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INTEGRATED HARMONIC SUPPRESSION IN FOC BASED PMSM DRIVE

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ABSTRACT

Permanent Magnet Synchronous Motors are increasingly used in household appliances, robots, electric vehicles and other portable machines due to their smaller size and less weight. Also it has high power density which results in high efficiency and performance. This paper presents Field Oriented Control also known as Vector Control method to effectively control the speed and torque of the PMSM. Field Oriented Control is a closed loop system in which Space Vector Pulse Width Modulation is used for variable frequency sinusoidal input voltage. However due to high frequency switching elements there will be harmonics in motor currents. To suppress this combination of LC filter and Adaptive Notch Filter is used.

KEYWORDS: *Adaptive Notch Filters, Harmonic LC Filter Permanent Magnet Synchronous Motor*

INTRODUCTION

PMSM has a three phase stator and a permanent magnet rotor. It does not need any slip rings or brushes as the permanent magnet in the rotor provides the required magnetic field. The materials used for the permanent magnet of the rotor can be ferrite magnets, Alnico or rare earth (neodymium) magnets. As the name suggests these motors run at synchronous

Field Oriented Control (FOC) is a method used to control the speed and the torque of the motor. It is a closed loop control system in which the three phase motor currents as well as the angular position of the rotor along with the desired value set as reference value is fed back continuously. The angular position can be determined by sensing speed. Speed can be calculated either by sensorless method or by using Hall effect sensors. To control the torque and speed separately the three phase motor currents are converted to two phase orthogonal vectors in D-Q axis using park-clarke transformations. Reference values are given separately to these components using PI controllers and the output is again transformed using inverse park transformation. This is fed to the Space Vector Pulse Width Modulation unit, which triggers the gate of switching element and thereby controlling the input frequency.

The following figure shows the FOC or Vector control method. Usually a 64 step pulse width modulation is used. This is because as the number of steps increase the waveform becomes more sinusoidal and higher order frequency interference will be lower.

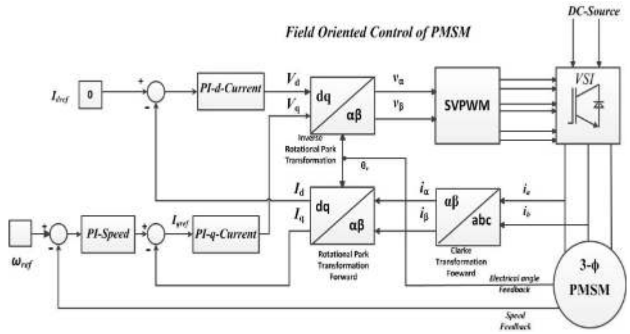

Figure 1: Field Oriented Control of PMSM.

IGBTs are now commonly used due to their better turn-on and turn-off characteristics and availability at different power ratings. However these high frequency switches create higher order harmonics in the motor current. It should be noted that high speed PMSM has low stator inductance values. In a PMSM harmonics cause more noise, core loss as well as torque ripple all of which will reduce the motor efficiency. The direct method to suppress harmonics is to connect identical inductors in series with the three phase stator winding. This will increase the equivalent inductance of the motor and will reduce the harmonics. But the total volume and weight of the motor assembly will be increased which is not desirable. The other method is to use an LC filter to suppress the harmonics. This will not make the motor assembly heavy and bulky. However the introduction of the LC filter will make a resonance frequency in this system which will further increase the harmonic content. To suppress the resonance peak generated due to the LC filter, a passive or an active method can be used. In passive method parallel resistors are connected at both end of the LC filter. This will suppress resonance peak but at the expense of energy loss. In active method we use the equivalent transfer function model and the current or voltage across filter capacitor is then fed back so as to simulate the resistances. Again the downside of this method is that even though there is no energy loss, additional sensors are needed to measure current and voltage which increase the total cost.

In this paper a combination of LC filter along with an Adaptive Notch Filter (ANF) is proposed. The LC filter is used to supress the motor current harmonics and the ANF is used to suppress the resonance peak generated by the LC filter.

II. MODELLING OF PMSM

To Analyse the PMSM Using Mathematical Modelling, the Following Assumptions are Made:

1. Three phase motor currents are symmetrical and sinusoidal.
2. PMSM rotor is not damped.
3. Eddy current loss and hysteresis loss are ignored.
4. Magnetic saturation of core is also

The voltage equation of PMSM is given by

$$u = Ri + \frac{d\psi}{dt} \tag{1}$$

The three currents are converted to d-q axis components using the equations

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} Cos\theta_e & Cos\left(\theta_e - \frac{2\pi}{3}\right) & Cos\left(\theta_e + \frac{2\pi}{3}\right) \\ -Sin\theta_e & -Sin\left(\theta_e - \frac{2\pi}{3}\right) & -Sin\left(\theta_e + \frac{2\pi}{3}\right) \end{bmatrix}\begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} \quad (2)$$

lux linkage is given by

$$\psi_d = L_d I_d + \psi_f \quad (3)$$

$$\psi_q = L_q I_q \quad (4)$$

Voltage is given by

$$u_d = Ri_d + L_d \frac{di_d}{dt} - \omega_e L_q I_q \quad (5)$$

$$u_q = Ri_q + L_q \frac{di_{dq}}{dt} - \omega_e (L_d I_d + \psi_f) \quad (6)$$

And the torque is given by

$$T_e = \frac{3}{2} p_n I_q [I_d (L_d - L_{dq}) + \psi_f \quad (7)$$

The following figure shows the equivalent circuit for a phase of PMSM with LC filter

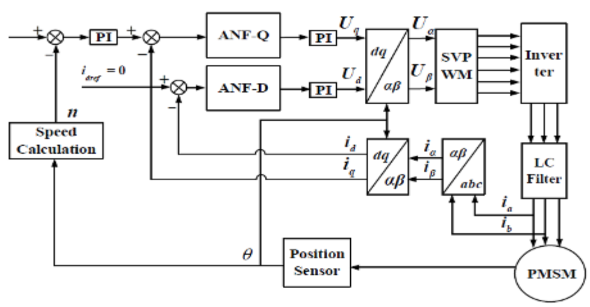

Figure 2: LC Filter for PMSM.

The transfer function of the PMSM with LC filter system is given by

$$\varphi(s) = \frac{I_a(s)}{U_a(s} = \frac{1}{LL_1 s^3 + RL_1 Cs^2 + (L_1 + L)s + R} \quad (8)$$

The resonant frequency of the motor drive system is given by

$$f = \frac{1}{2\pi}\sqrt{\frac{L_1 + L}{LL_1 C} - \frac{R^2}{2L^2}} \quad (9)$$

III. PMSM WITH NOTCH FILTER

Adaptive notch filter is similar to a band stop filter working based on the Least Mean Square (LMS) Algorithm. LMS algorithm for the implementation of Notch filter is as follows

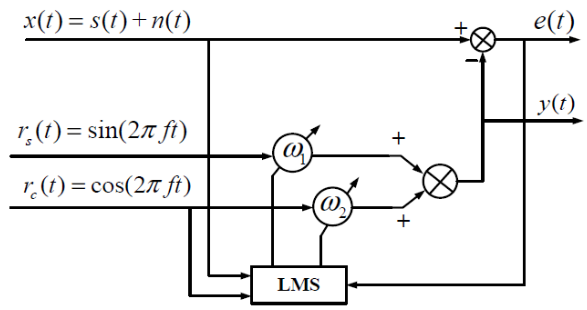

Figure 3: Notch Filter for PMSM.

$$y(k) = \omega_1(k)r_s(k) + \omega_2(k)r_c(k) \quad (10)$$

$$e(k) = x(k) - y(k)$$

$$\omega_1(k+1) = \omega_1(k) + \mu e(k) r_s(k)$$

$$\omega_2(k+1) = \omega_2(k) + \mu e(k) r_c(k)$$

Where the error transfer function is given by

$$\frac{e(s)}{x(s)} = \frac{s^2 + {\omega_0}^2}{s^2 + \frac{\mu A^2}{\tau}s + \omega^2} \quad (11)$$

The final circuit diagram after the introduction of ANF is given below

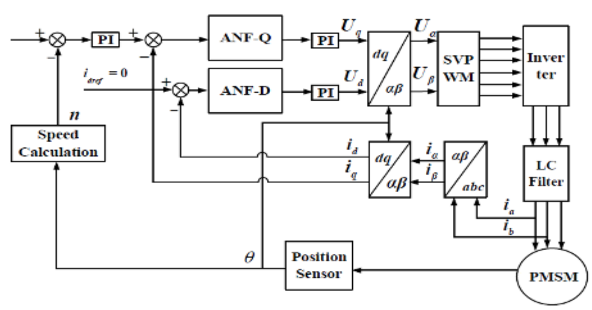

Figure 4: Field oriented control of PMSM with ANF.

IV. SIMULATION AND RESULTS

Using Matlab Simulink an ideal model of PMSM with FOC drive and integrated harmonic suppression using LC filters and ANF is simulated.

The motor current without filters is given below:

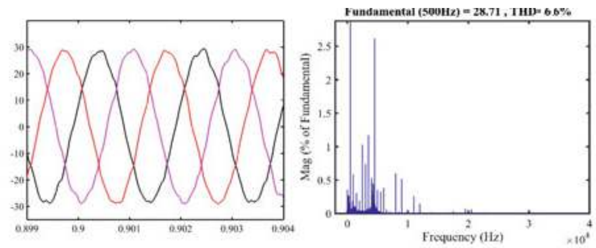

Figure 5: THD analysis with traditional feedback.

This has a THD (Total Harmonic Distortion) of around 20 percentages.

The following figure shows the result after introduction of filters.

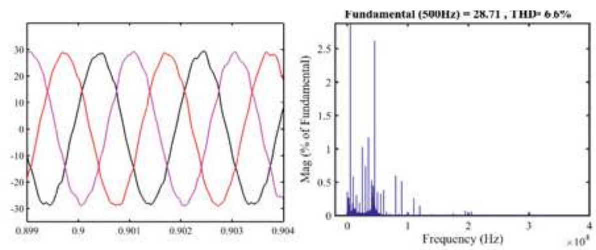

Figure 6: THD Analysis with Traditional Feedback.

It is observed that the introduction of filters have resulted in the reduction of THD to around 6.7 percentage.

V. CONCLUSIONS

This paper presents a cost effective method to reduce the THD of a PMSM drive system based on FOC. The reduction in THD is achieved by the introduction of LC filter along with an Adaptive Notch Filter and the same has been verified by simulation using Matlab Simulink.

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