A Study on the Fuzzy Modifier of PI Control for Improvement of Tracking properties in Induction Motor System

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Abstract – Because of simple control algorithm and easy implementation, the conventional PI controller has been widely used in industrial application. But, it is very difficult to find the optimal PI control gain. Therefore, in improperly tuned PI controller or parameter variation, to obtain optimal performance, the novel PI controller, which consist of conventional PI controller and 4-rule based fuzzy logic, are presented in this paper. The novel PI controller which exhibits a stabilizing effects on the closed-loop system, has good robustness regarding the improperly tuned PI controller or parameter variation. The simulations are performed to verify the capability of proposed control method on induction motor.

1. Introduction

Recently, in the high performance speed control, squirrel-cage induction motors is widely utilized because of their low cost and rugged construction. However, because it is a nonlinear coupled multivariable system, it is difficult to control the induction motor. In the recent years, owing to the development of high performance microprocessors and the power semiconductor device and the novel control method, it is possible to operate variable speed of the induction motor[1-5].

Because of the simple control algorithm and easy implementation, the PI controller has been widely utilized in industrial applications for speed control of the induction motor. But, it is very difficult to find the optimal PI control gain. Specially in case of varying the parameter of the system, the complicated process which select again the PI control gain exists to maintain the optimal operating state. To overcome such a demerits, if the conventional PI controller add to the compensator for maintaining the optimal operating state, the novel made-up controller will be able to maintain the optimal operating state similar to the previous state of the system parameter variation without selecting the new PI control gain. In this paper, as the compensator, the fuzzy logic controller, which dose not need the mathematical model of a system and basically is strong in the parameter variation of a system and relatively is easy the implementation, is selected. The paper presents a proposal and some simulation results the novel PI controller which consists of the conventional PI controller and a 4-rule based fuzzy logic. The novel PI controller acts as an independent control unit which functionally combines proportional and derivative actions in a nonlinear fuzzy fashion. The novel PI controller exhibits a stabilizing effects on the closed-loop system, has very good robustness regarding the improperly tuned PI controller or parameter variation, and ensures better transient characteristic[6,7].

2. Fuzzy Logic Modifier(FLM) and novel PI controller

If a PI controller be properly tuned, the overall control performance will be improved and a considerable reduction in the overshoot will result, the speed of system response will be retained or improved. This will be the case even when the comparison is made with the optimally tuned linear PI controller. This problem is solved in the paper by a suitable design of a FLM that can be added in parallel to the already implemented PI controller.

It is very simple as it utilizes only 4 fuzzy rules and has only one parameter for tuning. The internal function of the novel PI controller imitates the behavior of a driver who has to maintain the constant speed of a induction motor that has ascending and descending sections. The obtained control law improves tracking properties of the closed-loop system even when compared to the optimally tuned PI controller.

Let r and y denote the induction motor reference speed and control output signals, respectively. The operation of the FLM is given by

$$u_{fuzzy} = K_f F_{fuzzy}(e, De) \qquad (1)$$

where e is the error signal $(e = r - y)$, and

$D = d/dt$ is the derivative operator. The function represents the crisp value obtained as a result of the operation of the fuzzy logic consisting of (input normalization) + (fuzzification) + (fuzzy rule inference) - (defuzzification) + (denomalization). The gain K_f is the only tuning parameter of the fuzzy logic. The fuzzy logic has two crisp inputs, e and De associated with the input universe of discourse. The input crisp values from the operating range are first normalized to the range [-1, 1]. The normalized values e_n and De_n are further subject to the fuzzification phase. In this phase crisp values of each of e_n and De_n map into the fuzzy sets positive(P) and negative(N) which both have the supporting set equal to [-1, 1]. The membership functions of the fuzzy set P and N are μ_P and μ_N, respectively., and are given in Fig. 1, Fig. 2.

They are defined in the normalized domain by

$$\mu_P(x) = \{1 + \exp(-10x)\}^{-1} \qquad (2)$$

$$\mu_N(x) = \{1 + \exp(10x)\}^{-1} \qquad (3)$$

where x may be e_n and De_n. There are four fuzzy rules represented by the table.

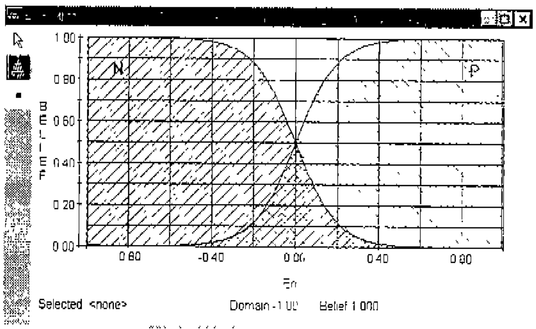

Fig 1. Membership function of e

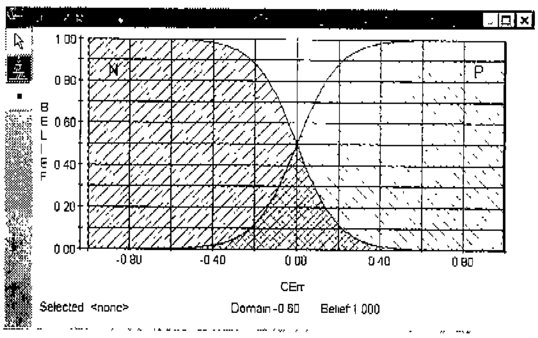

Fig 2. Membership function of De

Table 1. Rule base of fuzzy control

De \ E	N	P
N	NB	P
P	N	PB

where NB and PB denote negative-big and positive-big, respectively. Note that we did not use any fuzzy set to distinguish the value of zero. The interpretation of the result of rule firing is determined by the fuzzy set NB, PB, N, P and their respective membership functions μ_{NB}, μ_{PB}, μ_N and μ_P, shown in Fig 3.

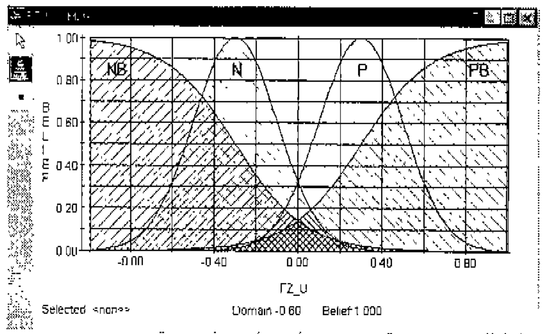

Fig 3. Membership function of F_{fuzzy}

These membership functions are defined for the normalized domain [-1, 1] as follows.

$$\mu_P(x) = \exp[-12.5(x - 0.3)^2] \qquad (4)$$

$$\mu_N(x) = \exp[-12.5(x + 0.3)^2] \qquad (5)$$

$$\mu_{PB}(x) = \{1 + \exp[-6(x - 0.3)]\}^{-1} \qquad (6)$$

$$\mu_{NB}(x) = \{1 + \exp[6(x + 0.3)]\}^{-1} \qquad (7)$$

where x has the meaning e_n and De_n. The FL operator AND and FL implication are determined by operation min, FL aggregation is determined by operation max, while the defuzzification uses the centroid method. The result of defuzzification is then denormalized, i.e. the values of the output variable are transformed to their physical range of values.

The control output for the novel PI controller which consist of the conventional PI controller and the FLM is determined by

$$u(t) = u_p(t) + u_i(t) + u_{fuzzy}(t)$$
$$= K_p e(t) + K_i \int e(t)dt \qquad (8)$$
$$+ K_f F_{fuzzy}(e, De)$$

3. Simulation

To control the speed of the induction motor, it is used the novel PI controller which consist of the conventional PI controller and the fuzzy logic.

Table 2 is the parameters of the induction motor using the simulation.

Fig. 4 is the speed control system of the induction motor, and as the switching method, it is used the space vector PWM method with excellent performance.

Table 2. Induction motor parameters

220[V], 2.2[kW], 4 pole

Rs = 0.687[Ω]	Rr = 0.842[Ω]
Ls = 0.08397[H]	Lr = 0.08528[H]
Lm = 0.08136[H]	J = 0.03[Kg•m^2]
Bm = 0.01[N•m/s]	

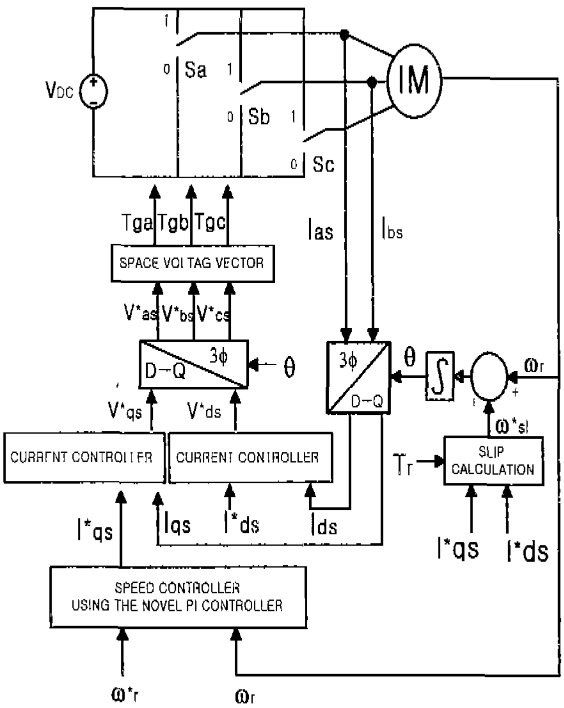

Fig 4. Speed control system of induction motor with the novel PI controller

The simulation of the total system was made using the C language in order to verify the novel PI controller which consists of the conventional PI controller and the 4-rule based fuzzy logic.

The speed sensing sampling time takes about 2[ms] and the current sensing sampling time takes about 100[μs]. The switching frequency is 5[kHz]. The once simulation time of the entire process including the indirect vector controller and the novel PI controller takes about 2[ms].

The performance of the system which has the novel PI controller, as the speed controller, is compared with that of the conventional PI controller with varying the PI control gain. And the both system are compared with regarding the parameter variation, namely the variation of the inertia moment.

The variation of speed reference is from -1000[rpm] to 1000[rpm] at 4 second. And the load with the capacity 1[kW] is applied at 2 second and 6 second.

Fig. 5 and Fig. 6 shows the conventional PI controller with the proper PI control gain and the novel PI controller the tracking performance of speed reference, and it is shown that the result is the similar control performance.

Fig. 7 and Fig. 8 shows the conventional PI controller with improper PI control gain compare with the novel PI controller. It is shown that the novel PI controller is better than the conventional PI controller regarding the tracking performance of speed reference.

Fig. 9 and Fig. 10 shows the simulation results of the conventional PI controller and the novel PI controller regarding the variation of the inertia moment. It is shown that the novel PI controller is better than the conventional PI controller.

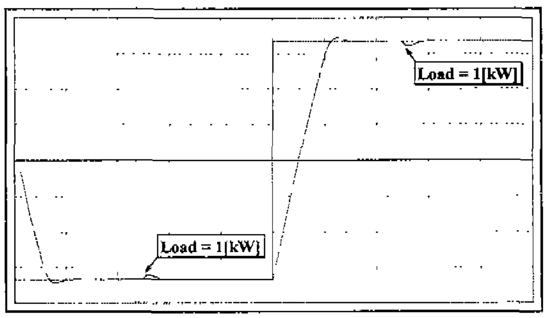

Fig 5. The speed response of conventional PI controller (Kp = 0.05, Ki = 0.5, J = 0.03)

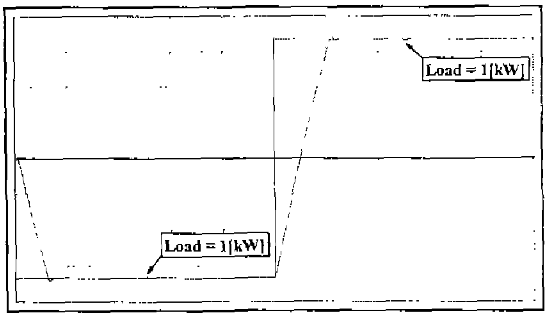

Fig 6. The speed response of novel PI controller
(Kp = 0.05, Ki = 0.5, J = 0.03)

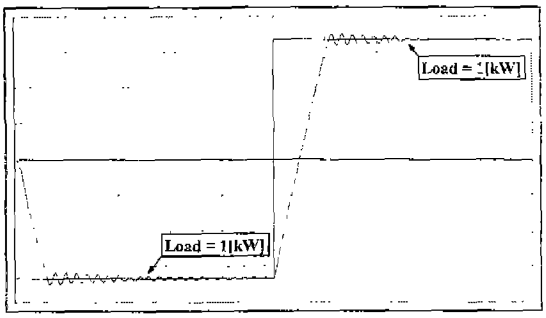

Fig 7. The speed response of conventional PI controller
(Kp = 0.005, Ki = 5.0, J = 0.03)

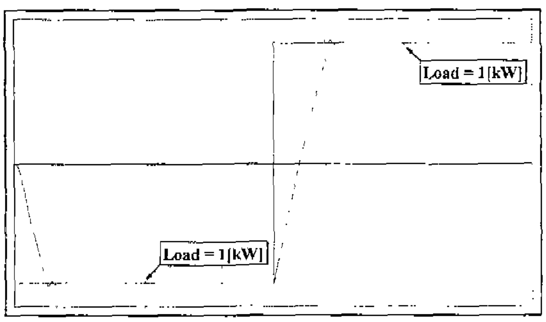

Fig 8. The speed response of novel PI controller
(Kp = 0.005, Ki = 5.0, J = 0.03)

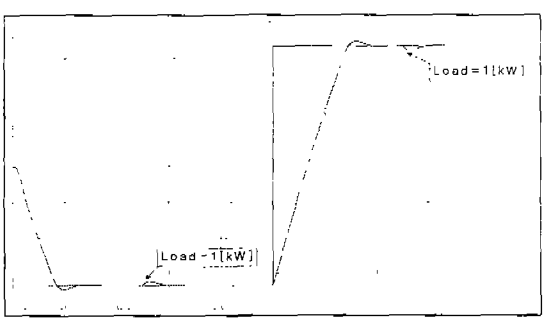

Fig 9. The speed response of conventional PI controller
(Kp = 0.05, Ki = 0.5, J = 0.04)

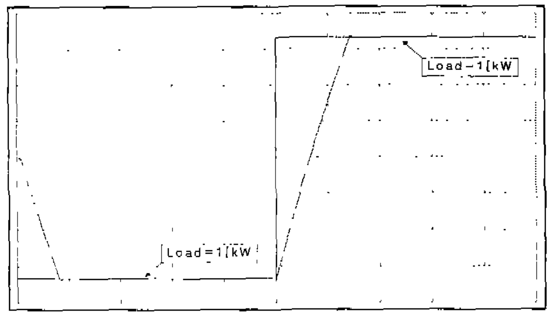

Fig 10. The speed response of novel PI controller
(Kp = 0.05, Ki = 0.5, J = 0.04)

4. Conclusion

In this paper, it is proposed the novel PI controller which consist of the conventional PI controller and the FLM with only 4 simple fuzzy rules. When this fuzzy logic is added in parallel to already the implemented PI controllers, the speed control performance of the induction motor improves considerably better than the conventional PI controller. The simulation results are shown that the novel PI controller is very robust for a wide range of improper tuning of the conventional PI controller and the variation of the inertia moment, and has strong stabilizing effects in a wide range of the speed reference.

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