A Buck Converter Design With Digitally Implemented P Controller

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ABSTRACT: This study involves developing a buck converter with digitally implemented P type controller. The converter output voltage is set to 15V for input source voltages ranging from 20V to 30V and also for various output loads. A controller card based on PIC18 series microcontroller is used to implement the controller. The work is performed experimentally and oscilloscope readings are given to demonstrate correctness of the design.

Keywords: *Buck Converter Design, Digital P Controller*

Sayısal Olarak Gerçeklenen P Tipi Bir Kontroller İle Kontrol Edilen İndirgeyen Çevirici Tasarımı

ÖZET: Bu çalışmada sayısal olarak gerçeklenen bir P kontroller ile kontrolü yapılan bir indirgeyen çevirici tasarımı yapılmıştır. İndirgeyici devresinin çıkışı, giriş voltaj kaynağının 20V ve 30V arası değerleri ve farklı çıkış yükü durumları için 15V'a sabitlenmiştir. Kontrollör devresi bir adet PIC 18 serisi mikrodenetleyicisi kullanılarak gerçeklenmiştir. Çalışma deneysel olarak yapılmış ve osiloskop ekran görüntüleri tasarımın doğruluğunu gösterir olarak verilmiştir.

Anahtar Kelimeler: *İndirgeyen Çevirici Tasarımı, Sayısal P Kontrollör*

1. INTRODUCTION

DC/DC converters are used in many sub-areas of power electronics such as motor control circuitry, battery charge systems fed by PV panels, grid-connected solar inverters and SMPS. Buck, boost, buck-boost, Cuk, sepic are some examples of different types of DC/DC converters. They operate based on converting a dc source voltage into a different level of dc output voltage. Due to lossless circuit elements such as capacitors, inductors and switches they consist of, they can transfer input power to the output of the circuit with a very high efficiency. Because of the switching involved in the conversion process, they are also called switch mode power converters [1-3].

Many research studies have been conducted on this type of converters over the years. We summarize 2 of them in this work. Sekkeli, Yildiz and Ozcalik made a simulation study on buck convertors conducting a comparison analysis of PI and fuzzy logic controllers. Simulations are performed using Matlab program. Results demonstrated that fuzzy logic controller based control over performed classical PI type controller based control in terms of rise time, settling time and robustness of system against parameter changes in the design. [4].

Tsang and Chan developed a cascade controller for a buck converter. The controller was used for applications subjected to sudden load and input voltage changes. The buck circuitry was composed of an outer voltage feedback loop with a slow dynamic and an inner current feedback loop with a much faster dynamic. The cascade controller used in their work was an analog controller. Experimental results given in their work demonstrated effectiveness of their controller over conventional single loop PI controllers [5].

In this study, we developed a buck convertor with digitally implemented P controller which utilizes a single voltage feedback loop taken from the output. It is required that the developed converter output voltage is set to 15V against changes in the input source voltage in ranges of 20V to 30V. Furthermore different output current requirements due to sudden changes in the load are required to be compensated by the developed controller and output voltage must stabilize to 15V. In order to realize the converter experimentally, a control board based on PIC 18F452 microcontroller is used.

2. BUCK CONVERTOR THEORY

Buck convertors convert a dc voltage at their input to a lower dc voltage at their output. During this process a switch which is an embedded part of the circuit is completely 'on' during a fraction of a period of time which is denoted as **DT** and completely 'off' for the remaining part of the period which is shown as **(1-D)T**. This result in a highly efficient power transfers from

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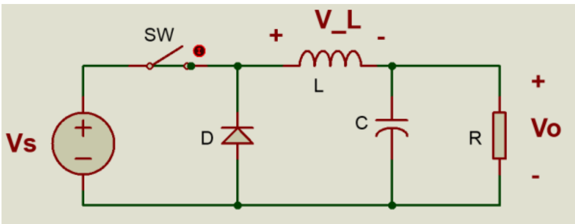
input side to the output and makes this type of power convertors far superior over linear type of voltage regulators. The Figure 1.a shows schematic of a switch mode buck convertor and Figures 1.b and 1.c show equivalent circuits for the cases where the switch is completely ‘on’ and completely ‘off’. The following analysis of the circuit assumes that the circuit operates in steady state, inductor current is continuous, capacitor is sufficiently large and components of the circuit are ideal.



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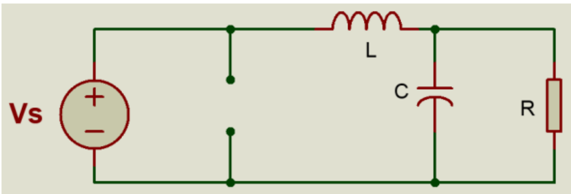

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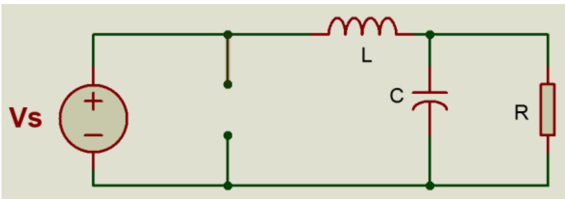


(c)

Figure 1: (a) Buck convertor schematic. (b) Equivalent circuit for switch closed. (c) Equivalent circuit for switch open

2.1. Analysis for the Switch Closed Case:

In this case, the diode is reverse biased for the time interval of **DT**. The source current both charges the capacitor and feeds the load. Peak to peak inductor current is computed as:

$$v_L = V_s - V_0 = L\frac{di_L}{dt} \quad (1)$$

$$\frac{di_L}{dt} = \frac{\Delta i_L}{\Delta DT} = \frac{V_s - V_0}{L} \quad (2)$$

$$\Delta i_{L(closed)} = \left(\frac{V_s - V_0}{L}\right) DT \quad (3)$$

2.2. Analysis for the Switch Open Case:

In this case, the diode is forward biased for the time interval of **(1-D)T**. The inductor current along with charges in the capacitor support the load. Peak to peak inductor current is:

$$\frac{di_L}{dt} = \frac{\Delta i_L}{(1-D)T} = \frac{-V_0}{L} \quad (4)$$

$$\Delta i_{L(open)} = -\left(\frac{V_0}{L}\right)(1-D)T \quad (5)$$

Since the net change in the inductor current is zero over one period when the circuit is operating in the steady state:

$$\Delta i_{L(closed)} + \Delta i_{L(open)} = 0 \quad (6)$$

which result in:

$$V_0 = V_s D \quad (7)$$

3. BUCK CONVERTOR WITH P-TYPE FEEDBACK CONTROLLER

The buck converter developed in this work converts an input voltage that could range from 20V-30V to fixed 15V output voltage. Furthermore, it’s also required that the output voltage to be robust to changes in the load. The developed circuit contains one output voltage feedback loop. The controller used is a digitally implemented P type controller. The block diagram of the circuit is given in the Figure 2.

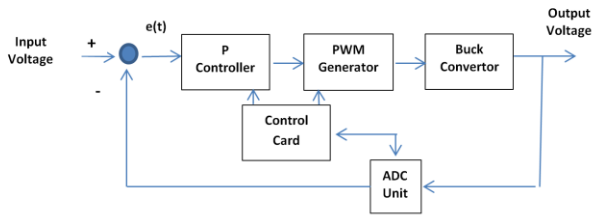


Figure 2: Block diagram of feedback controlled buck convertor

In the buck circuitry, a mosfet is used as a switch. This is because $R_{D(on)}$ of the mosfet is very small, often in the range of tens of miliohms. The controller card used in this project is developed based on PIC18F452 microcontroller. The card includes ADC unit, P type controller which is implemented by software and PWM generation unit. The frequency of the mosfet switching frequency is selected as 4 kHz. In the design process, we allowed peak to peak ripple of inductor current Δi_L

to stay within %25 of it's mean value and the output voltage ripple ΔV_0 to be %1 of V_0.

The values of inductor and capacitor used in the circuit are calculated from following equations [1]:

$$L = \frac{V_s - V_0}{\Delta i_L\, f}\, D \tag{8}$$

$$C = \frac{1 - D}{8\, L\, \frac{\Delta V_0}{V_0}\, f^2} \tag{9}$$

For the input voltage of 20V and the output voltage of 15V, the value of the inductor is calculated as 3.5 mH and the value of the capacitor as 56 µF. For 30V, the value of the inductor is calculated to be 6.5 mH and the value of the capacitor as 60 µF.

The developed feedback controlled buck convertor works as follow: The analog output voltage of the converter is measured by the ADC unit and converted to a 10-bit digital value. This value is compared with a preset value corresponding to digital equivalent of the desired output voltage. The difference in between these 2 values forms the error signal. The error is then processed by the P type controller in order to generate suitable PWM signal which drives the mosfet. Described buck convertor with P type feedback controller successfully implemented on the board. The Figure 3 shows a picture of the experimental setup.

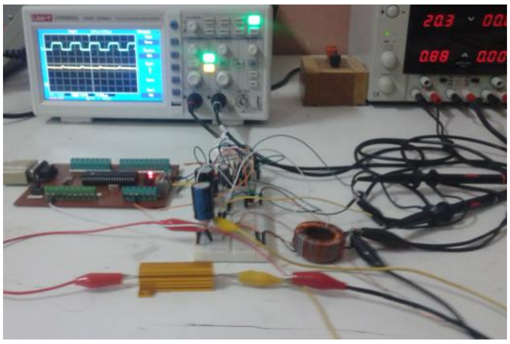
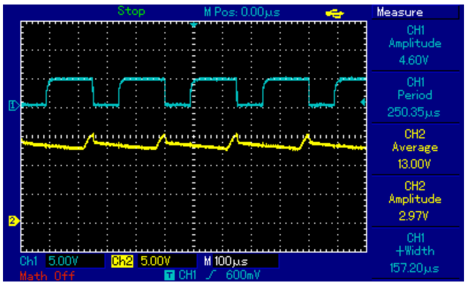


Figure 3: A picture of the experimental setup.

During the experiment, we have investigated the effect of the input voltage change on the output for 2 different cases, namely input voltages of 20V and 30V. Similarly 2 different output loads are considered: a 10 Ω and 100 Ω resistors. The Figure 4 shows oscilloscope readings of PWM control signals of the mosfet, the input voltage and the output voltage values corresponding to above mentioned 4 cases.



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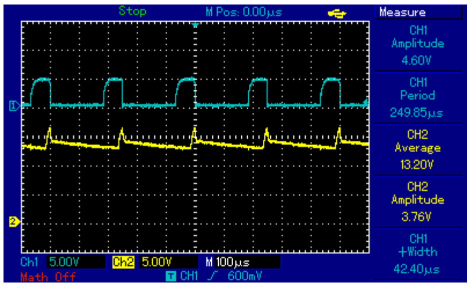

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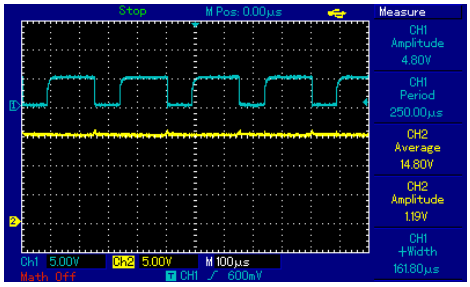

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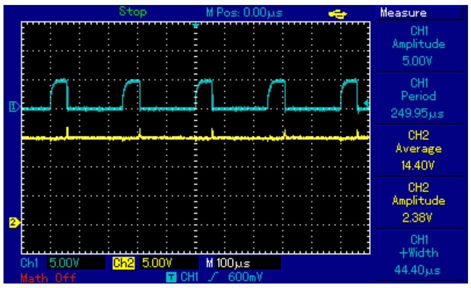

(d)

Figure 4: Oscilloscope readings along with PWM signals for the cases of: (a) 20V input, 10 Ω load. (b) 30V input, 10 Ω load. (c) 20V input, 100 Ω load. (d) 30V input, 100 Ω load.

In the actual circuit, an 8 mH ferrite core inductor and 220 µF electrolytic capacitor are used. This was because esr of the capacitor, wire resistance of the inductor and other non-idealities was not considered in the design. Also not that PWM output amplitude drops to 4.6 V from 4.8V for input source voltage values of

30V. This is because the dc source we have used at the input was not an ideal source.

4. CONCLUSIONS

We have designed a digitally implemented P type feedback controlled buck converter. A controller card based on PIC 18F452 is used to implement P type controller, ADC unit and PWM signal generation. Developed buck converter successfully worked. It is shown that the output of the circuit was set to 15V for various input voltage and load combinations. It's also shown that the effect of non-idealities of circuit components and input source reflects on the output voltage amplitude and generated PWM control signal quality.

5. REFERENCES

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