International Journal of Engineering Research and Science & Technology

IJERST

www.ijerst.org

ISSN : 2319-5991



Vol. 21 No. 3 (1) 2025

ijerst.editor@gmail.com

editor@ijerst.com

International Journal of Engineering Research and Science & Technology

ISSN 2319-5991 www.ijerst.com
Vol. 21, No. 3(1), 2025
© 2025 IJERST. All Rights Reserved

Research Paper

PERFORMANCE AND COMPARISON ANALYSIS OF SPEED CONTROL OF INDUCTION MOTOR USING HYBRID PID-FUZZY CONTROLLER

U.KRISHNA PRASAD
Assistant Professor Electrical and Electronics Engineering
Malla Reddy College of Engineering &Technology College Hyderabad, Telangana. kittueee@gmail.com
G.MADHU YADAV
Electrical and Electronics Engineering
Malla Reddy College of Engineering &Technology College
Hyderabad, India. 22N3A0213@mrcet.ac.in
B.BHARATH
Electrical and Electronics Engineering
Malla Reddy College of Engineering &Technology College Hyderabad, India.
22N35A0204@mrcet.ac.in
A.HARSHAVARDHAN CHARY
Electrical and Electronics Engineering Malla Reddy College of
Engineering &Technology College
Hyderabad, India. 22N35A0203@mrcet.ac.in

ABSTRACT

This paper is about performance &comparison analysis of speed control in induction motors using an improved hybrid PID-Fuzzy Logic Controller (FLC). Induction motors are widely used in industrial applications due to their robustness and simplicity, but precise speed control remains a challenge due to their inherent nonlinearity and parameter variations. Traditional PID controllers, while popular, often fall short in dynamic performance and adaptability. To address these limitations, this study proposes an enhanced hybrid control strategy that integrates the precision of PID with the adaptability of fuzzy logic.

The proposed controller dynamically adjusts PID parameters using fuzzy inference rules, enabling better response under varying load conditions and improving transient performance. Simulation models are developed in MATLAB/Simulink to evaluate and compare the performance of the hybrid PID-Fuzzy controller against conventional PID and standalone fuzzy logic controllers. Key performance indicators such as rise time, settling time, overshoot, and steady- state error are analyzed.

The proposed controller is implemented and tested in a MATLAB/Simulink environment. A detailed performance analysis is conducted under various operating scenarios, including load disturbances and reference speed changes. Comparative evaluation is performed between the improved hybrid controller, conventional PID, and standalone fuzzy controllers based on key performance indices such as rise time, settling time, overshoot, and steady-state error.

Keywords: Speed Control, Induction Motor, PID-Fuzzy Controller, Hybrid Controller.

Received: 15-08-2025 Accepted: 17-09-2025 Published: 24-09-2025

I. INTRODUCTION

The Induction motors play a critical role in modern industrial applications due to their ruggedness, low cost, and maintenance-free operation. Their widespread use spans across manufacturing, transportation, and automation systems. Despite these advantages, precise speed control of induction motors remains a complex task due to their nonlinear dynamic behavior, strong coupling between flux and torque, and sensitivity to load disturbances and parameter variations. Traditionally, Proportional-Integral-Derivative (PID) controllers have been employed for induction motor control owing to their simple design and ease of implementation. However, conventional PID controllers often struggle to maintain performance under changing system dynamics or external disturbances, leading to issues such as overshoot, longer settling times, and steady-state errors. These shortcomings have driven the exploration of more adaptive and intelligent control strategies.

To overcome the individual limitations of PID and fuzzy logic controllers, this paper proposes an Improved Hybrid PID-Fuzzy Controller. This controller combines the advantages of both techniques: the precise control and responsiveness of PID with the adaptive, nonlinear handling capabilities of fuzzy logic. The hybrid controller dynamically adjusts PID parameters in real-time based on fuzzy inference, allowing for more effective speed regulation under varying operating conditions.

This study presents a performance and comparative analysis of the proposed hybrid controller with conventional PID and standalone fuzzy controllers. Simulations are carried out using MATLAB/Simulink to evaluate parameters such as rise time, overshoot, settling time, and steady-state error. The results confirm that the hybrid controller significantly enhances the dynamic and steady-state performance of the induction motor drive system.

II.VECTOR CONTROL

In squirrel-cage induction motor, the rotor current is not fed directly by an external source but it result from induced e.m.f in the rotor winding. Therefore, the induction motor control is not as simple as in DC motor because of the interaction between the stator field and rotor field whose orientation is not always occurring at 90° with respect to each other but it is varying depending on the operation conditions. Induction motor can be empowered with similar performance to that of DC motor by holding orthogonal orientation between the stator and rotor fields to achieve control of flux and torque independently.

Field oriented control (FOC) consists of controlling the stator current components, represented by a vector, in a synchronously rotating reference frame d-q, in which the electromagnetic torque of the air gap of the induction motor has the same mathematical expression of the torque in a separately excited DC motor. The FOC is based on transformation of three phase time and speed variable system into two coordinate time variant system, where the sinusoidal variable appears as DC quantities in steady state. Thus, this transformation leads to a structure similar of that in DC motor.

III. MODEL OF SPEED CONTROLLER

We integrated three of the conventional controllers with vector control in our proposed system. These are: namely PI, PD, and PID.

In figure 1, we show the control system integrating the PID conventional controller and with vector control. The error, as usual, represents the difference between the demanded motor angular speed and the actual one as in equation (1):

$$E = \omega_{ref} - \omega_{act} \quad \text{.....(1)}$$

The PID controller transfer function is expressed as

The rise time and the steady state error can be reduced by using the proportional controller (P). But, the proportional controller will not eradicate the error. Therefore, the integral controller can be used to eradicate the error close to zero value and increase the stability of the system. But, the disadvantage of using the integral controller is that it will effectively increase the response time. To expect the future behavior of the error signal, the derivative control can be used to correct actions basing on the rate of change in the error signal. Thus, it will reduce the overshoot value, increasing the stability, and improving the transient response of the system.

When compared to conventional controllers, the fuzzy logic controller has a significant advantage of not requiring a mathematical model for the controller design. The system of fuzzy is based on a group of written terms which replicate the operator's knowledge. The operator's knowledge is generally in the shape of if-then laws that are easily applied by fuzzy conditional statements in the fuzzy logic. The grouping of fuzzy control laws that are stated as fuzzy conditional statements form the rule base of an FLC. The error and change in error signals are fuzzified by the membership functions into fuzzy variable represented by linguistic labels. Then the control decisions are made based on conditional rules.

IV. DESIGN OF HYBRID SPEED CONTROLLER

We propose a hybrid system as a single controller with the utilization of indirect field oriented control to control the speed of (SQIM). The designed hybrid controller block diagram is shown in figure 2. The inputs of the fuzzy controller are the error E and the change in error CE. The output signal U of FLC represents a new error signal that feed to PID controller. The hybrid controller looks on the loop error signal and coincidently changes the output value of U so that the real output signal matches the commanded signal. Some particular features that appear with conventional controllers such as overshoot and undershoot will be eliminated with the implementation of this model. Also this hybrid controller provides higher levels of stability against load variations.

$$\frac{U(s)}{E(s)} = K_P + \frac{K_i}{S} + K_d S \quad \text{.....(2)}$$

Where Kp represents the proportional gain, ki represents the integral gain, Kd represents the derivative gain, and U is the output control signal which represent reference torque Te* in vector control drive.

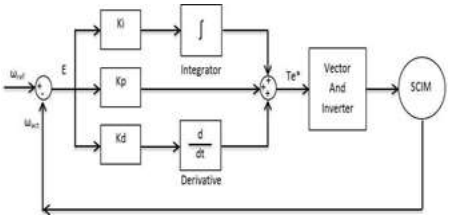


Fig. 1. PID Controller with vector control that controls the speed of SCIM by controlling the reference torque T *.

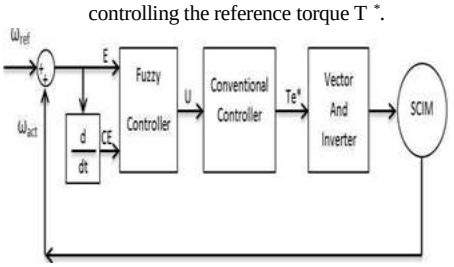
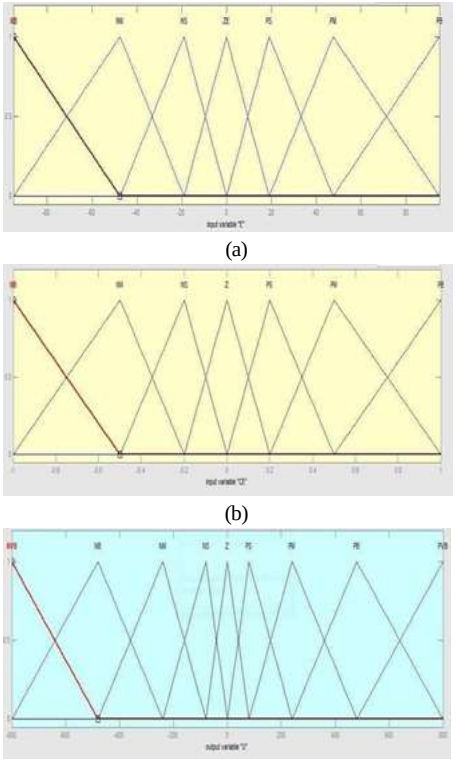


Fig. 2. The Block diagram of the proposed hybrid controller that combines the conventional controller and fuzzy logic controller with utilization of vector control to drive SCIM.

Selection of Membership Functions

Membership function MF is a curve that determines how the values of the input signals to the fuzzy controller are converted to a membership value (μ) between 0 and 1. In the proposed system, there are seven triangular membership functions for error E, change in error CE, and nine triangular membership functions for the output U. All membership functions have to be covering the entire range of error. To obtain a precise control, the membership functions close to zero have to be narrow and wider at regions away from zero to provide faster response to the system. The proposed fuzzy sets (linguistic definitions) for membership functions of the inputs and output are defined as follow: PVB = positive very big, PB = positive big, PM = positive medium, PS = positive small, Z = zero, NVB = negative very big, NB = negative big, NM= negative medium, NS = negative small. Figure 3 shows the membership

functions and linguistic variables for the inputs and output.



(a)

(b)

(c)

Fig. 3. (a) Seven triangular membership functions for input E, (b) seven triangular membership functions for input CE, (c) nine triangular membership functions for output U.

The rule base for the inference engine unit of the speed controller is written as shown in table I. The left column and the above row of the table refer to the fuzzy sets of the values CE and E respectively, and the body of the matrix refers to the fuzzy sets of the output value U. In the designed inference engine, there are 7x7 = 49 rules base developed in Mamdani method, for example a typical rule expressed as

IF E=NM AND CE=Z THEN U=NM

Once the values of error and change in error signals are fuzzified into fuzzy values by fuzzification process and the degree of each input membership functions is specified, the degree of fulfillment (DOF) is determined by applying the fuzzy (AND) operator. In Mamdani method the output membership function of each rule is truncated by DOF and the total fuzzy output is the combination of all the components. Finally the Height defuzzification method is applied to compute the output fuzzy variable that fed to conventional controller.

TABLE 1.The Rule Base of Fuzzy Controller

E / CE	NB	NM	NS	Z	PS	PM	PB
NB	NVB	NVB	NVB	NB	NM	NS	Z
NM	NVB	NVB	NB	NM	NS	Z	PS
NS	NVB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PVB
PM	NS	Z	PS	PM	PB	PVB	PVB
PB	Z	PS	PM	PB	PVB	PVB	PVB

V. SIMULATION RESULTS

This section demonstrates simulation outputs of the suggested speed controllers using MATLAB software to analyze the performance of three-phase SCIM. A complete Simulink model is shown in figure 4. In this simulation we used a 50 HP, 460 V, 60Hz, squirrel cage having the parameters listed in table 2. The fuzzy tool box that is available in MATLAB is used to design the fuzzy logic controller.

TABLE 2. Parameters of Induction Motor

Parameter	Symbol	value	Unit
Stator resistance	RS	0.087	Ω
Rotor resistance	Rr	0.228	Ω
Mutual inductance	Lm	34.7	mH
Stator inductance	LIs	0.8	mH
Rotor inductance	LIr	0.8	mH
Inertia	J	1.662	kg.m^2
Friction factor	F	0.1	N.m.s
Pole pairs	P	2	()

The performance of the conventional PI controller and three proposed hybrid PI-, PD-, PID-like fuzzy speed controller for the squirrel cage induction motor are evaluated under various operating conditions and compared with PI controller. The computational time interval for PI controller is fixed at 3 second and for hybrid controller is fixed at 1 second.

The Simulink models of conventional PI controller, PI-, PD-, PID-fuzzy are shown in figures 5 through 8 and the speed response curves are shown in figures 9 through 12 respectively. The various performance parameters values like settling time (ts), rise time (tr), steady state error (ess), and peak overshoot (Mp), of each controller are also shown in table 3.

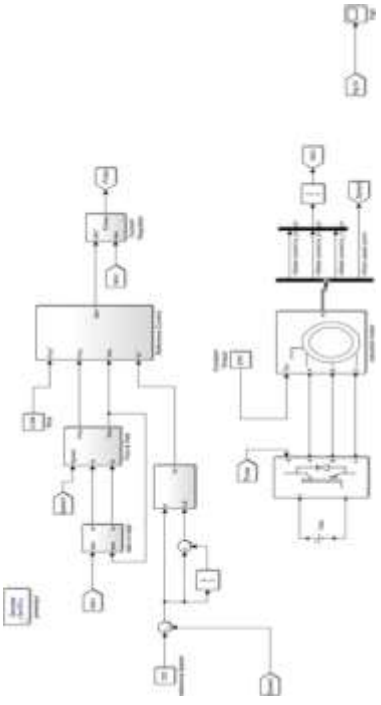


Fig. 4. Complete Simulink Model of Speed Controller System for three-phase Squirrel Cage Induction Motor.

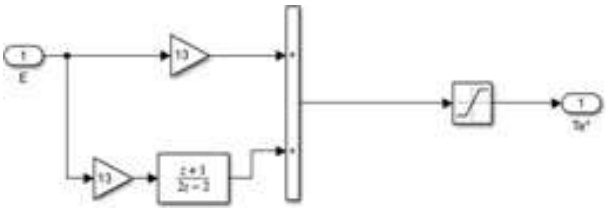


Fig. 5. The PI controller MATLAB model.

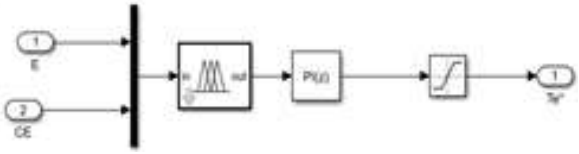


Fig. 6. The PI-Fuzzy controller MATLAB model.

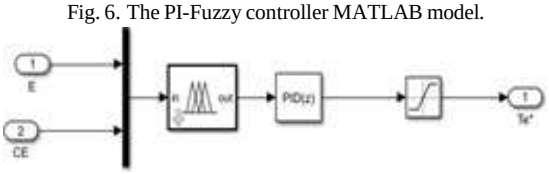


Fig. 7. The PID-Fuzzy controller MATLAB model.

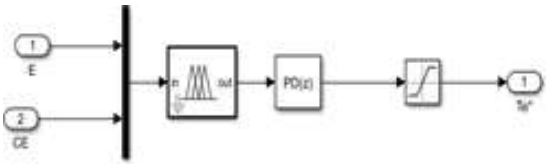


Fig. 8. The PD-Fuzzy controller MATLAB model.

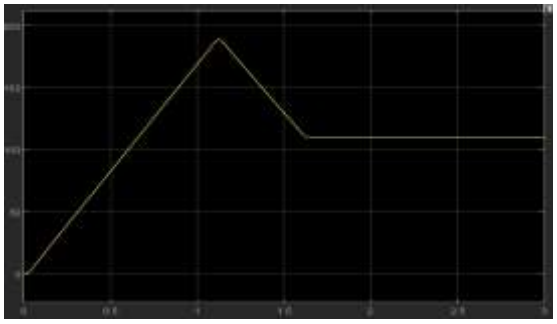


Fig. 9. Speed response curve of SCIM at 0 N.m load and 120 reference speed using PI controller.

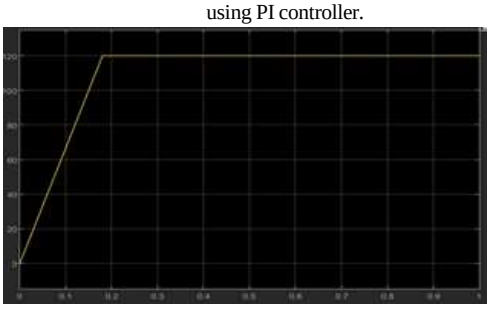


Fig. 10. Speed response curve of SCIM at 200 N.m load and 120 reference speed using PI-Fuzzy controller.

Fig. 11. Speed response curve of SCIM at 200 N.m load and 120 reference speed using PID-Fuzzy controller.

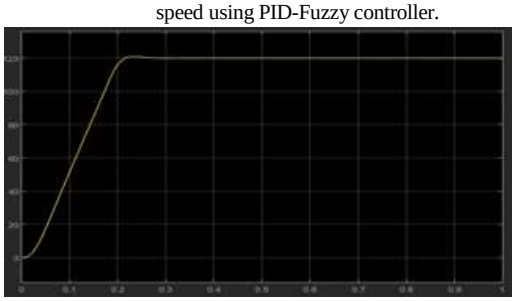


Fig. 12. Speed response curve of SCIM at 200 N.m load and 120 reference speed using PD-Fuzzy controller.

TABLE 3. Performance Analysis of Different Speed controllers

Load (N.m)	Controller	t_r (sec)	t_s (sec)	M_p	E_{ss}
0	PI	0.5439	1.9326	61.2028	0.015
	PD-Fuzzy	0.1649	0.2246	0	0.004
	PI-Fuzzy	0.1071	0.1386	0.1423	0.1600
	PID-Fuzzy	0.1071	0.1386	0.0763	0.0860
100	PI	0.8264	2.6355	69.8537	0.005
	PD-Fuzzy	0.1815	0.2444	0	0.0570
	PI-Fuzzy	0.1146	0.1484	0.0994	0.1100
	PID-Fuzzy	0.1146	0.1484	0.0384	0.0420
150	PI	1.1171	3.3759	74.3692	0.0040
	PD-Fuzzy	0.1915	0.2563	0	0.0835
	PI-Fuzzy	0.1189	0.1539	0.0792	0.0880
	PID-Fuzzy	0.1189	0.1539	0.0200	0.0250
200	PI	1.7215	4.9398	77.3644	0.007
	PD-Fuzzy	0.2027	0.2698	0	0.1098
	PI-Fuzzy	0.1234	0.1598	0.0591	0.0650
	PID-Fuzzy	0.1234	0.1598	0.0022	0.0005

VI. CONCLUSIONS

This paper demonstrated a hybrid system to control a three-phase squirrel cage induction motor. Hybridization of fuzzy logic and conventional controllers is used as a single controller. Moreover, we used vector control in the proposed hybrid system which solved the coupling effects problem of induction motor that makes the system response sluggish and easily prone to instability. PI-, PD-, PID-fuzzy is designed and simulated in MATLAB/Simulink. The FLC was modeled using a set of 49 fuzzy rules. The major advantage of the suggested hybrid control system is to increase dynamic performance in terms of settling time (ts), rise time (tr), steady state error (Ess), and peak overshoot (Mp) and to provide good stabilization. From the simulation results, it is noted that the output performance curve of the hybrid controller takes less time to reach the final steady state value with less overshoot compared to the PI conventional controller. The outputs demonstrates that the proposed hybrid controller has better performance over the PI conventional controller and that it gives better speed response and shows higher levels of effectiveness.

REFERENCES

[1] Pabitra Kumar Behera, Manoj Kumar Behera, and Amit Kumar Sahoo, "Comparative Analysis of scalar & vector control of Induction motor through Modeling & Simulation," international journal of innovative research in electrical, electronics, instrumentation and control engineering, vol. 2, no. 4, pp. 1340-1344, April 2014.

[2] Ch. Chengaiah and Silva Prasad, "Performance of Inductoin Motor Drive by Indirect vector controlled method using PI and Duzzy Controllers," International Journal of Science, Environment, vol. 2,

no. 3, pp. 475-469, 2013.

[3] Sharda Patwa, "CONTROL OF STARTING CURRENT IN THREE PHASE INDUCTION MOTOR USING FUZZY LOGIC CONTROLLER," International Journal of Advanced Technology in Engineering and Science, vol. 1, no. 12, pp. 27-32, December 2013.

[4] Ashok Kusagur, S. F. Kodad, and B. V. Sankarram, "Modelling of Induction Motor & Control of Speed Using Hybrid Controller Technology," Journal of Theoretical and Applied Information Technology, 2009.

[5] Amanulla and Manjunath Prasad, "Artificial Neural Network Based Speed and Torque Control of Three Phase Induction Motor," International Journal of Science and Research (IJSR), vol. 2, no. 8, pp. 462-465, August 2013.

[6] L. M. Contreras-Medina, R. de Jesus Romero-Troncoso, E. Cabal-Yepez, J. de Jesus Rangel-Magdaleno, and J. R. Millan-Almaraz, ‘‘FPGA-based multiple-channel vibration analyzer for industrial applications in induction motor failure detection,’’ *IEEE Trans. Instrum. Meas.*, vol. 59(1), pp. 63–72, Jan. 2010.

[7] Bemal K. Bose, Modren Power Electronics and Ac Drives, 1st ed., Bernard Goodwin, Ed. USA: Prentice Hall, Inc., 2002.

[8] Shelby Mathew and Bobin K. Mathew, "Direct Torque Control of Induction Motor Using Fuzzy Logic Controller," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 2, no. 1, pp. 386-394, December 2013.

[9] T. H. dos Santos, A. Goedtel, S. A. O. da Silva, and M. Suetake, ‘‘Scalar control of an induction motor using a neural sensorless technique,’’ *Electr.Power Syst. Res.*, vol. 108, pp. 322–330, Mar. 2014.

[10] Ahmed J. Fattah Graduate Student & Dr. Ikhlas Abdel-Qader, P.E. Professor, Western Michigan University, Kalamazo, Michigan. “Performance and Comparison Analysis of Speed control of Induction Motor using hybrid PID-Fuzzy Controller”