Improvement in Transient Response of Fast P Control DC-DC Converter with Static Model

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Abstract—**The purpose of this paper is to propose the digital control method that is comprised of the fast P control and model control for an improvement of the transient response of the dc-dc converter. The electronic devices are required the operation in the standby mode and the quick return to the active mode. The fast transient response of the dc-dc converter in such condition is important. In this paper, the fast P control is combined with the model control. Therefore, the transient response in such situation is improved because the operating point is optimized according to the load current. From the results, in the case of the load step from DCM to CCM, the undershoot and the convergence time are improved by about 80%.**

Keywords-dc-dc converter; digital control; model control; fast P control

I. INTRODUCTION

In recent years, the lack of the fossil fuel is concern in the near future. For saving energy, the electronic devices are required the operation in the standby mode and the quick return to the active mode. When the electronic devices return to the active mode, the dc-dc converter must deal with the large load step from the discontinuous current mode (DCM) to the continuous current mode (CCM). Therefore, the fast transient response is important.

Various control methods for the improvement in the CCM have been proposed [1]-[3]. Also, the authors have proposed the unique digital control method for the improvement of the transient response in [3]. Also, the various considerations are discussed in [5]-[8] (e.g., the capacitance of the output smoothing capacitor, sampling frequency, the resolution of the A-D converter and so forth). The many advantages of the proposed method are revealed in the simulation and experiment. However, the fast P control is not effective for the quick response from the DCM to the CCM because the undershoot is not suppressed enough.

This paper presents the improvement of the transient response of the fast P control in the transient from the CCM to the DCM. The model control is combined with fast P control to achieve it. The operation point is quickly optimized by the model control [9] and the proposed method shows the superior transient response. The validity of the proposed method is confirmed in simulation.

II. OPERATION PRINCIPLE

Figure 1 illustrates the digital control dc-dc converter. The symbols denote the circuit parameters as follows: e_i is the input voltage, e_o is the output voltage, *R* is the load resistance, *L* is the energy storage reactor, i_L is the reactor current, *C* is the output smoothing capacitor, *D* is the diode, T_r is the main switch, R_S is the sensing resistor to detect the output current i_o, e_s is the voltage across R_S. e_i, e_o and e_s are detected and processed in the digital control circuit. The PWM signal is outputted according to the calculation result of the digital control and the drive circuit drives T_r.

The scheme of the digital control circuit is illustrated in Fig. 2. $e_i[n]$, $e_{o1}[n]$, $e_{o2}[n]$ and $e_s[n]$ are the digital values of e_i, e_o and e_s, respectively. $e_i[n]$ and $e_s[n]$ are used for the calculation of the model control. $e_{o1}[n]$ and $e_{o2}[n]$ are used for the fast P and the ID controls. Also, the digital value of the on time $T_{on}[n]$ of T_r is computed by following equation:

$$T_{on}[n] = T_{on\_model}[n] + T_{on\_PID}[n], \tag{1}$$

where $T_{on\_model}[n]$ and $T_{on\_PID}[n]$ are the digital value of the model and PID controls, respectively.

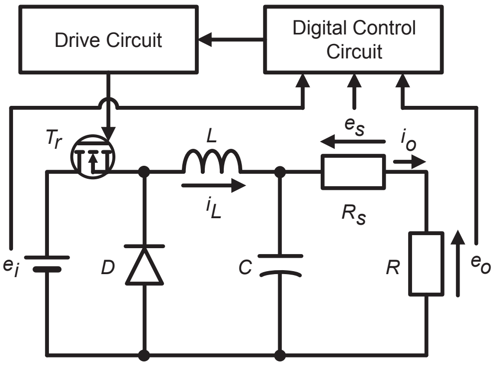

Figure 1. Digital control dc-dc converter.

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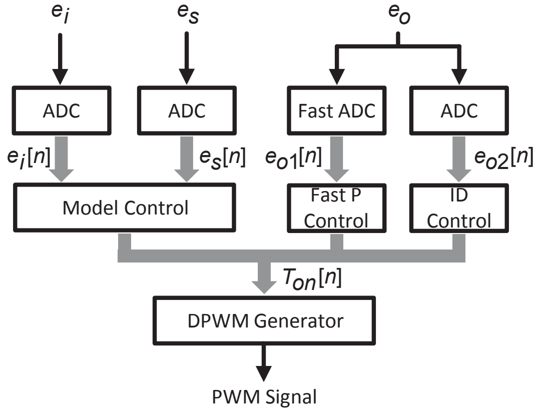


Figure 2. Scheme of digital control circuit.

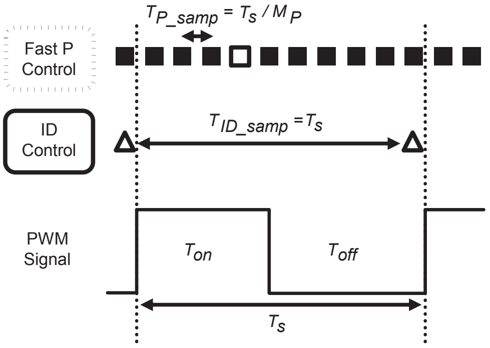


Figure 3. Timing of fast P control.

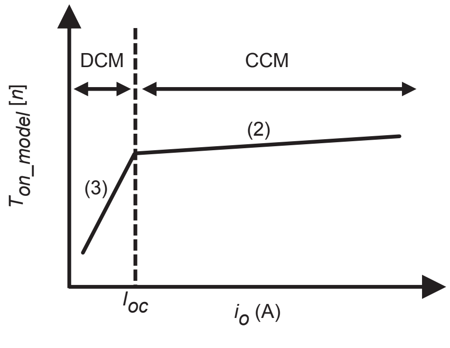


Figure 4. Input-Output Characteristics of Model Function.

A. Fast P Control Method

The fast P and the ID controls configure the fast P control method. The high-speed A-D converter is utilized for the fast P control and the fast P control is calculated by every sampling point. In other words, it is processed several times during a switching period T_S. Thus, the latest sampling point becomes valid for the decision of $T_{on}[n]$ and the delay-time is suppressed. On the other hand, the low-speed A-D converter is utilized for the ID control and the ID control is calculated once during T_S. This setting is the same as that of the conventional PID control.

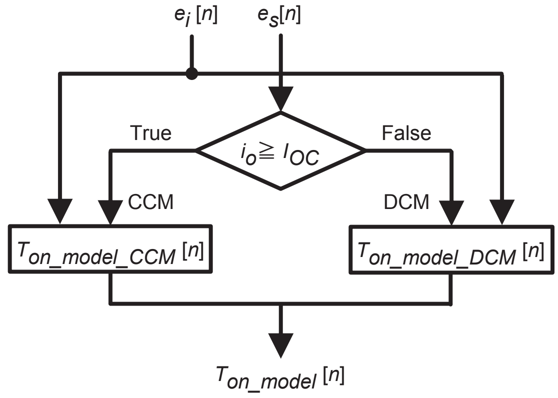


Figure 5. Flow Chart of Model Function.

The timing chart of the fast P control is illustrated in Fig. 3. The black and white square symbols denote the invalid and valid sampling point for the fast P control. Likewise, the valid sampling point for the ID control is denoted with the white triangle symbol. T_{on} and T_{off} are the on and off time of T_r. M_P is the number of the sampling point for the fast P control during T_S. Therefore, the sampling period T_{P_samp} of the fast P control is equal to T_S / M_P. The fast P control calculation is processed each sampling point and its result is updated in turn. The effect of delay-time is suppressed in this way. The sampling period T_{ID_samp} for the ID control is equal to T_S.

B. Model Control Method

In the model control, the operating point is varied properly by using the static model. The following equations are used for the calculation of bias value. The equation in CCM is

$$T_{on\_model\_CCM}[n] = \frac{N_{Ts}}{b+V_D}(E_o^* + ra + V_D), \tag{2}$$

and also the equation in DCM is

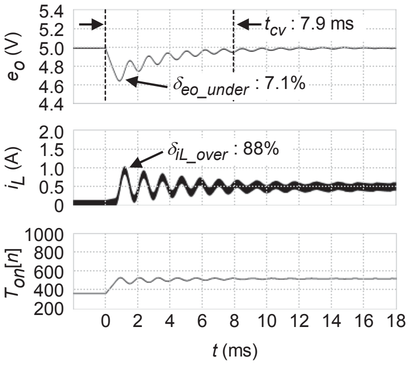
$$T_{on\_model\_DCM}[n] = N_{Ts}\sqrt{\frac{2La(E_o^*+V_D)}{bT_s(b+V_D)(b-E_o^*)}}, \tag{3}$$

where $E_O{}^*$ is the reference output voltage, r is the internal loss resistance of dc-dc converter, V_D is the forward voltage of D, the resolution of digital PWM generator is N_{TS}. Also, a and b , which are the analog values converted into i_O and e_i by $e_S[n\text{-}1]$ and $e_i[n\text{-}1]$, is given by

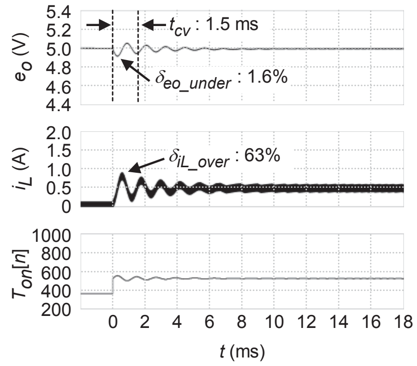
$$a = \frac{e_s[n-1]}{A_{es}G_{AD\_es}R_s} \tag{4}$$

$$b = \frac{e_i[n-1]}{A_{ei}G_{AD\_ei}}. \tag{5}$$

In (4) and (5), A_{es} and A_{ei} are the gains of the pre-amplifier for e_S and e_i, G_{AD_es} and G_{AD_ei} are the gains of the A-D converter for e_S and e_i. Figures 4 and 5 depict the input-output characteristics and the flow chart of the model function. Although the model control is classified by i_O, actually, a is

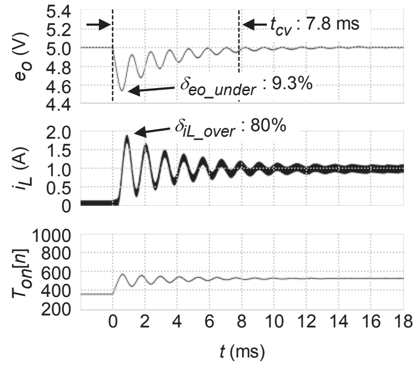


(a) Fast P control.

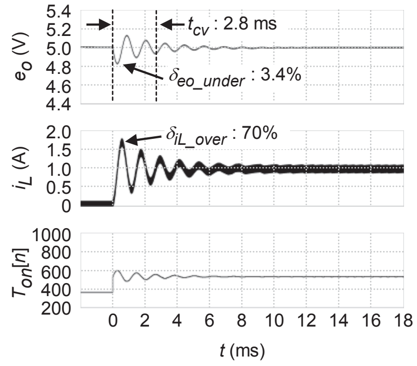


(b) Proposed method.

Figure 6. Wave form of transient response in case of load step from 100 Ω to 10 Ω.



(a) Fast P control.



(b) Proposed method.

Figure 7. Wave form of transient response in case of load step from 100 Ω to 5 Ω.

compared with the critical load current I_{OC}. If a is equal to I_{OC} or larger, the model control uses (2). If a is smaller than I_{OC}, the model control uses (3). Therefore, the model control optimizes the operating point and the wide output voltage stabilization range is realized. In addition, the integral gain is minimized.

III. TRANSIENT RESPONSE

The transient responses are discussed in the case of the load step from DCM to CCM. PSIM is used as the simulator. The switching frequency f_S is 100 kHz, circuit parameters are E_i = 20 V, E_O* = 5V, L = 196 μH, C = 891 μF and R_S = 0.05 Ω. The internal loss resistances r_1 and r_2 of dc-dc converter, which exists the on and off duration of T_r, are 0.125 Ω and 0.126 Ω. Also, r is 0.125 Ω. The resolution of A-D converter is 11 and N_{TS} is 2000. M_P is equal to 10. The fast proportional coefficient K_{FP} is 4 and the differential coefficient K_D is 1. Evaluated items are the overshoot δ_{iL_over} of i_L, the undershoot δ_{eo_under} of e_O and the convergence time t_{cv} of e_O, when e_O converges within 1% of the reference voltage.

At First, the transient responses of the fast P control and the proposed method are indicated in Fig. 6 when the step change of load is 100 Ω to 10 Ω. As shown in Fig. 6(a), δ_{eo_under} is 7.1%, δ_{iL_over} is 88% and t_{cv} is 7.9 ms in the fast P control. Similarly, Fig. 6(b) shows the transient response of the proposed method. δ_{eo_under} is 1.6%, δ_{iL_over} is 63% and t_{cv} is 1.5 ms. Comparing two methods, δ_{eo_under}, δ_{iL_over} and t_{cv} are improved by 77%, 28% and 81%, respectively. $T_{on}[n]$ changes gradually in the fast P control, while it changes quickly by model control in the proposed method.

Next, the transient responses are depicted in Fig. 7 when the step change of load is 100 Ω to 5 Ω. In the fast P control, δ_{eo_under} is 9.3%, δ_{iL_over} is 80% and t_{cv} is 7.8 ms as shown in Fig. 7(a). On the other hand, in Fig. 7(b), δ_{eo_under} is 3.4%, δ_{iL_over} is 70% and t_{cv} is 2.8 ms in the proposed method. δ_{eo_under}, δ_{iL_over} and t_{cv} of the proposed method are improved by 63%, 13% and 64%, respectively. $T_{on}[n]$ changes similar to Fig. 6.

IV. CONCLUSION

The digital control method that is comprised of the fast P control and model control for an improvement of the transient response of the dc-dc converter in DCM to CCM is proposed. The proposed method can indicate a quick response compared with the fast P control because the model varies the operating point properly. Especially, the undershoot and the convergence time are improved by at most about 80%.

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