost converter for high power application is how to handle the high current at the input and high voltage at the output [5]. An interleaved boost dc-dc converter is a suitable candidate for current sharing and stepping up the voltage on high power application [5-10]. In the interleaved boost converter topology, one important operating parameter is called the duty cycle D. For the boost converter, the ideal duty cycle is the ratio of voltage output and input difference with output voltage.

In this paper, a 2-phase interleaved boost converter is considered. As already well known, the input current and output voltage ripple of interleaved boost dc-dc converter can be minimized by virtue of interleaving operation. Moreover, the converter input current can be shared among the phases, which is desirable for heat dissipation [26-28].

Therefore, the converter reliability and efficiency can be improved significantly. In this paper, comprehensive simulation analyses are presented to illustrate the performance of the interleaved boost dc-dc converter. The features of the interleaved boost dc-dc converter, the principle of operation and the design procedure are discussed in this paper. Microcontroller based hardware is developed to verify the performance of the interleaved boost dc-dc converter. The simulation and experimental results are presented and compared [5-6].

3.2.4.1 Interleaved Boost converter Operation

Figure-3.14 shows the schematic of the dual interleaved boost dc-dc converter. The interleaved boost dc-dc converter consists of two parallel connected boost converter units, which are controlled by a phase-shifted switching function (interleaved operation). To illustrate interleaving operation, Figure-3.15 shows the timing diagram of control signals to the switches.

Since this converter has two parallel units, the duty cycle for each unit is equal to $(V_{out}-V_{in})/V_{out}$, and it is same for each unit due to parallel configuration. A phase shift should be implemented between the timing signals of the first and the second switch. Since there are two units parallel in this converter, the phase shift value is 180 degree [26-28].

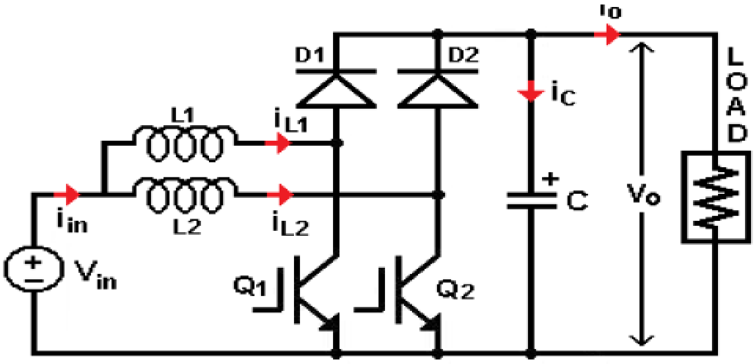


Figure-3.14: Interleaved Boost DC-DC Converter

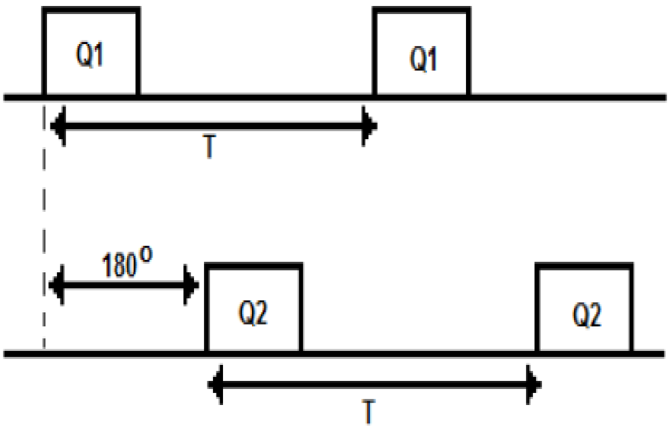


Figure-3.15: Timing diagram of Control Signal

The states of operation of this converter are explained as follows. In order to simplify the calculation, it is assumed that the inductance value of both inductor are L_1 and L_2, where $L_1=L_2=L$, and the duty cycle of Q_1 and Q_2 denoted as $D_1$and D_2, with $D_1=D_2=D$.

1). State a:
At time t0, Q_1 is closed and Q_2 is opened. The current of the inductor L_1 starts to rise, while L_2 continues to discharge. The rate of change of i_{Ll} is $di_{Ll}/dt = V_i/L$, while the rate of change of i_{L2} is $di_{L2}/dt = (V_i – V_o)/L$.

2). State b:
At time t_1, Q_1 and Q_2 are opened. The inductors L_1 and L_2 discharge through the load. The rate of change of i_{Ll} and i_{L2} are $di_{Ll}/dt = di_{L2}/dt = (V_i – V_o)/L$.

3). State c:
At time t_2, Q_2 is closed while Q_1 still opened. The current of the inductor L_2 starts to rise, while L_1 continues to discharge. The rate of change of i_{L2} is $di_{L2}/dt = V_i/L$, while the rate of change of i_{L1} is $di_{L1}/dt = (V_i – V_o)/L$.

4). State d:
At time t_3, Q_2 is opened and Q_1 still opened. The situation is same as state b. The inductors L_1 and L_2 discharge through the load. The rate of change of i_{Ll} and i_{L2} are $di_{Ll}/dt = di_{L2}/dt = (V_i – V_o)/L$.
Due to the symmetry of the circuit, the next state is similar to the previous [26-28].

3.2.5 Multiple (or Dual) input converter

Most power electronic systems input power, output demand or both instantaneously change and are not exactly identical with each other at any time instant. Hence providing a good match between them is a complicated task to deal with if not impossible. Furthermore due to the wide variation of processed power, overall efficiency of the system is not high. Hence, additional energy sources are required to assist main source in fulfilling the load demand. In that case the operating point of the main source will have a much smaller variation window. The additional energy sources may be energy storage devices which can be recharge d in case they are out of power [16].
The conventional approach of connecting multiple energy sources is placing them either in series or parallel with each other. Sources that are placed in series have to conduct the same current which is not always desirable. Also as different sources have different voltage levels they cannot be directly connected in parallel.
Hence multiple power electronic converters are required to connect multiple sources in a single system in order to supply the load demand [16,30].

An example of a system which requires multiple converters is a photovoltaic system which is depicted in figure-3.16.
The system consists of two sources of power which are “PV cells and battery pack. A solar power system can supply energy only during the day time or in particular only during clear sky day on a cloudy sky day or at night they are not capable of supplying power that is required by the load the system requires an additional voltage sources batteries or ultra-capacitors to fulfill the additional load demand also during clear sky days the excess power generated by the solar power can be used to recharge the batteries. Hence the use of multiple converters is inevitable for a photovoltaic system [16, 29-30].

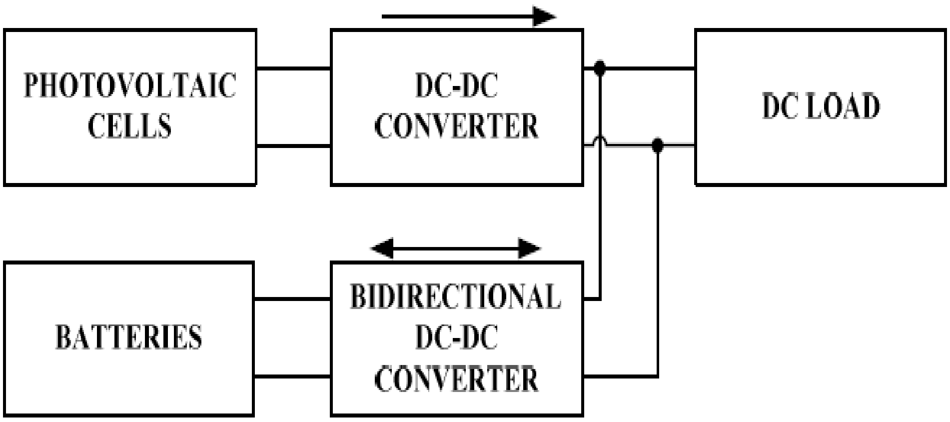


Figure-3.16: Photovoltaic system using multiple converters

Another example of a system which requires multiple converters is a hybrid electric vehicle (at basic hybrid vehicle consists) of an internal combustion engine and a battery pack. Batteries are used as an electric power source or as an energy storage unit. Other sources like ultra-capacitors or fly wheels can be used in place of batteries. To improve the performance of an HEV, more than one of these sources may be used. Hence the use of multiple converters is inevitable. Use of multiple converters makes it possible to run the ICE at optimal rating with maximum efficiency and any additional energy requirement (say during acceleration) can be made available by batteries and ultra-capacitors. Block diagram of an HEV which consists of ultra-capacitors and batteries is shown in figure-3.17. One can observe that the system consists of two bidirectional dc-dc converters to connect batteries and ultra-capacitors.

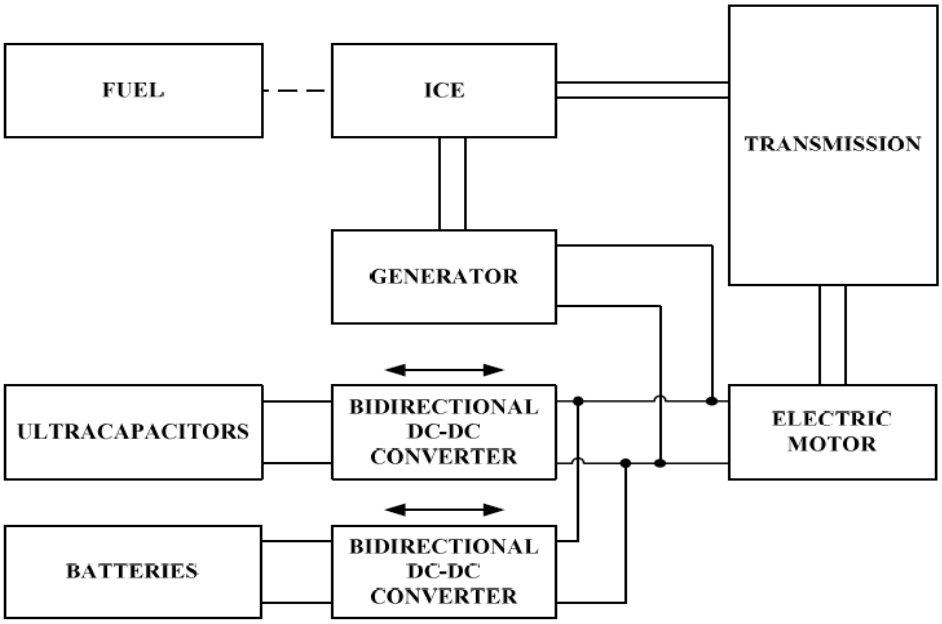


Figure-3.17: Hybrid Electric Vehicle system using multiple converters

It is more advantageous to use multi input converters rather than several independent converters as it results in less number of components, simple control more stability and also lower losses in the system. An example of a system using multi input converters is shown in figure-3.18. The system consists of a single multi input converter instead of using two separate converters [16, 29-30].

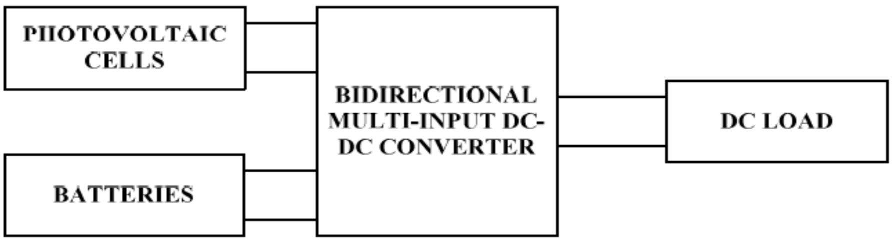


Figure-3.18: Photovoltaic system using a multiple input converters

In this chapter several multiple converter systems are discussed first followed by the existing multi input converters.

3.2.5.1 Conventional Parallel-Connected Converters

Figure-3.19 shows the block diagram of a system in which converters are connected in parallel. Separate dc-dc conversion stages are employed for individual sources. These converters are linked together at the dc bus and controlled independently. In some systems at communication bus may be included to exchange information and manage power flow between the sources. Various examples of such converters are in interleaved boost converter, current-fed push-pull converter, phase-shifted full bridge converter, three phase converter etc. the main drawback of this of such system lies in the fact that it is inherently complex and has a high cost due to the multiple conversion stages and communication devices between individual converters [16].

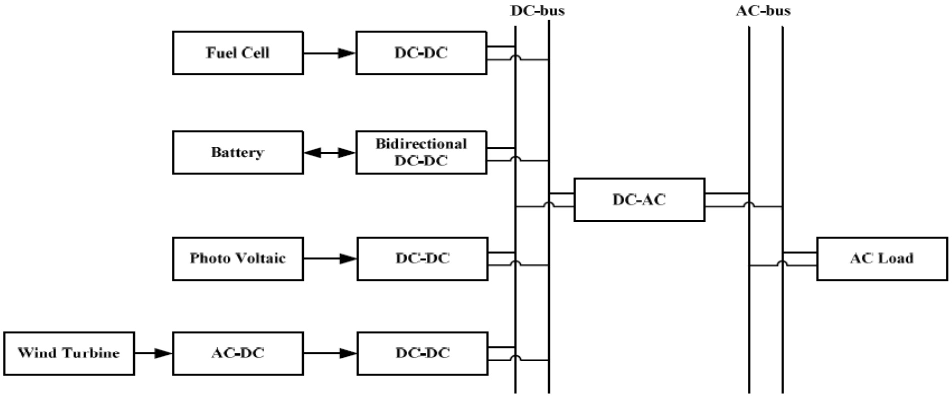


Figure-3.19: Parallel connected converters

3.2.5.2 Conventional Series-Connected Converters

An example of a system consisting series connected converters is shown in figure-3.20. This type of configuration is used for low power wind and solar applications. Such a converter layout results from the series connection of the output stages of two switch mode dc-dc step up converters. In this circuit configuration output voltage and current regulation is difficult, since both of the sources used may have the intermittent nature [29-30]. The main disadvantage of such systems is that output current flows through both converters hence power loss is high. Also the gating signals for the two input voltage sources are conjunctive which may produce circulating current in the two input sources [29-30].

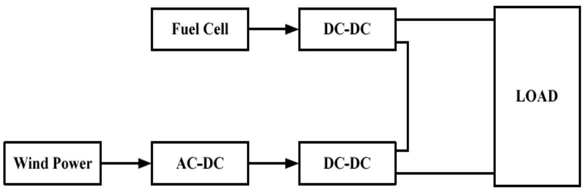


Figure-3.20: Series connected converter

Chapter-4

Design of a Novel Dual Input DC/DC Boost Converter

4.1 Introduction

By analyzing the topologies of converters, the method for synthesizing multi-input converters was inspired by adding an extra pulsating voltage or a current source to a converter with an appropriate connection. Waiet presented multi-input converters with high step up ratios, and the goal of high-efficiency conversion was obtained. However, these topologies are not economic for the non-isolated applications because of the complexity with numbers of electrical components. Tao and Matsuo utilized multi-winding type transformers to accomplish the power conversion target of multi-input sources. Although these topologies were designed based on time-sharing concept, the complexity of driving circuits will be increased by the control techniques. Marchesoni and Vacca investigated a newly designed converter with the series-connected input circuits to achieve the goal of multiple input power sources [16]. The installation cost of the converter with few components was certainly reduced. The feature of is that the conduction losses of switches can be greatly reduced, especially in the dual power supply state. Unfortunately, the hard-switching problem and the huge reverse-recovery current within the output diode degrade the conversion efficiency as a traditional boost converter. Kwasinski discussed the evolution of multiple input converters from their respective single-input versions. Based on several assumptions, restrictions, and conditions, these analyses indicate some feasible and unfeasible frameworks for multiple-input development. Lim investigated a set of basic rules for generating multiple-input converter topologies, and systematically generated two families of multiple-input converters. Qian*et* designed a novel converter topology with four power ports including two sources, one bidirectional storage port, and one isolated load port [16].

In this study, a high-efficiency ZVS dual-input converter is investigated, and this converter directly utilizes the current source type applying to both input power sources. Based on the series-connected input circuits and the designed pulse width modulation (PWM) driving signals, the conduction loss of the switches can be greatly reduced in the dual power-supply state. Lee performed zero-current-transition dc–dc converters without additional current stress and conduction loss on the main switch during the resonance period of the auxiliary cell. Consequently, the proposed dual-input converter can efficiently convert two power sources with different voltages to a stable dc-bus voltage [16]. According to the power dispatch, this converter could be operated at two states including a single power-supply state and a dual power-supply state.

4.2 Circuit description

Dual input dc-dc converters utilize voltage boost circuit at the front of conventional dc-dc converters. By incorporating voltage boost circuit with dc-dc converters, the desired gain of the input to the load can be achieved at a lower frequency and higher duty cycle. With an aim to have high voltage gain at acceptable efficiency a new dual input boost converter circuit is proposed in this thesis. The performance of the proposed circuit as shown in figure-4.1 is studied by simulation. The circuit has two boost cells with two power sources. Each cell has a switch of MOSFET. There is a phase angle of 180 degree between two switches so that both two cells cannot stay on at a same time. When one cell is on, another is off. For this reason there is continuous voltage at load.

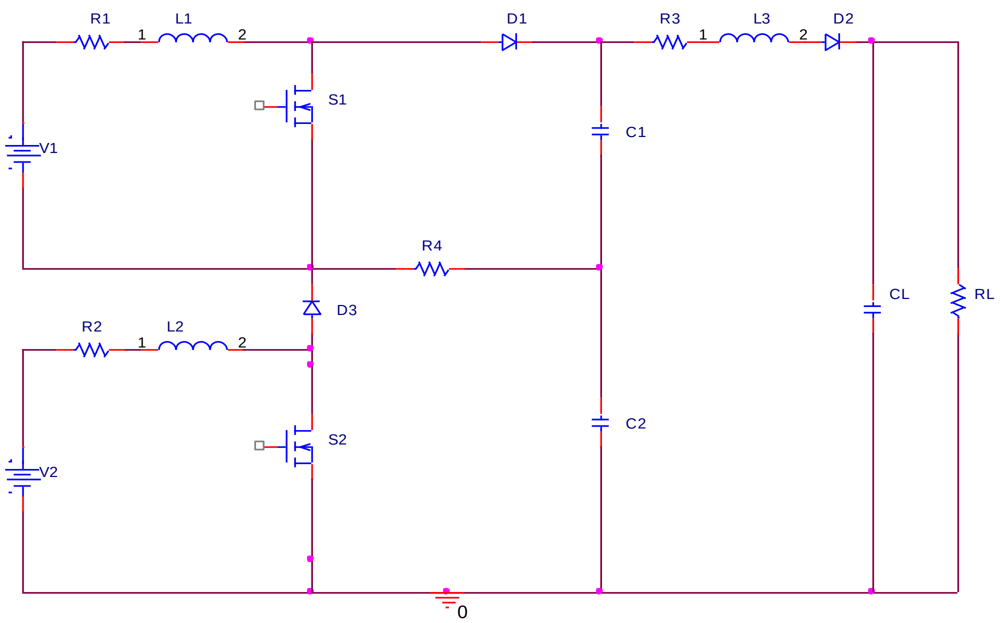


Figure-4.1: proposed Dual Input Boost Converter

Table-4.1: Component specification for proposed Dual Input Boost Converter

Devices	Value
Inductances (L_1, L_2 , L_3)	500uH
Capacitances (C_1, C_2, C_L)	100uF
Power switches	IRF630
Input voltage	24V
Output voltage	180 V
Maximum power output	1008 W
Switching frequency (F)	10 kHz
Diode	D1N3491
Resistive load (R_L)	50 Ω

4.3 RESULT AND SIMULATION

Figure-4.2 shows the simulated circuit with the values of all parameters. Figure-4.3 shows switching pulse for 90% duty cycle. From figure-4.4 to figure-4.61 shows various waveforms of output voltage, output current, input currents by varying frequency, duty cycle and resistive load.

4.3.1 At Frequency, f=10 kHz; D=0.90; RL=50 ohm; L=500uH; C=100uF;

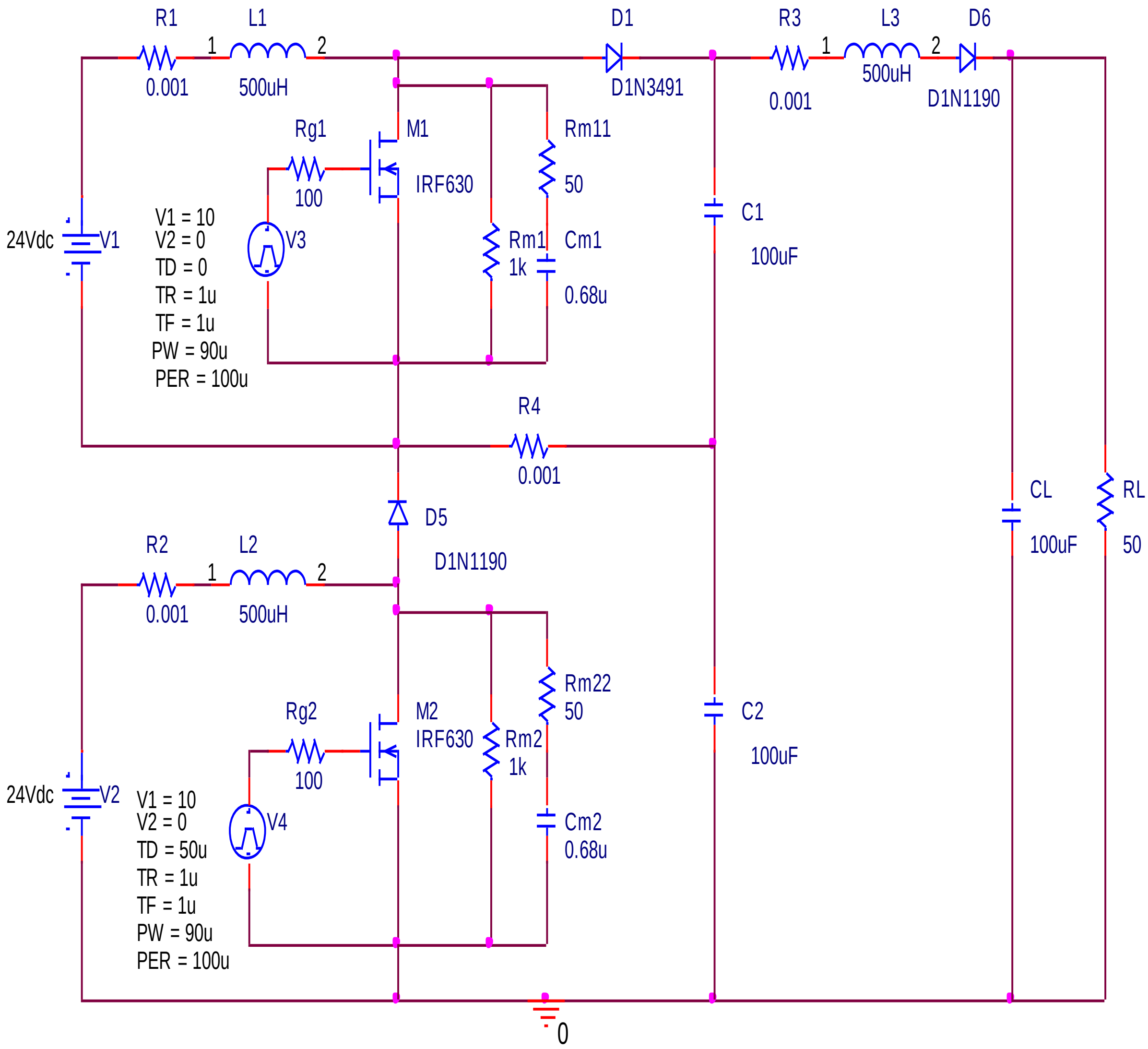


Figure-4.2: Dual input dc-dc boost converter at f=10 kHz, D=0.90, RL=50Ω

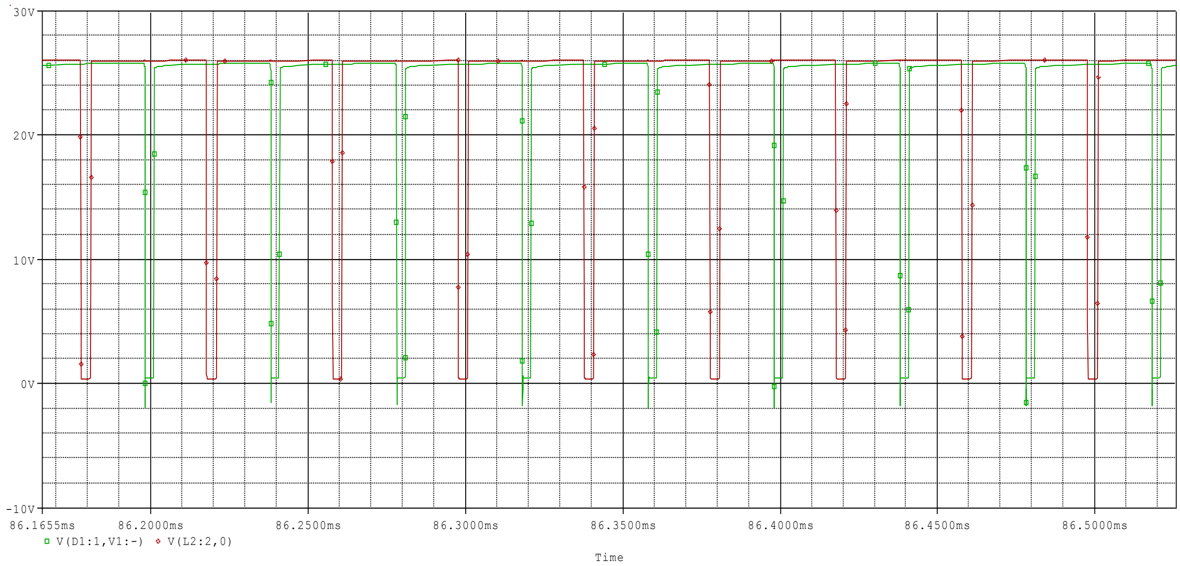


Figure-4.3: Switching pulse of Dual input dc-dc boost converter at f=10 kHz, D=0.90, RL=50Ω

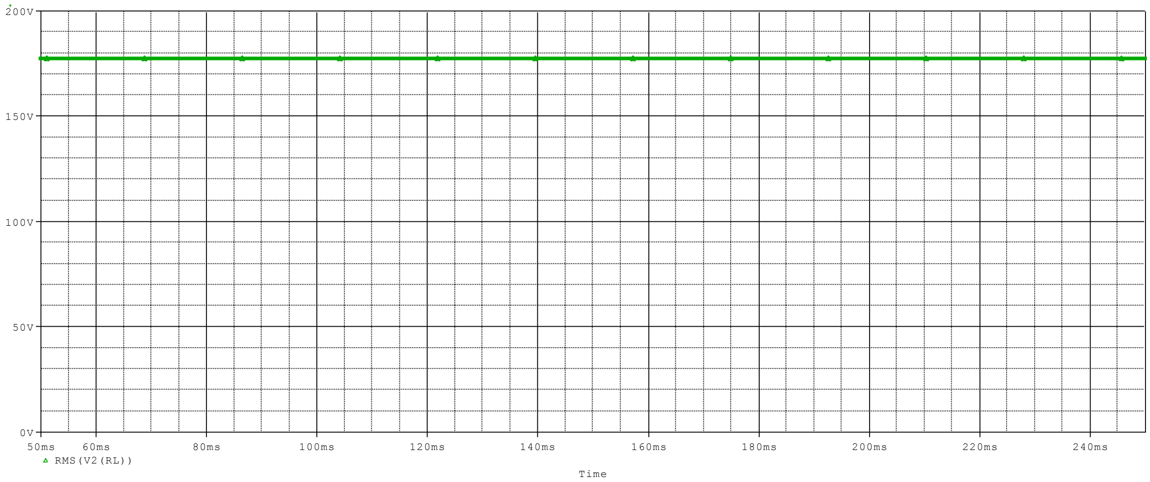


Figure-4.4: Output voltage of Dual input dc-dc boost converter at f=10 kHz, D=0.90, RL=50Ω

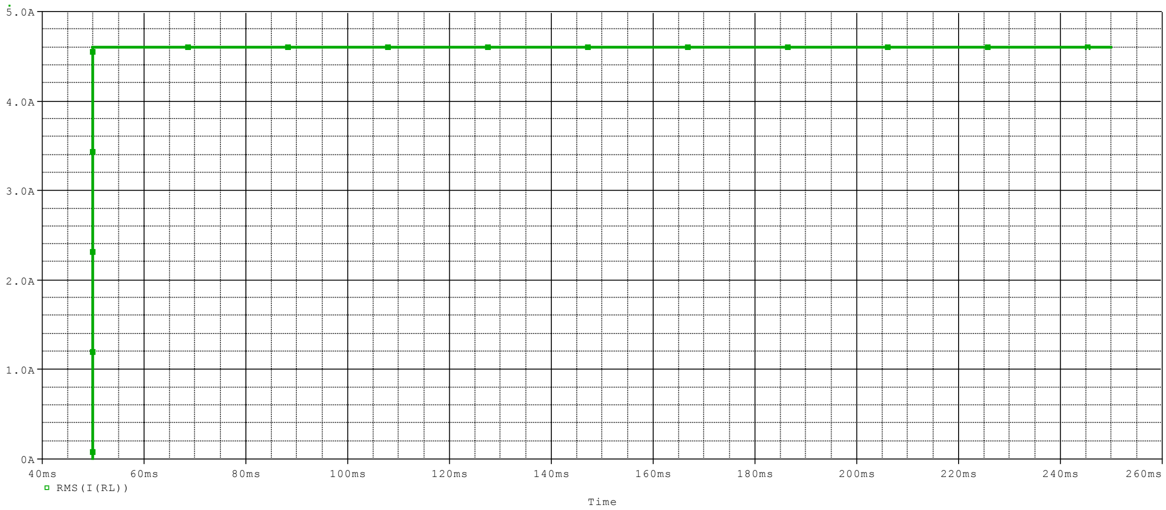


Figure-4.5: Output current of Dual input dc-dc boost converter at f=10 kHz, D=0.90, RL=50Ω

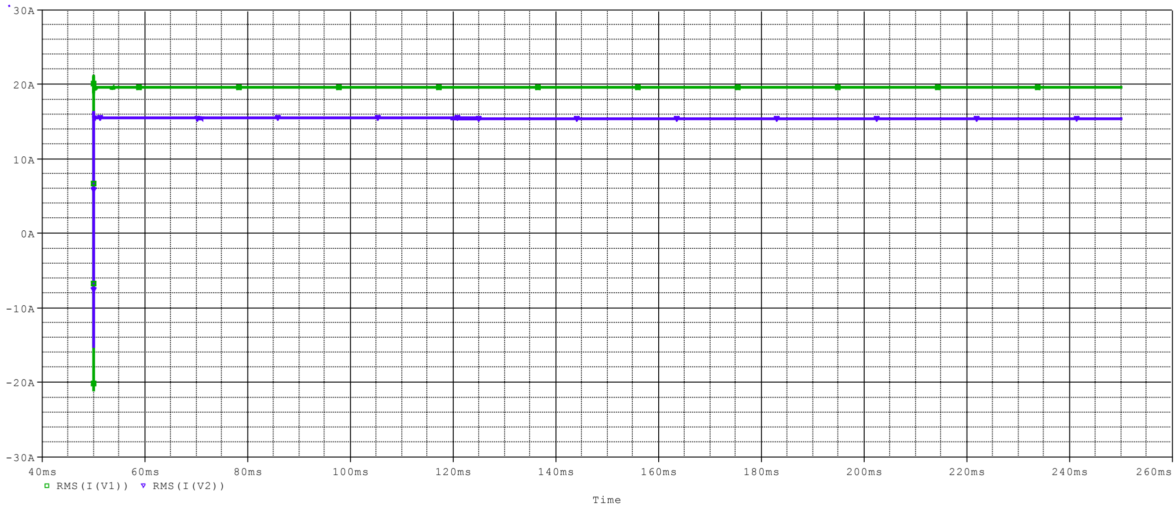


Figure-4.6: Input current for power source-1&2 of Dual input dc-dc boost converter at f=10 kHz, D=0.90, RL=50Ω

Calculation:

Input Voltage, V_{in1}=24V;
Input voltage, V_{in2}=24V;
Output Voltage, V_{out}=178V
Input Current, I_{in1}=19.5A;
Input current, I_{in2}=16A;
Output Current, I_{out}=4.5A
Input Power, P_{in}= (24*19.5+24*16) =852W
Output Power, P_{out}=V_{out} *I_{out}=178*4.5=801W
Efficiency=P_{out}/P_{in}= (801/852)*100%=94.01%
Voltage gain=V_o/V_{in}=178/ (24+24) =3.7

4.3.2 At Frequency, f=10 kHz; D=0.9; RL=100 Ω;

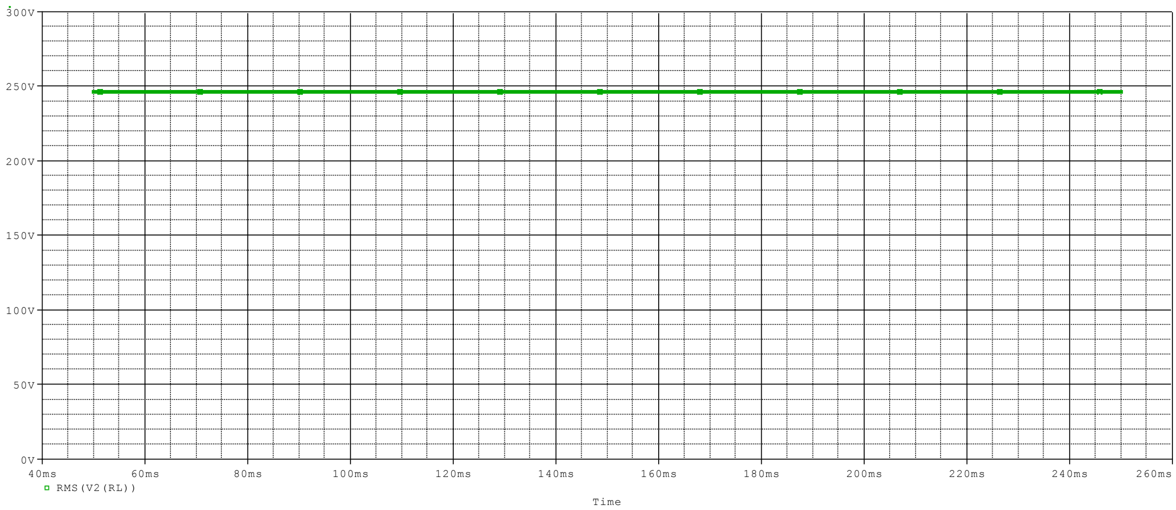


Figure-4.7: Output voltage of Dual input dc-dc boost converter at f=10 kHz, D=0.90, RL=100Ω

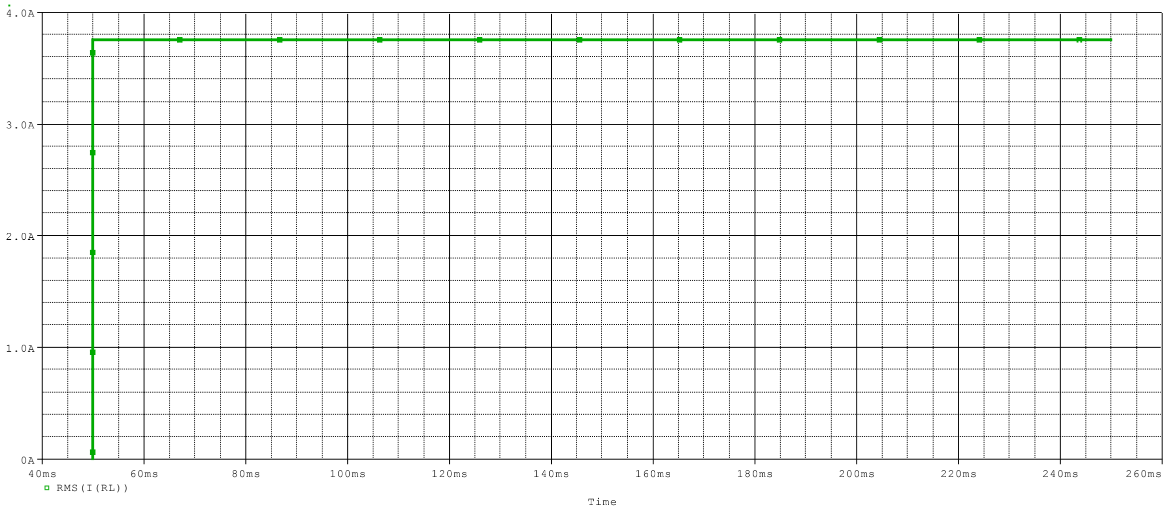


Figure-4.8: Output voltage of Dual input dc-dc boost converter at f=10 kHz, D=0.90, RL=100Ω

Figure-4.9: Input current for power source-1&2 of Dual input dc-dc boost converter at f=10 kHz, D=0.90, RL=100Ω

Calculation:

Input Voltage, V_{in1}=24V;
Input voltage, V_{in2}=24V;
Output Voltage, V_{out}=245V
Input Current, I_{in1}=23A;
Input current, I_{in2}=19A;
Output Current, I_{out}=3.8A
Input Power, P_{in}= (24*23+24*19)=1008W
Output Power, P_{out}=V_{out} *I_{out}=245*3.8=931W
Efficiency=P_{out}/P_{in}= (1008/931)*100%=92.36%
Voltage gain=V_o/V_{in}=245/ (24+24) =5.1

4.3.3 At F=10 kHz;   D=0.75;   RL=20 ohm; L=500uH; C=100uF

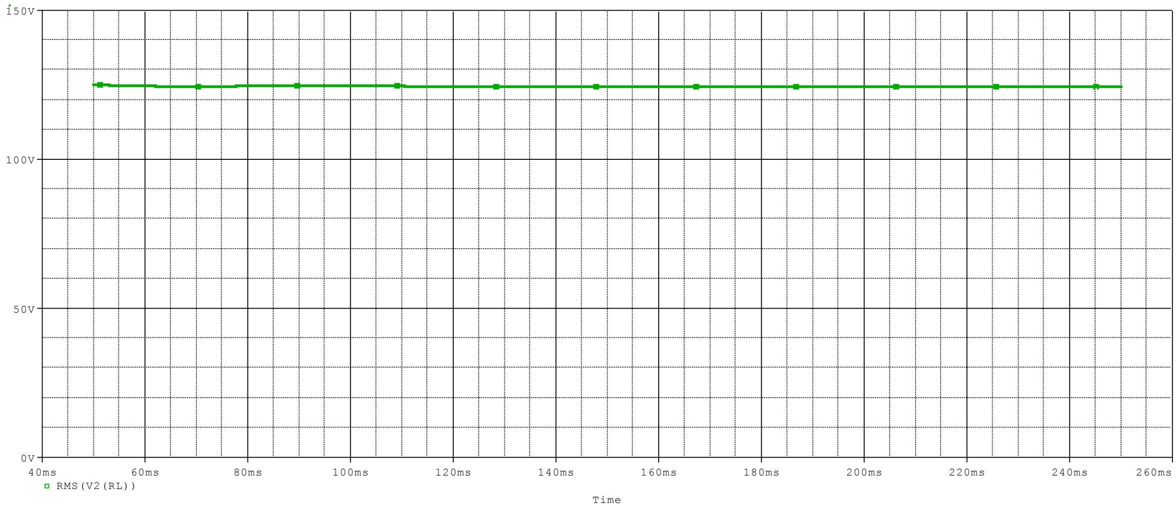


Figure-4.10: Output voltage of Dual input dc-dc boost converter at f=10 kHz, D=0.75, RL=20Ω

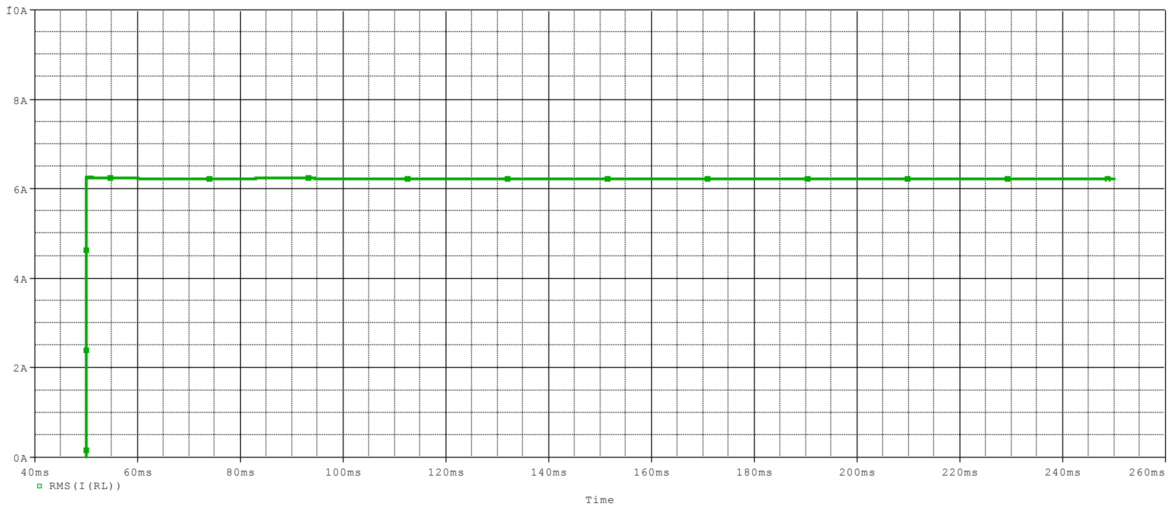


Figure-4.11: Output voltage of Dual input dc-dc boost converter at f=10 kHz, D=0.75, RL=20Ω

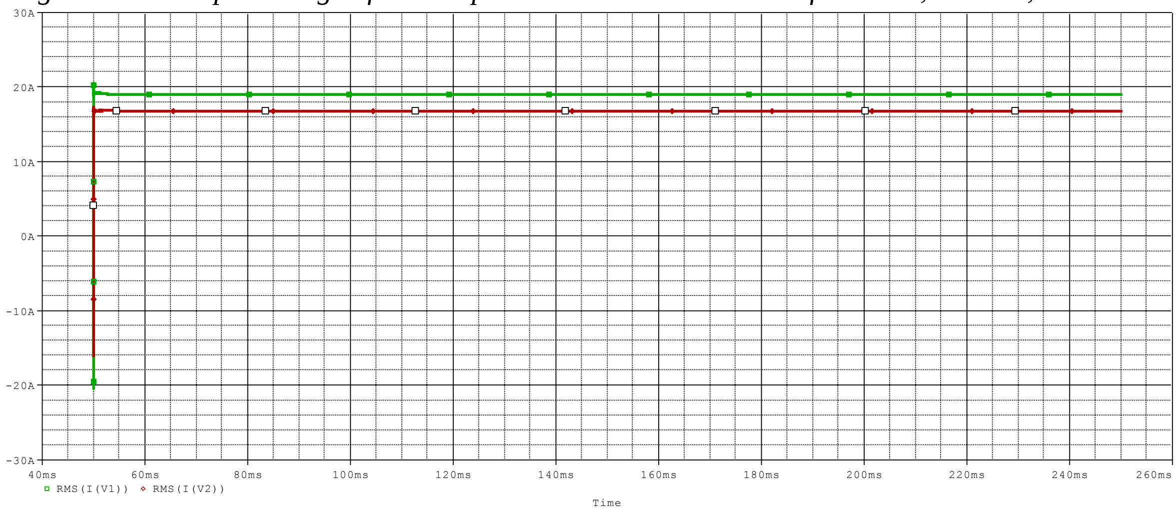


Figure-4.12: Input current for power source-1&2 of Dual input dc-dc boost converter at f=10 kHz, D=0.75, RL=20Ω

4.3.4 AT F=10 kHz; D=0.75; RL=50 ohm; L=500uH; C=100uF

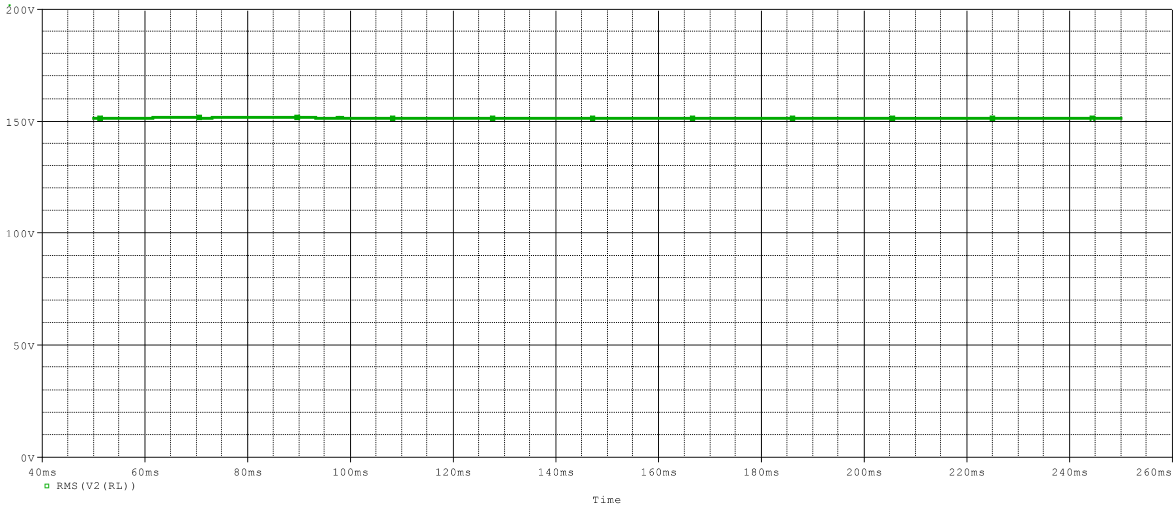


Figure-4.13: Output voltage of Dual input dc-dc boost converter at f=10 kHz, D=0.75, RL=50Ω

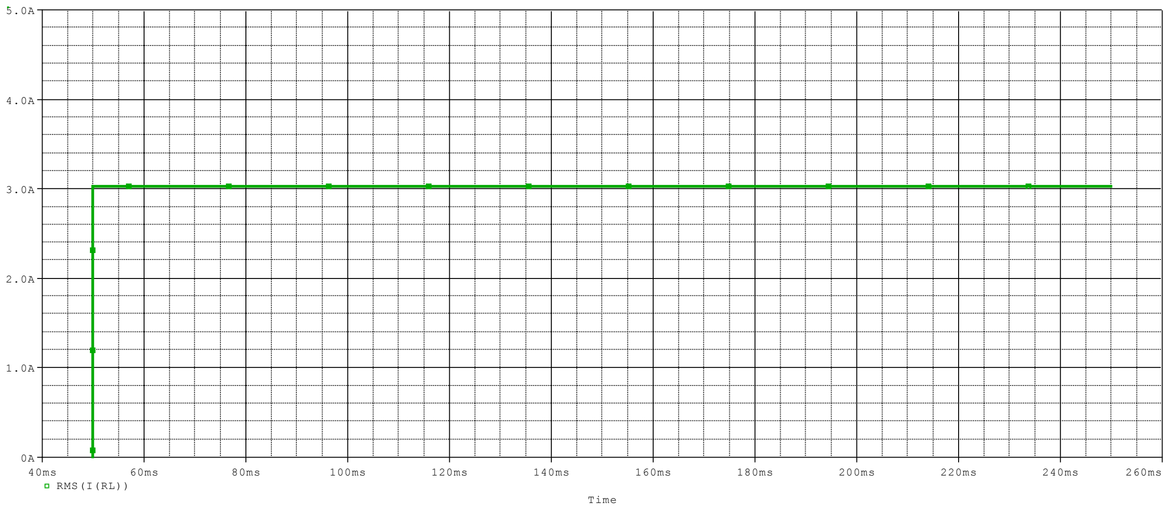


Figure-4.14: Output current of Dual input dc-dc boost converter at f=10 kHz, D=0.75, RL=50Ω

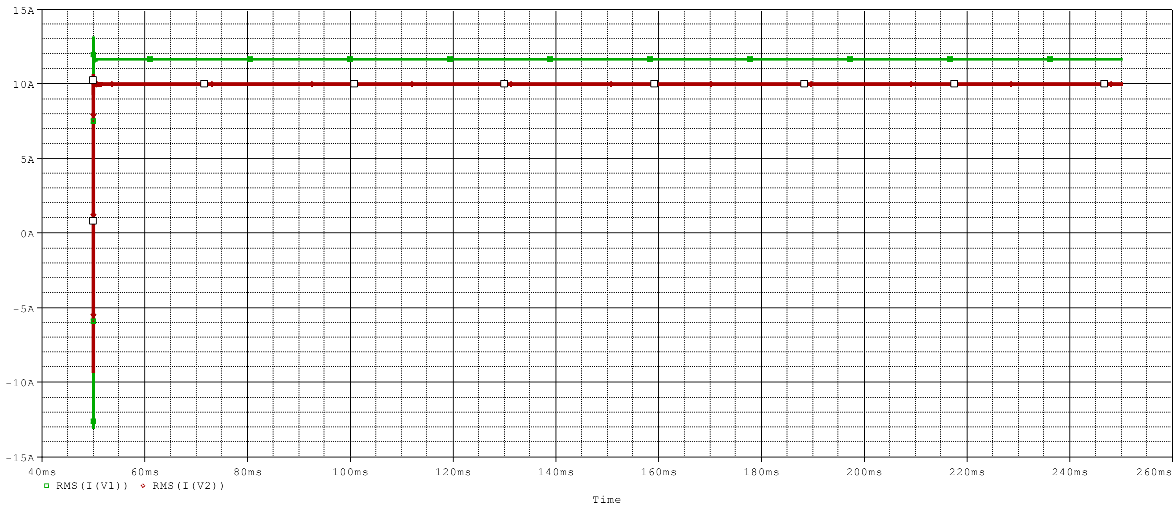


Figure-4.15: Input current for power source-1&2 of Dual input dc-dc boost converter at f=10 kHz, D=0.75, RL=50Ω

4.3.5 AT F=10 kHz; D=0.75; RL=200 ohm; L=500uH; C=100uF

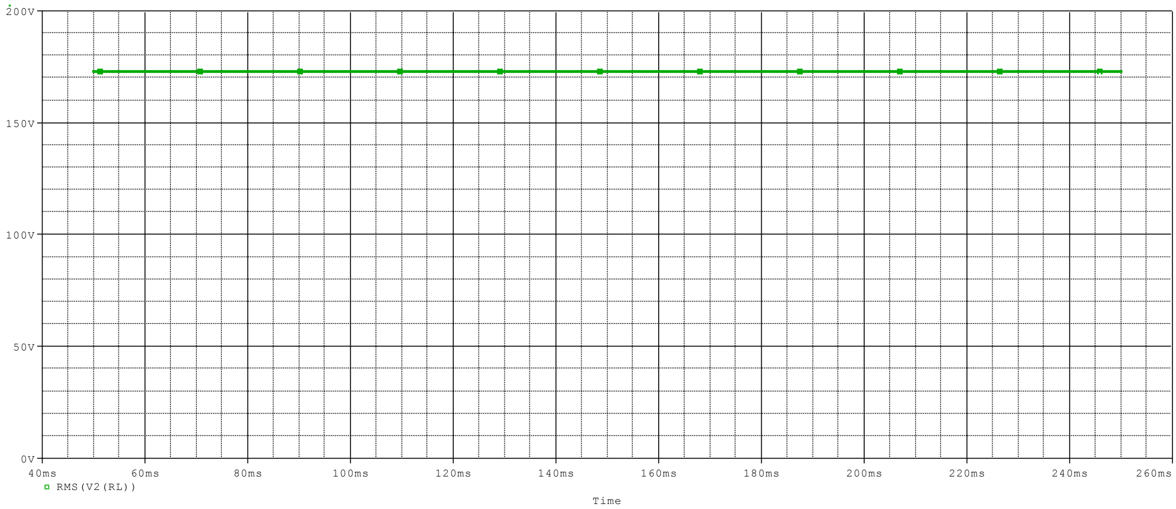


Figure-4.16: Output voltage of Dual input dc-dc boost converter at f=10 kHz, D=0.75, RL=200Ω

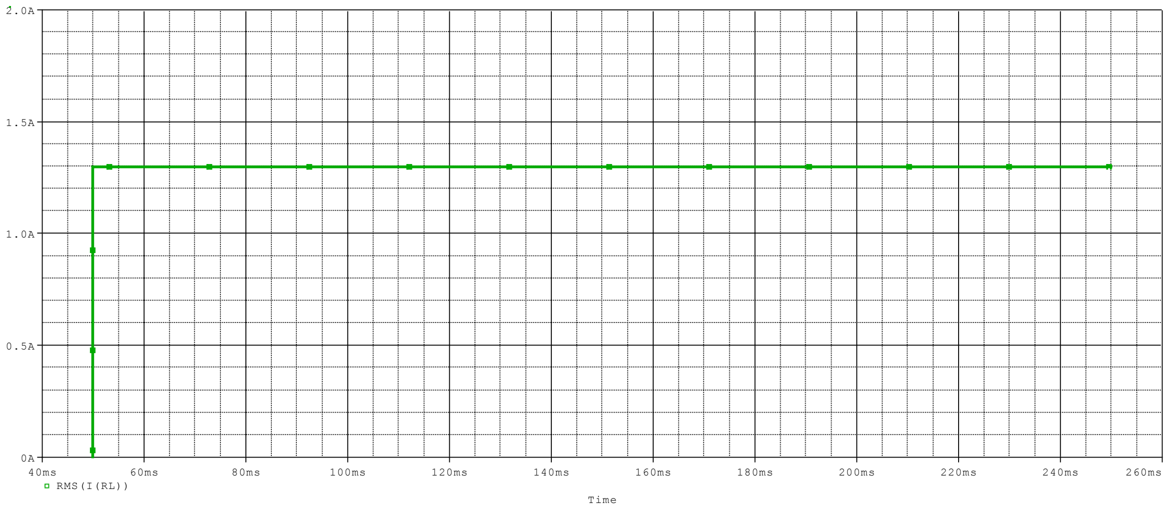


Figure-4.17: Output current of Dual input dc-dc boost converter at f=10 kHz, D=0.75, RL=200Ω

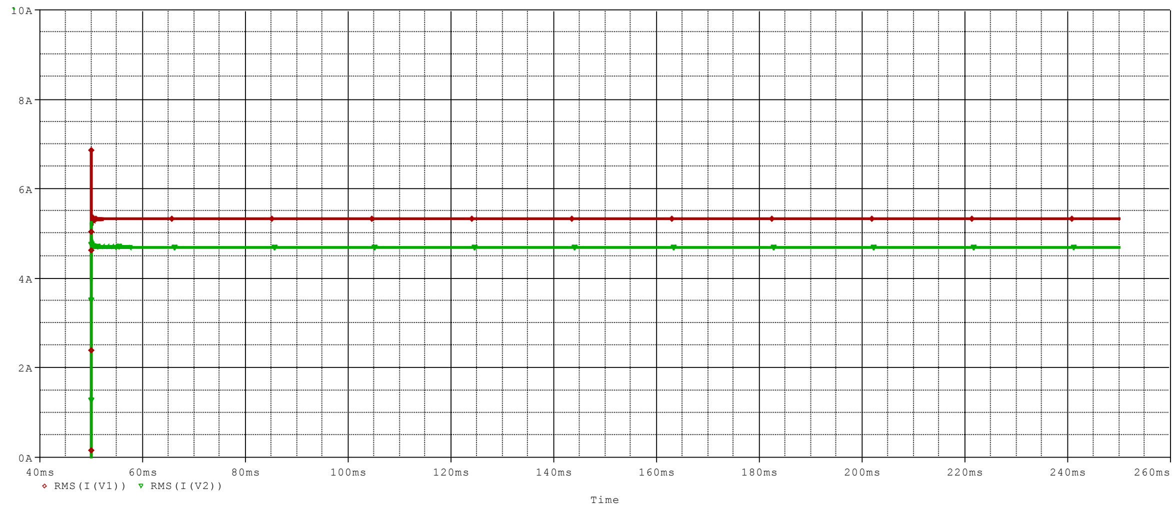


Figure-4.18: Input current for power source-1&2 of Dual input dc-dc boost converter at f=10 kHz, D=0.75, RL=200Ω

4.3.6 AT F=10 kHz; D=0.5; RL=50 ohm; L=500uH; C=100uF

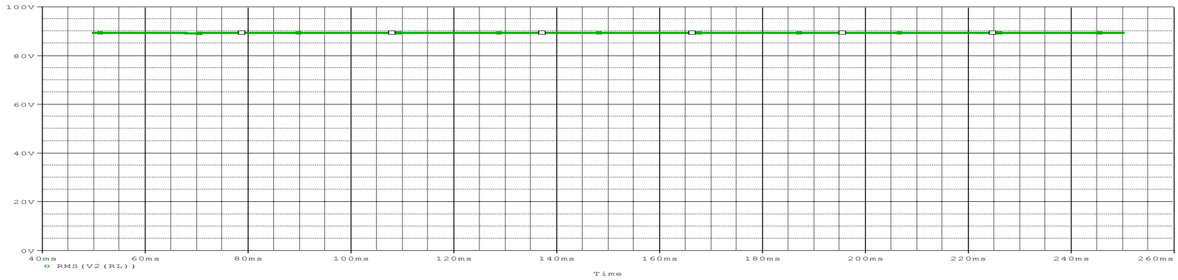


Figure-4.19: Output voltage of Dual input dc-dc boost converter at f=10 kHz, D=0.50, RL=50Ω

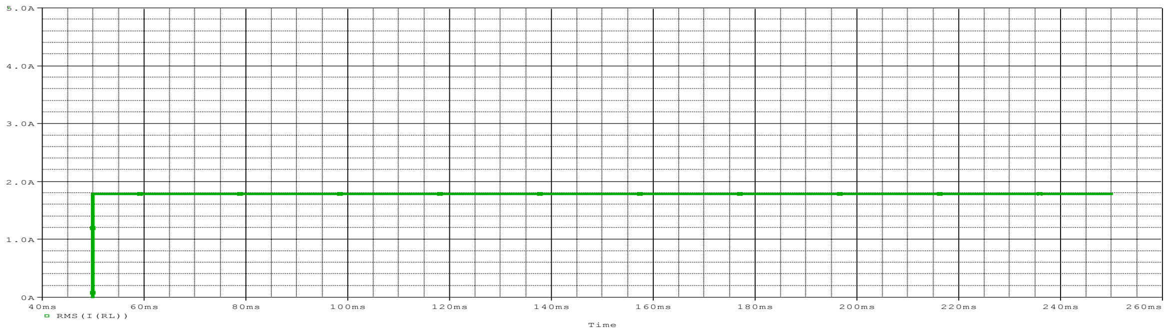


Figure-4.20: Output current of Dual input dc-dc boost converter at f=10 kHz, D=0.5, RL=50Ω

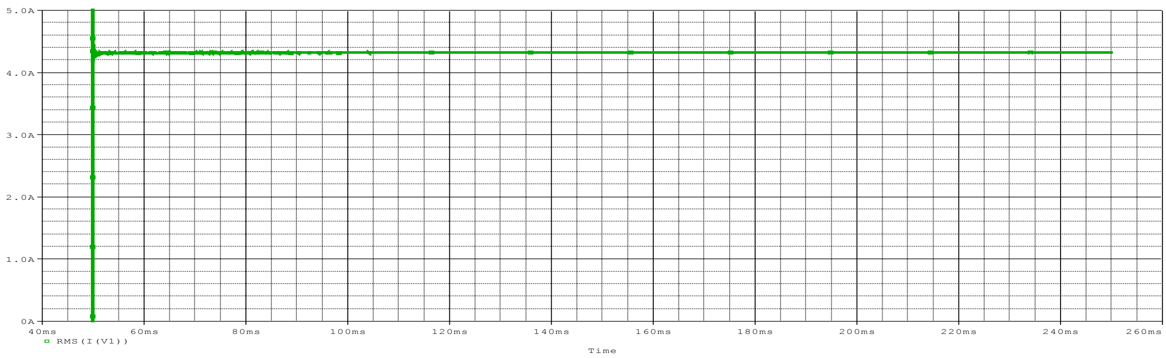


Figure-4.21: Input current for power source-1of Dual input dc-dc boost converter at f=10 kHz, D=0.50, RL=50Ω

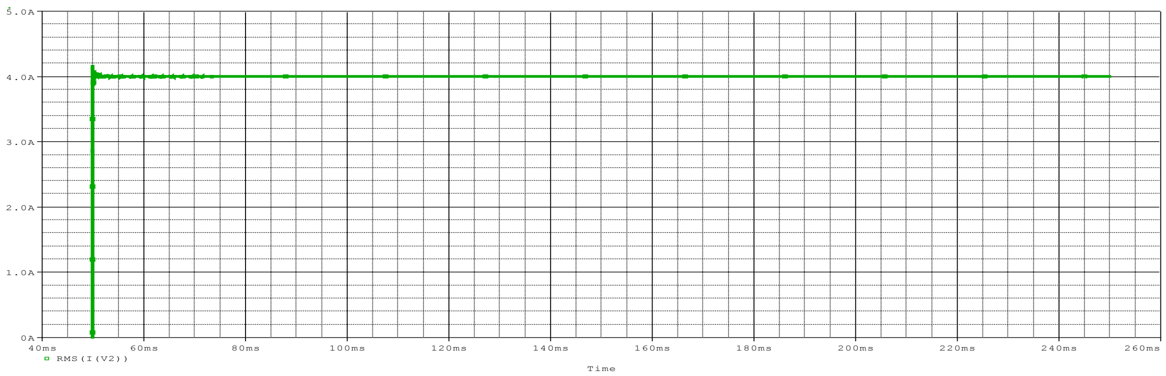


Figure-4.22: Input current for power source-2 of Dual input dc-dc boost converter at f=10 kHz, D=0.50, RL=50Ω

4.3.7 AT F=10 kHz; D=0.25; RL=50 ohm; L=500uH; C=100uF

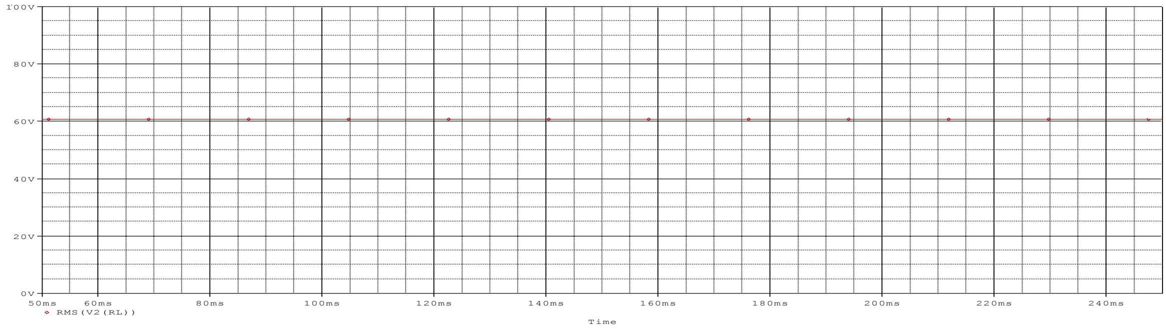


Figure-4.23: Output voltage of Dual input dc-dc boost converter at f=10 kHz, D=0.25, RL=50Ω

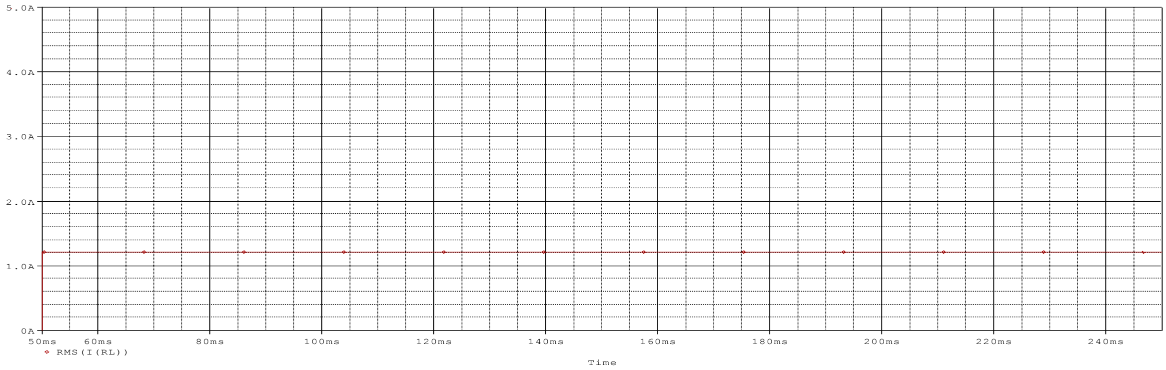


Figure-4.24: Output current of Dual input dc-dc boost converter at f=10 kHz, D=0.25, RL=50Ω

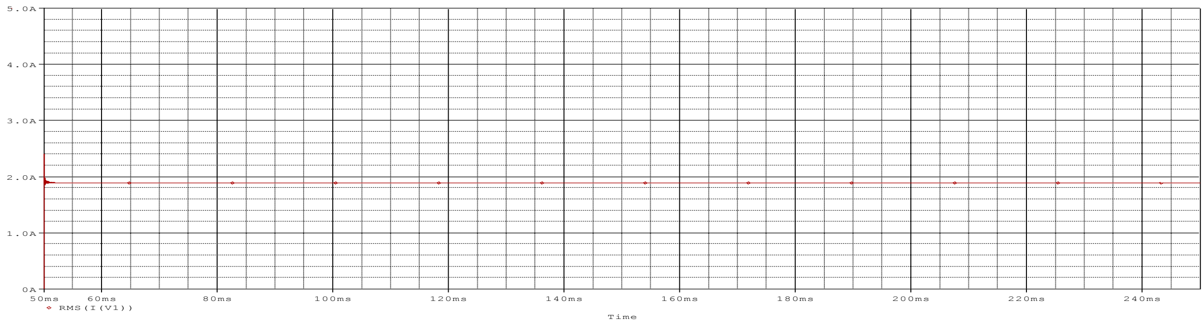


Figure-4.25: Input current for power source-1 of Dual input dc-dc boost converter at f=10 kHz, D=0.25, RL=50Ω

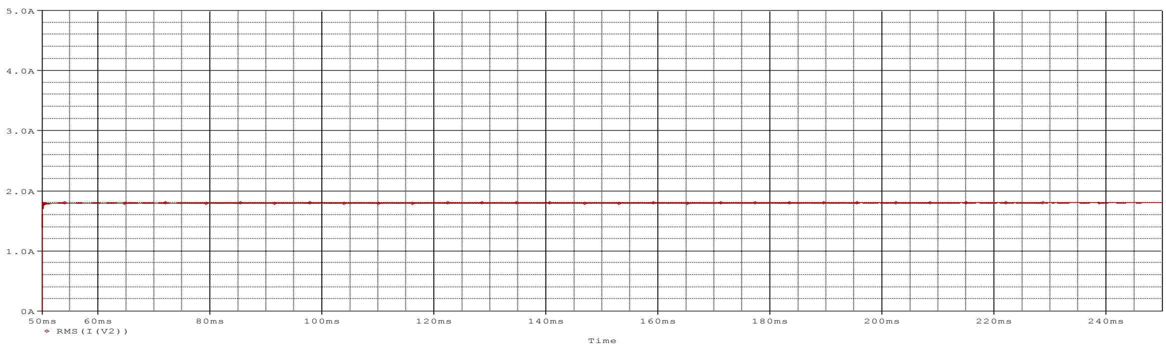


Figure-4.26: Input current for power source-2 of Dual input dc-dc boost converter at f=10 kHz, D=0.25, RL=50Ω

4.3.8 AT F=10 kHz; D=0.15; RL=50 ohm; L=500uH; C=100uF

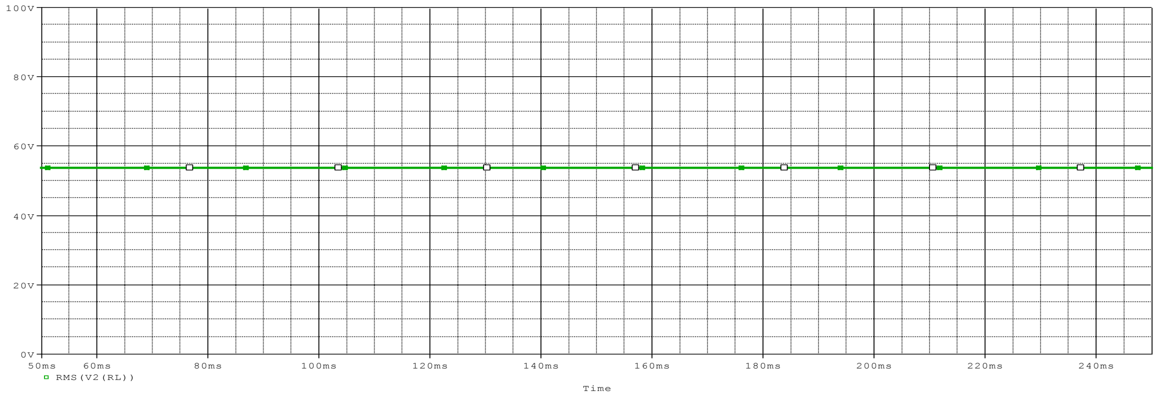


Figure-4.27: Output voltage of Dual input dc-dc boost converter at f=10 kHz, D=0.15, RL=50Ω

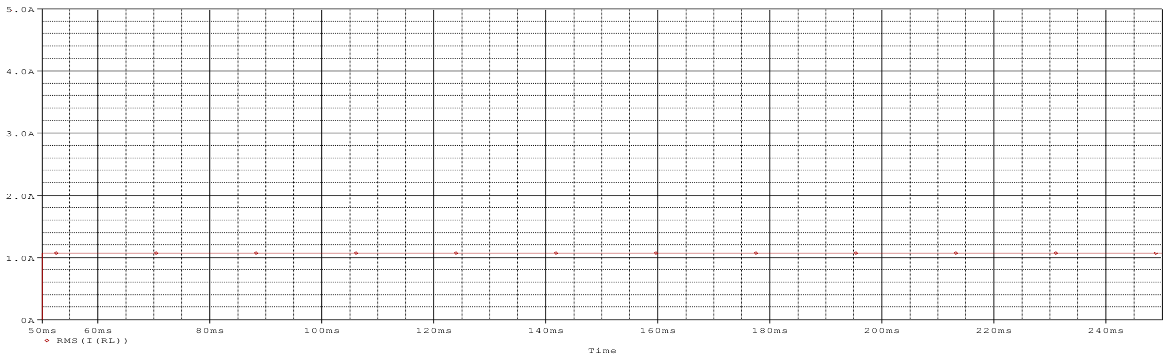


Figure-4.28: Output current of Dual input dc-dc boost converter at f=10 kHz, D=0.15, RL=50Ω

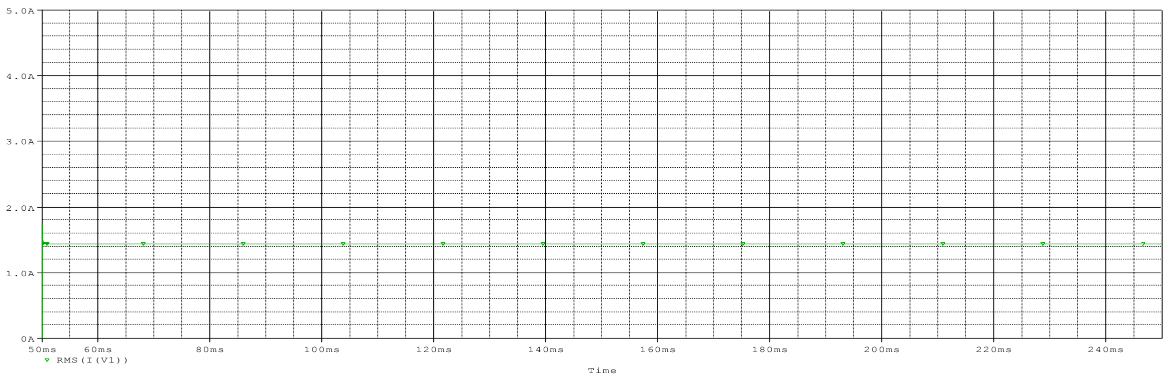


Figure-4.29: Input current for power source-1 of Dual input dc-dc boost converter at f=10 kHz, D=0.15, RL=50Ω

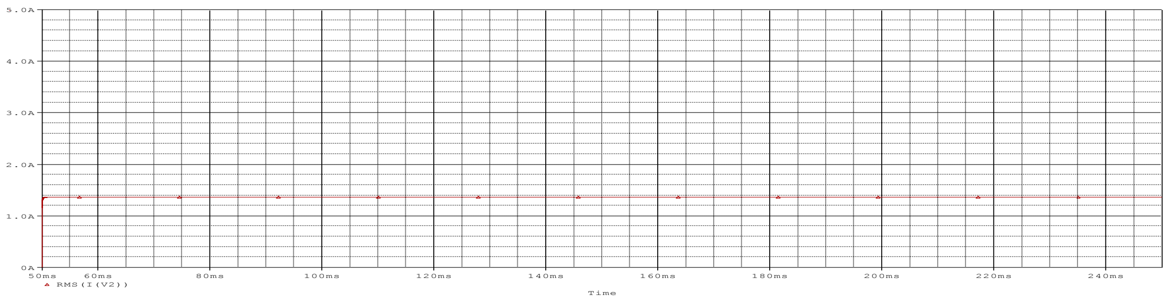


Figure-4.30: Input current for power source-2 of Dual input dc-dc boost converter at f=10 kHz, D=0.15, RL=

4.3.9 AT F=20 kHz; D=0.75; RL=50 Ω; L=500uH; C=100uF

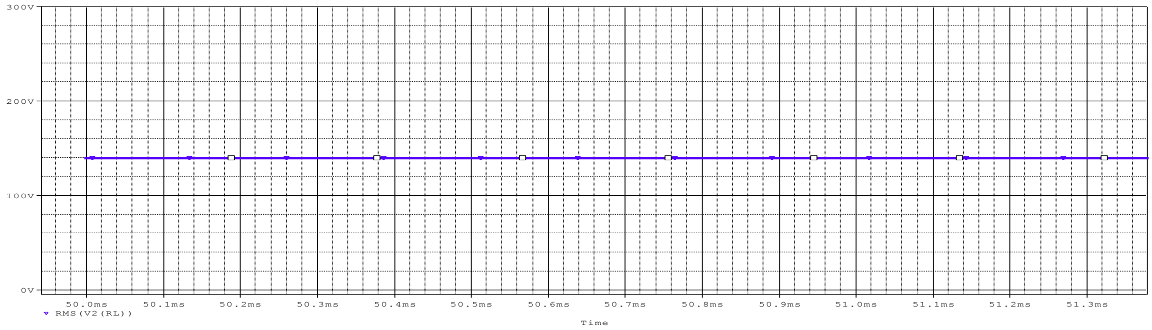


Figure-4.31: Output voltage of Dual input dc-dc boost converter at f=20 kHz, D=0.75, RL=50Ω

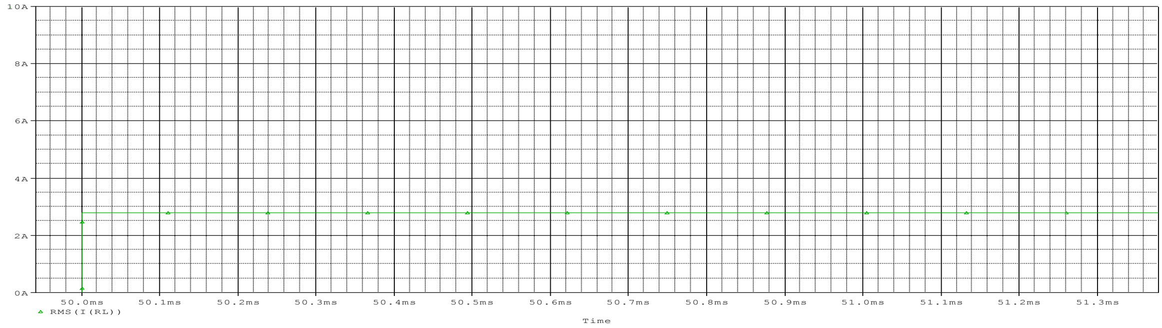


Figure-4.32: Output current of Dual input dc-dc boost converter at f=20 kHz, D=0.75, RL=50Ω

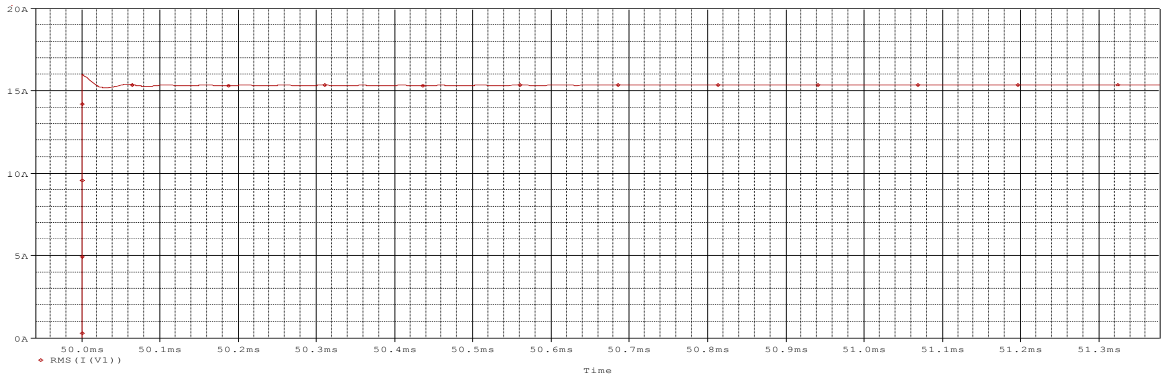


Figure-4.33: Input current for power source-1 of Dual input dc-dc boost converter at f=20 kHz, D=0.75, RL=50Ω

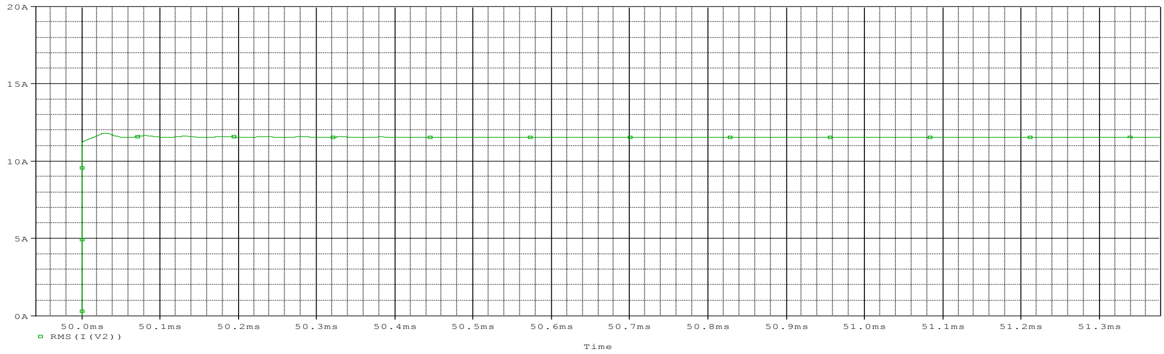


Figure-4.34: Input current for power source-2 of Dual input dc-dc boost converter at f=20 kHz, D=0.75, RL=50Ω

4.3.10 AT F=20 kHz; D=0.5; RL=20 Ω; L=500uH; C=100uF

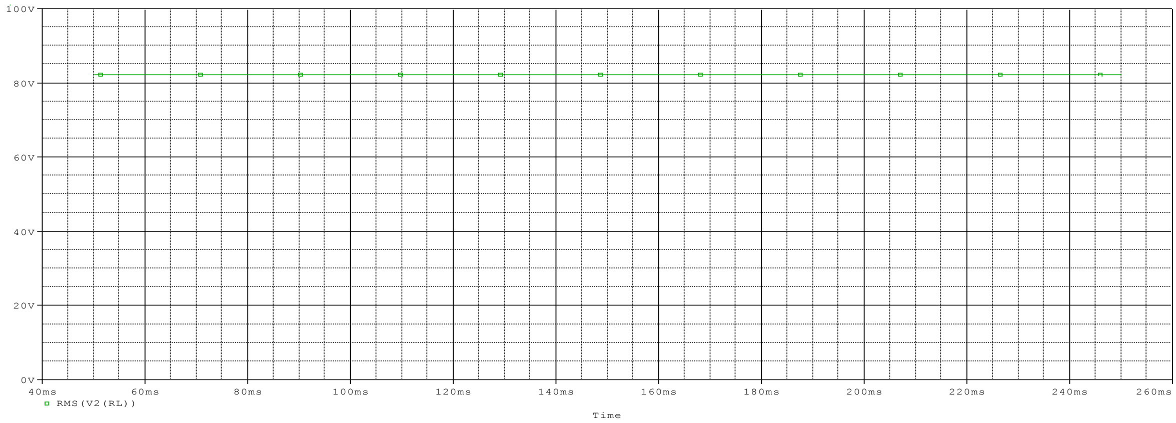


Figure-4.35: Output voltage of Dual input dc-dc boost converter at f=20 kHz, D=0.5, RL=20Ω

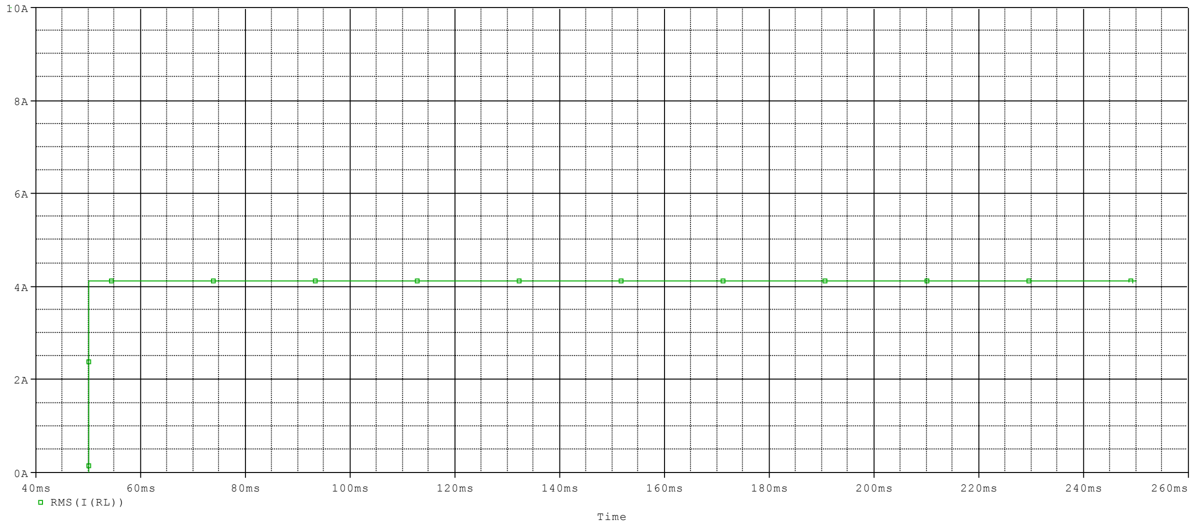


Figure-4.36: Output current of Dual input dc-dc boost converter at f=20 kHz, D=0.5, RL=20Ω

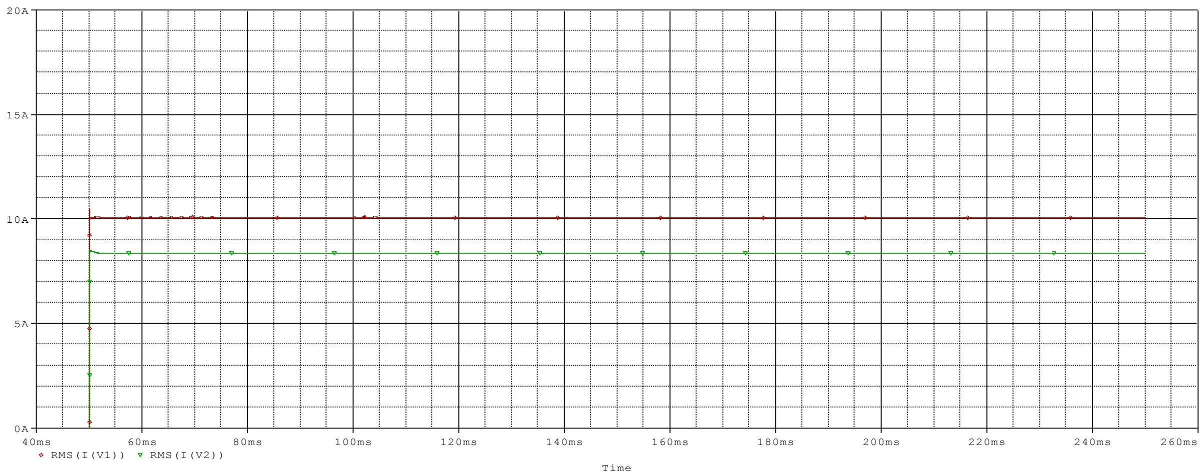


Figure-4.37: Input current for power source-1&2 of Dual input dc-dc boost converter at f=20 kHz, D=0.5, RL=20Ω

4.3.11 AT F=20 kHz; D=0.25; RL=50 Ω; L=500uH; C=100uF

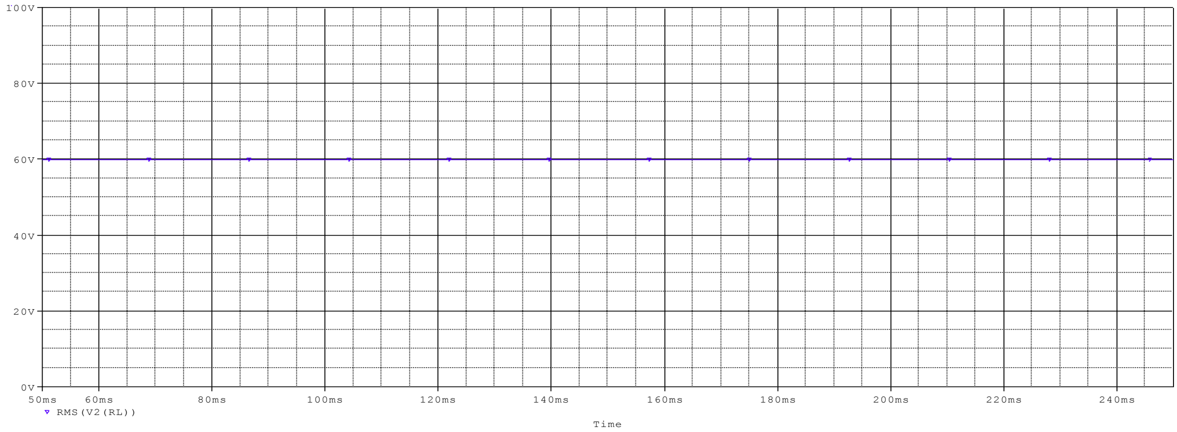


Figure-4.38: Output voltage of Dual input dc-dc boost converter at f=20 kHz, D=0.25, RL=50Ω

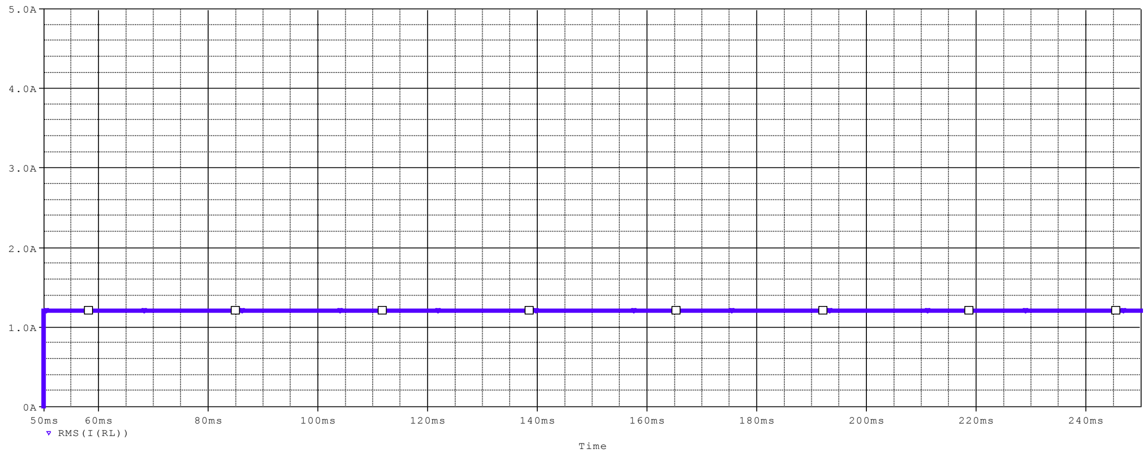


Figure-4.39: Output current of Dual input dc-dc boost converter at f=20 kHz, D=0.25, RL=50Ω

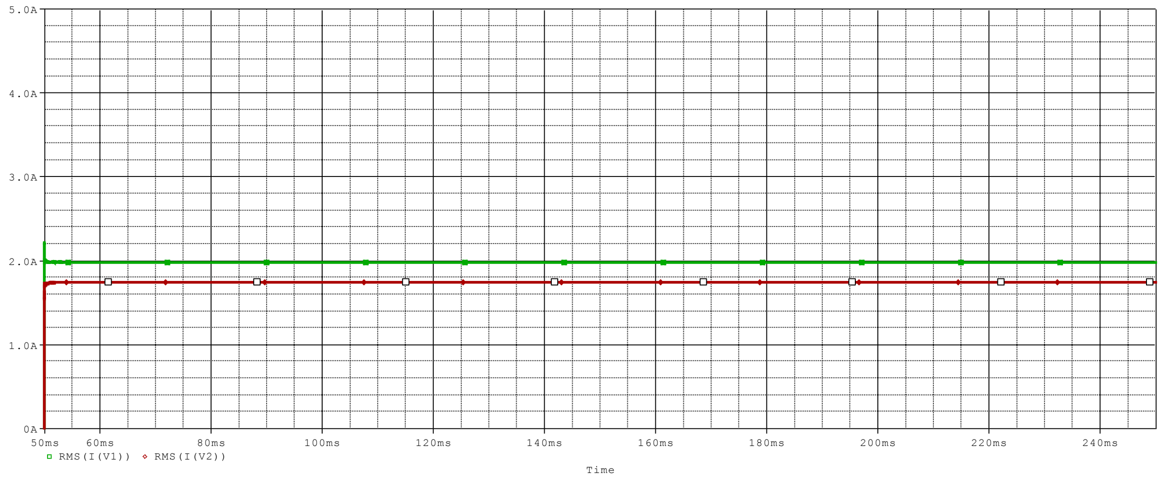


Figure-4.40: Input current for power source-1&2 of Dual input dc-dc boost converter at f=20 kHz, D=0.25, RL=50Ω

4.3.12 AT F=20 kHz; D=0.1; RL=50Ω; L=500uH; C=100uF

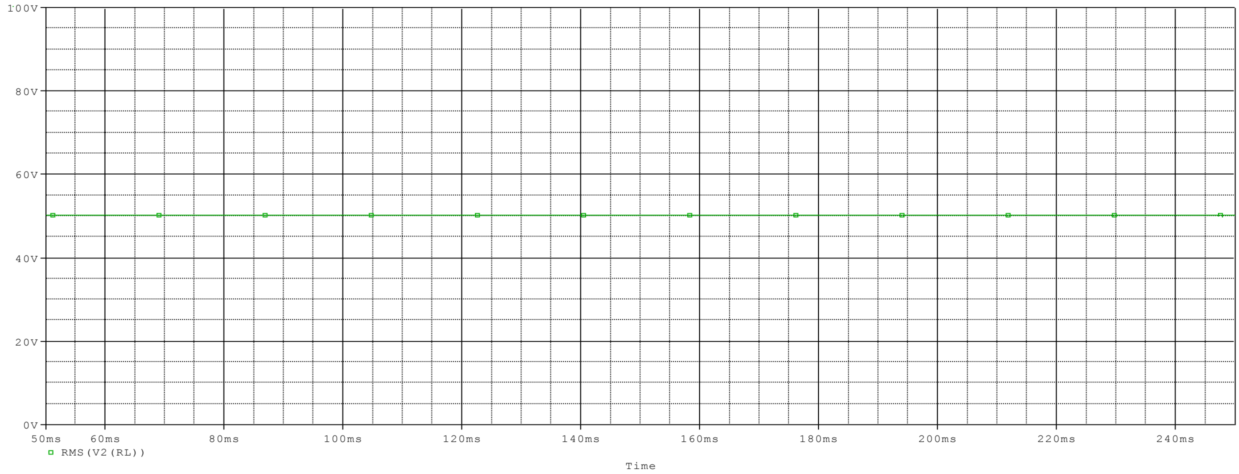


Figure-4.41: Output voltage of Dual input dc-dc boost converter at f=20 kHz, D=0.1, RL=50Ω

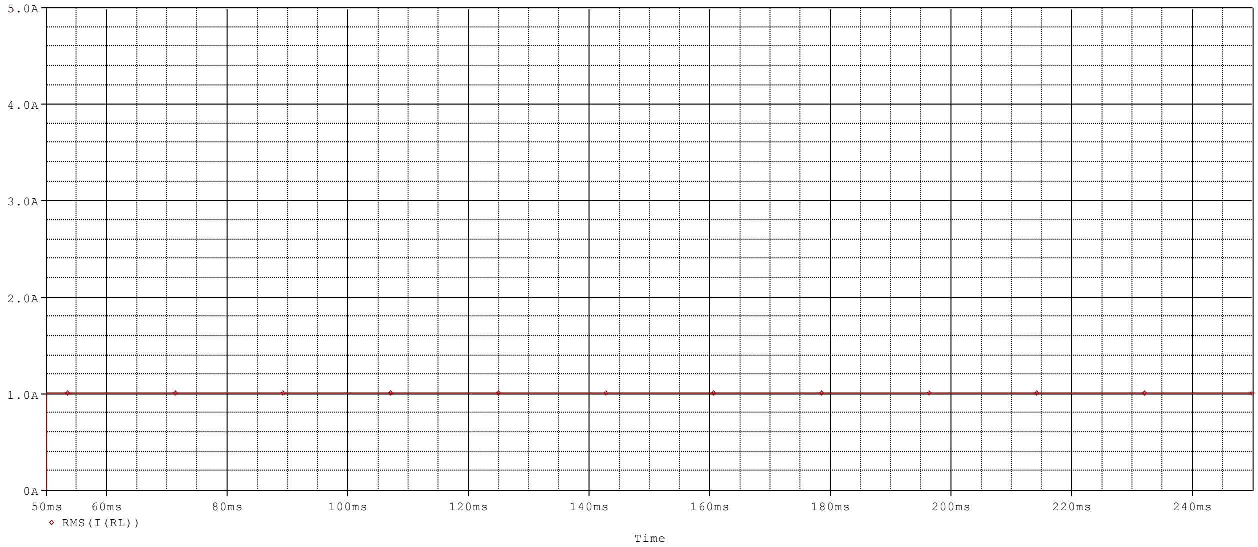


Figure-4.42: Output current of Dual input dc-dc boost converter at f=20 kHz, D=0.1, RL=50Ω

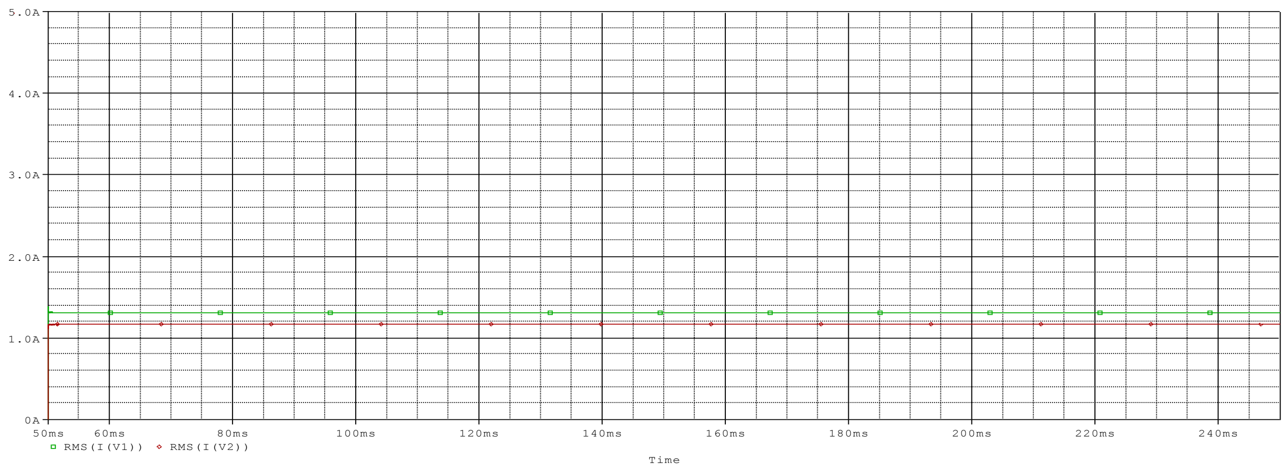


Figure-4.43: Input current for power source-1&2 of Dual input dc-dc boost converter at f=20 kHz, D=0.1, RL=50Ω

4.3.13 AT F=25 kHz; D=0.9; RL=50 Ω; L=500uH; C=100uF

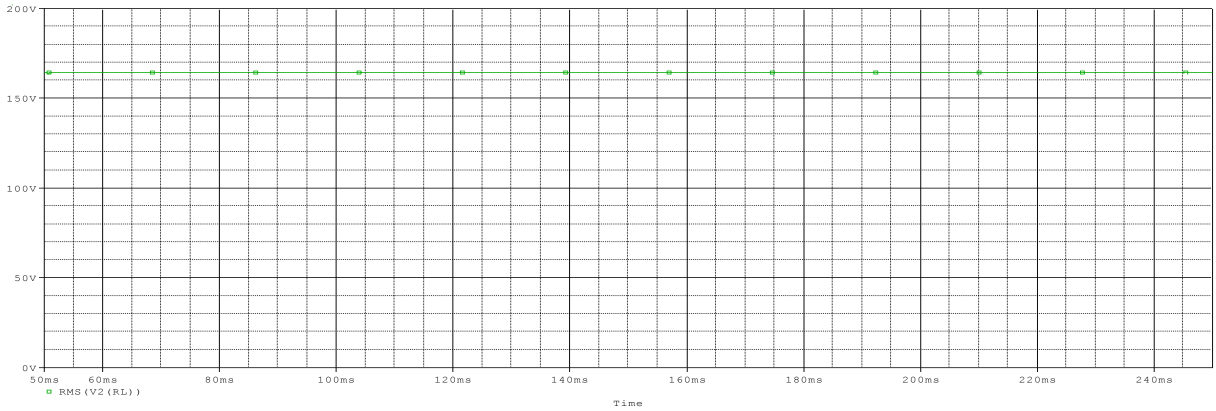


Figure-4.44: Output voltage of Dual input dc-dc boost converter at f=25 kHz, D=0.9, RL=50Ω

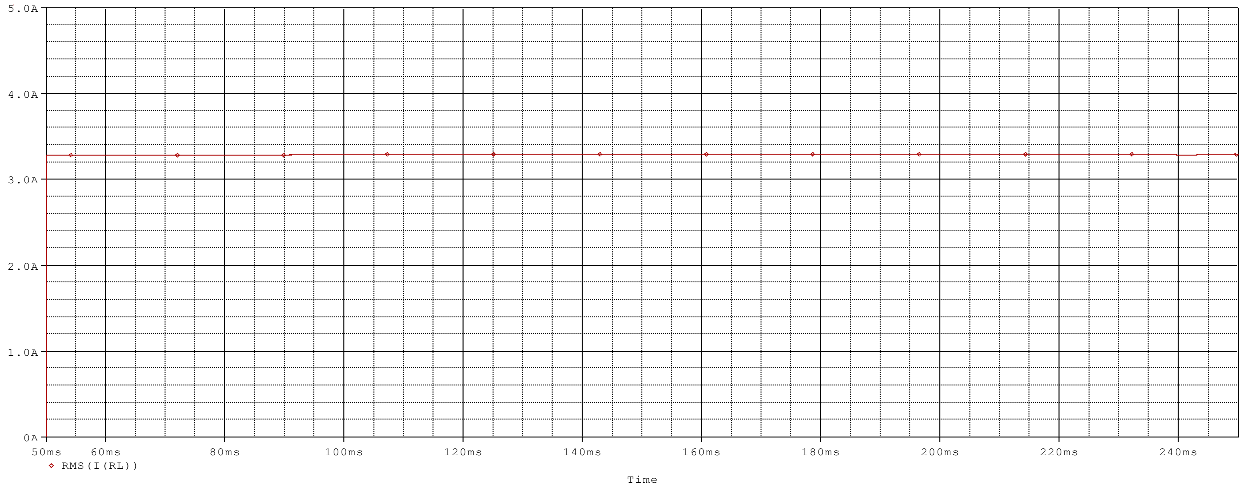


Figure-4.45: Output current of Dual input dc-dc boost converter at f=25 kHz, D=0.9, RL=50Ω

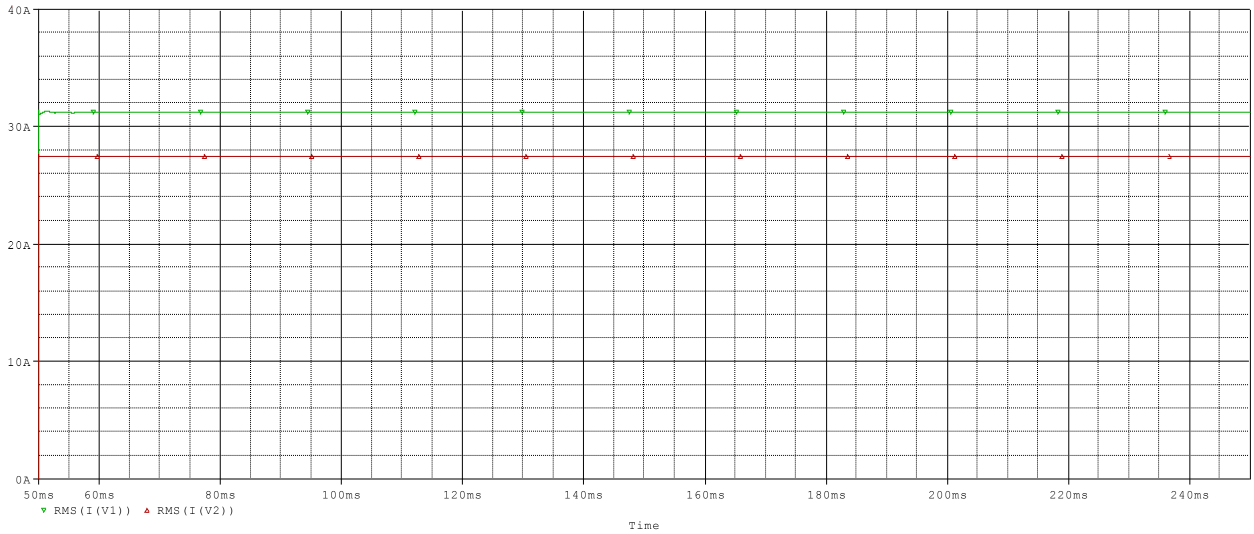


Figure-4.46: Input current for power source-1&2 of Dual input dc-dc boost converter at f=25 kHz, D=0.9, RL=50Ω

4.3.14 AT F=25 kHz; D=0.9; RL=100 Ω; L=500uH; C=100uF

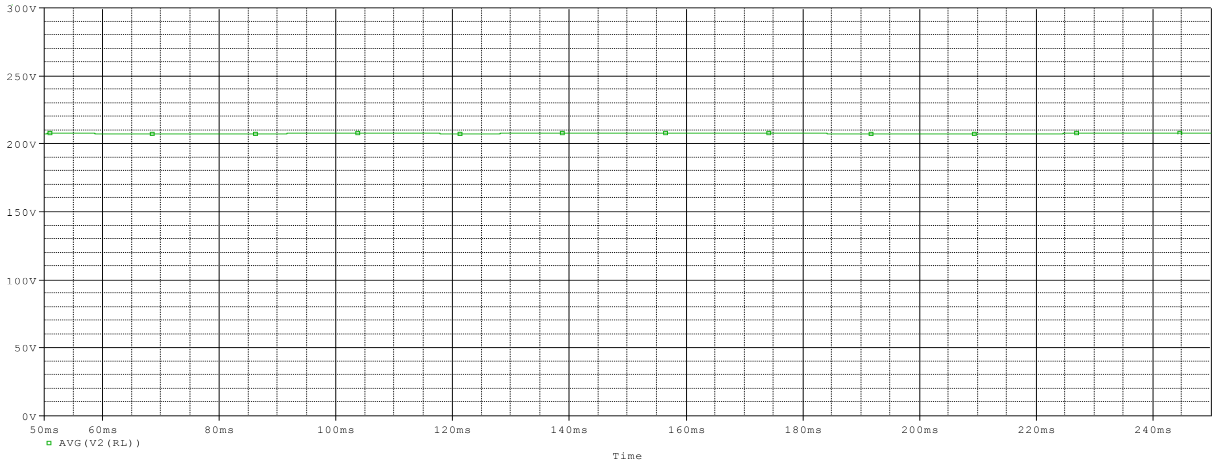


Figure-4.47: Output voltage of Dual input dc-dc boost converter at f=20 kHz, D=0.9, RL=100Ω

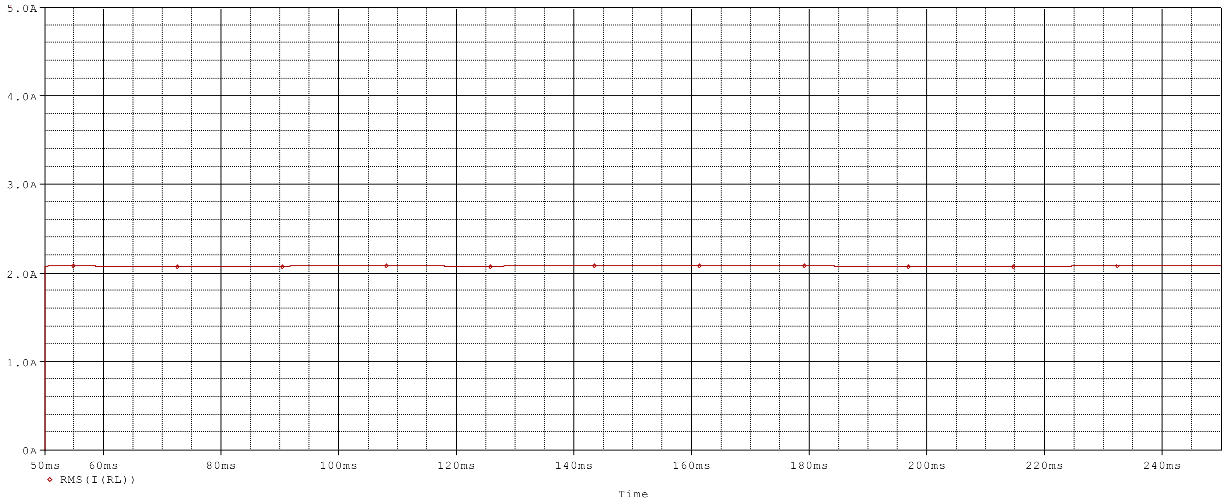


Figure-4.48: Output current of Dual input dc-dc boost converter at f=25 kHz, D=0.9, RL=100Ω

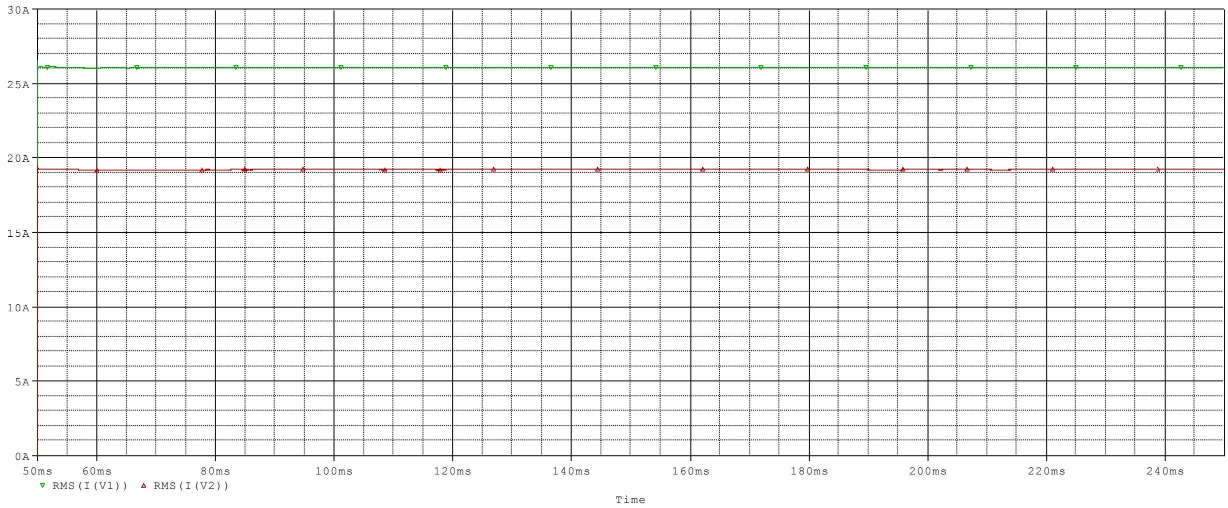


Figure-4.49: Input current for power source-1&2 of Dual input dc-dc boost converter at f=25 kHz, D=0.9, RL=100Ω

4.3.15 AT F=25 kHz; D=0.75; RL=100 Ω; L=500uH; C=100uF

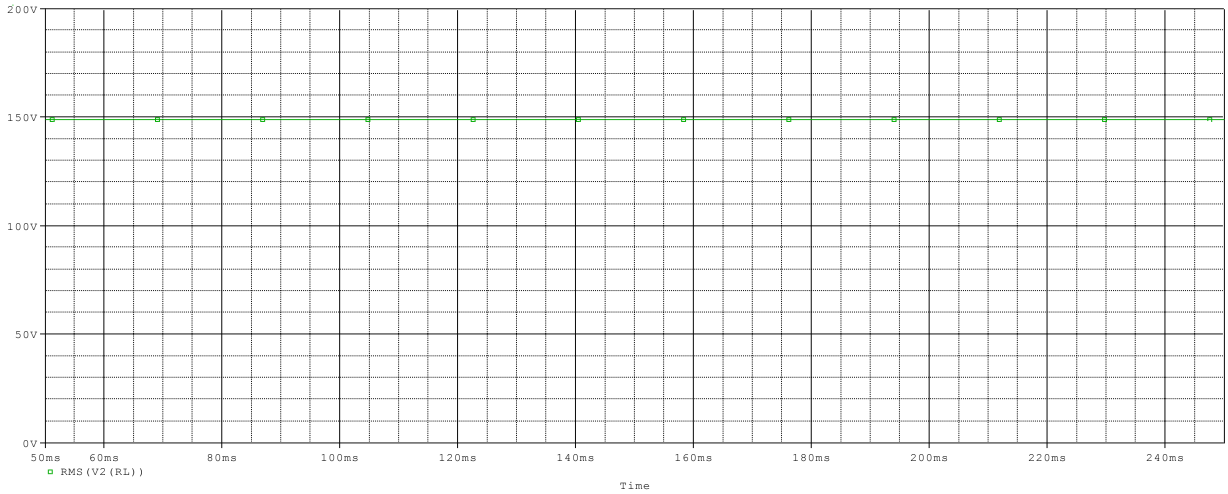


Figure-4.50: Output voltage of Dual input dc-dc boost converter at f=25 kHz, D=0.75, RL=1000Ω

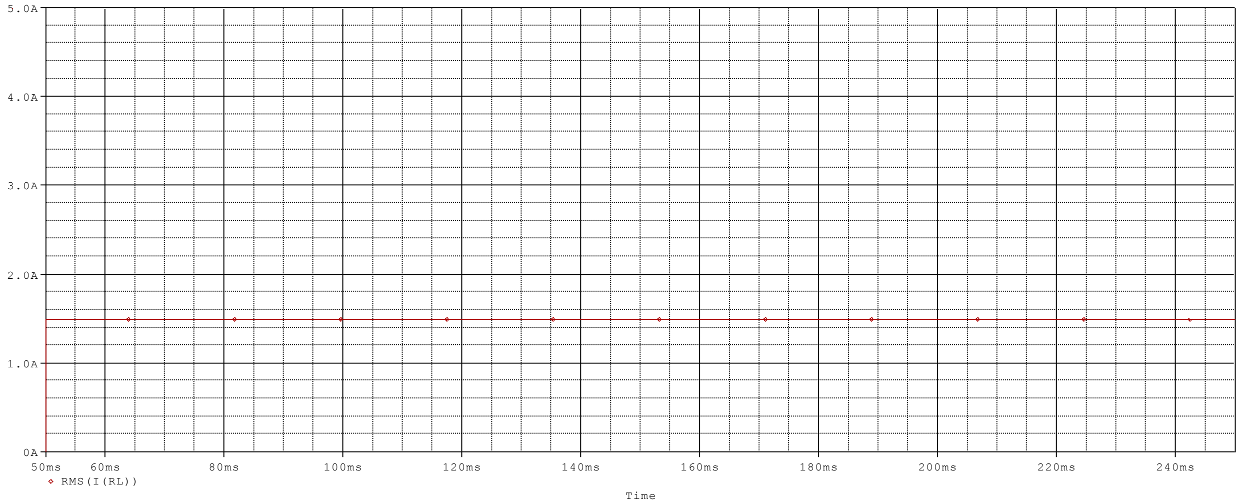


Figure-4.51: Output current of Dual input dc-dc boost converter at f=25 kHz, D=0.75, RL=100Ω

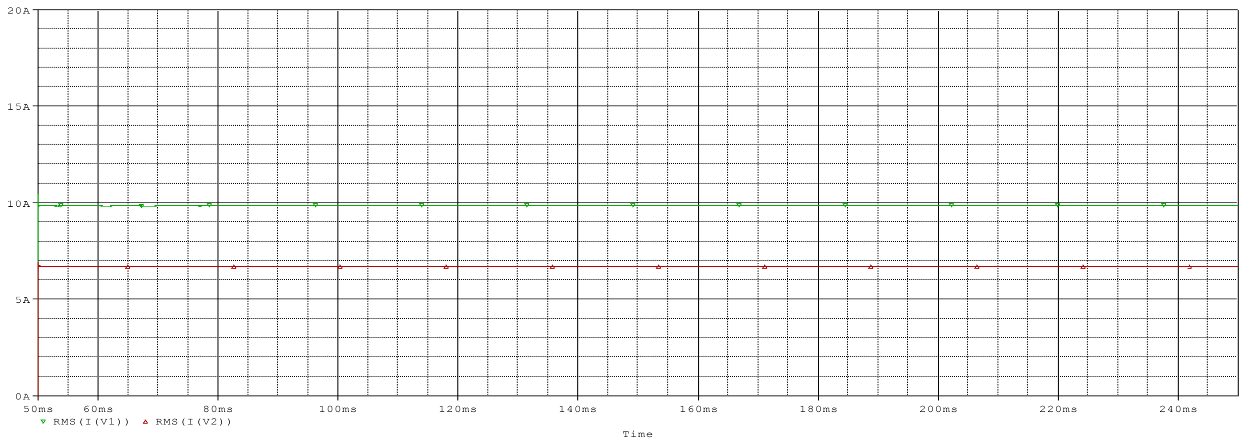


Figure-4.52: Input current for power source-1&2 of Dual input dc-dc boost converter at f=25 kHz, D=0.75, RL=100Ω

4.3.16 AT F=25 kHz; D=0.5; RL=100 Ω; L=500uH; C=100uF

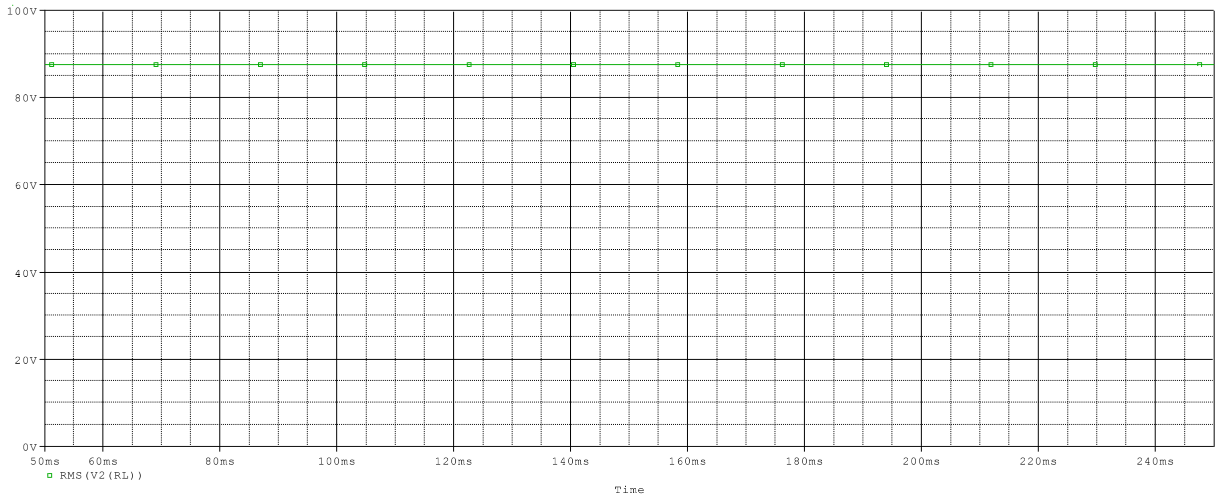


Figure-4.53: Output voltage of Dual input dc-dc boost converter at f=25 kHz, D=0.5, RL=100Ω

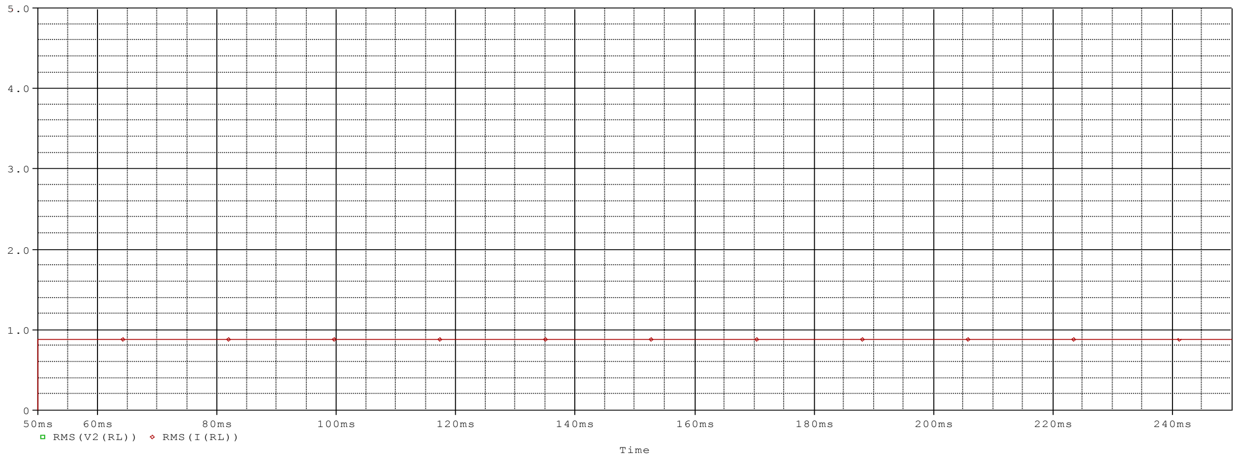


Figure-4.54: Output current of Dual input dc-dc boost converter at f=25 kHz, D=0.5, RL=100Ω

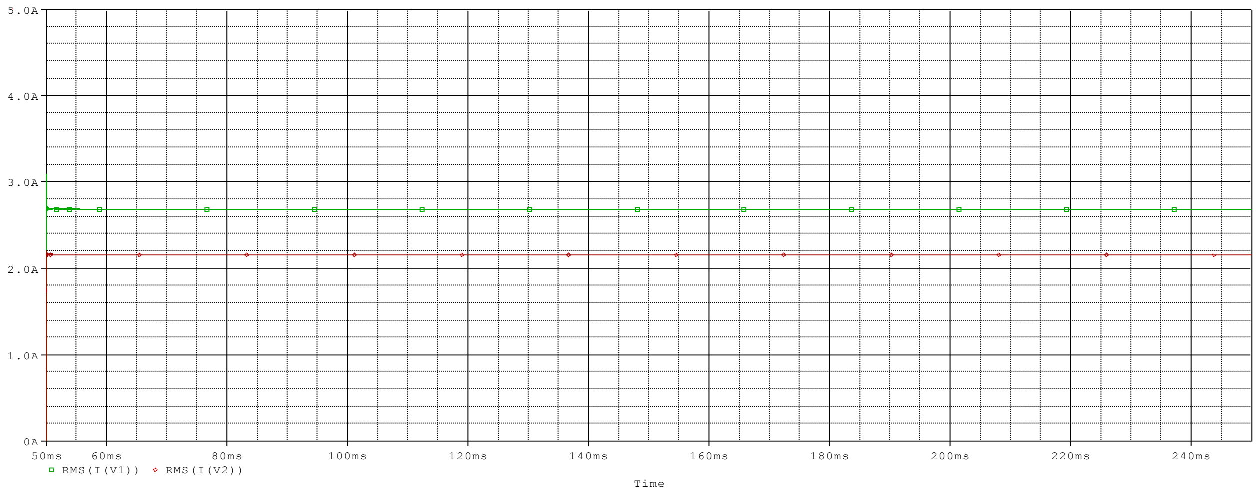


Figure-4.55: Input current for power source-1&2 of Dual input dc-dc boost converter at f=25 kHz, D=0.5, RL=100Ω

4.3.17 AT F=25 kHz; D=0.25; RL=50 Ω; L=500uH; C=100uF

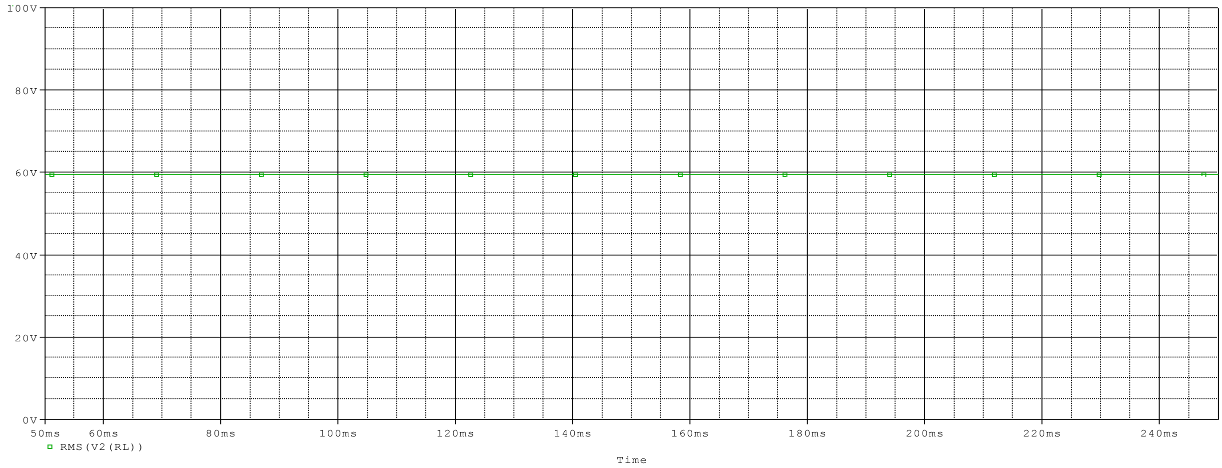


Figure-4.56: Output voltage of Dual input dc-dc boost converter at f=25 kHz, D=0.25, RL=50Ω

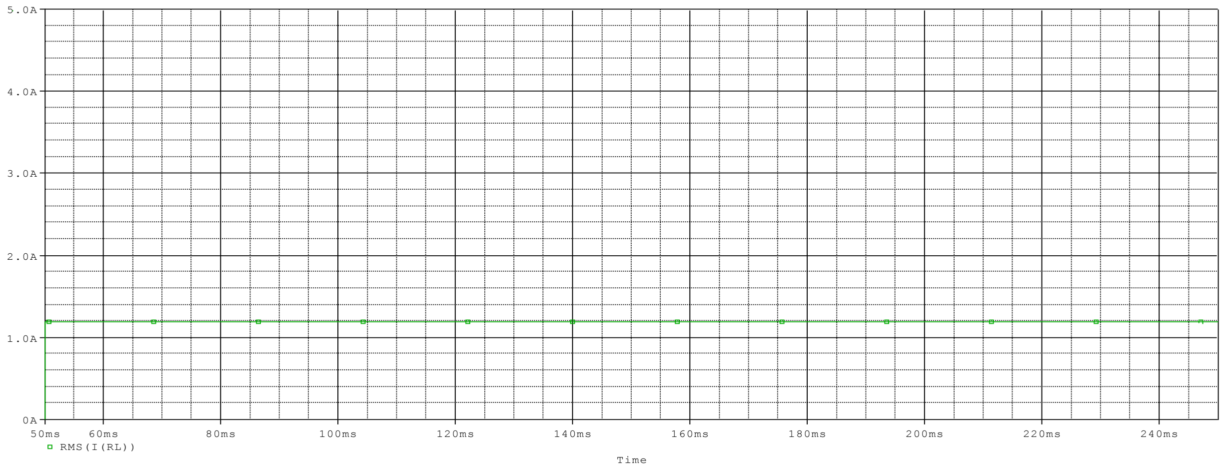


Figure-4.57: Output current of Dual input dc-dc boost converter at f=25 kHz, D=0.25, RL=50Ω

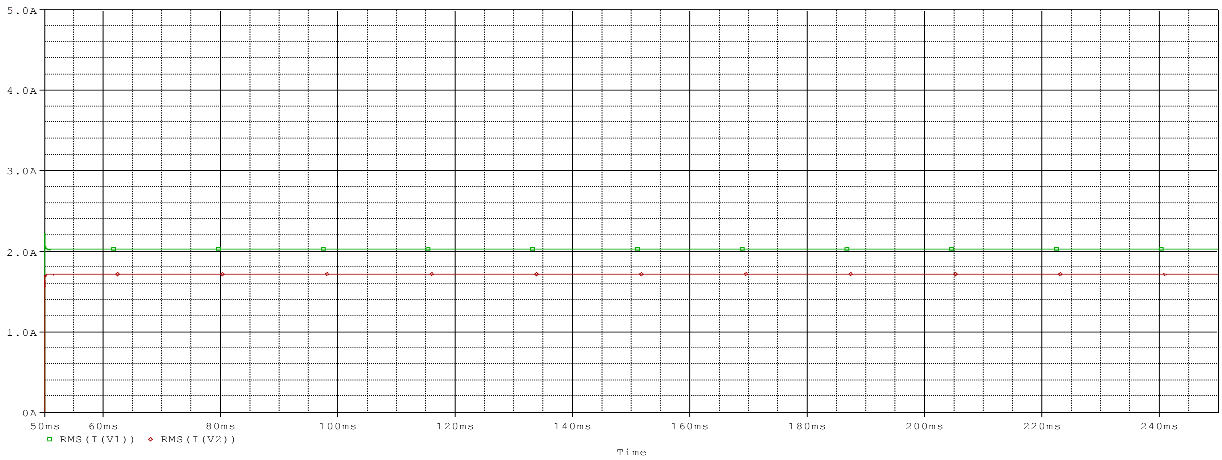


Figure-4.58: Input current for power source-1&2 of Dual input dc-dc boost converter at f=25 kHz, D=0.25, RL=50Ω

4.3.18 AT F=25 kHz; D=0.1; RL=20 Ω; L=500uH; C=100uF

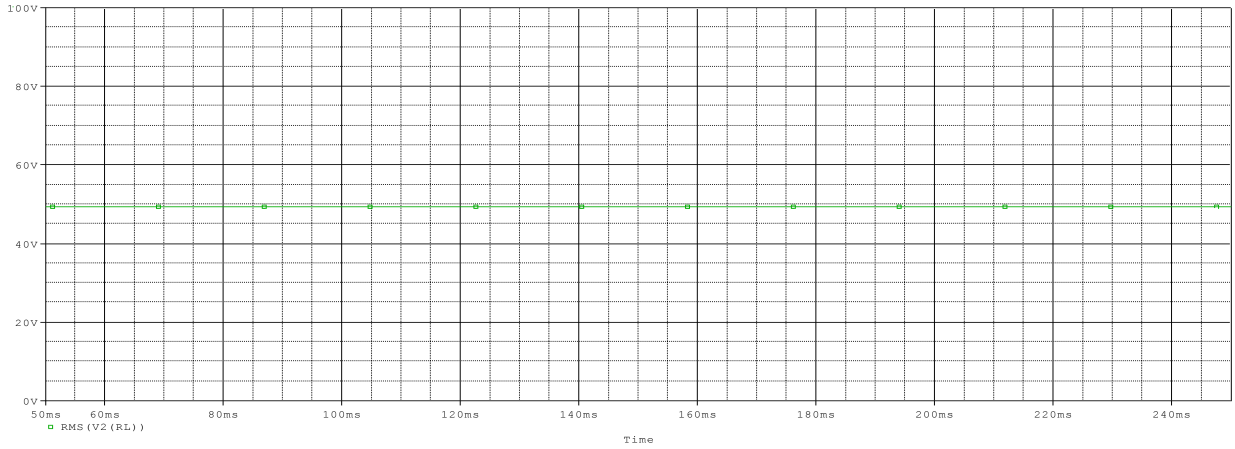


Figure-4.59: Output voltage of Dual input dc-dc boost converter at f=25 kHz, D=0.1, RL=20Ω

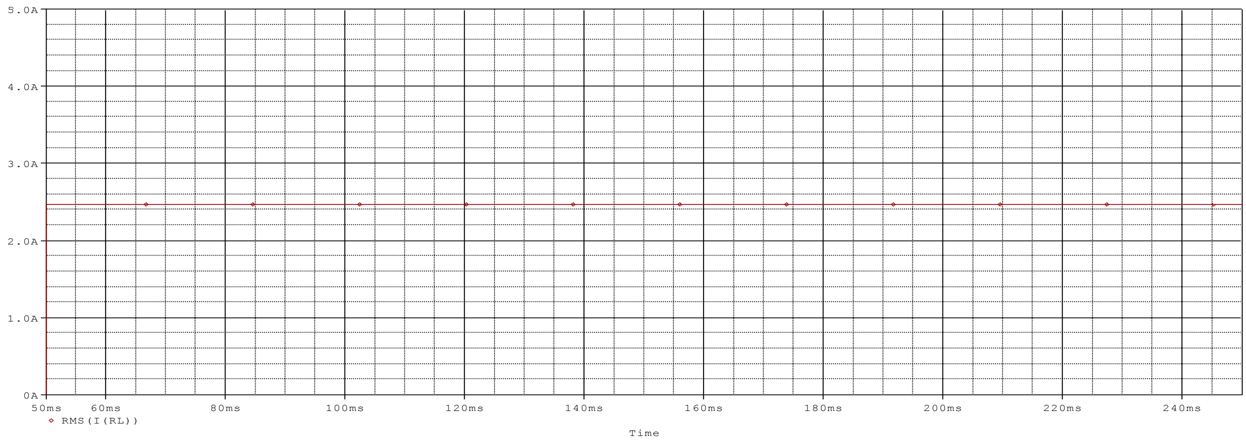


Figure-4.60: Output current of Dual input dc-dc boost converter at f=25 kHz, D=0.1, RL=20Ω

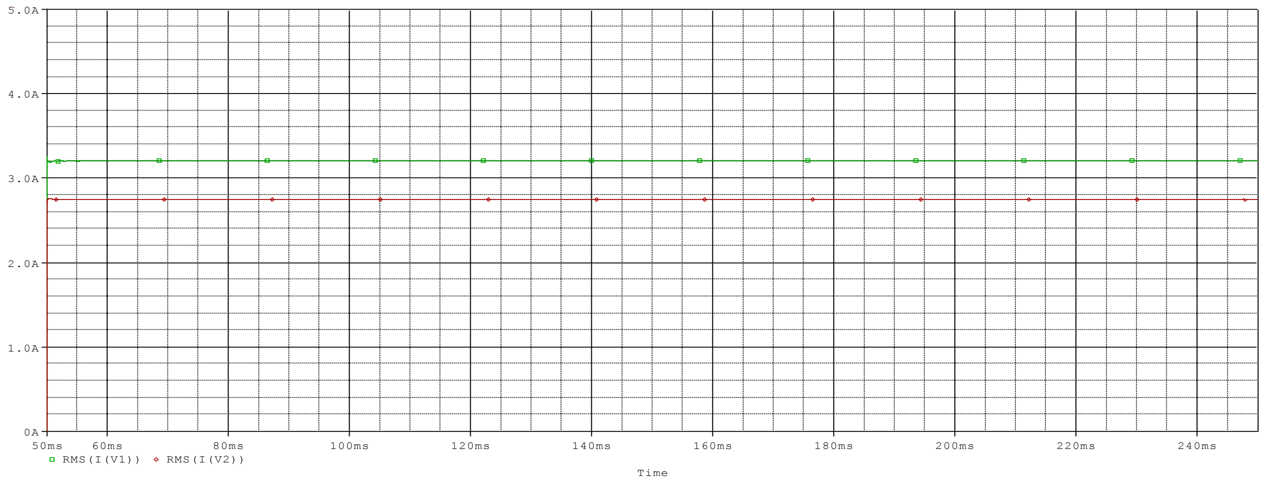


Figure-4.61: Input current for power source-1&2 of Dual input dc-dc boost converter at f=25 kHz, D=0.1, RL=20Ω

4.4 Summary of Data

Input voltage, V_{in1}=24 V; Input voltage, V_{in1}=24 V
Inductor, L= 500uH; capacitor, C=100uF

Table-4.2: Experimental Data

Frequency (kHz)	Duty Cycle	R_L (Ω)	I_{in1} (A)	I_{in2} (A)	P_{in} (W)	V_{out} (V)	I_{out} (A)	P_{out} (W)	Efficiency, η (%)
10	**0.90**	**50**	**19.5**	**16**	**852**	**178**	**4.5**	**801**	**94.01**
10	0.90	100	23	19	1008	240	3.8	931	92.36
10	0.75	20	19	17	864	125	6.2	775	89.7
10	0.75	50	13	10	552	151	3	453	82.06
10	0.75	200	5.5	4.5	240	171	1.3	222.3	92.62
10	0.50	50	4.3	4	199.2	89	1.8	160	80
10	0.25	50	1.9	1.8	88.8	61	1.2	73.2	82.4
10	0.15	50	1.4	1.4	67.2	54	1.1	59.4	88.4
20	0.75	20	26	22.5	1164	112	5.6	627.2	53
20	0.75	50	15.2	11.2	633.6	140	2.8	392	61.8
20	0.75	10	10	9	456	154	1.5	231	50.6
20	0.50	20	10	8.2	436.8	82	4.1	336.2	76.9
20	0.50	50	10	3.8	201.6	86	1.7	146.2	72.5
20	0.50	100	4.6	2.2	115	88	0.9	79.2	67.2
20	0.25	20	2.6	4	206.4	59	2.9	171	82.8
20	0.25	50	4.6	1.7	88.8	60	1.2	72	81
20	0.25	100	1.08	0.9	64.8	60	0.7	36	55.5
20	0.10	20	3.1	2.8	141.6	50	2.5	125	88.3
20	0.10	50	1.25	1.2	58.8	50	1	50	85
25	0.90	20	34	34	1632	90	4.5	405	24.48
25	0.90	50	31.2	27.3	1404	162	3.3	534.6	38
25	0.90	100	26	19	1080	209	2.1	438.9	40.6
25	0.75	20	25.5	21	1116	110	5.5	605	54.2
25	0.75	50	15.5	11	636	136	2.7	367.2	58.2
25	0.75	100	10	6.8	403.2	150	1.5	225	55.8
25	0.50	20	10.2	8	436.8	80	4	320	73.3
25	0.50	50	4.8	3.7	204	85	1.7	144.5	70.8
25	0.50	100	3.7	2.2	117.6	87	0.9	78.3	64.4
25	0.25	20	4.7	3.9	206.4	58	2.9	168.25	81.5
25	0.25	50	2	1.7	88.8	60	1.2	72	81.08
25	0.25	100	1.1	0.98	50	60	0.6	36	72
25	0.10	20	3.2	2.7	141.6	50	2.5	125	88.3
25	0.10	50	1.3	1.1	57.6	50	1	50	86.8

Table 4.2: Summary of Experimental Data

4.5 Comments on Results

By analyzing the entire simulation it has seen that this dual input DC/DC boost converter gives high efficiency and high voltage gain at low frequency (about 10 kHz). The optimum voltage gain at a standard load (about 50 Ω) with some fixed parameters can be obtained. The optimum efficiency of the converter has shown about 94.01%. It is seen that if the value of resistance is increased, the output voltage is increased. The efficiency goes low if the duty cycle is decreased and frequency is increased.

Chapter-5

Conclusion

5.1 Conclusion

In this study, a high-efficiency dual-input converter is investigated, and this converter directly utilizes the current source type applying to both input power sources. By analyzing the topologies of multi-input converters, the method for synthesizing converters was inspired by adding an extra pulsating voltage or a current source to a converter with an appropriate connection. The proposed converter not only can be used for a dual power source to obtain high-efficiency conversion, but also can be effectively operated at single and multi-power-supply state. Based on the series-connected input circuits and the designed pulse width modulation (PWM) driving signals, the conduction loss of the switches can be greatly reduced in the dual power-supply state. Consequently, the proposed dual-input converter can efficiently convert two power sources with different voltages to a stable dc-bus voltage.

When the proposed converter is operated in the dual power supply state with two input power sources, it can be taken as a superposition process of the primary and secondary input circuits.

The proposed converter utilizes the primary and secondary input circuits to be connected in series and operates in continuous conduction mode (CCM). The phenomenon of a high reverse-recovery current in a traditional step-up converter will be greatly alleviated via the utilization of an auxiliary inductor in series connected with a diode when the diode current falls to zero in comparison with the traditional step-up converters.

The proposed high-efficiency dual-input converter also can work well in high-power level applications because the switching losses can be greatly reduced due to the ZVS property. The effectiveness of the designed circuit topology and the ZVS properties are verified by experimental results, and the goal of high-efficiency conversion can be obtained. From the experimental results, the maximum efficiency is measured about 94% where the conduction loss can be effectively reduced by the proposed topology and switching mechanism.

5.2 Limitation

Conventional converter structures have the disadvantages of large size, complex topology, and expensive cost. In addition, the hard-switching problem and the huge reverse-recovery current within the output diode degrade the conversion efficiency as a traditional boost converter.

If the proposed dual-input DC/DC boost converter in this study is used for renewable energy applications, the ground leakage current issue due to the high-frequency voltage swing

between the two negative terminals of the input sources also may cause safety and electromagnetic interference (EMI) problems because the input power sources do not share the same ground.
Moreover, the multi-input inverter topologies are not economic for the non-isolated applications because of the complexity with numbers of electrical components. Although these topologies were designed based on time-sharing concept, the complexity of driving circuits will be increased by the control techniques. The control signals for the primary and secondary input circuits connected in parallel can be widely designed without regard to the series-inductor problem. Again, it would reduce the inductor volume and save two level shifter circuits for the floating switches.

In order to protect the natural environment on the earth, the development of clean energy without pollution such as fuel cell (FC), photovoltaic (PV), wind energy, etc. have been rapidly promoted. Due to the electric characteristics of clean energies, the generated power is critically affected by the climate or has slow transient responses, and the output voltage is easily influenced by load variations.

5.3 Recommendation for Future Work

In order to solve the problem of slow transient response and of being influenced by load variation, a storage element is necessary to ensure proper operation of clean energies. The corresponding installed capacity of clean energies can be further reduced to save the cost of system purchasing and power supply.

The electromagnetic interference (EMI) problems could be solved by the adoption of an EMI filter for a dc power supply application or the integration with advanced inverter topologies for an ac-module application in the future research.

In order to simplify circuit topology, to improve system performance and to reduce manufacturing cost, the above circuit can be implemented with high efficient switching MOSFET (selection of MOSFET model) and can be implemented with hybrid power source in MIST campus.

Moreover, as it is used only resistive load, this circuit can be implemented with RL and RLC load.

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