Comparative analysis of total harmonic distortion on the current waveform by PWM fed and Vector Controlled Permanent magnet synchronous motors

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Abstract—This paper involves analysis, control and modeling of PMSM and It involves the use of Permanent magnet synchronous motors. It also observes its effects on Total current harmonic distortion by making use of PWM generator and Vector control method . By making use of Park's transformation ,one can convert three phase system to two phase and then convert it to stationery two axes system (d, q) and finally to synchronously rotating reference frame system By varying both the vectors of flux and torque,(one on quadrature and other on direct axis) one can control the rotor current and therefore, speed of the motor and then THD for current and voltage can be calculated. Adjustable speed drive are becoming a important load component for power distribution Harmonics are lesser in amplitude and more in frequency as compared to the fundamental. Vector control and direct torque control are employed 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. Then, 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, three phase stator currents**

I.NOMENCLATURE

L_r=Mutual Inductance
R_r= Rotor inductance
i_{mr} = magnetizing current
ΔT= Sampling time
$\tau_r = L_r / R_r$
σ = Rotor Leakage Factor
Te= Electromagnetic torque
J= Moment of Inertia
$\omega_{r=}$ Angular rotor speed
F= Friction constant
T_m =motor torque

II. INTRODUCTION

Adjustable Speed drives are required in many applications. The use of ASDs gives current harmonics pollution in the power grid and Electromagnetic interference (EMI) with the ambient atmosphere. Quality of power and EMI are the constraints on electric induction motor drives and PMSM. These loads are distributed all over an Electric system. Harmonics are undesirable as this interference with power devices can result in voltage distortion. Harmonic measurements require special apparatus, which is quite costly and not always available.. 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 regular grid, the efficiency of inverter controlled drives can be vastly increased.

III.PERMANENT MAGNET SYNCHRONOUS MOTORS

An electric drive may be operated in one direction of rotation or both directions of rotations depending upon requirements. Per-phase equivalent circuits widely used in steady-state analysis and design of ac machines , are not appropriate to predict the dynamic performance of the motor. A dynamic model is required to know and analyze vector control of ac motor drives. A significant point was achieved in the analysis of three-phase ac machines through the development of the reference frame theory. The machine model can be transformed to another reference frame by using these methodologies. It is possible to lessen the complexity of the mathematical machine model by choice of the reference frame. In older times these techniques were used for the analysis and simulation of ac machines, but are now being dynamically used in the digital control of such machines. The necessity for small sized and accurate machine models has been seen these days, as digital control methods are being used to control current, torque and flux of the ac machines.

Permanent magnet (PM) synchronous motors are generally used in low and mid power requirements such as computer peripheral devices, robotics, adjustable speed drives and electric vehicles. The growth in the market of Permanent Magnet motor drives has demanded the necessity of simulation tools which can handle motor drive simulations..
In this work, the simulation of a field oriented controlled Permanent Magnet motor drive system is developed using Simulink. The simulation circuit will include all realistic components of the drive. This allows the calculation of currents and voltages in different parts of the inverter and motor under transient and steady conditions.

IV. 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 Hz. 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.

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).

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.

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

V. PULSE WIDTH MODULATION

The inverter is controlled by the PWM scheme. In a sampling interval T= 1/ f $_C$, the pulse width angle can be changed only once. Therefore the PWM inverter is working in discrete state. The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time The main advantage of PWM is that power loss in the switching devices is very low. PWM block generates two set of pulses. One is a triangular wave and the second one is sinusoidal wave and a comparison of two will generate a sampled wave ,which can be fed to the IGBT Inverter for switching purposes

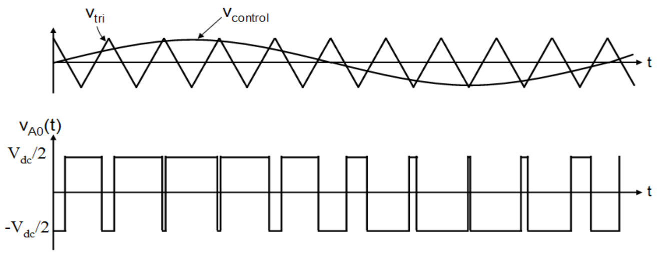

Fig.1 Comparison of a triangular wave with sinusoidal wave and hence getting a sampled wave.

VI. VECTOR CONTROL,

This 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. The closed loop PI speed controller is used to compare the reference speed (ω_r *) with motor speed (ω_r) and generates reference torque If we provide an electromagnetic torque to the motor, we will get the motor speed according to the following differential equation that explains the mechanical system dynamics:

$T_e = J*d/dt(\omega_r) + F(\omega_r) + T_m$

Park's transformation is used for the conversion of i_{abc} to i_{dq}

$i_d = 2/3\{i_a sin\omega t + i_b sin(\omega t - 2\pi/3) + i_c sin(\omega t + 2\pi/3)\}$

$i_q = 2/3\{i_a cos\omega t + i_b cos(\omega t 2\pi/3) + i_c cos(\omega t + 2\pi/3)\}$

$i_0 = = 1/3(i_a + i_b + i_c)$

Now,

In the rotor-flux-oriented reference frame, the d-component of the stator current reference vector is given as

$i^*_{sd} = i_{mr} + \tau_r(\Delta i_{mr}/\Delta T)$.

The *q*-component of the stator current reference vector is obtained from the output of the PI controller as

$i^*_{sq} = T^* / k\ i_{mr}$

$k = (3/2)(P/2)\{L_r/(1 + \sigma)\}$

These currents, (i^*_{sd}, i^*_{sq}) are in synchronously rotating reference Frame and these are converted into stationary reference frame three-phase currents as $(i^*_{sa}, i^*_{sb}, i^*_{sc})$

$i^*_{sa} = i^*_d sin\ \omega\ t + i^*_q cos\omega t + i_0$

$i^*_{sb} = \{ i^*_d sin(\omega\ t - 2\pi/3) + i^*_q cos(\omega\ t - 2\pi/3) + i_0$

$i^*_{sc} = \{i^*_d sin(\omega\ t + 2\pi/3) + i^*_q cos(\omega\ t + 2\pi/3) + i_0$

$i^*_{sa}, i^*_{sb}, i^*_{sc}$ are the three-phase reference currents. These three-phase reference currents generated by the vector controller are compared with the sensed motor currents

(i_{sa}, i_{sb}, i_{sc})

The calculated current errors are

$i_{ke} = i_{ks}* - i_{ks}$, where k = a, b, c.

Now these current errors are fed to switching devices after passing through the PI controller

VI. SIMULATION

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

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.3. It converts the power supply ac voltage into dc voltage with a few ripples.

The DC link is generally know as DC bus The diodes in the rectifier converts the input sinusoidal ac voltage to a rectified dc voltage which is then smoothed down by the dc link in order to produce a dc voltage with fewer ripples. It also known as energy backup to mains whenever the supply fails.

The purpose of the inverter is to convert the low ripple dc voltage to compatible ac voltage for the speed control of a PMSM.

When we simulate the MATLAB diagram after making it by the use of various library blocks, we can get the figure as shown here

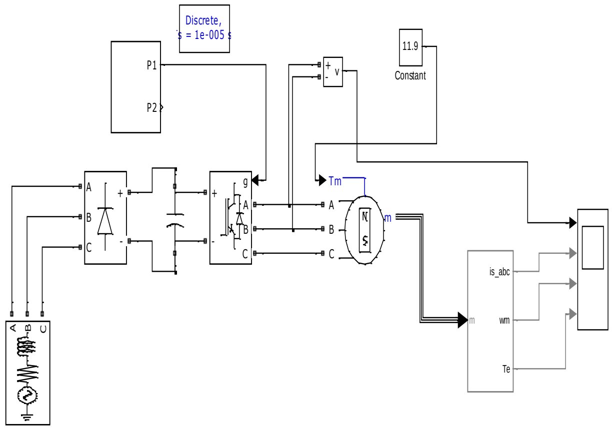

Fig2. MATLAB simulation of Pulse width modulated Permanent magnet synchronous motor drive

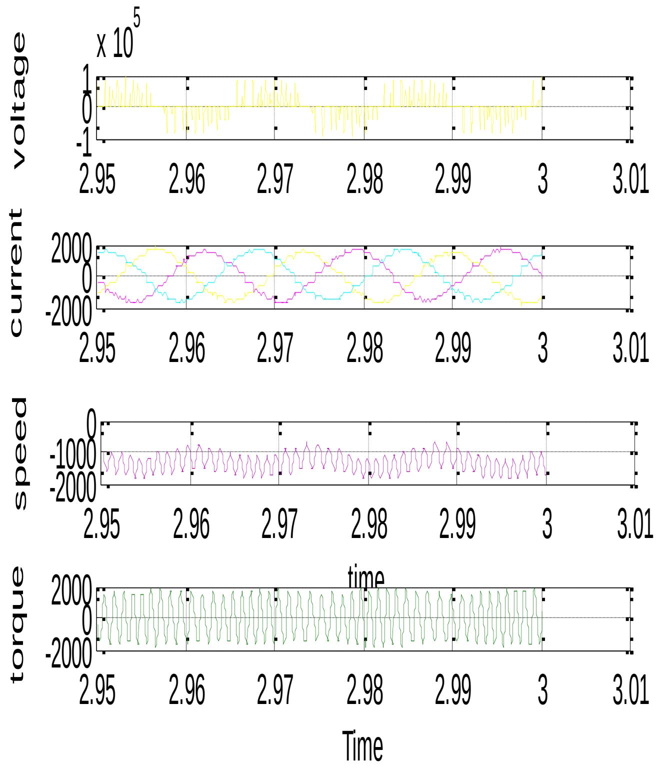

Fig2a. Voltage, Current ,Speed and torque waveforms of PWM fed Permanent magnet Synchronous motor drive

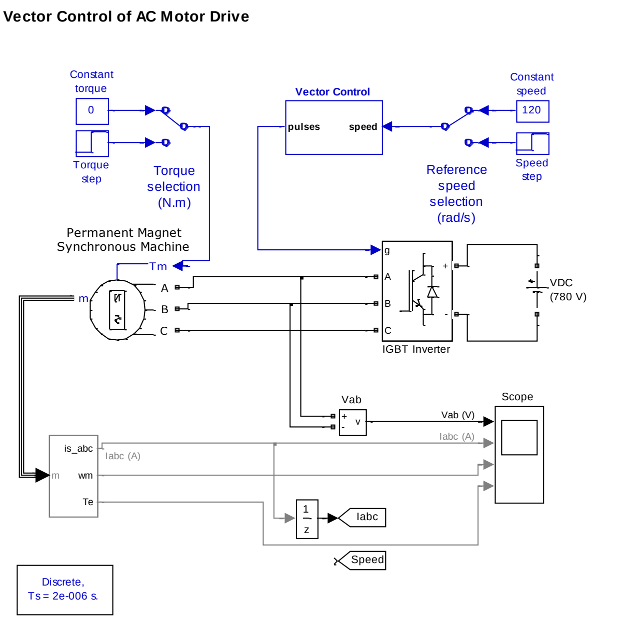

Fig3.MATLAB simulation of Vector controlled Permanent magnet Synchronous motor

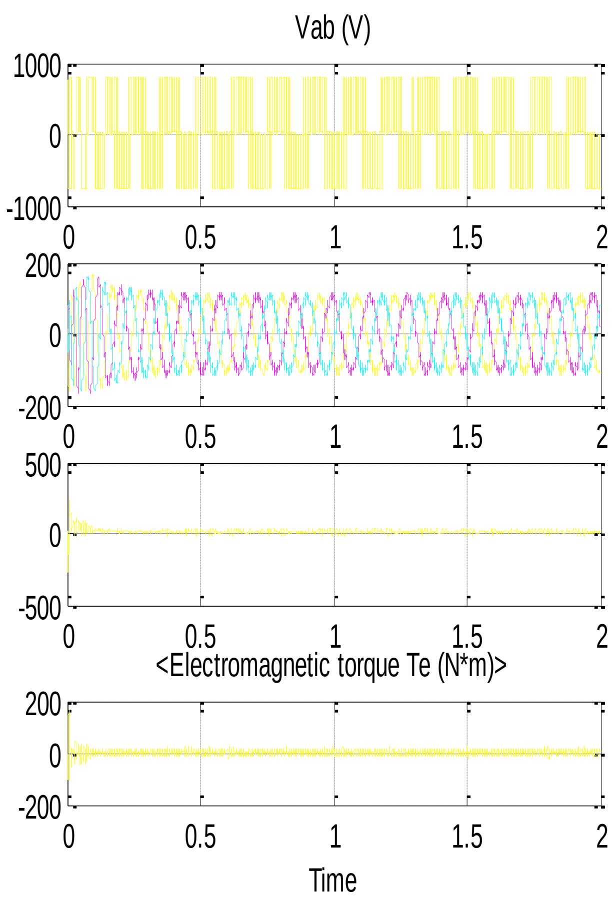

Fig.3.a Voltage, Current, Speed and torque waveforms of Vector controlled Permanent magnet Synchronous motor

VII. FFT ANALYSIS

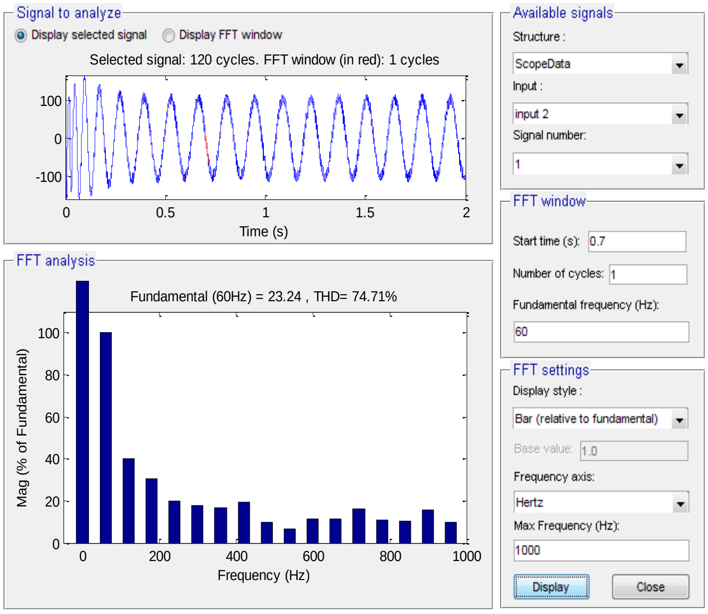

Fig4.FFT Analysis for PWM controlled Permanent magnet Synchronous motor drive

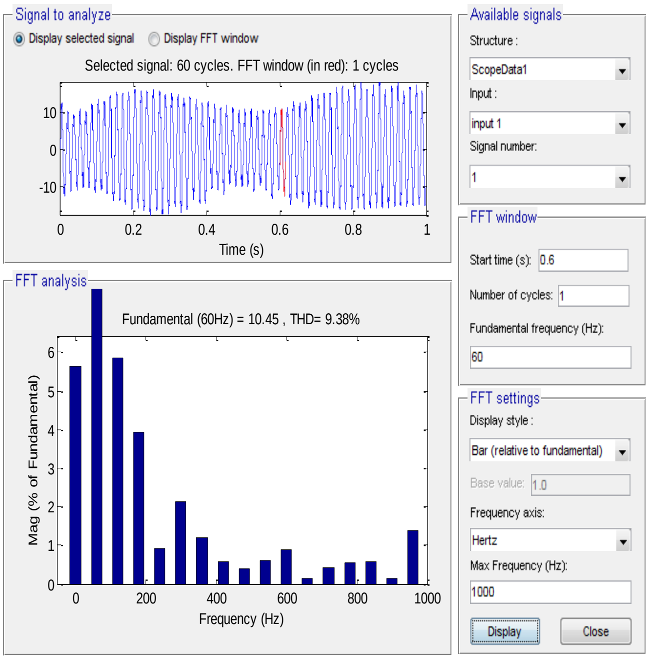

Fig5. FFT Analysis for Vector controlled Permanent magnet Synchronous motor drive

The FFT analysis shows that when IGBT is fed from PWM method, the THD was 74.7 %but when it is fed from Vector control method, the THD reduces to 9.3% for Permanent magnet synchronous motor

VIII. RESULT AND CONCLUSION

Phase	Vector Controlled PMSM (% THD)	PWM CONTROLLED PMSM (% THD)
A	74.7	9.38
B	75.5	9.46
C	73.4	9.44

.Speed is getting constant earlier when applying Vector control instead using PWM system.

APPENDICES

Motor ratings:
Stator phase resistance: 2.8750 Ω
Inductances: 8.5e-3 for (d,q)
Flux linkages established by magnets: 0.175
Current Regulator: 20
Pulse Width Modulation
Switching frequency 2000
Modulation Index 0.4
DC Supply 780 V
Vector Controlled Induction Motor Drive
PI Controller K_p= 2 K_i= 26
Current Controller 20 db

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