Design of Predictive Digital Current Control for Series-Parallel Compensation Type DC-DC Converter

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This paper describes an implementation of a predictive digital current control for the series-parallel compensation type DC-DC converter in order to control the current and the output voltage at improved voltage loop dynamic responses. A dynamic response of the current control and the voltage control are compared between the predictive current control and a PI control. As a result of simulations, it is confirmed that the predictive current control can achieve high dynamic responses compared with that of the PI control.

Keywords : Series compensation, Parallel compensation, PI control, Predictive current control

1. Introduction

Recently, hybrid power supplies using both a fuel cell and a battery have been researched. A series-parallel compensation type DC-DC converter have been proposed by authors for one of hybrid power supplies(1). When the fuel cell voltage is closed to the output voltage, the output power is directly provided by the fuel cell without any switching operation; therefore, high efficiency is obtained by the series compensation circuit. When the load condition has changed, the parallel converter compensates the quick variation of the fuel cell current.

On the other hand, in DC-DC converters, a reduction of output smoothing capacitors is required in order to achieve a downsizing of DC-DC converters. However, it results in a large fluctuation of the output voltage. Therefore, a high speed response of a current regulator and an output voltage regulator are required.

In this study, the predictive digital current control is implemented for the proposed circuit in order to suppress the fluctuation of the fuel cell current and the output voltage when the load is changed. This paper shows simulation results with a PI control and the predictive current control.

2. Series-parallel compensation type DC-DC converter

Fig. 1 shows the circuit configuration of the proposed circuit. The series converter generates a positive and negative voltage according to the boost mode and buck mode, respectively. When the load condition is changed, the series converter compensates the differential voltage between the fuel cell voltage and the output voltage, and the parallel converter compensates the quick variation of the fuel cell current.

3. Predictive current control

A predictive current control is a kind of digital controls in power converters(2)-(3). In one switching period, the duty cycle for the next switching cycle is calculated based on the sensed or observed state and input/output information.

4. Simulation result

Fig. 2 shows block diagrams of the proposed circuit. As in Fig. 2, the feedback control consists of an output voltage outer loop and the current inner loop. The outer output voltage loop is based on PI regulator with output voltage command.

In the proposed circuit, the series converter and the parallel converter work at the same time. Therefore, the predictive duty cycle of two converters include the predictive duty cycle of another converter. The predictive duty cycle $d_{S1}[n+1]$ and $d_{S4}[n+1]$ are expressed by (1) and (2) in the boost mode, and then from m_1 to m_6 are slopes of the current shown in Fig. 3.

$$\begin{aligned} & d_{S1}[n+1] \\ & = \frac{1}{(m_3 - m_2)T_s}\left[i_{fc\_command} - i_{fc}\right] \qquad ..(1) \\ & - \frac{1}{m_3 - m_2}\left\{2m_1 + (m_2 - m_1)(d_{S4}[n] + d_{S4}[n+1])\right\} - d_{S1}[n] \end{aligned}$$

$$\begin{aligned} & d_{S4}[n+1] \\ & = \frac{1}{(m_6 - m_5)T_s}\left[i_{comp\_command} - i_{comp}\right] \qquad ..(2) \\ & - \frac{1}{m_6 - m_5}\left\{2m_5 + (m_4 - m_6)(d_{S1}[n] + d_{S1}[n+1])\right\} - d_{S4}[n] \end{aligned}$$

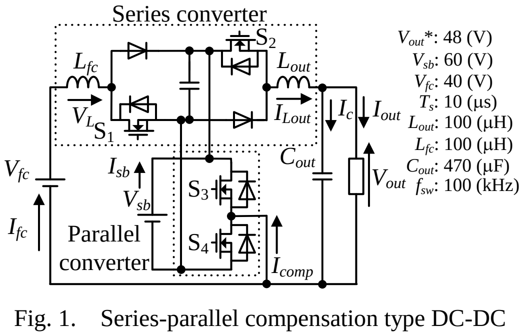

Fig. 1. Series-parallel compensation type DC-DC converter.

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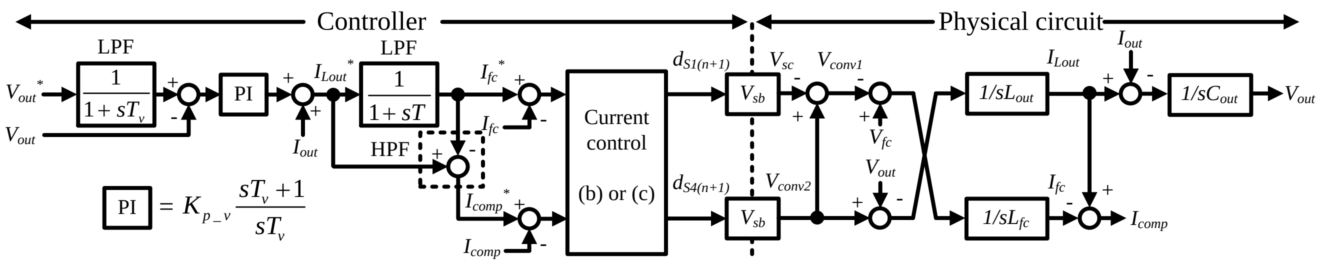
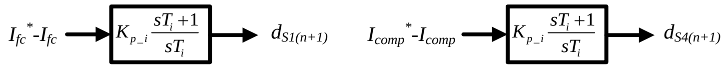
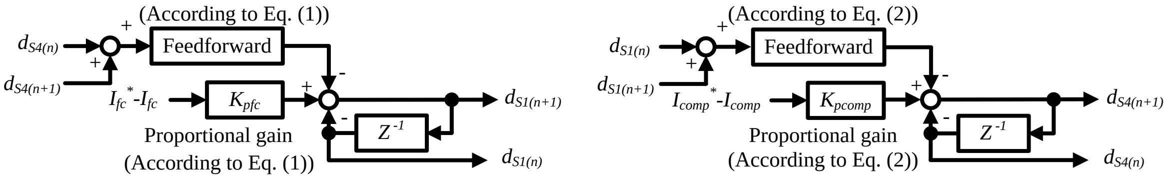


(a) Whole control diagram.



(b) PI control.



(c) Predictive current control.

Fig. 2. Block diagrams of series parallel compensation type DC-DC converter.

$$m_1 = m_3 = V_{fc} / L_{fc} \tag{3}$$

$$m_2 = \left(V_{fc} - V_{sb}\right) / L_{fc} \tag{4}$$

$$m_4 = -\left\{V_{fc} L_{out} - \left(V_{sb} - V_{out}\right) L_{fc}\right\} / L_{fc} L_{out} \tag{5}$$

$$m_5 = -\left(V_{fc} L_{out} + V_{out} L_{fc}\right) / L_{fc} L_{out} \tag{6}$$

$$m_6 = \left\{\left(V_{sb} - V_{fc}\right) L_{out} + \left(V_{sb} - V_{out}\right) L_{fc}\right\} / L_{fc} L_{out} \tag{7}$$

where V_{fc} is the fuel cell voltage, V_{sb} is the battery voltage, V_{out} is the output voltage, i_{fc} is the fuel cell current, $i_{fc\_command}$ is the command of the fuel cell current, i_{comp} is the compensation current, $i_{comp\_command}$ is the command of the compensation current, L_{fc} is an inductance that is connected to the fuel cell in series, L_{out} is an output inductor, T_s is a sampling time, $d_{S1}[n]$ is a previous duty cycle for the switch S_1 and $d_{S4}[n]$ is a previous duty cycle for the switch S_4.

Fig. 4 shows comparisons of the output voltage and each current with the PI and the predictive current control when the load condition is changed. In Fig. 4(a), the voltage drop of over 4.1% occurs at the point of the load change. On the other hand, in Fig. 4(b), the voltage drop is suppressed within 1%. Therefore, it is confirmed that the predictive current control can achieve high dynamic response compared with that of the PI control.

References

(1) Koji Orikawa and Jun-ichi Itoh : “A comparison of the series-parallel compensation type DC-DC converters using both a fuel cell and a battery”, Energy Conversion Congress and Exposition (ECCE), pp.1414-1421 (2010)

(2) A. H. Mitwalli, S. B. Leeb, G. C. Verghese, and V. J. Thottuvelil : “An adaptive digital controller for a unity power factor converter”, IEEE transaction on Power Electronics, Vol.11, No.1, pp.374-382 (1996)

(3) Jingquan Chen, Aleksandar Prodic, Robert W. Erickson, and Dragan Maksimovic : “Predictive Digital Current Programmed Control”, IEEE transaction on Power Electronics, Vol.18, No.1, pp.411-419 (2003)

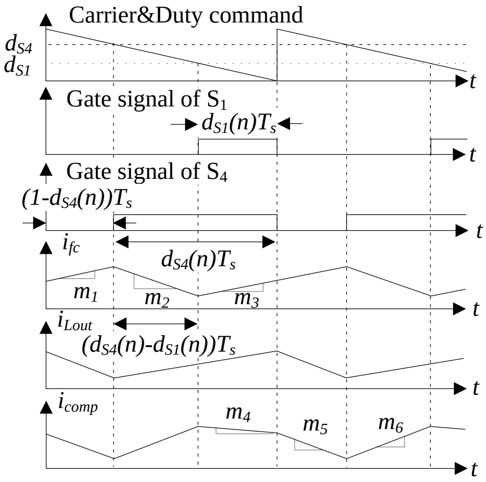
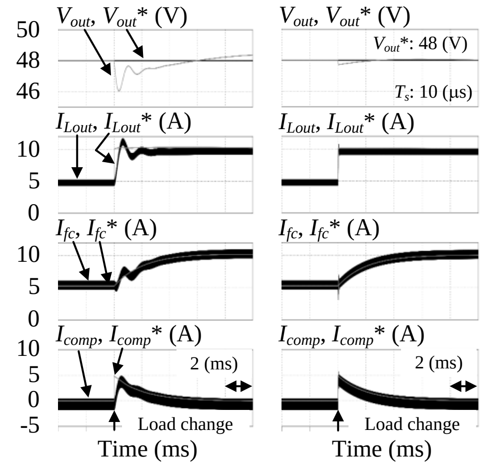


Fig. 3. Current waveforms and gate signals.



(a) PI control (b) Predictive current control

Fig. 4. Simulated voltage and current waveforms.