A New Digital Control for Forward Type Multiple-Output DC-DC Converter

Fujio Kurokawa¹, Tomoyuki Mizoguchi¹, Shohei Sukita¹ and Hiroyuki Osuga¹,²

¹ Nagasaki University
1-14 Bunkyo-machi, Nagasaki, 852-8521 Japan
² Mitsubishi Electronic Corporation
325 Kamimachiya, Kamakura, Kanagawa, 247-8520, Japan
E-mail: fkurokaw@nagasaki-u.ac.jp

Abstract — The purpose of this paper is to present a new digital control method of the forward type multiple-output dc-dc converter with both the P-I-D control and the static equation model. The dynamic characteristics of digital control dc-dc converter are improved as compared with the conventional one.

As a result, it is seen that the forward type multiple-output dc-dc converter with a new digital control has a superior transient response compared with that of the conventional control. The overshoot of reactor current is improved 28%.

I. INTRODUCTION

Recently, the power supply has been receiving increasing attention in the telecommunications and data communications systems because the power supply system requires the high performance characteristics, the high energy management function, the high reliability and the small size more. Therefore, the digital control techniques have been growing to apply to these switching power supplies [1]-[5]. Since the conversion time of the A-D converter and the calculation time for control have a significant effect on the dynamic characteristics in the digital control method, the central research target of digital control circuit is to improve the influence. An example of improvement is to develop the high performance A-D converter [5]. Another example is to supplement the auxiliary control measures [4], [6]. We already reported that the reference value of the output voltage is changed by the static model [6]. However, in this method, the circuit becomes unstable under some condition. So, a new model method is presented in this paper.

This paper presents a new digital control method of the forward type multiple-output dc-dc converter with both the P-I-D control and the static equation model. In this proposed control method, not only the P-I-D control as the feedback loop but also the model control as the feedforward loop are performed to improve the transient response. The model consists of the static relational equation between the resistors of loads and the output voltages of the forward type multiple-output dc-dc converter.

II. OPERATION PRINCIPLE

Figure 1 shows a new digital control forward type multiple-output dc-dc converter. In the circuit, the reset winding Np2 is added to avoid the saturated flux. The turn ratio Np1/Np2 is equal to unity. Ei is the input voltage, eo1 and eo2 are the output voltages, respectively. io1 and io2 are the output currents. IL1 and IL2 are the reactor currents. D11, D12, D21 and D22 are the diode. C1 and C2 are the output smoothing capacitor. Np1, Np2, Ns1 and Ns2 are the numbers of turn for the transformer T. R1 and R2 are the load. L is energy storage reactor with the cross regulation function. NL1 and NL2 are the number of turn for energy storage reactor L. The output voltage eo1 is detected and controlled. The output voltage is controlled by the cross regulation of the transformer T and reactor L. Particularly, the output currents io1 is detected as the voltage es by a sensing resistor Rs and the input voltage Ei is also detected.

Figure 2 shows the configuration of the proposed digital control circuits. The function of this controller is divided into the P-I-D controller and the model controller.
In the P-I-D controllers, the output voltage $e_{o1}$ of the dc-dc converter is input to the A-D converter through a pre-amplifier circuit, and converted to the $N_{e_{o1}}$. In this case, the suffix n denotes the n-th period of the switching period $T_S$. The value is sent to the P-I-D controller and the model controller. Similarly, the input voltage $E_i$ and output current $i_{o1}$ are sent to the model controller.

In the P-I-D controller, the following equation is calculated and the numerical value $N_{Ton_c}$ corresponded to the on-time from the P-I-D controller is sent to the subtractor.

$$N_{Ton_c,n} = K_p(N_{e_{o1},n-1} - N_R) + K_I \sum N_{I,n-1} + K_D N_{D,n-1}$$  \hspace{1cm} (1)

$N_R$ is the numerical reference value and $K_p$ is the proportional coefficient, respectively. $N_{D,n-1}$ is given by the deference between $N_{e_{o1},n-1}$ and $N_{e_{o1},n}$, $N_{D,n-1}$ is multiplied by the differential coefficient $K_D$ and $K_D N_{D,n-1}$ is generated at the multiplier. $\Sigma N_{I,n-1}$ is given by the integral deference between $N_{e_{o1},n-1}$ and $N_{INT}$. In this case, $N_{INT}$ is the predetermined reference value in the I-control and corresponds to the desired output voltage of the dc-dc converter. $\Sigma N_{I,n-1}$ is also multiplied by the integral coefficient $K_I$.

In the model controller in Fig. 2, the following equation is calculated and the numerical value $N_{Ton_m}$ corresponded to the on-time from the model controller is sent to the subtractor.

$$N_{Ton_m,n} = N_{Ton_m,n} - N_{Ton_c,n}$$
$$N_{Ton_m,n} = N_{Ton_m,n} - [K_p(N_{e_{o1},n-1} - N_R) + K_I \sum N_{I,n-1} + K_D (N_{e_{o1},n-1} - N_{n-1})]$$ \hspace{1cm} (10)

Therefore, the on-time $T_{on,n}$ of n-th switching period in the drive circuit is represented as follows:

$$T_{on,n} = \frac{\left(N_{Ton,n}/N_{Ts}\right)}{I_S}$$ \hspace{1cm} (11)

### III. REGULATION CHARACTERISTICS

Figure 3 shows the regulation characteristics against the changes of input voltage $E_i$ and output current $I_{o1}$. The solid line denotes the simulated results of the proposed model control method of the forward type multiple-output dc-dc converter and the broken and dot line denotes those of the conventional digitally P-I-D controlled the forward type multiple-output dc-dc converter without a model controller. It is often observed that the dynamic characteristics of the digitally controlled dc-dc converter are deteriorated when the relatively large integral coefficient is used to extend the regulation range of the output voltage for the variations of the input voltage and load current. However, in the proposed
model controlled the forward type multiple-output dc-dc converter, the integral coefficient $K_I$ is very small and is equal to 0.00001, because the proposed model controller is presented to extend the regulation range of the output voltage.

In the conventional digitally P-I-D controlled dc-dc converter, the integral coefficient $K_I$ over 0.024 is necessary to regulate the output voltage. Provided that the regulation range of the output voltage is set from 28V to 52V.

Furthermore, the regulation from no load to full load is obtained as shown in Fig. 3(b) because the mmf (magneto motive force) of the reactor L is continuous in Fig. 1 and regulation range is enough wide [7]-[9].

IV. TRANSIENT RESPONSE

Figures 4 and 5 show the simulated transient response of the conventional P-I-D control of the forward type multiple-output dc-dc converter in step change of the load resistor $R_1$ from 25Ω to 2.5Ω. The simulator is PSIM. The switching frequency is 200kHz. The circuit parameters are $E_i=36V$, $E_{o1}^*=5V$, $C_1=C_2=1000\mu F$, $R_S=0.001\Omega$, $A_{eo1}=0.5$, $A_{es}=100$, $A_{ei}=0.0625$ and $G_{AD}=819$. The integral coefficient $K_I$ is 0.024 and the differential coefficient $K_D$ is 2. The number of bit of A-D converter is 12 bits.

Figure 6 shows the relationship among the transient time $t_{st}$ of the output voltage, the overshoot ratio $\Delta I_{Lmax}/I_L$ of the reactor current and the proportional coefficient $K_P$ of the moving average in P-I-D control.
In Fig. 4, the proportional coefficient $K_P$ is equal to 2. The undershoot and overshoot of output voltage $e_{o1}$ is over 2.3% and 1.5%. The convergence time $t_{st}$ that the output voltage $e_{o1}$ is settled within 1% is 0.88 ms. The overshoot of the reactor current $i_{L1}$ is 35%. Figure 5 shows that the undershoot, overshoot and transient time of the output voltage are 1.8%, 0.8% and 0.21 ms in case of $K_P=5$. The overshoot of the reactor current is 39%. The superior transient response is obtained in case of $K_P=5$. However the overshoot of the reactor current $i_{L1}$ is not suppressed.

Figure 7 shows the simulated transient response of the proposed model control method of the forward type multi-output dc-dc converter. The digital control circuit parameters are $K_P=2$, $K_I=0.00001$ and $K_D=2$. The overshoot and undershoot of the output voltage is over 2.2%, 0.7%. The convergence time $t_{st}$ that the output voltage $e_{o1}$ is settled within 1% is 0.34 ms. The overshoot of reactor current $i_{L1}$ is under 28%.

As a result, it is revealed that the deference between the undershoot of output voltage $e_{o1}$ in the digital P-I-D control in case of $K_P=5$ and that in the proposed model control are a few. However, the overshoot of reactor current in the model method can be improved 28% compared with that in the P-I-D control one.

V. CONCLUSION

The transient response to step change of the load is discussed in a new digital control method of the forward type multi-output dc-dc converter:

It seems that excellent characteristic is obtained when the digital control parameter is selected, that is, the proportional coefficient is 2 and the differential coefficient is 2. As a result, it is clarified that the overshoot and undershoot of the output voltage is over 2.2%, 0.7%, and the convergence time that the output voltage is settled within 1% is 0.34 ms. The overshoot of reactor current is over 28%.

As a result, it is revealed that the deference between the undershoot of output voltage $e_{o1}$ in the digital P-I-D control and that in the proposed model control are a few. However, the overshoot of reactor current in the model method can be improved 28% compared with that in the P-I-D control one.

It is confirmed that the proposed model control method of the forward type multi-output dc-dc converter is useful to realize the high performance digital control circuit of dc-dc converter.

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


