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Analysis of PID Controller with Auto Tuning In Digitally Controlled Boost Converter

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Abstract: Switched mode supplies can be used for many purposes including DC to DC converters. In This paper a digitally controlled boost converter with PID controller is analyzed to achieve desired output response with high conversion ratio. An auto tuning PID controller is implemented based on frequency response measurement is adopted to compensate the output voltage with variable gain and variable corner frequency. PFM is also included in this controller to improve light load efficiency

I. Introduction

Many digitally controlled buck converters have been implemented whose performance can be comparable to their analogy counter parts. Due to superiorities in some applications, the digital buck topologies have been utilized in some commercial products. However, analogy topologies are still dominant in implementing boost converters, in commercial products.

Constant off-time PWM is compared with some inherent issues becomes the bottleneck of designing digital boost converters. LCO can occur in a digital constant frequency PWM boost converter with a high conversion ratio due to sharp increasing of the gain of the output stage. Besides, the variable gain and corner frequency of the output filter make the loop compensation very difficult when expecting that the converter can operate over wide ranges of input voltages, load currents, and external components.

A simple and practical auto tuning technique with automatic PWM/PFM mode switching should be further investigated. This paper analyzes main issues related to digitally controlled boost converters and proposes several techniques that can systematically solve them.

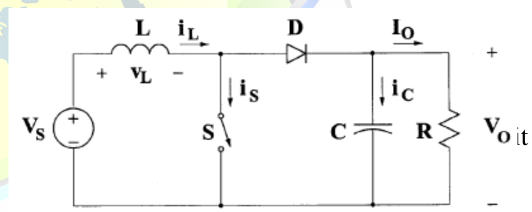
The rest of this paper is organized as follows. Section II reviews main issues related to digitally controlled boost converters and points out some practical solutions. Section III describes modeling of discrete-time constant off time PWM and issues of practical implementation. A simple and practical PID auto tuning technique and a scheme of automatic PWM/PFM mode switching are introduced.

Today most of the equipments are working on dc voltage supply. Normally, the supply coming from power station tithe homes, offices, industries etc. is ac supply. So it is needed to convert ac supply into D.C. supply to make useful for the equipment which works on dc.

II. Boost Converter Analysis

2.1 Boost Converter modelling

The topology of Boost converter is shown in Figure 3 which consists of inductor, diode, capacitor, resistor and power electronic switches like IGBT, MOSFET, GTO control by algorithm for the generation of pulses.

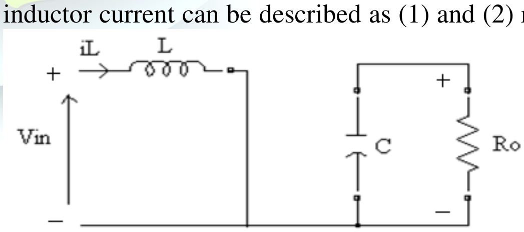


The proposed predictive PFC algorithm is derived based on the following assumptions

i) Boost converter operates at continuous conduction mode.

ii) The switching frequency is much higher than the line frequency, so the input voltage can be assumed as a constant during one switching cycle.

Based on these assumptions, when the switch S is ON or OFF, the circuit of Figure 4 (a) or (b) are obtained and the inductor current can be described as (1) and (2) respectively,



(a)

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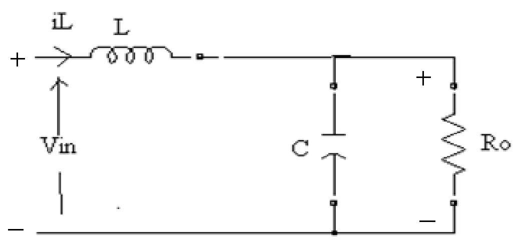
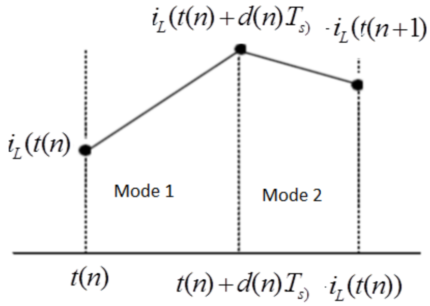


(b)

Boost converter circuit: (a) switch is ON(b) switch is OFF.



From figure 2.2 (a)
In a Boost Converter, During 'ON' Mode:
By applying KCL and KVL, we get

$$L\frac{di_L(t)}{dt} = Vin(t) - R_{ON}i_L(t) - R_L i_L(t) \quad (1)$$

$$Vout(t) = I_o(t).R \quad (2)$$

$$C\frac{dV_c(t)}{dt} + \frac{Vout(t)}{R} = 0 \quad (3)$$

And

$$Vout(t) = V_c(t) + Ic(t).R \quad (4)$$

$$Vout(t) = V_c(t)\left[\frac{R}{R+R_c}\right] \quad (5)$$

From Eq. (3) and Eq. (4)

$$C\frac{dV_c(t)}{dt} = -\frac{Vc(t)}{R+R_c} \quad (6)$$

$$Iin(t) = I_l(t) \quad (7)$$

State space representation of the model is,

$$\begin{bmatrix} L & 0 \\ 0 & C \end{bmatrix}\begin{pmatrix} \frac{di_L(t)}{dt} \\ \frac{dV_c(t)}{dt} \end{pmatrix} = \begin{bmatrix} -(R_{on}+Rl) & 0 \\ 0 & -\frac{1}{R+R_c} \end{bmatrix}\begin{pmatrix} i_L(t) \\ V_c(t) \end{pmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} Vin(t)$$

(8)

$$\begin{bmatrix} Vout(t) \\ I\,in(t) \end{bmatrix} = \begin{bmatrix} 0 & \frac{R}{R+R_c} \\ 1 & 0 \end{bmatrix}\begin{bmatrix} i_L(t) \\ V_c(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} Vin(t) \quad (9)$$

therefore,

$$A = \begin{bmatrix} -(R_{on}+Rl) & 0 \\ 0 & -\frac{1}{R+R_c} \end{bmatrix}$$

$$B = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & \frac{R}{R+R_c} \\ 1 & 0 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

During OFF Period,

$$L\frac{di_L(t)}{dt} = Vin(t) - R_{ON}i_L(t) - R_L i_L(t) - Vout(t) \quad (10)$$

$$aI_c(t) = i_L(t) - i_R(t) \quad (11)$$

$$Vout(t) = Vc(t) + I_c(t)\,Rc$$

$$Vout(t) = Vc(t)\left[\frac{R}{R+R_c}\right] + I_L(t)\,Rc\left[\frac{R}{R+R_c}\right]$$

(Or)

$$Vout(t) = Vc(t)\left[\frac{R}{R+R_c}\right] + (R\,II\,Rc)\;I_L(t)$$

(12)

From Eq(15) and Eq (16)

$$L\frac{di_L(t)}{dt} = Vin(t) - [R_{ON} + R_L + (R\,II\,Rc)]\,I_L(t) - Vc(t)\left[\frac{R}{R+R_c}\right]$$

(13)

→ E.q (1.22)
The state space representation

$$\begin{bmatrix} Vout(t) \\ I\,in(t) \end{bmatrix} = \begin{bmatrix} R\,II\,Rc & \frac{R}{R+R_c} \\ 1 & 0 \end{bmatrix}\begin{bmatrix} i_L(t) \\ V_c(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} Vin(t) \quad (14)$$

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There fore

$$A=\begin{bmatrix} -(R_{on}+RI)(R \parallel Rc) & -\left[\frac{R}{R+R_c}\right] \\ \left[\frac{R}{R+R_c}\right] & -\frac{1}{R+R_c} \end{bmatrix}$$

$$B=\begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

$$C=\begin{bmatrix} R//Rc & \frac{R}{R+R_c} \\ 1 & 0 \end{bmatrix}$$

$$D=\begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

The transfer function of boost converter is given by

$$\frac{Vo}{d}=\frac{V_{ap}(D-1)+sLI_c}{(1-D)^2\left[s^2\frac{LC}{(1-D)^2}+\frac{L}{R(1-D)^2}+1\right]} \qquad (15)$$

The transfer function of boost converter for the following parameters: V_{in} = 10 V, V_o = 20 V, f_s = 1 kHz, L = 10 mH, C = 100 μF and R_L = 20Ω. The reference voltage is 5 V

$$Gp(s)=\frac{-0.01s+10}{1e^{-6}s^2+1e^{-3}s+.25} \qquad (16)$$

the step response the boost converter transfer function model.

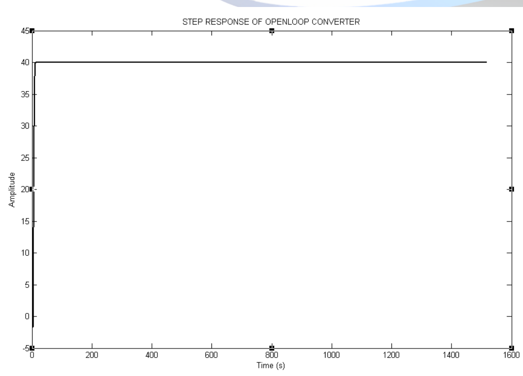

Fig 2.3. Step response of Boost converter

2.2 Controller parameters

"Tuning" is the engineering work to adjust the parameters of the controller so that the control system exhibits desired property. Currently, more than half of the controllers used in industry are PID controllers. In the past, many of these controllers were analog; however, many of today's controllers use digital signals and computers. When a mathematical model of a system is available, the parameters of the controller can be explicitly determined. However, when a mathematical model is unavailable, the parameters must be determined experimentally. Controller tuning is the process of determining the controller parameters which produce the desired output. Controller tuning allows for optimization of a process and minimizes the error between the variable of the process and its set point.

Types of controller tuning methods include the trial and error method, and process reaction curve methods. The most common classical controller tuning methods are the Ziegler-Nichols and Cohen-Coon methods. These methods are often used when the mathematical model of the system is not available. The Ziegler-Nichols method can be used for both closed and open loop systems, while Cohen-Coon is typically used for open loop systems.

A closed-loop control system is a system which uses feedback control. In an open-loop system, the output is not compared to the input.

The general form of the PID controller is,

$$u(t)=K_p\left[e(t)+\frac{1}{T_i}\int_0^t e(t')dt'+T_d\left(\frac{de(t)}{dt}\right)\right] \qquad (17)$$

Ziegler-Nichols (Z-N) Oscillation Method

This procedure is only valid for open loop stable plants and it is carried out through the following steps

i. Set the true plant under proportional control, with a very small gain.

ii. Increase the gain until the loop starts oscillating. Note that

linear oscillation is required and that it should be detected at the controller output.

iii. Record the controller critical gain *Kp* = *Kc* and the oscillation period of the controller output, *Pc*.

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iv. Adjust the controller parameters according to Table 2.1

we first observe that the underlying model being obtained in the experiment is only one point on the frequency response, namely the one corresponding to a phase equal to $-\pi$[rad] and a magnitude equal to Kc^{-1} , since the Nyquist plot for $K_pG(j\omega)$ crosses the point (−1, 0) when Kp = Kc. The settings in Table 2.3 were obtained by Ziegler and Nichols who aimed to achieve an under damped response to a step for those plants for which a satisfactory model has the form,

2.3 Ziegler-Nichols Tuning Rule Based on Step Response

Type of controller	K_p	T_i	T_d
P	0.5 Kc		
PI	0.45 Kc	0.833 Tc	
PID (Tight control)	0.5 Kc	0.5Tc	0.125 Tc
PID (Some overshoot)	0.33 Kc	0.5Tc	0.33 Tc
PID (No overshoot)	0.2 Kc	0.3 Tc	0.5 Tc

Table 2.1 - Ziegler-Nichols Tuning Rule

Figure 2.4,shows the step response of boost converter closed loop system for Proportional gain 1.1, This is obviously the point of sustained oscillation at Kp = 0.1

Therefore,

$K_C = 0.1$

$T_C = 6$ ms (time for one period)

Obtain PID parameters from Table 2.1.

$K_P = 0.006$

$Ki = 20$

$K_d = 4.5 \times 10^{-5}$

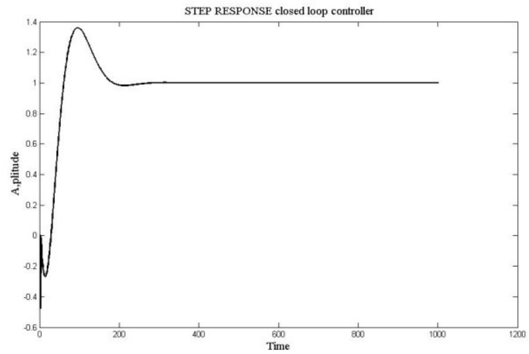

Fig.2.4. Step response of Boost converter with PID controller

III. Results And Conclusion

3.1 Proposed System

MATLAB/ Simulink model of boost converter is consist of Boost converter model, PID controller model, Voltage divider model, LC circuit model, PWM controller with PFM controller and scopes.

3.2.Input voltage waveform

Input voltage of the system (Vin) Boost converter output is shown in below waveform. The PWM wave form and PWM wave forms are need for switching process i.e. to make on and off process. The input voltage is given as gate voltage to MOSFET.

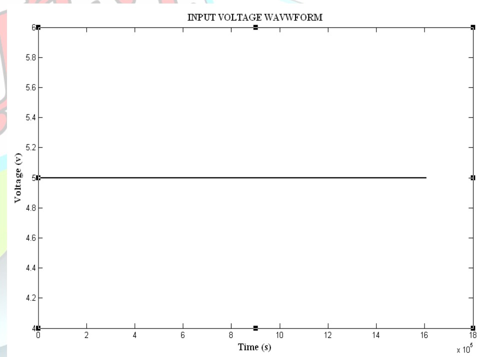

Fig 3.2.Input voltage waveform

The input voltage of boost converter shown in above figure 3.2. The output voltage of the converter is depends on corresponding input. Tuning process for constant frequency PWM, constant off-time PWM, and zoomed-in view of the input voltage waveform after auto tuning at Vg = 5V.

3.3. Input Current waveform

The input current wave form is shown in below figure. If Vout = 10V during 10–150mA load step from PFM to PWM and from PWM to PFM. constant off-time

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PWM mode is selected when load current switches to 150mA.

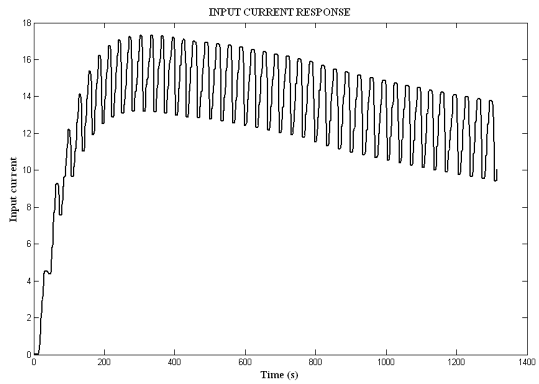

Fig 3.3. Input Current waveform

The input current value is too low when compared to output current. because this booster coverter is the steep up device. during10–150mA load step from PFM to PWM and from PWM to PFM. The above figure indicates current value at input during initial time of step up process.

3.4. Output voltage waveform (Vout)

Boost converter output is shown in above waveform. The boost converter is a step up device which is used to step up the input voltage. The output voltage is depends on corresponding input voltage and current values. Output voltage V_{out} = 12volt .The auto tuning process for constant frequency PWM (V_0 = 2V/div, time = 2 ms/div)and zoomed-in view of the output voltage waveform after a process ($V0$ =1V/div, time =200 μs/div) shown in above figure. The auto tuning process for constant off-time PWM ($V0$ = 2V/div, time = 5 ms/div) shown in above figure.

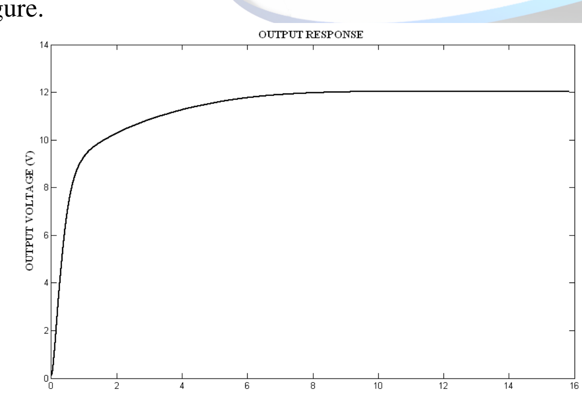

Fig. 3.4 Output waveform of converter

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