Study on the Dynamic Performance of DC-DC Power Supply

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Abstract. Load regulation and input voltage regulation are the important parameters of DC-DC power supply. The quality of them determines the dynamic performance of the whole system. In order to improve the two parameters, hysteresis current control strategy is studied and some improvements are made, not only inductor current is considered, but also capacitance charge balance cannot be ignored. A simulation model adopting the improved hysteresis current control strategy based on Matlab/simulink is constructed. The results indicate that the DC-DC power supply posses good dynamic performance, and also verify the correctness of the design.

Introduction

Switching power supply can be divided into AC-DC and DC-DC converters. The selection and design of control strategy are very important to its performance, and different detecting signal and control circuit adopted will have different control effects [1].

The hysteresis current controller is to adjust the turn on and turn off time of the power switch when input voltage or load changes so that the output voltage can be kept constant.

Take Buck-Boost converter as an example, a detailed analysis is made when the input voltage or load change, and the improved hysteresis current control strategy is proposed corresponding. A simulation model is set up based on Matlab/Simulink and the results have proved its feasibility.

Control Strategy

Principle of Hysteresis Current Strategy. DC-DC converter includes Buck, Boost, and Buck-Boost converter, ect. This paper takes Buck-Boost converter as an example. Sampling its output current i_o(t), output voltage u_o(t), input voltage $u_i(t)$ and inductor current i_L(t), the average inductor current $I_L(t)=I_o(t)(U_e+u_i)/u_i$ is calculated, where Ue is rated output voltage, then set the hysteresis current width ΔI, so hysteresis current upper and lower threshold are get. Inductor current waveform is shown in Fig. 1.

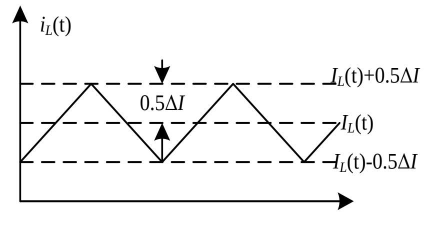


Figure 1. Inductor current waveform

When converter works in steady state, the average inductor current intends to equal I_L(t), therefore the output voltage can be controlled as $Ue=I_o$(t) R_L(t). Control strategy is shown in (1).

$$\begin{cases} i_L(t) < I_L(t) - 0.5\Delta I, \text{S turns on} \\ I_L(t) - 0.5\Delta I \le i_L(t) \le I_L(t) + 0.5\Delta I, \text{S keeps on} \\ i_L(t) > I_L(t) + 0.5\Delta I_1, \text{S turns off} \end{cases} \quad (1)$$

Principle of Load Change. If load current decreases, power switch S of Buck-Boost DC-DC converter will turn off, inductor offers energy to both the load and the capacitance, $i_L(t)$ decreases simultaneously. Compared with the steady state control strategy shown in Fig.1, keep off time of S should be longer to satisfy capacitance charge balance principle. So the inductance current will appear with a minimum value $i_{L1,\ min}$ which is the lower threshold of transient hysteresis current control strategy. When the inductor current reduces to $i_{L1,\ min}$, S turns on and capacitor discharges. The ideal waveforms of inductance current, output current and the output voltage are shown in Fig. 2

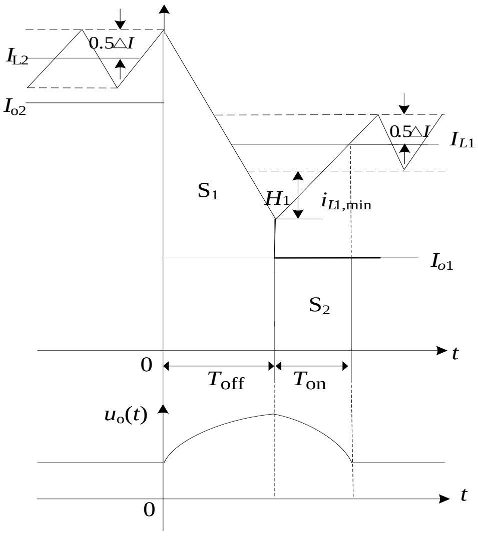


Figure 2. Waveforms of load change

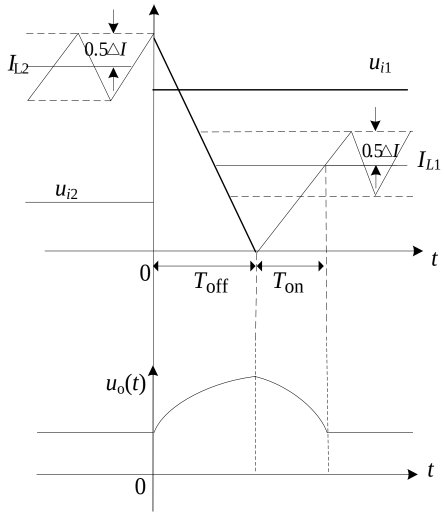


Figure 3. Waveforms of input voltage change

In Fig. 2, I_{o1} and I_{o2} are the average output current when the load is R_{L1} and R_{L2} respectively, I_{L1} and I_{L2} are the average inductor current and $I_{L2}>I_{L1}+\Delta I$. Define the difference between $I_{L1,min}$ and I_{L1}-0.5ΔI is H_1. The calculation process of $H1$, conduction time T_{on} and off time T_{off} of S are shown below.

When load current decreases, the total charged charge Q_1 is the area of the S₁, so Q_1 is

$$Q_1 = \frac{1}{2}\times(I_{L2}+0.5\Delta I - I_{o1} + I_{L1,min} - I_{o1})\times T_{off} \tag{2}$$

Where

$$\frac{I_{L2}-I_{L1}+H_1}{T_{off}} = \frac{U_e}{L} \tag{3}$$

At the lower threshold S turns on, discharged charge Q2 is the area of the S2, so Q2 is

$$Q_2 = I_{o1}\times T_{on} \tag{4}$$

Where

$$\frac{H_1+0.5\Delta I}{T_{on}} = \frac{u_i}{L} \tag{5}$$

Due to Q1=Q2, H1 can be obtained

$$H_1 = \sqrt{(I_{L2}+I_{L1}-2I_{o1})(I_{L2}-I_{L1})} \tag{6}$$

It can be seen from equation (3) and (5) that both Toff and Ton are relevant to H1. By comparing the real-time inductance current with inductor current threshold can decide turn on and turn off time .Therefore, the improved hysteresis current control strategy is shown as follows.

$$\begin{cases} i_L(t) \ge I_{L2}+0.5\Delta I, \text{S turns off} \\ I_{L1} - 0.5\Delta I - H_1 < i_L(t) < I_{L2}+0.5\Delta I, \text{S keeps on} \\ i_L(t) \ge I_{L1} - 0.5\Delta I - H_1, \text{S turns on} \end{cases} \tag{7}$$

Principle of Input Voltage Change. It can be seen from formula $I_L(t)=I_o(t)(U_e+u_i)/u_i$ that the average inductor current $I_L(t)$ and input voltage u_i are linear relationship, so if the input voltage disturbance happens, $I_L(t)$ will change at the same time. When input voltage increases, the ideal waveforms of inductance current, input voltage and the output voltage are shown in Fig. 3.

In Fig.3, when the input voltage changes from u_{i2} to u_{i1}, the average inductor current will decrease which is similar to the process of load current decreases, so control strategy (7) is suitable for input voltage increases.

The process of load current increases is similar to the load current decreases. If the input voltage decreases, the average inductor current will increase, so it can be converted into the state of load current increases.

The Simulation Model

A simulation model is built based on Matlab/Simulink and the process of Buck-Boost converter is imitated when load or input voltage change.

The simulation parameters are: the input voltage is 20±5V, the rated output voltage Ue is 20V, load current ranges from 350mA to 500mA, switching frequency f=60kHz, L=1mH, C=220μF and supposed ΔI=120mA. Simulation model is shown in Fig. 4.

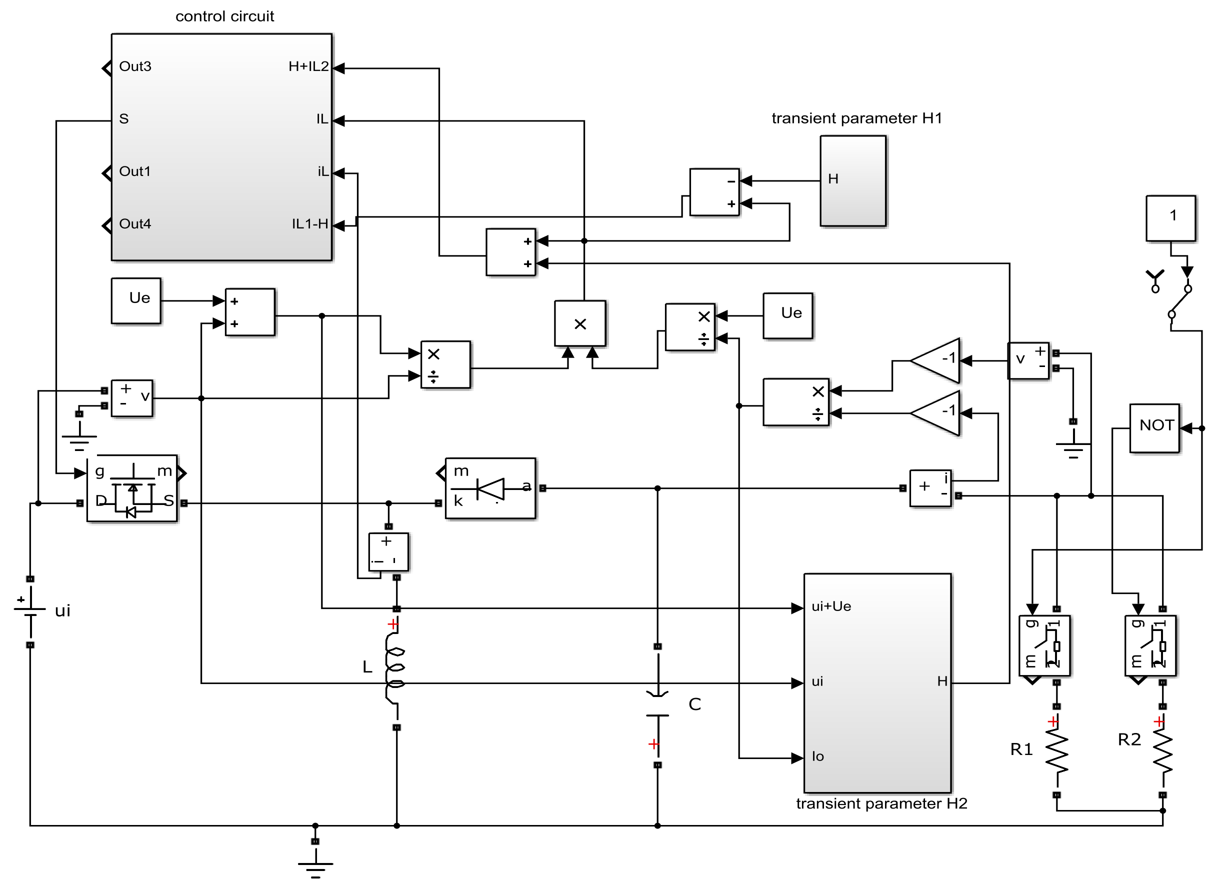


Figure 4. The simulation model

In Fig. 4, hysteresis current control Buck-Boost converter mainly consists of two parts, DC-DC converter and control circuit. Transient parameter H_1 part is the subsystem that can calculate transient parameters H_1 when load current decrease or input voltage increases. Transient parameter H_2 part is the subsystem that can calculate transient parameters when load current increase or input voltage decreases.

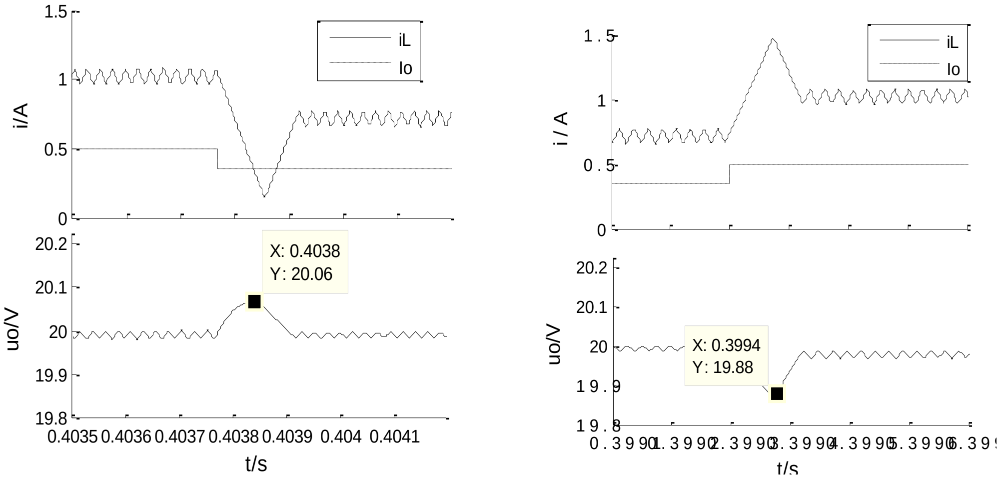
The control circuit is the hysteresis current control subsystem. By comparing the inductor current value of the time with the previous time to judge the system state, be steady state or load change or input voltage change, then corresponding hysteresis current control strategy is adopted. Accurate T_{on}

and T_{off} time can be calculated out to control S to keep the output voltage stable.

The Simulation Result

Make a simulation on Buck-Boost converter adopting the improved hysteresis current control strategy in the Matlab/simulink environment.

Load Change. In the condition that load current changes from 0.500A to 0.350A and input voltage is 20V, waveforms are obtained in Fig. 5.



(a) Load current decreases (b) Load current increases

Figure 5. Waveforms when load current change

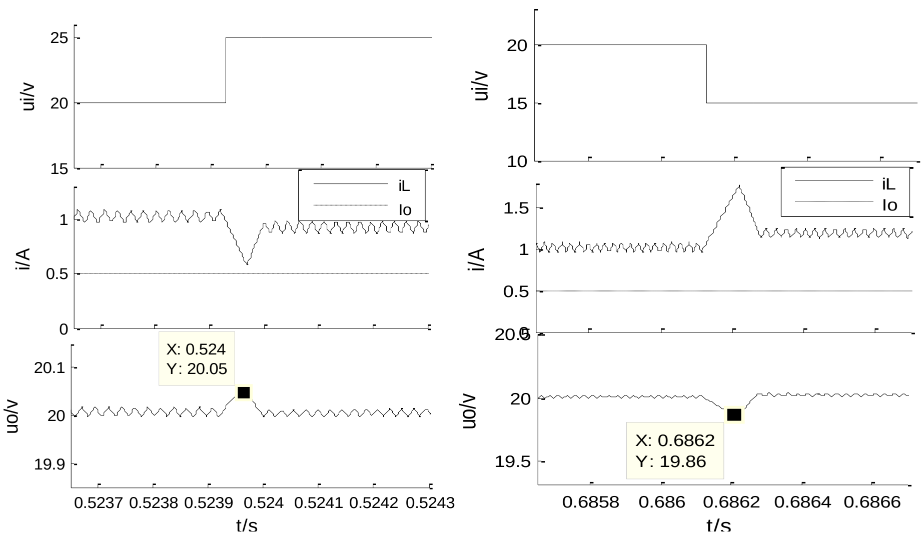
In Fig. 5(a), when the load current decreases, the inductor current decreases, too. There will be a minimum inductor current $i_{L1,\ min}$. accordingly, the maximum output voltage is 20.06V. The steady output voltage is about 20V and load regulation is high. Simulation and theoretical calculation results are the same almost.

In Fig. 5(b), when the load current increases, the inductance current increases, too. There is a maximum inductor current. The minimize output voltage is about 19.88V. The steady output voltage is about 20.0V. The load regulation is high.

Input Voltage Change. When the input voltage changes and load current remains is 0.5A, waveforms are obtained in Fig. 6.

In Fig. 6(a), the load current is 0.5A. When the input voltage changes from 20V to 25V, the inductance current will decreases, and there will be a minimum inductor current $i_{L1,min}$. At the time, the output voltage is up to the maximum of 20.05V. The steady state output is 20V, so the input voltage regulation is high.

In Fig. 6(b), the load current is 0.5A. When the input voltage changes from 20V to 15V, the inductance current will increase. When the inductor current increased to the maximum, the minimum output voltage is 19.86V. The steady output voltage is about 20.0V. The input voltage regulation is high.



(b) Input voltage increases (b) input voltage decreases

Figure 6. Waveform when input voltage change

Conclusions

The improved hysteresis current control strategy expand the turn on or turn off time of power switch when load or input voltage change compared with hysteresis current control strategy in steady state. Buck-Boost converter adopted it has high load regulation and input voltage regulation, and present the DC-DC power supply of good dynamic performance.

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References

[1] Kabeya Musasa,Michael Njoroge Gitau, Ramesh C. Bansal. Analysis of a DCCollector-based Power Converter Topology for an Offshore Wind Farm [J]. Electric Power Components and Systems, 2015, 438-10.

[2] Fang Wei, Qiu H-jie,et al. Research of Boost converter control Based on the capacitor charge balance[J].Journal of UEST of China, 2013,42(2):10-28.

[3] QIU Ying, Chen Xi-you, al. Charge balance digital controlled the negative DC-DC converter [J]. Proceedings of the CSEE，2013,33(18):42-44.

[4] Wenbin Zhang, Xiangyu Tan, Ke Wang, Tianwen Li, Junhua Chen. Design for boost DC-DC converter controller based on state-space average method [J].Integrated Ferroelectrics,2016,1721.

[5] Ajami, Farakhor，Amir. Design，analysis and implementation of a buck–boost DC-DC converter[J]. IET Power Electronics, 2014, 7(12):1-7.

[6] Subramanian Vijayalakshmi, Thangasamy Sree Renga Raja. Time domain based Digital PWM controller for DC-DC converter [J]. AUTOMATIKA: Journal for Control, Measurement, Electronics, Computing and Communications, 2015, 554.

[7] P. Karthigeyan, M Senthil Raja,T Siva Kumar,S.R Sivaa Ganesh,J. Lavanya. Simulation of Bi-directional DC-DC Converter Using FPGA [J]. Procedia Computer Science, 2016, 79.

[8] Prabhakar Mahalingam. Soft Switched Voltage Multiplier Cell based DC-DC Converter for Automotive Applications [J]. AUTOMATIKA: Journal for Control, Measurement, Electronics,

Computing and Communications, 2015, 553.

[9] Annop Nakpin, Sudarat Khwan-on. A Novel High Step-up DC-DC Converter for Photovoltaic Applications [J]. Procedia Computer Science, 2016, 86.

[10] Ronnakorn Khambuya, Sudarat Khwan-on. A New High Step-down DC-DC Converter for Renewable Energy System Applications [J]. Procedia Computer Science, 2016, 86.

