DESIGN CRITERION OF DIGITALLY CONTROLLED MULTIPLE-OUTPUT DC-DC CONVERTER

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Abstract: The last few years, a considerable number of studies have been made on a digital control. One reason is that this technique will lead to a future energy management and system integration. At a first step, it may be helpful to begin with a study of the design criterion of the digital control. Although studies have been made on the digital unique characteristics, there is little agreement on the total design criterion. This paper presents a digital criterion for the forward type multiple-output dc-dc converter. In this case, the central problem of design criterion is the relationship between the digital control parameter and the number of bits of the calculation part of the digital control circuit.

Key words: Digital control**,** Forward type multiple-output dc-dc converter, Design criterion

1. INTRODUCTION

In switching dc-dc power converters, analog control circuits have been widely used. However, over the last few years, a considerable number of studies have been made on a digital control to improve reliability and controllability [1]-[3]. At a first step, it may be helpful to begin with a study of the design criterion of the digital control. Although studies have been made on the digital unique characteristics, there is little agreement on the total design criterion. Now, there is the forward type multiple-output dc-dc converter as a circuit system of typical switching power source [4]-[6]. This circuit is a good example to examine a design criterion of the digital control circuit for the dc-dc converter.

This paper presents a digital criterion for the forward type multiple-output dc-dc converter. In this case, the central problem of design criterion is the relationship between the digital control parameter and the number of bits of the calculation part of the digital control circuit. The design of the number of bits of the a-d signal converter and/or the digital PWM generator is not difficult, what matter is rather the number of bits of the calculation part of the digital control circuit. In this paper, at first, the relationship among the regulation range against the input voltage and the load current, the number of bits of the calculated part and the digital control parameter is discussed. Next, the transient characteristics are shown.

2. CONFIGURATION OF THE MAIN CIRCUIT AND OPERATION PRINCIPLE

2.1 Configuration of the Main Circuit

Figure 1 shows the forward type multi-output dc-dc converter. In the circuit, the reset winding n_{p2} was added to avoid saturated flux. The turn ratio n_{p1}/n_{p2} is equal to unity. In Fig. 1, E_i is the input voltage, e_{o1}, is the output voltage and the output current $I_{o1}(=E_{o1}/R_1)$. D is the fly wheel diode, C is the output smoothing capacitor, L is the energy storage reactor, n_{p1}, n_{p2}, n_{s1} and n_{s2} are the numbers of turn for the transformer and R is the load. Moreover, L is the reactor which has the function of the cross-regulation.

2.2 Operation Principle

Figure 2 shows the digital control circuit of forward type multi-output dc-dc converter. The output voltage e_o is the control target. e_o is sent to the a-d converter through the anti-aliasing filter and is converted into digital amount N_n.

Figure 3 shows the input vs. output signals characteristic of the a-d converter. The relation between the input and output values of the a-d converter is given by Eq. (1) when it approximately shows the linear expression by considering the width of the quantization to be small.

$$N_n = AG_{AD}\, e_{o1,n} \tag{1}$$

where n denotes a n-th switching cycle, and the digital amount N_n is a positive integer number. A is the gain of the anti-aliasing filter. G_{AD} is the gain of the a-d converter.

$$G_{AD} = \frac{N_{n,max}}{e_{o,ADmax}} \tag{2}$$

The digital amount N_n is sent to the calculation part. The PID control is performed by the calculated part as shown the following equation,

$$N_{Ton,n+1} = N_b - K_P(N_n - N_R) - K_I \sum (N_n - N_{INT}) - K_D(N_n - N_{n-1}) \tag{3}$$

where K_P, K_I and K_D are the proportional, integral and differential coefficients, N_R and N_{INT} are the reference value of the proportional and integral parts, respectively. N_b is the basis value, r is internal resistance and E_{o1}* are the reference value of the output voltage N_b is represented as follows;

$$N_b = N_{Ts}(1 + r/R)\frac{E_{o1}^*}{n_{s1}/n_{p1}\, E_i} \tag{4}$$

the numerical value equivalent to the width is turned on with N_{Ton} and it's set in a PWM signal generation circuit.

When the number of bits of the a-d converter is set to Q, N_{Ts} is given by the following equation.

$$N_{Ts} \le 2^Q - 1 \tag{5}$$

the duty ratio $S_{Ton/Ts}$ is represented as follows;

$$S_{Ton/Ts} = \frac{N_{Ton,n+1}}{N_{Ts}} \tag{6}$$

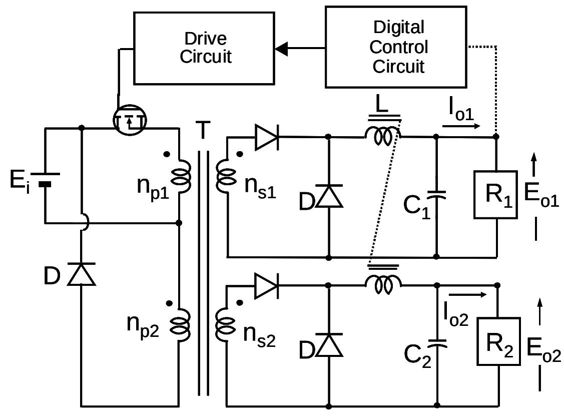


Fig.1 Digitally controlled multiple-output DC-DC converter.

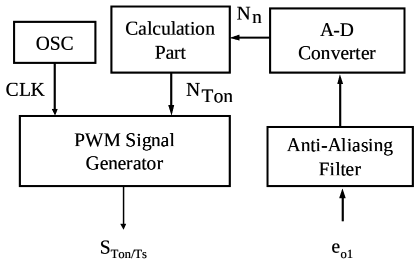


Fig. 2 Digital control circuit.

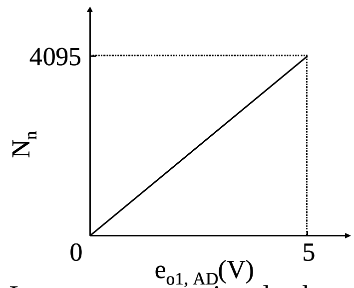


Fig.3 Input vs. output signals characteristic of a-d converter.

3. THE DESIGN CRITERION AND RESULT OF SIMULATION

The circuit parameters are C=1030μF, n_{p1}:n_{p2}:n_{s1}:n_{s2}=2:2:1:2, E_{o1}*=5V, E_{o2}*=10V and R_2=20Ω. The mutual inductance L_{m2} of the transformer is 48μH, the leakage inductances L_{l21} and L_{l22} of the transformer are 0.1μH and 0.2μH, respectively. Furthermore, Q = 12bits, G_{AD} = 819V^{-1} and N_S = 4000. The sampling frequency f_{smp} is equal to the switching frequency f_s and is 200kHz.The simulator is PSIM.

3.1 Static Characteristics

The regulation range against the output voltage and current is shown in Eqs. (7) and (8) in Table 1. L_l shows the leakage inductance of the transformer T. As shown in these equations, the regulation range depends on K_I and Q_I. In this case, the typical input voltage E_i* is 40V and the specification of the regulation range of the output voltage is set from 28V to 52V.

The relationship between the number Q_I of bits of the calculation part and the digital integral coefficient K_{Imin} is shown in Fig. 4. In this figure, the dot line denotes the condition of E_i*=40V. It is seen that the integral coefficient K_I can be selected small when the number of bits is large.

Next, in order to improve the dynamic characteristics, it is necessary to change the typical input voltage E_i*. The solid line shows the relationship in E_i*=36V. It is seen that K_{Imin} in case of E_i*=36V is smaller than that in case of E_i*=40V against each Q_I. The superior dynamic characteristics are obtained when the integral coefficient K_I is relatively small.

Therefore, the E_i*is set to 36V as shown in Fig. 5(a). In this figure, the integral coefficient K_{Imin} is equal to 0.012 and R_1 is 25Ω. Therefore, it is important to set the suitable typical input voltage.

Figure 5(b) shows the regulation of the output voltage E_{o1} against the change of the load current Io1. The good regulation from no load to full load is obtained because the mmf (magneto motive force) of the reactor L is continuous [5]-[7].

3.2 Dynamic Characteristics

Figures 6 and 7 show the transient response when the load R_1 is step changed from 25Ω to 2.5Ω. The circuit parameters are same to Fig. 5(b).

In Figs. 6 and 7, K_P is 2.0, K_D is 2.0 and K_I is changed as parameters. Figure 6 shows that the overshoot and undershoot of the output voltage e_{o1} is over 2.4% and 1.4% in case of K_I=0.012. The convergence time t_{st} that the output voltage e_{o1} is settled within 1% is 0.84 ms. Figure 7 shows that the overshoot and undershoot of the output voltage e_{o1} is over 2.3% and 0.8% in case of K_I =0.003. The convergence time t_{st} that the output voltage e_{o1} is settled within 1% is 0.38 ms. Furthermore, the overshoot of reactor current is over 35% and 30%. It is seen that the transient response is improved a little when KI is small as shown in Fig. 7.

3.3 The Design Criterion

As mentioned before, the problem which becomes important at design criteria is the relationship between the integration coefficient K_I and the number Q_I of bits of a calculation part. The regulation range is enlarged when Q_I and/or K_I are large. However, the superior transient response is realized when K_I is relatively small. Therefore, the design criterion is that Q_I is large and is relatively small. Furthermore, it is important to set the suitable typical input voltage because the smallest integral coefficient must be selected to improve the dynamic characteristics.

Table 1 Regulation range against output current.

$\frac{n_{p1}}{n_{s1}}\frac{(1+r/R_1)e_{o1}^*+L_l i_{o1}/Ts}{m_1}<E_i<\frac{n_{p1}}{n_{s1}}\frac{(1+r/R_1)e_{o1}^*+L_l i_{o1}/Ts}{m_2}$ (7)	
$\frac{J_2}{L_l/T_s+r}<i_{o1}<\frac{J_1}{L_l/T_s+r}$ (8)	
$J_1=m_1\frac{n_{s1}}{n_{p1}}E_i-e_{o1}{}^*$	$J_2=m_2\frac{n_{s1}}{n_{p1}}E_i-e_{o1}{}^*$
$m_1=\frac{N_b+K_I\times 2^{Q_I-1}}{T_S}$	$m_2=\frac{N_b-K_I\times 2^{Q_I-1}}{T_S}$

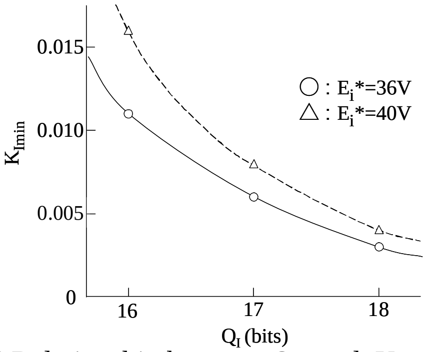
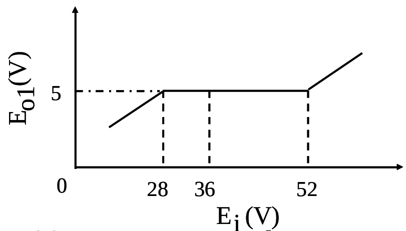
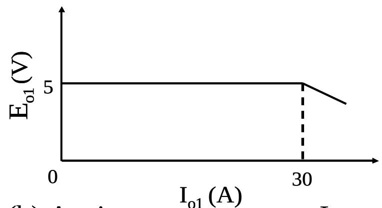


Fig.4 Relationship between Q_I and K_{Imin} against regulation range (Calculated).

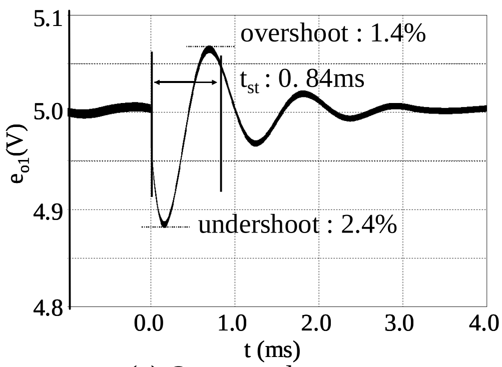


(a) Against input voltage E_i.

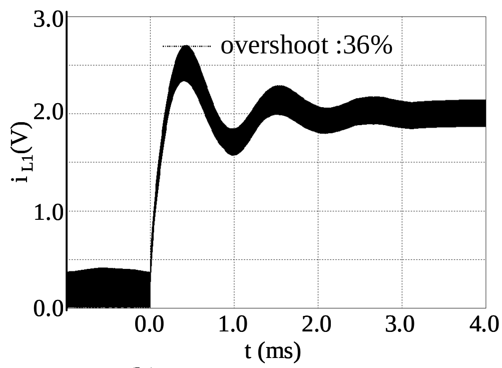


(b) Against output current I_o.

Fig. 5 Regulation characteristics (Calculated).

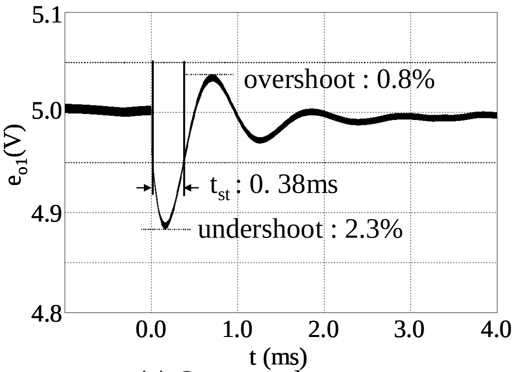


(a) Output voltage.

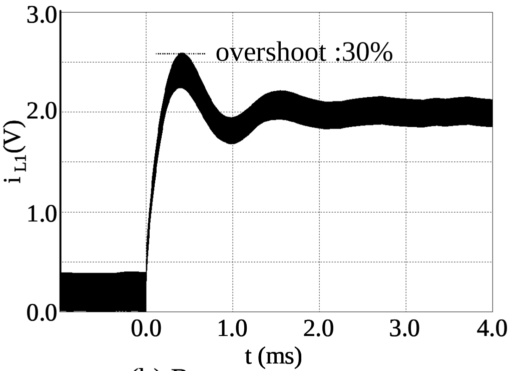


(b) Reactor current.

Fig. 6 Transient response in case of K_P=2 and K_I=0.012.



(a) Output voltage.



(b) Reactor current.

Fig. 7 Transient response in case of K_P=2 and K_I=0.003.

4. CONCLUSION

The transient response to step change of the load is discussed in the digital control circuit for the forward type multi-output dc-dc converter. Moreover, it introduced the design criterion. As a result, the followings are concluded:

(1) It is important to set the suitable typical input voltage because the smallest integral coefficient must be selected to improve the dynamic characteristics.

(2) The regulation range is enlarged when the number of bits of the calculation part and/or integral coefficient are large. However, the superior transient response is realized when integral coefficient is relatively small. Therefore, the design criterion is that the number of bits of the calculation part is large and integral coefficient is relatively small.

(3) It seems that excellent characteristic is obtained when the digital control parameter is selected, that is, the proportional coefficient is two, the integral coefficient is 0.003 and the differential coefficient is two. As a result, it is clarified that the overshoot and undershoot of the output voltage is over 2.3%, 0.8%, and the convergence time that the output voltage is settled within 1% is 0.38 ms.

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