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DC/DC boost converter using DSP controller for fuel cell

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Abstract: This article presents the DC/DC boost converter using the DSP controller for fuel cell. The fuel cell economy is considerably improved due to the plenty of source available in our day to day life. The core technology behind this application of fuel cell is "power electronics" which influence the developing of greener and safer transportation system. The aim of this paper is to present the simple and the practical boost converter topology to regulate both input voltage and output voltage simultaneously. The performance of conditioning system is evaluated in simulation results. The design of the DSP processor is mainly based on the frequency response method which is analyzed by using PID gains and also used for implementing the controller.

Keywords: Fuel cells; Design of boost converter; frequency response and controller; design PID controller; Design DSP controllers and processors

I. INTRODUCTION

Digital Signal Processing (DSP) has widely used in telecommunication, intelligent control and motion control etc. Because of its high speed computation ability, high reliability and cost reduction digital controller of DC/DC converter using DSP is becoming more and more commonly used in the industry today.

The effort on making the fuel cells is efficient energy conversion devices which are in the progress around the research communities. These fuel cells are very attractive since by product mainly produces heat and water .So this current technology having the great sense in reducing the vehicle emission and fuel consumption. The conventional Diesel/petrol powered impacts in the environment are of two ways (i) exhaust emission and (ii) evaporative emissions. The eco-friendly of fuel cell technology eliminates these major problems due to its ecofriendly nature process of extracting the energy.

The main objective in this paper is mainly to presents a simple and efficient design of DC/DC converter, with a digital converter for fuel cell. Then its simplicity in the design makes the system in helping the reduction of volume and weight of the converter which is becoming more common in all the industries. And the DSP chips are more available with the integrated AC to DC convertor and pulse width modulation (PWM).

II. BOOST CONVERTER'S SMALL SIGNAL MODEL

A. Mathematical model

A mathematical model of the system helps us to realize the controller design. Hence, we will derive the equations concerning the DC/DC Boost converter model from basic laws.

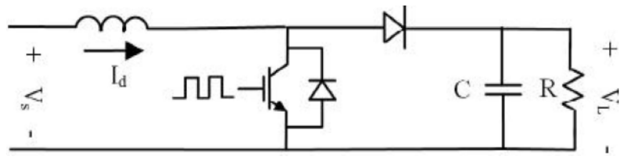
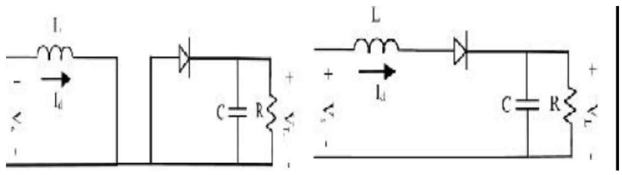


Fig 1. Boost Converter's Model



(a) (b)

Fig 2. (a) ON state of SW (b) OFF state of SW

Consider the conventional PWM switching boost DC/DC conversion in continuous conduction mode (CCM). Transistor and diode switch are considered as ideal.

To define fig 2(a),

$$L\frac{di_l(t)}{dt}=V_s(t) \qquad (1)$$

$$C\frac{dV_C(t)}{dt}=-\frac{Vc(t)}{R} \qquad (2)$$

To define fig 2(b),

L=Vs(t)-Vc(t) (3)

C=Id(t)-Vc(t)/R (4)

To define control input,

$$\delta(t)=\begin{cases}1 & nt < t < nT + DT \\ 0 & nt + DT < t < nt = T\end{cases} \qquad (5)$$

Then by combining these equations (1-5), we get the figure 2 as,

$$L\frac{di_l(t)}{dt}=V_s(t) - Vc(t)\ \delta'(t) \quad (6)$$

$$C\frac{dV_C(t)}{dt} = Id(t)\ \delta'(t)\ \frac{Vc(t)}{R} \quad (7)$$

$$Vc=Vo \quad (8)$$

$$\text{Where, } \delta'(t) = 1 - \delta(t) \quad (9)$$

The time variant and topology variant characteristics of the system have been isolated to single control input variable δ(t) .Based on the equations we have arrived we can do both dc steady state and ac small signal analysis of boost DC/DC converter.

Input to output transfer function of the system is derived as,

$$\frac{Vo(s)}{Vs(s)} = \frac{1}{D'1+\frac{sL}{RD'^2}+s^2LC/d'^2} \quad (10)$$

Control to output transfer function is derived as,

$$\frac{Vo(s)}{d(s)} = \frac{Vs}{D'^2}\frac{1-SL/RD'^2}{1+\frac{sL}{RD'^2}+s^2LD/D'^2} \quad (11)$$

Where,

D’= (1-D)

B. Design of a boost converter elements

The boost converter proposed in this paper is designed to operate in continuous conduction mode (CCM) which means the inductor current is always meant to be higher than zero. So,the chosen inductor value has to be higher than the minimum inductance required for operation in CCM given by,

$$Lmin=\frac{D(1-D)^2}{2fs}/R \quad (12)$$

Where Lmin denotes the minimum inductance, D-duty cycle, resistance R, and fs denotes the switching frequency of switch. The minimum capacitance required [for certain output voltage ripple is given by,

$$Cmin=\frac{D}{RfsVr} \quad (13)$$

Where Cmin denotes the minimum capacitances and Vr denotes the amount of the voltage ripple.

C. Closed loop control of boost converter.

We are aware that the constant dc output voltage from the converter is achieved through the closed loop control of the output which means the adjustment of the duty cycle is done to obtain the desired output voltage. The control specifications of the converter will be generally in two parts

(i) steady state accuracy

(ii) settling time and allowed transient overshoot in the event of disturbances.

Open loop transfer function of boost converter is

$$Gs=\frac{Vs}{D^{12}}\frac{1}{1+\frac{sL}{RD^{12}}+s^2LC/D^{12}} \quad (14)$$

Where

D’=(1-D)

D. Prototype boost converter

For the Prototype boost converter we have been designing the fuel cell and the parameters are,

Table 1. Prototype Boost Converter

Parameters	rating
Input voltage ,Vin	10V
Resistance(Load)	30Ω
Capacitance C	220µf
Inductance L	400µh

The continuous time model of the plant transfer function is,

$$Gs=\frac{10}{0.44} * \frac{1}{1.96*e^{-7}+3.03*e^{-5}s+1}$$

Discrete time transfer function is,

$$Gz=\frac{(0.0231z+0.0231)}{Z^2-1.9949z+0.9969} \quad (15)$$

III. FREQUENCY RESPONSE AND CONTROLLER DESIGN

A. Frequency response and phase margin adjustment

The frequency response of the converter gives the stability limit in terms of the phase margin .lower the phase margin lesser will be the stability, hence adjusting the phase margin through the SISO tool help us to make the system more stable.

B. Controller tuning approach

The tuning of proportional, integral and integral and derivative gain has been done by taking care of the design requirements like reduced overshoot, settling time and steady state error .The PID control algorithm is developed in discrete domain for the proposed boost converter.

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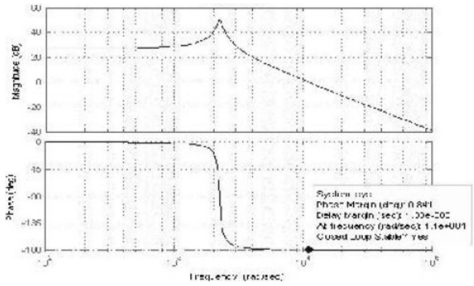

Fig 3. Frequency response of boost converter uncompensated

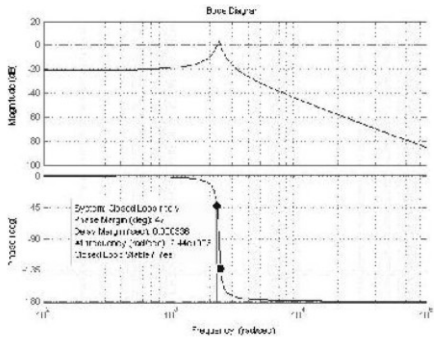

Fig 4. Frequencyresponse of boost converter compensated

a) Tuning proportional gain

The controller has been tuned for different proportional gains and best valve chosen from the results.

Table 2. Proportional Adjustment

Proportional gain(kp)	Steady state error
0.2	0.1844
0.6	0.0709
0.8	0.0494

Hence , The kp value of 0.8 can be chosen and set

b) Tuning integral gain

The controller has been tuned for different integral gains and best valve chosen from the results.

Table 3. Integral Adjustment

Integral gain(ki)	Steady state error
0.1	0.0164
0.2	0.0267(not recommended)

c) Tuning derivation gain

The most important feature of the manually designed PI controller is there is minimal amount of steady state error in the closed loop response

The chosen derivative gain is to set to be Td=0.6.The response will have smaller overshoot. Hence, the gain value of best from the trial and error valve has been chosen for the prototype boost converter.

Table 4. Derivative Adjustment

Derivative gain(kd)	Steady state error
Upto 0.6	0.0011
>0.6	increases

d) Simulation Results Of Power Stage

The steps involving in the coding the converter will be explained here. The coding is not given in this paper. The output voltage has been fixed hence prototype is used as parameters for the converter for obtaining these results.

Step1: Get all the input values which are going to vary for like duty cycle (K), Sample time (h), desired no of samples (n).

Step2: Enlist the technical parameters in the code itself like Vi , R ,f ,c ,l

Step3: Calculate switching time ,maximum time and 'ON' and 'OFF' duration using the formulas

Step4 : Define initial time for Il & Vc.

Step5: Define and initialize an array for storing il & Vc for both forward and backward approximation

Step6: Calculate diL/dt and dvc/dt for 'on' and 'off' period.

Step7: Calculate output voltage from trapezoidal technique, perform forward and backward eular approximation and get the mean value as final values

Step8: Calculate output current (Vout/R), input current using trapezoidal method.

Step9: Make necessary labelling for final understanding,

The results of converter stage is,

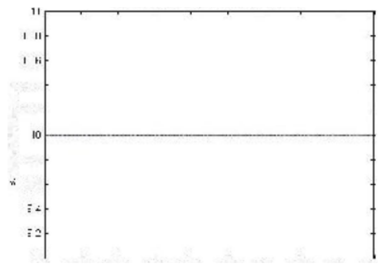

Fig 5. Input voltage of boost converter

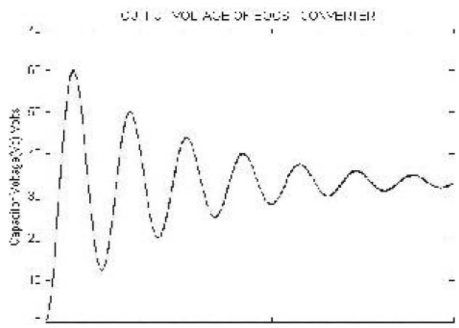

Fig 6. Output voltage of boost converter

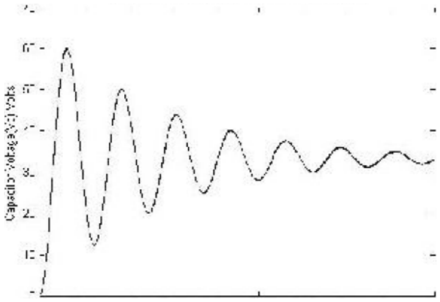

Fig 7. Input current of boost converter

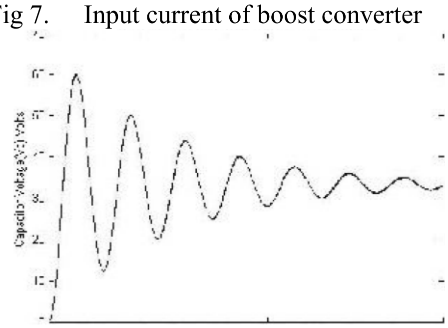

Fig 8. Output current of boost converter

IV. CONCLUSION

This paper presents a design by emulation for designing a boost converter. And this also tells about the small signal boost converter models .increasing the phase margin will results in increasing the stability of the system. Hence, the stability is adjusting the bode plot with the help of the SISO tool. The future work will be implementing the boost converter with PID algorithm in the DSP processor.

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