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Enhancing the speed-torque performance of an induction motor drive using adaptive control technique

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ABSTRACT: This research investigates the efficacy of adaptive control techniques in enhancing the presentation of induction engine drives. An adaptive framework leveraging fuzzy logic was developed to address torque control, speed control and power loss reduction in induction motors. A comparative analysis was conducted between the proposed adaptive model and the conventional PID model to evaluate performance improvements. The results demonstrate significant enhancements achieved by the adaptive model across various performance parameters. Compared to the conventional PID model, the adaptive framework exhibits a remarkable improvement in torque control, achieving an increase of approximately 36.92%. Moreover, speed control was enhanced by 17.67% through the adaptive control approach. The adaptive control framework demonstrates its effectiveness in reducing power loss, with a reduction rate of 13.6%. Simultaneously, the adaptive model boosts the output power by 33.5%, thereby enhancing the overall operational efficiency of the induction motor with an 8% increase in motor efficiency, signifying its potential for enhancing energy utilization and operational performance. This exploration highlights the importance of adaptive control strategies in improving the efficiency and performance of induction motor drives. The findings give significant bits of knowledge to the advancement of more advanced control strategies aimed at optimizing industrial motor systems.

KEYWORDS: *induction motor, adaptive control techniques, senorless control, parameter estimation*

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I. INTRODUCTION

Induction motors are the most generally utilized gadgets for electromechanical energy change (Chapman, 2019). Since their development in the last part of the 1890's, they have been utilized in different applications involving power generation and transformation (Jawad et al ,2017), mobility and transport utilization, as well as a great deal of modern based applications like siphoning, penetrating, oil &gas, petrochemical, hydroelectric, power plants, and others. Their far reaching utilization because of their easy handle, proficiency, strength, and unwavering quality makes them an imperative piece of the cutting edge industry (Gyftakis et al, 2019).Induction engines are the significant central prime movers and actuators in modern movement control frameworks. Various benefits are related with these sorts of engines (Usha et al, 2022): Reliability is one of the essential parameters based on which the motor is selected, worked on development and rugged based plan; direct association with an air conditioner power supply (Hema et al, 2020).They are, however, subject to high energy consumption, stator/rotor losses, difficult torque control, the rotor speed is challenging to control, sounds, low productivity and low influence factor at light burden, and high beginning current (Chapman, 2019).

High energy consumption in electric motor high power cost is the primary motivation to develop models and systems that will be able to reduce power losses and provide energy efficient systems (Rodrigo et al, 2016). Then again, the induction engines consume over 50% of total electric power (Sadegh et al, 2017). Given the huge measure of consumed energy, it is important to decrease loss in induction engines, particularly in variable speed applications. The requirement for variable driving rate of a few modern machines suggests the utilization of strategies to control the speed and force of induction machines. However, achieving accurate control is crucial for optimizing performance, enhancing energy efficiency and enabling the motors to meet the demands of various applications (Gudey et al, 2023).

a. Alternating Current (AC) Induction Motors

AC induction motors (ACIM) are electric motors powered by alternating current (AC). They consist of two primary components: the stator and the rotor. The stator, which is fixed and located on the outer side of the motor, receives an AC flow that generates a turning magnetic field. The rotor, positioned inside the motor, has a shaft that creates a secondary rotating magnetic field. This magnetic field in the rotor can result from AC or DC coils, permanent magnets, or reluctance saliency. Currents flow from the stator to the rotor across the air gap, and both parts contain highly magnetizable core sheets designed to minimize eddy current and hysteresis losses. Although less common, linear AC motors operate similarly to rotating AC motors, with the main difference being their linear arrangement, which generates straight-line motion (Chapman, 2019). Fig.1 represents a normal AC induction motors.

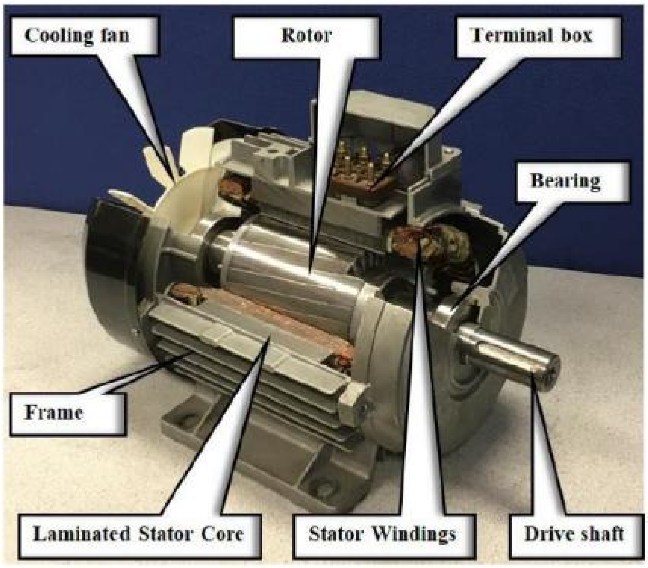

Fig. 1 : Normal AC induction motor (Chapman, 2019)

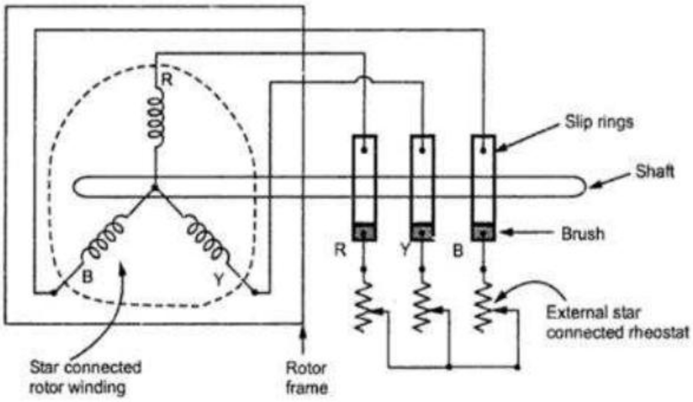

Fig. 2: Wound Rotor or Slip Ring Rotor (Nordin et al., 2019)

The exterior of the wound rotor core contains slots to hold three-phase windings, which are configured in a star arrangement. The wound rotor's number of poles matches the stator's pole count. The three coils of the wound rotor are associated with three slip rings, mounted on the rotor shaft as represented (Nordin et al.,2019).Slip rings facilitate an electrical link between the rotor circuit and external resistors through carbon brushes, allowing the starting current to be controlled and providing a means to regulate rotor speed. The squirrel cage rotor, on the other hand, is simpler to construct and is widely used (approximately 95% of three-phase induction motors). it consists of copper or aluminum bars running lengthwise and shorted by rings made from the same material, giving the rotor a cylindrical shape (Jawad et al., 2017). Unlike the wound rotor, the squirrel cage rotor lacks carbon brushes, meaning no outer resistors can be included to the rotor bars, and the rotor's operational characteristics cannot be adjusted. These bars are skewed rather than perfectly aligned with the rotor shaft axis to reduce magnetic noise and ensure smooth motor operation (Jawad et al., 2017). The rotor velocity never matches the synchronous frequency (the stator's rotating magnetic field speed) because the rotor frequency depends on the motor's slip. At zero slip, no voltage is induced in the rotor, resulting in zero current in the rotor windings and, consequently, no torque production (Hou et al., 2014). Equation 1 represents the slip.

$$S = \frac{N_S - N}{N_S} \qquad (1)$$

The following equations provide the rotor frequency, rotor current, and the electromotive force (emf) generated in the rotor. (Panagiotou et al, 2018):

$$F_r = SF \qquad (2)$$

$$I_{2r} = \frac{C}{Z_{2r}} \qquad (3)$$

$$E_{2r} = SE_2 \qquad (4)$$

Where:

S represents the motor slip.
N denotes the rotor frequency..
Ns is the synchronous frequency of the stator's rotating magnetic field.
F refers to the stator frequency.
fr is the rotor frequency when in operation.
E_{2r} is the electromotive force (e.m.f) induced in the rotor under operating conditions.
E_2 is the rotor's e.m.f when locked, occurring when the rotor is stationary.

b. Adaptive Speed Control Algorithm for induction Motor

1. Inputs motor parameters L,V,J
2. Define Fuzzy input variable

   Speed-error= linspace (-1000,2000,3000) (speed error range)

   Load Torque = linspace (0, 1500,3000) (Load torque range)
3. Define membership functions for input variables
   Speed-error Low= gaussmf= (speed error,[-1000,-700,-200])
   Speed-error Low= gaussmf= (speed error,[-200,-100,-1])
   Speed-error Low= gaussmf= (speed error,[-1, 500, 2000])
   Load torque Low= gaussmf= (load torque,[0,250,700])
   Speed-error Low= gaussmf= (load torque,[700,-1200,1500)
   Speed-error Low= gaussmf= (load torque,[1500, 2200, 3000])
4. Define Output Variables
   Gate switching signal = linespace(0,1);
   Output Frequency linespace(49.5,50.5.100);
5. Define Membership functions for output Variables
   Gate switching signal _off;
   Gate switching signal _on;
   Output Frequency linespace(49.5,50.5.100);
6. Define fuzzy rules
7. Apply fuzzy rules to calculate Output

II. MATERIALS AND METHOD

A. MATERIALS

Materials used for this research are as follow:

- PST2200 Power System Trainer
- hypotonic
- clamp meter
- insulation resistance tester
- multi meter.
- tachometer

B. METHOD

The design method adopted to actualize improvement in induction motor drive using an adaptive control strategy compasses the following steps:

- Characterization of an induction motor drive.
- Development of a mathematical model for an induction motor drive.
- Development of a MATLAB/SIMULINK model of an induction motor drive.
- Development of an adaptive control framework for speed control of induction motor.
- Development of an adaptive control framework for torque control of induction motor.

Fig 3 : Induction motor Setup

Algorithm for adaptive speed control of induction motors:

a. Adaptive Fuzzy logic for Speed control :

Adaptive Fuzzy Logic System (FLS) for speed control in induction motors combines the flexibility of fuzzy logic with adaptive mechanisms to achieve robust and efficient torque regulation in dynamic and uncertain environments. This approach allows the control system to adapt its rules and parameters based on real-time feedback. Fuzzy logic will be deplored to design the controller for the control of speed in a three phase induction motor by making adequate changes to the switching of the inverter gate voltage.

The fuzzy outputs are the gate switching and frequency. Fuzzy logic switching in the context of gate control involves using fuzzy logic principles to determine the switching behavior of gate signals in the inverters. Instead of relying on crisp binary logic (0 or 1), fuzzy logic allows for gradual transitions between states, enabling more flexible and robust control in uncertain or nonlinear systems.

b. Adaptive Fuzzy rule Base speed control

The rule base system for speed control was formulated based on expert knowledge and capture the control strategy for speed regulation. The inference engine evaluates the firing strength of each rule based on the degree of match between the input variables and the rule's antecedents. It aggregates the outputs of all fired rules using fuzzy reasoning mechanisms such as fuzzy operation to generate a fuzzy output. The adaptive mechanisms are incorporated into the FLS to adjust its parameters and rules based on real-time feedback and performance evaluation. These mechanisms ensure that the control system can adapt to changes in the motor's dynamics. Table 3.1 shows fifteen (15) rule base linguistic variables for the speed control of an induction motor.

Table 3.1: Fuzzy Rules for the Proposed adaptive speed Controller

$\Gamma_{em}(t)$ e(t)	L	M	H
NL	I, H	D,M	D,L
NM	I, H	D,M	D,L
Z	D,H	D,M	I,L
PM	D,H	D,M	I,L
PL	DH	D,M	I,L

The linguistic variables used in this work are, negative Large (NL), negative medium (NM), Zero (Z), positive medium (PM) and Positive Large (PL).decrease (D), Low (L), Increase (I) ,Medium(M).

By using these linguistic variables the fuzzy logic control signal is generated for the adaptive speed control. The control of the system is based on fifteen (15) fuzzy control rules, which are represented as shown in table3.1.

III. RESULTS AND DISCUSSION

A. Result of Characterization of three phase induction motor

Characterization results play a pivotal role in understanding the performance characteristics of electric machines, particularly in the case of three-phase induction motors. This sample report aims to provide a comprehensive overview of the characterization results obtained from a 3kVA three-phase induction motor. The characterization involves conducting various measurements to assess the electrical and mechanical properties of the motor under different operating conditions. Table 4.1 represents the parameters used for the characterization of the three phase induction motor.

Table 4.1: Operating Parameters for induction Motor

S/N	Parameters	Units
1	Phase Voltage	220V
	Line Voltage	415V
	Power Factor	0.9
	Apparent Power	3KVA
	Speed	1800rpm
	Torque	

Table 4.2. represents results obtained during the motor's operation.

S/N	Va	I_f (mA)	N(rpm)
1	8	0.02	1290
2	12	0.03	1653
3	16	0.05	1823
4	20	0.06	1912
5	24	0.07	1956

From table 4.2, the motor operates by converting electrical energy into mechanical energy through the interaction of magnetic fields. When voltage is applied across the motor's terminals, it creates an electric field that induces current flow through the motor's windings. This current, in turn, generates a magnetic field around the windings according to Ampère's law. The interaction between this magnetic field and the magnetic field produced by the motor's permanent magnets or field windings creates a torque that drives the motor's rotation.

As seen in table 4.2, as the voltage is increased, more electrical potential is applied across the motor's windings, leading to a corresponding increase in current flow. This increase in current results in a stronger magnetic field which, in turn, produces a greater torque output, driving the motor to higher speeds and enabling it to overcome greater mechanical loads. The relationship between voltage and current is governed by Ohm's law, which states that the current passing through a conductor is directly proportional to the voltage applied across it, given a constant resistance.

Table 4.3

S/N	External Resistance (ohms)	Armature Current I_a (A)	Armature Voltage (Va)	N(rpm)
0	0		19.9	1908
1	10	0.22	18.6	1773
2	20	0.121	19.0	1627
3	30	0.123	15.2	1470
4	40	0.123	13.8	1323
5	50	0.122	12.3	1184
6	60	0.121	10.9	1046

Resistance in motor primarily refers to the electrical resistance of its armature windings. This resistance can affect the motor's speed in several ways. Firstly, applying Ohm's law; higher resistance leads to a higher voltage drop across the windings for a given current. This means that a motor with higher resistance will experience a lower effective voltage, resulting in reduced speed compared to a motor with lower resistance when supplied with the same voltage.

Table 4.4: Parameters for induction motor simulations

Parameters	Value	Units
Phase voltages (Va, Vb, Vc)	220	V
Synchronous speed (Ws)	3000	rpm
Number of Poles (P)	2	
Frequency (F)	50	hz
stator resistance (R_s)	0.86	Ω
Rotor resistance (R_r)	0.83	Ω
self inductance of a stator (l_s)	85	mH
self inductance of a Rotor (l_r)	85	mH
stator mutual inductance (m_s)	55	mH
rotor mutual inductance (m_r)	40	mH
stator − rotor mutual inductance (m_{sr})	50	mH
self − inductance of a rotor in dq(L_r)	45	mH
self − inductance of a stator in dq(L_s)	30	mH
Mutual inductance between two stator phases in dq (L_m)	33.3	mH
Frictional coefficient (Kf)	0.0058	Kg.m^2.s^{-1}
Moment of inertia (j)	0.02	Kg.m^2

However, controlling the speed of induction motors is essential for optimizing their performance, improving efficiency, and meeting specific operational requirements. The speed control of induction motors involves regulating the rotational speed of the motor shaft to achieve desired operating conditions. The speed control were achieved with the development adaptive control mechanism and also using a conventional PID controller.

The comparisons of speed control were based on the Simulink model developed in the figures above. This paper contributes to knowledge by introducing an innovative adaptive frame for torque and speed control in induction motors. By combining theoretical insights with practical implementation through MATLAB simulations, researchers can gain valuable insights into the capabilities, limitations, and potential applications of adaptive control in motor systems. The adaptive control technique for the control of induction motor provides the following additional improvements:

- An improvement in speed control to about 17.67%.

IV. CONCLUSION AND RECOMMENDATIONS

a. CONCLUSION

In conclusion, this paper has made significant strides in advancing the performance of induction motor drives speed through the implementation of adaptive control techniques. By addressing the inherent challenges associated with conventional control methods; this study has demonstrated the efficacy and potential of adaptive control in enhancing motor performance, efficiency, and reliability.

Through a comprehensive review of literature, theoretical analysis, and practical experimentation, development of Matlab /Simulink models using mathematical equations, key findings have been established, highlighting good performance of the induction motor.

a. RECOMMENDATIONS

Based on the findings and conclusions presented in this journal on improving the performance of induction motor drives using adaptive control techniques, the following recommendations are proposed for future research and practical implementation:

Further Investigation into Adaptive Control Algorithms:

Exploration and development of more advanced adaptive control algorithms tailored specifically for induction motor drives.

Experimental Validation in Practical Applications:

Conduct extensive experimental validation of adaptive control techniques in real-world industrial applications.

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