Dynamic Characteristics of Digitally Controlled Buck-Boost DC-DC Converter

Fujio Kurokawa  
Nagasaki University  
Nagasaki, 852-8521 Japan  
fkurokaw@net.nagasaki-u.ac.jp

Taku Ishibashi  
Nagasaki University  
Nagasaki, 852-8521 Japan  
d709131e@cc.nagasaki-u.ac.jp

Abstract – The purpose of this paper is to present the dynamic characteristics of the digitally controlled buck-boost dc-dc converter. Furthermore, the relationship between the parameters of control circuit and the dynamic characteristics is discussed. We examine the design criterion to improve the dynamic characteristics. As a result, it is revealed that the wide range of input voltage is realized by setting not only the appropriate filter but also the suitable gain in the digitally controlled buck-boost dc-dc converter.

Index Terms— Buck-boost DC-DC converter, Digital control, FIR filter

I. INTRODUCTION

Recently, the power supply system plays the important role of renewable energy systems controllability. The high controllability and monitoring function are required in the switching power supply to improve the energy management performance of these systems.

In switching dc-dc power converters, analog control circuits have been widely used. The analog control circuit has many superior characteristics for example fast response, high accuracy, low cost and so forth. However, over the last few years, a considerable number of studies have been made on a digital control [1]-[6]. One reason is that this technique will lead to a future high performance smart power converter and its power management technique.

On the other hand, the buck-boost dc-dc converter has been receiving increasing attention because this type converter is able to control a wide range voltage of the source.

This paper presents the dynamic characteristics of the digitally controlled buck-boost dc-dc converter. Furthermore, the relationship between the parameters of control circuit and the dynamic characteristics is discussed. After reviewing the fundamental configuration of digitally controlled dc-dc converter with the minimum phase FIR filter control[7] and its operation principle, we analyze the dynamic characteristics of digitally controlled buck-boost dc-dc converter. Furthermore, we discuss the design criterion to improve the dynamic characteristics. The key point of this paper is to describe the possibility to realize the high performance and stable digitally controlled buck-boost dc-dc converter using DSP.

II. CIRCUIT CONFIGURATION AND OPERATION PRINCIPLE

Figure 1 shows the block diagram of the proposed digitally controlled buck type dc-dc converter using DSP. $E_i$ is the input voltage, $e_o$ is the output voltage and $i_o$ is the output current. $T_s$ is the main switch, $D$ is the fly wheel diode, $L$ is the energy storage reactor, $C$ is the output smoothing capacitor and $R$ is the load. The output voltage $e_o$ is sent to the A-D converter through the anti-aliasing filter and is converted into digital amount $N_n$. The relation between the input and output values of the A-D converter is given by equation (1) when it approximately shows the linear expression by considering the width of the quantization to be small.

$$ N_n = G_{AD} e_n $$  

where $n$ denotes an n-th switching cycle, and the digital amount $N_n$ is a positive integer number. $G_{AD}$ is a gain of the A-D converter.

The digital amount $N_n$ is sent to DSP. In DSP, the numerical value $N_{Ton}$ that corresponds to the on-time interval $T_{on}$ is calculated. The relation between the on-time interval $T_{on}$ and the numerical value $N_{Ton}$ is shown as follows;

$$ T_{on} = \frac{N_{Ton} - 1}{N_{Ts}} $$  

where $N_{Ts}$ is a numerical value corresponding to the switching period $T_s$ (=1/f_s). $N_{Ts}$ is calculated in the PWM signal generation circuit which is composed of a digital comparator or a counter. According to the relation between the on-time interval $T_{on}$ and the numerical value $N_{Ton}$, $T_{on}$ is generated. This $T_{on}$ regulates the output voltage $e_o$.

The on-time interval $N_{Ton}$ of the minimum phase FIR filter control circuit is represented as follows [7];

$$ N_{Ton,n+1} = N_{B} - K \sum_{i=0}^{q} h_i (N_{n-i} - N_{R}) $$  

where $K$ is proportional gain, $h_i$ denotes the digital filter coefficients and $q$ is the amount of the sampling points.

III. TRANSIENT RESPONSE

Table 1 shows the parameters in each condition and the parameters is noted in Fig. 2. Figure 3 shows the frequency
characteristics corresponding to each condition. Figures 4(a) through (c) show the simulated transient response of the dc-dc converter with digital control in step change of the load resistor R from 100Ω to 10Ω in each condition. The simulator is PSIM. The switching frequency is 100 kHz. The circuit parameters are E₀*=10V, L=260μH, C=1400μF and the leakage inductance is 4μH.

Fig. 1 Block diagram of digitally controlled buck-boost type dc-dc converter using DSP.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Parameters in each condition.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Condition A</td>
</tr>
<tr>
<td>Pass band Frequency (kHz)</td>
<td>2.5</td>
</tr>
<tr>
<td>Transition band (kHz)</td>
<td>1</td>
</tr>
<tr>
<td>Stop band Frequency (kHz)</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Fig. 2 Frequency characteristics of FIR filter.

Fig. 3 Frequency characteristics in FIR filter.
Figure 4 shows simulated transient response in case of $E_i = 10V$. In Condition A, the transient time $T_{st}$ is 1.2ms and the steady-state error is 167mV. In Condition B, the transient time $T_{st}$ is 0.8ms and the steady-state error is 119mV. In Condition C, the transient time $T_{st}$ is 0.7ms and the steady-state error is 110mV.

In the Conditions A, B and C, the values of undershoot are almost same. However, the ripple and steady-state error is smallest in Condition C. So, the good transient response is realized in Condition C because the pass band frequency is high.

Figure 5 shows the simulated transient response in case of $E_i = 5V$ and Condition C. The steady-state error is 581mV and is very large. Figure 6 shows relationship between the gain and steady-state error in case of $E_i = 5V$ and Condition C.

It is seen that the steady-state error depends on the gain. So, we must set the large gain when the input voltage is low.

Figure 7 shows the transient response in case of $E_i = 5V$ and Condition C. K is equal to 10. Even if $E_i$ is small, the steady-state error becomes small by increasing the gain in this way.
Figure 8 shows the simulated transient response in case of $E_i=15V$ and Condition C. $K$ is equal to 8. The undershoot is 123mV, $T_{st}$ is 0.6ms. A good result is provided in this way when the $E_i$ is smaller than $E_o$ by setting an appropriate filter and gain.

CONCLUSION

The above discussion suggests the design criterion of digital control circuit of buck-boost converter with the minimum phase FIR filter control.

It is concluded that the minimum phase FIR filter controlled buck-boost dc-dc power converter has superior dynamic characteristics when the pass band frequency is high.

Moreover it is revealed that the wide range of input voltage is realized by setting not only the appropriate filter but also the suitable gain in the digitally controlled buck-boost dc-dc converter.

We confirm that these results are useful to realize the next generation model of the switching power supply for the renewable energy source.

ACKNOWLEDGMENT

This work is supported in part by the Grant-in-Aid for Scientific Research (No.21360134) of JSPS (Japan Society for the Promotion of Science) and the Ministry of Education, Science, Sports and Culture.

REFERENCES