A Study of Control Method of SRM for Variable Speed Control

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ABSTRACT – *In this paper, the fuzzy control logic of Switched Reluctance Motor(SRM) is introduced to apply the variable speed drive system. Since the speed-torque property of SRM has high speed variation to the changes of torque like a DC motor, to apply SRM to the variable speed driving system, the optimal speed-torque control method is required.*

As the control method like this, the fuzzy logic and PI control are proposed, and characteristics of them are compared and verified through the experimental results.

1. Introduction

As a variable speed drive, the Switched Reluctance Motor(SRM) has many attractive features by the fast development of the power switching devices and digital controllers. And also, SRM has been used in many industrial applications because it has inherent speed controllability and ability to produce full torque at wide range of operating speed.

SRM has similar characteristics to a DC motor, its speed variation rate is high to the changes of torque. Therefore, an optimal control method is needed for covering this weakness.

As a control technique, the conventional PI control, which has the advantage like simplicity and stability, has been applied in many application. But the PI controller is very difficult to obtain robust characteristic for parameter variation and disturbance[5].

To solve this problem, the fuzzy logic controller used in addition to the conventional PI controller result in the speed response characteristic is improved. The fuzzy logic controller can operate only using a experience data even though not having mathematical modeling. And if the lookup table is used appropriately, it can also possible the real time control.

This paper presents a fuzzy control for variable speed control of SRM. In second section, a modeling of SRM is introduced. And in third section, the fuzzy controller is designed. Finally, the characteristics of speed response using fuzzy logic control and conventional PI control are experimented and compared.

The results of experiment show that the characteristics of speed response of fuzzy logic controller are better than its of conventional PI controller.

2. SRM Modeling

Basically an SRM is a doubly salient, singly excited motor with one or more phase excited at a time. The torque production mechanism in SRM is based on reluctance principal as against the electromagnetic torque in other motors. Because of the double saliency, the stator and rotor poles tend to align together to offer minimum reluctance path for the main flux produced by the excited stator phase. Thus, by sequentially exciting the stator phases, a unidirectional torque can be generated and hence electromechanical energy conversion can be performed.

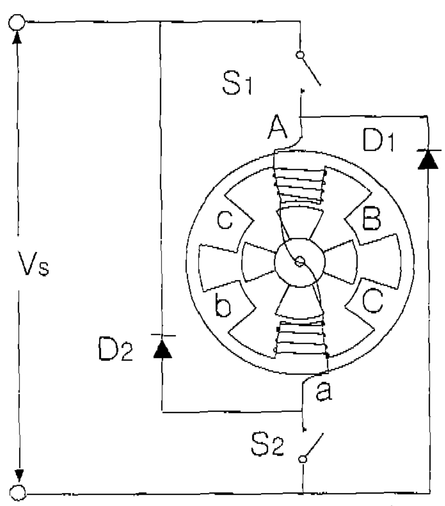

Fig.1. Schematic diagram for on phase of 6/4 SRM drive

Fig.1 shows the structure of SRM with 6/4 machine where 6 designates the number of stator poles and 4 designates the number of rotor poles. In fig. 1. if the switch S_1 turn on when the rotor is stopped, the energy is supplied to the phase winding current through path of $S_1 \rightarrow A \rightarrow a \rightarrow S_2$ from DC source by the excited current. On the contrary, if the switch S_1 and S_2 turn off, the magnetic energy is translated from the phase winding to the source through diode when the motor is driving by the excited current of phase winding.

The equation of phase winding voltage when the voltage is injected to the winding is derived as follows

$$V_s = Ri(t) + \frac{d\lambda}{dt} = Ri(t) + \frac{[L(\theta)i(t)]}{dt} \quad (1)$$

where, the term $\frac{\partial \lambda}{\partial i}$ and $\frac{d\theta}{dt}$ represent as follows, respectively

$$\frac{\partial \lambda}{\partial i} = L(\theta), \quad \frac{d\theta}{dt} = \omega_m \quad (2)$$

$\frac{\partial \lambda}{\partial i} = L(\theta)$ represents the incremental inductance variation of the winding, and $\frac{d\theta}{dt} = \omega_m$ represents the mechanical speed in radians per second.

In equation (1), the inductance of the phase winding is given by rotor angle according rotor position like inductance profile, therefore the equation (1) is expressed as the equation (2)

$$V_s = Ri(t) + L(\theta)\frac{di(t)}{dt} + i(t)\frac{dL(\theta)}{d\theta}\omega \quad (3)$$

where, the first term on the right hand side of equation (3) represents the ohmic voltage drop, the second term represents the transformer voltage, and the last term represents the rotational voltage.

Then, the transient energy to supply power to the motor can be rewritten as

$$V_s = Ri(t)^2 + i(t)^2\frac{dL(\theta)}{d\theta}\omega + L(\theta)i(t)\frac{di(t)}{dt} \quad (4)$$

$$= Ri(t)^2 + \frac{d}{dt}[\frac{1}{2}L(\theta)i(t)^2] + \frac{1}{2}i(t)^2\frac{dL(\theta)}{d\theta}\omega \quad (5)$$

As shown in the equation (5), some of input energy is accumulated as magnetic energy, and rest of that is changed as mechanical energy

A single pulse mode drive method by variable voltage source is used to follow each torque and reference speed and to flow the constant current at the steady state

3. Fuzzy Logic Controller Design

In order to establish the fuzzy logic controller, firstly. variables of the input and the output for the controller must be clearly defined. Even though the fuzzy have controller several observed values as inputs, we just only use two observed values in this study.

These input variables are the speed error, e, and the change in speed error, e'_r. At a sampling point, m, e and e'_r are expressed as follows:

$$e(s) = \omega_{Command}(s) - \omega_{real}(s) \quad (6)$$

$$ce(s) = e(s) - e(s-1) \quad (7)$$

where $\omega_{Command}$ and ω_{real} are the speed command and the actual speed of the SRM.

The limit value of the membership function is used to simple and fast the calculation for fuzzy set as shown the table 1.

Table 1. Quantization for Coarse Control

e	ce	Quantized Level
-300	-30	-6
-250	-25	-5
-200	-20	-4
-150	-15	-3
-100	-10	-2
-50	-5	-1
0	0	0
50	5	1
100	10	2
150	15	3
200	20	4
250	25	5
300	30	6

The input variables should be fuzzification as fuzzy linguistic expression to fuzzy control. In this paper, fuzzy linguistic parameter is expressed by 7 level as follows

NB : Negative Big　　PB : Positive Big
NM : Negative medium　　PM : Positive medium
NS : Negative small　　PS : Positive small
ZE : Zero

Fig.2. Membership function

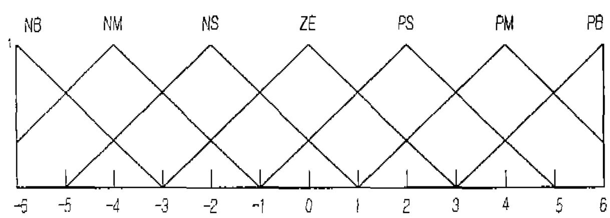

Fig.2 shows membership function values for quantized input parameters.

The next, the fuzzy reasoning is carried. This is the inference process of the output for the fuzzy input using the fuzzy control rule of Table. 2

In this paper, the min-max method, which is proposed by Mandani, is used. That is, it is composed as a set which made the max value of output by each control rule for a input variable.

Table 2. Rule Base

ce \ e	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

If Min-Max Methods express as a symbol, the i-th control rule is as follows

$$R_i : \textit{If } e \textit{ is } A_{ie} \textit{ and } ce\ A_{ice} \textit{ then } u \textit{ is } C_i \qquad (7)$$

A fuzzy relations is expressed as

$R_i = (A_{ie} \times A_{ice}) \times C_i$.

Then, total control rule is

$$R = R_1 \cup R_2 \cdots \cup R_n = \bigcup_{i=1}^{n} R_i \qquad (8)$$

In here, if the input parameter is A_1^0 , A_2^0 , the result of inference, C can be described as

$$C' = R \bullet (\ A_1^0 \times A_2^0\ ) \qquad (9)$$

The right term of Eq. (9) can be rewritten as

$$\max_{ce}[\max_e(\mu_R(e,ce,u),\ \mu_{A1}(e)) \wedge \mu_{A2}(ce)]$$
$$= \max_e \max_{ce}[\mu_R(e,ce,u) \wedge \mu_{A1}(e)) \wedge \mu_{A2}(ce)$$

Thus, the result, C is represented by

$$C' = R \bullet (\ A_1^0 \times A_2^0\ )$$
$$= \max_{e,ce}[R(e,ce,u) \wedge A_1^0(e) \wedge A_2^0(ce)] \qquad (10)$$

Finally, the membership function of the fuzzy output which is obtained by the inference, was transferred to real input values by defuzzification.

In defuzzification, there obtain the reference value which is compared to the saw waveform using a center of gravity method be a average of probability

This can be described as

$$\Delta u_i = \frac{\sum_{i=1}^{l} u_i m_i(u_i)}{\sum_{i=1}^{l} m_k(u_i)} \qquad (11)$$

4. Experimentation Results

The SRM considered in the paper is 6/4 pole motor, the maximum inductance is 68[mH] in 1A, the minumum inductance is 8[mH] in 1A, and the resistor value of per phase is 1.055[Ω].

Fig. 3 is the block diagram of the experiment setup. The controller was implemented using TMS320C40 DSP to real time control and the resolver with 360 resolution was used to check the rotor position . And also, the processed data was read through the digital input.

In fuzzy control, if the error of speed below 50, the system has the fine control with a detailed variation

The fine control is applied the control rule like the coarse control and just only the reference compared with the saw waveform is obtained by the decreasing the rated value of variation

Fig. 4 shows the speed response by using PI controller under the condition that command speed is 800rpm. And fig. 5 shows the speed response by using fuzzy controller under same condition.

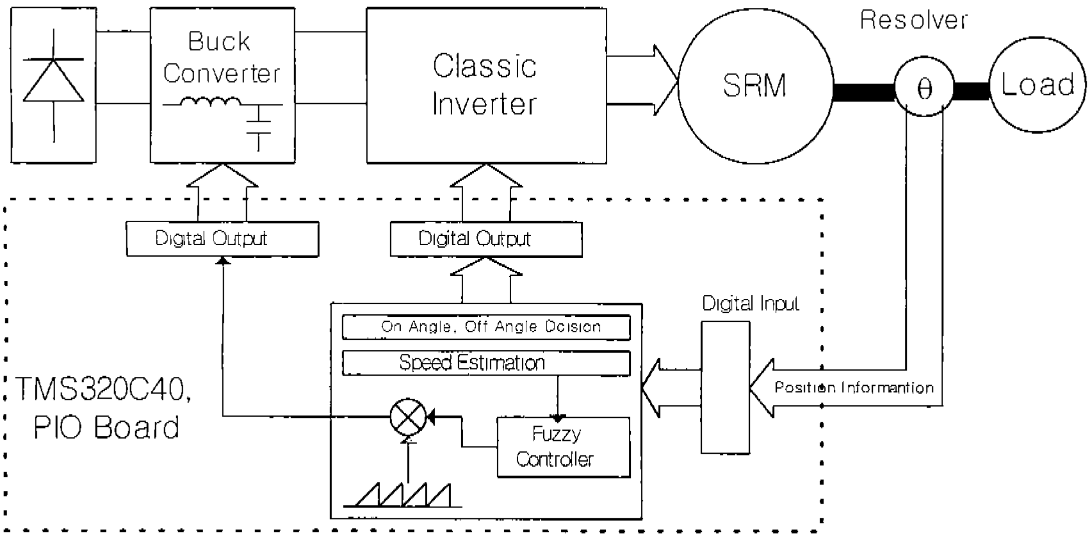

Fig. 3. Experimental Setup

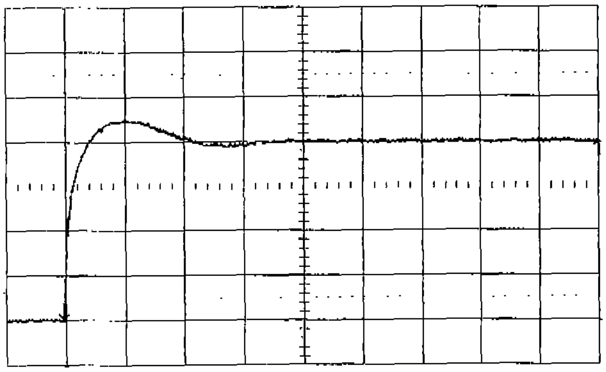

Fig. 4 Speed response of pi speed controller
(0.5 sec/div, 200 rpm/div)

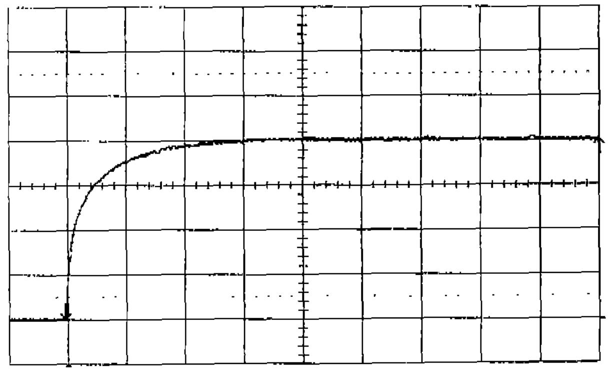

Fig. 5 Speed response of fuzzy speed controller
(0.5 sec/div, 200 rpm/div)

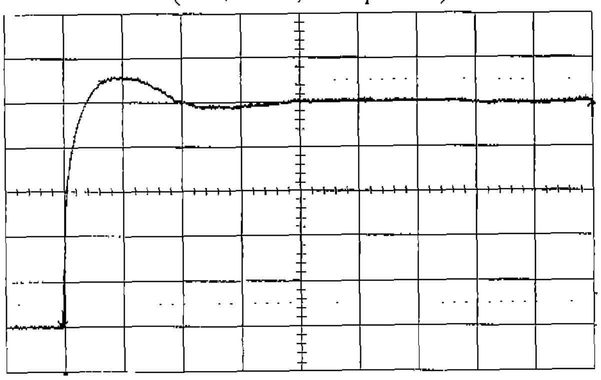

Fig. 6 Speed response of pi speed controller
(0.5 sec/div, 200 rpm/dev)

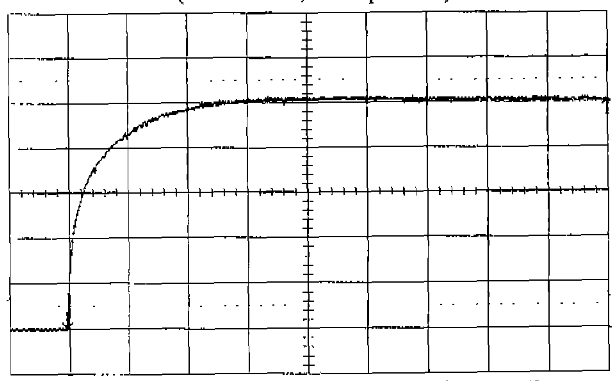

Fig. 7 Speed response of fuzzy speed controller
(0.5 sec/div, 200 rpm/div)

Fig. 6 shows the speed response by using PI controller under the condition that command speed is 1000rpm. And fig. 7 shows the speed response by using fuzzy controller under same condition.

All the experimentation is carried at no load case.

The experimental results are verified that the responses of fuzzy controller have a less overshoot and a shorter reaching time of the steady state than that of PI controller.

5. Conclusion

In this paper, a fuzzy logic control is proposed as a method for improving the performance of conventional PI controller.

The modeling of SRM is presented and the theory of fuzzy control is also introduced to establish the controller.

The speed response characteristics of the system are stabilized by using fuzzy controller properly.

The experimental results show that the speed property using the fuzzy controller is more robust than that using the conventional PI controller, and therefore the validity of this fuzzy controller is verified.

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