Indirect Vector Control of an Induction Motor using Space vector PWM of Three Phase Converters

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ABSTRACT:

This paper presents a new control strategy for three-phase induction motor drive using DC link measurement, i.e. an indirect vector control strategy is used which includes independent speed & torque control loops and the current regulation from which the rotor position is calculated thereby overcoming the limitation (i.e. sluggish response) of volts per hertz controlled industrial drives. For closed-loop control, the feedback signals including the rotor speed, flux and torque are not measured directly but are estimated by means of calculations. The inputs to these equations are the reconstructed waveforms of stator currents and voltages obtained from the dc link parameters i.e. Idc and Vdc and not measured directly on stator side.

The proposed drive thus requires only one sensor in the dc link to implement the closed-loop speed and torque control of a three-phase induction motor without using any sensor to the Induction Motor. The experiments have been conducted on an induction motor and the simulation results on a 36.77kW induction motor drive in MATLAB/Simulink software have been presented and the results show fast dynamic response and good agreement between the actual values and the estimated values of torque and speed. Replacement of the open-loop control strategy of existing v/f drive by the proposed closed-loop strategy appears to be possible without requiring any additional power components and sensors.

Key Words: Adjustable Speed Drives,Field Oriented Control,Induction Motor, Low-Pass Filter,Pulse Width Modulation,Voltage Source Inverter.

INTRODUCTION:

Electrical AC machines have been playing an important role in the industry progress during the last few decades. All kinds of electrical AC drives have been developed and applied, which serve to drive manufacturing facilities such as conveyor belts, robot arms, cranes, steel process lines and so on. With the advances in the power semi-conductor devise converter topologies , microprocessors application specific ICs (ASIC) and computer aided design techniques since 1980s, AC drives are currently making tremendous impact in the area of variable speed motor control methods.

Importance of Induction Motors in industrial applications

1.Simple construction.

2.High reliability.

3.Ruggedness.

4.Low cost.

5.Minimum maintenance.

6.Sufficiently high efficiency.
7.Needs no extra starting motor and need not be synchronized Furthermore, in contrast to the commutation dc motor, it can be used in an aggressive or volatile environment since there are no problems with spark and corrosion.

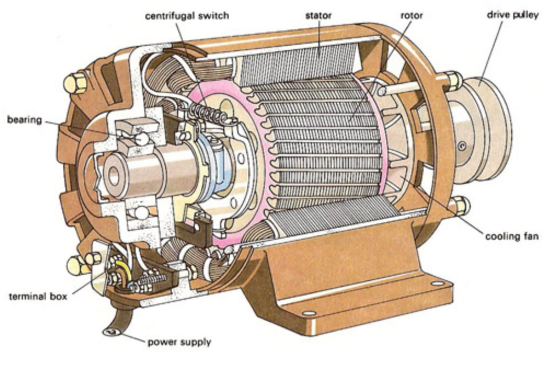

Figure11: A simple Induction Motor.

The stator and the rotor are electrical circuits that perform as electromagnets. Stator laminations are stacked together forming a hollow cylinder[1]. The rotor consists of a stack of steel laminations with evenly spaced conductor bars around the circumference.

The main advantage is that induction motors do not require an electrical connection between the stationary and the rotating parts of the motor. Therefore, they do not need any mechanical commutator (brushes), leading to the fact that they are maintenance free motors. Besides, induction motors also have low weight and inertia, high efficiency and a high overload capability. Therefore, they are cheaper and more robust, and less proves to any failure at high speeds. Furthermore, the motor can work in explosive environments because no sparks are produced.

Vector Control or Field Orientation Control Field Oriented Control (FOC) of a 3-phase AC motor involves imitating the DC motors' operation. All controlled variables are transformed to DC instead of AC via mathematical transformation. The goal is to control torque and flux independently[2].There are two methods for Field Oriented Control (FOC):

Direct FOC
Rotor flux angle is directly computed from flux estimation or measurement.
Indirect FOC

Literature Review:

The volts per hertz (v/f) IM drives with inverters are widely used in a number of industrial applications promising not only energy saving, but also improvement in productivity and quality. The low cost applications usually adopt v/f scalar control when no particular performance is required. Variable-speed pumps, fans are the examples. For those applications which require higher dynamic performance than v/f control, the dc motor like control of Induction Motor that is called, the field oriented control (FOC) is preferred.

During the last few years, a particular interest has been noted on applying speed sensor less FOC to high performance applications that is based on estimation of rotor speed by using the machine parameters, instantaneous stator currents and voltages [3]-[7]. The benefits of speed sensor less control are the increased reliability of overall system with the removal of mechanical sensors, thereby reducing sensor noise and drift effects as well as cost and size.

However to exploit the benefits of sensor less control, the speed estimation methods must achieve robustness against model and parameter uncertainties over a wide speed range. Instead of implying the orientation of the flux vector, the flux vector is directly measured from the terminal electrical quantities of voltage and current.

The adaptive observers like Luenberger observer or the extended Kalman filter gets accurate estimates under detuned operating conditions but these solutions are computationally intensive, require more memory space and are difficult to tune because the initial values of three covariance matrices have to be assumed and selected after much trial and error.

While the entire speed sensor less techniques eliminates the use of mechanical speed sensor, they require the stator current and stator voltage signals as input. This requires at-least two current sensors and two voltage sensors on the stator side. It is difficult to get current sensors with equal gains over the wide range of frequencies, voltages and currents used in a practical inverter. The problem is exacerbated if the motor windings are not perfectly balanced or if the current sensors have some dc offset. Over last few years, techniques of stator current reconstruction from the dc link current have been suggested in literature [8]-[9].

During recent years there has been significant interest in techniques for eliminating the current sensors at the inverter output terminal in favor of using the single dc link current sensor to regulate all three phase currents. Motivations for this research effort have included cost savings associated with reducing the number of current sensors, and elimination of potential load unbalances caused by unequal gains of the output terminal current sensors. To reduce the number of sensors, different methods have been reported in literatures which are used for the reconstruction of phase currents from dc link current measurement. Vector Control Analogy with Separately Excited DC Motor.

PROPOSED METHODLOGY:

In vector or field oriented control both the magnitude and phase alignment of vector variables are controlled. The invention of vector control in the beginning of 1970s and the demonstration that an induction motor can be controlled like a separately excited dc motor brought renaissance in the high performance of control of ac drives. Because of dc like performance vector control is also known as "decoupling" orthogonal or trans vector control. Field orientation is a technique that provides a method of decoupling the two components of stator current: one producing the air-gap flux and the other producing the torque.

Figure.2 explains the principal of vector control. Here analogy of three phase induction motor with separately excited dc motor is shown as from [2]. For field oriented control, three phase induction motor is run like a separately excited dc motor. For this a d-q axis model of induction motor is must.

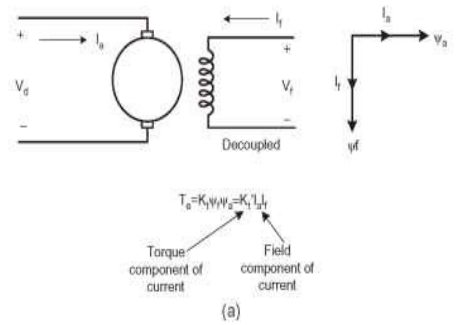

Figure12: Vector analogy of separately excited dc motor.

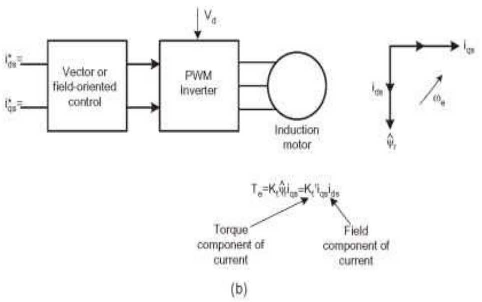

Figure13: Vector controlled induction motor.

In a DC motor the field flux ΦF produced by the field current IF is perpendicular to the armature flux ΦA produced by the armature current IA. These fields which are stationary in space with respect to each other are orthogonal or decoupled in nature. Therefore when the armature current is controlled to control torque, the field flux remains unaffected enabling a fast transient response.

DC machine like performance can also be extended to an Induction Motor if the machine is considered in a synchronously rotating reference frame where the sinusoidal quantities appear as DC commands.the Induction Motor with the inverter and vector control is shown with two control current inputs. These currents are the direct axis component and quadrature axis component of the stator current respectively in synchronously rotating reference frame. With vector control, irds is analogous to field current IF and irqs is analogous to armature current IA of a DC machine.

In a typical AC induction motor, three alternating currents electrically displaced by 120° are applied to three stationary stator coils of the motor. The resulting flux from the stator induces alternating currents in the 'squirrel cage' conductors of the rotor to create its own field these fields interact to create torque. Unlike a DC machine the rotor currents in an AC induction motor cannot be controlled directly from an external source, but are derived from the interaction between the stator field and the resultant currents induced in the rotor conductors.

Optimal torque production conditions are therefore not inherent in an AC Induction motor due to the physical isolation between the stator and rotor. Vector control seeks to recreate these orthogonal components in the AC machine in order to control the torque producing current separately from the magnetic flux producing current so as to achieve the responsiveness of a DC machine.

Space Vector Definition and Projection:

Assuming that, ia, ib, ic are the instantaneous currents in the stator phases, then the complex stator current vector is defined by: $i_s = i_a + \acute{a} i_b + \acute{a}^2 i_c$

Where $\alpha = e\frac{j2\pi}{3}$, $\alpha_2 = e\frac{j4\pi}{3}$ represent the

spatial operators:

The following diagram shows the stator current complex space vector where (a,b,c) are the three phase system axes. This current space vector depicts the three phase sinusoidal system.

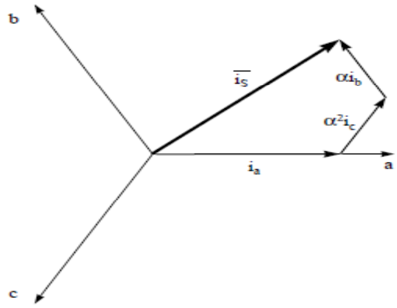

Figure14: Stator current space vector and its components in (a, b, c)

This transformation can be split into two steps:
•(a, b, c) to ( ) (the Clarke transformation) which outputs a two co-ordinate time variant system.
•( ) to (d, q) (the Park transformation) which outputs a two co-ordinate time invariant system.

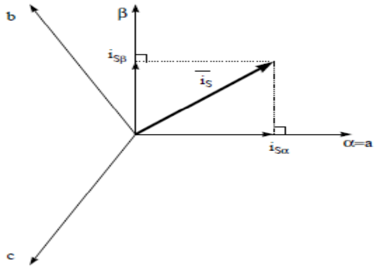

Figure 5: Stator current space vector and its components in (α, β)

The (α, β) to (d, q) projection (Park transformation):

$$i_{sd} = i_{s\alpha} \cos\theta + i_{s\beta} \sin\theta$$

$$i_{sq} = -i_{s\alpha} \sin\theta + i_{s\beta} \cos\theta$$

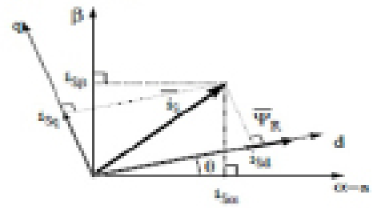

Figure 6: Stator current space vector and its component in (a,b) and in the (d,q) rotating reference frame

A three phase machine can be represented by an equivalent two phase machine using direct (d) and quadrature (q) axes for both stator and rotor as from [11].

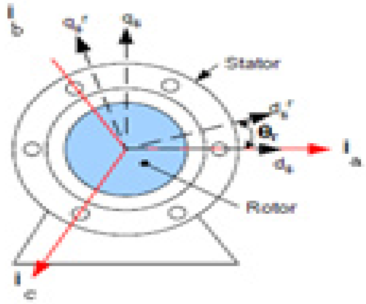

Figure 7: d-q representation of AC induction motor.

A further transformation is then required in order to relate these components of the stationary stator frame to the rotating reference frame of the rotor. This is achieved using the Park transformation as follows.

$$i_{ds}^{r} = i_{qs}\sin\theta_r + i_{ds}\cos\theta_r$$

$$i_{qs}^{r} = i_{qs}\cos\theta_r - i_{ds}\sin\theta_r$$

Where θ_r represents the angular position of the rotor flux

Reconstruction of stator voltages and currents from DC link current:

VSI fed induction motor :

A voltage source inverter-IM drive is shown in Fig.. Where Vdc is the dc link voltage, Idc is the instantaneous dc link current and ia, ib, ic are the instantaneous three-phase winding currents. It is assumed that the stator winding is star connected.

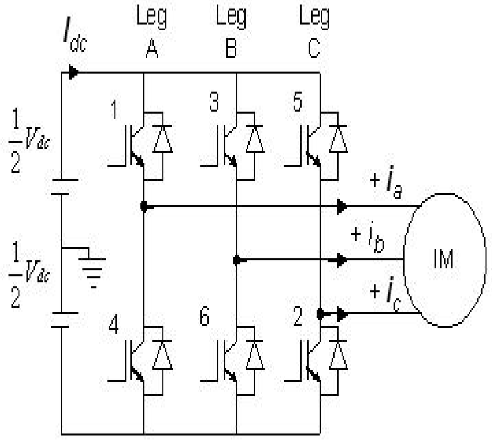

Figure18: VSI fed induction motor.

The stator currents as expressed in stationary d-q frame where superscript s refer to stationary frame are:

$$\bar{i}_{qs}^{s} = \bar{i}_a \; ; \; \bar{i}_{ds}^{s} = \frac{2\bar{i}_b + \bar{i}_a}{\sqrt{3}}$$

$$\bar{i}_{qs}^{s} = \bar{i}_a \; ; \; \bar{i}_{ds}^{s} = -\frac{2\bar{i}_c + \bar{i}_a}{\sqrt{3}} \quad \text{or}$$

$$\bar{i}_{qs}^{s} = -(\bar{i}_b - \bar{i}_c); \; i_{ds}^{s} = \frac{\bar{i}_b + \bar{i}_c}{\sqrt{3}}$$

Filter Stage

The transfer function of the filter is given below:

$$y = \left[\left(\frac{sT}{1+sT}\right)\left(\frac{T}{1+sT}\right)\right]x$$ Where *x*, *y* and *T* are input, output and time constant of the band-pass filter

Estimation of Flux-The stator flux in stationary d-q frame $\bar{\Psi}_{ds}, \bar{\Psi}_{qs}$ can be obtained by integration of the phase voltage minus voltage drop in stator resistance

$$\bar{\Psi}_{ds} = \int(\bar{v}_{ds}^{s} - R_s \bar{i}_{ds}^{s})\, dt$$

$$\bar{\Psi}_{qs} = \int(\bar{v}_{qs}^{s} - R_s \bar{i}_{qs}^{s})\, dt$$

$$|\bar{\Psi}_s| = \sqrt{\bar{\Psi}_{ds}^2 + \bar{\Psi}_{qs}^2}$$

Estimation of torque:

The electromagnetic torque can be expressed in stator currents and stator flux as

$$T_e = \frac{3P}{4}(\bar{\Psi}_{ds}\, i_{qs}^{s} - \bar{\Psi}_{qs}\, i_{ds}^{s})$$

Estimation of synchronous speed and rotor speed the synchronous speed can be calculated from the expression of the angle of stator flux

$$\theta_e = \tan^{-1}\frac{\Psi_{ds}}{\Psi_{qs}}, \; \omega_e = \frac{d\theta_e}{dt}$$

Indirect vector sensor less speed control-

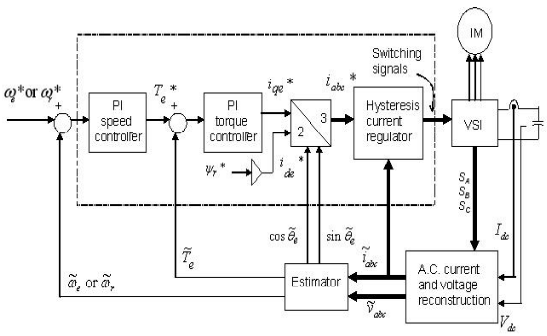

Figure 9 Block diagram of the new control strategy

The d-axis current command $\bar{i}^*_{de}$ is directly generated from the reference rotor flux $\bar{\psi}_r^*$ as given by

$$\bar{i}^*_{de} = \frac{\bar{\psi}_r^*}{L_m}$$

SIMULATION-:

The simulation was carried out for five different operating conditions.Simulink model of the VSI fed Induction motor for speed control using DC link measurements. The induction motor is simulated with the estimated values of flux, speed and torque which are reconstructed from the stator voltages and currents obtained from the DC link measurement.

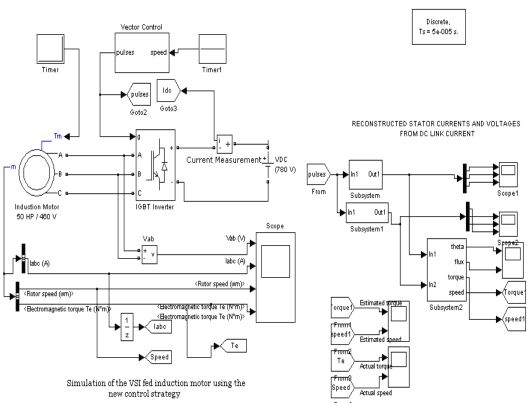

Figure 10-Simulink model of the VSI fed Induction motor speed control using DC link measurements Figure 11- Internal structure of control strategy.

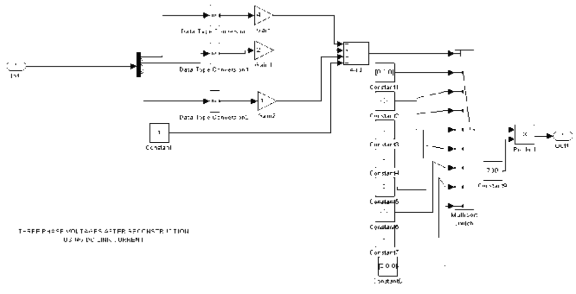

Figure112: Reconstructed three phase stator voltages from the Dc link measurements and switching signals

Figure13- Reconstructed three phase line currents from the Dc link measurements and switching signals

Estimation of the feedback signals:

All the feedback signals including the stator currents and voltages are estimated/reconstructed from the dc link quantities. From the reconstructed three phase stator voltages and currents the feedback signals flux, speed and torque are estimated. The estimator model is developed with inputs as reconstructed stator voltages and currents in the dq frame.

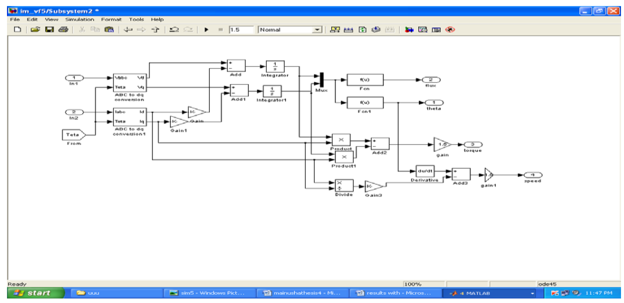

Figure14: Estimation of the feedback signals

SIMULATION RESULTS-:

The simulation results are presented for the indirect vector sensor less speed control using DC link measurement for different operating conditions and those results are compared with actualvalues.

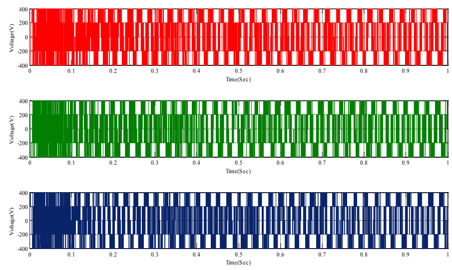

Figure 15-Reconstructedwaveform of three phase voltages.

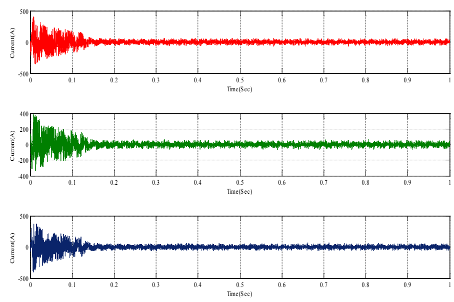

Figure16-Reconstructed waveform of three line currents

From these waveforms, it is clear that the samples of phase currents available in the dc link current are not evenly spread and being discontinuous, the set of resulting points do not constitute an acceptable reconstruction. Therefore they are allowed to pass through a band pass filter.

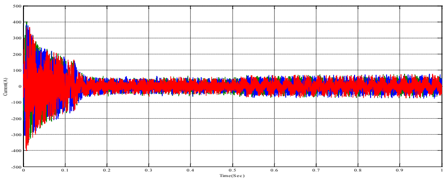

Figure117: Stator reconstructed AC line currents at rated load.

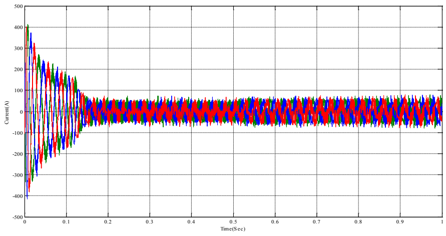

Figure118: Stator actual AC line currents at rated load.

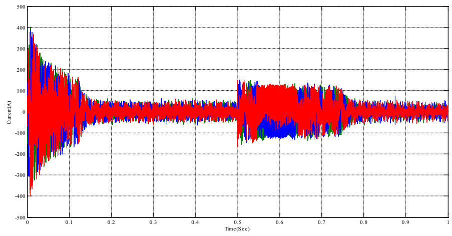

Figure 19 -Stator reconstructed currents during speed at no load reversal.

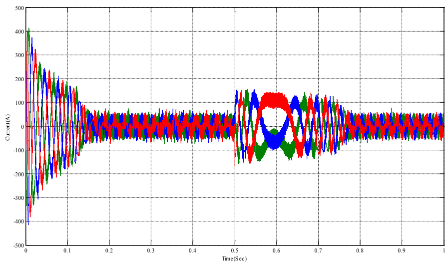

Figure 20- Stator actual currents during speed at no load reversal

Operating conditions – Free acceleration characteristics

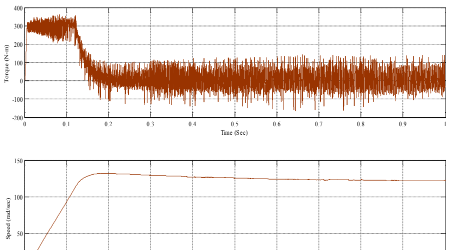

Figure121-Free acceleration characteristics of estimated torque and speed

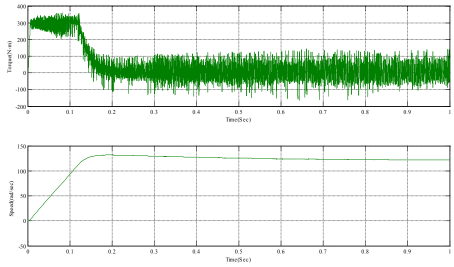

Figure122-Free acceleration characteristics of actual torque and speed.

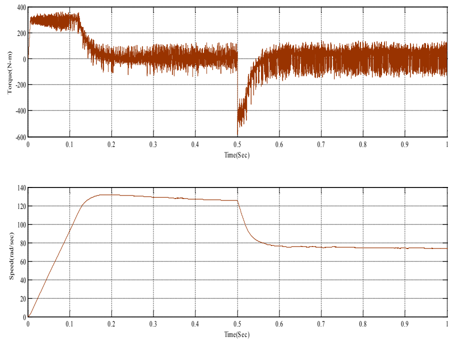

Figure123- Variation of Step change in speed reference for estimated values.

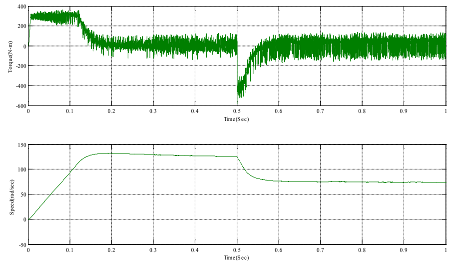

Figure 24-Variation of Step change in speed reference for actual values .

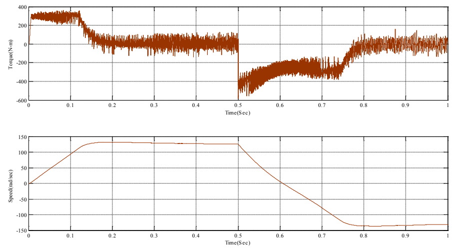

Figure 25- Variation of speed reversal for estimated values.

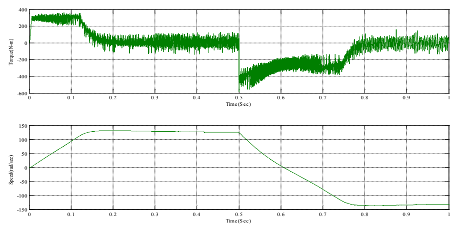

Figure126-Variation of speed reversal for actual values

Step change in load-

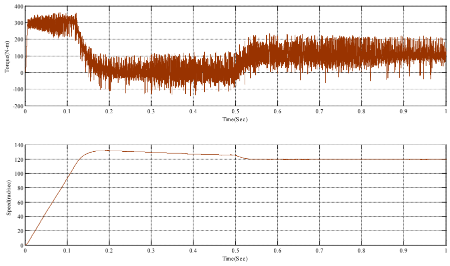

Figure 27-Variation in rotor speed and electromagnetic torque with step rise in load for estimated values.

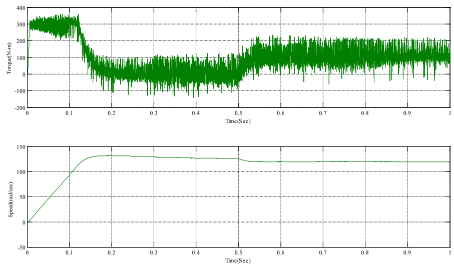

Figure128: Variation in rotor speed and electromagnetic torque with step rise in load for actual values

Low speed operation-

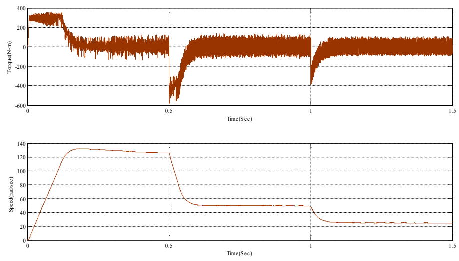

Figure129-Variation in rotor speed and electromagnetic torque in low-speed region estimated values.

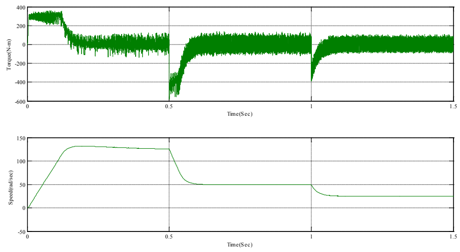

Figure130- Variation in rotor speed and electromagnetic torque in low-speed region actual values

Comparison chart for Estimated and Actual values of speed and torque for all the different operating conditions-

Free Acceleration Operating condition –

Actual speed-Speed reaches its rated value i.e. 120rad/sec within 0.13 sec

Torque -Torque reaches steady state with few ripples within 0.3 sec

Estimated Speed- Speed reaches its rated value i.e. 120rad/sec within Estimated 0.12 sec

Estimated Torque-Torque reaches steady state with few ripples within 0.2 sec

Observation-Estimated show faster response Step change in speed reference operation condition- Change in speed from 100 to 60 percent at 0.5 and vice-versa at 1sec

Actual speed- At 0.5 sec speed decreases gradually 60% of rated value from its rated and reaches steady state within 0.3 sec

Actual torque-At 0.5 sec torque becomes steady within in 0.3 sec and increases till load torque becomes equal to electro magnetic torque and reaches positive value as per set value of reference speed At 1 sec speed from 60% reference now increases to 100% of rated value and sets it as reference reaching steady state with few ripples within 0.3 sec

Estimated speed-At 1 sec torque decreases reaches steady state with few ripples within 0.3 sec Reaches steady state within 0.3 sec

Estimated Torque -
Torque reaches steady state with few ripples within 0 Estimated values of torque and speed vary in accordance with their corresponding actual values.

Observation- Estimated values of torque and speed vary in accordance with their corresponding actual values

Speed reversal-
Speed from 100 to -100 is applied at 0.5 seconds
Actual speed- speed decreases and becomes negative making phase sequence reverse to rotate motor in reverse direction

Actual Torque - Torque drops first and starts to increase reaches steady state with few ripples after change in speed reference within 0.3 sec .

Estimated speed-Speed decreases gradually within 0.3 sec becomes steady

Estimated torque-Torque drops first and starts increases steady state with few ripples within 0.3 sec

Observation-Speed estimation is stable even at very low speeds
Step change in load-
Change in load at 0.5 sec
Actual Speed - Speed drops at 0.5 sec and reaches steady state within 0.3 sec
Actual Torque- increases as speed drops at 0.5 sec and becomes even in 0.3 sec
Estimated Speed -Speed drops at 0.5 sec and reaches steady state within 0.2 sec
Estimated Torque - Torque increases as speed drops at 0.5 sec and become even in 0.2 sec
Observation-Estimated reaches steady state faster

Low speed operation
40 to20 percent of rated speed at 0.5 and 1 sec resp.
Actual Speed -Speed drops at 0.5 sec and reaches steady state within 0.3 sec
Actual Torque -Torque increases two times as speed changes in order to correct speed changes and reaches its rated value

Estimated Speed -Speed decreases to 40% of rated value within 0.2 sec sets to this value and at 1 sec drops to 20% speed within 0.2 sec

Estimated Torque -Torque increases two times as speed changes in order to correct speed changes and reaches its rated value within 0.2 sec
Observation-Estimated values show faster response even in low speed range

CONCLUSION:

This paper presents the indirect vector, sensorless speed control strategy of three phase induction motor using DC link measurements. The three phase induction motor drive with this new control strategy is simulated in MATLAB/Simulink for various operating conditions i.e. at different speeds and load.

The results of these conditions are analyzed and compared with actual values and we see that the control strategy is working well and the performance has been improved and there is a good agreement between actual and estimated values from the DC link measurement parameters Vdc and Idc and hence its an improvement over the existing conventional v/f control strategy.

Using the DC link measurement eliminates sensors on to the 3-phase induction motor and hence it is suitable for low-cost, moderate performance, Induction Motor drive applications. The proposed strategy appears to be a good compromise between the high cost, high performance field oriented drives and the low-cost, low-performance volts per hertz drives.

BIBLIOGRAPHY:

1.B.K.Bose, Power Electronics and Motor Drives, Delhi, India, Pearson Education, Inc., 2003.

2.Control Technologies Manual PWM AC Drives Revision 1.0

3.M. Rodic and K. Jezernik, "Speed-sensorless sliding-mode torque control of induction motor," IEEE Trans. Ind.Electron., vol. 49, no. 1, pp. 87-95, Feb. 2002.

4.L. Harnefors, M. Jansson, R. Ottersten, and K. Pietilainen, "Unified sensorless vector control of synchronous and induction motors," IEEE Trans. Ind. Electron., vol. 50, no. 1, pp. 153-160, Feb. 2003.

5.M. Comanescu and L. Xu, "An improved flux observer based on PLL frequency estimator for sensorless vector control of induction motors," IEEE Trans. Ind. Electron., vol. 53, no. 1, pp. 50-56, Feb. 2006.

6.Radu Bojoi, Paolo Guglielmi and Gian-Mario Pellegrino, "Sensorless direct field-oriented control of three-phase induction motor drives for low-cost applications," IEEE Trans. Ind. Appl., vol. 44, no. 2, pp. 475-481, Mar. 2008.

7.B. Saritha and P. A. Janakirman, "Sinusoidal three-phase current reconstruction and control using a dc-link current sensor and a curve-fitting observer," IEEE Trans. Ind.Electron., vol. 54, no. 5, pp. 2657-2662, Oct. 2007.

8.H. Kim and T. M. Jahns, "Current control for AC motor drives using a single dc-link current sensor and measurement voltage vectors," IEEE Trans. Ind. Appl., vol. 42, no. 6, pp. 1539-1546, Nov./Dec. 2006.

9."Field Orientated Control of 3-Phase AC-Motors" Literature Number: BPRA073 Texas Instruments Europe February 1998.

10."An introduction to vector control of AC motors using V850," Document No. U16483EE1V0AN00 Date published: November 2002 NEC Corporation 2002 Printed in Germany.

11.S. B. Bodkhe and M. V. Aware, "Reconstruction of phase currents from DC link in a single sensor induction motor drive using new algorithm,"

12.Zhenyu Yu "Space-Vector PWM With TMS320C24x/F24x Using Hardware and Software Determined Switching Patterns" Digital Signal Processing Solutions, March 1999 Application Report SPRA524.