Volume 1 Issue 1
Jan 2013 - Mar 2013
ISSN: Applied for

TRANSFORMING TECHNOLOGY, EXPLORING KNOWLEDGE

INTERNATIONAL RESEARCH JOURNAL OF ENGINEERING & APPLIED SCIENCES
www.irjeas.com

"Comparative Analysis of an SPWM Inverter and Vector Control Method for control of an Adjustable AC Drive"

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***Abstract* – Now-a-days, adjustable speed drive has became a significant load component for power distribution system. It involves the use of Induction motors (Wound rotor type & squirrel cage) The paper here is based on 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. With the help of Park's transformation ,we can convert three phase system to two phase and then it can be converted into two axes system (d, q). By varying two vectors of flux and torque, the rotor current can be controlled and therefore, THD and speed for current and voltage is calculated.**

***Keywords* - Adjustable speed drives, PWM generator, MATLAB/Simulink, squirrel cage induction motors, three phase stator currents, Vector control.**

I. ADJUSTABLE SPEED DRIVES

Now-a-days, 'Adjustable Speed drives' are widely used in many applications. The use of ASDs leads to current harmonics pollution in the power grid. Since these loads results in unacceptable levels of voltage distortion, these are highly undesirable. Harmonic measurements require special equipment, which is quite expensive and not always available. This paper investigates the modeling and control of an Induction machine for an adjustable speed drive and harmonic analysis was carried out. Using ac drives and ac motors have the advantages of lower maintenance, higher speeds and smaller size. Compared to dc drives, the higher cost of ac drives is in part compensated by a lower ac machine cost. Compared to uncontrolled ac motors, supplied by a power grid, the efficiency of inverter controlled drives can be vastly increased by, e.g. flux optimization.

II. INDUCTION MACHINE

Per-phase equivalent circuits which are often used in design and analysis of ac machines are appropriate for the static analysis but not to predict the dynamic behaviour of the motor. A dynamic model is necessary to understand and analyze vector control of ac motor drives. With the development of reference frame theory, a significant breakthrough was achieved in the analysis of three-phase ac machines. The machine model can be transformed to another reference frame to using these techniques. It is possible to simplify the complexity of the mathematical machine model by judicious choice of the reference frame. The need for compact and accurate machine models is obvious, as digital control techniques are being extended to control current, torque and flux of the ac machines.

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 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.

III. The Concept Of Harmonic

A harmonic is a component of periodic wave having frequency that is an integral multiple of the fundamental power line frequency of 50 H z. The fundamental wave is pure sine wave without distortion. The 2nd harmonic differs in frequency and amplitude from the fundamental wave. It has two times the frequency and half the amplitude. The 3rd harmonic has three times amplitude of the fundamental And so on. Fig. 6.1.1 depicts the fundamental, 2nd and 3rd harmonic.

Since any periodic waveform f(t) can be expressed as a Fourier series, it follows that the sum of the fundamental, the second harmonic, and so on, must produce the waveform f(t). Generally, the sum of two or more sinusoids of different frequencies produces a waveform that is not a sinusoid

The most commonly used index for measuring the harmonic content of a waveform is the total harmonic distortion (THD). It is a measure of the effective value of a waveform and may be applied to either voltage or current. Total harmonic distortion is the contribution of all the harmonic frequency currents to the fundamental. Just as waveforms can be added to produce distorted waves, distorted waves may be decomposed into fundamental and harmonic components.

$$\mathrm{THD} = \frac{P_2 + P_3 + P_4 + \cdots + P_\infty}{P_1} = \frac{\sum_{i=2}^{\infty} P_i}{P_1}$$

Total Current Harmonic Distortion (THDi) The THDi 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 following equation gives THD for current. where P_i is the rms value of harmonic component I of the current.

IV. Vector Control

It is also called **field-oriented control** (FOC), is a variable frequency drive (VFD) control method which controls three-phase AC electric motor output by means of three controllable VFD inverter output variables: Voltage magnitude, Voltage angle, Frequency.

FOC is a control technique used in AC synchronous and induction motor applications that was originally developed for high-performance motor applications which can operate smoothly over the full speed range, can generate full torque at zero speed, and is capable of fast acceleration and deceleration but that is becoming increasingly attractive for lower performance applications as well due to FOC's motor size, cost and power consumption reduction superiority. Not only is FOC very common in induction motor control applications due to its traditional superiority in high-performance applications, but the expectation is that it will eventually nearly universally displace single-variable scalar volts-per-Hertz (V/f) control.

V. Induction Motor Operation

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 1M are easily identified (with Us - ideal no-load speed, U - mover
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).

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. 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. For vector control of induction motor its model is considered in a synchronously rotating d-q reference frame.

VI. Simulation

An adjustable speed drive consists of rectifier and inverter. Its functioning depends on the joint action of the rectifier and the inverter.

1) Rectifier

The rectifier is a six pulse full-wave diode bridge rectifier (p=6), It is represented in the form of a universal bridge in the simulation circuit shown in Fig. 6.1. 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. To reduce the THD of the input current, the main obstacles are the gaps in the input current, present during the time intervals when the phase voltage of the considered phase is neither minimal nor maximal among the phase voltages, causing both the diodes connected to that phase to be reverse biased.

2) DC link

The DC link is commonly called DC bus The diodes in the rectifier convert the input sinusoidal ac voltage to a rectified dc voltage which is then smoothed by the dc link in order to produce a dc voltage with lower ripple. 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. 6.2 dc link is represented with an inductance L and 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.

3) Inverter

The inverter is controlled by the PWM scheme. In a sampling interval T= 11 f C, 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.

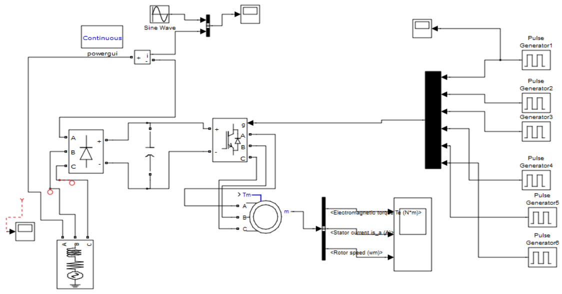

Fig 6.1 Matlab simulink of PWM induction motor

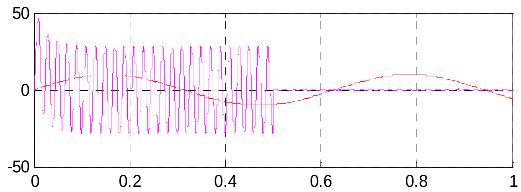

Fig 6.1.1 Waveforms of harmonic component

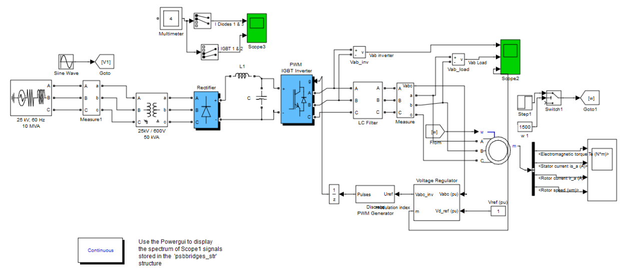

Fig 6.2 Matlab simulink by Vector control method

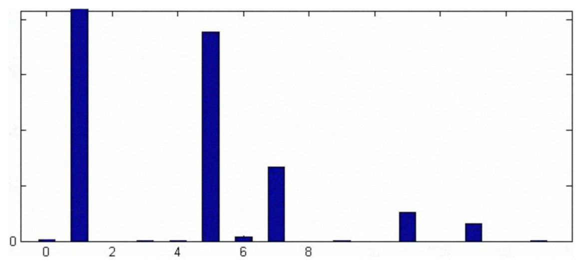

Fig 6.2.1 Waveforms of reduced harmonic component by vector control

Mathematical Equations

$$\mathbf{\Psi_{rd}=L_m\, i_{sd}/1+sT_r}$$

Where L_m =Mutual inductance

I_{sd} =direct axis stator current
s =Laplace Transform
T_r =Rotor Time costant, L_r/R_r

$$Tm = 3/2L_m/Lrz_p\ \Psi_{rd}\, i_{sq}$$

Where L_r= Rotor resistance
Z_p =number of pole pairs
I_{sq}= quadrature axis stator current
T_m = motor torque

$I_a = i_m \sin wt$
$I_b = i_m \sin(wt-120)$
$I_c = i_m \sin(wt-240)$

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

$$I_{abc} = T^{-1} I_{dqo} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & -\sin(\theta) & \frac{\sqrt{2}}{2} \\ \cos(\theta - \frac{2\pi}{3}) & -\sin(\theta - \frac{2\pi}{3}) & \frac{\sqrt{2}}{2} \\ \cos(\theta + \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) & \frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ I_o \end{bmatrix}$$

Rotor flux can be controlled by stator direct axis current and rotor torque can be controlled by the quadrature axis stator current.

We will get function fcn in user defined library which is given by 5.6e-4*u^2 and therefore the value of K can be given by 5.6 *10-4

Nominal torque of the motor is given by 19.8778Nm (P/w)

The rating of the given motor is 5Hp, 415V,60Hz, 4 –pole machine

This speed is once again given to the motor (squirrel cage induction motor), we are using machine measurement demultiplexer to get the values of stator three phase currents, electromagnetic torque , rotor speed and getting the result on the scope connected.

I have used various voltage and current measurement to know the values of voltages and current supplied from power grid to the adjustable drive for getting the harmonic free voltage to be fed to asynchronous motor, I am converting ac to dc firstly by the use of universal bridge and then converting dc to ac which is to be fed to the Induction motor

For vector control method, I am using AC3(field oriented control of induction motors) in electrical drives library.There are various methods to control the speed of an induction motor viz, V/f control, FOC, Direct torque control

Here my purpose is to reduce the harmonic current by using the vector control method or it is also known as Field oriented control of induction motor.

In this method we separate the component of stator currents, d and q, so that the direct axis component is responsible for controlling the rotor flux and quadrature axis component is responsible for controlling the torque.

For applying this method, one has to transform abc (three phase stator currents) to rotating axis d-q frame. A speed controller is also used so that it compares the rotor speed to the reference speed. This block can be obtained from electric drives library in sim power systems. Again the power grid ac voltage is converted to dc and then again to ac by the use of rectifier and inverter and finally fed to the induction motor.

Phase	PWM Inverter (%)	Vector Control (%)
A	20.89	1.29
B	21.40	1.40
C	23.77	1.30

Table 6.1 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 as compared to PWM scheme.

VII. 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.

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.

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