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

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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 N_{p2} is added to avoid the saturated flux. The turn ratio N_{p1}/N_{p2} is equal to unity. E_i is the input voltage, e_{o1} and e_{o2} are the output voltages, respectively. i_{o1} and i_{o2} are the output currents. i_{L1} and i_{L2} are the reactor currents. D_{11}, D_{12}, D_{21} and D_{22} are the diode. C_1 and C_2 are the output smoothing capacitor. N_{p1}, N_{p2}, N_{s1} and N_{s2} are the numbers of turn for the transformer T. R_1 and R_2 are the load. L is energy storage reactor with the cross regulation function. N_{L1} and N_{L2} are the number of turn for energy storage reactor L. The output voltage e_{o1} is detected and controlled. The output voltage is controlled by the cross regulation of the transformer T and reactor L. Particularly, the output currents i_{o1} is detected as the voltage e_s by a sensing resistor R_s and the input voltage E_i 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.

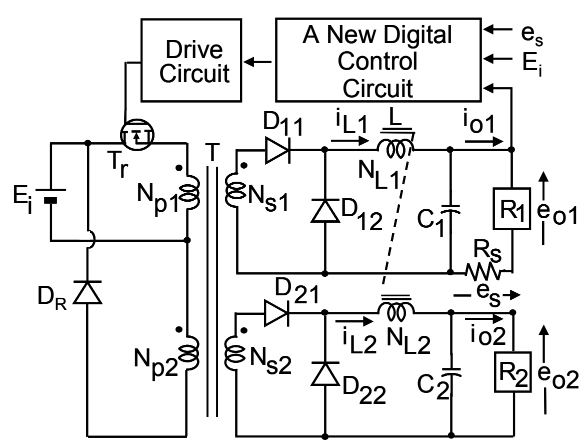


Fig. 1 A new digital control multiple-output dc-dc converter.

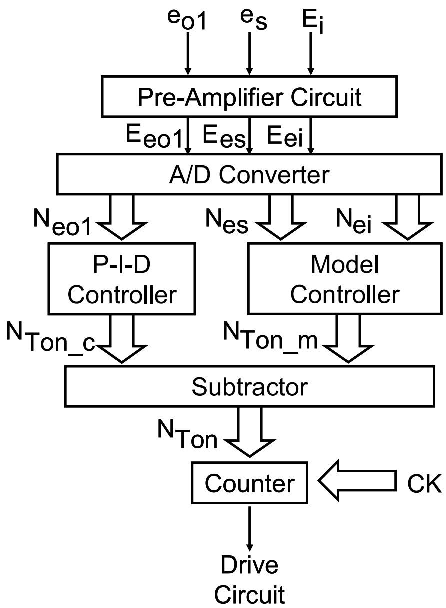


Fig. 2 A new digital control circuit.

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_{eo1}. 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.

$$N_{Ton\_c,n} = K_P\left(N_{eo,n-1} - N_R\right) + K_I\sum N_{I,n-1} + K_D N_{D,n-1} \tag{1}$$

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 $N_{eo,n-1}$ and $N_{eo,n-2}$. $N_{D,n-1}$ 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 $N_{eo1,n-1}$ 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 numerical values corresponded to the on-time from the model controller are given by the following equations;

$$N_{Ton\_m,n} = \frac{(1 + r_l/R_l)E^*_{o1}}{N_{s1}/N_{p1}\, b - r_p(a + I_{o2})} N_{Ts} + \frac{aL_l N_{Ts}}{N_{s1}/N_{p1}\, bTs} \tag{2}$$

$$a = N_{es,n-1}/A_{es}G_{AD}R_s \tag{3}$$

$$b = N_{ei,n-1}/A_{ei}G_{AD} \tag{4}$$

$$r_p = r_{Tr} + r_T \tag{5}$$

$$r_l = r_{L1} + R_s \tag{6}$$

The resistance R_1 is calculated by the sensed output voltage and output current.

In Eqs. (1), (3) and (4), $N_{eo1,n-1}$, $N_{es,n-1}$ and $N_{ei,n-1}$ are represented as follows;

$$N_{eo1,n-1} = A_{eo1}G_{AD}e_{o1} \tag{7}$$

$$N_{es,n-1} = A_{es}G_{AD}R_s i_{o1} \tag{8}$$

$$N_{ei,n-1} = A_{ei}G_{AD}E_i \tag{9}$$

A_{es} and G_{AD} are the gains of the pre-amplifier and A-D converter which sense the output current, and A_{eo1} is the gains of the pre-amplifier which sense the output voltage, respectively.

N_{Ton_m} is performed as the feedforward control element. N_{Ton_c} and N_{Ton_m} are sent to the subtractor and the modified N_{Ton} are represented as follows;

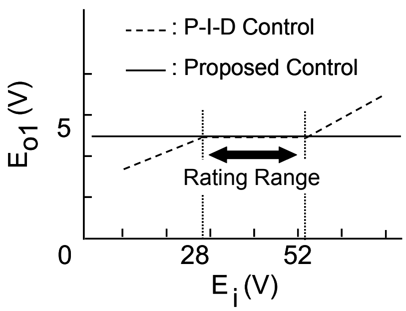
$$\begin{aligned} N_{Ton,n} &= N_{Ton\_m,n} - N_{Ton\_c,n} \\ &= N_{Ton\_m,n} - \{K_P\left(N_{eo1,n-1} - N_R\right) \\ &\quad + K_I\Sigma N_{I,n-1} + K_D\left(N_{eo1,n-1} - N_{n-1}\right)\} \end{aligned} \tag{10}$$

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

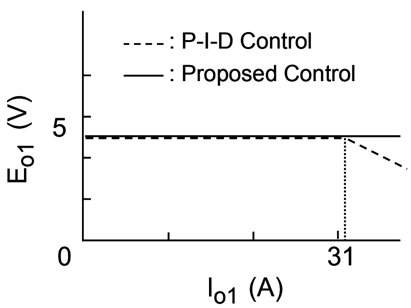
$$T_{on,n} = \left(N_{Ton,n}/N_{Ts}\right)T_s \tag{11}$$

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

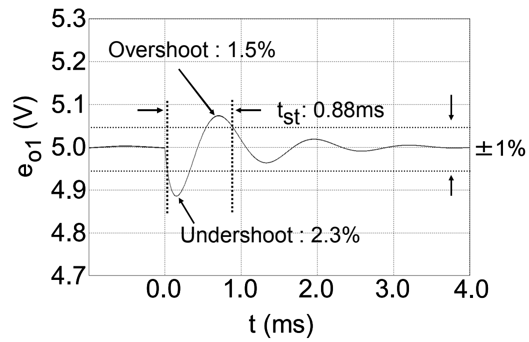


(a) Against the change of input voltage E_i.

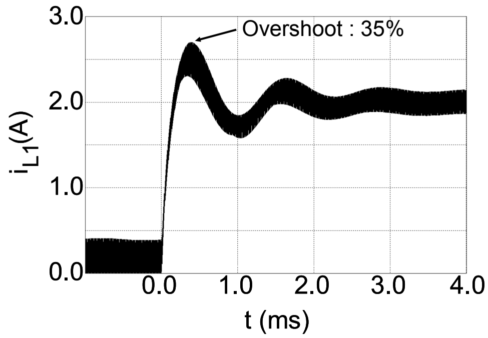


(b) Against the change of output current I_{o1}.

Fig. 3 Regulation characteristics.



(a) Output voltage e_{o1}.



(b) Reactor current i_{L1}.

Fig. 4 Transient response of conventional P-I-D control in case of K_P =2.

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.

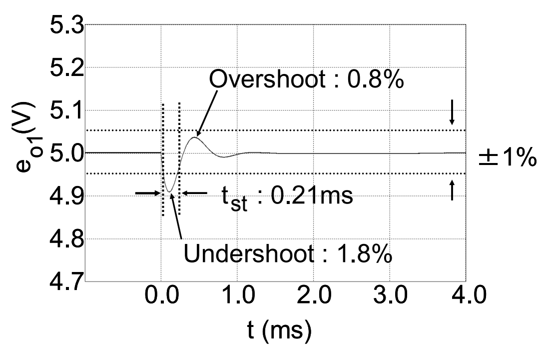
In the conventional digitally P-I-D controlled dc-dc converter, the integral coefficient K_I over 0.024 is necessary to regulate the output voltage. Provided that the regulation range of the output voltage is set from 28V to 52V.

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].

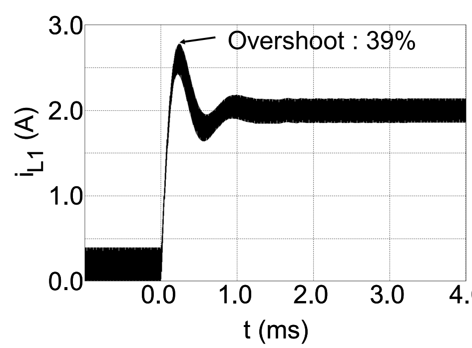
IV. Transient Response

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=1000μF, R_S=0.001Ω, 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.



(a) Output voltage e_{o1}.



(b) Reactor current i_{L1}.

Fig. 5 Transient response of conventional P-I-D control in case of K_P =5.

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 0.21ms 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 multiple-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 controland 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.

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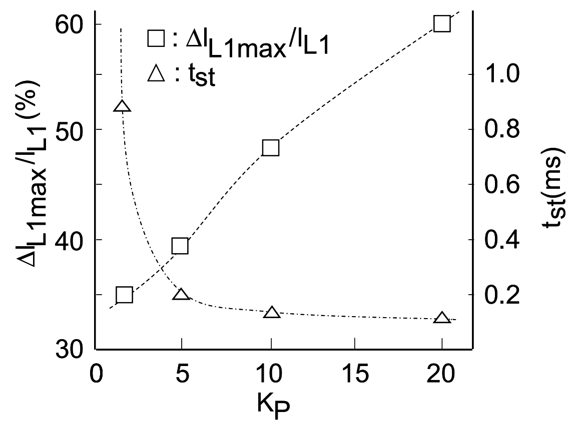
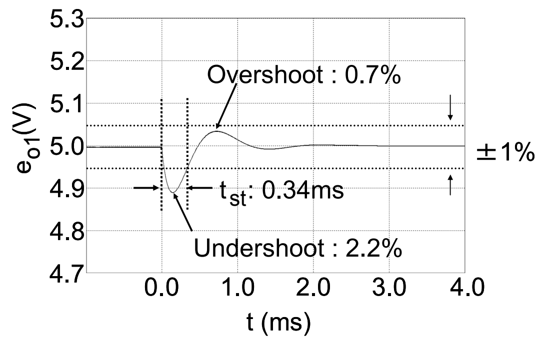
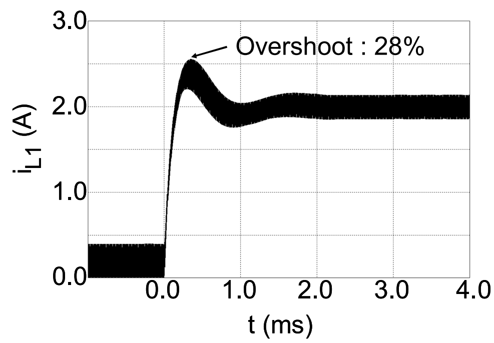


Fig. 6 Relationship among transient time t_{st} of the output voltage, overshoot of the reactor current and the proportional coefficient K_P of the moving average. K_I=0.024 and K_D=2.



(a) Output voltage e_{o1}.



(b) Reactor current i_{L1}.

Fig. 7 Transient response of proposed digital control method in case of K_P=2.

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