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MODELING, DESIGN, AND CONTROL OF ASYNCHRONOUS BUCK CONVERTER FOR MOBILE APPLICATION

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ABSTRACT

The aim of this paper is to model and design an open-loop and close-loop asynchronous Buck switching converter for mobile applications. The design of the converter is performed to step-down the input voltage 12V to an output voltage of 5V and current of 2A. The converter performance such as load voltage, capacitor and inductor currents, voltages and currents ripples, etc. are derived under continuous and discontinues operation. The Matlab/Simulink program is used to simulate the converter operation and the waveforms of circuit parameters are carried out. Due to changes in the supply voltage or circuit parameters, there is deviation of the circuit operation from the desired nominal performance. So a close-loop PID controller is designed such that any input variations produce a constant desired output voltage and current.

KEYWORDS: Buck converter, Matlab/Simulink simulations, PID controller.

INTRODUCTION

List of Symbols

Δ : Peak-to-peak ripple
C : Capacitor
D : Duty cycle
f_s : Switching frequency
L and Lc : Inductor and critical inductor
Ia : Average current passing through load
Ic, and I_L : Average current passing through capacitor and inductor respectively.
R : Load resistor
ton and toff : Transistor ON and OFF status time period
Va : Average output voltage
Vc : Capacitor voltage
Vs : Supply dc voltage

INTRODUCTION

DC/DC switching converters form the essential part of different portable electronic devices like cellular phones, laptops, MP3 players which are using batteries as their power supply. Between the most simplest and useful switching converter is the voltage steps down which called asynchronous Buck converter.

The most common and most effective method used is that of Buck converters which used to step down the voltage supply from a higher level to a lower level The analysis and design of power electronics converters presents significant challenges. These may be alleviated by using modeling and simulation of converters and their associated control structures, which help the design engineer better understand converter operation [1].

In the last few years many Buck converters are proposed for the renewable energy systems [2-6].In high performance converter, the output voltage can be regulated by using voltage mode pulse width modulation (PWM) method with one feedback loop. One widely adaptive feedback control loop is the proportional integral derivatives (PID) controller.

In this paper the open-loop and close-loop asynchronous Buck converter used to step down the input voltage of 12 V to 5 V , 2 A is designed and simulated.

MODELING OF ASYNCHRONOUS BUCK SWITCHING CONVERTER

The basic buck converter using a power MOSFET transistor is shown in Fig.(1). In the buck converter, the average output voltage (Va) is lower than its input voltage (Vs) . The duty cycle (D) is given by :

$$D = \frac{V_a}{V_s} \qquad \text{........(1)}$$

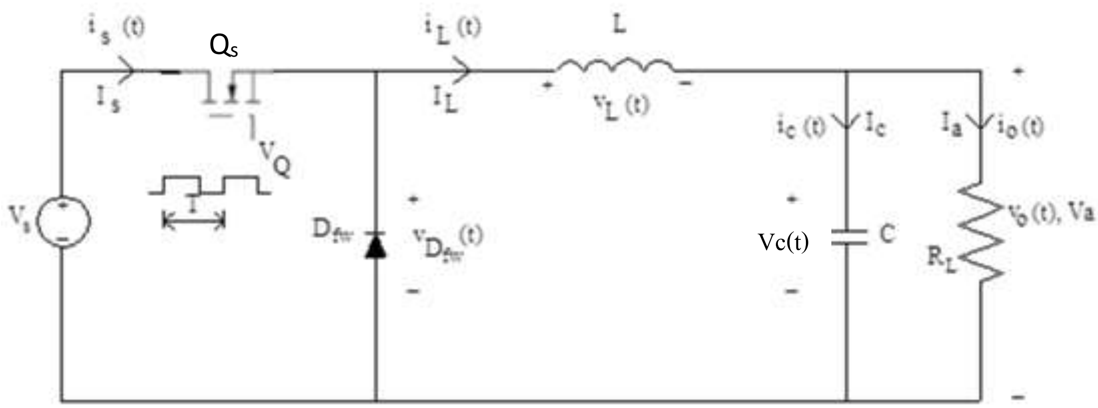

Figure (1) Circuit schematic of asynchronous buck converter

Depending on the continuity of the current flowing through the output inductor, the buck converter can be operated either in the continuous mode or discontinuous mode.

(a) Mode 1 ($0 < t \leq t_{on}$)

At the beginning of a switching cycle (at t = 0) during mode 1, the switching transistor , Q_s, is switched on . The equivalent circuit for mode 1 is shown in Fig.(2) . Since the input voltage (Vs) is greater than the average output voltage (Va), the current in the inductor, $I_L(t)$, ramps upward during this interval . The duration of mode 1 is:

$$t_{on} = \frac{L\ \Delta I}{V_s - V_a} \qquad \text{.........(2)}$$

Thus, mode 1 is characterized by inductor charging and the storage of electrical energy in magnetic from in the inductor.

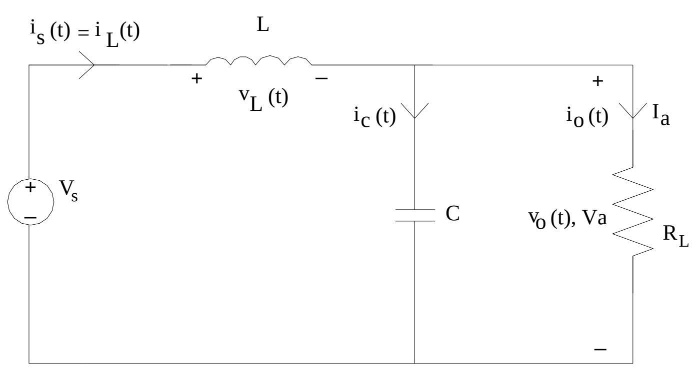

Figure (2) Mode 1 equivalent circuit for the buck converter ($0 < t \leq ton$)

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(b) Mode 2 ($t_{on} < t \leq T$)

Mode 2 begins when the switching transistor (Qs) is switched off at t = t_{on}. Its equivalent circuit is shown in Fig. (3).The inductor current decreases as the energy stored in the inductor is expended by the load. The voltage across the inductor, $V_L(t)$, is now $-V_a$, and the inductor current decreases linearly from I_2 to I_1 in time t_{off} .

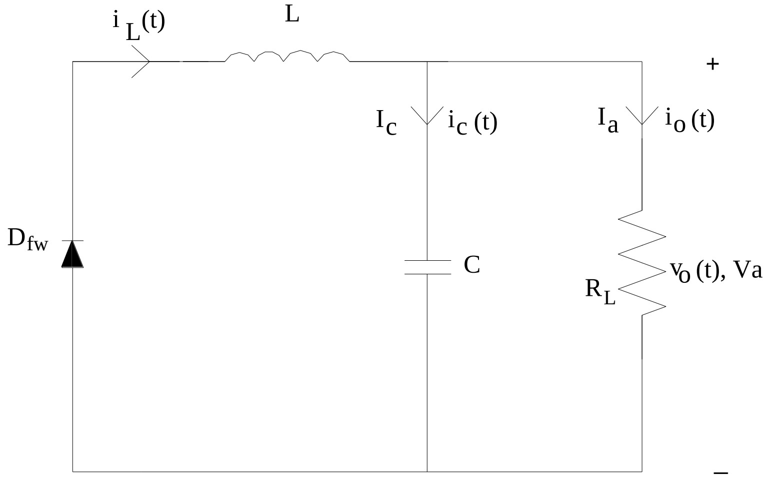

Figure (3) Mode 2 equivalent circuit for the buck converter (ton < t ≤ T)

The switching period , T, is the sum of t_{on} and t_{off} :

$$T = \frac{1}{f_s} = t_{on} + t_{off}$$

$$T = \frac{L\ \Delta I}{V_s - V_a} + \frac{L\ \Delta I}{V_a} = \frac{LV_s\ \Delta I}{V_a(V_s - V_a)} \qquad \text{...........(3)}$$

The peak to peak ripple current in the inductor, , can then be expressed as :

$$\Delta I = \frac{V_a(V_s - V_a)T}{LV_s} = \frac{DV_s(1-D)}{Lf_s} \qquad \text{...........(4)}$$

The peak-to-peak capacitor ripple voltage is given by:

$$\Delta \upsilon_c = \frac{\Delta V_s(1-D)}{f_s L}\left(\frac{1}{8 f_s C}\right) = \frac{V_s D(1-D)}{8LCf_s^2} \qquad \text{...........(5)}$$

Fig.(4) illustrate the currents and voltages waveforms of continuous mode operation (i. e. Mode1and Mode2) [7,8].

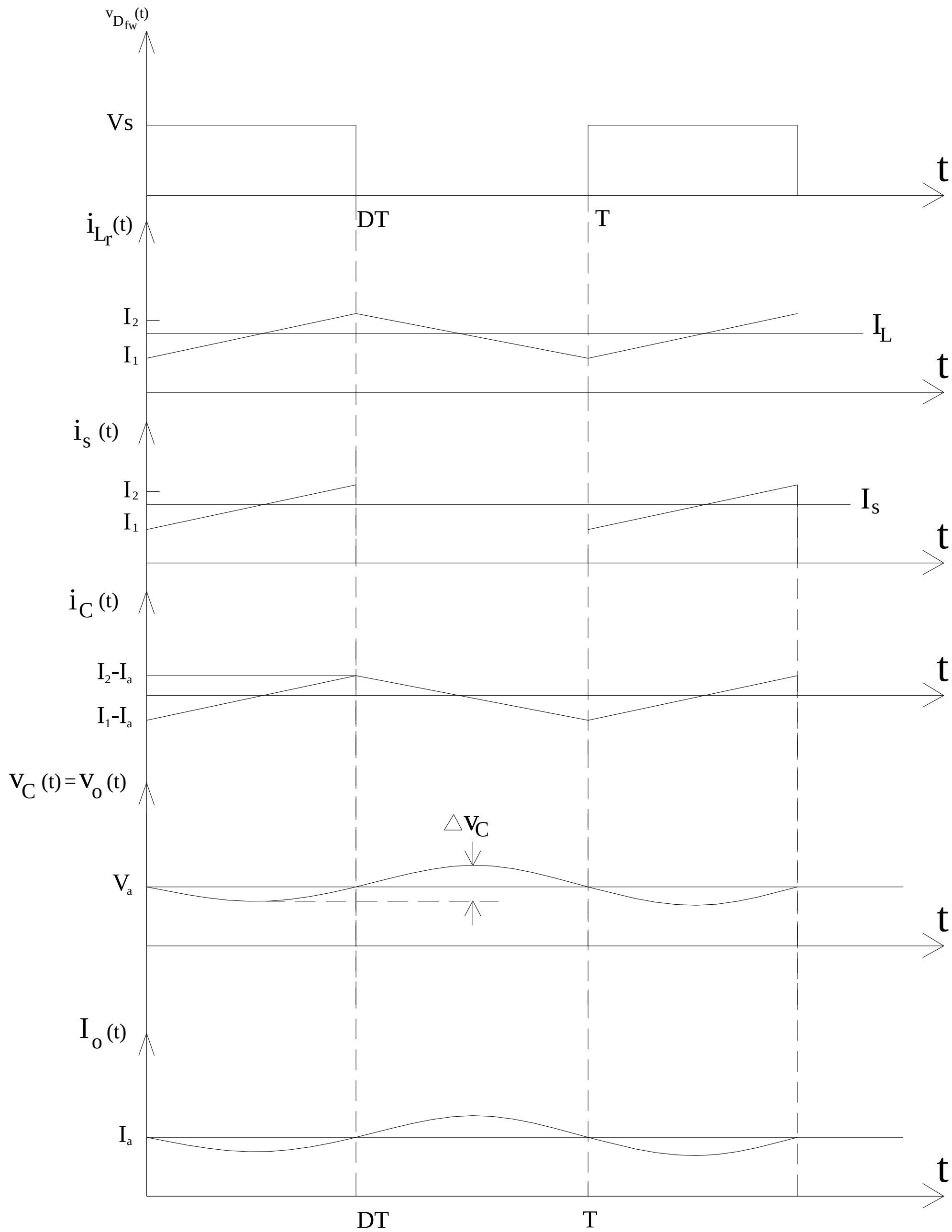

Figure (4) Asynchronous Buck converter equivalent switching waveforms

The efficiency of the buck converter can be calculated in terms of conduction losses in the switching transistor (Qs) and the freewheeling diode (Dfw) and given by :

$$\eta = \frac{P_{out}}{P_{out} + P_{loss}} = \frac{V_a}{V_a + V_{ce,sat}\left(t_{on}/T\right) + V_{D_{fw}}\left(1 - t_{on}/T\right)} \qquad \text{...............(6)}$$

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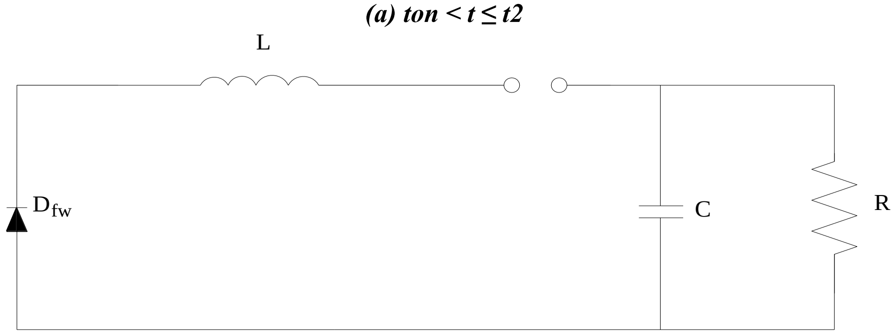
Where: $V_{ce.sat}$ is the saturated collector-to-emitter voltage of the switching transistor dring its ON state and $V_{D_{fw}}$ is the voltage drop of freewheeling diode.

(c) Discontinuous Mode
The value of L for which $I_L=0$ at one and only one point per cycle is defined as the critical inductance (L_c). Fig.(5) shows the equivalent circuits for the buck switching converter and Fig.(6) shows the inductor current in discontinuous mode.

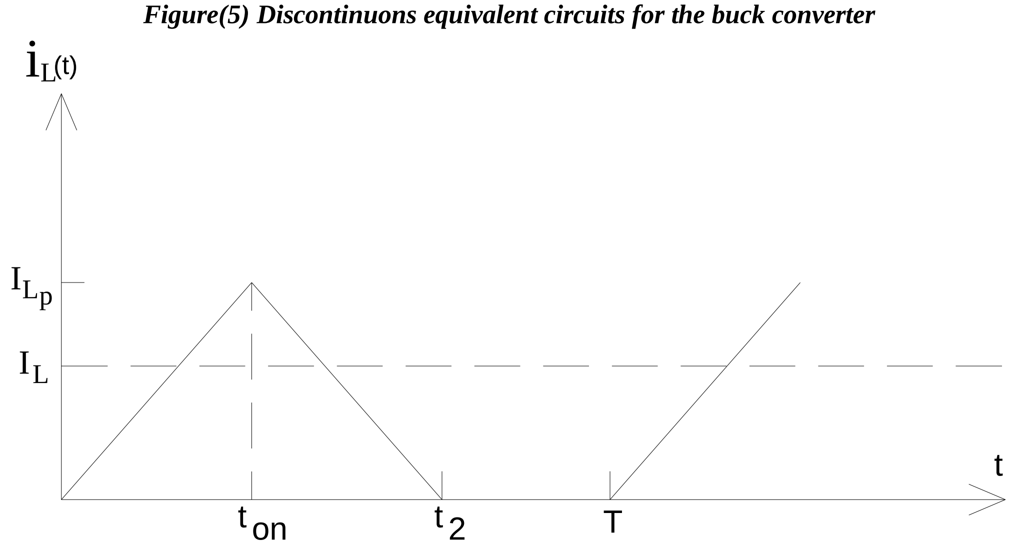
The critical inductor, L_c, is given by:

$$L_c = \frac{R(1-D)}{2 f_s} \qquad \text{...........(7)}$$

(a) ton < t ≤ t2



(b) t2 < t ≤ T
Figure(5) Discontinuons equivalent circuits for the buck converter



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Figure(6) Discontinuous mode inductor current waveform

DESIGN OF 12V/5V, 2A SWITCHING CONVERTER

The design of the converter is performed to step-down the input voltage of 12V to an output voltage of 5V, 2A which is suitable as mobile charging application. The required parameters for the design of the Buck converter are shown in Table (1).

Table (1) Required parameters for the design of the Buck converter

Parameters	Values
Input voltage (Vs)	12 V
Output voltage (Va)	5 V
Load current (Ia)	2 A
Switching frequency (fs)	400 KHz
Output voltage ripple (ΔVo)	< 0.05 V
Converter efficiency (η)	> 92 %

The inductor ripple current (ΔI) is usually taken as 30% of the load current. By using of Eq.s(1),(3), (4), (5) and (7) with a 2.5 Ω load resistor the converter elements are calculated and tabulated in Table (2).

The converter is operates in the continuous mode because the inductor value is greater than the critical inductor.
The forward voltage drop for the diode is about 0.4 volts at the peak current of 2 A and the saturated collector-to-emitter voltage of the switching transistor is about 0.35. By using Eq.(2) and Eq.(6) the converter efficiency is found to be 93%.

Table (2) Buck converter required elements

Converter elements	Values
Duty cycle (D)	41.6 %
Inductor ripple current (ΔI)	0.6 A
Inductor (L)	13.125 μH
Capacitor (C)	25 μf
Critical inductor (L_c)	1.72 μH

MATLAB/SIMULINK SIMULATION RESULTS

A Matlab/Simulink simulation program is used to simulate the considered asynchronous Buck switching converter. Fig.(7) shows the Matlab\Simulink model of the asynchronous Buck switching converter.

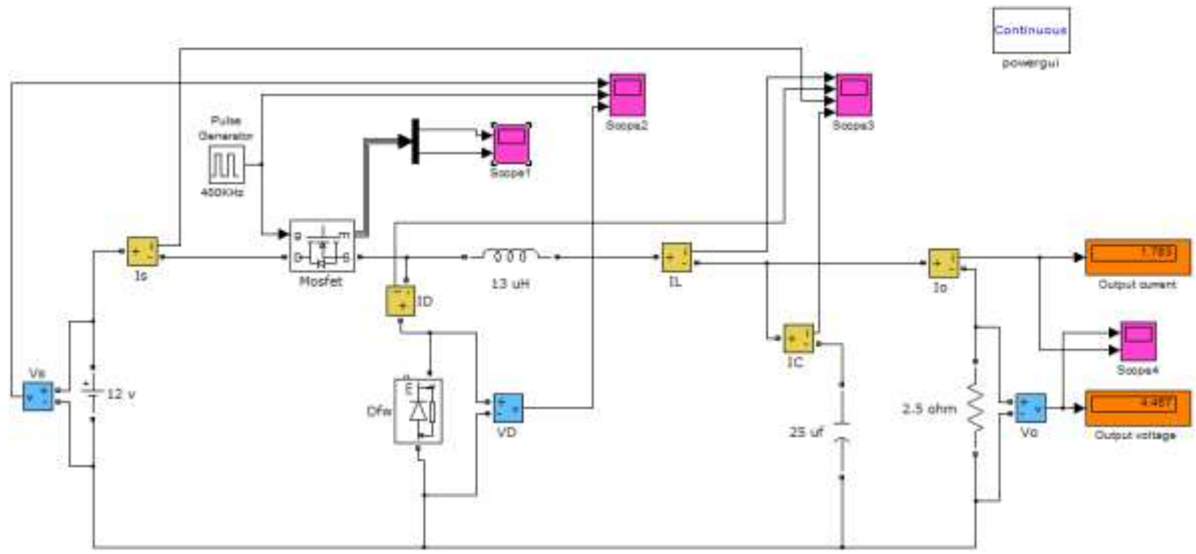

Figure (7) Model of open-loop asynchronous Buck switching converter

Fig.(8) shows the simulation waveforms of the input voltage of 12 V, pulse width modulation (PWM) voltage and the output voltage.

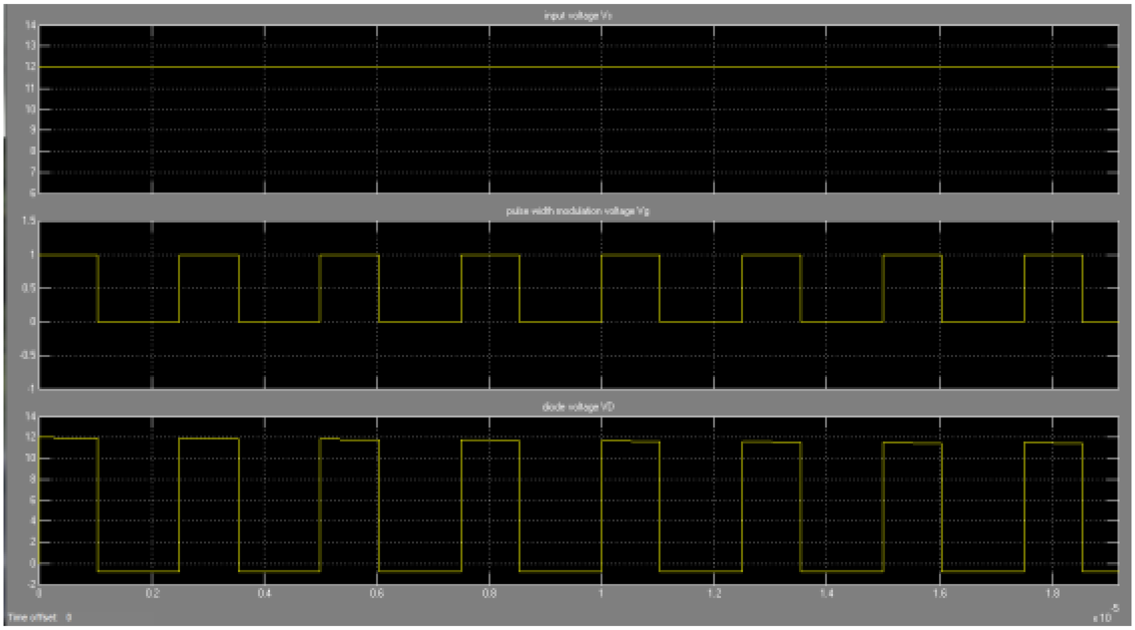

Figure (8) Simulation waveforms of the input voltage, pulse width modulation voltage and the diode voltage

Fig.(9) shows expand view of the waveforms of current passing through inductor, diode, input and capacitor. 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.

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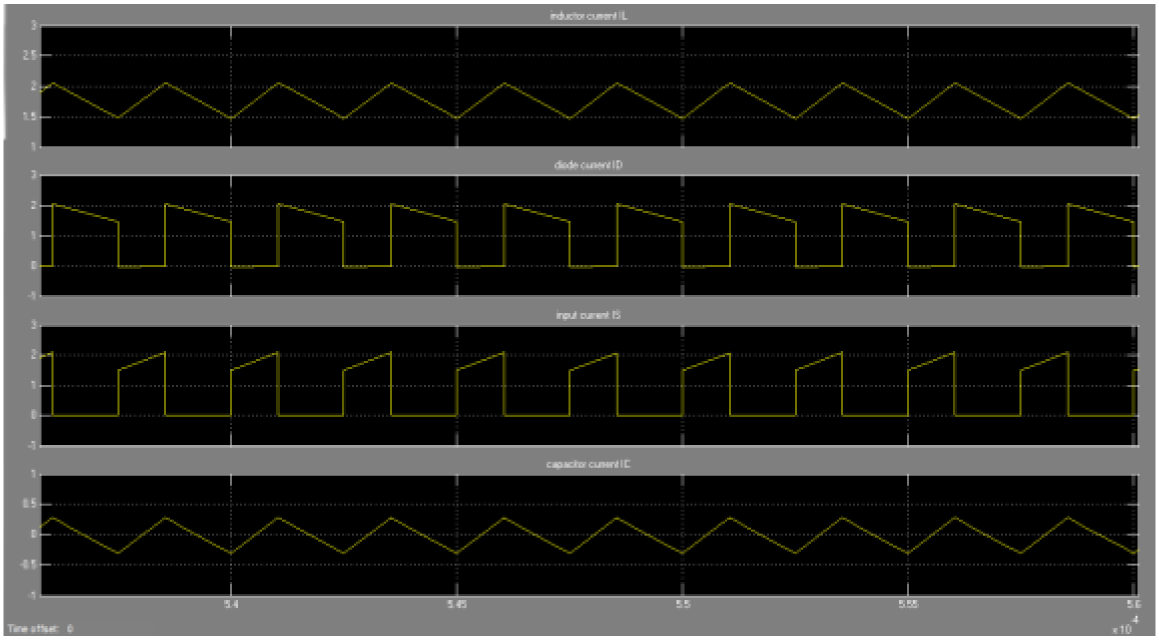

Figure (9) Expand view of currents of the inductor, diode, input and capacitor

As shown in Fig.(10), the response of the output voltage is under damped and reaches its steady – state voltage of 4.457 V compared with the theoretical of 5 V in about 0.6 ms . The simulated output ripple voltage is very small and less than 0.05 V. It can be noted that the output current reaches its steady state value of 1.785 A compared with the theoretical of 2 A and it has a very small ripple.

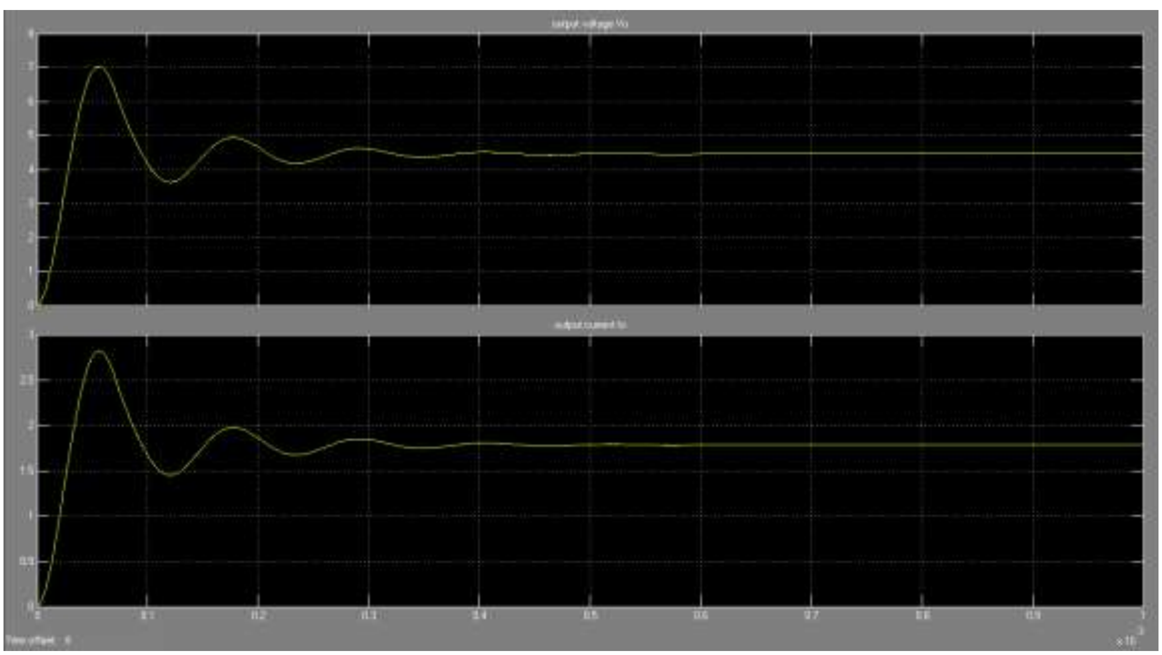

Figure (10) Simulation waveforms of the output voltage and output current

To simulate the change in operating condition, let the input voltage is stepped up to 15 V at time instant 1 ms. As shown in Fig.(11) the output voltage is increased to 5.686 V and the corresponding output current is 2.274 A. Therefore the open-loop converter does not satisfy the desired requirement and a close-loop PID control design is required.

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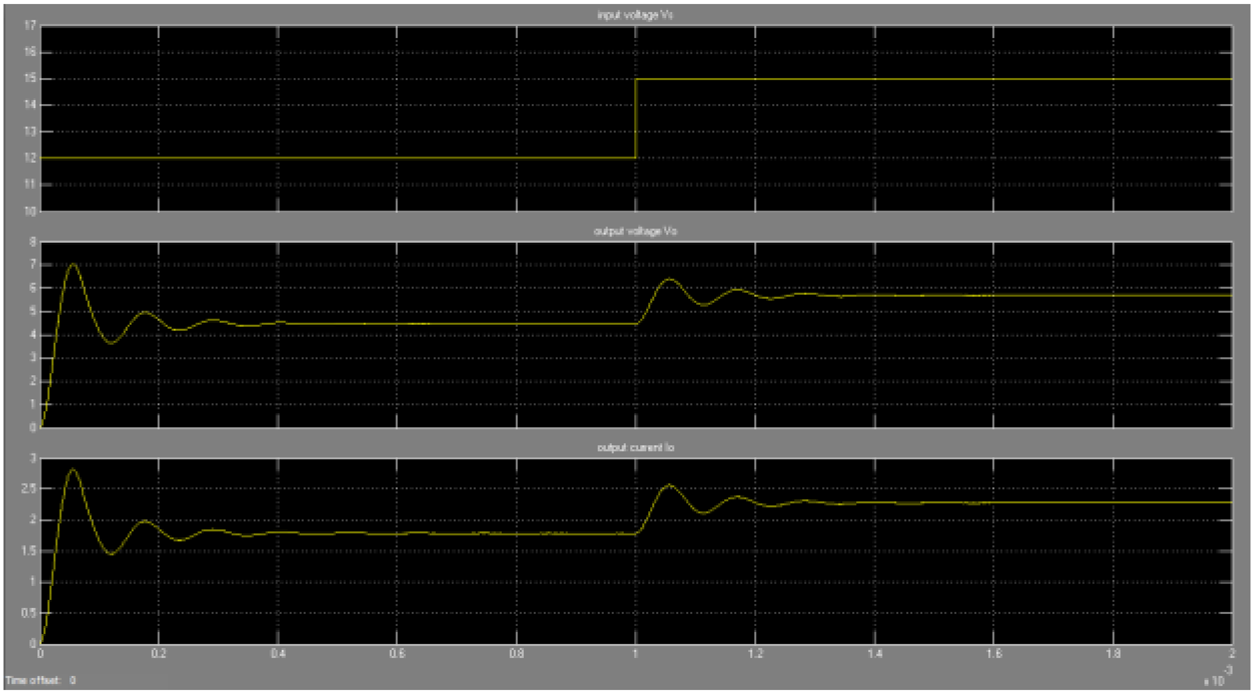
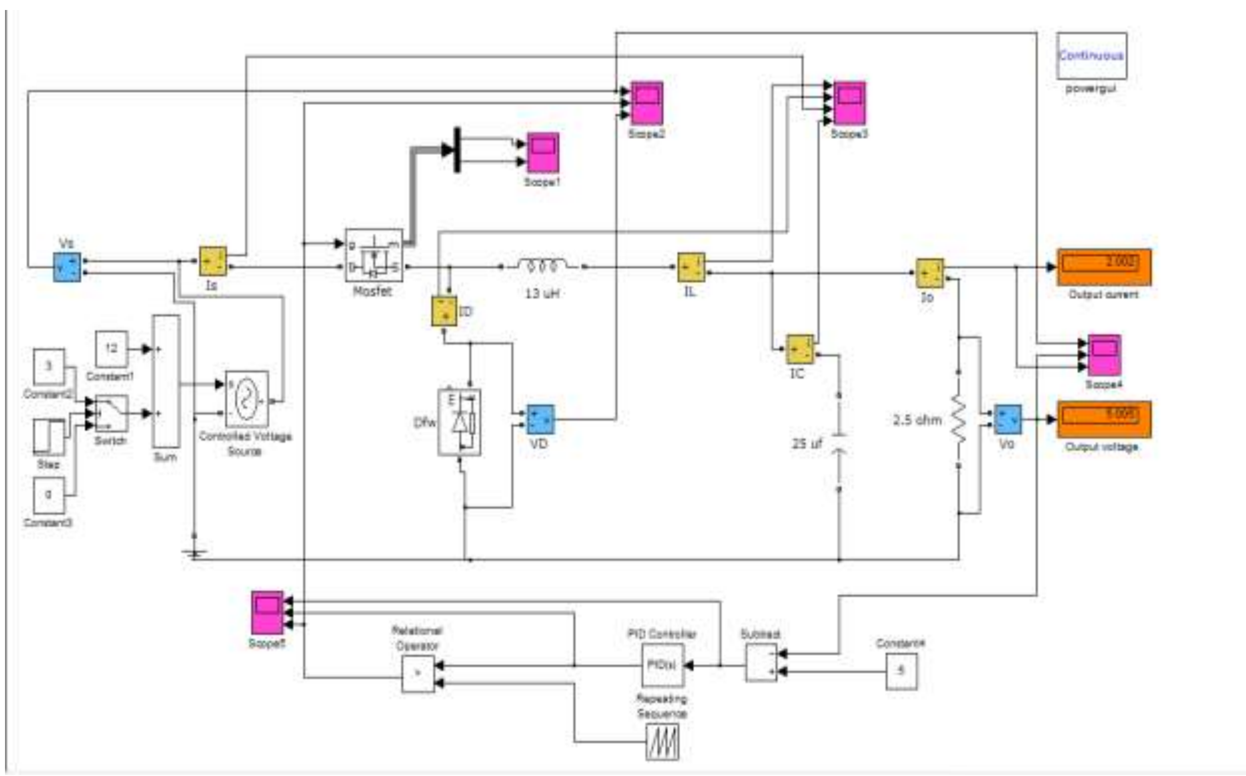


Figure (10) Open-loop simulation waveforms of the output voltage and output current when the input voltage is changed

PROPORTIONAL INTEGRAL DERIVATIVES (PID) CONTROLLER

A PID controller is feedback loop control system which corrects the error between a measured process value and a desired value and adjusts the process as required.

Based on the voltage error signal the PID controller generate the required duty cycle supplied to the MOSFET. The P, I, and D parameters can be tuned to give the required design. The Simulink model of close-loop Buck converter is shown in Fig.(11).The P, I and D values are set to 0.2, 0.2 and 0.5 respectively.



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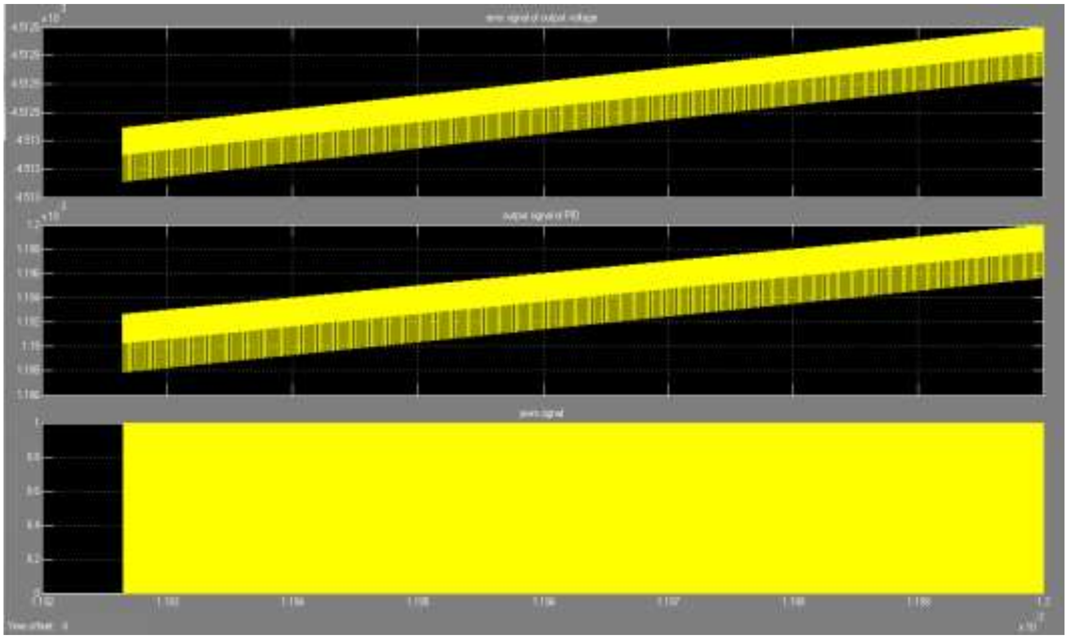
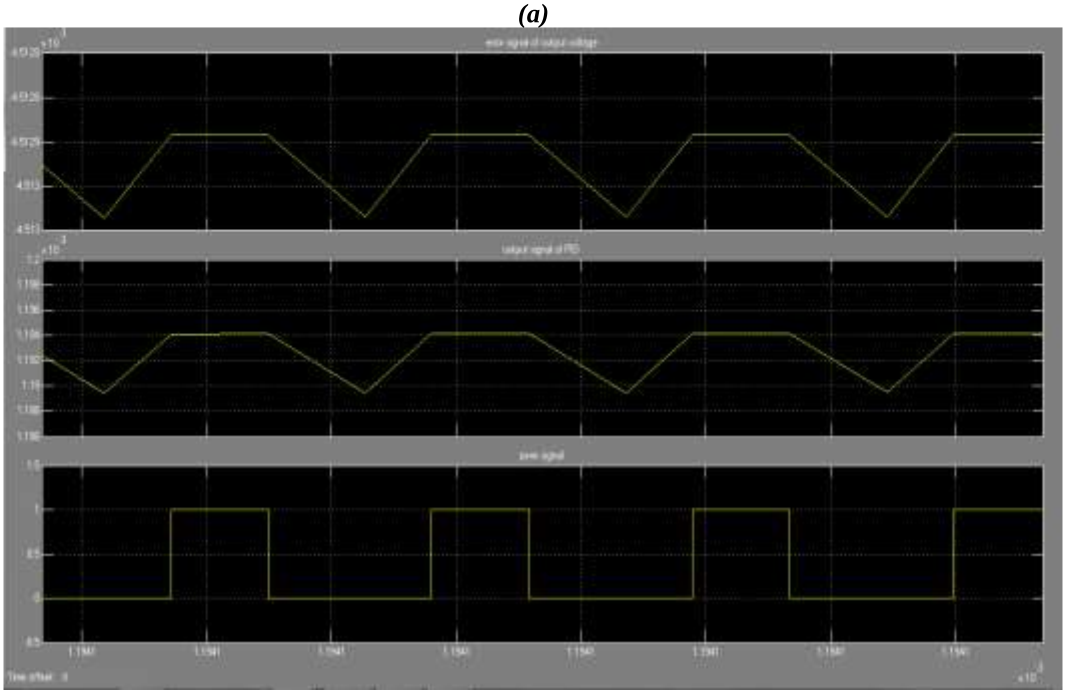
The error signal, PID output signal and the PWM signal are shown in Fig.(12). The response of the output voltage and output current is obtained as shown in Fig.(13) which show that the PID controller maintains the required output voltage of 5 V and the output current of 2 A.



(a)



(b)

Figure (12) (a)The error signal, PID output signal and the PWM signal (b) expand waveforms of (a)

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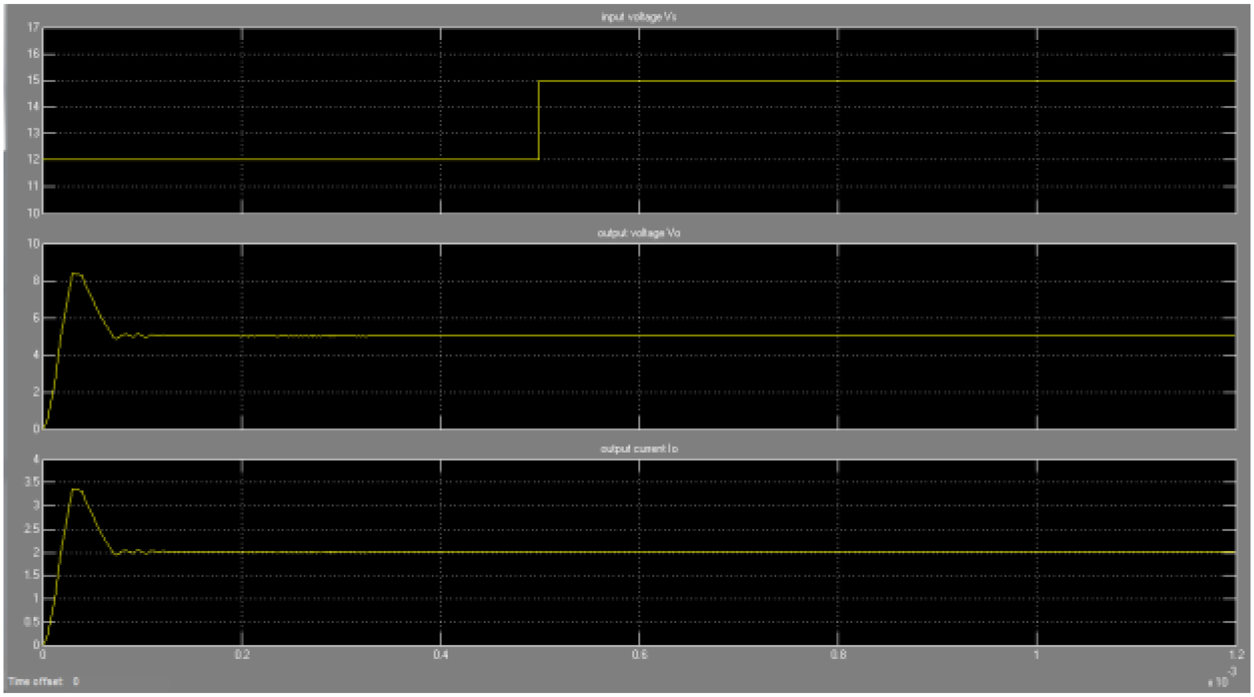

Figure (13) close-loop simulation waveforms of the output voltage and output current when the input voltage is changed

CONCLUSION

In this paper, the modeling and design of open-loop and close-loop of 12V/5V with 2 A output current Buck switching converter is presented. The converter performance are analyzed and derived theoretically under continuous and discontinuous operation. Matlab\Simulink program is used to simulate the switching converter using a very high speed MOSFET as a switch with 400 KHZ switching frequency. The desired output performance of open-loop converter is not satisfied under the change of supply voltage; therefore a close-loop PID controller is designed and simulated. The results show that the PID controller maintains the required output voltage of 5 V and the output current of 2 A.

REFERENCES

[1] Seddik Bacha, et al. "Power Electronic Converters Modeling and Control", Springer publishing London, 2014.
[2] Mohammad O. Hamdon, et al. " ICREGA'14 Renewable Energy: Generation and Application", Springer international publishing Switzerland, 2014.
[3] Thao N. M., et al. " Steady-State Analysis of the Buck Converter for Renewable Energy Systems", Power Electronics and Motion Control Conference (IPEMC), 2012 7th International, Harbin, China, Volume 3, pp. 2245 – 2249.
[4] Pattnaik S., et al. "Green Energy Powered Multiphase Buck Converter for Microprocessors", 4th IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG), 2013, Rogers US, pp. 1 – 5.
[5] M. A. Rojas-gonz and S. Edgar “An Integrated Dual-Output Buck Converter Based on Sliding Mode Control” IEEE third Latin American Circuits and System Sympo., 2012, pp. 1–4.
[6] Lili Zhu, et al. "A Novel High Efficiency High Power Density Three-Port Converter Based on Interleaved Half-Bridge Converter for Renewable Energy Applications", IEEE Energy Conversion Congress and Exposition (ECCE), 2014, pp. 5085 – 5091.
[7] Simon S. Ang and Alejandro Olva "Power Switching Converters", Third Edition, CRC Press INC, USA, 2011.
[8] Sanjaya Maniktala "Switching Power Supplies A - Z", Second Edition, Elsevier Inc. USA, 2012.