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Performance Analysis of Speed Control of Induction Motor Using Improved Hybrid PI – Vector Control

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Abstract**—** The induction motor is very popular right now, especially for industrial and household applications. It is amazing and commendable how far variable speed drive technology has come. Due to their durability and low maintenance requirements, induction motors are being used more and more in a variety of industries where the majority of applications require quick response times and sophisticated speed control. The primary challenge to achieving the highest efficiency and maximum torque is speed control. This research introduces the formulation of the speed control as well as the speed control approaches. In this research, a hybrid speed-control system for a three-phase squirrel cage induction motor (SCIM) is presented. The proposed approach applies vector control and combines FOC with conventional controllers. The three-phase induction motor's speed response is enhanced using this technique, which combines the benefits of conventional controllers with FOC. Proportional integral - field oriented control (PI- FOC) simulation results and implementation are used to evaluate the performance of the hybrid system controller. At different load scenarios, performance measures such as rise time (tr), maximum percent overshoot, and settling time (ts) are recorded. By using MATLAB/ Simulink, the results demonstrated improved speed tracking performance and system stability, and they demonstrated the effectiveness of the proposed hybrid speed controller under a range of operating conditions

Keywords— Vector Control, PI Controller, Torque Control, Speed Control, Induction Motor.

I. INTRODUCTION

Due to its low maintenance cost, durability, and dependable performance, induction motor utilisation has grown over the past three decades in both industry and daily life. The majority of the equipment used in industry, conveyer belts, elevators, drilling equipment, crane lifters, and crusher equipment is powered by electrical motor drive systems. Induction motors, either single-phase or three-phase, are used in all of the systems indicated above, and a motor drive system is needed to power these motors. For the purpose of constructing motor drive systems, it is crucial to mathematically describe a three-phase induction motor. In the course of production and testing, it helps to confirm the design process and reduce faults in design. The MATLAB / Simulink window is used to assist in dynamic modelling. It can be challenging to dynamically model three-phase induction motors. This work presents a streamlined modelling approach. This has been accomplished by several researchers utilising the direct, quadrature, and zero axis transformations. With the use of transformation often referred to as Clarke's transformation. This work aims to present an induction motor modelling. The findings from the transformation are more precise than those from the dq0 transformation (usually referred as Parks Transformation). By converting the three phase equations into two phase and axis values, modelling is accomplished.

Simulink/ MATLAB's primary benefit is that it uses a graphical user interface (GUI) as opposed to programming code. Different bricks are used to construct the system. The different functional blocks, each of which performs a distinct mathematical function, can be connected to describe a set of differential equations [1-2]. Induction motors are the focus on various research in the subject of asynchronous machines, particularly because of their versatility in functioning under stable and dynamic states as well as their affordability, robustness, and industrial application. Transient AC analysis of the motor must be studied in order to evaluate the dynamic performance of the motors [3 - 4]. Due to the widespread usage of induction machines in several industrial processes, they are known as the workhorses of the industry. It is essential to find and fix faults as soon as possible for the motor to function properly and efficiently. Modern motor analysis methods use simulation to examine the motor under various operating scenarios. By breaking the rotor bar, a fault is first introduced into the model of a healthy motor created using MATLAB/Simulink. To conduct a comparison examination in both circumstances, a model of a defective motor is then created. The suggested approach is better for figuring out the motor's current and frequency response to prevent breakdown maintenance [5 - 6].

Controlling the speed and torque of induction motors while a load is added is crucial because of their widespread use in the industry. Snapping a speed reading too soon reduces the stability of an induction motor. The motor drive system will become more expensive as a result. An alternative method of determining an induction motor's speed that uses VSI power is based on artificial intelligence control and combines scalar control technique with space vector modulation. PI, artificially intelligent controllers in open or closed loops can be fuzzy logic controllers, ANNs, or controllers. With this approach, simulations with different loads—like varying or full load—are compared. [7-8]. Traditionally, the frequency of the main voltage and the number of poles on the motor have governed the speed at which induction motors operate. It is significantly more difficult to regulate the speed of an induction motor than a DC motor since there is no direct relationship between the motor current and the generated torque [9]. Compared to dc motors, induction motors have a longer maintenance free life because of their brushless nature. The squirrel cage motor is the most affordable and widely available type of induction motor. No external current source is required to generate a magnetic field inside the rotor. This explains the high power and low cost of this motor [10]. Vector control, often called field-oriented control, is a method for varying the speed of an induction motor over a large range. In 1971–1973, Blaschke proposed this theory [11]. The vector control system's complex current is utilized in this concept to control the motor's output torque through the employment of the two quadrature components that govern the flux level. Field Oriented Control (FOC) was first designed for high-performance motor applications that needed to generate torque at zero speed, function reliably across the whole speed range, and have exceptional dynamic characteristics, like rapid acceleration and deceleration. For applications requiring lower performance, the FOC is also becoming in popularity because of its bigger motor size, lower cost, and lower power consumption [12].

Two key concepts serve as the foundation for the vector control technique's development. The currents produce the initial torque and flux [13]. The simplest simple way of defining and regulating an induction motor is by applying two quadrature currents instead of the more usual three phase currents. The direct (id) and quadrature (iq) currents are what generate the motor's flux and torque, respectively. Yet, although iq is by nature in phase with the stator flow, id flows in a path perpendicular to the stator. It is evident that actual motor voltages and resulting currents adhere to the widely recognized three-phase design. When a reference frame spins in time with the stator flux instead of remaining stationary, a problem arises. Thus, we introduce the second basic concept of vector control. A collection of reference frames with the same rotational amplitude constitutes the second essential idea. Selecting a reference frame correctly can convert a sinusoidal quantity into a constant value that can be managed using ordinary proportional integral (PI) controllers. Frequency is the only factor considered in vector control for induction motors. With the direct axis rotor flux, the recommended approach is easier to use [14]. Implementation is how this is done; a unit vector was used to change the command current being examined so that it would follow the trajectory. The findings indicate that it possesses a rotating d-q axis in addition to a stationary one. The following formulae [15] can be used to theoretically increase a PI controller's performance.

$$i_{ds}^{*} = i_{ds}\cos\theta - i_{qs}\sin\theta \quad (1)$$

$$i_{qs}^{*} = i_{ds}\sin\theta + i_{qs}\cos\theta \quad (2)$$

A component of mathematical modelling includes all of the equations for voltage, current, and flux between the motor's fixed and spinning elements. This study uses the induction motor's dynamic model to investigate the motor's steady state and transient properties. It has the following structure: The theoretical background is covered in Section II. Section III discusses the Controller, F.O.C., and mathematical modelling processes. The simulation model or mathematical model is presented in Section IV along with discussion of the findings. The conclusions are presented in Section V

II. Theoretical And Mathematical Equation Of Induction Motor

Mathematical representations of the stable states of electrical equipment under transient and unbalanced conditions are effective. In general, a mathematical model explains how the mechanical and electrical properties of electrical devices relate to one another. While building a mathematical model of an induction motor, the following assumptions must be made.

1. A squirrel-cage induction motor is required.
2. The air gap needs to be consistent.
3. The windings of the rotor and stator must be balanced with sinusoidal distribution [18 - 19].

Since the rotor currents in an induction motor are generated by induction much like they are in a transformer, induction motors are frequently referred to as rotating transformers. No internal or external exciter is required, unlike in other electrical machines. The rotor begins to revolve; the stator winding receives the three-phase supply, which creates the stationary magnetic flux that cuts the rotor slots. A mutual e.m.f. is produced as a result of the stator and rotor's relative motion [20].

A. Adaptation of Clarke:

It is highly challenging to mathematically describe an induction motor, and this is typically done by converting three-phase AC numbers into two-phase DC quantities. The term dq0 transformation (also known as Park's transformation) refers to this kind of transformation. The transformation (also referred to as Clarke's transformation) is used in this research to develop the mathematical model of an induction motor. The two changes are comparable to one another. Phase quantities are often projected onto a rotating two axis frame using the dq0 transformation, whereas they are projected onto a stationary two axis frame using the transformation. The transformation-derived mathematical model is the most accurate. [21]

$$V_a^*\ (t) = \sqrt{2}V_{rms}^*\ Sin\ (\omega t) \qquad \text{.......(3)}$$
$$V_b^*\ (t) = \sqrt{2}V_{rms}^*\ Sin\ (\omega t - 120°) \qquad \text{.......(4)}$$
$$V_c^*\ (t) = \sqrt{2}V_{rms}^*\ Sin\ (\omega t - 240°) \qquad \text{.........(5)}$$

Where $V_a^*(t)$, $V_b^*(t)$ and $V_c^*(t)$ are line voltage. And the relationship between abc and αβγ are described below:

a. Line Voltage Equations:

$$V_\alpha^* = \frac{2}{3}V_a^* + \frac{1}{3}V_b^* - \frac{1}{3}V_c^* \qquad \text{......................(6)}$$
$$V_\beta^* = \frac{\sqrt{3}}{3}V_b^* - \frac{\sqrt{3}}{3}V_c^* \qquad \text{.......................(7)}$$
$$V_\gamma^* = 0 \qquad \text{........................(8)}$$
$$I_\alpha^* = \frac{2}{3}I_a^* - \frac{1}{3}I_b^* - \frac{1}{3}I_c^* \qquad \text{...................(9)}$$
$$I_\beta^* = \frac{\sqrt{3}}{3}I_b^* - \frac{\sqrt{3}}{3}I_c^* \qquad \text{......................(10)}$$
$$I_\gamma^* = 0 \qquad \text{......................(11)}$$

B. Park Transformation:

Stationary to Rotating reference frame transformation.

There are two frames of reference in park transformation first is α - β reference and second is d-q reference [31]. In these frames of reference the d-q reference is rotating frame of reference and speed of rotation is .

$$V_{\alpha\beta}^* = |\ V^*\ |\ \angle\theta \qquad \text{.......(12)}$$

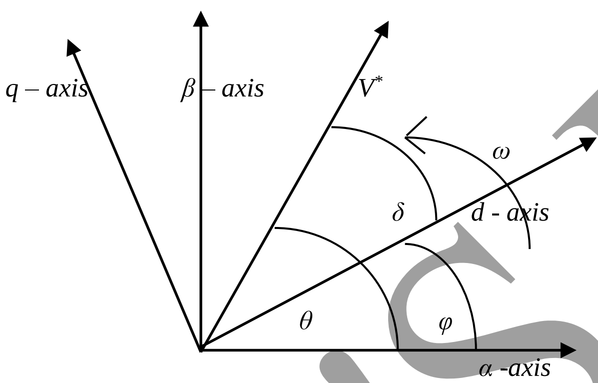

Figure 1: Phasor in the d–q reference frame

$$V_{dq}^* = |\ V^*\ |\ \angle\delta \qquad \text{......(13)}$$

In Equation (12) and (13) magnitude is same but angle is different. Hence, The relation between these two angle is –

$$\varphi = \theta - \delta \qquad \text{.........(14)}$$
$$\delta = \theta - \varphi \qquad \text{...........(15)}$$
$$V_{dq}^* = |\ V^*\ |\ \angle\theta - \varphi$$
$$V_{dq}^* = |\ V^*\ |\ \angle\theta - \varphi$$
$$V_{dq}^* = |\ V^*\ |\ \angle\theta * 1\angle - \varphi$$
$$V_{dq}^* = V_{\alpha\beta}^*\ 1\angle - \varphi$$
$$V_{dq}^* = V_{\alpha\beta}^* * e^{-j\varphi} \qquad \text{.......(16)}$$
$$V_{\alpha\beta}^* = V_{dq}^* * e^{j\varphi} \qquad \text{.......(17)}$$

Equation (16) is a park transformation and represents the phasor in the d-q reference frame.

III. Mathematical Equation Of Induction Motor In PI – Based Vector Control

The general electrical design of the induction motor is crucial for generating the mathematical equation and model. In Figure 2, a Rotating Reference Frame of induction motor's electrical configuration is depicted.

A control technique known as vector control or field-oriented control is used to recognise the stator currents of an AC induction motor as two orthogonal currents that can be represented as a vector. A three-phase system that is time and speed dependent is converted into a system that is time-invariant and only has two coordinates, axis d and q, through this projection-based control [32].

A field-oriented controlled machine's input references must have the following two constants:

1. The torque-producing element based on the q-axis (I_w).
2. The flux-producing d-axis component (I_m).

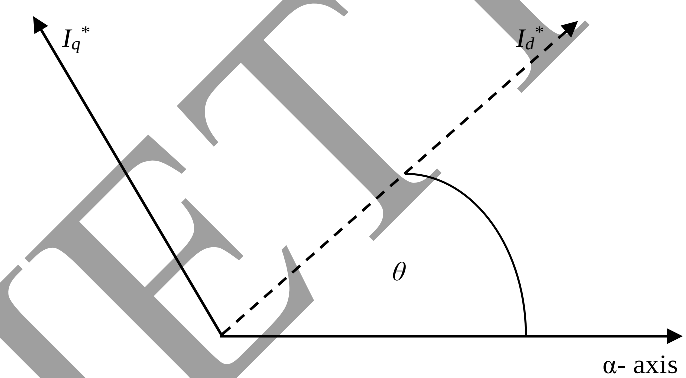

Figure 2: Rotating Reference Frame

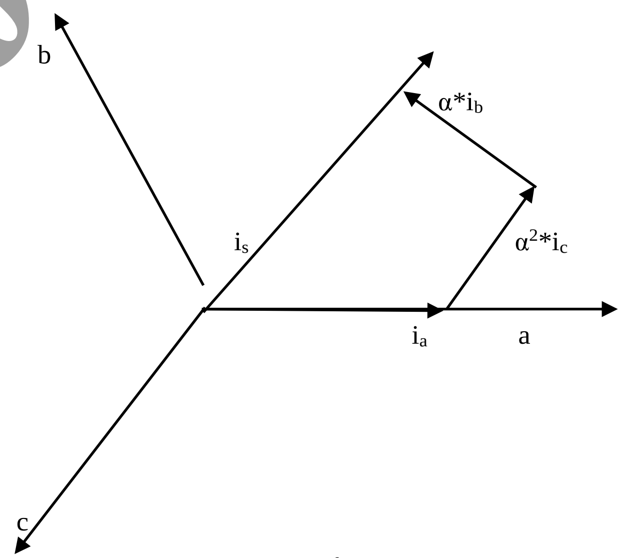

Figure 3: Projection of Space Vectors.

Field Oriented Control is projection-based, however since the control structure controls immediate electrical quantities; it is reliable in all working processes.

The torque and torque component have a linear relationship if the rotor flux amplitude is maintained constant. The stator current vector's torque component can then be altered to change the torque.

$$M^* = \psi_r\ i_{sq}^* \ \text{....... (18)}$$

- (a, b, c) to (α, β) The Clarke transformation creates a time-variant system with two coordinates

- (α, β) to (d, q) The Park transformation creates a system with two coordinates that is time-invariant.

$$V_{sd}^* = R_s^* I_{sd}^* + L_s^* (d (I_{sd}^*)/dt) - L_s^* \psi_m I_{sq}^* + M_{sr}^* (d (I_{rd}^*)/dt) - M_{sr}^* \omega_\psi I_{rq}^*$$

$$Torque = (3/2)\ M_{sr}^*\ P^* (I_{rd}^*\ I_{sq}^* - I_{sd}^*\ I_{rq}^*) \quad ….(19)$$

$$Speed = (Torque - T_{load}) / (J^* s + f_0^*) \quad ……..(20)$$

IV. MATLAB/SIMULINK INDUCTION MOTOR MODEL DISCUSSION AND RESULT

MATLAB/Simulink is used to simulate an induction motor vector control mathematical model. An evaluation and demonstration of the proportional plus integral (PI) controller's performance in a vector control drive are provided. Proportional integral (PI) control is a widely used method for linear control.

The three-phase supply, represented by V_a, V_b, and V_c is applied to the induction motor stator. Figure 4 illustrates the signal of the sine wave being time-based rather than sample-based. At the three-phase input output, a 3x1 Multiplexer is attached. Figure 4 also displays the multiplexer's function parameters. In this model the clock provides the time block with the simulation time as an output. A 1x3 Demultiplexer is linked after the output of the three-phase input function block, which then provides the outputs to the particular block in the form of various transformations as indicated in this hybrid model.

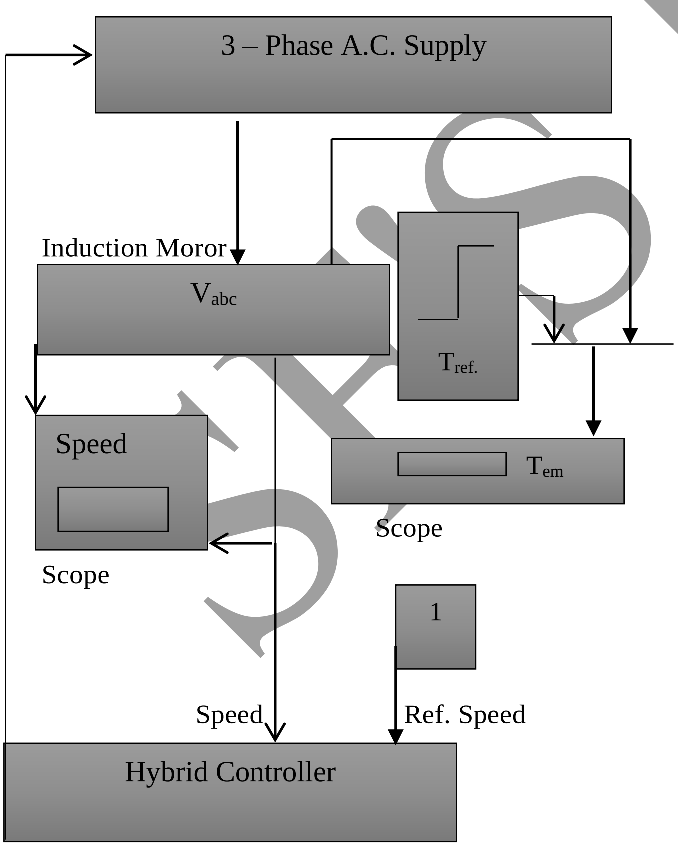

Figure 4: Simulation Model of Improved Hybrid PI-FOC Induction Motor

With this strategy, we can achieve maximum responsiveness in the shortest amount of time, making vector control superior to conventional induction motor speed control methods. The response is quick, precise, and produces good results for an induction motor with variable speed. Here, the field-oriented PI controller is used to describe controlling the induction motor's speed. The approach immediately draws the motor speed to the reference speed and uses a proportional integral controller to quickly modify the motor speed based on speed errors. The simulation results demonstrate the developed controller's excellent performance, which has very minimum overshoot. The simulation's outcomes are displayed as follows: According to Figure 5, the rotor currents β - component starts out 0, steadily increases over time, and finally eventually becomes constant. In contrast, the β-component exhibits the same behaviour but stabilises more quickly than the α -component. The electrical torque is highest at first, but as seen in Figure 6, it gradually diminishes and ultimately becomes constant. Figure 7 demonstrates that the stator speed's component reaches its maximum at start up and then progressively declines to a constant amount.

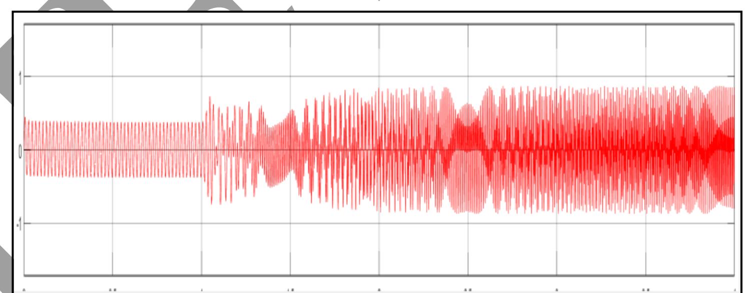

Figure 5: Simulation Result of Rotor Current on β – axis.

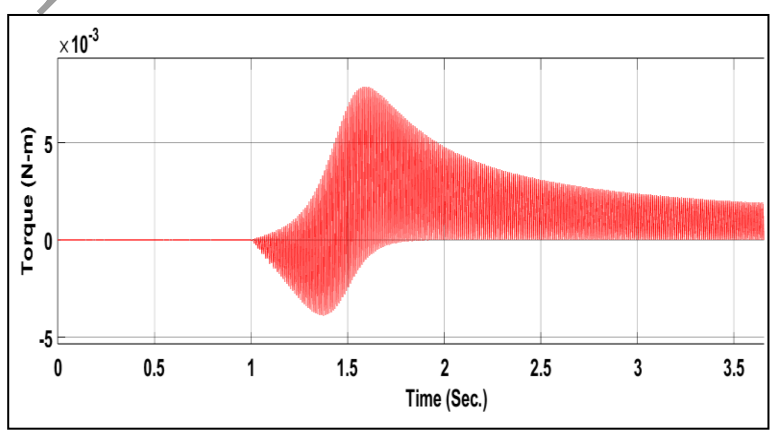

Figure 6: Simulation Result of output Torque using Vector Control in Induction Motor.

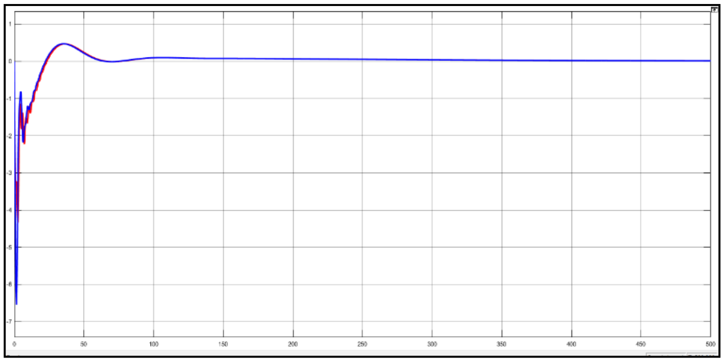

Figure 7: Simulation Result of Speed Trajectory in Induction Motor.

V. Conclusion

This research presents a three-phase squirrel cage induction motor hybrid technique. Conventional and FOC controllers are combined into one controller. The suggested hybrid system additionally uses vector control to handle the coupled effects issue of the induction motor, which causes a delayed and easily unstable system response. To simulate and use PI - FOC, MATLAB/Simulink is required. The suggested hybrid control strategy's main benefit is an improvement in dynamic performance in terms of settling time (t_s), rise time (t_r), steady state error (E_{ss}), peak overshoot (M_p), as well as greater stability. According to the results of the simulation, the hybrid controller's output performance curve overshoots less frequently than that of the other controller and does so more quickly. The results show that the presented hybrid controller performs better than the other traditional controllers in terms of efficiency, performance, and response times.

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