Comparative Study on Field Weakening Strategy for a Vector-Controlled Induction Motor

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Abstract: The electric drives used in industry are changeable Speed Drives and in most of these drives AC motors are applied. Induction motors are the standard in these drives. Induction motors are today the most extensively used ac machines due to the beneficial mix of low cost, reliability and presentation. So effective control of IM parameters e.g. speed, torque and current is of utmost importance. From the investigation of the control methods it is known that torque control of IM can be achieved according to different procedures ranging from inexpensive Volts/Hz ratio strategy to sophisticated sensorless vector control scheme. It is very much necessary to design a controller to obtain an ideal electric vehicle motor drive system which would have high efficiency, low torque ripple and minimum current distortion. The electric drives used in industry are Adjustable Speed Drives and in most of these drives AC motors are applied. Induction motors are the standard in these drives. Induction motors are today the most widely used ac machines due to the advantageous mix of low cost, reliability and presentation. So effective control of IM parameters e.g. speed, torque and flux is of utmost importance. This work investigate the control methods it is known that torque control of IM can be achieved according to different procedures ranging from inexpensive Volts/Hz ratio strategy to sophisticated sensorless vector control scheme.

Keywords - Induction Motor Drive, Current controller saturation, Field Weakening Strategy for Induction Motor Drive, field weakening, six-step mode.

I. INTRODUCTION

In excess of the preceding decades DC machines were utilized widely for variable speed applications due to the decoupled control of torque and flux that can be accomplished by armature and field current control separately. DC drives are worthwhile in numerous viewpoints as in delivering high starting torque, simplicity of control and nonlinear introduction. In any case, because of the real disadvantages of DC machine, for example, nearness of mechanical commutator and brush gathering, DC machine drives have turned out to be out of date today in modern applications.

The vigor, minimal effort, the better introduction and the simplicity of support make the asynchronous motor worthwhile in numerous modern applications or general applications. Squirrel cage induction motors (SCIM) are more generally utilized than all whatever is left of the electric motors as they have every one of the benefits of AC motors and are less expensive in taken a toll when contrasted with Slip Ring Induction motors; require less support and tough development. On account of the nonattendance of slip rings, brushes support duration and costs related with the wear and tear of brushes are limited. Because of these points of interest, the induction motors have been the execution component of a large portion of the electrical drive framework for every related viewpoint: starting, braking, speed change and speed reversal and so on.

To achieve the best effectiveness of induction motor drive (IMD), numerous new methods of control has been produced over the most recent couple of years. Presently a-days, utilizing current high switching recurrence control converters controlled by microcontrollers, the recurrence, stage and greatness of the contribution to an AC motor may be changed, finally the motor speed and torque may be proscribed. Presently, it may be possible to deal among the axis control of machine drives by variable speed in low power applications mostly because of combined growth of the power electronics and numerical electronics. The dynamic operation of the induction machine drive system has an important role on the overall presentation of the system of which it is a part.

II. FIELD WEAKENING CONTROL THEORY

A. Rule of DTC Conspire

The fundamental rule of DTC is to directly choose stator voltage vectors as indicated by the torque and flux blunders which are the contrasts between the references of torque and stator flux linkage and their real esteems. The administering condition for torque for this plan is because of the association of stator and rotor fields. Torque and stator flux linkage are registered from measured motor terminal amounts i.e. stator voltages and current. An ideal voltage vector for the switching of VSI is chosen among the six nonzero voltage vectors and two zero voltage vectors by the hysteresis control of stator flux and torque.

B. Types of control schemes

There are two important steps to design a control system for electrical drives

1. In order to accomplish the analysis and the evaluation of the system, first the drive system has to be converted into a mathematical model.

2. When external perturbations are present, through an optimal regulator the imposed response on the system is obtained.

There are two major directions of IM control

- Analogue: direct measurement of the machine parameters (for the most part the rotor speed), which are contrasted with the reference motions through shut control circles**.**
- Digital: estimation of the machine parameters in the sensorless control schemes (without measuring the rotor speed).

The parameter estimation can be done by implementing following methodologies

- Slip frequency calculation method •Speed estimation using state equation;
- Estimation based on slot space harmonic voltages;
- Flux estimation and flux vector control;
- Direct control of torque and flux;
- Observer-based speed sensorless control;
- Model reference adaptive systems;
- Kalman filtering procedures;
- Sensorless control with parameter adaptation;
- Neural network based sensorless control;
- Fuzzy-logic based sensorless control.

Classification of control procedures for IM from the view point of the controlled signal :
Scalar control**:** based on relationships valid in steady state, only magnitude and recurrence of voltage, current and flux linkage space vectors are controlled. Slights the coupling impact in the machine.

Vector control: based on relations substantial in dynamics state, size and recurrence as well as prompt position of voltage, current and flux linkage space vector are controlled. The most prevalent vector control strategies are the Field oriented control (FOC) and DTC.

Scalar controlled drives give fairly substandard introduction, however simple to actualize. Their significance has been decreased as of late due to the unrivaled introduction of vector controlled drives which is requested in numerous applications

C. Direct Torque Control

DTC was first presented by Takahashi in 1984 in Japan and by Dopenbrock in 1985 in Germany and today this control conspire is considered as the world's most developed AC Drives control innovation. This is a basic control methodology which does not require organize change, PI controllers, and Pulse width modulator and position encoders .This system brings about direct and free control of motor torque and flux by choosing ideal inverter switching modes. The electromagnetic torque and stator flux are figured from the essential motor sources of info e.g. stator voltages and currents . The ideal voltage vector choice for the inverter is made in order to confine the torque and flux blunders inside the hysteresis groups. The upsides of this control method are snappy torque reaction in transient operation and change in the relentless state efficiency.

D. Current Model

In stationary reference frame, current model is globally stable and the drives operation can be extended down to zero speed. But this model is much complex as compared to voltage model as here the knowledge of rotor speed and stator current is required to estimate rotor flux linkage and stator flux can be estimated based on the estimation of rotor flux linkage. so there is no integration drift problem in current model at low speed region. However estimation accuracy is affected due to motor parameter variation, particularly rotor resistance variation becomes dominant by skin effect and temperature.

It is ideal to have a hybrid model based on the unique features gained by both models respectively where the voltage model would be effective at higher speed range and current model at lower speed range.

E. Field Weakening Control

In specific applications such as propulsion purpose, the induction motor has to operate at speeds higher than the rated one, the field (flux) weakening is required which indicates the technique by which the motor's speed can be expanded over the evaluated speed. To expand the delivered torque to a greatest level in the field weakening district, it is fundamental to legitimately change the attractive field by keeping up the most extreme voltage and greatest current. The loss of torque and power on account of not appropriately modifying the machine flux is up to 35% [1]. Thus, the machine flux ought to be debilitated in such a way, to the point that it would ensure a most extreme conceivable torque in the entire speed range.

F. Field Weakening Control Methods

The essential rule for field weakening is that the attractive field of the machine working above appraised speed level would be diminished due to the limit in the machine's voltage capability, which is imposed by a stator winding voltage limit and the DC link voltage.

III. LITERATURE REVIEW

SR.NO.	TITLE	AUTHORS	YEAR	METHODOLOGY
1	Predictive Torque Control of Induction Motor Sensorless Drive Fed by a 3L-NPC Inverter	M. Habibullah, D. D. C. Lu, D. Xiao, J. E. Fletcher and M. F. Rahman	2017	A three-level neutral-point clamped inverter
2	Strategy for Restarting the Free-Running Induction Motor Driven by a High-Voltage Inverter Based on V/F Fuzzy Control	W. Hu, Z. Wu, L. Sun and X. Cai,	2016	A fuzzy-logic control method
3	Rotor Flux-Oriented Control of Induction Motor With Synchronized Sinusoidal PWM for Traction Application	S. K. Sahoo and T. Bhattacharya,	2016	A vector-controlled squirrel cage induction motor drive with synchronized sinusoidal pulse width modulation
4	A Speed-Sensorless FS-PTC of Induction Motors Using Extended Kalman Filters	M. Habibullah and D. D. C. Lu,	2015	An extended Kalman filter (EKF)-based
5	Low-Order Harmonic Suppression for Open-End Winding IM With Dodecagonal Space Vector Using a Single DC-Link Supply	S. Pramanick, N. A. Azeez, R. Sudharshan Kaarthik, K. Gopakumar and C. Cecati	2015	A procedure to suppress low-order harmonics for an open-end winding induction motor drive
6	Control for high momentary torque from vector-controlled induction machines	V. T. Buyukdegirmenci and P. T. Krein	2015	A short-term induction motor torque capabilities and investigates field-weakening strategies
7	Wide speed range six-step mode operation of IPMSM drives with adjustable dc-link voltage	T. Lange and R. W. De Doncker,	2014	A strategy that is based on a voltage angle control in order to improve dynamics
8	FPGA based Synchronized Sinusoidal Pulse Width Modulation with smooth transition into overmodulation and six step modes of operation for three phase AC motor drives	M. Aravind and T. Bhattacharya	2012	A triangular carrier comparison based Synchronized Sinusoidal Pulse Width Modulation

M. Habibullah, D. D. C. Lu, D. Xiao, J. E. Fletcher and M. F. Rahman, [1] A limited state prescient torque control framework for a speed-sensorless induction motor drive provided from a three-level impartial point braced inverter is proposed. For sensorless operation, the controller requires evaluated speed and rotor/stator flux. In this investigation, the rotor speed and the rotor flux are evaluated precisely by utilizing an expanded Kalman channel. Because of the vast number of accessible voltage vectors, the control calculation for a multilevel inverter-encouraged drive is computationally costly. As a result, the controller requires longer execution time that yields more awful torque, flux, and speed reactions, particularly at low-speed. With a specific end goal to diminish the computational weight, a lessened number of voltage vectors for forecast and improvement in the control calculation is proposed in this document. The indication of the stator flux deviation and the position of the stator flux are anticipated to reduce the quantity of voltage vectors tried. Exploratory outcomes represent that the proposed encoderless procedure can evaluate the speed precisely finished a wide speed range including field-weakening district while keeping up vigor and fantastic torque and flux reactions.

W. Hu, Z. Wu, L. Sun and X. Cai, [2] The adoption of the conventional V/f control strategy for restarting a free-running induction motor driven by a high-voltage inverter tends to cause an impact current on the stator side. This document proposes a fuzzy-logic control routine. The method makes the output frequency follow the motor speed without knowledge of motor parameters or speed feedback when the motor is in a field-weakening state. Then the motor can be accelerated to the rated speed after the stator flux is increased to the rated value, thereby avoiding a large stator current when restarting the motor. Besides, the proposed method is of good robustness to the load coefficient when the load coefficient deviates from the rated value. The simulations verify that the theoretical analysis and the proposed method are correct and effective.

S. K. Sahoo and T. Bhattacharya, [3] This document proposes a vector-controlled squirrel cage induction motor drive with synchronized sinusoidal heartbeat width tweak (PWM) for footing applications. In footing applications, switching misfortune in protected door bipolar transistors is imperative, and consequently, a switching recurrence of couple of hundred hertz is utilized as a part of these gadgets. A triangular carrier examination based synchronized sinusoidal PWM for medium-voltage inverters with low switching recurrence (under 500 Hz) is proposed in this document. To have great dynamic conduct of the synchronization plot, the triangular carrier is created from the prompt voltage references in a stage bolted manner.

A synchronous carrier-based overmodulation plot that guarantees linearity between the reference voltage and the key motor terminal voltage is likewise proposed. An inverse gain-based linearization technique is utilized to coordinate the reference and inverter yield voltage central. This over regulation procedure comes up short at the zone of high estimations of adjustment record and a reference change approach is utilized as a part of that zone. The proposed PWM and over tweak schemes incorporate techniques for field weakening and harmonic current estimation accessible in the writing and propose a solidified plan, which guarantees great dynamic reaction with wide speed variety for rotor flux-oriented induction motor drive. The scheme is experimentally verified and the results are presented.

M. Habibullah and D. D. C. Lu, [4] A sensorless limited state prescient torque control (FS-PTC) methodology utilizes stator current, evaluated stator and rotor flux, and assessed rotor speed to predict stator flux and torque. Direct utilization of measured stator currents and utilizing a loud evaluated speed in the forecast demonstrate corrupt the enduring state introduction as far as higher current aggregate harmonic twisting (THD), torque swell, and flux swell, especially at low speeds. This document proposes an expanded Kalman channel (EKF)- based, which is a promising state spectator, enhanced forecast model of sensorless FS-PTC for induction motor drives. The EKF has been utilized to gauge rotor speed, rotor/stator flux, and stator currents precisely. The evaluated stator currents, rather than measured currents, are sustained back to the expectation model, and in this way, little stator current THD is affirmed. Contingent upon the summoned speed, either the rotor current model or the open-circle stator voltage display is proposed for the EKF to accomplish better introduction in a wide speed range, including the field-weakening district. The proposed control framework has been confirmed tentatively, and great torque and flux reactions, heartiness, and stable operation at lower and higher speeds have been achieved.

S. Pramanick, N. A. Azeez, R. Sudharshan Kaarthik, K. Gopakumar and C. Cecati, [5] This document proposes a technique to stifle low-arrange harmonics for an open-end winding induction motor drive for a full adjustment range. One side of the machine is associated with a fundamental inverter with a dc control supply, though the other inverter is associated with a capacitor from the opposite side. Harmonic concealment (with finish end of fifth-and seventh-arrange harmonics) is accomplished by acknowledging dodecagonal space vectors utilizing a consolidated pulsewidth adjustment (PWM) control for the two inverters. The skimming capacitor voltage is intrinsically controlled during the PWM operation. The proposed PWM methodology is appeared to be legitimate for the whole adjustment range, including overmodulation and six-advance method of operation of the fundamental inverter. Experimental results have been presented to validate the proposed procedure.

V. T. Buyukdegirmenci and P. T. Krein, [6] This document evaluates here and now induction motor torque abilities and examines field-weakening systems to give high fleeting torque by means of vector controllers. Scalar controllers lessen voltage beneath the base speed to maintain a strategic distance from attractive saturation and don't totally use the accessible dc transport voltage. Vector controllers accomplish decoupled control of torque and flux, and can utilize accessible dc transport voltage beneath the base speed without soaking the machine. Contrasted with most extreme torque-per-ampere control, the examination meant to boost fleeting torque constrained just by the dc transport voltage. Results for vector controllers demonstrate that field-oriented-controlled induction motor drives give the most elevated pinnacle torque capacity at low speeds, though direct torque-controlled drives give higher pinnacle torque at high speeds. For the test machine, these controllers are appeared to help up to 2.5 times the breakdown torque below a critical speed.

I. Ralev, T. Lange and R. W. De Doncker, [7] Driving a synchronous machine in finished adjustment district and six-advance mode is a typical approach to diminish switching losses in the inverter and completely use inverter yield voltage. Principle issues concerning this working zone in mix with cutting edge field oriented control are saturation of the current controller and lessened torque dynamics. This document introduces a methodology that is based on a voltage point control with a specific end goal to enhance dynamics and defeat security issues of the PI-controller. An extra dc-interface voltage control circle for drive trains including a dc/dc converter gives the creator another level of opportunity to enhance the drives general productivity. Exact control of both dc-connection and inverter yield voltages makes the likelihood to move six-advance mode to a discretionary working locale including base speed.

M. Aravind and T. Bhattacharya, [8] This document shows a triangular carrier examination based Synchronized Sinusoidal Pulse Width Modulation (SPWM) for medium voltage inverters with low switching recurrence (under 500Hz). The fundamental necessities of synchronous PWM like 3-stage symmetry, quarter wave symmetry and half wave symmetry are kept up. To have great dynamic conduct of the synchronization plot, the triangular carrier is created from the prompt voltage references in a stage bolted way. The triangular carrier correlation based technique is stretched out in the overmodulation zone as well. An inverse gain based linearization technique is utilized to coordinate the reference and inverter yield voltage basic. This overmodulation procedure falls flat at the zone of high estimations of balance record and a reference adjustment approach is utilized as a part of that zone. These synchronization and overmodulation techniques are executed in a FPGA stage and the outcomes are exhibited.

IV. PROBLEM STATEMENT

To maintains current control even at the condition when the inverter output is saturated to six-step mode of operation. Whenever the inverter voltage saturation is detected, the q-axis current loop is executed through flux current control loop and, hence, current control is not lost at any point of time [1]. In field weakening mode while keeping the output power constant. During field weakening, the motor is running at the maximum available current from the inverter, while the maximum available voltage is getting smaller. At one point, while using a FOC method to run the motor, there is a high potential of saturating the PI current controllers. If the controllers saturate, the control over the motor is lost.

V. CONCLUSION

This work presents an extensive survey on the control strategies of an Interior Motor. The objective of this work is to review a Field Oriented Control capable of Field Weakening, taking into consideration the inverter limits, and to investigate the dynamics of the controllers while running the motor in field weakening mode. The total losses in the motor consist of the iron losses, copper losses (in the winding) and stray losses. The copper losses are the most dominant ones below base speed ωB while the iron losses grow significantly as the speed is further increased. In addition to high torque requirements at low speeds, traction applications require drive systems that provide constant power at high speeds. The speed of the motor increases with the terminal voltage up until the base speed. The Field Oriented Control FOC is an indirect closed loop control method. The speed of motor needs to be measured, and fed as a feedback, in order to perform this algorithm. The torque produced by the permanent magnet motor is controlled indirectly, by controlling the stator current.

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