

Analysis and Simulation of Permanent Magnet Synchronous Motor (PMSM) under Vibration Effect using Analytical Magnetic Field Calculations.

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Abstract: In recent years Permanent Magnet Synchronous Motor (PMSM) drives are gradually replacing induction motors drives in engineering fields. This is becoming a trend due to some key features of PM motors, including compactness, efficiency, and robustness, reliability, and shape adaptation to the working environment. Based on analytical magnetic field computation techniques, the analytical solutions for electromagnetic vibration sources such as torque ripple, cogging torque, and radial force density have been developed. By applying FFT analysis to these vibration sources, the specific harmonic orders and the corresponding frequencies that affect vibration of the PMSM's stator have been investigated. It is observed that results are in good agreement with the predicted values.

Key Words: - Permanent Magnet Synchronous Motor (PMSM), Electromagnetic vibration sources, Finite element (FE) analysis, Fast Fourier transformation (FFT) analysis.

1.0 Introduction

Vibration analysis is one of the most successful techniques for condition monitoring of rotating machines [1-2]. Motor vibration data contains significant analytical information about internal motor electrical problems such as stator and rotor winding and core condition, air gap eccentricity, and information about external electrical anomalies such as current/voltage imbalance, voltage distortions in the power line. Because of high torque density and efficiency, the permanent magnet synchronous motor (PMSM) is being investigated as a promising candidate for many industrial applications. Acoustic noises in the PMSM are critical issue due to noise over a frequency range from about 10 to 1000 Hz in the form of sharp coherent resonances as well as transient excitations [1-2]. The fast Fourier transformation (FFT) analysis is employed for investigating the specific harmonic orders of the electromagnetic vibration sources that affect the vibration of the PMSM.

2.0 Literature Survey

Many authors worked on analysis and design of permanent magnet machines [1-11]. FFT analysis was used to look into specific harmonic orders of the electromagnetic vibration sources that influence the vibration of PMSM. Some researchers looked into the radial and tangential

forces that deform the stator core and are primary causes of vibration and noise. Some researchers worked on spectrum of the measured acceleration according to the vibration order for various rotor speeds. They observed that for various rotor speeds, dominant vibration orders are 26th, 54th, 78th, and 104th. They also observed that for each dominant vibration order, the maximum acceleration varies on the basis of rotor speed.

3.0 Methodology

This work addresses analysis of the vibration characteristics of a permanent magnet synchronous motor (PMSM). Torque ripple, cogging torque, and radial force density are identified as a electromagnetic vibration sources. For this purpose, we derive an analytical solution for the magnetic fields generated by permanent magnets (PMs) in terms of a magnetic vector potential and a two-dimensional (2-D) polar coordinate system. A 2-D permeance function is also introduced in order to consider slotting effects. The electromagnetic vibration sources such as torque ripple, cogging torque, and radial force density are analyzed using these solutions. The analytical results are validated extensively with finite element (FE) analyses. The fast Fourier transformation (FFT) analysis is employed for investigating the specific harmonic orders of the

electromagnetic vibration sources that affect the vibration of the PMSM. Finally, vibration

measurements are obtained to confirm the validity of the analysis methods.

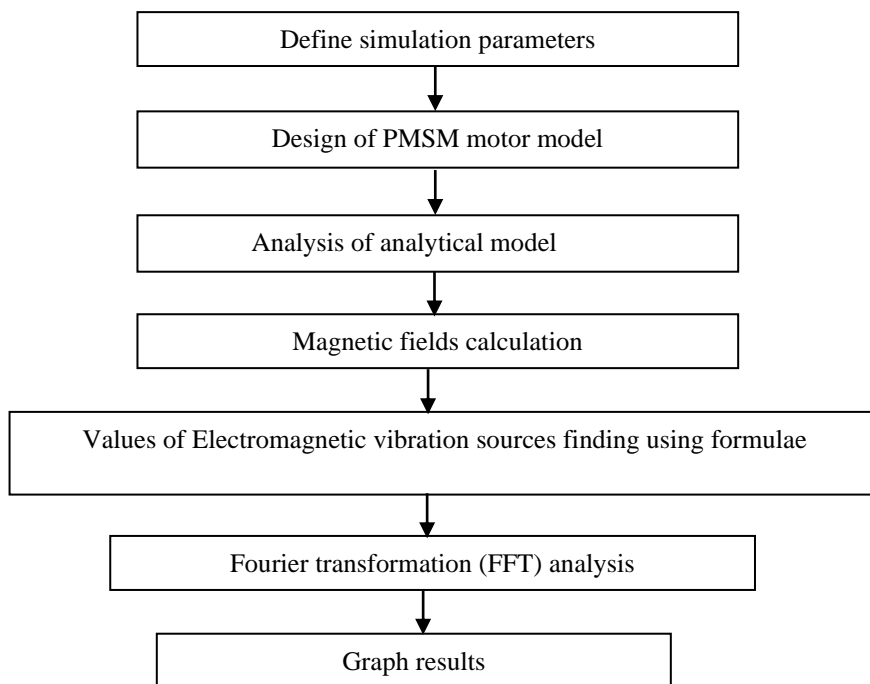


Fig.4.1 Flow of Project

Figure 3.1: Methodology to carry out vibration analysis of Permanent Magnet Synchronous Motor (PMSM)

The design parameters mentioned in PMSM table (radius, frequency, rotor speed) are initialized in the beginning. Using these parameters and simulator the PMSM model is designed. The mathematical equations mentioned in the base paper [2] are realized using simulator script. The magnetic fields' distribution is obtained by using distributive function of simulator software. The values are placed in vector parameter. Using Fast fourier transform algorithm, the features of motor are obtained. Then by analyzing the FFT results

we can determine the noise (vibration) effect. The graphs such as electromagnetic torque Vs time, radial force Vs time, FFT analysis, cogging torque are obtained.

4.0 Case Study:

Permanent Magnet Synchronous Motor with 6 pole rotor and 27 slot stator is chosen as model to validate analysis methods [2]. Table 1 shows main specification of Permanent Magnet Synchronous Motor. Figure 4.1(a) shows actual image of Permanent Magnet Synchronous Motor with 6 pole rotor and 27 slot stator and Figure 4.1 (b) shows position of acceleration sensor to measure vibration.

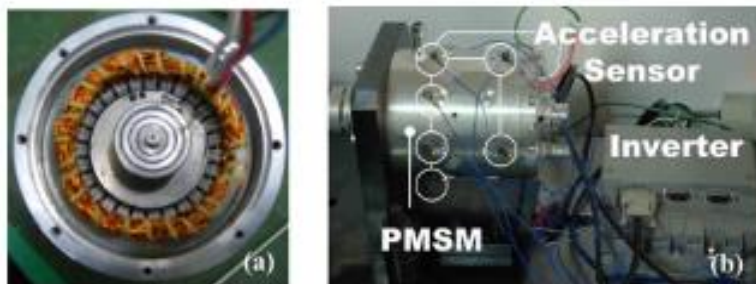


Figure 4.1 Photograph of (a) PMSM with 6-pole PM rotor and 27-slot stator (b) Testing apparatus to measure vibrations.

Table 1: Principal data of Prototype PMSM

Parameters	Values
Inner radius of PM(ri)	23.3mm
Outer radius of PM(ro)	28mm
Inner radius of stator(rs)	28.7mm
Active length of motor (la)	50mm
Number of coils per phase (Nc)	9
Pole arc ratio of PM	0.8
Pole –Pairs (p)	3
Remanence (Br)	1.28(T)
Rated speed(w_r)	314 rad/s
Number of turns per coil (Ns)	7

Correlation of results among between analytical and simulation for air gap density and back emf is done. True to form the consonant orders of the torque ripple are products of 6. Under a rated rotor speed of 3000 rpm, its frequencies are 900 Hz, 1.8 kHz, 2.7 kHz, and so on; This is because the

presence of the 6-pole rotor makes the motor's frequency at 3000 rpm 150 Hz.

5. Simulation Results

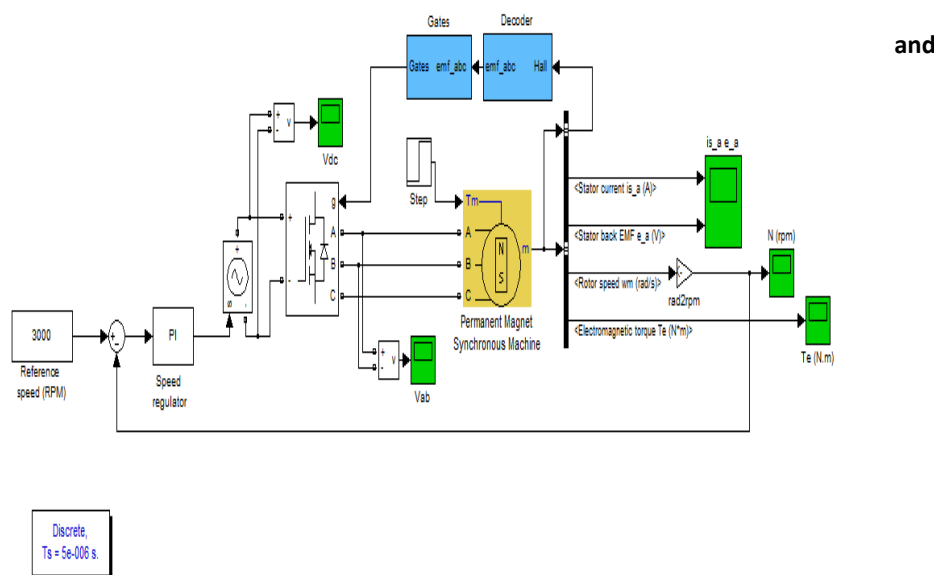


Fig.5.1 Design of PMSM Model

Model is designed using Mat lab simulator. Motor reference speed is 3000 rpm. PI Controller is used. Controlled voltage source used, converts the Simulink input signal into an equivalent voltage source. The generated voltage is driven by the input signal of the block. In this model logic gates and decoders are used. PMSM model consists of 3 phase permanent magnet synchronous machine with sinusoidal or trapezoidal back EMF. The sinusoidal machine is modeled in the dq rotor reference frame and the trapezoid machine is

modeled in the abc reference frame. Stator windings are connected in wye to an internal neutral point. Output of Bus selector block accepts a bus input which can be created from bus creator, bus selector, or a block that defines its output using a bus object. Current 4A electromagnetic force 220 N used to excite vibrations. Figure 5.2 a) and Figure 5.2 b) shows Time verses stator 'ia' and electromagnetic force 'ea'. Torque production in a brushless permanent magnet motor is due to the mutual coupling

between a permanent magnet and one or more

energized coils.

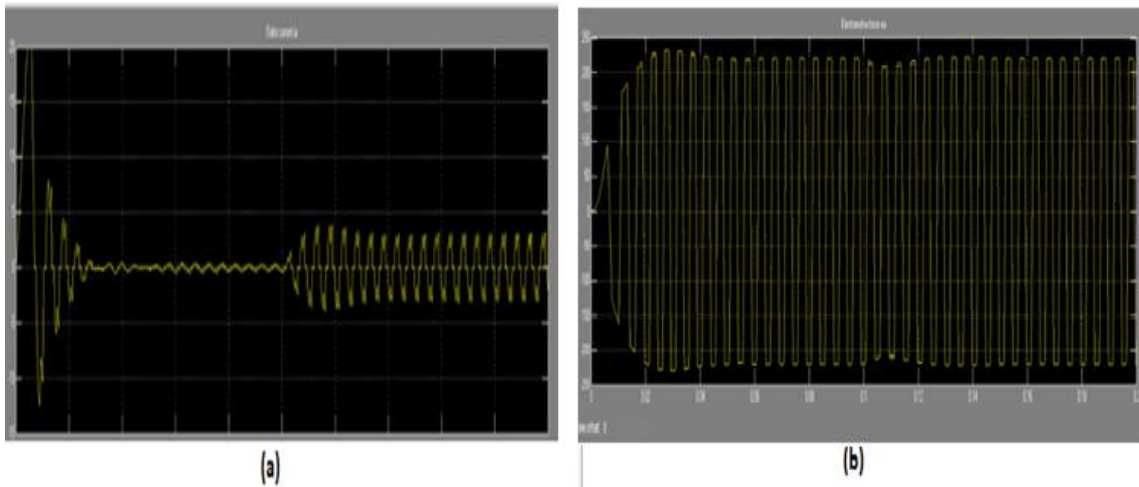


Fig.5.2 (a) Time vs Stator current 'ia' and (b) Time vs electromagnetic force 'ea'.

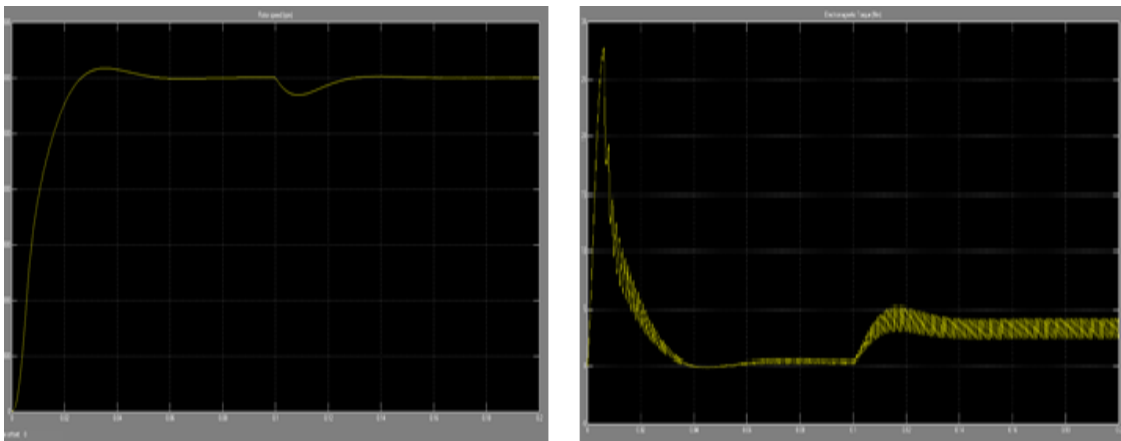


Fig.5.3 a) Time vs Rotor speed(rpm) and b) shows Time vs Electromagnetic Torque (Nm)

The torque of a synchronous motor is produced by the phase difference between the rotating magnetic field and the rotor. The torque is low when there is a small phase difference between the rotating rotor and the rotating magnetic field.

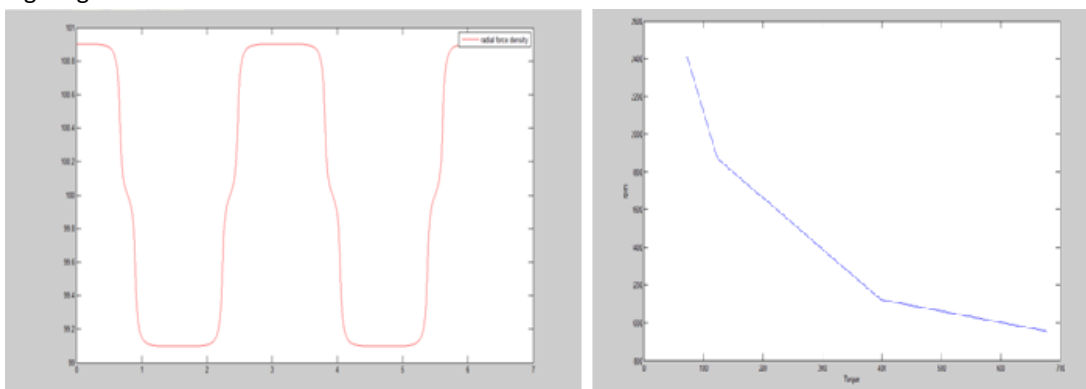


Fig.5.4 a) shows Time vs Radial Force Density b) Torque vs rpm

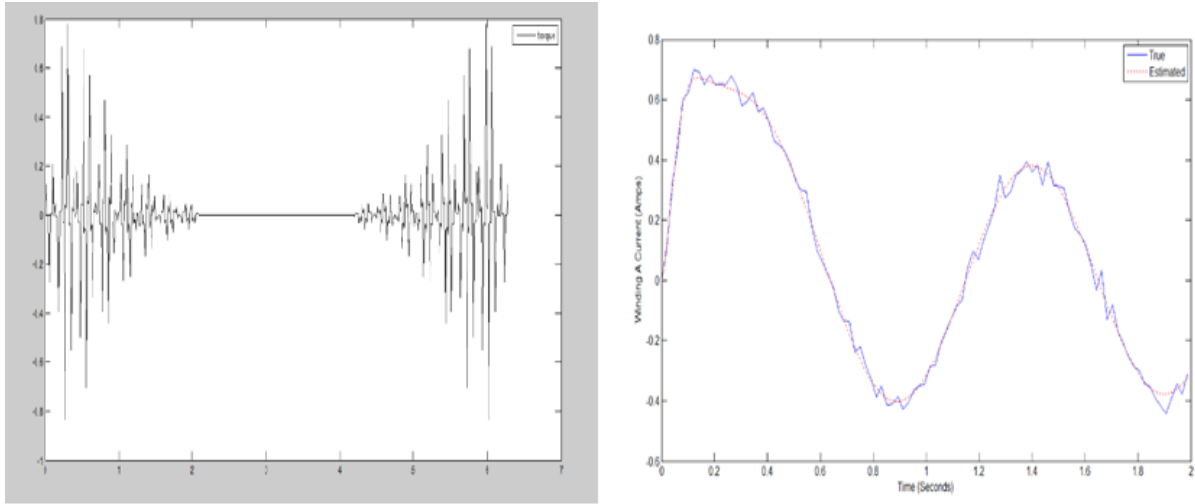


Fig.5.5 a) Torque-Torque in synchronous motor is directly proportional to the stator filed strength, rotor field strength and the sine of angle between them. b) Time vs winding A current(amp)

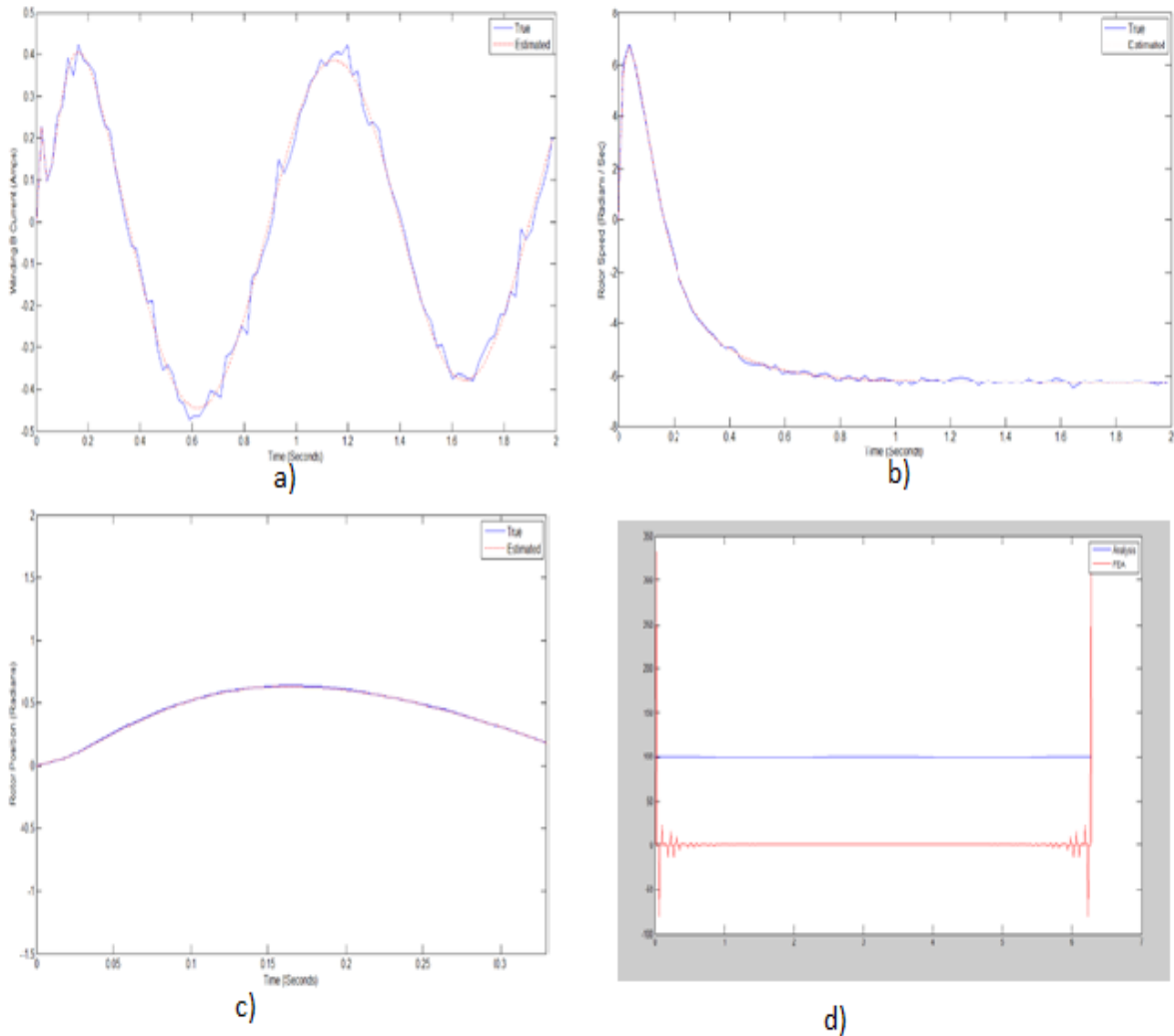


Fig.5.6 a) shows Time vs Winding B current (amp) b) Timevs Rotor Speed(radians/sec) c) shows Time vs Rotor position (radians) d) FEA Analysis

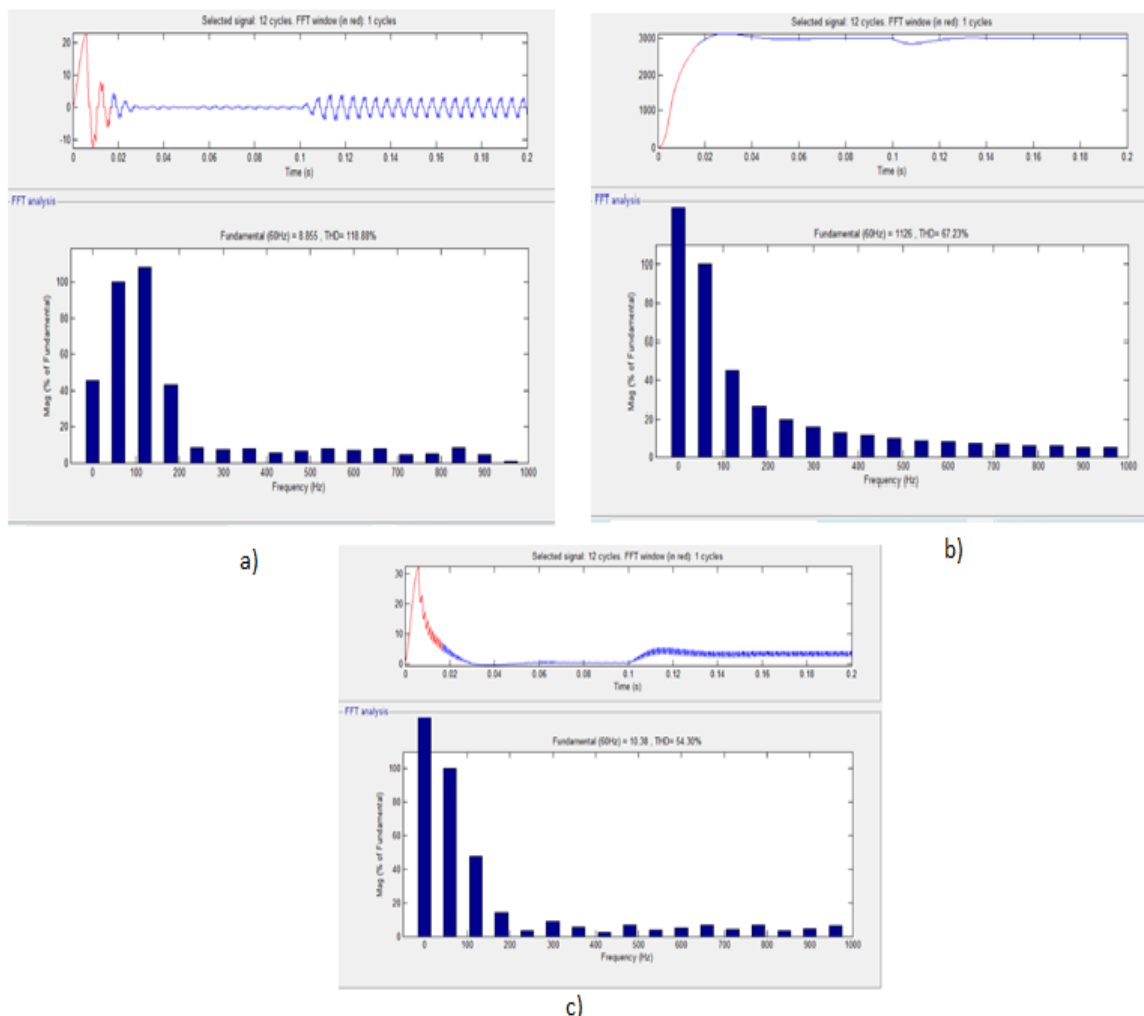


Fig 5.7 a) FFT Analysis of stator current 'ia' b) FFT Analysis of rotor speed of motor c) FFT Analysis of electromagnetic Torque

Fig.5.5 a) Torque-Torque in synchronous motor is directly proportional to the stator field strength, rotor field strength and the sine of angle between them. b) Time vs winding A current(amp)

(FFT) is used to convert discrete signals from time domain to frequency domain.

6. Conclusion

This paper is efficiently simulated and implemented using synchronous motor model. We have measured electromagnetic torque, rotor speed, stator current, back e.m.f. from the model. Analytical magnetic field techniques are used for various electromagnetic vibration sources like torque ripple, cogging torque, radial force density, power spectral density etc. By applying FFT analysis to these vibration sources, the specific harmonic orders and the corresponding frequencies that affect vibration of the PMSM's stators have been studied. Fast Fourier Transform

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