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INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Analysis, Design and Simulation of 12v/24v Boost Switching Converter

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Abstract

The objective of this paper is to analyze, design and simulate the Boost (step-up) switching converter which is one of the main parts of solar electric system. The converter performance such as load voltage, currents in capacitor and inductor, ripples of voltages and currents, etc. are analyzed and derived under continuous operations. The design of the converter is performed to step-up the input voltage 12 v from the battery storage equipment to an output voltage of 24v which will be the input to the inverter in solar system. LTspice and Matlab\Simulink programs are used to simulate the Boost switching converter operation using a very high speed MOSFET as a switch with 20 KHZ switching frequency. The simulated results are compared with theoretical and the percentage error is found to be very small**.**

Keywords: Boost converter, Spice and Matlab simulations.

List of Symbols
Δ : Peak-to-peak ripple
C : Capacitor
D : duty cycle
f_s : Switching frequency
Ia : Average current passing through load
Ic, and I_L : Average current passing through capacitor and inductor respectively.
Va : Average output voltage
Vc : Capacitor voltage
Vs : Supply dc voltage.

Introduction

A switching converter or switch-mode power converter (SMPC) is a power electrical system which converts one level of electrical energy into another level of electrical energy at the load by switching action [1,2].

DC/DC converters are considered to be of great economical in today's society, and are perhaps one of the few electronic circuits that are commonly used in switching power supplies, generally are widely used at home solar systems to produce the desired output power. DC-DC converters are becoming the main stream elements in DC generation and distribution systems. From DC transmission systems to highly sensitive low power integrated circuits these converters are becoming highly focused research area, make it clearer for applications ranging from light current devices to heavy current appliances. DC-DC switching converters being reported these days suggest many modern techniques for making an efficient and stable supply almost independent of the environmental changes. The most common and most effective method used is that of Boost converters which used to step up the voltage supply from a lower level to a higher level [3]. In the last few years many Boost converters are proposed for the renewable energy systems [4-7].

The Matlab simulation platform (by Math Works, Inc.) offers a versatile and robust option in design and simulation of power electronic converter systems. Matlab is matrix based, offering diverse options in data manipulation, preparation, and presentation. Simulink, a sub-program of Matlab included in the standard software package, offers a relatively high-level programming language utilizing drag-and-drop function blocks that mask embedded functions [8].

User friendliness is a key factor for the commercial success of any simulation program. The growing complexity of integrated circuits and equipment makes this aspect more and more important. Despite numerous publications devoted to the Simulation Program with Integrated Circuit

Emphasis (SPICE), it still scares the novice when its name is mentioned [9].

In this paper a 12v/24v Boost switching converter is analyzed, designed, and simulated.

A Matlab/Simulink and Spice simulation programs are used to simulate the converter.

Theoretical analysis of boost switching converter

The Boost converter is capable of providing as output voltage that is greater than the input voltage. It is also known as a step-up converter. A boots converter using a MOSFET transistor as the switching transistor is shown in Fig.(1) [1,2]. The operation of the boots converter can be divided into two modes either continuous or discontinuous mode.

A. Mode 1 ($0 < t < t_{on}$)

Mode 1 begins when the switching transistor, M_1, is switched on at a time $t = 0$ and it terminates at $t = t_{on}$. The equivalent circuit for mode 1 is shown in Fig.(2). The diode D_{fw} is reverse biased since the voltage drop across the collector-emitter junction of the switching transistor is smaller than the output voltage. The inductor current, $i_L(t)$, ramps up linearly from I_1 to I_2 in time t_{on} so that:

$$V_s = L\frac{I_2 - I_1}{t_{on}} = L\frac{\Delta I}{t_{on}}$$

(1)

The duration of the interval t_{on} can be expressed as:
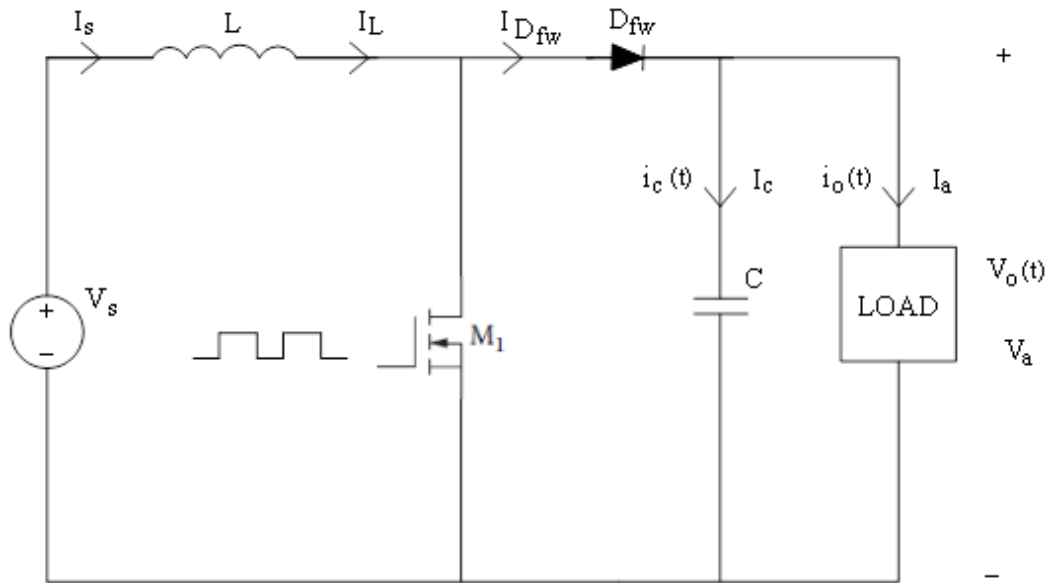
$$t_{on} = \frac{L\Delta I}{V_s}$$

(2)

Fig.(1) Circuit schematic of a boost switching converter

The output current during this interval is supplied entirely from the output capacitor, C, which is chose large enough to supply the load current during t_{on} with a minimum specified drop in output current.
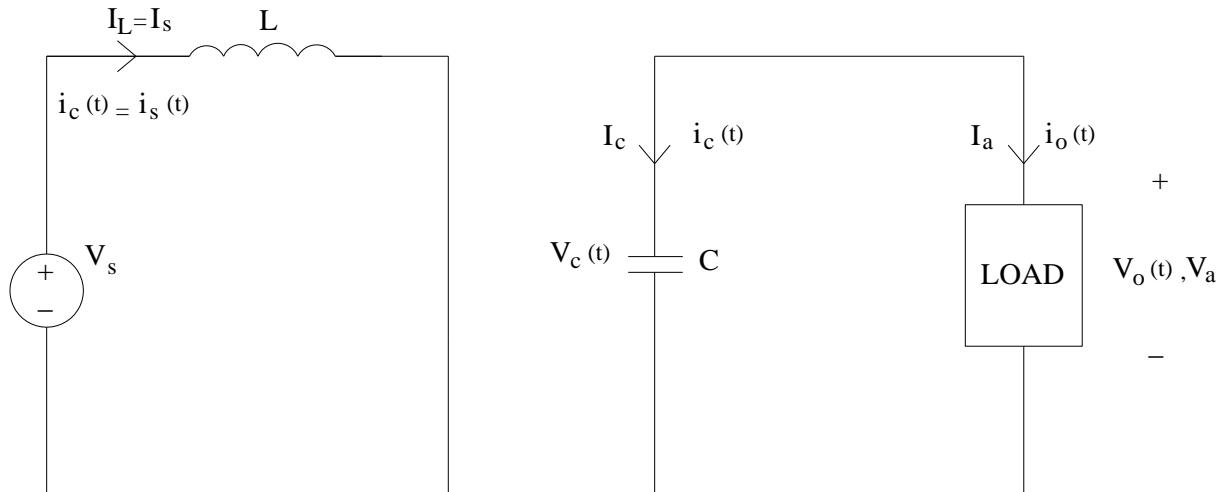
Fig.(2) Mode 1 equivalent circuit for the Boost converter (0 < t ≤ ton) .

B. Mode 2 (t$_{on}$ < t ≤ T)

Mode 2 begins when the switching transistor, M_1, is switching off at $t = t_{on}$. The equivalent circuit for this mode is shown in Fig.(3). Since the current in the inductor cannot change instantaneously, the voltage in the inductor reverses its polarity in an attempt to maintain a constant current. The current which was flowing through the switching transistor will now flow through L, C, diode D_{fw} and load. The inductor current decreases until the switching transistor is turned on again during the next cycle.
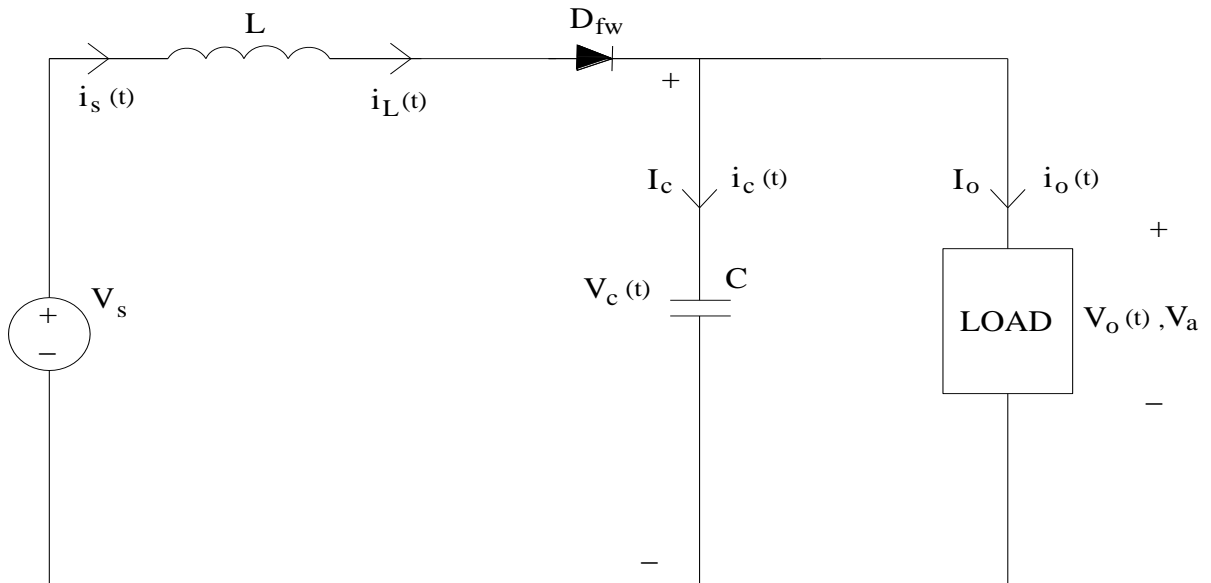

Fig.(3) Mode 2 equivalent circuit for the Boost converter (t$_{on}$ < t ≤ T) .

The inductor delivers its stored energy to the output capacitor, C, and charges it up via D_{fw} to a higher voltage than input voltage, V_s.

This energy supplies the current and replenishes the charge drained away during the on time.
Fig.(4) illustrate the currents and voltages waveforms of continuous mode operation (i. e. Mode I and Mode II) [1,2].

The average output voltage, V_a, for a boots converter is given by:

$$V_a = \frac{V_s}{1-D}$$

(3)

Thus, V_a is inversely proportional to $(1-D)$. It is obvious that the duty cycle, D, cannot be equal to 1 otherwise would be no energy transfer to the output.
The peak-to-peak inductor ripple current, ΔI, is given by:

$$\Delta I = \frac{V_s D}{f_s L}$$

(4)

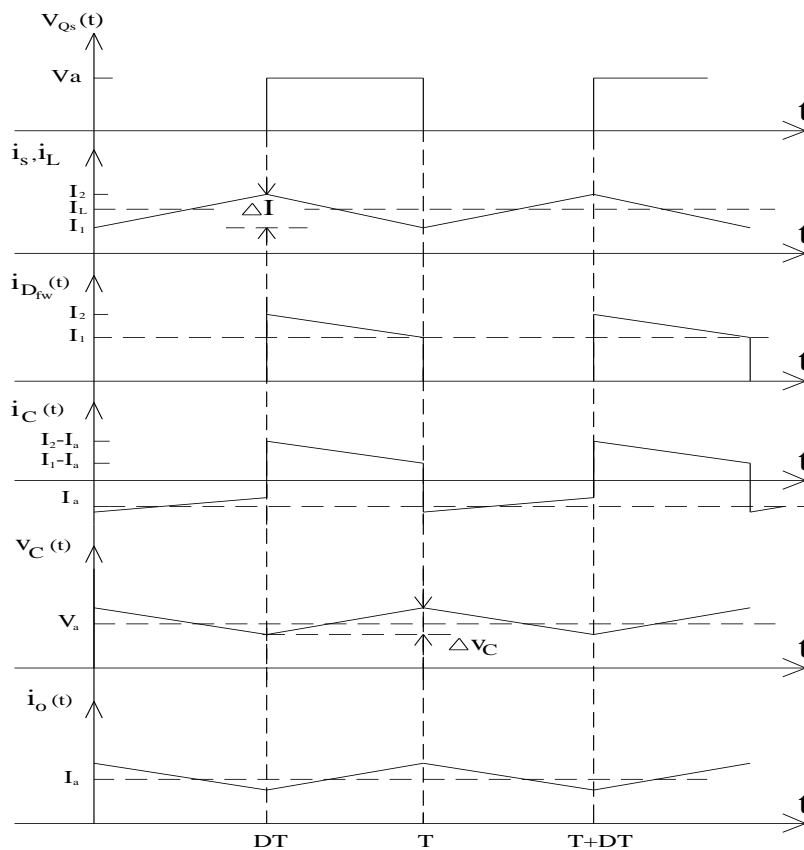Thus, the magnitude of ΔI is inversely proportional to f_s and L.

Fig.(4) Waveforms for the Boost converter

The peak-to-peak output ripple voltage, $\Delta \upsilon_o$, is equal to the peak-to-peak capacitor ripple voltage, $\Delta \upsilon_c$, and given by :

$$\Delta \upsilon_c = \frac{I_a D}{f_s C}$$

(5)

It is evident that $\Delta \upsilon_o$ can be reduced by increasing either the switching frequency or the capacitance of the output capacitor. The inductor is used for energy storage and does not act as part of the output filter.

If the current flowing through the inductor falls to zero before the next turn-on of the switching transistor, M_1, the Boost converter is said to be operating in the discontinuous mode. To ensure that the Boost converter is operates in continues mode the inductor L must be less than critical inductor, L_c, which given by:

$$L_c = \frac{RD(1-D)^2}{2f_s} \qquad (6)$$

Design of boost switching converter

The design of the converter is performed to step-up the input voltage of 12 v , from the battery storage equipment, to an output voltage of 24v , which is the input to the inverter in solar system or supply to other appliances operate on 24v. The following parameters are required for the design of the Boost converter:

Input voltage (Vs): 12V
Output voltage (Va): 24V
Switching frequency (fs): 20KHz
Maximum load current (Ia): 2A
Maximum inductor current (I_{Lmax}): 4.25A
Minimum inductor current (I_{Lmin}) 0.5A
Ripple in the output voltage (ΔVo): 1.2V
Ripple in the output current (ΔIo): 0.03A.
To find the elements of the Boost switching converter, a simple Matlab code program (Matlab

version of 2010b) is written using Eq. 8, 14, 19 with a 20 Ω load resistor. The Matlab program results give the following converter elements:
Duty cycle% (D) = 50 %
 Inductor ripple current (ΔI) = 3.75 A
 Inductor value (L) = 7.9787e-005 $\approx$ 80 µH
 Capacitor value (C) = 4.1666e-005 $\approx$ 42 µf
Critical Inductor (L_c) = 62.5 µH
The converter is operates in the continuous mode because the inductor value is greater than the critical inductor.

Matlab/Simulink and spice simulation results

A Matlab Release 2010b and LTspice IV version 4.20q 2014 simulation programs are used to simulate the considered Boost switching converter. Fig.(5) shows the Matlab\Simulink and Spice models of the Boost switching converter.
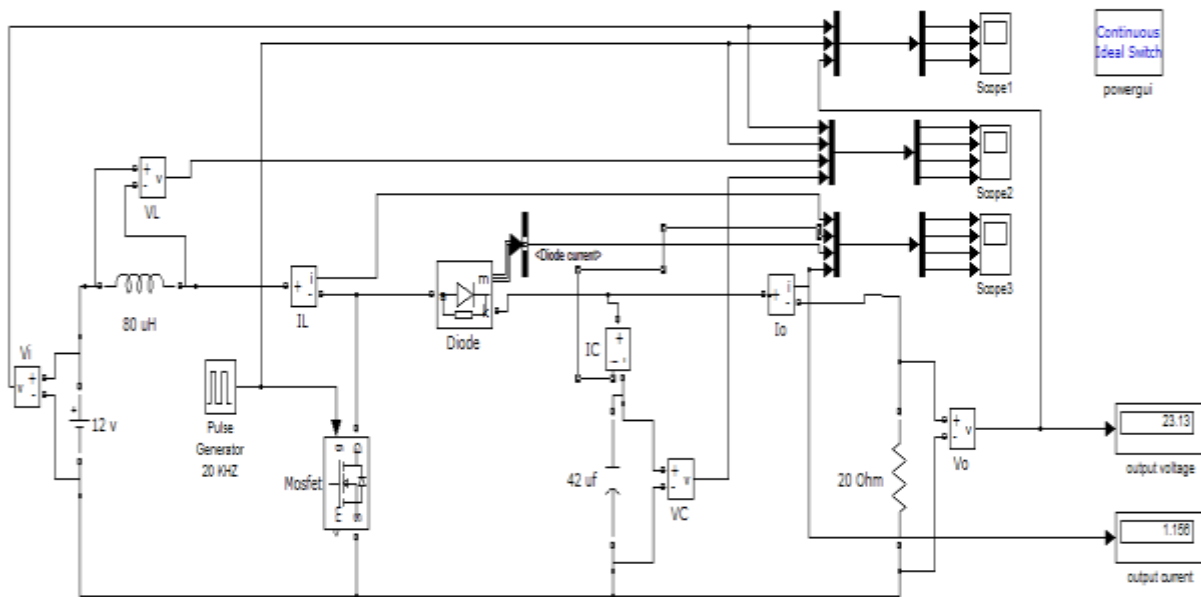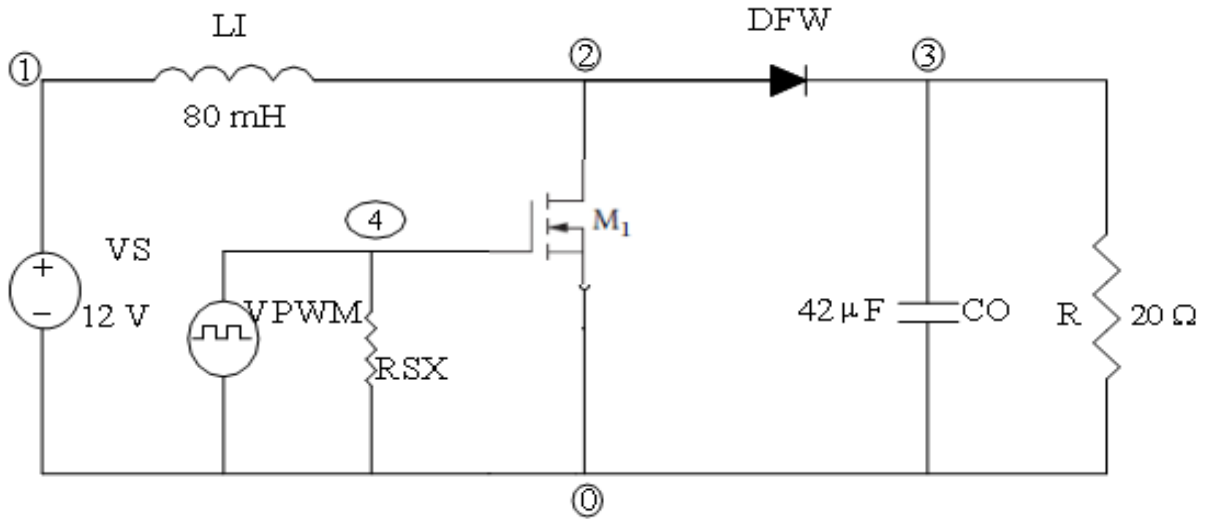

(a) Matlab\Simulink model

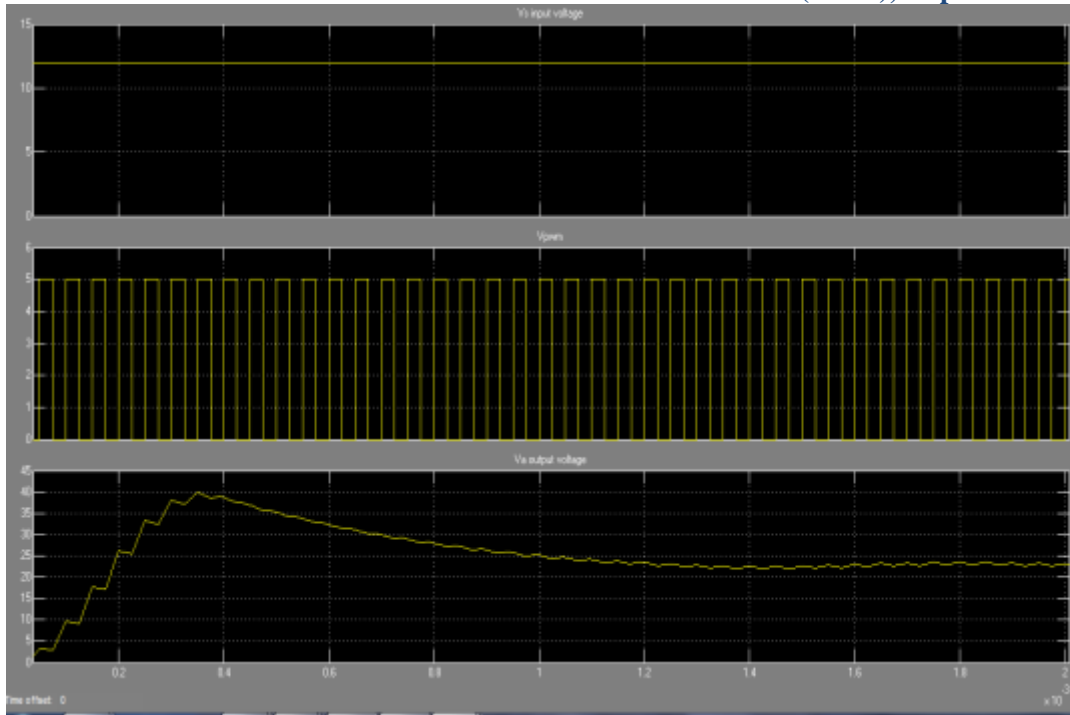*Fig.(5) Models of the Boost switching converter.*

Fig(6) shows the simulation waveforms of the input voltage, pulse width modulation voltage and the output voltage of the simulated Boost converter .
It can be noted that the simulated waveforms are similar to each other and consistent with the theoretical waveforms. The response of the output voltage is under damped and reaches its steady – state voltage in about 1.4 ms . The simulated output ripple voltage is about 0.75 V.

The average output voltage is found to be 23.151V compared with the theoretical of 24V.
Fig.(7) shows the waveforms of the input voltage, pulse width modulation voltage , inductor voltage and capacitor voltage waveforms of the simulated Boost converter . The inductor voltage is a square wave while the capacitor voltage is the same wave of the output waveform. The average output voltage is 23.151V compared with the theoretical of 24V.

Fig.(8) shows expand view of the input inductor and output capacitor currents along with the switching pulses. The input inductor current is under damped with maximum value of 4.2A and minimum value of 0.6A with a ripple current of 3.6A and therefore the percentage error with the theoretical results are very small.

Fig.(9) shows the waveforms of current passing through inductor, capacitor, diode (Idfw), and output current (Io). It can be noted that the output current reaches its steady state value of 1.156A after 1.5ms and has a very small ripple of 0.036A.
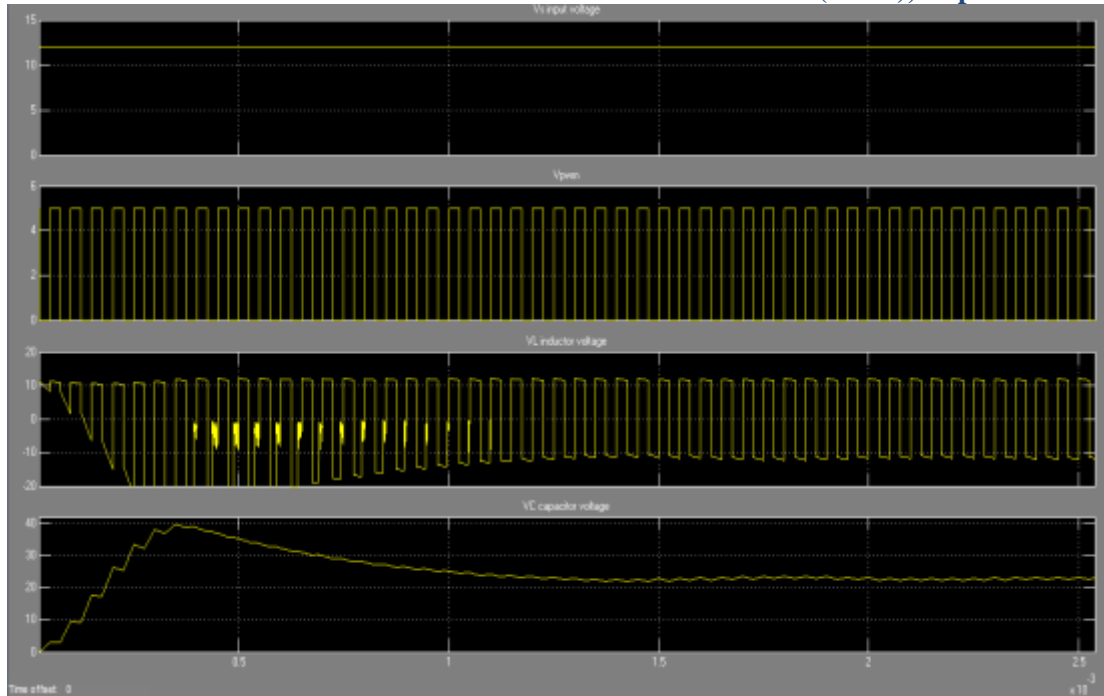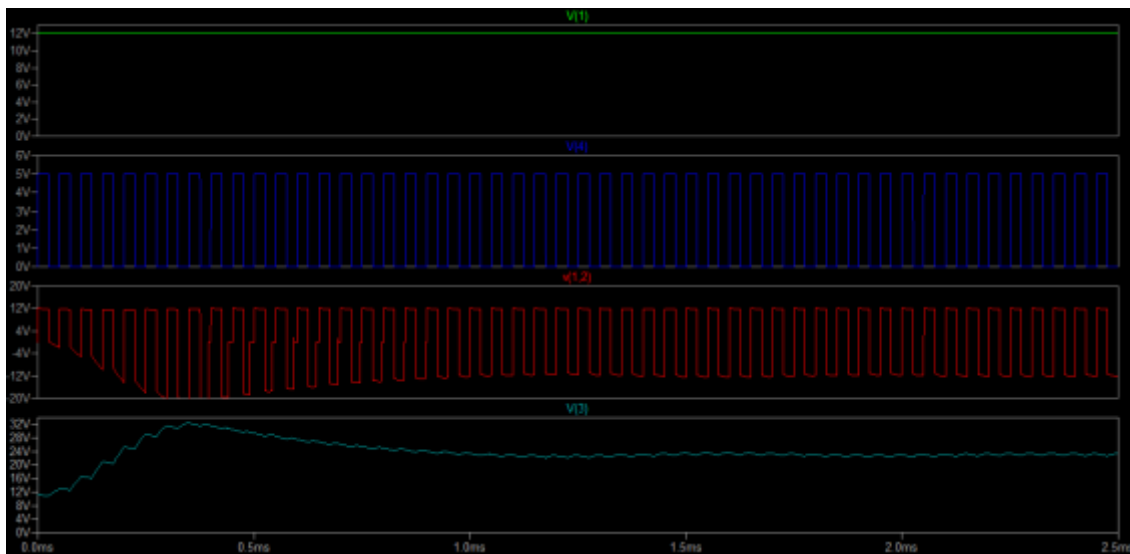
Matlab/Simulink
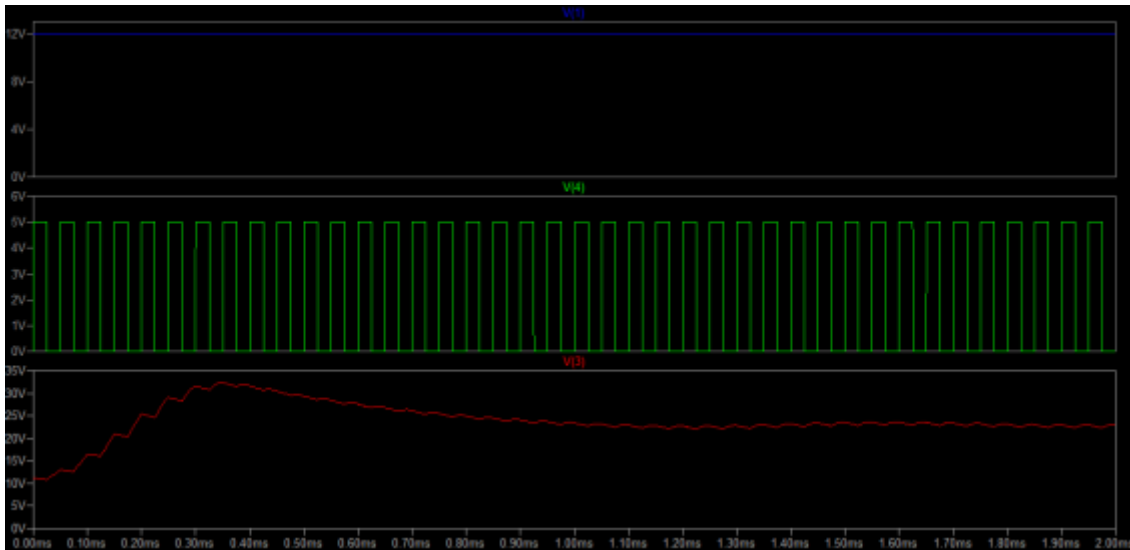
Spice
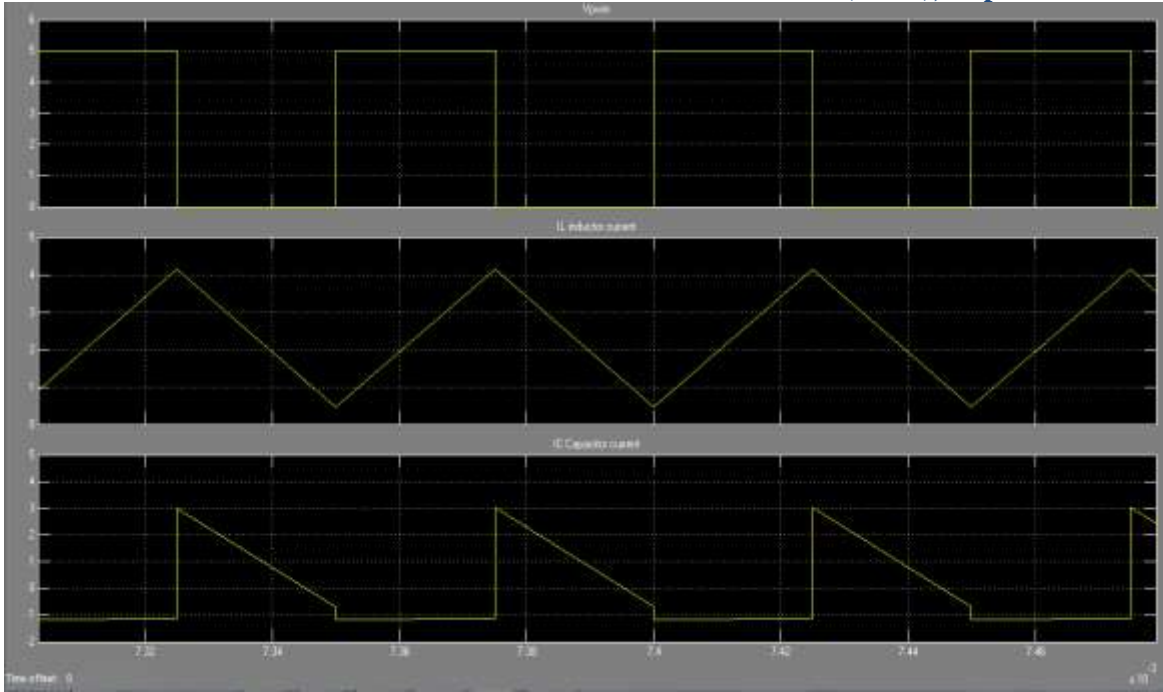*Fig.(6) simulation waveforms of the input voltage, pulse width modulation voltage and the output voltage.*
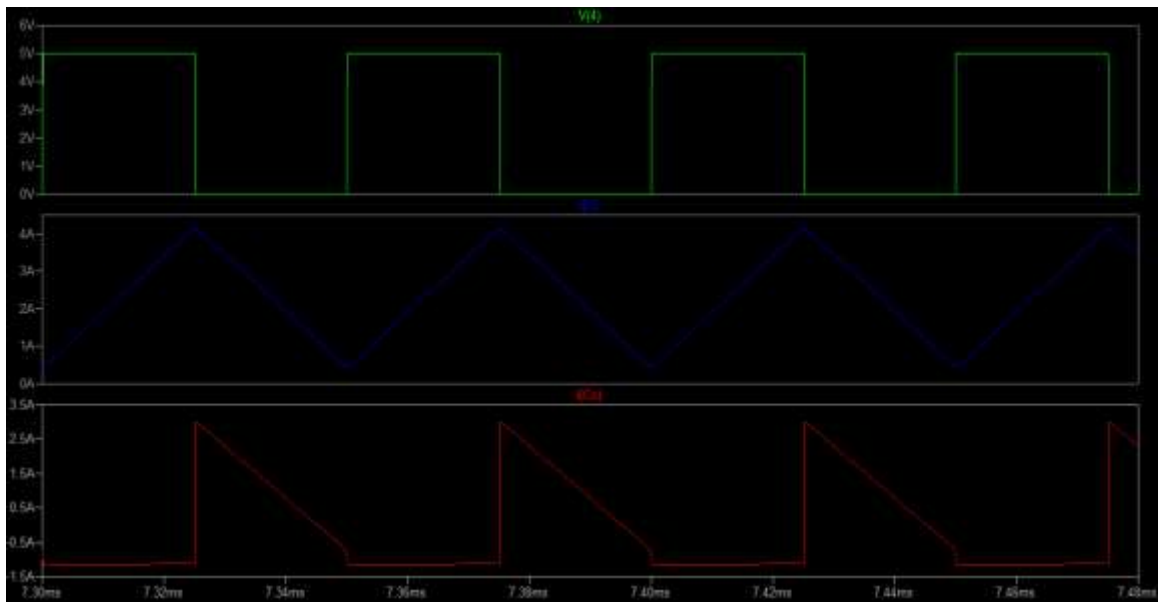
Matlab/Simulink

Spice

Fig.(7) Simulated waveforms of the input voltage, pulse width modulation voltage , inductor voltage and capacitor voltage.
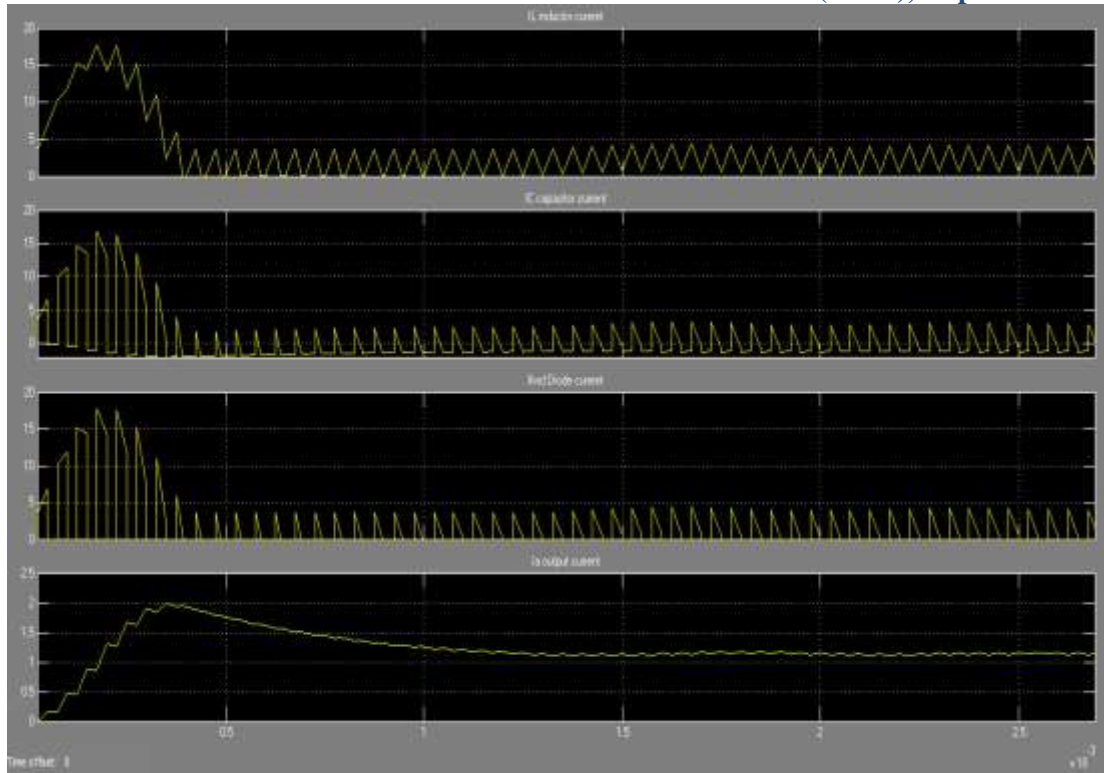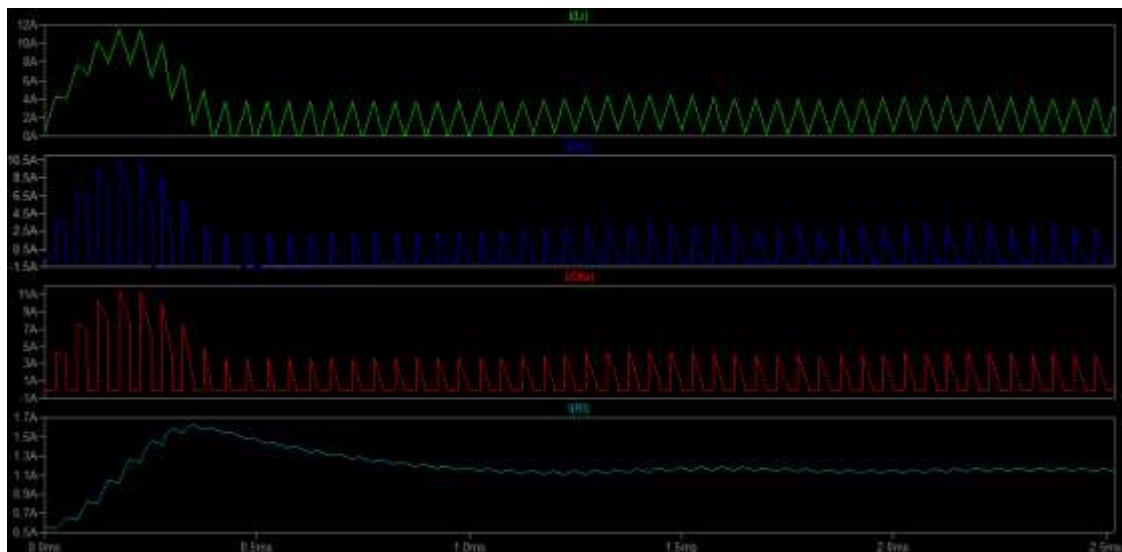
Matlab/Simulink

Spice
Fig.(8) Expand view of the inductor and capacitor currents along with the switching pulses.

Matlab/Simulink

Spice
Fig.(9) Simulated waveforms of current passing through inductor, capacitor, diode and output current.

A compression between the theoretical and simulation results is shown in table (1).

Table (1) Compression between the theoretical and simulation results

Parameters	Theoretical	Simulation
Input voltage	12 V	12 V
Output voltage	24 V	23.13 V
PWM Voltage	5 V	5 V
Output current	1.2 A	1.156 A
Ripple in output current	0.03 A	0.036 A
Maximum inductor current	4.25 A	4.142 A
Minimum inductor current	0.5 A	0.44 A
Ripple in inductor current	3.75 A	3.702 A

Conclusion

In this paper, the analysis and simulations of 12v/24v Boost switching converter is presented. The converter performance such as load voltage, capacitor and inductor currents, voltages and currents ripples, etc. are analyzed and derived theoretically under continuous operation. The design of the converter is performed to step-up the input voltage 12 v from the battery storage equipment to an output voltage of 24v which will be the input to the inverter in solar system. Matlab\Simulink and LTspice IV programs are used to simulate the switching converter using a very high speed MOSFET as a switch with 20 KHZ switching frequency. The simulated waveforms are consistent with the theoretical waveforms and the percentage error between simulated and theoretical results is found to be very small**.**

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