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전류 모드 제어 방식을 이용하는 DC/DC 컨버터의 퍼지 논리 제어기 설계

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Controller Design of Current Mode Controlled DC/DC Converter using Fuzzy Logic Control

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Abstract : The current mode controlled DC/DC converter using fuzzy logic controller is proposed. With the poposed control method, the robust and safty guaranteed operation are achieved. For comparison with conventional controller, the PI controller is selected. By the computer simulation results, the validities of the proposed control method will be shown.

I. Introduction

In recent years there has been increasing interest in the development of efficient control strategies to improve dynamic behaviour of power converters. There are two approaches to control power converter, that are the voltage mode control and current mode control[1-3]. The voltage mode control uses only one contol loop to regulate the output voltage of power converter. But the current mode control uses two control loop. One is current control loop which control the current to be desired value. And the other is voltage control loop which control the output voltage. The conventional control methods which use PI controller implemented for the both methods are very sensitive to the variation of system parameters such as load condition[4]. So it is desirable to use other type of robust controller.

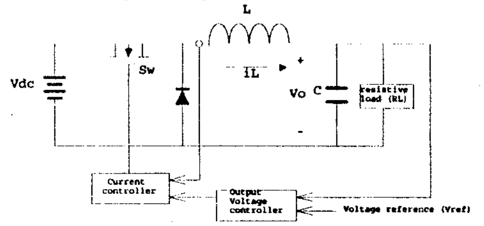
To obtain the robust control performance for power converter, the fuzzy control method has been studied in recent years with the advent of high speed microprocessor. The fuzzy logic controller implemented in the voltage mode control and the current mode control is reported[4-5]. In this case, the performance of transient response has been greatly improved. But the steady state response is not satisfied.

So, to obtain the satisfactory transient response and steady state response while guaranteeing the safe operation for the power converter system, the fuzzy logic controller with reference model is proposed. To obtain the safe operation of the power converter system, the internal current dynamics of the static power converter should be bounded as the ratings of devices used. The reference model will be used to give a well-defined dynamics to the power converter. So this can restrict the largest value of internal current. And the fuzzy controller will be used to obtain the desired tracking response even in the presence of load variations.

II. Modeling of the power converter

There are some kind of power converter, such as buck, boost, buck-boost converter. Among them, the buck converter is concerned in this paper. Fig. 1 shows the buck converter system with inner current controller and outer voltage controller.

The actual output voltage is compared to reference voltage V_{ref} to produce the current command which is used to control the inner current of the converter system. Here the fuzzy logic controller with reference model is located in the output voltage controller.

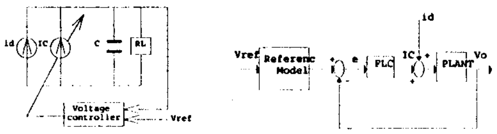


(Fig. 1) Circuit diagram of Buck converter

The state equation of buck converter can be written as follows:

$$\begin{pmatrix}\dot{i}_L\\ \dot{v}_o\end{pmatrix}=\begin{pmatrix}0 & -\dfrac{1}{L}\\ 1/C & -\dfrac{1}{C\cdot R_L}\end{pmatrix}\begin{pmatrix}i_L\\ v_o\end{pmatrix}+\begin{pmatrix}\dfrac{S}{L}\\ 0\end{pmatrix}V_{dc} \qquad (2\text{-}1)$$

where, S is the state of switch, Sw which is 1 for on state and 0 for off state. By the concept of current mode control which control the inductor current to be the desired value, the buck converter system can be considered as simply first order system with disturbance which comes from the difference between the real current and the current command, IC. Fig. 2 shows the simplified circuit diagram and system block diagram of current mode controlled buck converter.



(a) Circuit diagram (b) Block diagram

(Fig. 2) circuit diagram and system block diagram of current mode controlled buck converter.

The disturbance term depends on the condition of the inductor current, current command and the value of inductor. Here, the transfer function of plant is given as follows:

$$P(s) = \frac{R_L}{(C \cdot R_L)s + 1} \qquad (2\text{-}2)$$

III. Reference Model

To guarantee the safe operation and fast transient response of system, it is necessary to give a desired response to the system. This can be accomplished by the reference model. The reference model will give the system desired output reference response for desired voltage level. By the properly defined model, the maximum internal inductor current can be restriced as below the maximum device rating. The reference model is selected as follows:

$$T_d(s) = \frac{1.25s + 750}{0.0013s^2 + 2.25s + 750} \qquad (3\text{-}1)$$

IV. Design of Fuzzy Logic Controller

A fuzzy logic controller basically comprises four principle components, i.e., a fuzzification interface. a knowledge base, a decision-making logic and a defuzzification interface. The design of the fuzzy controller used in this paper is briefly described as follows.

4.1 Fuzzification

The control variable is the output voltage, V_O. In the proposed fuzzy logic controller, the system variables are defined as the output voltage model following error (the error between the output voltage of the plant and the output of the reference model) and error change $\Delta e(k)$:

$$e(k) = v_m(k) - v_o(k)$$
$$\Delta e(k) = e(k) - e(k-1) \qquad (4\text{-}1)$$

The error and error change are all quantized into corresponding universe of discourse. In Table I, the quantization of error and error change is given. Having made the quantization of the system variable, the quantized input data are then converted into suitable linguistic variables. The shape of the membership function used in this paper is the triangular-type.

4.2 Fuzzy Control Rules

The fuzzy control rules are developed based on the expert experience and control engineering knowledge. From the behaviour of the plant, the control rule is constructed. In the Table 2, the control rules are listed. This table shows that if the error or error change is decreased, then the change of control input is decreased.

4.3 Inference method

If the knowledge is presented as follow, the fuzzy relation can be obtain.

R_1 : IF E_1 AND CE_1 THEN U_1
•
•
R_n : IF E_n AND CE_n THEN U_n

$$R = R_1 \cup R_2 \cup \cdot \cup R_N = \sum_{i=1}^{N} (E_i \times CE_i \times U_i) \qquad (4\text{-}2)$$

By the eq. (4-2), the fuzzy relation R has the membership function:

$$R(e_i, e_j, e_k) = \max_{1 \le i \le N} [E(e_i) \wedge CE(e_j) \wedge U(u_k)] \qquad (4\text{-}3)$$

For any input of controller, i.e., error(E) and error change(CE) that are obtained from the output of power converter, the fuzzy control rules are evaluated by the means of a compositional rule of inference:

$$U = (E \times CE) \bullet R \qquad (4\text{-}4)$$

Inserting the value of the membership function of E and CE as well as R on eq. (4-4), one can get:

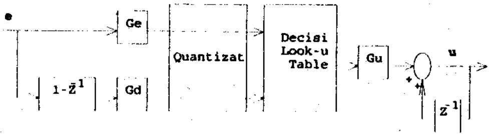
$$U = \bigvee_{\substack{e \in E \\ ce \in CE}} [E(e_i) \wedge CE(ce_j) \wedge U(e_i, ce_j, u_k)] \qquad (4\text{-}5)$$

4.4 Defuzzification

The defuzzification is a mapping from a space of fuzzy control actions defined over a output universe of discourse into a space of nonfuzzy control actions. There are many defuzzification methods. Among them, the center of gravity method is used in this paper.

4.5 The Structure of Fuzzy Logic Controller

In Fig. 3, the overall system block diagram of fuzzy logic controller is presented. The output voltage error and error change is used for the input of fuzzy logic controller.



(fig. 3) The Overall System Block Diagram of FLC

There are two gains associated with the inputs, that is, G_e for error and G_d for error change. This gains will affect the sensitivity of the error and error change. The gain G_u is selected as high at transient period and as low at steady state. So, $G_u(x)$= Kx^2.

V. Simulation

The parameters used in computer simulation is listed in below:

Vdc	Vref	C	L	Sampling Freq.	Switching Freq.	Max. Power
50V	20V	500uF	100uH	10KHz	100KHz	160W

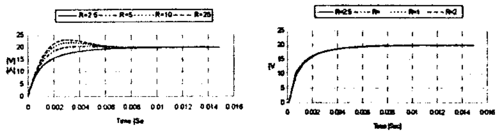
Fig. 4 shows the transient response for both controller, that are PI controller and fuzzy logic controller with reference model. This simulation has been carried out for the different load condition(R_L= 2.5, 5, 10, 25). In fig. 4(a), the transient response of output voltage for PI controlled system is presented and in Fig. 4(b) shows the response of output voltage for proposed algorithm. It shows that the response of PI controller with different load conditon is varying, but that of fuzzy logic controller with reference model is not affected by load conditions. In fig. 5(a), the system response employing the conventional PI controller is presented. The gains of conventional PI controller is designed not to hurt the devices used in the static power converter. For this case, the 50V and 15A ratings of switching devices can be used safely. In this case, the gains are Kp=0.5, Ki=300. But, the response of output voltage in sudden load change from full load to half load and vice versus is not satisfactory. Fig. 5(b) shows the output voltage response which is employing fuzzy logic controller with reference model. This shows that the inductor current can be restricted by the reference model which gives the system predefined dynamics. And the response is better than conventional PI controller. The results indicate that the output voltage response obtained by the proposed fuzzy logic controller with reference model are insensitive to the load variations. Fig. 6 shows the simulation results of voltage and current response for tuned gain to have the same transient response. The steady state responses reveal that the chattering problem for high constant gain G_u is severe. And Fig. 7 shows the simulation results for tuned gain to have the simillar steady state response. In this case, the transient response of the constant gain is poor.

VI. Conclusion

The output voltage control of current mode controlled DC/DC converter employing fuzzy logic control with reference model is presented in this paper. In order to guarantee the safe operation of the system, reference model is first selected properly. Then fuzzy logic controller, which is driven by the error between the reference error and the plant, is designed to compensate the error. The proposed algorihm is tested by the computer simulation. The simulated results have comfirmed the validity of the proposed controller.

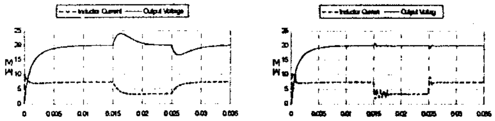
Table 1.
Quantization Error and Error Change

Error e (mV)	Error change Δe(k) (mV)	Quantized level
~ -1000	~ -1000	-6
-1000 ~ -500	-1000 ~ -500	-5
-500 ~ -200	-500 ~ -200	-4
-200 ~ -100	-200 ~ -100	-3
-100 ~ -50	-100 ~ -50	-2
-50 ~ -20	-50 ~ -20	-1
-20 ~ 20	-20 ~ 20	0
20 ~ 50	20 ~ 50	1
50 ~ 100	50 ~ 100	2
100 ~ 200	100 ~ 200	3
200 ~ 500	200 ~ 500	4
500 ~ 1000	500 ~ 1000	5
1000 ~	1000 ~	6



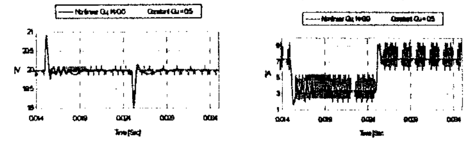
a) PI controller b) FLC

(Fig. 4) The transient response



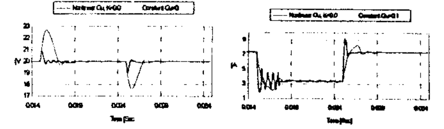
a) PI Controller b) FLC

(fig. 5) Responses of step load change



a) Voltage Response b) Current Response

(fig. 6) Response for different gain G_u :
for nonlinear gain(K=0.03) and constant gain(G_u=0.5)



a) Voltage Response b) Current Response

(fig. 7) Response for different gain G_u :
for nonlinear gain(K=0.03) and constant gain(G_u=0.1)

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Table 2.
The Linguistic Rule Table

e Δe(k)	NB	NM	NS	NE	PS	PM	PB
NB	NB	NB	NM	NM	NS	NS	ZE
NM	NB	NM	NM	NS	NS	ZE	PS
NS	NM	NM	NS	NS	ZE	PS	PS
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NS	NS	ZE	PS	PS	PM	PM
PM	NS	ZE	PS	PS	PM	PM	PB
PB	ZE	PS	PS	PM	PM	PB	PB