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Comparative study of total harmonic distortion on the current waveform by PWM fed and Vector controlled Induction Motor drives

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Abstract— Adjustable speed drive is becoming a significant load component for power distribution .It involves the use of Induction motors comprising of Wound rotor type & squirrel cage. This paper involves analysis ,control and modeling of induction motors and also investigates its effects on Total current harmonic distortion on an adjustable speed by the use of PWM generator and Vector control method .By using Park's transformation ,we can convert three phase system to two phase and then convert it to stationery two axes system (d, q) By varying two vectors of flux and torque,(one on quadrature and other on direct axis) we can control the rotor current and therefore, speed and THD for current and voltage can be calculated. Harmonics are lesser in amplitude and more in frequency as compared to the fundamental. Vector control and direct torque control are employed extensively in variable-speed ac drive systems, particularly for induction machine drives. In order to generate PWM signals, an error value is calculated by comparing the current reference and actual current, and it is used as an input for hysteresis control. The voltage vector is obtained, and the motor is driven by using the inverter to follow current reference values.

Index Terms— Adjustable speed drives; Vector control; PWM generator; MATLAB/Simulation; squirrel cage induction motors; three phase stator currents**.**

I. INTRODUCTION

In adjustable speed drives three main components are used. The first one is, a six pulse diode bridge, the second one is a dc link capacitor which is used to lower down the ripples in the waves. The third one is a rectifier made up of IGBT/diodes is used, the pulses to this rectifier for switching purposes can be given by the two methods viz. PWM fed adjustable speed drive and vector controlled induction motor drives.

Adjustable Speed drives are required in many applications. It produces current harmonic distortion. The use of ASDs leads to current harmonics pollution in the power grid and to electromagnetic interference (EMI) with the environment. Power quality and EMI are the constraints on electric induction motor drives. These loads are distributed all over electric network.

M.Farhney [1] in 2010 investigates modeling and control of induction machine with adjustable ac drive and harmonic analysis was carried out. Harmonics are undesirable as this interference can lead to unacceptable levels of voltage distortion. Harmonic measurements require special equipment, which is quite expensive and not always available.

According to Yu Yu; Yang Zhao [3],The voltage source converter (VSI) fed adjustable speed drives (ASDs) frequently generates significant amount of harmonic and interharmonic currents into the supply system and may cause undesired effects on other power system components. This method directly sets up a mathematical module of the carrier in one period which is independent on the parity and the periodicity of frequency-modulated wave. The harmonic and interharmonic currents of the VSI-fed ASD injected into the supply system are calculated. By means of the electromagnetic simulation software PSCAD/EMTDC, the harmonic and interharmonic principle of the supply side is analyzed and the validity of the analysis method is confirmed by the simulation results.

II. INDUCTION MACHINES

The law of electromagnetic induction is used in Induction motors. An electric drive may be operated in one direction of rotation depending upon requirements. The magnetic field produced by stator poles is revolving, having the constant magnitude of 120f/p. Now due to the induction Principle, an emf will be produced in the rotor circuit and a current starts flowing in the rotor (may be Squirrel cage type or wound rotor type) the magnetic field developed in the rotor circuit is quite slower than that of the synchronous speed. Since there is a difference between the stator and rotor magnetic fields, a torque is developed in the machine.

An induction motor (1M) is only a part of an adjustable speed drive assembly. As such the 1M is fed from power electronics converter (PEC), but indirectly in most cases from the industrial power grid.

Based on the JxB force principle, three operation modes of lM are easily identified
(with Us - ideal no-load speed, U – rotor speed):

- Motoring: lUI < I Us I; U and Us either positive or negative.
- Generating: lUI > IUs I; U and Us either positive or negative.
- Braking: (U>O & Us <0) or (U<O & Us >0) [2].

III. ADJUSTABLE SPEED DRIVES

The induction motor is the most widely used motor type in industry because of its good self-starting capability, low cost, simple and rugged structure, and reliability, etc. Induction motors are used in adjustable speed applications where fast dynamic response is not required. With the concept of vector

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control it is possible to control the induction motors to achieve dynamic performance comparable to that of dc motors. The dynamic model of the induction motor is necessary in order to understand and analyze vector control. The characteristics of induction motors are easily described by the dynamic model equations developed on a rotating reference frame and then it is converted to stationery frame [1].

A. *Rectifier*

It converts the power supply ac voltage into dc voltage with a certain ripple. Traditional modeling for controlled rectifiers is a time-delay element in the s-domain.

Rectified dc voltage has mean voltage slightly less than peak line voltage due to voltage drops in the power switches and ripple frequency of 300 Hz.

B. *DC link*

The DC link is commonly called DC bus. It also acts as energy reserve to supply the inverter when the supply fails. ASD immunity against disturbances therefore depends on the energy stored in this circuit and energy demanded by the load. In Fig.1 dc link is represented with a shunt capacitance C. Representation of the DC link filter is essential for the correct simulation of ASDs. It is the filter that makes the ASD harmonic current waveforms different from those of the DC drives.

C. *Inverter*

The inverter is controlled by the PWM scheme. In a sampling interval T= 1/fc, the pulse width angle can be changed only once. Therefore the PWM inverter is working in discrete state. The purpose of the inverter is to convert the low ripple dc voltage to adjustable ac voltage to allow the speed control of an induction motor. The purpose of the inverter is to convert the low ripple dc voltage to adjustable ac voltage to allow the speed control of an induction motor. The PWM inverter cannot be considered only as a proportional element. Since its output voltage is out of control once the pulse width is applied, it should be looked as a sample and linear-varying element.

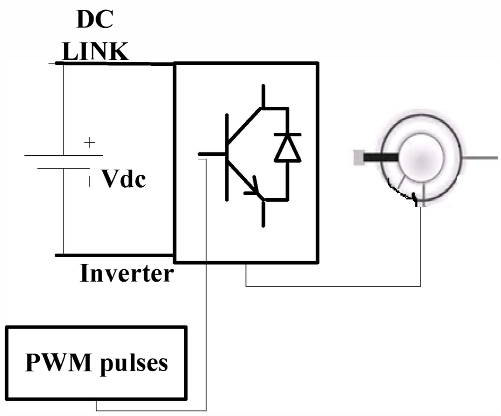

Fig.1 Schematic diagram of vector and pwm control of Induction motor drive

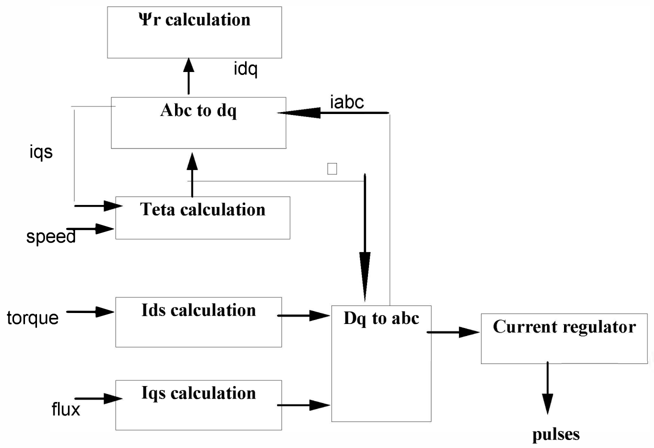

Fig.2 Vector control Simulink schematic

IV. TOTAL HARMONIC DISTORTION

If we connect the induction motor directly to the grid, there might be some electromagnetic interference or some harmonics which are introduced in the current and voltage waveforms. Harmonics are lesser in magnitude and more in number than the fundamental. The frequency for odd harmonics (3^{rd}, 5^{th}, 7^{th}….), are the odd integral multiples of power line frequency. A harmonic is a component of periodic wave having frequency that is an integral multiple of the fundamental power line frequency. The total harmonic current distortion for current waveform can be expressed as the summation of the fundamental value and various harmonics. This index can also be measured for voltage waveform. Total Current Harmonic Distortion (THD) The THD is a measure of the effective value of the harmonic components of a distorted waveform. This index can be calculated for either voltage or current. The summation of the fundamental wave and all of its harmonic values will provide the level of total harmonic distortion.

$$THD = \sqrt{[(V_2^2 + V_3^2 + V_4^2 \ldots\ldots\ldots\ldots\ldots V\alpha^2) / V_1]} \quad (1)$$

The THD provides a good idea of how much extra heat will be realized when a distorted voltage is applied across a resistive load [3].

V. PULSE WIDTH MODULATION

PWM can be generated by making use of two waves. The first one is the carrier wave and the other is a triangular wave. Both these waves are compared and their error signal is fed to the rectifier for switching it on and off .Now the speed is fed back to the motor in the terms of torque ,by making use of dynamic response equations. Now connect the induction motor with a de multiplexer, so that it shows the waveforms for stator voltage, current, electromagnetic torque and speed. By doing the FFT analysis, we can get the Total Harmonic distortion index for current and voltage waveform.

VI. VECTOR CONTROL

A. Dq theory –

The overall control strategy of the machine is divided in two ways, one is scalar control and the other is vector control. The limitations of scalar control give an importance to vector control. The basic of the vector control theory is d-q theory. To understand vector control theory knowledge about d-q theory is necessary.

The basic principle of vector control is to separate the components of stator current responsible for production of flux and the torque. The vector control is obtained by the magnitude, frequency and the phase of the stator current by inverter control by Park's transformation. Since the control is obtained by controlling both phase angle and magnitude of current this method of control is called vector control.

The main objective of vector control is to achieve superior performance under torque and speed change. With the concept of vector control it is possible to control induction motor comparable to that of dc motor. The dynamic model of induction motor drive is [3]

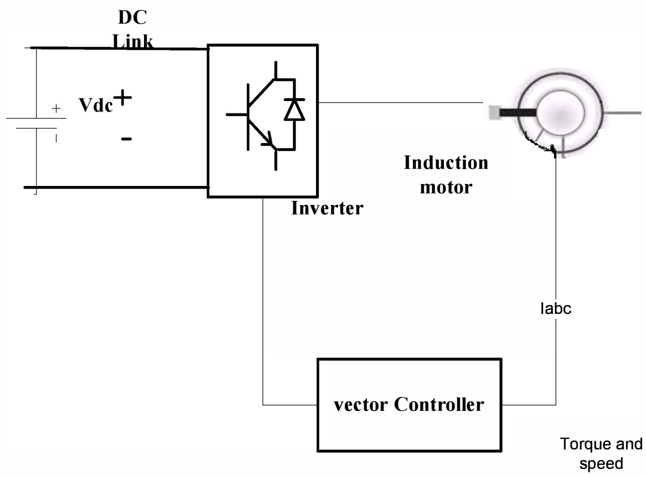

Fig 3 Schematic diagram of vector control of Induction motor

B.Field Oriented Control Theory

Vector control is also called field-oriented control (FOC), we can consider, the dq theory of machines for the conversion of three phase currents (Isa, Isb, Isc) to (Ids and Iqs). These three phase currents displaced by 120 degrees are supplied by the three phase voltage sources. Direct axis current is responsible for the production of flux in the machine and the quadrature component of the current is responsible for the production of the torque. In dc motors, the mmf produced by rotor is at 90 degrees to that of the mmf wave produced by the stator. Both these fields are stationery in contrast to ac machines. The main aim is to transform the three phase stationary frame variables into two phase stationary frame variables (ds-qs) and then transform these to synchronously rotating reference frame variables (d-q), and vice versa.

C. *Park's transformation –*

Park transformed the stator variables to a synchronously rotating reference frame fixed in the rotor. Park proposed a new theory to overcome the problem of time varying parameters with the ac machines. With such transformation (Park's transformation) he showed that all the time varying inductances that occur due to an electric circuit in relative motion and electric circuit with varying magnetic reluctances can be eliminated

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta-120^\circ) & \sin(\theta-120^\circ) & 1 \\ \cos(\theta+120^\circ) & \sin(\theta+120^\circ) & 1 \end{bmatrix}\begin{bmatrix} V_{qs}^{s} \\ V_{ds}^{s} \\ V_{0s}^{s} \end{bmatrix} \qquad (2)$$

The following relationships describe the dq-to-abc reference frame transformations applied to the Asynchronous Machine phase current [11].

$$\begin{bmatrix} i_{as} \\ i_{bs} \end{bmatrix} = \begin{bmatrix} \cos\Theta & \sin\Theta \\ \frac{-\cos\Theta+\sqrt{3}\sin\Theta}{2} & \frac{-\sqrt{3}\cos\Theta-\sin\Theta}{2} \end{bmatrix}\begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix} \qquad (3)$$

VII. MATHEMATICAL EQUATIONS

$I_a = i_m \sin\omega t$
$I_b = i_m \sin(\omega t-120)$
$I_c = i_m \sin(\omega t-240)$ (4)

These are the instantaneous values of three phase stator currents displaced by 120 degree each

Now these three phases can be converted into stationery d-q axis by using the formula

$i_{sd}^* = i_{mr} + \tau r(\Delta i_{mr}/\Delta T)$.
$i_{sq}^* = T^*/(k\, i_{mr})$
$k = (3/2)(P/2)\{M/(1+\sigma)\}$ (5)

where, P ,M ,σ are the number of poles, mutual inductance and rotor leakage factor

Now, again the dq components are converted to reference

$i_{as}^* = -i_{sq}^* \sin\Psi + i_{sd}^* \cos\Psi$ (6)
$i_{bs}^* = [-\cos\Psi + \sqrt{3}\sin\Psi]isd^*(1/2) + [\sin\Psi + \sqrt{3}\cos\Psi]isq^*(1/2)$
$i_{cs}^* = -(i_{as}^* + ibs^*)$ (7)
$i_{ke} = i_{ks}^* - i_{ks}$, where k = a, b, c.

These errors are fed to current controller, which controls the on and off period of different switches in voltage source inverterThe VSI generates the PWM voltages being fed to motor to develop the desired torque for running the motor at reference speed under various loading conditions.

The rating of the given motor is 50Hp, 400V,60Hz, 4 –pole machine.We have used various voltage and current measurement to know the values of voltages and current supplied from power grid to the adjustable drive.

For applying this method, one has to transform abc (three phase stator currents) to rotating axis d-q frame. A speed controller (PI) is also used to compare the rotor speed to the reference speed. An error is obtained as torque. This error is fed to get the value of Iqs and similarly Ids can also be calculated. This block can be obtained from electric drives library in simpowersystems.

VIII. SIMULATION

MATLAB simulation of PWM fed induction motor

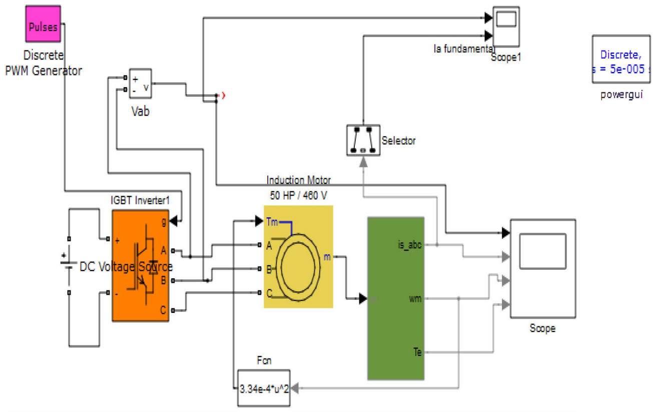

Fig.4 Matlab model of PWM fed Induction motor drive

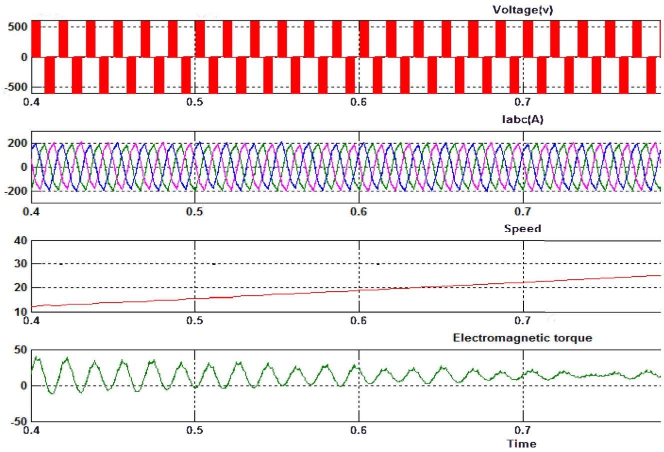

Fig.5 Waveform of PWM fed Induction motor drive(a) Line voltage,(b) Iabc,(c)speed,(d) torque),

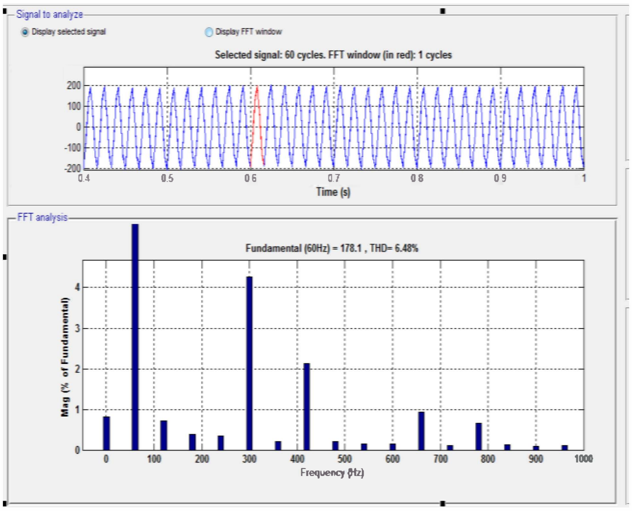

Fig.6.a waveforms of ac-dc converter at full load and it's harmonic spectrum by conventional Pulse width modulated signal fed to Induction motors

MATLAB simulation by Vector control method

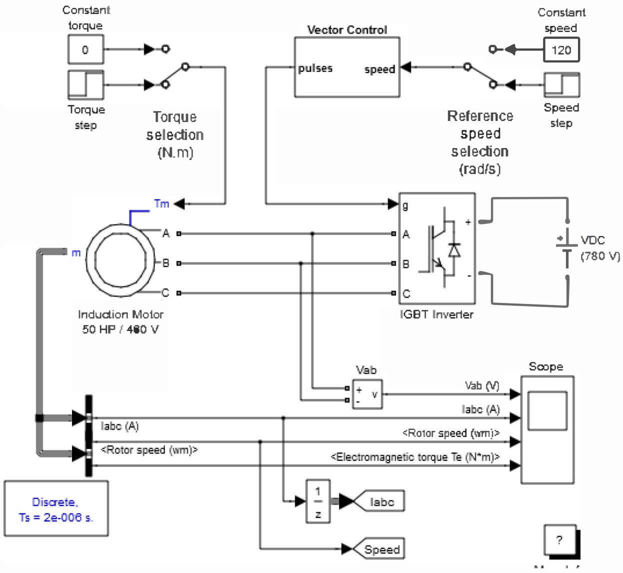

Fig.7 Simulation of Vector control technique

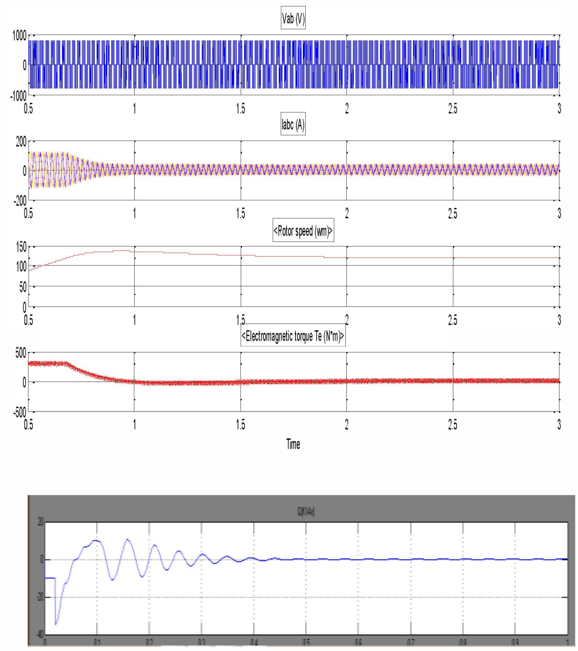

Fig.8 Waveform of armature current, line voltage, rotor speed and electromagnetic torque. And reactive power

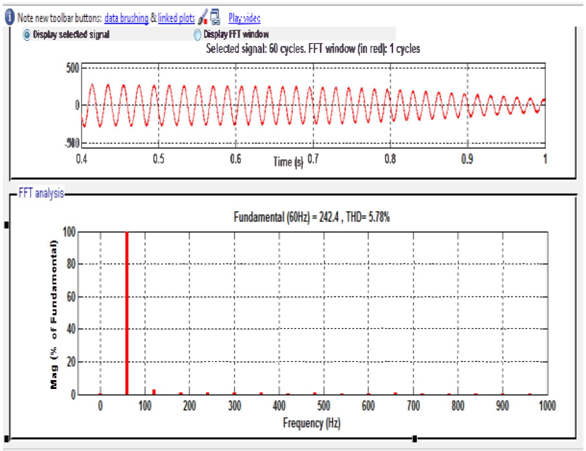

Fig.9 a waveforms of ac-dc converter at full load and it's harmonic spectrum by vector control method for Induction motors.

IX. RESULT & DISCUSSION

Vector controlled ASD

By evaluation of the harmonic distortion spectra of PWM inverter fed ASD and Vector controlled ASD it is clear that harmonic distortion is very less in vector control rather in PWM scheme

The following table gives the total current harmonic distortion levels for all the phases A, B and C for both the schemes considered namely, PWM inverter fed and Vector controlled ASD [5].

TABLE

Phase	PWM Inverter (%)	Vector Control (%)
A	6.4	5.7
B	6.7	5.3
C	6.8	5.2

X. CONCLUSION

The issue of power quality has become more apparent due to the ever increasing number of non-linear loads. The low frequency harmonic current produced by these loads can cause damage to the power system equipment. Adjustable speed drive (ASD) is becoming a significant load component for power distribution nowadays.

Designing of these loads to reduce the problems arising from harmonic pollution is done in this paper. This paper involves simulation of ASD such that power quality is significantly improved by reducing the harmonics to a significant level. By this technique the efficiency can be improved much better since reactive power can be reduced giving reduced losses through vector control technique.

Appendix

Induction Motor Ratings
50 HP , 460 V ,1480 rpm, 60 Hz
Lm= 0.02711 H, Lr=0.000724 H   Rr= 0.0503 Ω
Rs=0.02233 Ω   Ls=0.000724 H
Pulse Width Modulation
Switching frequency=2000
Modulation Index=0.4
DC Supply= 780 V
Vector Controlled Induction Motor Drive
PI Controller   Kp= 2, Ki= 26

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