

State feedback controller using pole placement method for linear boost converter to improve overshoot and settling time

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ABSTRACT

Switched mode DC-DC converters are electronic circuits which convert a voltage from one level to a higher or lower level voltage. This paper presents a new solution approach to control DC-DC Boost converter. State-space controller is used in this project. The fundamental concepts of controllability, observability and stability are important properties in linear state space. Controllability and observability represent two major concepts of modern control system theory. In summary, the results obtained indicate that the state space controller using pole placement is an effective approach for DC-DC converter output voltage regulation where it reduce the overshoot and reduces the settling time.

Keywords - DC-DC Boost converter, State feedback controller, Feedforward controller

INTRODUCTION

A boost converter, as its name suggests steps up the input DC voltage value and provides at output. This converter contains basically a diode, a transistor/mosfet as switches and at least one energy storage element. Usually capacitors are added to output for implement the function of producing the output voltage ripple and sometimes inductors are combined. This converter used such as battery, solar panel, rectifier and DC generator.

In the state space system, internal state of this system clearly taken into account by establishing the equation knows as the similarities. The system output is provided in terms of a combination of the current state of the system, and when the system input output equation. These two equations formed an equation system is called the equation of the state space. State space vector space consisting of all possible states of the internal system.

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There are many commercially available power electronic modelling and simulation software in the market. Few well known platform includes PSim, PLECS, PSCAD, Simulink and etc. Each software platform have its own merit [1]. In this paper, Simulink is chosen as a modelling and simulation platform for state space modelling of Boost DC-DC converter. Design state space using Simulink has many advantages like state space model is matrix base and Simulink is runs on top of MATLAB, where MATLAB is an acronym of MATric LABoratory, it uses matrix as basis for computation. This allows state space model to take advantage on the platform to improve the speed of simulation. Second, the basic Simulink block set does not comes with DC-DC converter block. It require additional SimPowerSystems or SimElectronic blockset in order to model and simulate DC-DC converter [1]. This paper presents method of developing DC-DC Boost converter model block using basic Simulink building blocks without any additional block set.

RESEARCH METHODOLOGY

Analysis for Switch OPEN

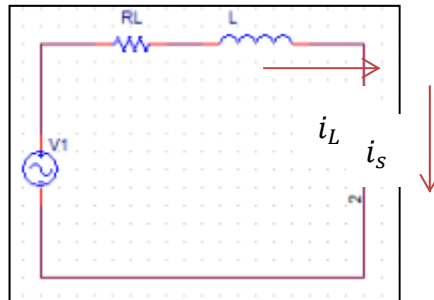


Figure 1: DC-DC Boost Converter During On Mode

The R_L is the parasitic resistance of inductor branch and R_C is the parasitic resistance of capacitor branch.

State equation matrix are given as:

$$\begin{bmatrix} L & 0 \\ 0 & c \end{bmatrix} \begin{bmatrix} \frac{d i_L(t)}{dt} \\ \frac{d v_c(t)}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R_L}{L} & 0 \\ 0 & -\frac{1}{c(R+R_C)} \end{bmatrix} \begin{bmatrix} i_L(t) \\ V_C(t) \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{in}(t) \quad (1)$$

$$\begin{bmatrix} V_{out}(t) \\ i_{in}(t) \end{bmatrix} = \begin{bmatrix} 0 & \frac{R}{R+R_C} \\ 0 & 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} V_{in}(t) \quad (2)$$

Therefore

$$A1 = \begin{bmatrix} -\frac{RL}{L} & 0 \\ 0 & -\frac{1}{c(R+RC)} \end{bmatrix}, \quad B1 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}, \quad C1 = \begin{bmatrix} 0 & \frac{R}{R+RC} \end{bmatrix}, \quad D1 = 0 \quad (3)$$

Analysis for Switch CLOSE

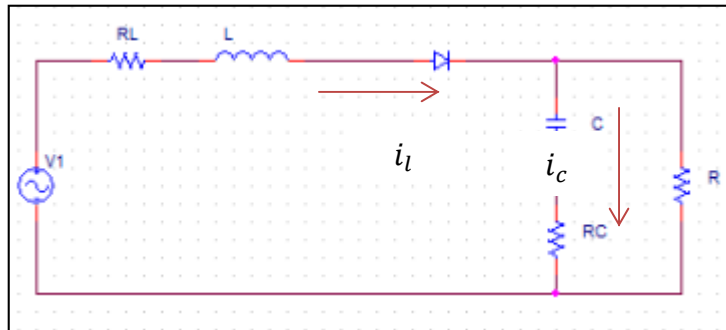


Figure 2: DC-DC Boost Converter During OFF Mode

State equation matrices are given:

$$\begin{bmatrix} L & 0 \\ 0 & c \end{bmatrix} \begin{bmatrix} \frac{di_L(t)}{dt} \\ \frac{dv_c(t)}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{RL+R\backslash RC}{L} & -\frac{R}{L(R+RC)} \\ \frac{R}{L(R+RC)} & -\frac{1}{c(R+RC)} \end{bmatrix} \begin{bmatrix} i_L(t) \\ V_c(t) \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{in}(t) \quad (4)$$

$$\begin{bmatrix} V_{out}(t) \\ i_{in}(t) \end{bmatrix} = \begin{bmatrix} R\backslash RC & \frac{R}{c(R+RC)} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} i_L(t) \\ V_c(t) \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} V_{in}(t) \quad (5)$$

Therefore:

$$A2 = \begin{bmatrix} -\frac{RL+R\backslash RC}{L} & -\frac{R}{L(R+RC)} \\ \frac{R}{c(R+RC)} & -\frac{1}{c(R+RC)} \end{bmatrix}, \quad B2 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix}, \quad C2 = \begin{bmatrix} R\backslash RC & \frac{R}{(R+RC)} \end{bmatrix}, \quad D2 = 0 \quad (6)$$

Averaging the state variable description using the duty ratio, D_{sw} .

$$x(t) = [A1D_{sw} + A2(1 - D_{sw})]x(t) + [B1D_{sw} + B2Cu(t)] \quad (7)$$

$$y(t) = [C1D_{sw} + C2(1 - D_{sw})]x(t) \quad (8)$$

$$x(t) = [A]x(t) + [B1D_{sw}]u(t) \quad (9)$$

$$V_{out} = C2x(t) \quad (10)$$

$$A = \begin{bmatrix} -\frac{R \setminus \setminus RC}{L} D_{sw} - \frac{RL+R \setminus \setminus RC}{L} & \frac{R}{L(R+RC)} D_{sw} - \frac{R}{L(R+RC)} \\ -\frac{R}{C(R+RC)} D_{sw} + \frac{R}{C(R+RC)} & -\frac{1}{C(R+RC)} \end{bmatrix}, B = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix},$$

$$C = \begin{bmatrix} -R \setminus \setminus RC D_{sw} + R \setminus \setminus RC & \frac{R}{(R+RC)} \end{bmatrix}, D = 0 \quad (11)$$

Where $x(t) = \begin{bmatrix} i_L \\ V_C \end{bmatrix}$; be the two state variable corresponding to the inductor current and capacitor voltages;

$u(t) = [V_{in}]$; is the input and
 $y(t) = V_{out}$; is the output.

Controller and Observer Design

Boost converter needs to yield a settling time 1-ms and the overshoot must be smaller than 0.5%. Then, the steady-state error of the system must be eliminated.

To determine desired damping ratio,

$$\zeta = \sqrt{\frac{\left[\frac{\ln OS}{-\pi}\right]^2}{1 + \left[\frac{\ln OS}{-\pi}\right]^2}} = 0.86$$

To desired natural frequency, ω :

$$\omega_n = \frac{4.6}{\zeta \times T_s} = 5.349 \times 10^3$$

To determine desired characteristic equation:

$$(s^2 + 2\zeta\omega s + \omega^2) = 0$$

$$s^2 + 9200.28s + 2.8612 \times 10^7$$

Table 1: The Boost Converter Parameter

Parameter	Description	Value
V_{in}	Input voltage	12V
L	Inductance	100uH
C	Capacitance	200uF
RL	Resistor Inductance	10mH
RC	Resistor Capacitance	8mF
R	Resistor	6Ω
F_s	Switching Frequency	100KHz

RESULTS AND DISCUSSION

State-Space Representation

Figure 3 and Figure 4 shows the performance of state-space representation using Simulink model. This state-space shown before a controller was designed.

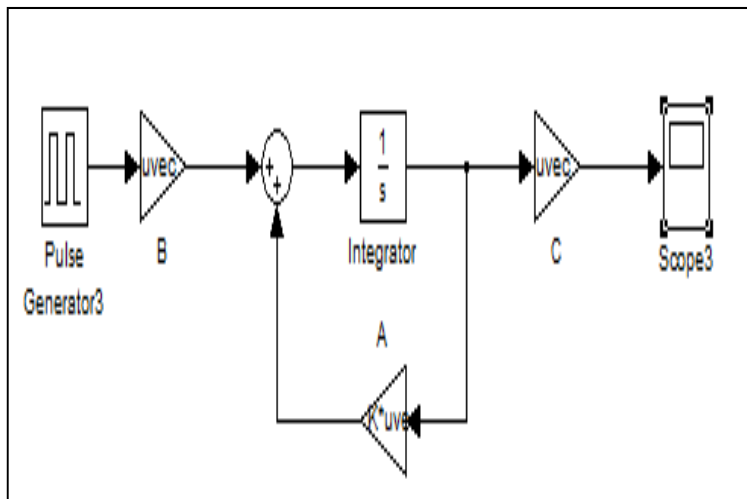


Figure 3: Boost Converter using Simulink model

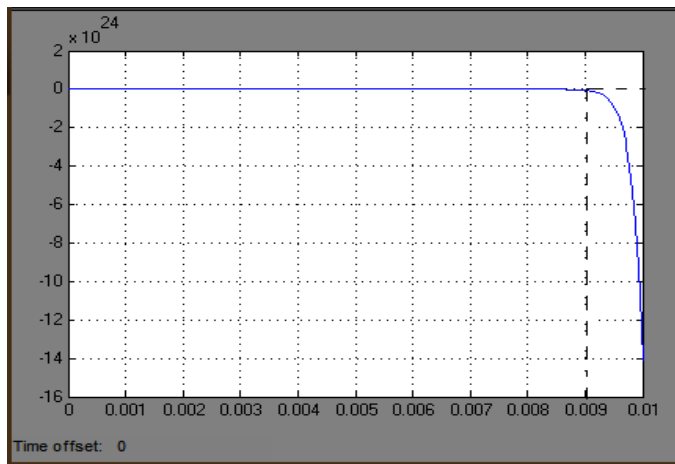


Figure 4: Output voltage from Simulink model

Pole Placement Method

I. State-Feedback control

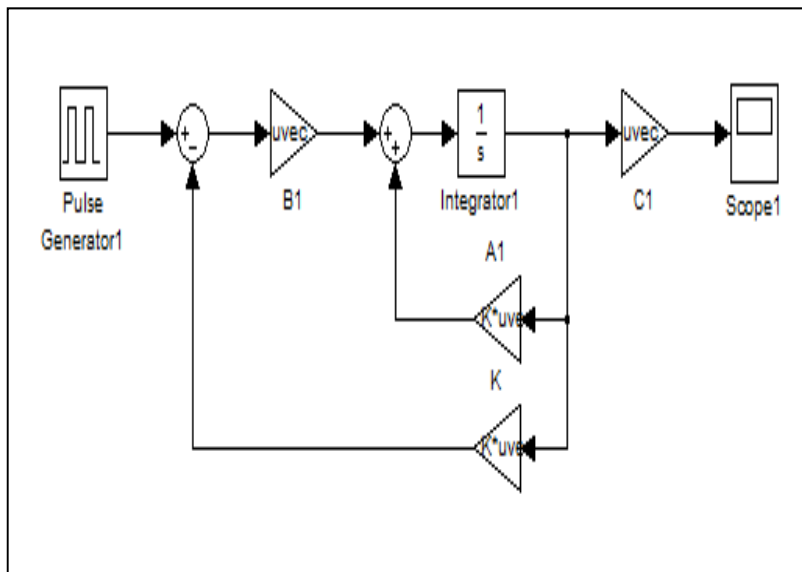


Figure 5: Boost Converter with a State-Feedback Controller

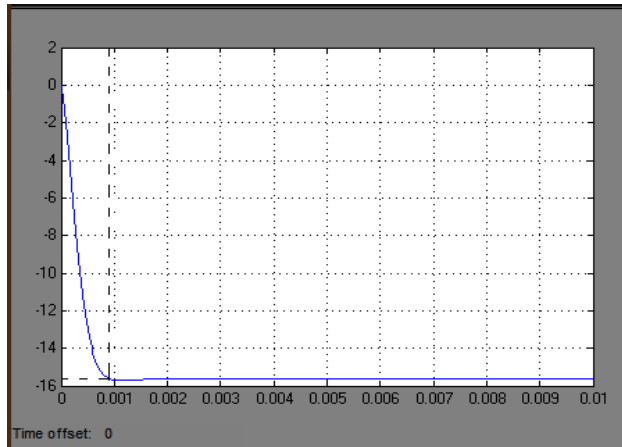


Figure 6: Output voltage after added the State-Feedback Controller

Fig. 5 shows the performance result MATLAB Simulink for output voltage of feedback controller response. Fig 6 shows that the result performance for settling time less than 1ms. However, feedback controller produced an output voltage of -15.8V less 102.6% from the required output voltage. It can be concluded the state-feedback controller reduces the settling time and overshoot but it cannot produced the required output voltage.

II. Feed-Forward Control

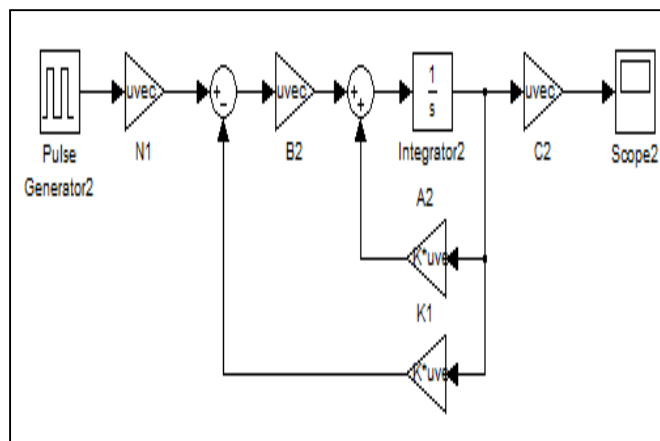


Figure 7: Boost Converter with a State-Feedback and Feed-Forward Controller

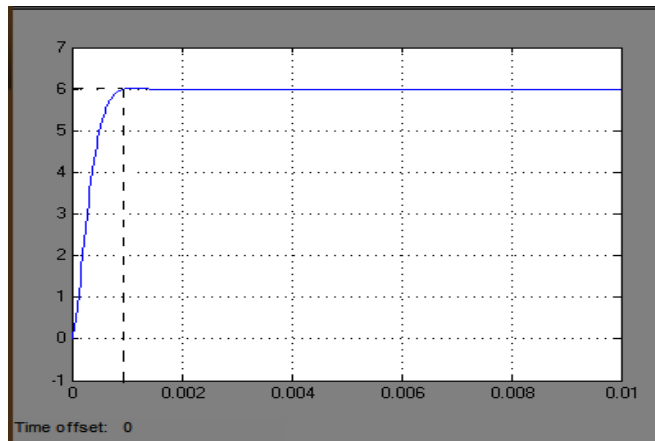


Figure 8: Output voltage after added the State-Feedback and Feed-Forward Controller.

Fig. 7 and Fig. 8 show the MATLAB Simulink result performance for output voltage of feed forward control. From this performance the output voltage achieved the required voltage 6V and the system become more stable.

CONCLUSIONS

This paper discusses about the simulation and analysis the result of DC-DC Boost converter using MATLAB Simulink® software. The pole placement controller is introduced in order to control DC-DC Boost converter. There are few types of controllers have been designed to achieved the suitable controller for linear boost converter. The controllers such as state feedback and feed forward gain. It can be concluded that the pole placement controller are reduce the settling time, overshoot and produced the required output voltage same with theoretical.

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