Induction Motor Drive Employing Vector Control Technique for Enhanced Performance

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Abstract: The current source inverter (CSI) architecture is widely recognized for its suitability for high-power medium voltage (MV) driving applications. Nevertheless, the task of attaining independent control of machine flux and torque is difficult, leading to a preference for the indirect vector control (IVC) approach. The computing efficiency of this method and its reduced reliance on machine characteristics make it favored. Conventional IVC CSI drives, on the other hand, suffer from poor dynamic performance and short-term field misalignment due to the absence of a flux control loop. To resolve this problem, we incorporate two more proportional integral controllers that utilize machine current feedback signals. This integration guarantees enhanced decoupling and field orientation. Nevertheless, the inconsistency in slip frequency rotor resistance adds complexity to the alignment of magnetic flux and the capacity to respond quickly. In order to overcome this issue, a model reference adaptive controller (MRAC) utilizes reactive power to accurately determine the real-time resistance of the rotor. Furthermore, the system incorporates a load torque observer and feedforward control mechanism to improve its dynamic performance. By utilizing simulation in MATLAB/SIMULINK.

Keywords — **Current source inverter (CSI), Indirect Vector Controlled (IVC) Drive.**

I. INTRODUCTION

Induction motors are widely utilized in medium-voltage, high-power applications such as pipeline pumps, fans, traction systems, and steel rolling mills due to their dependable performance, durability, cost efficiency, and ability to handle heavy loads. Nevertheless, the task of regulating the velocity of these motors is difficult due to intricate mathematical models and nonlinearity resulting from coupling and core saturation. In order to enhance efficiency, we prioritize the utilization of vector control techniques, which closely mimic the control methods employed for DC motors. Current source inverter (CSI)-fed induction motor drives are increasingly used in such scenarios due to their straightforward converter design, excellent waveforms, and several advantages that enhance their usability. Indirect vector control (IVC) approaches, namely, are becoming more popular due to their lower processing cost and less reliance on machine characteristics.

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The integration of supplementary controllers and feedback signals in improved IVC systems enables more effective decoupling and field orientation. Nevertheless, alterations in the characteristics of the induction machine, particularly the rotor resistance, need the use of more sophisticated control techniques for real-time estimate. Model reference adaptive control (MRAC) is a specific approach that may be used. Utilizing a load torque observer with feedforward control improves the dynamic performance of a system, providing increased resistance to disruptions caused by changes in load torque and mechanical characteristics.

II. CONTROL OF INDUCTION MOTORS

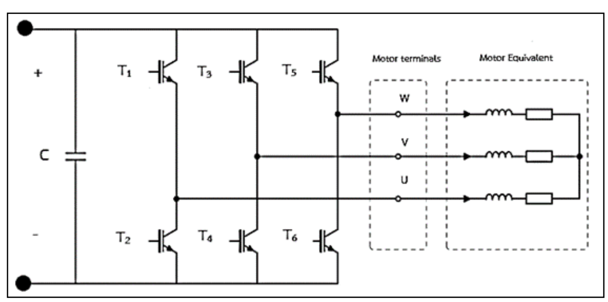

Fig. 1. Three-phase inverter circuit

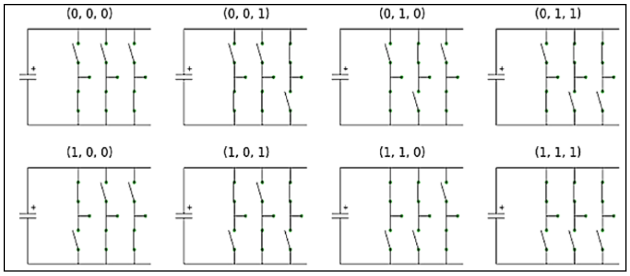

Fig. 2. Inverter switches in conducting and non-conducting states.

This process entails utilizing a three-phase voltage vector to provide a reference signal that can be compared with triangle signals. The goal, akin to the HIPWM method, is to enhance the output voltage throughout the harmonics by 15%. Contrary to the approach discussed before, SVPWM produces a reference signal by manipulating 8-switch states, as seen in Fig. 2. Numbers 1 to 6 can be used to indicate this, simplifying the sequencing of SVPWM in each branch of the switch, as shown in Fig. 1. For instance, when switch T1 is in the ON state (allowing current to flow), it functions in the contrary condition to switch T2, which is in the OFF state (not allowing current to flow), and this pattern continues for each state, as seen in Fig. 1.

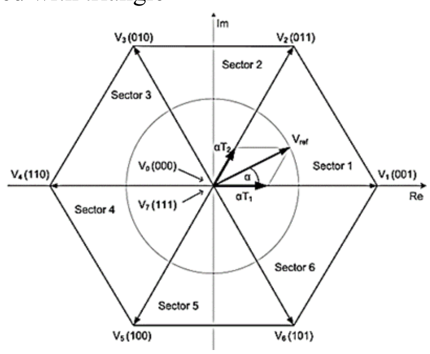

Fig. 3. Space vector

Table 1. Inverter voltage status as shown in Fig. 3.

No. status	Phase A	Phase B	Phase C
1	0	0	0
2	0	0	1
3	0	1	0
4	0	1	1
5	1	0	0
6	1	0	1
7	1	1	0
8	1	1	1

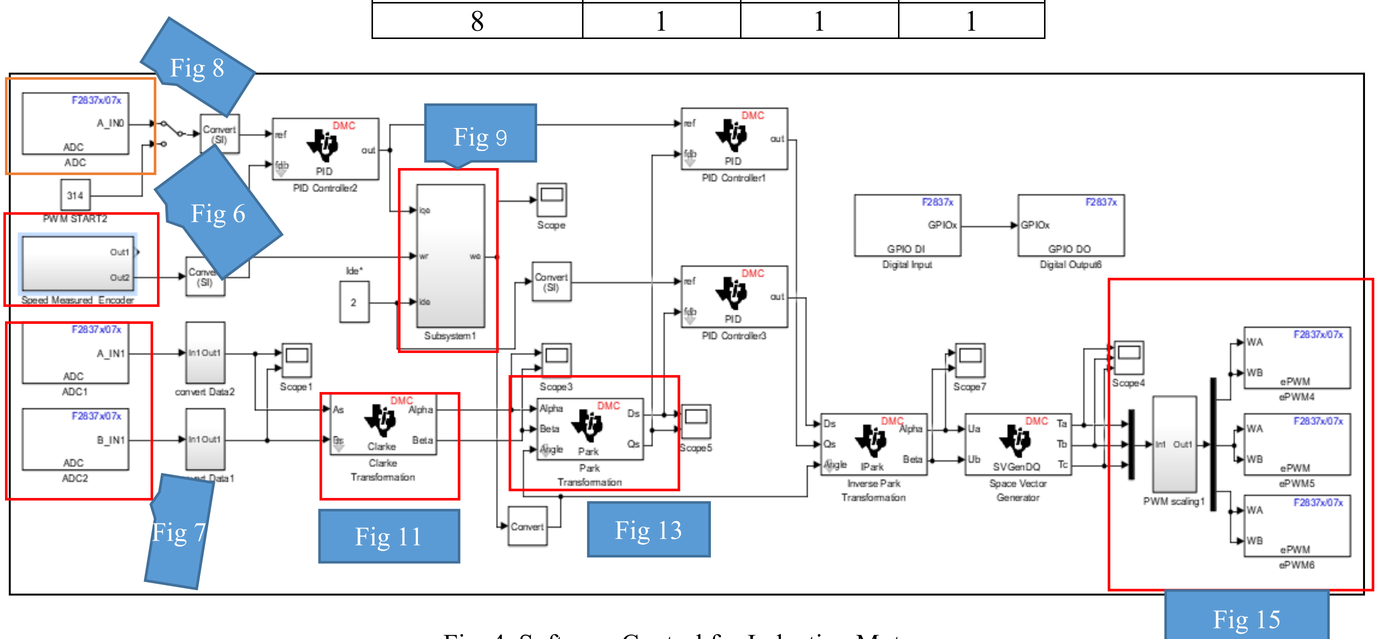

Fig. 4. Software Control for Induction Motors

The signal is modulated (Modulating Waveform) as in Equation (1).

$$V_{control} = \sin(\omega t) + \frac{1}{\sqrt{3}\,\pi}\sum_{\alpha=0}^{\infty}\frac{(-1)^{\alpha}}{\left[(2\alpha+1)-\left(\frac{1}{3}\right)\right]\left[(2\alpha+1)+\left(\frac{1}{3}\right)\right]}\sin\big((2\alpha+1)3\omega t\big)$$
(1).

PID control equations

The parameters of the PID controller used will vary according to the nature of the system. The PID parameters can be found from equation (2).

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{(de)t}{dt} \qquad (2).$$

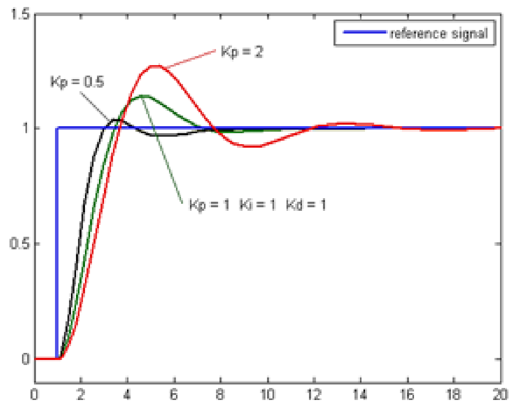

Fig. 5. Graph of control in the case of changes in the values of P, I, and D.

Encoder

The measurement from the encoder in the software defines eQEP1 (enhanced quadrature encoder pulse) and connects it to the TMS320F28377S board, where the received signal is separated into the motor's speed and the motor's angular speed, as shown in Fig. 6.

Fig. 6. Encoder

Current signal reception block and speed adjustment set

The signal obtained from the measurement is in analog form, so the SCALING block is used to convert it into a digital signal. The design allows for current measurement circuits to be only 2 phases to reduce equipment and operational costs. The measured signal from phase U is connected to the ADCA1 signal pin, and the signal from phase V is connected to the ADCB1 signal pin, as shown in Fig. 7.

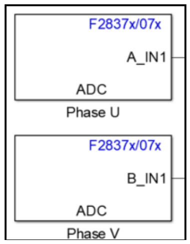

Fig. 7. Current Signal Reception Block

The speed adjustment in the circuit is designed to receive a voltage value that changes according to a variable resistor and is connected to the ADCA0 signal pin, as shown in Fig. 8.

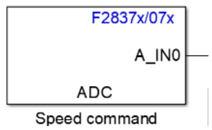

Fig. 8. Speed Adjustment Unit

Determining the Angular Velocity of the Rotor

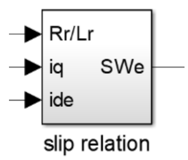

Fig. 9. Angular velocity of the rotor

When receiving input from the speed adjustment and encoder, it will be processed in the block to calculate the angular velocity, as shown in Equation (3).

$$\theta = \int \omega_e dt = \int (\omega_r + \omega_{sl})dt = \int \left(\omega_r + \frac{i_{qs}^{g}}{\tau_s i_{ds}^{g}}\right) \qquad (3).$$

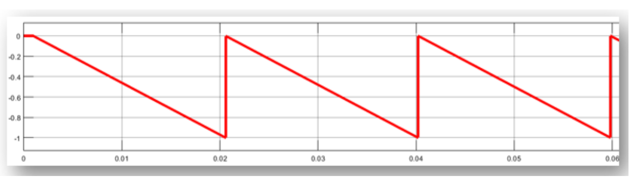
Fig. 10. Angular velocity graph

Clarke Transformation

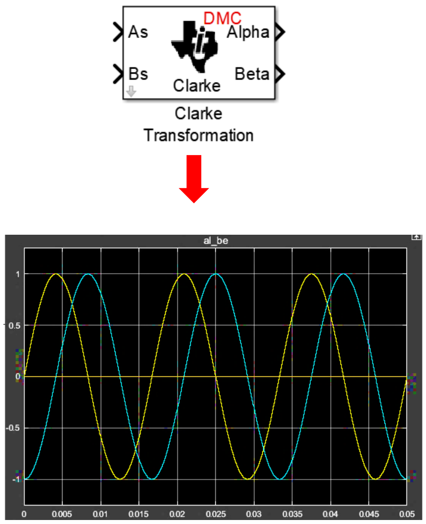

Fig. 11. Convert a graph from 3-phase to 2-phase.

From the signal block that passes through the current sensor, it proceeds to the Clarke transformation. This transformation converts the signal from three phases to two phases, as shown in Fig. 11.

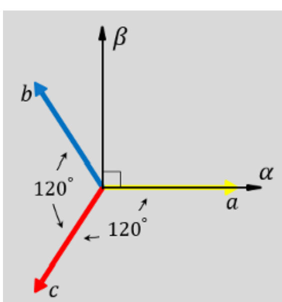

Fig. 12. Transforming three-phase quantities abc onto the $\alpha\beta 0$ axis, Clarke transformation.

The Clarke transformation equation is shown in Equation (4).

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = K \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (4).$$

By choosing the value K= 3/2, the transformation ensures that the peak voltage magnitude of the two-phase and three-phase systems are equal.

Park Transformation

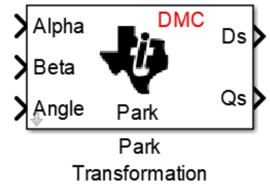

Fig. 13. Clarke Transformation

The Park transformation is an extension of the Clarke transformation to convert two- phase quantities on a stationary frame to two-phase quantities on a rotating frame, as shown in Fig. 14.

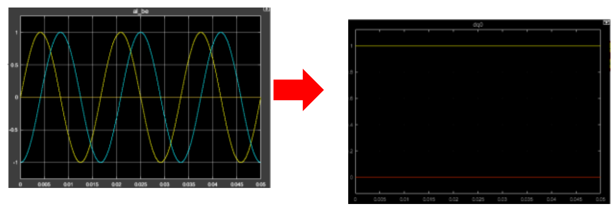

Fig. 14. Park Transformation

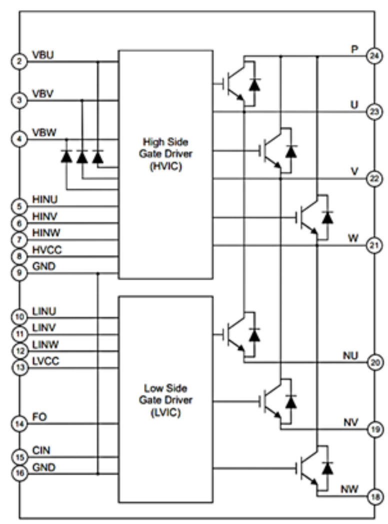

Fig. 15. Block Diagram Power Module

Fig. 15 depicts the internal circuitry of the power module, which is divided into two distinct sections.

The High Side IGBT Drive (HVIC, Bootstrap Diode) is a circuit designed to convert voltage levels in order to effectively drive high- side IGBTs. This is achieved by utilizing Bootstrap diodes. The device incorporates features that restrict current flow and safeguard against excessive voltage levels.

A low-side IGBT drive, also known as LVIC, is an electronic circuit designed specifically to control and operate low-side Insulated Gate Bipolar Transistors (IGBTs). The circuit includes protective mechanisms for short circuit currents, overvoltage protection, system shutdown in response to excessive heat, and signals when these mechanisms are activated.

This module utilizes the IC (integrated circuit) IR2113 as its foundation, which is responsible for controlling 3 sets of IGBTs (6 individual components). Each set functions in the following manner: The IR2113 IC contains a circuit seen in Fig. 16.

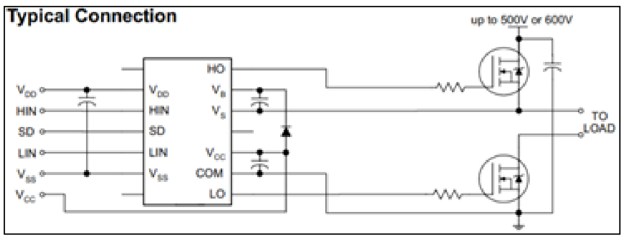

Fig. 16. Block Diagram IR2113

III. SIMULATION AND RESULTS

The MATLAB/SIMULINK environment is utilized for the purpose of modeling and simulating an enhanced indirect vector-controlled squirrel cage induction machine powered by PWM-CSI. The appendix provides a comprehensive description of the simulation parameters. We subject the system to a torque of 1000 Nm after a time interval of 1.5 seconds, commencing at an initial rotational speed of 1425 rpm. A speed proportional-integral (PI) controller adjusts the speed error to match the reference speed. The load torque feed-forward observer produces the torque reference command. The parameters for the decoupling network are determined by this, in addition to the rotor flux reference command. The traditional method involves comparing the currents of capacitors with the currents of a reference machine. The enhanced method involves comparing the real motor currents that have been transformed into d-q values. A unit vector computation block computes the error signal to provide switching pulses for the CSI. Fig. 17 depicts the misalignment of rotor flow in the traditional approach. The enhanced technique utilizes error signals processed with PI (proportional-integral) control to obtain greater decoupling and field orientation. The regulation of the firing angle in a phase-controlled rectifier is achieved by utilizing error signals obtained from comparing the reference and real currents of the capacitor. Fig. 18 illustrates the process of aligning the real machine speed with the desired speed at both the initial starting and while the machine is under stress. Fig. 19 depicts the torque response of the drive.

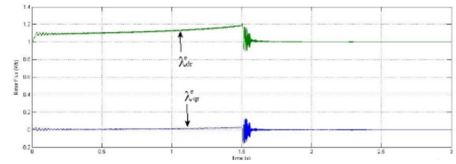

Fig 17 (a). d-q Components of rotor flux in synchronously rotating frame by conventional IVC CSI fed IM drive

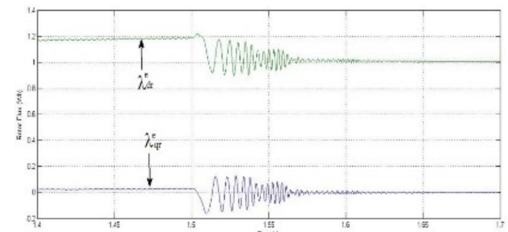

Fig 17 (b). Enlarged view of d-q Components of rotor flux

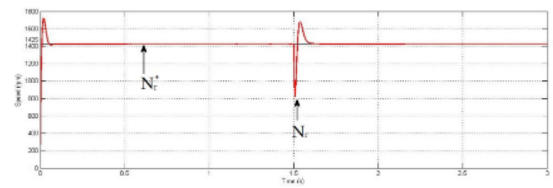

Fig 18. Speed Response of improved IVC CSI fed IM drive

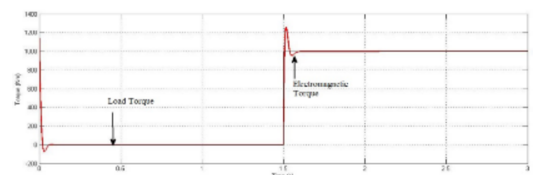

Fig 19. Torque Response of improved IVC CSI fed IM drive

IV. CONCLUSION

We performed studies on an upgraded indirect vector-controlled PWM current source inverter-fed induction machine drive, which includes two current proportional-integral (PI) controllers to enhance field direction and decoupling. The simulation results demonstrate a reasonable level of performance. Implementing load torque feedforward control leads to improved speed responsiveness, less machine vibration, and enhanced dynamic performance. Moreover, a model reference adaptive controller accurately predicts the fluctuation in rotor resistance caused by temperature fluctuations during operation by adjusting its parameters in real-time. An examination of the fluctuation in machine parameters reveals that the system possesses a satisfactory level of resilience.

APPENDIX		
Motor Ratings	**Motor Parameters**	**Value**
Output Power 800hp	Stator resistance Rs	4.55 Ω
Voltage VL-L 3.3kV	Rotor resistance Rr	3.05 Ω
Stator Current 105A	Stator inductance Lls	6.198 mH
No. of poles 4	Rotor inductance Llr	6.198 mH
Rated Torque 3490Nm	Mutual inductance Lm	258 mH
Rated Speed 1425 rpm	Polar moment of inertia J	0.05 kgm2

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