Advanced Direct Torque Control of Induction Motor

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Abstract

Torque ripples during Operation of an Induction Motor may be dampened with the use of a model of the motor's Direct Torque Control. In order to ascertain the efficiency of a motor drive system, traditional methods use a number of different regulating tactics. Since direct torque control (DTC) is simple to implement and provides for excellent transient and steady-state performance when combined with a PI controller and a rotation of coordinates, it has been chosen as the control technique. The suggested model is meant to fix the issue of modulation at high-speed Induction motor. Using the multilevel inverter model as a starting point, the suggested DTC of the induction motor will introduce the control variables and the switching table of the hysteresis controller. PWM's gated pulse is used as part of a switching method. Results from experiments demonstrate improved suppression of torque and flux ripples. Because of this, the Induction motor may be run with the precision of a clock. When activated, the closed-loop flux regulation technique ensures optimal performance in terms of rated speed, torque, and stator flux. The suggested model was validated using MATLAB/Simulink to improve upon previous techniques of analysis.

Key Words: motor, induction, advanced.
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Introduction

In recent years, induction motors have found widespread application in industry as a result of their low cost, great reliability, and rugged construction. Scalar, vector, and direct torque control were all used in the induction motor driving system. In this configuration, an inverter block based on a switching table regulates the stator flux and torque of the induction motor. Stator transition edge and repercussions of stator torque must be taken into account when determining the appropriate inverter state from the duty cycle table. This shift in force is a direct result of the hysteresis regulator being present. In order to regulate the speed of an induction machine, often a three-level inverter logic is used [1]. To eliminate the problems, a DTC-based stable Volt/Hertz approach is adopted. Since stator voltage affects force more than stator motion size does, it may be used to regulate engine speed. To this aim, the stator voltage reference, which is generated by the force regulator, and the stator recurrence, or stator angle, are included in the output of the stator motion regulator.The induction motor's rotational speed is regulated using AI methods. Because of the benefits it provides in terms of improved engine force management and overall execution, fuzzy logic is put into practise by means of the Field Oriented Control technique [3]. Depending on the limits of the engine type, enrollment capabilities are set up. AI has found useful applications in many nonlinear contexts, such as engine drive systems [5].

The DTC method regulates the engine at a predetermined speed without the need for speed sensors. Low-speed errors in voltage estimation and stator resistance render the transition inaccurate [6]. The transition estimation is largely dependent on engine stage voltage. The absence of makes switching between edges that are either fixed or coordinated, and proportional-integral controllers easier inside the vector control framework.

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It also doesn't call for mechanical transducers such as a position encoder or pulse width modulator, both of which may cause delays. DTC regulates the torque without the need for mechanical transducers [7]. Typically, a DTC would use hysteresis comparators to factor in mistakes in flux and stator transition magnitude to decide which stator voltage vector is sent to the engine terminals. We divide the complex plane into six regions, and using an exchange table we can determine which region has the required vector from the results of the hysteresis comparators. It is difficult to keep the machine power inside the hysteresis sections because of the rapid time durations of stator components. There are options available, like expanding the frequency range. DTC refers to the practice of controlling a machine by flux and torque using methods similar to those used in engine regulators. [8]. DTC approach has its own set of benefits and drawbacks [9], just like any other control method. While lower limits make the framework more robust and easier to implement, they also come with a number of drawbacks, including an imprecise ability to control flux and force at low revs, force and current flexing during the variation in the portion in the d-q axis, and differential frequencies with K shifting constants[10].

DTC's massive current and force increase is caused by the close proximity of hysteresis comparators and a limited availability of sufficient voltage vectors. It is possible to reduce the force surge by having the control instrument output any voltage vector and checking the stator changeover vector, which is needed to balance the force and voltageripples [13]. Can further voltage vectors than those utilized in traditional DTC be employed for effective engine control?Due to lack of reliability in both intensity and control circuit, this approach is not suitable for use with mild to moderate pressure. Model-predictive methods [14] are used to regulate induction machine speed by the discrete switching of duty cycle. Creating a balance between active and inactive vectors in real time is one way to increase the total number of available vectors. For the purpose of calculating the inverter yield voltage, it was assumed that the back-EMF waveform would be negligible winding opposition. It makes use of inverter logics at the level of six here [15]. This technique utilized a torque regulator with a spatial PWM and other design tweaks while continuously estimating the back EMF using an adaptive technique based on the model reference. [16]. Recently, a 3 stage BLAC drive was analyzed using the classical approach, and an unusual relationship was discovered between both the voltage level at the shaft and torque ripples.In [17], we see the results of a research that compares the performance of the induction machine in its different operational states. Direct current (DTC)-based drives are regulated in a closed-loop manner. The Induction Machine's DTC system is combined with a photovoltaic sensor-based gadget [18].

The induction motor drive system is modelled in Simulink using a direct torque controlling approach [19], which is then implemented in Matlab. Maxwell is also used to assess the method behind controlling the motor drive system of an induction machine [20]. The AC drive system is controlled by a discontinuous pulse-width modulation method. Here, a space vector technique is used to conduct continuous and split clamping of DPWM on an induction machine [21]. An improvement in ripple reduction [22] is achieved by combining SVM with DTC. The Asymmetric Six-Phase Induction Motor Drive System Utilizes a Synthetic Vector of Direct Current (DTC). Modeling the switching sequence as a function of induction machine performance is aided by this [23]. The circumvent zero-voltage vector, a five-phase, three-level inverter supplied by digital thyristor control (DTC) is simulated in this work [25]. DTC's five-phase induction motor is described in detail in [26]. The linear IM used in urban rail transportation is subject to both continuous and discontinuous switching time control [27]. Torque regulation under two situations is achieved by the current sensor included into the Induction Motor design [28]. In [29], we see a cascading three-level inverter designed to dampen torque ripples in an induction motor. It is the switching activity via different controlling techniques that makes the Induction motor work. Here, a nine-switch inverter type model is used to regulate the symmetrical IM, with the help of a redundant switching table [30]. This standard approach features over-modulation with traditional pulse generating scheme, prolonged time compile by fuzzy logics, and greater drive system voltage ripples. The suggested approach uses a PI controller to generate pulses from pulse width modulation (PWM), allowing for discrete switching. Here, the induction motor's speed serves as the basis for the regulation of the drive system. As a result of using this cutting-edge direct torque control method, flux and torque ripples are being tamed to unprecedented lows. The suggested switching activity is thus enhanced by the use of several control methods for the drive system. Induction motor advanced DTC technology using PI and PWM control methods.

Literature Survey

This section explores numerous research works which are reported best outcomes till date. Saurabh S, et, al. (2018) reported a sensor-based photovoltaic model coupled with Induction Motor DTC. This layout is put to use in the water pumping industry. In order to calculate a vehicle's speed, the flux transition is applied to the stator transition. Altering the dynamic voltage vector is used to recreate the engine stage flows measured using a DC interface current sensor. This framework uses a single current sensor and a single voltage sensor to monitor the voltage and current flowing via the DC interface, respectively, without requiring any external power. Through these two discovered signals, all other necessary quantities are weighed. A photovoltaic display, operated at maximum force, provides energy for the induction machine (MPP). MPPT and P&O methods are used to the PV array to achieve maximum power tracking. In this mash-up mode, the battery life is extended thanks to the employment of water-pumping apps. Narongrit P,et,al.(2012)reported a DTC starting of an induction motor through the constant voltage or frequency methods. By lowering the ripples in the torque and the total harmonic distortion, the switching system helps boost performance. The Direct Torque Control approaches were used to lessen ripples in the stator's flux and torque, which was used in the IM simulation model. As the voltage across the stator increases or decreases, the motor's speed changes accordingly. The inverter's phase transfer during space - vector controls the motor's motion when the stator voltage is statistically controlled. Inefficient multi-inverter systems may switch between single- and three-phase configurations. Furthermore, the motor driving system verifies the reliability of the predicted results.

Najib O, et, al. (2019) reported an Induction Machine DTC Methodology Analysis in detailed Fashion. The many methods of Induction Machine drive system control are outlined in this article. This research explores fuzzy, PI, constant power cycle switching tables, Support vector machines, and neural network models. At low speeds, the DTC's high-frequency switching causes acoustic noise that corrupts the control displays. By focusing just on force and motion, several specific force control strategies seemed to resolve these issues. Several ways to improve DTC demos are described. This study examines wave attenuation, velocity monitoring, exchange interruption, calculation uncertainty, and boundary sensitivity. Vikramarajan J, et, al. (2016) reported a Change the torque to make a three-phase induction motor. By decreasing the speed controller system, the direct torque control approach improves performance. This is mostly decided by the torque and flux axes d-q. When measuring torque, the flux and electromagnetic force are looked at. So, the estimate depends on how the engine is running and how fast it is going. Specifically, the alpha-beta is the location of the change vector. The vector controlling technique is used to discover alpha beta. The hysteresis band finished off the torque and flux regulation. The current control is carried out using a three-phase hysteresis, while the transition control is carried out using a 2-phase hysteresis. Utilizing a comparator on the hysteresis band improves the circuit's switching. The speed controller utility, on the other hand, requires a long-time scale.

Abdul H F, et, al. (2008)reported a Modeling the Induction Machine's DTC with Simulink. There are two methods used to regulate the IM's torque and flux. This study demonstrates an innovative strategy for regulating IM processes. Using switching action, vector control and direct torque control may be implemented. Dynamic behaviour study of stator current performance along the d and q axes. Drive system switching modes made use of the hysteresis band's continuously fluctuating frequency range. Torque and flux in an Induction machine may be modulated using decoupled and independent controlling approaches. Mohammad R N, et, al. (2017) reported that Using DTC, a discrete duty-cycling strategy is used to manage an induction motor. The motor drive system was created using a model predictive technique. The zero voltage vectors are integrated using embeddings alongside different duty cycles. At last, the MPC method is implemented to select the optimal output voltages to lessen the occurrence of motions and force errors. Motor state factors, such as rotor-to-stator transitions, and yield element state predictions, such as electrical force, require a separate conceptual model of the engine for analysis. A SVM for induction motor DTC was described by Farouk M. et al. (2008). In Space Vector Modulation, where PWM, PI, fuzzy, steady switching, switching tables, etc. are utilized to regulate flux and torque. The review demonstrates that the PI-based SVM method on DTC yields superior controlling results. The transition times and duty cycles are varied across several use cases. Here, we derive the stator current by modifying the transition durations for two different controller configurations. DTC may achieve its continuous states without resorting to the torque and flux hysteresis band. In an IM drive system, the controller is implemented by switching activity, and flux is modulated using vector voltage.

Abhinav G K, et, al. (2017)reported a Simulation of an induction motor drive system's direct torque regulating technique. The goal of this research is to develop an induction motor with improved precision in terms of both torque ripple and offset. The inductive machine's power may be adjusted using a controller. There are a few small problems with the standard DTC reception method, such as a gain error, an imbalance in DC, and so on. One solution to these problems is to utilize the PID regulation in the DTC approach, or to replace the integrator with a better one. The accepting engine concept should also be replaced with a new pay structure based on the principles of pleasing outcomes. Authors Pratibha N., et al., 2020, reported Motor speed can be diminished with the aid of induction. where the Induction motor's switching action is supplied into a three-level H Bridge inverter. Inverter's pulse generator employs pulse width modulation (PWM), with the zero-offset voltage providing the carrier signal. In order to lower the overall harmonic content, the inverter makes use of sinusoidal pulse signals. Ripples are mitigated thanks to the steady-state transition response modelled in this study for an IM supplied by an SPWM-based inverter. However, switching loss may happen if the regulator on the pulse generator block is absent. The CSF-DTC method achieves a number of features, including a lower level of harmonics, and a number of other benefits.

Jayakumar T, et, al. (2019) reported Induction motor of DTC based on fuzzy logic system. Where dynamic states of the executing vector regulating technique successfully regulate the motor speed. On the switching activity, the controlling approach employs PI and fuzzy logic controllers. Vector control procedures are carried out using the electromechanical force of a motor. The performance of IM will improve whether it chooses flux or torque reductions. In this scenario, the hysteresis zone of IM exhibits speed-dependent amplitude variation. The inverter output quality may be improved by comparing the flux value to a standard flux.PI and fuzzy combination, on the other hand, takes a long time to execute. It improves performance for various load circuits.

Proposed Method

For an asynchronous machine to provide the desired torque and flux, the incoming signal transmitted to the static converter's switches must be calculated directly. A DTC may maintain the electromagnetic torque and the stator flux module within their hysteresis bands by carefully choosing the inverter's output voltage. Once the torque or the stator flux modules surpass the increase or decrease range of its hysteresis, an appropriate voltage vector is given. Using a switching approach with PWM in conjunction with the Pid, the Induction Motor design in the Simulink model is able to achieve improved direct torque regulation. The induction motor's rotational speed may be controlled via a pulse width modulation (PWM) signal, which is generated by a programmable integrator (PI) controller. Through modelling, we are able to reduce the motor drive system's torque ripple and flux. Using DTC, you may have more precise control over your AC drive system's force output. The standard drive has two hysteresis, a torque assessor, a grid power determination table or pulses, and a torque limiter.

Hysteresis Comparators

For optimal torque management to be effective, the stator flux and torque of the motor must be tightly controlled. The DTC is based on two hysteresis comparators that receive switching pulses based on discrepancies between measured and predicted values of stator flux and torque of the motor. These two controllers set the bar for the voltage vector applications of future switches and/or inverters. If the errors (er or eT) are increasing and reach a higher level, the hysteresis regulator will set its output to one.

Switching Table

The switching table then uses this information to choose the required voltage vector of the inverter, which will set the stator flux and torque of the motor to their desired levels while compensating for any errors in the supply voltage vector. To guarantee the best possible error reduction, we adopted a streamlined comparison of shifting tables in this article.

A popular approach is to employ an acceleration- and guiding-dependent transformation algorithm. The provided reference voltage vector is then read in with the help of a voltage vector modifier. Many different hypotheses and analyses of DTC appeared in published works. In fig.1, a Simulink model of the proposed PWM-based regulating of DTC-IM is shown

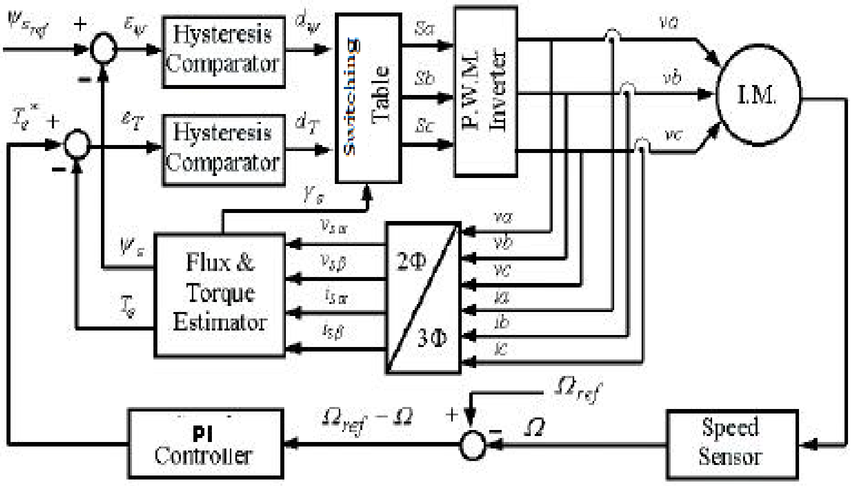

Fig.1 PWM-based control for an induction motor.

The magnitude and direction of the prompt wave vector shift as the voltage vector rotates due to the IM force. Waves may be stabilized in two states, one dynamic and one at rest, by using a dq reference that pivots at the same time as the wave. In this instance, pulses for the PWM inverter were generated by the PI controller, and the design model was verified by comparing the reference speed, synchronization range, and actual speed to the clock timing.. The primary goal is to smooth out the motor drive system's torque fluctuations. Improvements in the controlling section due to less voltage loss as a result of drive system switching activity. Since smoothing out fluctuations in the Induction machine's flux and torque using an adaptive method improves its performance, this is how we've chosen to handle this task. Reducing torque ripples is one way in which the switching technique enhances the outcome.

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The standard DTC method involves rapidly exchanging previously implemented adjustments while keeping torque ripple inside the hysteresis region. Power swell is also a major issue at slow IM speeds. Therefore, at cruising speeds, where it matters, it is feasible to use a constant exchange rate of an ideal power pulse. This ADTC's force expansion has greatly improved, and the frequency of swaps is being handled regularly.

Flux model

$$\omega r = \int \frac{T}{I} dt \quad (1)$$

$$\omega s = \frac{2\pi fh}{P} \quad (2)$$

Rotation frame of the induction motor is $Vq(s) = RsIs + \frac{d}{dt}\phi q(s)$ (3)

$$Vd(s) = RsIs + \frac{d}{dt}\phi d(s) \quad (4)$$

The d-q stator flux is given as $Vq(s) = RsIq(s) + \frac{d}{dt}\phi q(s) + \omega\phi d(s)$ (5)

$$Vd(s) = Rs\, Id(s) + \frac{d}{dt}\phi d(s) + \omega\phi q(s) \quad (6)$$

Speed of the rotor is determined with relation of ω and the axis is

$$Vq(r) = RrIq(r) + \frac{d}{dt}\phi q(r) + (\omega - \omega r)\phi d(r) \quad (7)$$

$$Vd(r) = Rr\, Id(r) + \frac{d}{dt}\phi d(r) + (\omega - \omega r)\phi q(r) \quad (8)$$

Torque of the motor is $T = Tload + I\frac{d}{dt}\omega = Tload + \frac{2}{N} I\frac{d}{dt}\omega(r)$ (9)

The torque under load is equal to the cube root of the product of the rotor's inertia (I) and its rotating speed (r). The numerical results confirmed the benefits of the ADTC approach over the traditional

DTC. Controlling the torque and flux of the speed controller at the precise instant by providing appropriate voltages and by restricting these variables inside corresponding hysteresis sections can allow for decoupled management of force and transition. Significant improvements in terms of flux and torque ripples are brought about by the proposed management strategy. The DTC drives that use hysteresis comparators have the shortcomings of other hysteresis-based systems, including a high force wave and variable exchange repetition.

System Switching Frequency

Providing appropriate voltage vectors to the drive system at a certain time and enclosing these variables within corresponding hysteresis groups can allow for decoupled control of force and transition. While effective, comparators used in DTC motors have the shortcomings of other hysteresis architectures, including high power output and inconsistent exchange frequency. The evaluated stator motion has to be applied all at once in order to generate the maximum excess force below the rated value. In the weak field area, rotor velocity is inversely related to stator velocity and force. As the field weakens, "1/flow rate" restricts stator speed (alpha rate).

Accordingly, the PI controller has modified its gain value to initiate the wave through the flux calculation in the calculator block. In a motor, the rotor and stator flux and torque are both set by the rotary velocity. With the current regulator's adaptive function, the necessary flux range is made available for the motor's control module to work. Via doing these computations, the active state is being determined, and the gate pulse for activating the IM by inverters is being created with the aid of the PWM generating block.

The rotor flux is equated as,

$$\varphi s\ (t+1) = \varphi(t) + T.\ (t) - RsIs, T \qquad (10)$$

In Figure 1, we see how the PI- APWM method prevents the DTC of an induction drive system. To prove the model's validity, a numerical replication using a machine that accepts a different type of load was performed using an IGBT PWM inverter. Results from DTC-based recreation have validated the created DTC system based on the swapping table technique. The flux in the stator and rotor of an induction motor are shown in Figure 2.

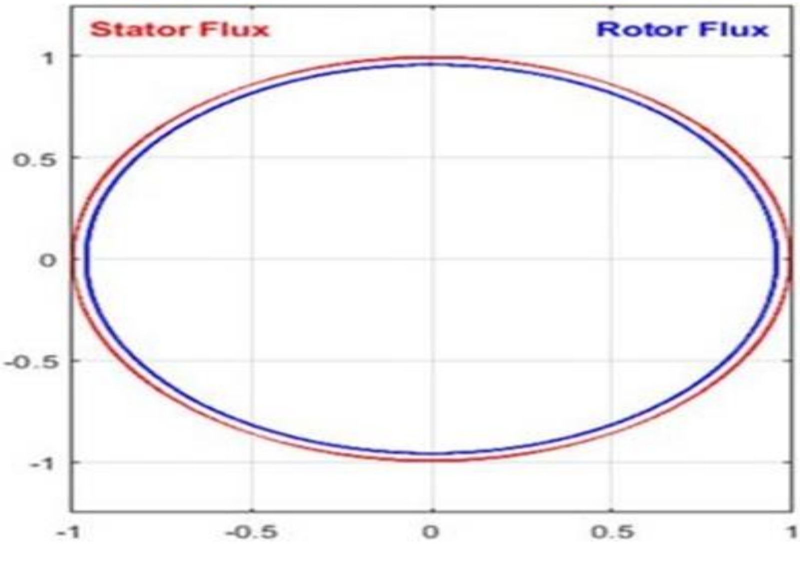

Fig.2 Stator and rotor fluxes

Depending on the characteristics of the distribution buses, a different load balancing system may be used. By carefully choosing the pole pairs, the motor drive system can balance the load and keep the load torque constant. The IM stator winding is supplied with voltage, and the resulting current balances to keep the IM's moment of inertia within the range of 1 to 1 Nm, as seen by the trajectory of the flux vector in space. The suggested IM drive architecture uses an adaptive pulse generating technique and a rapid speed-decreasing control mechanism. This effect model is used to calculate the torque pressure. The response from conventional style spectators is not encouraging. Adjusting the PI controller may, in a sense, enhance this response. The results of the suggested switching strategy employing PWM by tweaking parameters with a PI controller are superior to those of the alternative current technique.

Results and Discussions

As a result, an adaptive PWM switching strategy based on a PI controller was used in the design of a state-of-the-art direct torque regulation drive system for an induction machine. Overall performance is enhanced as ripples in the flux and torque are reduced. The specific flux and torque with reduced ripples have been found in line with the speed of the motor and the available flux via the procedure of testing the reference speed. The induction motor's stator flux is depicted in Figure 3; it is 0.95 wb, as in the reference.

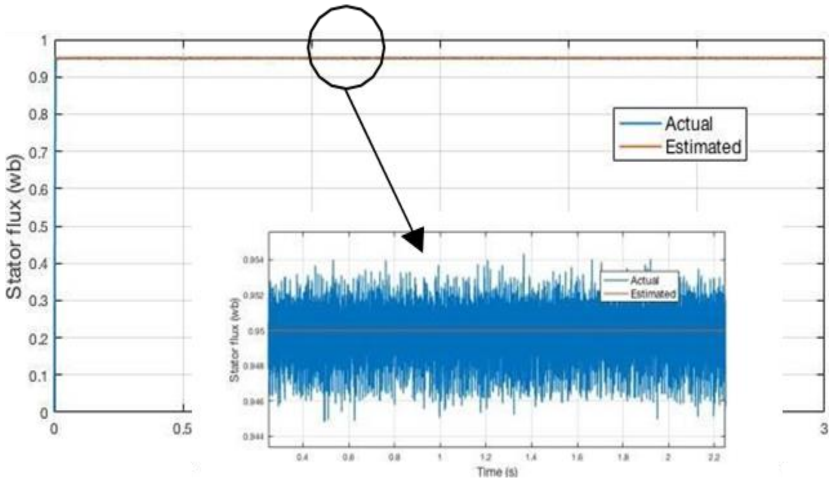

Fig.3 Stator flux of IM

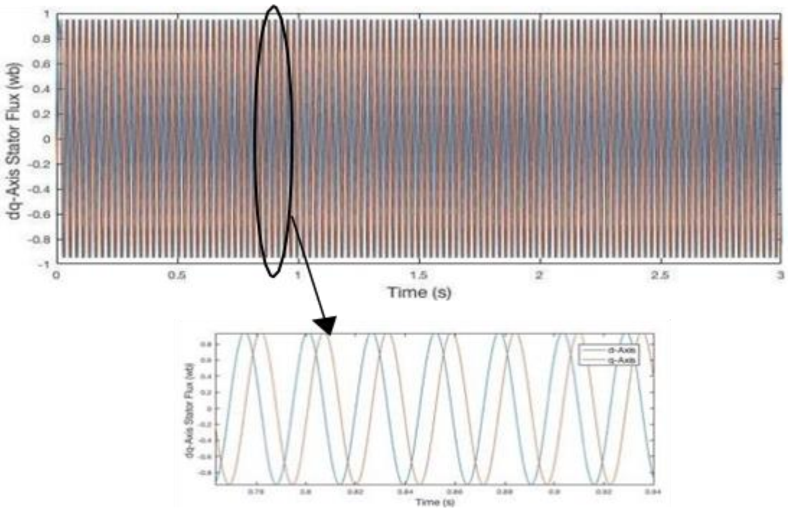

Fig 4.D-q axis stator flux of IM.

The flux stator is shown in Fig. 4 long awith the d-q axis. When the stator currents are clearly circular and its direction is practically sinusoidal, as shown in Fig. 5, the suggested system's capability is proven. As can be seen in fig. 4, the induction motor operates in the d-q stationary reference mode. This made use of the 18Hz spectrum, which corresponds to the 1.2-rpm torque ripples.

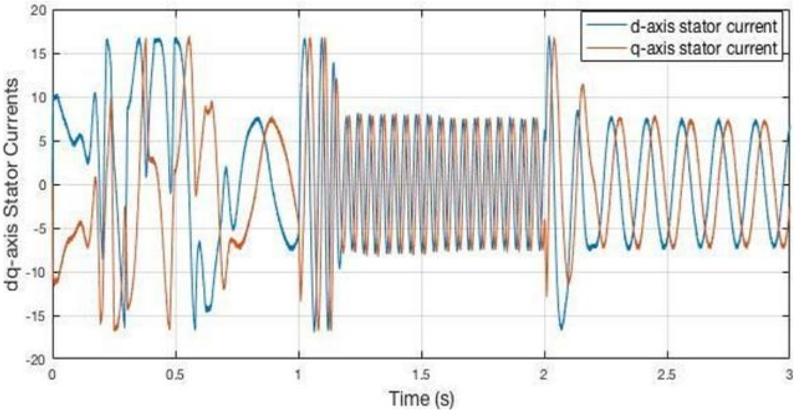

Fig.5.D-qaxisstatorcurrentsofinductionmotor.

As shown in Figure 6, when there is an abrupt shift in speed from -.5 to 1pu, and when the load torque is varied to the following values of (2, 6, 4.2) N.m, the motor speed follows the reference with a little bit of overshoot. . With the speed regulator in mind, the standard torque is determined and compared to the actual torque. Next, the torque error is compared to the torque hysteresis controller to see if it falls beyond the tolerance range. Measured flux is compared to the standard flux in the torque hysteresis range. Changing the inverter's yield to control the acceptance motor requires calculating the motor's phase transition, force, and voltage vector.Fig. 7 illustrates the difference in speed between what was estimated and what was really travelled.

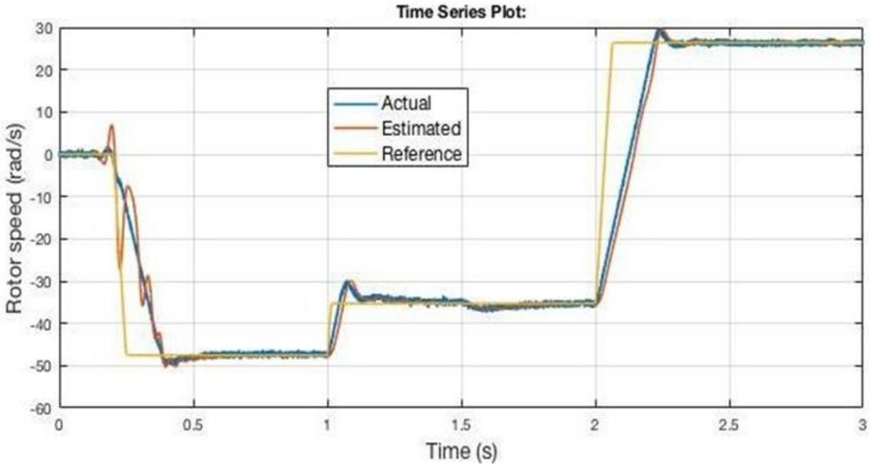

Fig. 6 Rotor speed of IM

The data above demonstrate the control system's efficacy by showing how the proposed DTC immediately rejects the load interruption with a modest error signal, with the exception of time when the load is suddenly adjusted. With MATLAB/Simulink simulations serving as feedback in the closed loop to ensure the speed estimator structure's validity, we can see that the real and projected motor speed converged to the reference speed during trajectory tracking. Nonetheless, there seems to be a little static problem when the motor speed changes.

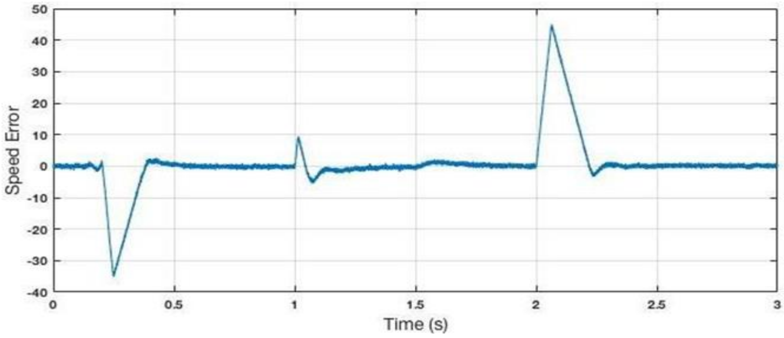

Fig.7 The error of the estimated and reference speed

Table 1. Comparison of Existing method with the proposed method

Parameter	Vdc	Speed/Time	Torque	Torque ripple (%)	Flux ripple (%)
Existing Method	520V	1000rpm at 0.5sec	1.2Nm	5	2
Proposed method	580V	1000rpmat 0.25sec	1.2Nm	2.5	1.3

When compared to the typical switching table methodology of DTC, the suggested method achieves a reduction in the ripple and overshoot, which can be seen when the waveforms are analyzed. In conclusion, a high tracking accuracy is seen regardless of the speed, both external and internal disturbances can be rejected, and the reaction time may be improved.

Conclusion

As a result, adaptive PWM is optimized by tuning using a PI controller, allowing for a large current to flow through the rotor while minimizing torque ripples. To evaluate the ripple in the flux,and statorvoltages in the d-q are synchronized. Torque is calculated by squaring the product of the predicted engine current vector and the calculated stator flux vector. Next, we compare the assessed transition's scope and power to our baseline values. Time spent computing and the energy lost from the motor's constant spin are two factors that slow down this project. If the measured flux deviates too much from the reference value or the tolerance for deviation is exceeded, the variable frequency drive is turned off and the measured torque and flux may revert. Therefore, the findings of the Advanced DTC of Induction motor design model were superior than those of the conventional method. The motor speed controller unit in the proposed design uses a PI controller based PWM method to regulate torque. This adaptive method improves functionality by lowering torque ripples.

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