STUDY OF NON-IDEALITIES OF DC-DC CONVERETERS AND DESIGN USING SIMULATION

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***Abstract*—** In present times DC-DC converters are used in vast number of applications. To acquire high recital control of a dc-dc converter, a good model of the converter is needed. This work consists of modeling of Buck-Boost, Buck and Boost converters (non-isolated DC-DC converters).Each converter is analyzed separately considering the significant non-idealities that affect the converters behavior. Firstly theoretical analysis for each converter (in continuous conduction) is done taking necessary conditions and considerations and certain models are developed. The validity of these models is determined by comparing theoretical results with simulation results. The converters are simulated using PSIM software and the corresponding results are obtained. The theoretical calculations and simulated results along with circuit diagrams and waveforms are presented in this model

Keywords*—*DC- DC converter, buck converter, boost converter, buck- boost converter, PSIM

I. INTRODUCTION

Every electrical circuit is meant to work with a constant supply voltage. A voltage control is a power electronic circuit that maintains a consistent output voltage regardless of load current or line voltage variations. Voltage regulators are available in a range of shapes and sizes, as well as control methods. With the increasing complexity of the circuit and technological developments, there is a higher demand for accurate and quick control. As a result, more reliable dc-dc converter designs are necessary. A direct current to direct current converter converts an uncontrolled direct current voltage input to a constant or regulated voltage output. Linear and switching regulators are the two most prevalent types of regulators. Every regulator has a power transfer stage and control circuitry that senses the output voltage and adjusts the power transfer stage to keep it constant. DC–DC converters are wield in many modern electrical staging, such as electric/hybrid automobiles. These are electronic devices that are used when converting DC electrical power from one voltage level to another. Alternatively, we want the conversion to be as efficient as feasible. In transportation networks with frequent pauses, dc converters can be utilized in regenerative braking of dc motors to return energy to the source, conserving energy.

The author presents a non-isolated large gain DC-DC converter that does not employ a voltage multiplier cell or a hybrid flipping capacitor strategy. The suggested steady-state analysis of a converter with two distinct duty cycles ratios is discussed in detail [1]. The goal of this work is to offer a new way for managing the initialization of fuel cells as a major source in a micro-grid. The frequency and step responses for various gain-scheduling are analyzed to determine the practicality of the suggested approach [2]. This paper is about a boost dc-dc converter for use in fuel cells. The fuel ripple is also reduced by this converter [3]. The design of a 50-kW bidirectional DC-DC converter with ultra-high efficiency in ZVS operation is presented in this paper, followed by a high-precision efficiency measuring technique based on regenerative approach [4]. This research suggests a modular quasi-resonant bidirectional dc-dc converter constructed of half-bridge gallium nitride modules with reduced switch voltage stress. [5]. Satellite DC/DC power converters must be EMI compatible as well as very reliable. The authors of this study built satellite DC-DC power converters. [6].

II. METHODLOGY AND PROPOSED METHOD

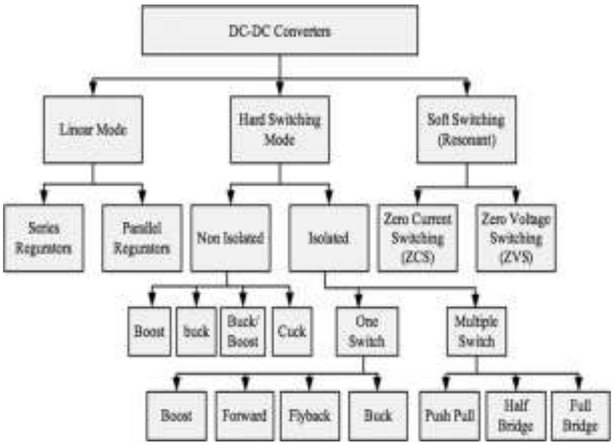

Fig.1: Types of DC-DC converters

A. Magnetic Conversion: In these DC-DC converters, energy is hoard and let go on a regular basis from a transformer or magnetic field in an inductor at frequencies ranging from 300 KHz to 10MHz. The transformer-based converter isolates the input and output. The amount of power provided to a load may be easily controlled by adjusting the charging voltage's duty cycle. This control can also be sought to the output and input currents to maintain a consistent power. The transformer-based converter isolates the input and output.

B. Electronic Conversion: In electrical circuits, the switching method is wield in DC to DC converters. A mode that is switched The DC-DC converter changes the DC voltage level by briefly retaining the input energy before releasing it at a different voltage output. Magnetic field components like as inductors and transformers, as well as electric field components such as capacitors, are wield to store data. This type of conversion can be wield to increase or decrease the voltage level. A switched-mode converter's excellent efficiency decreases the amount of heat sinking necessary, extending the battery life of portable devices.

C. Isolated converters: The input and output parts of these converters are separated. The voltage isolation is quite high. They have the ability to filter out noise and interference. As a result, they are able to provide a cleaner DC supply. They are divided into two categories.

1. Fly back converter 2. Forward converter

D. Non-Isolated Converters: Non-isolated converters are used when the voltage change is nominal. The input and output parts of this circuit share a common ground. Different non-isolated converters are:

1. Buck Converter: A buck converter is a DC-to-DC power converter that lowers the voltage from input to output. It is a smps that has at least three different semiconductors and one energy storage device (capacitor, inductor, or both). To lessen voltage ripple, capacitor-based filters are routinely added to the load-side and input-side filters of a follower, sometimes in conjunction with inductors.

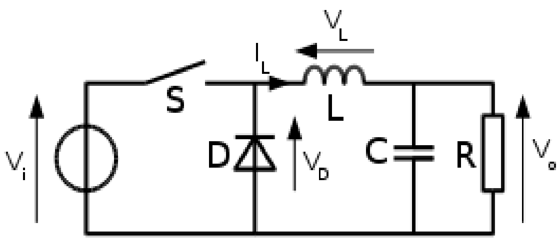

Fig.2 : Ideal Buck Converter

2. Boost Converter: A step-up conversion is a DC-to-DC device that service which allows while dropping current from input to output. It is a smps that has at least two semiconductors, a diode and a transistor, as well as at least one energy storage device, such as a capacitor, inductor, or a combination of the two. To lower ripple voltage, capacitor filters, generally in cooperation with inductors, are traditionally applied to the output and input side filters of such a converter.

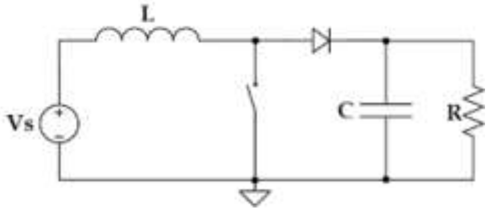

Fig.3 : Ideal Boost Converter

3. *Buck-Boost Converter*: A buck–boost converter is a DC–DC converter that has an output voltage magnitude that is more or less than the input voltage magnitude. It works in the same way as a flyback converter, except instead of a transformer, it uses a single inductor. This is a switched-mode power supply featuring a step-up converter and buck converter-like circuit architecture. The duty cycle of the switching transistor is wield to modify the output voltage.

In this study, investigate the buck, boost, and buck-boost converters and build a buck-boost diagram while taking into account the circuit's various non-idealities. We consider five alternative scenarios, each with its own set of non-idealities, and obtain the required equations for the buck-boost converter in each case.

3.1 *Ideal Buck-Boost Converter:*

Fig.4 gives the diagram of an Clasical Buck-Boost Converter

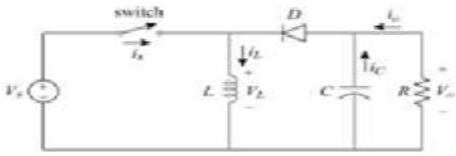

Fig.4 : Ideal Buck-Boost Converter

V_s = input or source voltage
V_O = output voltage
I_o = output current
V_L = voltage across inductor
I_L = inductor current

(1).During switch on $V_L = Vs$

During switch off $V_L = Vo$

Considering *volt-sec balance*

$$V_{L(on)}t_{on} + V_{L(off)}t_{off} = 0$$
$$Vs(DT) + (Vo)\big((1-D)T\big) = 0$$

Output voltage, $Vo = -\frac{DVs}{1-D}$ (1)

By rearranging the terms, duty ratio,

$$D = \frac{-Vo}{Vs - Vo} \qquad (2)$$

Because the duty cycle spans from 0 to 1, the output voltage's polarity is always negative, and its absolute value grows with D, theoretically reaching minus infinity as D approaches 1. Aside from polarity, this converter may be step-up or step-down. As a result, it is known as a buck–boost converter.

ISSN: 2278-4632
Vol-12 Issue-10 No.02 October 2022

(2).During on state $I_C = -I_O$

During off state $I_C = -I_L - I_O$

Using amp-sec balance

$I_C(on)t_{on} + I_C(off)t_{off} = 0$

$(-I_O)(DT) + (-I_L - I_O)((1-D)T) = 0$

By rearranging the terms we get,

$$\boldsymbol{I_L = \frac{-I_O}{(1-D)}} \qquad (3)$$

(3).During on

$V_{L(ON)} = Vs$

$L\frac{dI_{on}}{dt_{on}} = Vs$

$L\frac{\Delta I_l}{DT} = Vs$

Ripple in inductor current,

$$\boldsymbol{\Delta I_L = \frac{DVs}{fL}} \qquad (4)$$

(4).Ripple in voltage,

$I_C = -I_O$

$\int_{V_{max}}^{V_{min}} dV_C = \int_0^{DT} -\frac{I_o}{C}DT$

$V_{min} - V_{max} = -\frac{I_O}{C}DT$

$$\boldsymbol{\Delta V_C = \frac{DI_O}{fC}} \qquad \textbf{(5)}$$

(5).Critical inductance:

$I_{L(\min)} = 0$

$I_L - \frac{\Delta I_L}{2} = 0$

$\frac{-Io}{(1-D)} = \frac{-V_O}{R(1-D)} = \frac{\Delta I_L}{2}$

$\frac{DV_S}{(1-D)R(1-D)} = \frac{1}{2}(\frac{DV_S}{fL_C})$

$$\boldsymbol{L_C = \frac{(1-D)^2R}{2f}} \qquad (6)$$

(6).Critical capacitance:

$V_{C(min)} = 0$

$Vc - \frac{\Delta Vc}{2} = 0$

$Vo = \frac{\Delta Vc}{2}$

$Vo = \frac{1}{2} * \left(\frac{DI_O}{fC}\right) = \frac{1}{2} * \left(\frac{DV_O}{RfC}\right)$

$$\boldsymbol{C_C = \frac{D}{2fR}} \qquad (7)$$

3.2 *When inductor is non-ideal*:

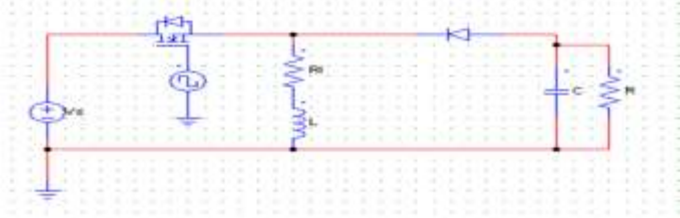

Fig. 5: Buck-Boost Converter considering inductor as non-ideal

Fig.5 is the diagram of buck-boost converter considering inductor as non-ideal
From the diagram,
During on state, $V_L = Vs - I_L R_L$
During off state, $V_L = Vo - I_L R_L$
Applying *Volt-sec* balance:
$V_{L(on)} t_{on} + V_{L(off)} t_{off} = 0$
$(Vs - I_L R_L)(DT) + (Vo - I_L R_L)\big((1-D)T\big) = 0$
By rearranging the terms we get,

$$\boldsymbol{D} = \frac{-\boldsymbol{Vo}+\boldsymbol{I_L R_L}}{-\boldsymbol{Vo}+\boldsymbol{Vs}} \qquad (8)$$

Here, Vo=output voltage
Io=output current
Vs=input current
IL=inductor current
3.3 *When switch is non-ideal*:

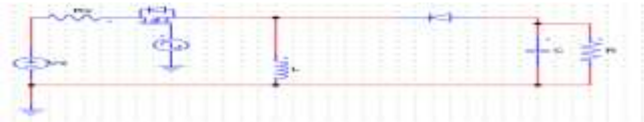

Fig.6: Buck-Boost Converter considering switch as non-ideal

Rs is the series resistance representing the power loss of the switch.
From the diagram,
When switch is on, $V_L = V_S - I_L R_S$
When switch is off, $V_L = V_O$
Taking Volt-sec balance:
$V_{L(on)} t_{on} + V_{L(off)} t_{off} = 0$
$(V_S - I_L R_S)(DT) + (V_O)\big((1-D)T\big) = 0$
$V_S D - I_L R_S D + V_O - V_O D = 0$
By rearranging the terms, we get,

$$\boldsymbol{D} = \frac{-\boldsymbol{V_O}}{-\boldsymbol{V_O}-\boldsymbol{I_L R_S}+\boldsymbol{Vs}} \qquad (9)$$

Here, Vo=output voltage
Vs=input voltage
I_L=inductor current

ISSN: 2278-4632
Vol-12 Issue-10 No.02 October 2022

3.4 *When diode is non-ideal:*

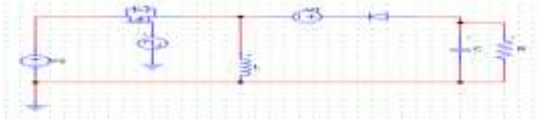

Fig.7: Buck-Boost Converter considering diode as non-ideal

Here Vf represents the diode cut-in voltage.
From the diagram,
When switch is on, $V_L = V_S$
When switch is off, $V_L = -V_F + V_O$
Applying volt-sec balance:

$V_{L(on)}t_{on} + V_{L(off)}t_{off} = 0$
$(V_S)DT+(-V_F + V_O)\big((1-D)T\big) = 0$
$(V_S)D+(-V_F + V_O)\big((1-D)\big) = 0$

By rearranging the terms, we get

$$\boldsymbol{D} = \frac{-V_O+V_F}{Vs-V_O+V_F} \qquad (10)$$

Here, Vo=output voltage
Vs=input voltage

3.4 *When all elements are non-ideal:*

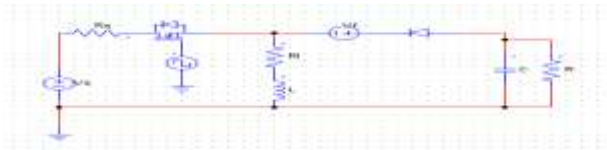

Fig. 8: Buck-Boost Converter considering all elements as non-ideal

In this scenario, we combine all of the non-idealities and investigate the circuit. In the circuit, Rl inductor series resistance represents inductor loss, Rs switch series resistance represents switch loss, and Vf diode cut-in voltage represents diode loss. In this situation, we can now calculate the duty ratio of the converter.
From the diagram,
When switch is on, $V_L = V_S - I_L R_L - I_L R_s$
When switch is off, $V_L = Vo - I_L R_L - V_F$
Taking volt-sec balance equation:

$V_{L(on)}t_{on} + V_{L(off)}t_{off} = 0$
$(V_S - I_L R_L - I_L R_s)DT + (-I_L R_L - V_F + V_O)((1-D)T) = 0$

On rearranging the terms we get,

$$\boldsymbol{D} = \frac{-V_O+I_L R_L+V_F}{Vs-V_O-I_L R_S+V_F} \qquad (11)$$

Here, Vo=output voltage
Io=output current
Vs=input current
IL=inductor current

4**.** *Selection of the Switch***:**
The minimization of losses is considered while selecting an appropriate power MOSFET for each application. The duration of the switching rise and fall is determined by the current, duty cycle,

ISSN: 2278-4632
Vol-12 Issue-10 No.02 October 2022

switching frequency, and durations of the switching rise and fall. MOSFET selection generally takes into account the device's rating as well as its capacity to manage the system's power. The intrinsic MOSFET characteristics investigated in this system are high breakdown voltage VDSS, current carrying capacity ID, and resistance RDS (on).The switch uses an IRFP350 power MOSFET with a low RDS(on) = 0.3.

5. *Selection of the Diode:*

The reverse breakdown voltage, Vrr, forward voltage drop, Vf, and forward current are the diode selection parameters. The OFF time of a diode is essential for efficiency in high frequency applications. A quick recovery diode is necessary to reduce voltage and current overlapping across the diode, which increases power losses. It is also critical to have a high Vrr (reverse breakdown voltage) (the stress on the diode when the switch is closed). A lower forward voltage drop Vf is also required, as is a higher forward current If. The diode type BYT12P was chosen since its ratings are enough for maintaining the system's ratings.

6. *Selection of passive components:*

The inductor and capacitor are types of passive components. The inductor must be able to withstand a peak current without saturating in this system. It is important that the inductor retains its inductance at high operating temperatures based on board temperature and inductor loss. High current in the MOSFET is caused by a saturating inductor, which reduces application reliability and may induce electrical overstress, which may damage the MOSFET.

The winding resistance of an inductor is defined as r_L.

The believable capacitor ESL and ESR are both included. ESL, or equivalent series inductance, is often neglected but becomes important at high frequencies. The capacitor's voltage rating must be greater than the output voltage.

7. *Duty ratio:*

The duty ratio for each converter in each case is determined based on the above parameters by inserting the values in the equations derived in above equations. Because of the influence of various non-idealities, the duty ratio differs in each situation. The input voltage is known, therefore we calculate the output voltage and power based on our requirements. The other parameters, such as the ratings of circuit components, are calculated based on these parameters. The duty ratio is now determined by plugging all of these variables into duty ratio formulae. The duty ratio in each case is represented in the table below.

Cases	Buck converter	Boost converter	Buck-Boost converter	
			Buck mode	Boost mode
Ideal	0.4545	0.375	0.3093	0.619
When inductor is non-ideal	0.4687	0.4062	0.3192	0.6391
When switch is non-ideal	0.5263	0.5357	0.341	0.7613
When diode is non-ideal	0.4871	0.4252	0.3702	0.6389
When all elements are non-ideal	0.5072	0.6267	0.4141	0.7982

TABLE II DUTY RATIO

III. Simulation and Results

A. *Under ideal condition:*

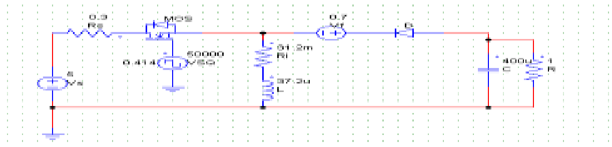

Fig.9 : Ideal Buck-Boost Converter Circuit

Waveforms:

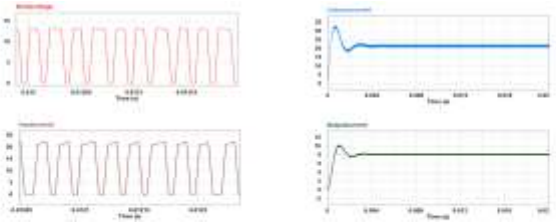

Fig.10: a) Diode voltage, b)Inductor current, c)Input current, d)Output current

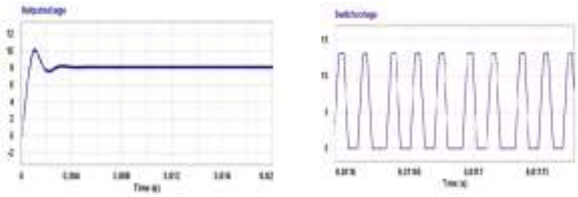

Fig.11: a) Output voltage, b) Switch voltage

Fig.9 is a buck-boost converter circuit connected in PSIM software. Whereas Fig.10 & Fig.11 depicts waveshape of a) Diode voltage, b)Inductor current, c)Input current, d)Output current and a) Output voltage, b) Switch voltage under ideal conditions.

B. *When inductor is non-ideal:*

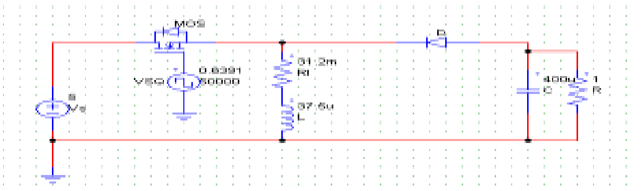

Fig.12: Buck-Boost converter with non-ideal inductor

Waveforms:

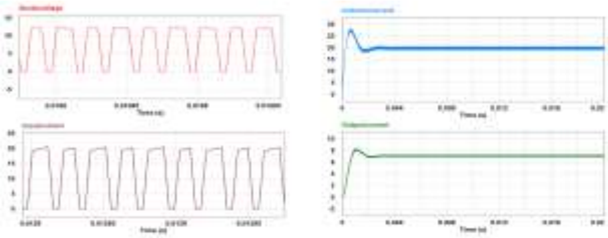

Fig.13: a) Diode voltage, b)Inductor current, c)Input current, d)Output current

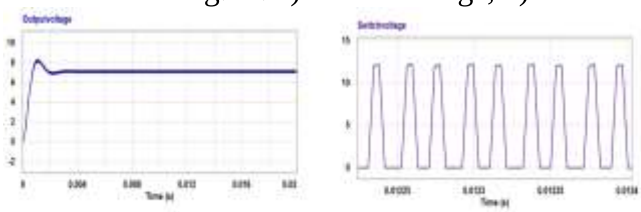

Fig.14: a) Output voltage, b) Switch voltage

ISSN: 2278-4632
Vol-12 Issue-10 No.02 October 2022

Fig.12 is a buck-boost converter circuit connected in PSIM software. Whereas Fig.13 & Fig.13 depicts wave shape of a) Diode voltage, b)Inductor current, c)Input current, d)Output current and a) Output voltage, b) Switch voltage

When inductor is non ideal.

C. When the switch is non-ideal

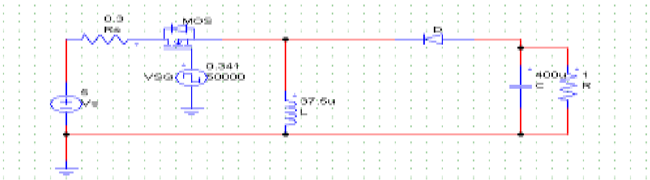

Fig.15: Buck-Boost Converter with non-ideal switch

Waveforms:

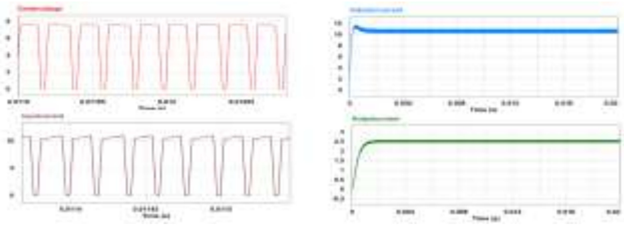

Fig.16: a) Diode voltage, b)Inductor current, c)Input current, d)Output current

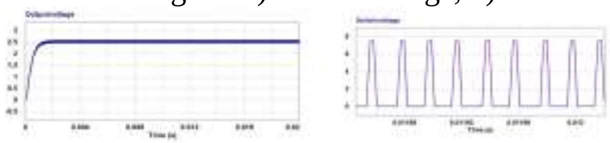

Fig.17: a) Output voltage, b) Switch voltage

Fig.15 is a buck-boost converter circuit connected in PSIM software. Whereas Fig.16 & Fig.17 depicts waveforms of a) Diode voltage, b)Inductor current, c)Input current, d)Output current and a) Output voltage, b) Switch voltage When the switch is non-ideal.

D. When diode is non ideal:

Fig.18: Buck-Boost converter with non-ideal diode

Waveforms:

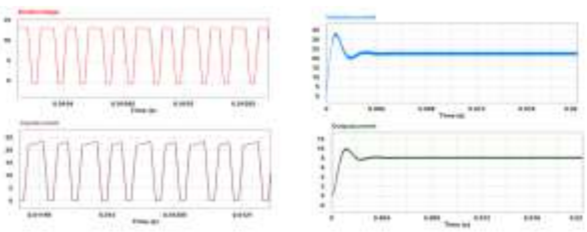

Fig.19: a) Diode voltage, b)Inductor current, c)Input current, d)Output current

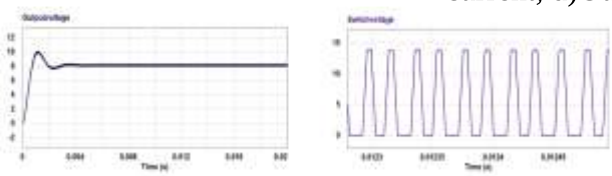

Fig.20: a) Output voltage, b) Switch voltage

ISSN: 2278-4632
Vol-12 Issue-10 No.02 October 2022

Fig.18 is a buck-boost converter circuit connected in PSIM software. Whereas Fig.19 & Fig.20 depicts waveforms of a) Diode voltage, b)Inductor current, c)Input current, d)Output current and a) Output voltage, b) Switch voltage

When diode is non ideal.

E. When all elements are non-ideal:

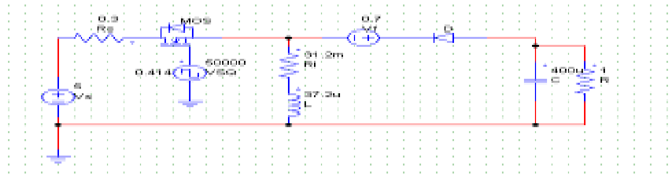

Fig.21: Buck-Boost converter with all non-ideal elements

Waveforms:

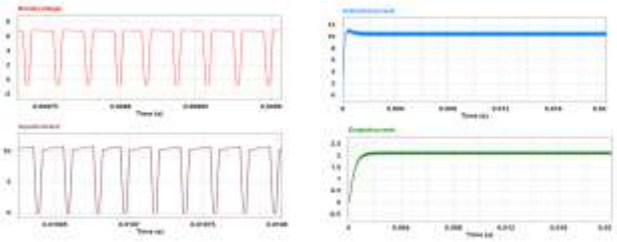

Fig.22: a) Diode voltage, b)Inductor current, c)Input current, d)Output current

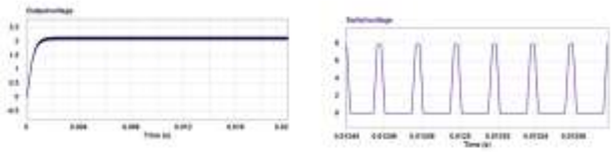

Fig.23: a) Output voltage, b) Switch voltage

Fig.21 is a buck-boost converter circuit connected in PSIM software. Whereas Fig.22 & Fig.23 depicts waveforms of a) Diode voltage, b)Inductor current, c)Input current, d)Output current and a) Output voltage, b) Switch voltage

When all elements are non-ideal.

TABLE I. SPECIFICATION OF PARAMETERS

	Buck converter	Boost converter	Buck-Boost converter	
			Buck mode	Boost mode
Vin(V)	11	5	5	5
Vo(V)	5	8	2.24	8.15
Po(W)	25	64	5	66.4
Io(A)	5	8	2.25	8.15
R(ohms)	1	1	1	1
Ts(uS)	20	20	20	20
L(uH)	37.5	37.5	37.5	37.5
C(uF)	400	400	400	400
rL(m-ohm)	31.2	31.2	31.2	31.2
rC(m-ohm)	14	14	14	14
Rs(ohm)	0.3	0.3	0.3	0.3
Vf(V)	0.7	0.7	0.7	0.7

IV. CONCLUSION

This paper conducted a non-ideal steady-state analysis of a DC–DC converter. Despite the fact that the converter architecture was first described, the literature did not provide a full explanation of the non-ideal performance. The simulation of non-isolated DC-DC converters is part of this research. Each converter is evaluated separately, with the significant non-idealities that impact the converter's

ISSN: 2278-4632
Vol-12 Issue-10 No.02 October 2022

behavior taken into account. The non-ideal studies were entirely based on state-space models, with dynamic losses and conduction calculated for each operating mode separately.

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