Hardware Performance Comparison of PI and Space Vector PWM Techniques for Speed Ripple Minimization in Permanent Magnet Synchronous Motor with and without Iterative Learning Control

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Abstract— Permanent-magnet synchronous motor (PMSM) drives are widely used in high-performance industrial servo applications where torque smoothness is an essential requirement. However, one disadvantage of PMSM is parasitic torque pulsations, which induce speed pulsations that deteriorate the drive performance particularly at lower speeds. This paper propose the proportional plus integral controller (PI)working in transient state in parallel with Iterative learning control (ILC) working in steady state with Space Vector Pulse Width Modulation (SVPWM) to suppress the speed ripples in PMSM driven by field oriented control. The speed controller compares the reference motor speed with actual motor speed, and produces the reference current i_q ref value which in turn reduces the speed error. According to i_q ref value SVPWM pulses are produced and given to the three phase voltage source inverter. The advantages and effectiveness of the proposed method for speed ripple reduction is designed, analysed and simulated using simulink library in MATLAB R2009a and implemented in hardware using TMS320F2812. The results obtained from PEC16DSMO1 show the significant reduction in speed ripples using proportional plus integral controller (PI) plug in Iterative learning control (ILC) with Space Vector Pulse Width Modulation (SVPWM). This method shows better speed ripple reduction in comparison with the conventional method.

Keywords— Permanent Magnet Synchronous motor (PMSM), Torque ripple, Field oriented Control (FOC), Proportional plus Integral Controller (PI), Iterative learning control (ILC), Space Vector Pulse Width modulation (SVPWM)

I. INTRODUCTION

Permanent magnet synchronous motors (PMSM) are widely used in low and mid power applications such as computer peripheral equipments, robotics, adjustable speed drives and electric vehicles. PMSMs are still favoured for high-performance servo applications because of their high efficiency, power density and torque-to-inertia ratio, which make them a suitable choice for variable-speed direct-drive applications. However, the main disadvantage of PMSMs is the parasitic torque pulsations. Presence of these torque pulsations results in instantaneous torque that pulsates periodically with rotor position. These pulsations are reflected as periodic oscillations in the motor speed.These oscillations produce undesirable mechanical vibration on the load side.

The various sources of torque pulsations in a PMSM can be minimised by both motor design and control schemes which have been proposed in literature[5] . Smooth torque is obtained by tracking of a modified current reference with electrical time period. To achieve constant torque repetitive reference current signal is tracked and is controlled in a field oriented PMSM drive.[7]

Space Vector PWM (SVPWM) refers to a special switching sequence for the three-phase power inverter. It generates less harmonic distortion in the output voltages and or currents applied to the phases of an AC motor and to provide more efficient use of supply voltage compared with sinusoidal modulation technique.[1,14]

This paper presents an application of proportional integral controller with plug in iterative learning control to minimise the speed ripple associated with the field oriented control when used in control of a PMSM. A SVPWM based FOC with iterative learning control and PI is proposed to produce an effective selection of the stator voltage vector to obtain smooth torque performance. The advantage of FOC is that it increases efficiency, letting smaller motors replace larger ones without sacrificing torque and speed. The ILC is known for its best anticipatory character and ability to ensure the compensation for repetitive external disturbances by learning based on previous iterations without further modelling burdens.

II. OVERVIEW OF FIELD ORIENTED CONTROL

Field-oriented control (FOC), also known as vector control or decoupling control is an efficient method to control a PMSM in adjustable speed drive applications with quickly changing load in a wide range of speeds. FOC consists of controlling the stator currents

represented by a vector. This control is based on projections which transform a three phase time and speed dependent system into a two co-ordinate (d and q co-ordinates) time invariant system. These projections lead to a structure similar to that of a DC machine control. Field orientated controlled machines need two constants as input references: the torque component (aligned with the q coordinate) and the flux component (aligned with d co-ordinate). As FOC is simply based on projections, the control structure handles instantaneous electrical quantities. This makes the control accurate in every working operation (steady state and transient) and independent of the limited bandwidth mathematical model. The FOC thus solves the classic scheme problems, in the following ways:

1. The ease of reaching constant reference (torque component and flux component of the stator current).

2. The ease of applying direct torque control, because in the (d,q) reference frame the expression of the torque is:

$$T \propto \Psi_R i_{sq} \qquad (1)$$

By maintaining the amplitude of the rotor flux (Ψ_R) at a fixed value, we have a linear relationship between torque and torque component (i_{sq}). We can then control the speed by controlling the speed component of stator current vector. The block diagram of conventional FOC of PMSM is shown in Fig. 1.
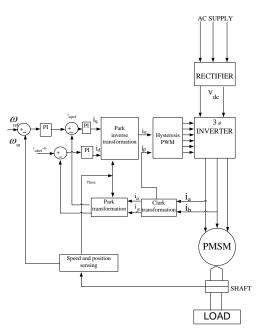
proportional- integral (PI) speed controller, which compares the actual speed w_m with the reference speed w_{ref} provides the main reference current i_{sqref}. During steady state, the proposed ILC controller generates a compensation current Δ iqs*that together with the main reference current iqo* which is utilized to minimize the speed ripples. Conventional PI current controllers are used in the inner control loops to generate the control voltages to shape Space vector pulse width-modulated (SVPWM) signals. Test results obtained shows improvement in the steady-state speed response and therefore validate the effectiveness of both ILC and PI controllers. During the transient state, the ILC is made inactive and is provided only by the PI speed controller output, when steady state is reached, the ILC is applied and it provides the additional compensation term to so as to minimize the speed ripples. The performance of the drive system using the ILC scheme is compared with the scheme using only the PI controller. The block diagram of proposed FOC with the Iterative Learning based controller for the PMSM drive is shown in the figure 2.
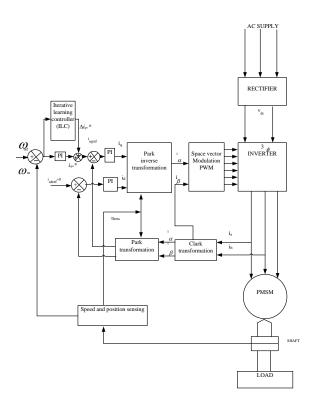

Fig.1 Block Diagram of PMSM drive with FOC using conventional PI controller

III. PROPOSED SYSTEM

The proposed iterative learning control (ILC) controller is applied in parallel with the conventional

Fig.2　Proposed Block diagram of PMSM driven by Field Oriented Control using ILC-SVM Controller

A. *Space Vector Pulse Width Modulation*

SVPWM supplies the AC machine with the desired phase voltages. There are eight possible combinations for the switch commands which determine eight phase voltage configurations. This PWM technique

Vector	A⁺	B⁺	C⁺	A⁻	B⁻	C⁻	V_{AB}	V_{BC}	V_{CA}
V_0 ={000}	OFF	OFF	OFF	ON	ON	ON	0	0	0
V_1 ={100}	ON	OFF	OFF	OFF	ON	ON	$+V_{dc}$	0	$-V_{dc}$
V_2 ={110}	ON	ON	OFF	OFF	OFF	ON	0	$+V_{dc}$	$-V_{dc}$
V_3 ={010}	OFF	ON	OFF	ON	OFF	ON	$-V_{dc}$	$+V_{dc}$	0
V_4 ={011}	OFF	ON	ON	ON	OFF	OFF	$-V_{dc}$	0	$+V_{dc}$
V_5 ={001}	OFF	OFF	ON	ON	ON	OFF	0	$-V_{dc}$	$+V_{dc}$
V_6 ={101}	ON	OFF	ON	OFF	ON	OFF	$+V_{dc}$	$-V_{dc}$	0
V_7 ={111}	ON	ON	ON	OFF	OFF	OFF	0	0	0

approximates the reference voltage Vref by a combination of the eight switching patterns (V0 to V7). The vectors (V1 to V6) divide the plane into six sectors (each sector: 60 degrees). Vref is generated by two adjacent non-zero vectors and two zero vectors. The switching vectors and sectors is shown in the figure 3.The table I shows the switching sequence of vectors for inverters.
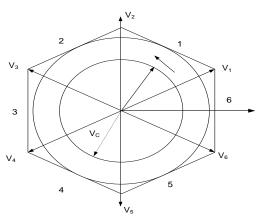

Fig.3 Switching vectors and sectors

To implement the space vector PWM, the voltage equations in the abc reference frame can be transformed into the stationary αβ reference frame that consists of the horizontal (α) and vertical (β) axes, as a result, six non-zero vectors and two zero vectors are possible. Six nonzero vectors (V1 - V6) shape the axes of a hexagonal as depicted in Fig 3 and feed electric power to the load or DC link voltage is supplied to the load. The angle between any adjacent two non-zero vectors is 60 degrees. Meanwhile, two zero vectors (V0 and V7) are at the origin and apply zero voltage to the load. The eight vectors are called the basic space vectors and are denoted by V0, V1, V2, V3, V4, V5, V6, and V7. The same transformation can be applied to the desired output voltage to get the desired reference voltage vector Vref in the d-q plane. The objective of space vector PWM technique is to approximate the reference voltage vector Vref using the eight switching patterns.
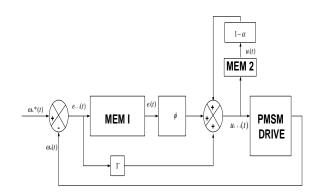
B. *Iterative Learning Control*

Iterative learning control is an approach to improve the tracking performance of a system that operates repetitively over a fixed time interval. It is basically an error correction algorithm and a memory that stores previous control effort and error and computes the new control effort based on that information. The advantages of ILC is the invariance of the system dynamics is maintained. The output can be measured within a small specified noise level.[1,8,9]The formula used for ILC is given in the equation 2 and the block diagram is shown in the fig 4.

$$u_{i+1}(t) = (1-\propto)u_i(t) + \emptyset e_i(t) + \Gamma e_{i+1}(t) \qquad (2)$$

Where i=1,2,3…….is the iteration number; $u_i(t)$ is the control signal, namely reference compensation q-axis current generated from ILC; $e_i(t)$ is the speed error signal; $\propto$ is the forgetting factor; $\emptyset$ is the previous cycle feedback; Γ is the current cycle feedback.

Fig. 4 Block diagram of ILC

C. *PI Controller Tuning*

The speed loop PI controller compares the reference speed with actual speed and produces the reference current i_{sqref}. The current loop PI controllers compares the actual current with reference current and produce i_q and i_d current respectively. PI tuning is done by trial and error method.

IV. HARDWARE RESULTS AND DISCUSSION

A. *OUTPUT CURRENT WAVEFORM FOR 50%LOADING*

The figure 5 shows the output current waveform at 50%loading.The current value is 3.3A at 2300 rpm. The parameters are

X-Axis –Time in ms,(1 div=5ms)
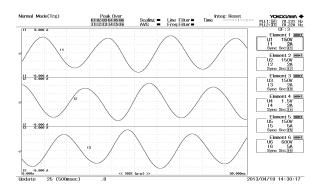
Y axis-(I1,I2,I3)- current in Amps,(1div = 2A)

Figure 5 Waveform of Output currents (Ia,Ib,Ic =3.3A) at speed 2300rpm

B. *OUTPUT VOLTAGE WAVEFORM FOR 50%LOADING*

The figure 6 shows the output voltage waveform at 50%loading.The voltage value is 100V at 2300 rpm. The parameters are

X-Axis –Time in ms,(1 div=5ms)

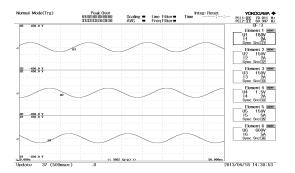Y axis-(U1,U2,U3)- Voltage in volt,(1div = 150V).

Figure 6 Waveform of Output Voltage (Va,Vb,Vc =100V) at

C. *DYNAMIC SPEED WAVEFORM OF PI-SVPWM*

The figure 7 shows the dynamic speed response of PI-SVPWM at the speed range of 1000 rpm to 4000rpm

Figure 7 Dynamic speed waveform of PI-SVPWM

D. *WAVEFORM OF SVPWM,LINETO LINE VOLTAGE WITHOUT FILTERING AND WITH FILTERING*

The figure 8 shows the SVPWM pulses,inverter output voltage for each phase without filtering and with filtering.The voltage value is 220V at 4000 rpm. The parameters are

X-Axis –Time in ms,(1 div=5ms)
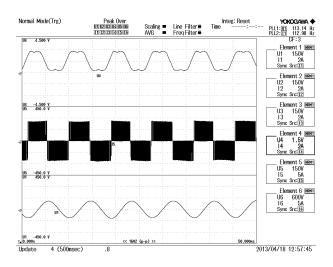
Y axis-(U1,U4,U5)- Voltage in volt,(1div = 150V).

Figure 8 Waveform of SVPWM , line to line voltage without filtering and line to line voltage with filtering.

E. *DYNAMIC SPEED WAVEFORM OF PI-ILC-SVPWM*

The figure 9 shows the dynamic speed response of PI-ILC-SVPWM at the speed range of 300 rpm to 2000rpm

Figure 9 Dynamic speed waveform of PI-ILC-SVPWM

F. *WAVEFORM OF GATEPULSES FOR THREE PHASES G1,G3,G5*

The figure 10 shows the gate pulses for three phases G1,G3,G5 waveforms of switching frequency f=30KHz and having magnitude peak –peak voltage=2.66V.

Figure 10 Gate pulses waveform for phases G1,G3,G5

G. *WAVEFORM OF GATEPULSES FOR THREE PHASES G4,G6,G2*

The figure 11 shows the gate pulses for three phases G1,G3,G5 waveforms of switching frequency f=30KHz and having magnitude peak –peak voltage=2.66V.
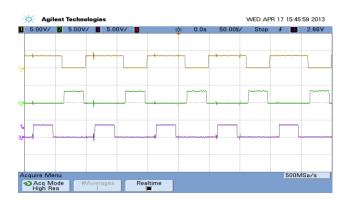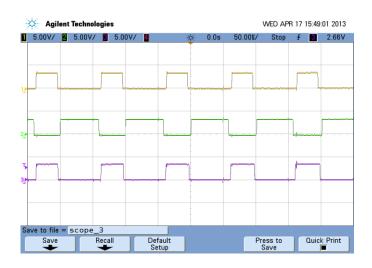

Figure 11 Gate pulses waveform for phases G4,G6,G2

TABLE II
COMPARITIVE RESULTS OF CONTROL TECHNIQUES OF PMSM

FIELD ORIENTED CONTROL	SPEED RIPPLE FACTOR (%)
FOC with ILC-SVM	12.3
FOC with PI-ILC-SVM	2.6

From the above table it is inferred that the percentage of ripples obtained by each case are shown and compared, by PI controller it is 12.13% of ripple, and by PI-ILC-SVPWM based controller the ripple is 2.6%. Thus in PI-ILC-SVPWM based controller has better performance by reducing 9.53%.

V. CONCLUSION

Speed pulsations are less in case of PI-Iterative learning controller. It is clear that a PI-ILC based speed controller achieves the minimum speed ripple in both transient state and steady state respectively than with only PI based speed controller. The results obtained from PI-ILC based speed demonstrate fast and satisfactory response both in transient state and steady state with less speed ripples.

VI. REFERENCES

[1]   Adhavan.B, Kuppuswamy.A, Jayabaskaran.G, Jagannathan. V (2011) "Field oriented control of Permanent Magnet Synchronous Motor (PMSM) using fuzzy logic controller", Recent Advances in Intelligent Computational Systems (RAICS), IEEE, pp.587-592.

[2]   Ahn H.S, Chen Y.Q (2007), Moore K.L, "Iterative Learning Control: Brief Survey and Categorization". *IEEE Transactions*

on Systems, Man and Cybernetics –part c:application and reviews, vol.37, no.6, pp.1099-1121.

[3] Bimal. K. Bose (2002), "Modern Power Electronics and AC-Drives", PHI Learning Private Limited.

[4] Favre E, Cardoletti L, Jufer M (1993),"Permanent Magnet Comprehensive Approach to Cogging Torque Suppression*", IEEE Transactions on Industry Applications*, pp.1141-1149.

[5] Gulez K, Adam A.A, Pastaci H (2008)," Torque Ripple & EMI Noise Minimization in PMSM Using Active Filter Topology & Field–Oriented Control". *IEEE Transactions on Industrial Electronics*, vol.55, no.1, pp.251-257.

[6] Jahns T.M, Soong W.L (1996)," Pulsating Torque Minimisation Techniques for Permanent Magnet AC Motor Drives -   a review". *IEEE Transactions on Industrial Electronics*, vol.43, no.2, pp.321-330.

[7] Juria Mat Lazi, zulkifilie Ibrahim, Marizan Sulaiman, Irma Wani Jamuludin, Yusuf Lada (2011),"Performance Comparison of SVPWM and Hysterisis Current Control for Dual Motor Drives". *IEEE Transaction on Applied Power Electronics*, pp.75-80

[8] Mattavelli P, Tubiana L, Zigliotto M (2005), "Torque Ripple Reduction in PM Synchronous Motor Drives Using Repetitive Current Control". *IEEE Transactions on Power Electronics*, vol.20 , no.6, pp.1423-1431.

[9] Qian W, Panda S.K, Xu J.X (2005), "Speed Ripple Minimization in Permanent Magnet Synchronous Motor Using Iterative Learning Control". *IEEE Transactions on Energy Conversion,* vol.20, no.1, pp.53-61."

[10] Qian W, Panda S.K and Xu J.X (2004),"Torque Ripple Minimization in PM Synchronous Motors Using Iterative Learning Control", *IEEE Transactions on Power Electronics*, vol.19, no.2, pp.272-279.

[11] Rahmi M, Abbaszadeh K, Radanb A (2010), "Torque Ripple Suppression   of Surface Mounted Permanent Magnet Synchronous Motor Using Harmonic Injected Currents".1st *power electronics and drives systems &technologies conference*, pp.279-283.

[12] Rivas D, Moran L, and Jose R.E (2003), "Improving Passive Filter Compensation Performance With Active Techniques", *IEEE transaction on power Electronics*, pp.161-170.

[13] Rahimi M, Abbaszadeh K, Radan A(2010), "Torque ripple suppression of surface mounted permanent magnet synchronous motor using Harmonic Injected Currents". *IEEE Transaction on Power Electronics and Drive Systems*, pp.279-283.

[14] Shin-Hung Chang,Pin-Yung Chen (2010)"Self–tuning Gains of PI Controllers for Current Control in a PMSM". *IEEE transaction on power Electronics,* pp.1282-85.

[15] Texas instruments, Europe "Field Oriented Control of Three Phase AC   Motors *".

[16] www.motioncontrol.com

[17] www.mathworks.com