Simultaneous Control of DC-DC Converters by DSP Controller

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Abstract—**This paper presents a multi output converter system that controls, simultaneously and independently, the separate Buck converter and Boost converter with the different specification by one DSP digital controller. As two separate converters are regulated by only one DSP, it is possible to achieve the simple digital control circuit for regulating the multi output DC-DC converter. By setting the software switch state, PI or Fuzzy controller can be applied as a controller for each converter without any change of hardware. Also, PI and Fuzzy control characteristics of each DC-DC converter is validated by experimental results.**

Keywords— **DC-DC converter, DSP, Simultaneous control.**

I. INTRODUCTION

Even though lots of research results to increase the efficiency, stability, and power density have been continued in the field of DC-DC converter control technique, most results are based on the analog control method such as the change or improvement of device, control circuit, and converter topology. But it is very difficult to design the high performance controller in the analog control method that requires the complex mathematical modeling for the nonlinear system [1]-[3].

Lately, with the trend of digitalization that is appeared in the whole fields of industry, the research in digital control of DC-DC converter has been increased. Digital controller using a microprocessor can monitor and control the internal parameters of converter from the remote, can change the operating condition without making the change of hardware, and can achieve simply the high performance for even nonlinear system. Especially, because fuzzy control algorithm applies the human linguistic concepts to the system control, it is possible to achieve the high performance real time controller without any complex mathematical modeling. But, despite of lots of merits, digital controller has not been applied widely due to the complex and expensive control circuit. So, the need of simple and inexpensive digital controller has been increased highly [4]-[6].

As an alternative proposal to supplement the demerits of digital controller, this paper presents the simultaneous control system that controls, simultaneously and independently, the separate Buck converter and Boost converter with the different specification by one DSP digital controller. As two separate converters are regulated by only one DSP, it is possible to achieve the simple digital control circuit for regulating the multi output DC-DC converter. PI and fuzzy control algorithm are applied in this control system. The control characteristic of PI and fuzzy control algorithm for each DC-DC converter is validated by experimental results.

Buck converter is designed to operate with the switching frequency 10kHz, the output voltage 5V, the input voltage 15V, and the output current 1A. Boost converter has the switching frequency 10kHz, the output voltage 24V, the input voltage 15V, and the output current 1A. Also, TMS320C32 of Texas Instruments is applied as a controller [7].

II. SIMULTANEOUS CONTROL ALGORITHM

The simultaneous control is to control simultaneously the two separate systems in one hardware. Two systems are controlled by the separate control algorithm, which is selected by the software switch. Here, the control algorithm can be the different or the same algorithm due to the setting state of switch. Fig. 1 shows the block diagram of the simultaneous control.

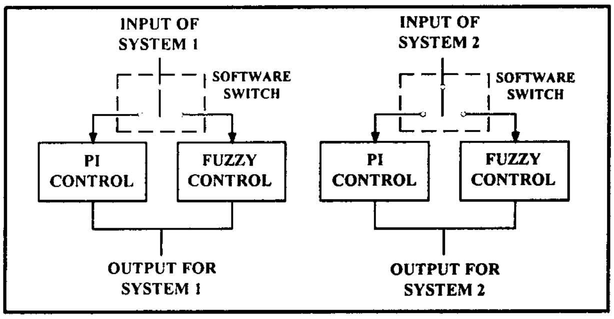

Fig. 1. Block diagram of the simultaneous control

To confirm the control characteristics of the simultaneous control, DC-DC converter is selected as an application system. Also, PI and fuzzy algorithm are selected as the control algorithm.

A. PI control of DC-DC converter

The proportional controller (P controller) gets the control value to compensate the error of output voltage by multiplying the proportional gain by the error between the reference voltage and the sampled output voltage. But, because the controller that has only P part can't compensate the steady state error, PI controller, which is composed of the proportional and the integral part, is generally applied. Fig. 2 shows a block diagram of PI controller.

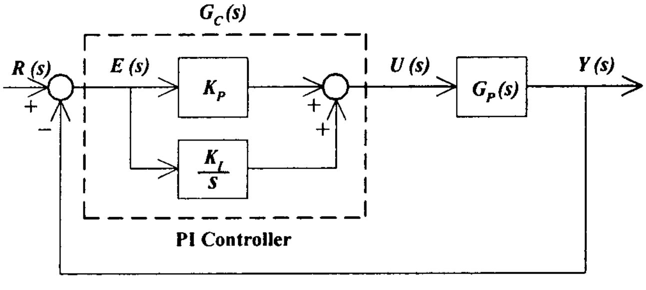

Fig. 2. Block diagram for PI controller

The transfer function of PI controller, $G_C(s)$, is consisted of the proportional gain K_P and the integral gain K_I. $G_C(s)$ is expressed such as (1). The error $E(s)$ is the difference between the output $Y(s)$ and the reference $R(s)$.

$$G_C(s) = K_P + \frac{K_I}{s} \qquad (1)$$

The output equation of PI controller to control DC-DC converter is in (2).

$$U(k) = K_I\left[\sum_{z=1}^{k-1} e(z) + e(k)\right] + K_P \cdot e(k) \qquad (2)$$

$e(k)$ means the difference between the reference voltage V_{ref} and the kth sampled output voltage $V_O(k)$. $\sum_{z=1}^{k-1} e(z)$ is the sum of error up to $(k-1)$th.

$$e(k) = V_{ref} - V_O(k) \qquad (3)$$

B. Fuzzy control of DC-DC converter

Fuzzy controller is composed of three parts : fuzzification, inference, defuzzification. Fuzzification is the procedure to transfer the fuzzy input data into the linguistic value or function. Inference is to determine the compensation value by using fuzzy control rule. Defuzzification is to transfer the compensation value into the output value for controlling the converter.

The inputs of fuzzy controller are defined as the error $e_1(k)$, $e_2(k)$, and the change of error $ce_1(k)$, $ce_2(k)$ of each converter. The input for buck converter is shown in (4).

$$\begin{aligned} e_1(k) &= V_{ref1} - V_{O1}(k) \\ ce_1(k) &= e_1(k) - e_1(k-1) \end{aligned} \qquad (4)$$

And, the input for boost converter is shown in (5).

$$\begin{aligned} e_2(k) &= V_{ref2} - V_{O2}(k) \\ ce_2(k) &= e_2(k) - e_2(k-1) \end{aligned} \qquad (5)$$

Here, subscripts 1 means the parameter for buck converter, subscripts 2 means the parameter for boost converter. k means the kth sampled value, $(k-1)$ means the $(k-1)$th sampled value. V_o is the output voltage of converter, V_{ref} is the reference voltage. The outputs of fuzzy controller are defined as the duty ratio of converter $D_1(k)$, $D_2(k)$, they are shown in (6),(7).

$$D_1(k) = D_1(k-1) + \eta_1 \cdot \delta d_1(k) \qquad (6)$$

$$D_2(k) = D_2(k-1) + \eta_2 \cdot \delta d_2(k) \qquad (7)$$

η is the gain of fuzzy controller, $\delta\ d(k)$ is the duty ratio compensation value which is determined by inference.

As the number of fuzzy function depends on the converter system, it should be optimally determined with considering the interrelation of control accuracy and calculation capacity. In this paper, fuzzy function is defined as the subsets that is made by combing 5 fuzzy rules such as PB(Positive Big), PS(Positive Small), ZO(Zero), NS(Negative Small), and NB(Negative Big). As two converters should be controlled simultaneously and independently by one DSP, it is necessary to consider the calculation processing time. And, because the output voltage variation shape by the variation of duty ratio of two converters is same, the same fuzzy rules table can be applied. So, it is possible to omit the subscripts of fuzzy inputs like e, ce. Table 1 shows the fuzzy rules table.

Table 1. Fuzzy rules table

e \ ce	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NB	NB
NS	ZO	NS	NS	NS	NS
ZO	PS	ZO	ZO	ZO	NS
PS	PS	PS	PS	PS	ZO
PB	PB	PB	PB	PB	PB

Also, to avoid the complex calculation process, the triangular shape such as Fig.3 is selected for fuzzy membership function.

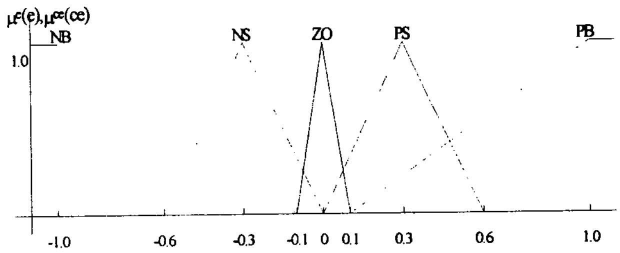

Fig. 3. Fuzzy membership function

As the maximum number of fuzzy membership function that includes the fuzzy inputs e, ce at any sampling moments is just two, the maximum number of fuzzy rule that should be considered at that sampling moments is four. For example, for $e=-0.4$ and $ce=0.05$, the membership functions of error e are NS and NB, the membership functions of error change ce are ZO and PS. Hence, the subsets of e, ce are (NB,ZO), (NB,PS), (NS,ZO), and (NS,PS). And, fuzzy rules for two inputs and four rules are expressed as (8).

R_1 : IF e is NB and ce is ZO, THEN $D(k)$ is NB.
R_2 : IF e is NB and ce is PS, THEN $D(k)$ is NB.
R_3 : IF e is NS and ce is ZO, THEN $D(k)$ is NS.
R_4 : IF e is NS and ce is PS, THEN $D(k)$ is NS. (8)

The fuzzy function value for each input are as follows, $\mu_{NS}(e)=0.67$, $\mu_{NB}(e)=0.33$, $\mu_{ZO}(ce)=0.5$, $\mu_{PS}(ce)=0.17$. Fig. 4 shows the procedure of fuzzy inference for $e=-0.4$ and $ce=0.05$.

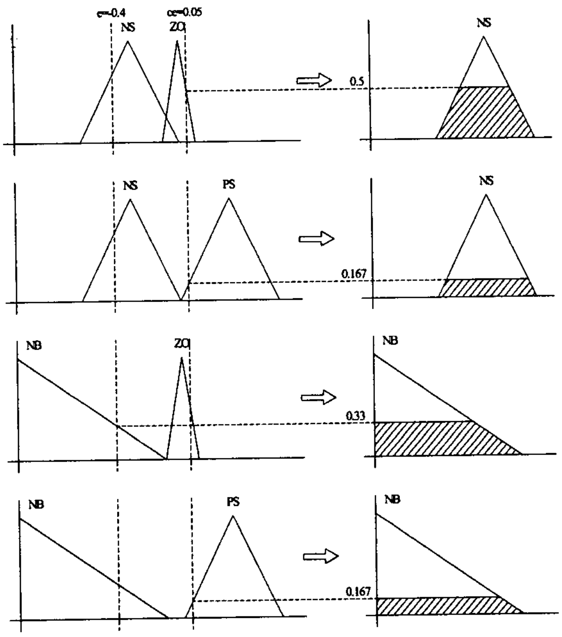

Fig. 4. Fuzzy inference procedure

Inference result is composed of the weighting factor w_i for each rule, and the degree of duty ratio change C_i. Inference result is given as (9) by Mamdani's min fuzzy implication.

$$z_i = \min\{\mu_e(e), \mu_{ce}(ce)\} \cdot C_i = w_i \cdot C_i \qquad (9)$$

z_i is the change of duty ratio inferred by the ith rule.
Because z_i of (9) is the linguistic result, it is necessary to transfer the result into the output of fuzzy controller through the defuzzification procedure. The defuzzification result can be written as (10) by using the gravity center method.

$$\delta d(k) = \frac{\sum_{i=1}^{N} z_i}{\sum_{i=1}^{N} w_i} = \frac{\sum_{i=1}^{N} w_i \cdot C_i}{\sum_{i=1}^{N} w_i} \qquad (10)$$

$\delta\, d(k) = -0.599$ from $e=-0.4$, $ce=0.05$, and $N=4$. The final compensation value of duty ratio is -0.599η that is multiplied by the gain of fuzzy controller η. Hence, duty ratio is as (11) for $e=-0.4$, $ce=0.05$.

$$D(k)=D(k-1)+(-0.599)\cdot\eta \qquad (11)$$

Fig. 5 describes the result of fuzzy inference by gravity center method.

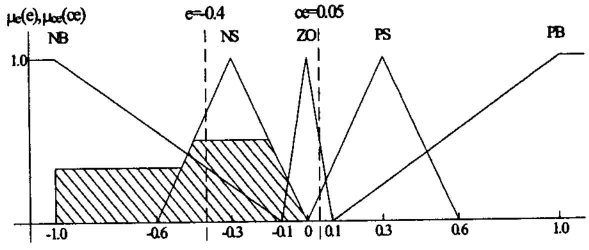

Fig. 5. Fuzzy inference by gravity center method

III. Simultaneous Control of DC-DC Converter

Fig. 6 shows a block diagram for the simultaneous control of buck and boost PWM DC-DC converter by a digital controller.

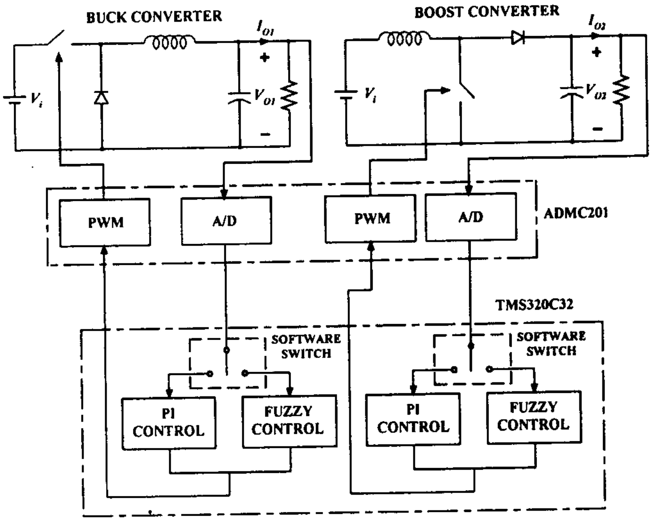

Fig. 6. Block diagram for the simultaneous control of buck and boost PWM DC-DC converter

V_i is the input voltage, V_{O1} is the output voltage, and I_{O1} is the output current for buck converter. V_{O2} and I_{O2} are the parameters for boost converter.
The input variable of controller is the sampling output voltage that is sampled by A/D converter at any moments. Controller decides independently and simultaneously the compensation value of duty ratio for each PWM converter by comparing the difference between the reference voltage and the sampled output voltage, and by applying the control algorithm of each converter. Because the control algorithm for each converter is chosen between the two algorithms of PI and Fuzzy by the separate software switch, it is possible to apply the same or the different control algorithm at the same time. The decided compensation values are sent out to the PWM generation part.

IV. Experimental Result

The specification of two converters, which are designed to confirm the control characteristics of simultaneous controller, is in Table 2.

Table 2. Specification of buck converter and boost converter

	Buck	Boost
Input voltage (V)	15	15
Output voltage (V)	5	24
Output current (A)	1	1
Switching frequency (kHz)	10	10
Fuzzy gain η	0.0003	0.0001
Main switch	TIP122	IRF540
Filter inductance (μH)	1670	879
Filter capacitance (μF)	2200	2200

Fig. 7-10 show the load current and the output voltage of each converter, when the load current is periodically changed 0.2A to 1A with the interval of 500ms. The controller of each converter is chosen between PI and fuzzy by setting the software switch. The comparison of control characteristics for PI and fuzzy controller is in Table 3.

Table 3. The control characteristics comparison for PI and fuzzy controller

		Rising load		Falling load	
		Time (ms)	Overshoot (mV)	Time (ms)	Overshoot (mV)
Buck	PI	100	300	200	300
	Fuzzy	40	150	60	150
Boost	PI	80	500	160	500
	Fuzzy	80	300	50	230

Table 3 shows that fuzzy controller has the better control characteristics than PI controller for load regulation.
The setting state for each channel of oscilloscope in Fig.7-10 is as follows.

Ch 1 : the load current of buck converter
Ch 2 : the output voltage variation of buck converter
Ch 3 : the load current of boost converter
Ch 4 : the output voltage variation of boost converter

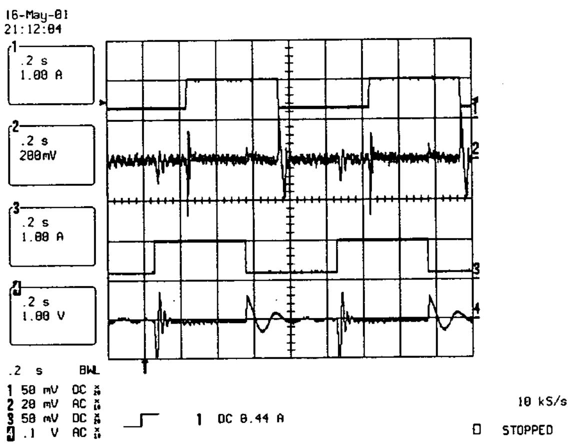

Fig. 7. Simultaneous control by PI(buck) and PI(boost)

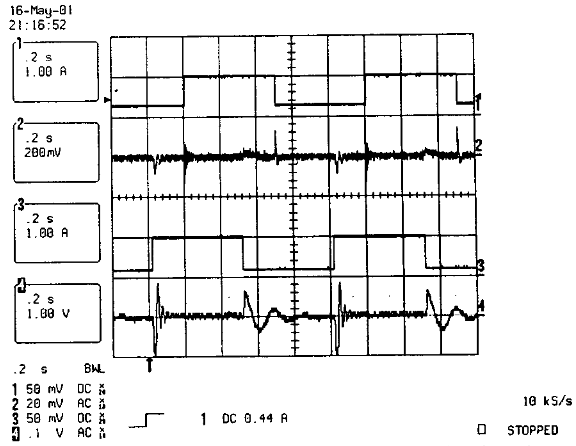

Fig. 8. Simultaneous control by fuzzy(buck) and PI(boost)

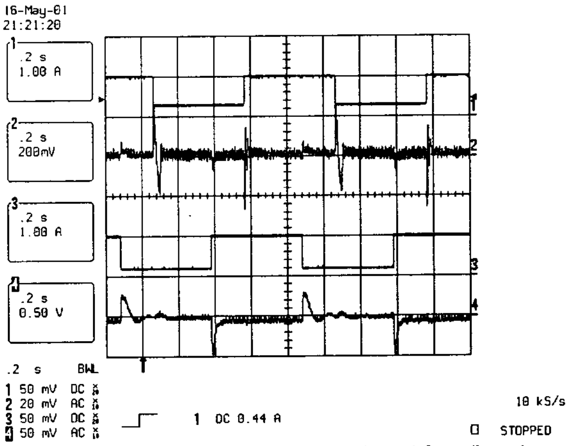

Fig. 9. Simultaneous control by PI(buck) and fuzzy(boost)

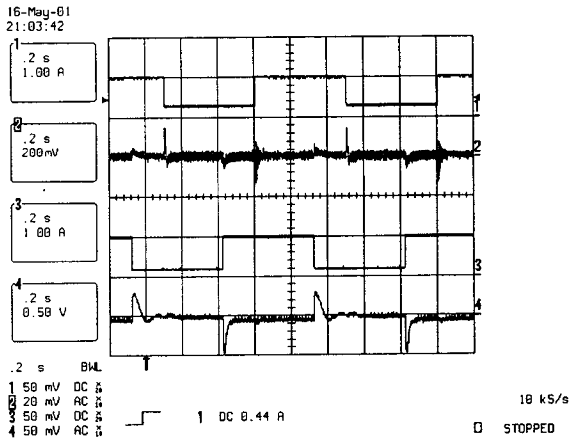

Fig. 10. Simultaneous control by fuzzy(buck) and fuzzy(boost)

V. CONCLUSION

As a substitute proposal for solving the problem of digital controller for DC-DC converter, this paper presents the simultaneous control system. It is a multi output DC-DC converter system that controls, simultaneously and independently, the two separate converters with the different specification by one digital controller. As two separate converters are regulated by only one DSP, it is possible to achieve the simple digital control circuit for regulating multi output DC-DC converter.

The presented system is validated by the experiment results. Specially, as the controller for each converter is selected by the separate software switch, regardless of the selected controller, each converter is controlled simultaneously and independently for all cases : ← buck-PI, boost-PI, ↑ buck-fuzzy, boost-PI, → buck-PI, boost-fuzzy, ↓ buck-fuzzy, boost-fuzzy.

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