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Design of voltage controller - voltage stabilizer booster DC voltage

Truong Thi Quynh Nhu
Automation Department, Thai Nguyen University of Technology, Vietnam

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ABSTRACT: Today, along with the industrial development of the country, the need for electric energy is urgent, but resources are increasingly depleted, so it is necessary to create renewable energy sources to serve for production needs and long-term, sustainable, and environmentally friendly use.

KEYWORDS: Converters, DC-DC voltage converter, DC- DC Boost, Current controller, Voltage controller

I. INTRODUCTION

Currently, DC power is widely used. But in fact, it is mainly voltage regulation from high voltage to low voltage, so the problem is that if there is a low voltage source available but we need a high voltage source, we will use a voltage booster to serve for production machine requirements.

We use a Boost type converter to increase the voltage from low to high voltage. The boost converter is nonlinear, and easily affected by external factors, so the design and control of the BOOST converter are pretty complicated. The rest of the paper is organized as follows: Part II: Overview of DC-DC BOOST converter and Mathematical model, Part III: boost converter control method. Part IV: Simulation results. Part V: Conclusion

II. OVERVIEW OF THE BOOST. DC-DC CONVERTERAND MATHEMATICAL MODELING.

The BOOST type voltage booster has the following schematic diagram:

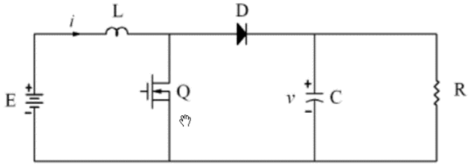


Figure1: Principle diagram of turbocharger type BOOST

Assuming that the passive and active elements used in the above diagram are ideal. The Q electronic switch (MOSFET) has a high switching frequency, and the DS on terminal impedance is extremely small. Diode with voltage Low threshold, fast Fak frequency response.

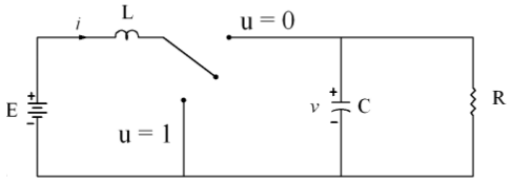
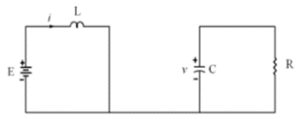


Figure 2: The kinematic model of the converter



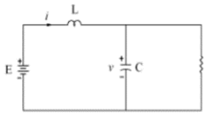


Figure3: Switching diagram when u = 1
Figure4: Switching diagram when u = 0

To determine the kinematic model of the converter, we apply Kirchoff's law to each circuit diagram as a consequence of the two switching positions. The first circuit diagram is received when the switch takes the value u = 1, the second circuit diagram is received when the switch takes the value u = 0

When the switching position is set u = 1, We get the system of dynamic equations:

$$L\frac{di}{dt}=E$$

$$c\frac{dv}{dt}=\frac{-v}{R}$$

When u = 0 (Switch in position 0) $L\frac{di}{dt}=-v+E$

$$c\frac{dv}{dt}=i-\frac{v}{R}$$

So when the circuit works, we have the following system of general equations:

$$L\frac{di}{dt}=-(1-u)v+E$$

$$c\frac{dv}{dt}=(1-u)i-\frac{v}{R}$$

Returning to the canonical form, we have the following system of equations:

$$\begin{bmatrix}x_1\\x_2\end{bmatrix}=\begin{bmatrix}\frac{1}{E}\sqrt{\frac{L}{C}} & 0\\ 0 & \frac{1}{E}\end{bmatrix}\begin{bmatrix}i\\v\end{bmatrix}$$

$$x_1=\frac{1}{E}\sqrt{\frac{L}{C}}.i$$

$$\Rightarrow\frac{dx_1}{dt}=\frac{1}{E}\sqrt{\frac{Ldi}{Cdt}}=\frac{1}{E}\frac{1}{\sqrt{LC}}L\frac{di}{dt}$$

$$x_2=\frac{1}{E}v$$

$$\Rightarrow\frac{dx_2}{dt}=\frac{1}{E}\frac{dv}{dt}=(\frac{1}{E}\frac{1}{\sqrt{LC}}\sqrt{\frac{L}{C}})C\frac{di}{dt}$$

From there we have:

$$\frac{1}{E}\frac{1}{\sqrt{LC}}L\frac{di}{dt}=-(1-\mathrm{u})\frac{1}{\sqrt{LC}}\frac{1}{E}+\frac{1}{\sqrt{LC}}\frac{1}{E}E$$

$$\frac{dx_1}{dt}=(1-\mathrm{u})\frac{1}{\sqrt{LC}}x_2+\frac{1}{\sqrt{LC}}$$

$$\frac{dx_1}{dt}=-(1-\mathrm{u})x_2+1$$

$$\frac{1}{E}\frac{1}{\sqrt{LC}}\sqrt{\frac{L}{C}}C\frac{dv}{dt}=(1-\mathrm{u})\frac{1}{E}\frac{1}{\sqrt{LC}}\sqrt{\frac{L}{C}}i-\frac{1}{R}v\frac{1}{E}\frac{1}{\sqrt{LC}}\sqrt{\frac{L}{C}}i$$

$$\frac{dx_2}{dt}=(1-\mathrm{u})\frac{1}{E}\frac{1}{\sqrt{LC}}x_1-\frac{1}{R}\frac{1}{\sqrt{LC}}\sqrt{\frac{L}{C}}x_2$$

$$\frac{dx_2}{dt}=(1-\mathrm{u})x_1-\frac{1}{R}\sqrt{\frac{L}{C}}x_2=(1-\mathrm{u})\,\mathrm{x}_1-\frac{x_2}{Q}$$

We get the BOOST turbocharger model as follows:

$$\frac{dx_1}{dt}=-(1-\mathrm{u})x_2+1$$

Set $u=1-u_{va}$

$$\frac{dx_1}{dt}=-u.x_2+1$$

$$\frac{dx_1}{dt}=-u.x_1-\frac{x_2}{Q}$$

Where Q is the reciprocal of the circuit quality factor $Q=R\sqrt{\frac{C}{L}}$

$x_{1:}$ Normalized inductance current, x2 normalized output voltage.

*Equivalent point and static transfer function

With a DC-DC converter, it is very important to stabilize the output voltage. In a steady-state, for equilibrium values, all the time derivatives of the state variables describe the system. The system is given zero, so the control input must also be constant, i.e. Uav = Const.

This condition entails a system of equations whose solutions describe the equilibrium point of the system.

$$\begin{cases}0=-(1-\mathrm{u}_{av})\,\mathrm{x}_2+1\\ 0=(1-\mathrm{u}_{av})\,\mathrm{x}_1-\dfrac{x_2}{Q}\end{cases}$$

Solving we get:

$$\overline{x_1}=\frac{1}{Q}.\frac{1}{(1-U)^2}$$

$$\overline{x_2}=\frac{1}{(1-\mathrm{U})}$$

Another form of parameterization is obtained by expressing the equilibrium value within the limits of the desired output voltage of the converter, denoted by:

$\overline{x_2} = V_d$:

$$\overline{x_2} = V_d ; \overline{x_1} = \frac{1}{Q} V_d{}^2 ; U = \frac{V_d - 1}{V_d}$$

we get the static normalized transfer function of the boost converter given by:

$$H(\mathrm{U}) = \overline{x_2} = \frac{1}{(1-\mathrm{U})}$$

We see that the gain of the converter circuit is always greater than 1, so the converter is called a turbocharger

The characteristic of the static transfer function of the boost converter is illustrated as follows:

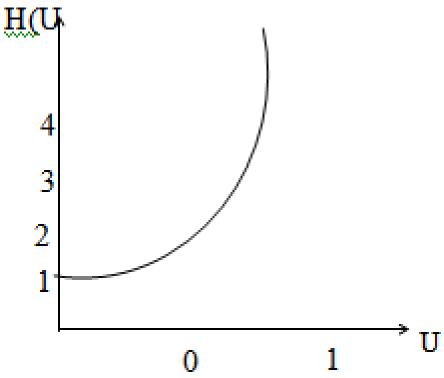


Figure 5: Boost converter transfer function characteristic

Transfer function characteristic of the boost converter

Through the variation of the duty cycle or the average control input U, we can read the value of the stable output voltage of the desired value v greater than 1.

The balanced voltage and current values of the circuit are:

$$i = \frac{1}{R}\frac{\overline{v^2}}{E} ; \bar{v} = \frac{E}{(1-\mathrm{U})}$$

is the equation of state for the boost converter

III. BOOST CONVERTER CONTROL METHOD.

Controlling the boost converter can have many methods. In this paper, the sliding controller method is used to control the object by indirect control

We consider the control process of systems represented by nonlinear state space models in the form:

$$\dot{x} = f(\mathrm{x}) + \mathrm{g}(\mathrm{x})\mathrm{u}; \mathrm{y} = \mathrm{h}(\mathrm{x})$$

Trong đó: $x \in R^n ; u \in \ 0,1 \ , y \in R$

f(x) and g(x) represent smooth vector fields

The output function h(x) is a smooth scalar function

The variable x with the value on the real axis R is the state variable, and the variable y is the output of the system

f(x) is the error vector field.

g(x) is the control input field.

Indirect control

To change the selection of the slip surface, the slip function, reaching the zero point produces the desired equilibrium value of the current in the inductor, which $\mathrm{h}_1(\mathrm{x}) = \mathrm{x}_1 - \overline{x_1}$ then corresponds to the output voltage reaching the desired value.

To determine this function, to achieve the desired output voltage, we calculate the equilibrium point of the system under the ideal slip condition, the balance value of the current on the inductor according to the output voltage balance value is :

$$\overline{x_1} = \frac{1}{Q}\overline{x_2}^2$$

$$h(\mathrm{x}) = \mathrm{x}_1 - \overline{x_1} = x_1 - \frac{1}{Q}\overline{x_2}^2$$

Directional derivatives:

$$L_f h(\mathrm{x}) = \frac{\partial h}{\partial x^T} f(\mathrm{x}) = 1$$

$$\mathrm{L}_g \, h(\mathrm{x}) = \frac{\partial h}{\partial x^T}\mathrm{g}(\mathrm{x}) = -x_2$$

The equivalent control is

$$u_{eq}(\mathrm{x}) = -\frac{L_f h(\mathrm{x})}{L_g h(\mathrm{x})} = \frac{1}{x_2}$$

h(x)=0; $\mathrm{x}_1 - \overline{x_1}$

$$x_2 = \frac{\overline{x_2^2}}{Qx_2} - \frac{x_2}{Q}$$

It is easy to see that the only equilibrium of the "dynamic zero" state is asymptotically stable. Consider the Lyapunov function in the x2 state space describing the ideal dynamic sliding or "dynamic zero".

$$\mathrm{V}(\mathrm{x}_2) = \frac{1}{2}(\mathrm{x}_2 - \overline{x_2})^2$$

Of course, the above function determines the negative around the equilibrium value x_2 , more specifically with $x_2>0$ around the equilibrium The ideal dynamic sliding represents an asymptotically stable point given by the desired voltage value.

According to the theorem, the sliding surface can be reached or crossed , that is, according to the law of opening and closing:

$$u=\begin{cases}1, h_1(\mathrm{x})>0\\0, h_1(\mathrm{x})<0\end{cases}$$

$$u=\begin{cases}1, \mathrm{x}_1-\overline{\mathrm{x}_1}>0\\0, \mathrm{x}_1-\overline{\mathrm{x}_1}<0\end{cases}$$

According to the desired tuning with the global stability of the system, with the expression in current and voltage then:

$$u=\frac{1}{2}\left[1+sign(\mathrm{i}-\mathrm{I}_{ref})\right]$$

In which I is the actual current across the inductor and $I_{ref}=\bar{i}$

IV.SIMULATION RESULTS

Simulate the BOOST circuit with the following parameters:

$L=15.91mH,\ C=50\mu F,\ \ \mathrm{E=12V},\ \ \mathrm{R=52\Omega}$

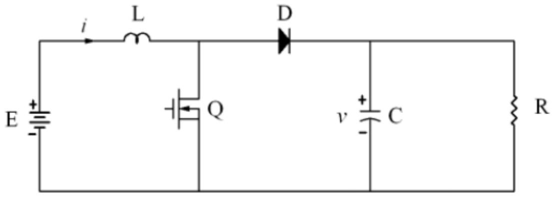


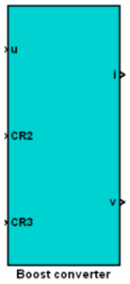
Figure 6: Type Boots. turbocharger

The equation describing the converter is as follows:

$$L\frac{di}{dt}=-(1-\mathrm{u})\,\mathrm{v}+\mathrm{E}$$

$$C\frac{dv}{dt}=-(1-\mathrm{u})\mathrm{i}+\frac{v}{E}$$

Modeling on Plecs-Matlab simulink



The Model above :PLECS

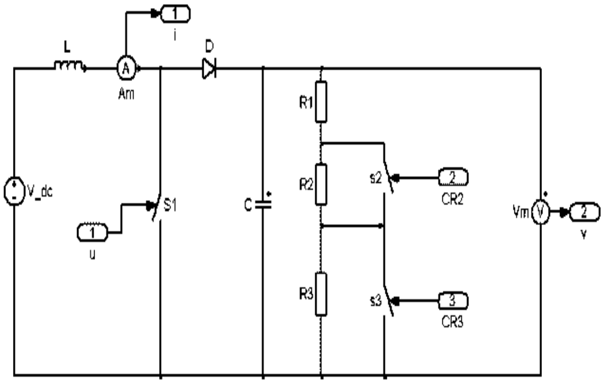


Figure 7:Model on PLESC

- Current regulator

The simulation diagram is as follows:

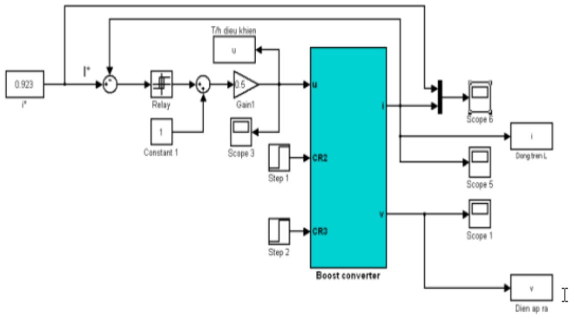


Figure 8:Simulation diagram when there is a current regulator

When the output voltage value U = 24v, the circuit reaches equilibrium, and the value of the balance currently on the inductors I = 0.92A runs the program for the results shown in the following diagrams:

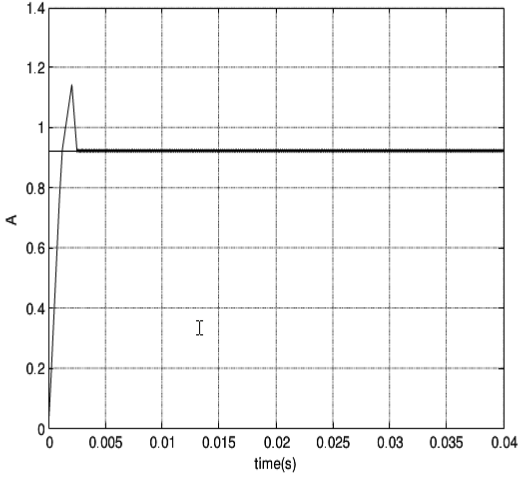


Figure 9:The current value on the inductor

The current i rapidly approaches the equilibrium value set I = 0.923 and slips through this equilibrium current value, observing over a small period to see the "chattering" of i

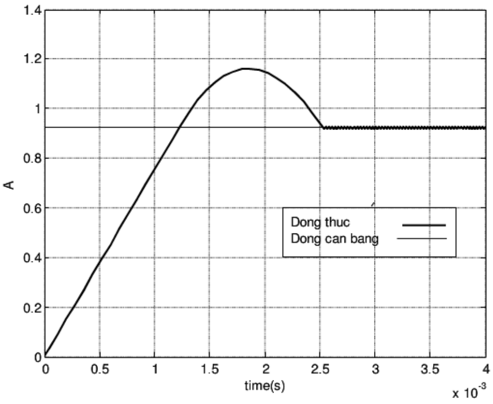


Figure 10:Equilibrium current value

Voltage regulator
The structure diagram is as follows:

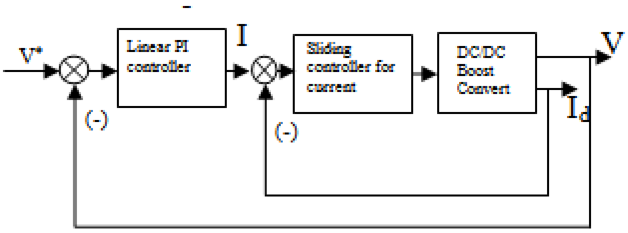


Figure 11:Structure diagram with voltage regulator

We have a structure diagram on Simulink as follows:

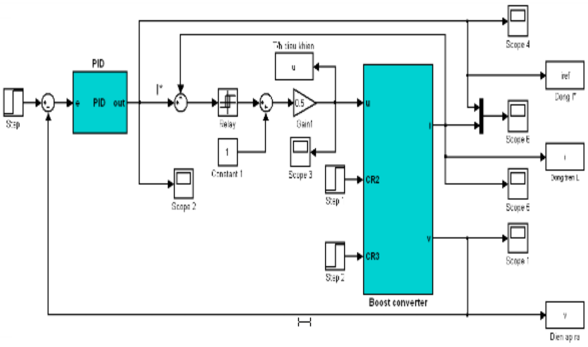


Figure 12:Structural diagram on Simulink

the current response i* when simulating with load change.

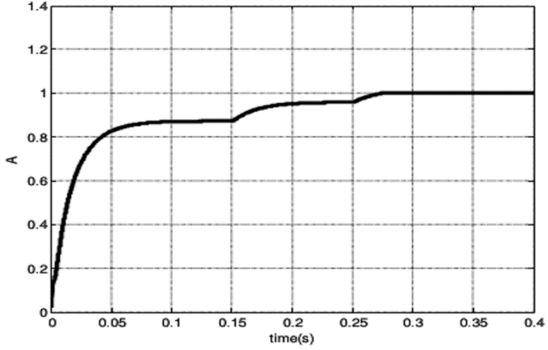


Figure 13: Response of the current to a changing load

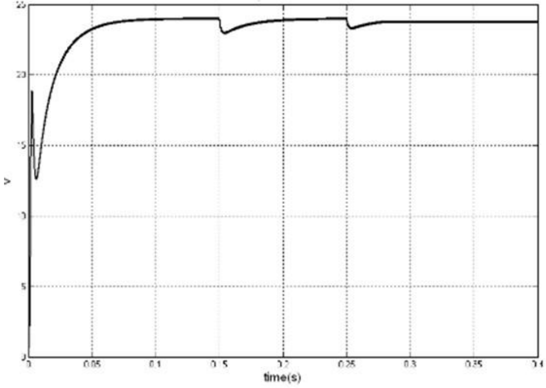


Figure 14: The current of inductor L when PID is used

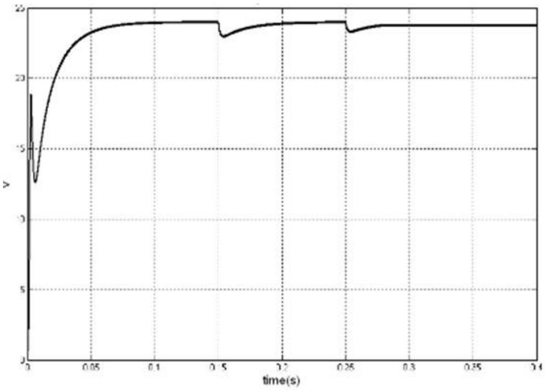


Figure15: Output voltage with PID unit

From the simulation and experimental results, we see the output voltage characteristics of the converter with the process of starting from 0V to the required voltage of 24V in a time interval of approximately 0.06s, the amount of over-regulation is small. When the load fluctuates, leading to a change in system parameters, this voltage remains stable, the transient time is small (approximately 0.05s) and the instantaneous voltage drop is small. The system meets the dynamic and static quality criteria, and the output voltage meets the requirements.

V.CONCLUSION

After setting up a simulation model for the converter, and calculating the controller using Matlab & Simulink software to investigate the results, we found that using a sliding controller improves the conversion efficiency and stabilizes the voltage for the converter, the above controller can be applied in practice

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