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# Hybrid Controller based Intelligent Speed Control of Induction Motor

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## Abstract

This paper presents a hybrid system controller, incorporating fuzzy controller with vector-control method for induction motors. The vector-control method has been optimized by using fuzzy controller instead of a simple P-I controller. The presented hybrid controller combines the benefits of fuzzy logic controller and vector-control in a single system controller. High quality of the regulation process is achieved through utilization of the fuzzy logic controller, while stability of the system during transient processes and a wide range of operation are assured through application of the vector-control. The hybrid controller has been validated by applying it to a simulation model.

Keywords: Fuzzy logic, fuzzy controller, vector-control, speed control, induction motor

## I. INTRODUCTION

The traditional approach to building system controllers requires a prior model of the system. The quality of the model, that is, loss of precision from linearization and/or uncertainties in the system's parameters negatively influences the quality of the resulting control. At the same time, methods of soft computing such as fuzzy logic possess non-linear mapping capabilities, do not require an analytical model and can deal with uncertainties in the system's parameters. Although fuzzy logic deals with imprecise information, the information is processed in sound mathematical theory [1].

Based on the nature of fuzzy human thinking, Lofti Zadeh originated the "fuzzy logic" or "fuzzy set theory", in 1965. Fuzzy logic deals with the problems that have fuzziness or vagueness. In fuzzy set theory based on fuzzy logic a particular object has a degree of membership in a given set that may be anywhere in the range of 0 (completely not in the set) to 1 (completely in the set) [2]. For this reason fuzzy logic is often defined as multi-valued logic (0 to 1), compared to bi-valued Boolean logic [3].

The induction machine is an important class of electric machines which finds wide applicability as a motor in industry and in its single phase form in several domestic applications. More than 85% of industrial motors in use today are in fact induction motors [4]. It is substantially a constant speed motor with a shunt characteristic. Various methods have been developed for this purpose including direct torque control, vector control etc. But due to their peculiar limitations none of them has been found failure-proof. Here speed of induction motor is successfully controlled over wide range with appreciable accuracy using fuzzy logic controller in vector control method.

## II. CONTROL PRINCIPLE

The fuzzy controller in a vector-controlled drive system is used as presented in Fig. 1. The controller observes the pattern of the speed loop error signal and correspondingly updates the output DU so that the actual speed $w_r$ matches the command speed $w_r$*. There are two input signals to fuzzy controller, the error $E = w_r^* - w_r$ and the change in error, CE, which is related to the derivative dE/dt of error. In a discrete system, $dE/dt = \Delta E/\Delta r = CE/T_s$, where $CE = \Delta E$ in the sampling time $T_s$. with constant $T_s$, CE is proportional to dE/dt. The controller output DU in a vector controlled drive is $\Delta i_{qs}^*$ current. This signal is summed or integrated to generate the actual control signal U or current $i_{qs}^*$.

### A. *Fuzzy Controller as P-I Controller*

The fuzzy controller is basically an input/ output static non-linear mapping, the controller action can be written in the form

$$K_1E + K_2 CE = DU$$

Where $K_1$ and $K_2$ are non-linear coefficients or gain factors. Including the summation process above equation can be written as

$$\int DU = \int K_1 E dt + \int K_2 CE dt$$

or

$$u = K_1 \int E dt + K_2 E$$

which is a fuzzy P-I controller with non-linear gain factors.

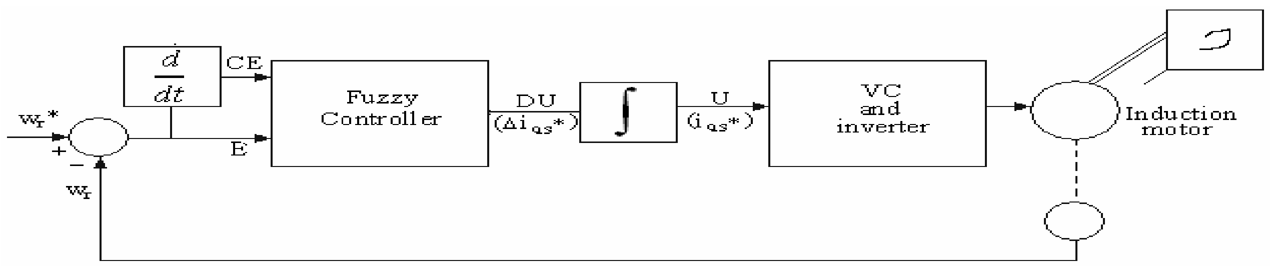
### *B. Fuzzy Set & Rule Formation*

From the physical operation principle of the system, a simple control rule can be written in fuzzy logic as:

IF E is near zero (ZE) AND CE is slightly positive (PS)

THEN the controller output DU is small negative (NS)

Fig.1. Block diagram of vector-control of induction motor using fuzzy controller



where E and CE are the input fuzzy variables, DU is the output fuzzy variable, and ZE, PS and NS are the corresponding fuzzy set membership functions (MFs). The implication of this fuzzy control can be done by triangular MFs. The fuzzy sets are defined as follows:

Z = Zero PS = Positive Small PM = Positive Medium
PB = Positive Big NS = Negative Small
NM = Negative Medium NB = Negative Big
PVS = Positive Very Small NVS = Negative Very Small

The universe of discourse of all the variables, covering the whole region, is expressed in per unit values. All the MFs are asymmetrical because near the origin (steady state), the signals require more precision. Seven MFs are chosen for *e(pu)* and *ce(pu)* signals and nine for output. All the MFs are symmetrical for positive and negative values of the variables. Thus, maximum 7x7 = 49 rules can be formed as tabulated in Table I. The graphical presentation of the rules is shown in Fig. 2, using a 3-d plot.

| e(pu)<br>ce (pu) | NB | NM | NS | Z | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NB | NB | NM | NS | NVS | Z |
| NM | NB | NB | NM | NS | NVS | Z | PVS |
| NS | NB | NM | NS | NVS | Z | PVS | PS |
| Z | NM | NS | NVS | Z | PVS | PS | PM |
| PS | NS | NVS | Z | PVS | PS | PM | PB |
| PM | NVS | Z | PVS | PS | PM | PB | PB |
| PB | Z | PVS | PS | PM | PB | PB | PB |

TABLE I

RULES FOR FUZZY CONTROLLER

## III. CIRCUIT DESCRIPTION

The induction motor is fed by a current-controlled PWM inverter which is built using a Universal Bridge block as presented in Fig. 3. The motor drives a mechanical load characterized by inertia J, friction coefficient B, and load torque $T_L$. The speed control loop uses a fuzzy logic controller instead of a simple proportional-integral controller to produce the quadrature-axis current reference iq* which controls the motor torque. The motor flux is controlled by the direct-axis current reference id*. Block DQ-ABC is used to convert id* and iq* into current references ia*, ib*, and ic* for the current regulator. Current and Voltage Measurement blocks provide signals for visualization purpose. Motor current, speed, and torque signals are available at the output of the 'Asynchronous Machine' block. The system (control and power system) has been discretized with a 2 us time step. In order to reduce the number of points stored in the scope memory, a decimation factor of 20 is used. Fig. 4 (a), (b) and (c) show the membership functions of e(pu), ce(pu) and du(pu) respectively.

*Fig.2.Graphical presentation of rules using surface rule viewer*

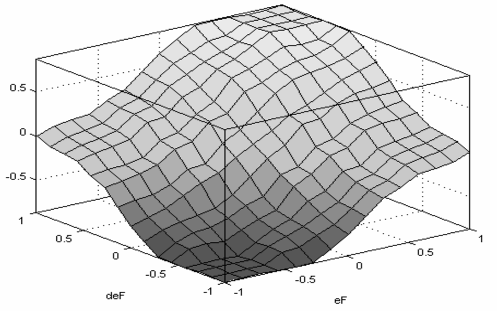
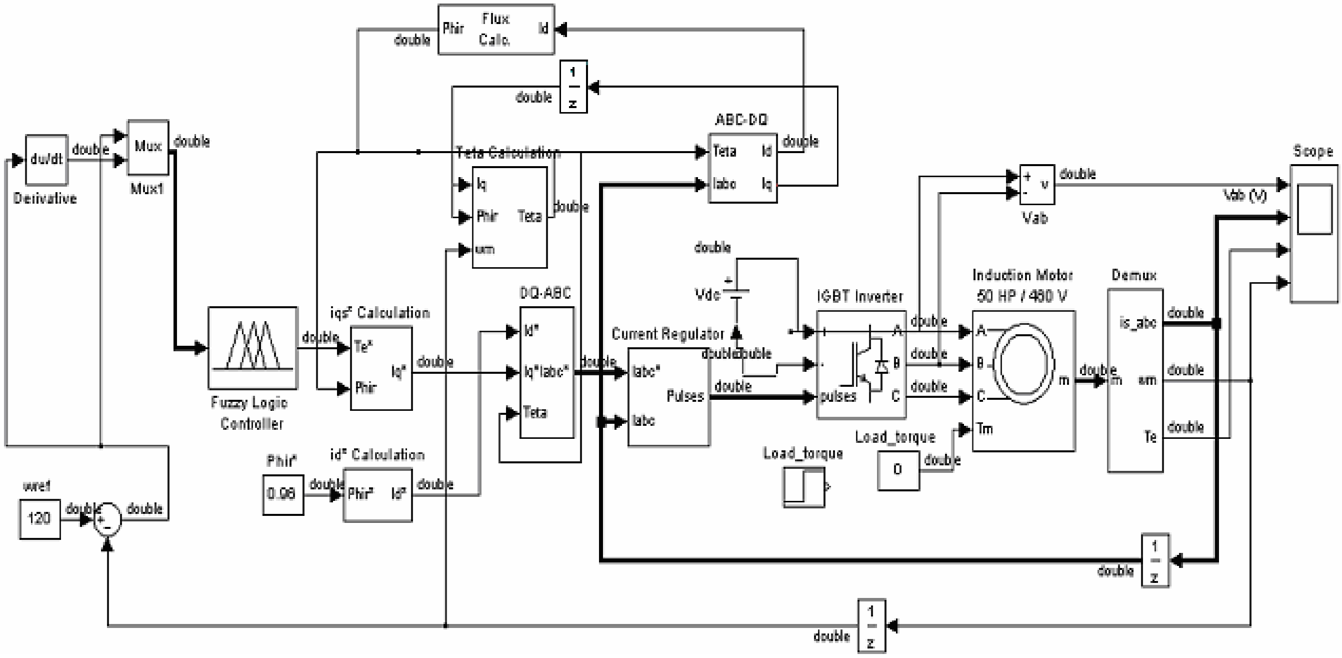


Fig.3. Circuit diagram for vector-control drive with fuzzy controller



## IV. SIMULATION RESULTS

Several tests were performed to evaluate the performance of the proposed FLC-based vector control of the IM drive system in MATLAB / SIMULINK. The speed-control loop of the drive was also designed, simulated with the PI controller in order to compare the performances to those obtained from the respective FLC-based drive system. The speed responses are observed under different operating conditions such as a sudden change in command speed, step change in load etc. some sample results are presented in following sections.

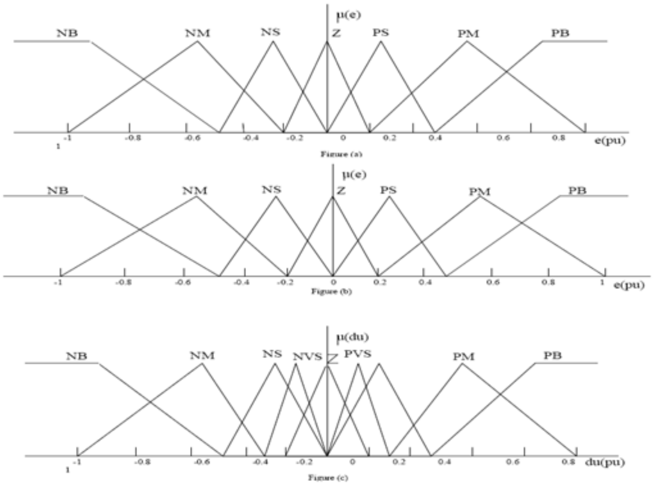


Fig.4. Membership functions of inputs and output

### A. Comparison of Fuzzy and PI controller during starting conditions

The PI controller is tuned at rated conditions in order to make a fair comparison. Fig. 5 and Fig. 6 show the simulated starting performance of the drive with PI- and FLC-based drive systems, respectively. Although the PI controller is tuned to give an optimum response at this rated condition, the fuzzy controller yielded better performances in terms of faster response time and lower starting current.

It is worth mentioning here that the performance obtained by the proposed model is 13 times faster than the P-I controller, i.e. it achieves the steady state 13 times faster than the P-I controller. Also it is 2.1 times faster than that obtained earlier by using fuzzy controller [7].

### B. Comparison of Fuzzy and P-I controller during step change in load torque

Fig.5. Speed, Torque, Iabc characteristics with P-I controller

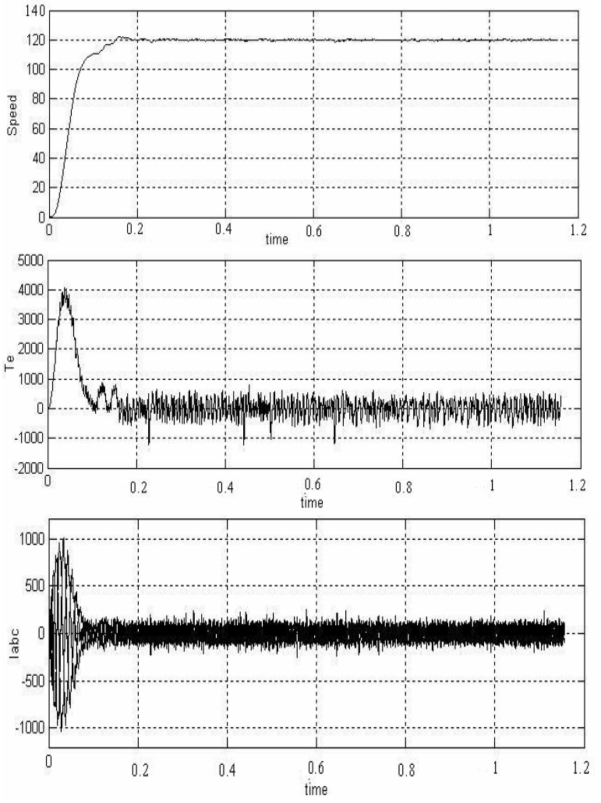


Fig.6. Speed, Torque, Iabc characteristics with Fuzzy-logic controller

Fig.7 & Fig.8 show the speed responses for step change in the load torque using the PI and fuzzy controller, respectively. The motor starts from standstill at load torque = 2 N.ms and, at t =0.3 s, a sudden full load of 200 Nms is applied to the system controlled by fuzzy controller but because the time taken by the P-I controlled system to achieve steady state is much higher than fuzzy controlled system, so the step change in load torque is applied at t = 1.25 sec.

The motor speed follows its reference with zero steady-state error and a fast response using a fuzzy controller. On the other hand, the PI controller shows steady-state error with a high starting current. It is to be noted that the speed response is affected by the load conditions. This is the drawback of a PI controller with varying operating conditions. It is to be noted that the fuzzy controller gives better responses in terms of over-shoot, steady-state error, and fast response.

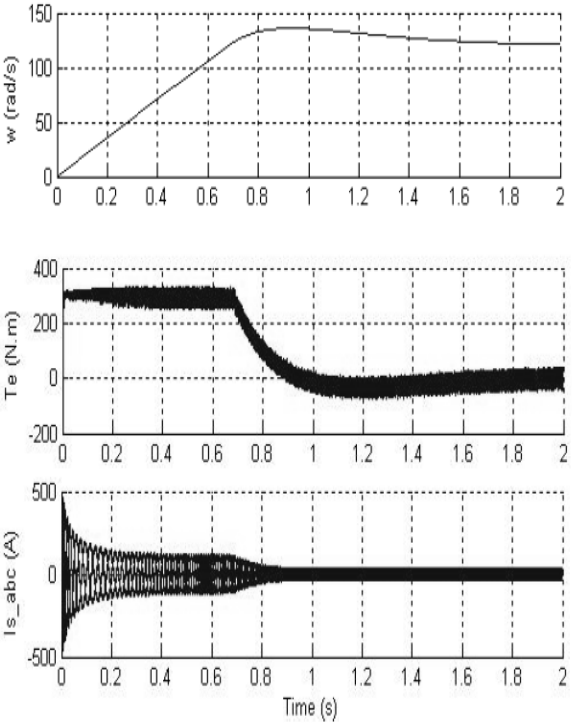
These figures also show that the FLC-based drive system can handle the sudden increase in command speed quickly without overshoot, under- shoot, and steady-state error, whereas the PI-controller-based drive system has steady-state error and the response is not as fast as compared to the FLC. Thus, the proposed FLC-based drive has been found superior to the conventional PI-controller-based system.

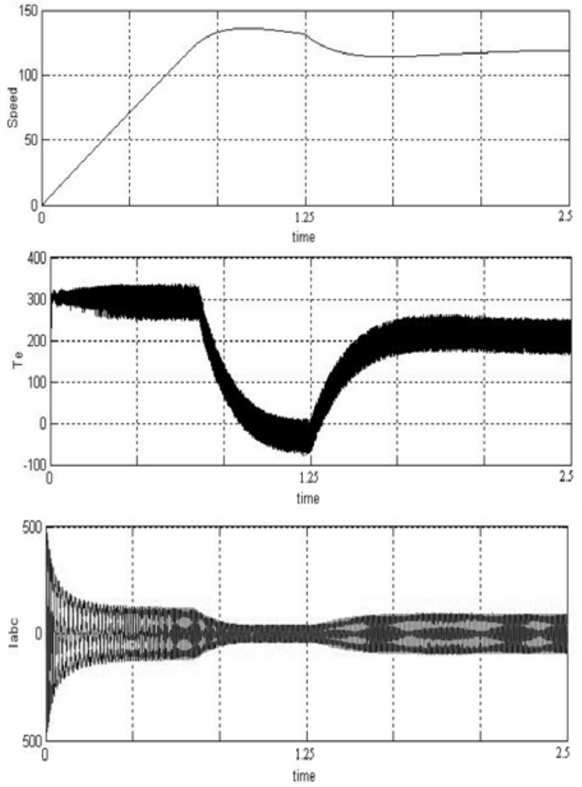
Fig.7. Speed, Torque, Iabc characteristics during step change in load torque at t = 1.25 sec with P-I controller

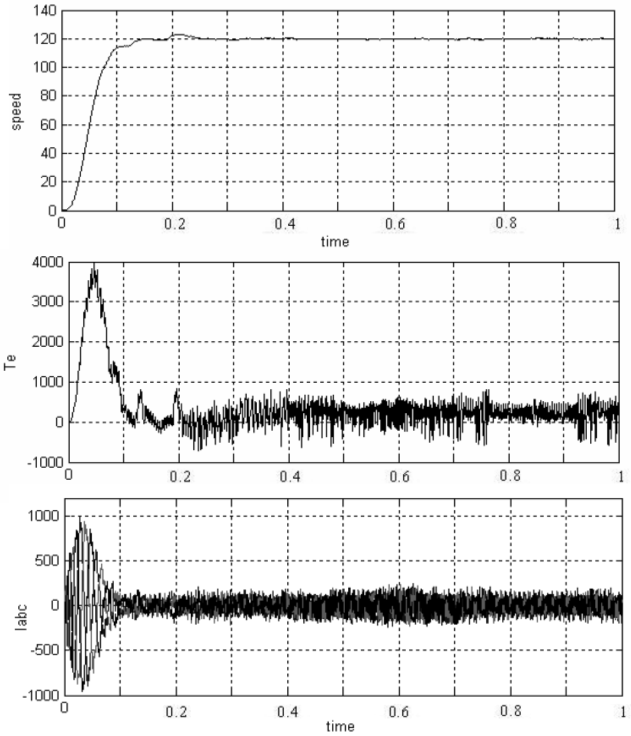
Fig.8. Speed, Torque, Iabc characteristics during step change in load torque at t = 0.3 sec with Fuzzy-logic controller

## V. CONCLUSION

The comparative results of case A and case B proves that the performance of vector-control drive with fuzzy controller is superior to that with conventional P-I controller. Thus, by using fuzzy controller the transient response of induction machine has been improved greatly and the dynamic response of the same has been made faster. The robustness in response is evident from the results. Since exact system parameters are not required in the implementation of the proposed controller, the performance of the drive system is robust, stable, and insensitive to parameters and operating condition variations. The performance has been investigated at different dynamic operating conditions. It is concluded that the proposed FLC has shown superior performances over the PI controller and has its transient response 13 times faster than a simple P-I controlled system and also 2.1 times faster than earlier proposed system [7].







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