Digital PID Based Two-Compensator for DC-DC Converter

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***Abstract*—The purpose of this paper is to present the performance characteristics of the digital PID based two-compensator for the dc-dc converter. Authors have already presented a fast PD control method, which can reduce the influence of the delay time. In this paper, the transient characteristics of output voltage are confirmed in the simulation when the sampling frequency of the PID control is slowed down. As a result, the tendency of the transient characteristics of output voltage is revealed. Therefore, the slower sampling frequency of PID control can be applied to the dc-dc converter compared with the conventional PID control.**

Keywords—switching power supply; dc-dc converter; digital control; PID control; fast PD control

I. INTRODUCTION

The increase of the power consumption is caused by the wide use of the telecommunication equipment. The energy management in such system becomes necessary to save the energy. The digital control switching power supply has been attracted attention because it has advantages of realizing the high performance control [1]-[5].

Meanwhile, the digital control has the assignment. There is a delay time in the digital control process. The A-D conversion time occurs in the A-D converter. Also, processing time occurs in the digital controller such as digital signal processor (DSP) and field programmable gate array (FPGA). The delay time adversely affects the transient response.

In the previous research, the fast PD control method has been presented in [6]-[10]. The PID control is divided into two parts, which are the fast PD and the slow PID controllers. The sampling frequency for the fast PD control is shorter than the switching frequency. The P control requires the high-speed sampling in order to compare the desired value with the current value. It is related to the transient response directly. The fast D control compensates the phase in the high frequency area. The calculation result of the fast operation part is updated several times in one switching period. The fast PD control method is hardly affected by the delay time. Therefore, it is revealed that it has the superior performance in transient response compared with the conventional PID control method. Although a superior transient response of proposed method is shown, the discussion about the performance characteristics is necessary.

This paper presents the performance characteristics of the digital PID based two-compensator for dc-dc converter. The tendency of transient response of proposed method is revealed when the sampling frequency of PID control is changed and the capacitance of output smoothing capacitor is changed. These characteristics are confirmed in simulation.

II. OPERATION PRINCIPLE

Figure 1 illustrates the digitally controlled buck type dc-dc converter and the scheme of digital control circuit. In where, E_i is an input voltage and e_o is an output voltage. L is an energy storage reactor, C is an output smoothing capacitor, T_r is a main switch, D is a flywheel diode and R is a load. The switching frequency f_S is equal to 100 kHz. e_o is sent to two A-D converters and converted into the digital values $e_{o1}[n]$ and $e_{o2}[n]$. Each digital value is processed in the fast PD control part and the PID control part in parallel. The control calculation is carried out and its result is updated by each sampling point.

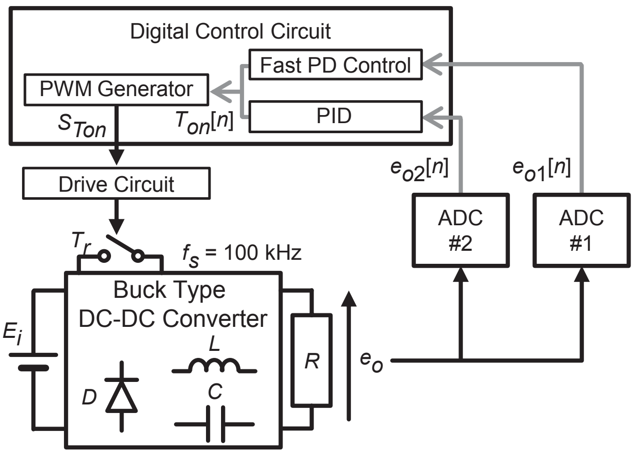


Fig. 1. Digitally controlled buck type dc-dc converter and scheme of digital control circuit.

The digital value $T_{on}[n]$ of on time of main switch is determined by those calculation results. The PWM generator outputs the PWM signal S_{Ton} depending on $T_{on}[n]$. The drive circuit shapes S_{Ton} and drives the main switch.

A. PID Control

Figure 2 shows the timing chart of the PID control. The open circle denotes the valid sampling point for the PID control. The calculation result of the PID control is applied after M_{PID} switching periods. M_{PID} denotes a number of switching periods between the sampling points in the PID control. Usually, M_{PID} is equal to one because the sampling frequency f_{PID_samp} for the PID control is set to f_s. The PID control calculation is carried out each $M_{PID}T_s$ because the sampling point for the PID control is obtained only once in $M_{PID}T_s$. The transfer function $H_{PID}(s)$ of the PID control is represented as follows:

$$H_{PID}(s) = \left(H_P + \frac{H_I}{s} + sH_D \right) e^{-s\tau 2}\ , \tag{1}$$

where H_P is the proportional gain, H_I is the integral gain and H_D is the differential gain. $\tau 2$ is the delay time of the PID control including the A-D conversion time and the processing time. Moreover, each gain is given by

$$H_P = \frac{A_{eo} G_{AD2} K_P}{N_{Ts}} \tag{2}$$

$$H_I = \frac{A_{eo} G_{AD2} K_I}{N_{Ts} T_{PID\_samp}} \tag{3}$$

$$H_D = \frac{A_{eo} G_{AD2} T_{PID\_samp} K_D}{N_{Ts}}\ , \tag{4}$$

where A_{eo} is the gain of pre-amplifier, G_{AD2} is the gain of A-D converter for the PID control, N_{Ts} is the resolution of DPWM. K_P, K_I and K_D are coefficients of P, I and D controls, respectively. T_{PID_samp} is the sampling period of the PID control and is equal to $M_{PID}T_s$.

B. Fast PD Control

Figure 3 shows the timing chart of the fast PD control. The open square and the closed square denote the valid and the invalid sampling point for the fast PD control, respectively. M_{FPD} is the number of the sampling point during the switching period T_s. m_{PD} means the m_{PD}-th (m_{PD}=1, 2, …, M_{FPD}) sampling point during T_s. Though the fast PD control calculation is updated each sampling point during T_s, only one calculation result using latest sampling point becomes valid to turn off the main switch. For example, the second sampling point is used for the fast P control in the (n-1)-th switching period. Similarly, the second sampling point is used for the fast P control in the n-th switching period as shown in Fig. 3. In the n-th switching period, the fast D control is calculated using the valid sampling point at the n-th switching period and the valid sampling point at the (n-1)-th switching period. For example, the second sampling point in the (n-1)-th switching period and the second sampling point in the n-th switching period are used for the fast D control calculation in the n-th switching period as depicted in Fig. 3. The sampling frequency f_{FPD_samp} for the fast PD control is higher than f_s. Therefore, the A-D conversion time T_{AD} is suppressed and the fast PD control calculation is repeated several times during T_s and its calculation result is

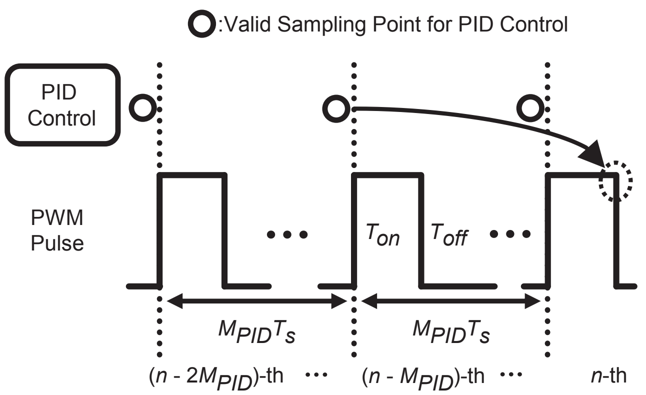


Fig. 2. Timing chart of PID control.

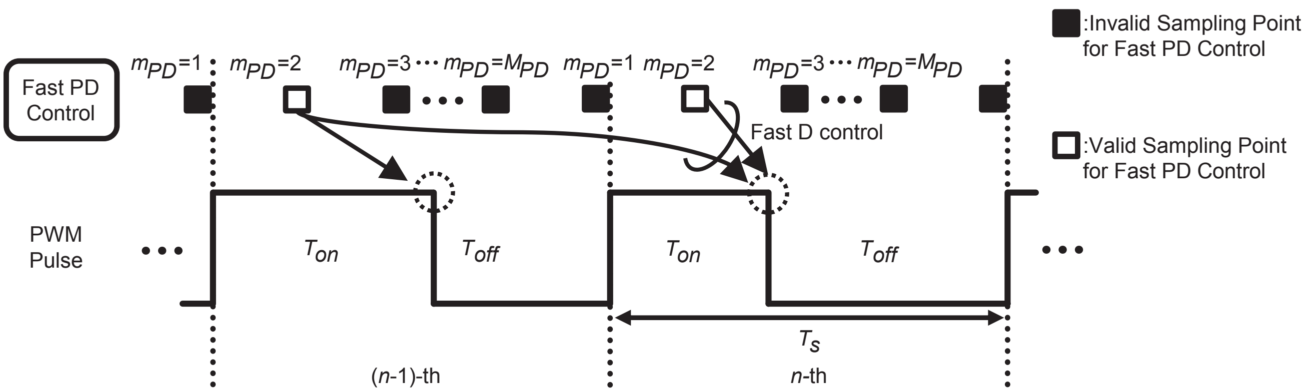


Fig. 3. Timing chart of fast PD control.

applied immediately. The transfer function $H_{FPD}(s)$ of fast PD control is represented as follows:

$$H_{FPD}(s) = \left(H_{FP} + sH_{FD}\right) e^{-s\tau_1}, \tag{5}$$

where H_{FP} is the proportional gain and H_{FD} is the differential gain in the fast PD control. τ_1 is the delay time of fast PD control including the A-D conversion time and the processing time. Each gain is given by

$$H_{FP} = \frac{A_{eo} G_{AD1} K_{FP}}{N_{Ts}} \tag{6}$$

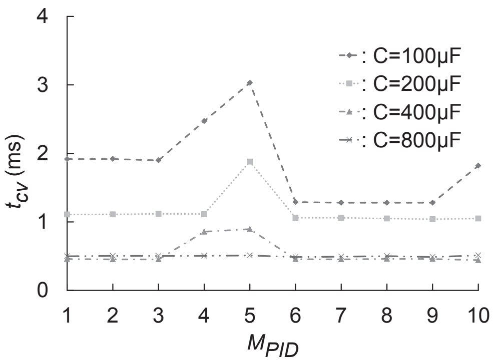
$$H_{FD} = \frac{A_{eo} G_{AD1} T_{FPD\_samp} K_{FD}}{N_{Ts}}, \tag{7}$$

where G_{AD1} is the gain of A-D converter for the fast PD control. Also, K_{FP} and K_{FD} are coefficients of fast P control and fast D control, respectively. T_{FPD_samp} is the period of the fast D control and is almost the same as T_s.

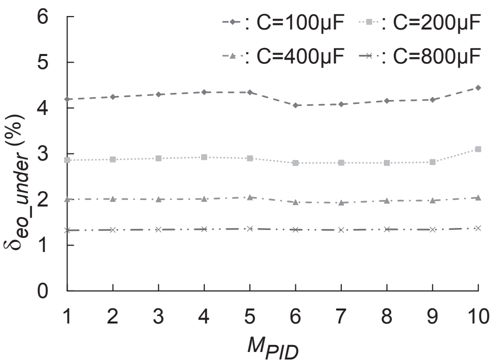
III. Performance Characteristics

In this section, the performance characteristics of the dc-dc converter with the proposed method are discussed when M_{PID} is varied. Main evaluation items are the undershoot δ_{eo_under} of e_o and the convergence time t_{cv} when the output voltage converges within plus-minus 1% of the reference voltage E_o* in the load transient. E_i and E_o* are 20 V and 10 V, respectively. When the main switch is on, the internal loss resistance r_1 of dc-dc converter is 0.28 Ω. When the main switch is off, the internal loss resistance r_2 of dc-dc converter is 0.32 Ω. The forward voltage drop V_D of diode is 0.3 V and the reactance of L is 510 μH. The step change of the load is from 20 Ω to 10 Ω. The simulator is PSIM. M_{FPD} is equal to 10. Control gains are given as follows: H_{FP} = 0.2 (1/V), H_{FD}=1.0 (μs/V), H_P = 0.05 (1/V), H_I = 41 (1/sV), H_D = 0.5M_{PID} (μs/V).

Figure 4 illustrates the properties of the proposed method in the load transient taking C as a parameter. The vertical axis is δ_{eo_under} or t_{cv}, and the horizontal axis is M_{PID}, respectively. As shown in Fig. 4(a), when M_{PID} is set to 4 or 5 , t_{cv} gets worse. On the other hand, δ_{eo_under} is almost constant against the variation of M_{PID} as shown in Fig. 4(b). In the case of the large value of C, M_{PID} can be set to larger

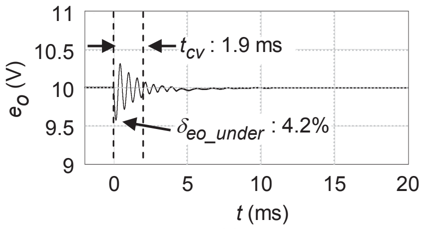


(a)

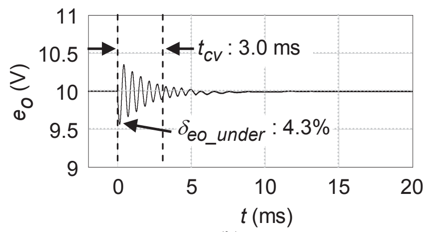


(b)

Fig. 4. Transient characteristics of output voltage, e_o, against a number of switching periods between sampling points in PID control, M_{PID}: (a) convergence time of e_o within plus-minus 1% of reference voltage, t_{cv}, (b) undershoot of e_o, δ_{eo_under}.



(a)



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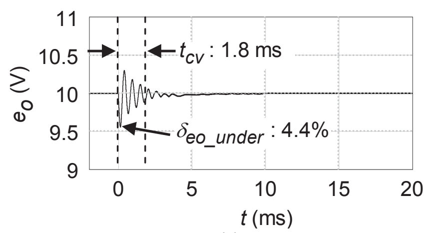
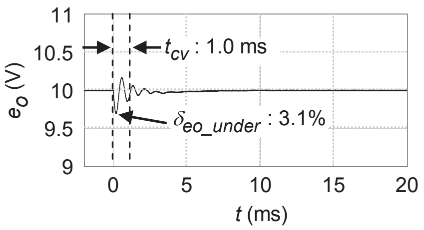


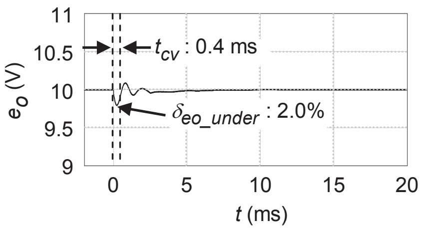
(c)

Fig. 5. Transient response of output voltage, e_o, when output smoothing capacitor, C, is equal to 100 μF: (a) a number of switching periods between sampling points in PID control, M_{PID}, is 1, (b) M_{PID} is 5, and (c) M_{PID} is 10.

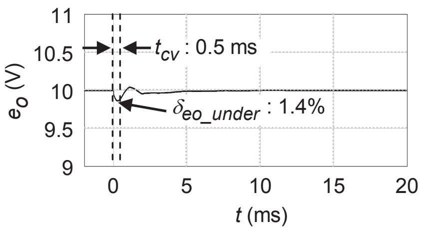
value. The transient response of e_O is given in Figs. 5 and 6. Figure 5 explains the transient response when M_{PID} is equal to 1, 5 and 10, and C is equal to 100 μF. δ_{eo_under} is 4.2%, 4.3% and 4.4%, and t_{CV} is 1.9 ms, 3.3 ms and 1.8 ms. Likewise, Figure 6 shows the transient response when M_{PID} is equal to 10, and C is equal to 200 μF, 400 μF and 800 μF. δ_{eo_under} is 3.1%, 2.0% and 1.4%. t_{CV} is 1.1 ms, 0.4 ms and 0.5 ms.



(a)



(b)



(c)

Fig. 6. Transient response of output voltage, e_O, when a number of switching periods between sampling points in PID control, M_{PID}, is 10: (a) output smoothing capacitor, C, is equal to 200 μ:, (b) C is 400 μF, and (c) C is 800 μF.

IV. CONCLUSION

In this paper, the performance characteristics of the digital PID based two-compensator for dc-dc converter is discussed. Even if a number of switching periods between the sampling points in the PID control becomes larger, the transient characteristics are kept excluding $M_{PID} = 4$ and 5. Therefore, the sampling frequency of PID control can be set smaller value than conventional PID control by using the proposed method. Also, the tendency of the transient response of the proposed method is confirmed.

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