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Control Method for DC-DC Boost Converter Based on Inductor Current

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Abstract—This paper introduces a new control method for DC-DC Boost converter that is the control method based on inductor current on the basis of balance of power. The simulation results have proven to be that: proposed control method ensured the accuracy and output voltage ripple is within the required limit.

Keywords— DC-DC converter, DC-DC Boost converter, PI controller, inductor current

I. Introduction

The DC-DC voltage converter in general and DC-DC Boost voltage converter in particular has played a very important role in the creation of a DC voltage that has an amplitude as requested and very small output voltage ripple [1-3]. The input of Boost converter input is usually a DC resource supplied by the solar battery source, so it doesn't have the ability to adjust. Moreover, this source is influenced by light intensity and temperature of the environment. So it will have low amplitude and changes constantly. Boost converters have the task of creating a DC voltage at the output is larger and more stable DC voltage at the input.

Normally, the DC-DC converters are controlled according to the output voltage [4-10]. The output voltage is compared with the reference voltage. With this control, we need to build the transfer function of the converter. To adjust the desired output voltage we use pulse width modulation techniques PWM to change the time on-off of the switch. The output voltage of the converter is monitored by the voltage subtraction, the voltage at the positive pole is signed with the reference voltage and the negative pole assigned with the feedback voltage, when its archived error will be passed to the controller, the transfer function of the converter and the create pulses to close/open the MOSFETs.

However, according to the structure of the DC-DC Boost converter, the electric current through the inductor depending on the input voltage, output voltage and load resistance [11]. Moreover, according to the principle of balance of power, then the consumption power will equal to the generated power or input power will equal to the output power. So when the input voltage of the converter and load resistors do not change, then the electric current through the inductor will depend on the output voltage. So, we can control the output voltage by adjusting the electric current through the inductor. Therefore, this article gives a new control method for DC-DC Boost converter based on the inductor current. With this method we might not need to build the transfer function of the converter

The structure of the paper is presented as follows: part I overview introduces the converter DC-DC Boost. Part II presents the mathematical model of DC-DC Boost converter. Control method based on the inductor current for DC-DC Boost converter is given in part III. Part IV is the simulation results and section V concludes.

II. Mathematical Model of DC-DC Boost Converter

The structure of DC-DC Boost converter shown as in figure 1.

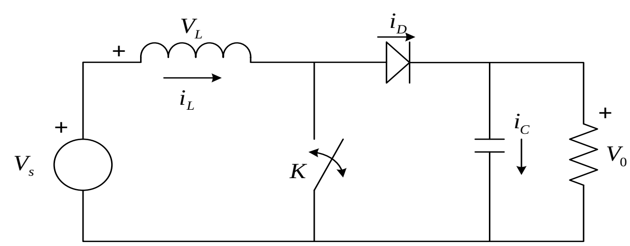

Figure 1. Topology of DC-DC Boost converter

Mathematical model of DC-DC Boost converter built in [11] and summarized as follows:

+ When K closed:

Equivalent circuit of the DC-DC Boost converter is shown as in figure 2.

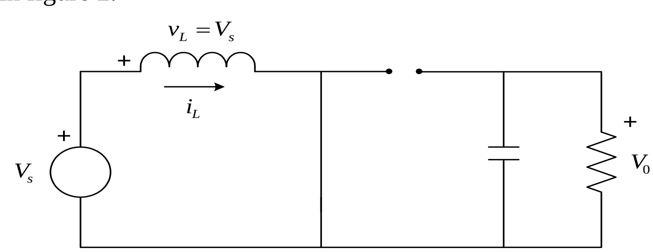

Figure 2. Equivalent circuit of DC-DC Boost converter when K closed

According to Kirchoff 2 law, we have:

$$v_L = V_S = L\frac{di_L}{dt} \quad (1)$$

The rate of change of current is a constant. Therefore, the change in inductor current is computed from

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_S}{L} \quad (2)$$

Solving for Δi_L for the switch closed as follows

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$$(\Delta i_L)_{close} = \frac{V_S DT}{L} \quad (3)$$

+ When K open:

Equivalent circuit of DC-DC Boost converter is shown as in figure 3.

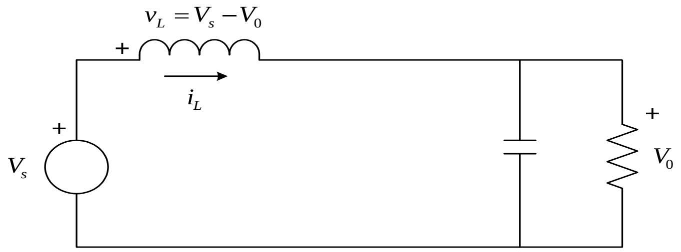

Figure 3. Equivalent circuit of DC-DC Boost converter when K open

Similarly, we have:

$$v_L = V_S - V_0 = L\frac{di_L}{dt} \quad (4)$$

or $\frac{di_L}{dt} = \frac{V_S - V_0}{L}$

The rate of change of current is a constant. Therefore, the change in inductor current is computed from

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{V_S - V_0}{L} \quad (5)$$

Solving for Δi_L for the switch open as follows

$$(\Delta i_L)_{open} = \frac{(V_S - V_0)(1-D)T}{L} \quad (6)$$

For steady-state operation, the net change in inductor current must be zero. From (3) and (6) we have equation as follows:

$$(\Delta i_L)_{close} + (\Delta i_L)_{open} = 0 \quad (7)$$

$$\frac{V_S DT}{L} + \frac{(V_S - V_0)(1-D)T}{L} = 0 \quad (8)$$

Solving for *Vo*

$$V_S(D+1-D) - V_0(1-D) = 0 \quad (9)$$

$$V_0 = \frac{V_S}{1-D} \quad (10)$$

Equating input and output powers, we have:

$$V_S I_L = \frac{V_0^2}{R} = \frac{[V_S/(1-D)]^2}{R} = \frac{V_s^2}{(1-D)^2}R \quad (11)$$

Soloving Eq. (11) we find out I_L as follows:

$$I_L = \frac{V_S}{(1-D)^2 R} = \frac{V_0^2}{V_S R} = \frac{V_0 I_0}{V_S} \quad (12)$$

Maximum and minimum inductor currents are determined by using the I_L value and the change in current $(\Delta i_L)_{close}$.

$$I_{max} = I_L + \frac{\Delta i_L}{2} = \frac{V_S}{(1-D)^2 R} + \frac{V_S DT}{2L} \quad (13)$$

and

$$I_{min} = I_L - \frac{\Delta i_L}{2} = \frac{V_S}{(1-D)^2 R} - \frac{V_S DT}{2L} \quad (14)$$

Equation (14) was developed with the assumption that the inductor current is continuous, meaning that it is always positive. A condition necessary for continuous inductor current is for *I*min to be positive. Therefore, the boundary between continuous and discontinuous inductor current is determined from

$$I_{min} = 0 = \frac{V_s}{(1-D)^2 R} - \frac{V_s DT}{2L} \quad (15)$$

or

$$\frac{V_s}{(1-D)^2 R} = \frac{V_s DT}{2L} = \frac{V_s D}{2Lf} \quad (16)$$

From (16) we calculated L_{min} as follows:

$$(Lf)_{min} = \frac{D(1-D)^2 R}{2} \quad (17)$$

$$L_{min} = \frac{D(1-D)^2 R}{2f} \quad (18)$$

Output voltage ripple can calculated from capacitor current :

$$|\Delta Q| = \frac{V_0}{R}DT = C\Delta V_0 \quad (19)$$

Find out

$$\frac{\Delta V_0}{V_0} = \frac{D}{RCf} \quad (20)$$

$$C = \frac{D}{Rf\frac{\Delta V_0}{V_0}} \quad (21)$$

$\frac{\Delta V_0}{V_0}$ is output voltage ripple

where f is the switching frequency

III. Control method based on Inductor Current

The method control scheme based on output voltage shown as in Fig. 4

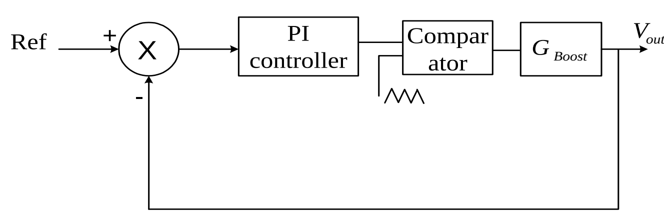

Figure 4. Control method scheme based on output voltage

Where G_{Boost} is transfer function of converter $G_{Boost} = \frac{V_{out}}{V_S}$

In the method control based on output voltage scheme [4-10] shown in Fig. 4, the converter output voltage is sensed and subtracted from a reference voltage in an error amplifier. The

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error amplifier produces a control voltage is passed to PI controller. The output of PI controller is compared to a constant- frequency and amplitude sawtooth waveform. The comparator produces a logic "0" or "1" signal that is fed to drivers of controllable switches in the dc-dc converter. The duty ratio of the signal depends on the value of the control voltage. The frequency of the pulse width modulation signal is the same as the frequency of the sawtooth waveform.

Control method based on inductor current is shown as in Figure 5.

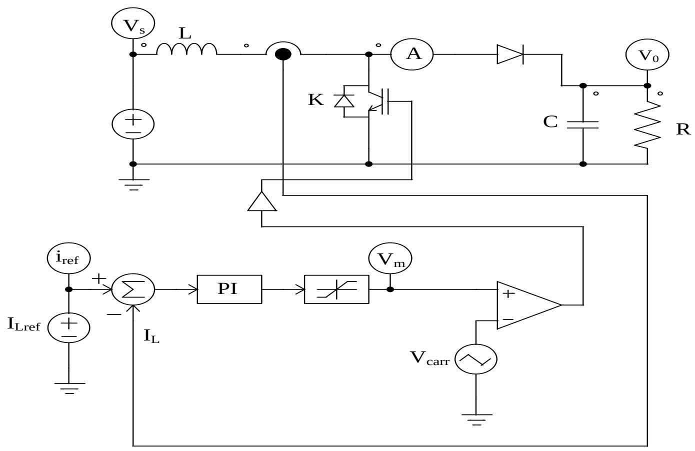

Figure 5. Control method based on inductor current

Different with the control method based on voltage [5-8], here the reference signal is the output voltage. In this control method, the reference signal is inductor current and it calculated I_{Lref} form Eq.(14), Which is compared with actual I_L measured from inductor current. The achieved error between above two signals is passed to PI controller. The output of the PI controller will be compared with triangle carrier wave high frequency to generate logic levels 0 or 1, to close or open switch K. So, to the desire output voltage is constant, then the inductor current also invariant. The PI controller aims to minimum error between the reference and actual signals.

IV. Simulation results and discussion

To demonstrate the proposed control method, Simulation results made with PSIM software of the DC-DC Boost converter. These parameters of DC-DC Boost converter is given as follows:

Input voltage: 12VDC
Output voltage: 30VDC
Load resistance: 50Ω
Output voltage ripple < 0.5%
Switching frequency: 100kHz

The values L and C are calculated by Eq.(20) and Eq. (23). PI controller with Kp=10, Ki=0.1.

Simulation results of the DC-DC Boost converter based on inductor current are shown as in figure 6 and figure 7.

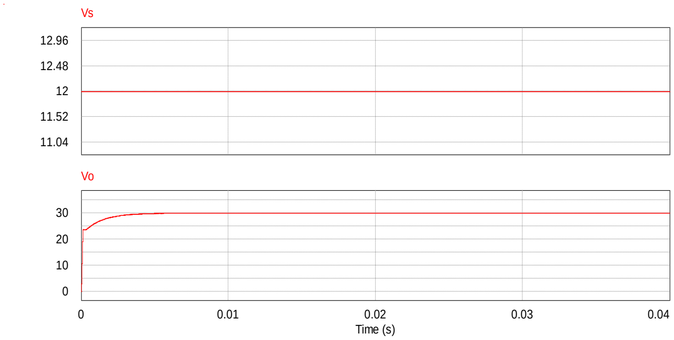

Figure 6. Input voltage wave form V_s and output voltage wave form V_0

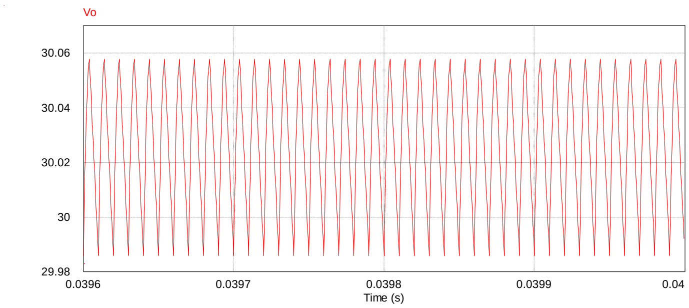

Figure 7. Output voltage ripple

From figure 7, we can see that the output voltage ripple is

$$\frac{\Delta V_0}{V_0} = 0.216\% .$$

From the simulation results we can see that: proposed control method satisfied demands of degree of accuracy and ripple of the output voltage.

V. Conclusion

This paper has been given a new method for the DC-DC Boost converter, which is controlled based on inductor current. This method has the advantage is not having to search for transfer function of the converter and can used for all DC-DC converter. The simulation results have proven to be that: the proposed control method has satisfied the requirements of degree of accuracy and ripple of the output voltage when designing DC-DC Boost converter.

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