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Comparative Analysis of Hysteresis and PWM Current Controllers for PMSM Drive

Abstract: *This paper presents comparative analysis of hysteresis and PWM current controllers applied to vector controlled PMSM drive. Both the controllers are analyzed and modeled and block diagram of vector control method is presented for PMSM drive. The performance of both models is simulated in MATLAB/Simulink environment.*

Keywords: *Hysteresis Controller; PMSM; PWM Controller; Vector Control.*

I. INTRODUCTION

Controllers are the heart of the feedback system. They are used to minimize the error of any system so that system can work on the desired state. In case of current controllers, they are used to minimize the current error in the system between the sensed current and reference current. Most commonly used controllers are hysteresis controller and PWM controller. Both the controllers have their own advantages over other.

The hysteresis controller needs less computational resources and makes the simulation fast. Non-deterministic pulsing method is used in hysteresis controller. PWM controller is able to minimize the current errors effectively and generate the desired wave. Deterministic pulsing method is used in PWM controller.

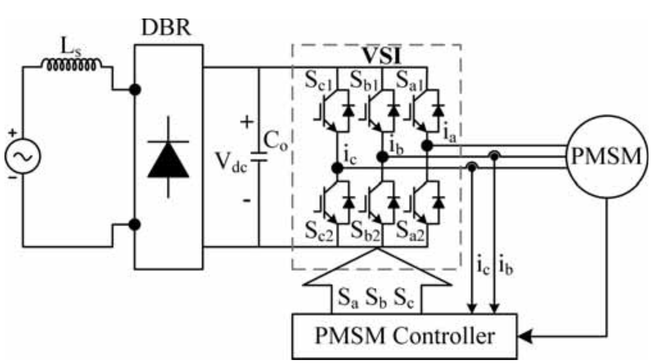


Fig. 1: Schematic diagram of DBR-VSI fed Vector controlled PMSM Drive

The permanent magnet synchronous motor (PMSM) is a compact and high efficiency drive used for many speed/position control system and needs current control for various applications [1]. The schematic diagram of DBR-VSI fed vector controlled PMSM drive is shown in Fig. 1, in which current control is executed in closed loop by sensing stator current through current sensor and their rotor position through position encoder. These sensed values are fed to PMSM controller which generates switching sequence to operate the Voltage Source Inverter (VSI) IGBT switches for smooth running of PMSM. Fig. 1 depicts the control scheme of vector controlled PMSM drive where the current controller can be either Hysteresis or PWM controller.

II. HYSTERESIS CURRENT CONTROLLER

Hysteresis controller is the simple one in which a hysteresis band, $2*\Delta i$, is defined for reference current, i^* and phase current follow the path of reference current in between hysteresis band. Hysteresis band consist of two limits i.e. Upper limit and Lower limit. Upper limit should have positive value and lower limit should have negative value. Magnitude of these limits may be either same or different, here same magnitude, N has been considered. N may be any positive number. Number of hysteresis band [2] like Constant Hysteresis Band, Sinusoidal Hysteresis Band, Adaptive Hysteresis Band and Simplified Adaptive Hysteresis are available for hysteresis controller, out of which constant hysteresis band is proposed here. If phase current crosses lower bound of hysteresis band then switch 1 becomes OFF and switch 2 becomes ON and if phase current cross upper bound of hysteresis band then switch 1 becomes ON and switch 2 becomes OFF. This logic is shown in Fig. 2 and given in Eq. 1-6, for all three phase.

$$S_{a1} = 1 \text{ and } S_{a2} = 0, \text{ if } i_a \geq i_a^* + \Delta i \quad (1)$$

$$S_{a1} = 0 \text{ and } S_{a2} = 1, \text{ if } i_a < i_a^* - \Delta i \quad (2)$$

$$S_{b1} = 1 \text{ and } S_{b2} = 0, \text{ if } i_b \geq i_b^* + \Delta i \quad (3)$$

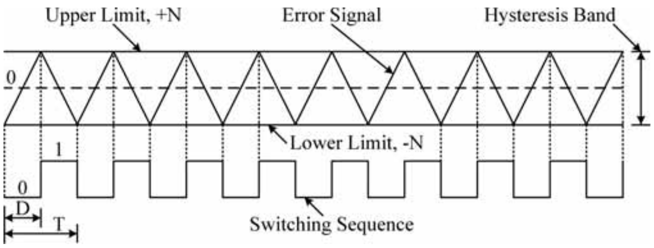


Fig. 2: Sequence generation using Hysteresis Controller

$$S_{b1} = 0 \text{ and } S_{b2} = 1, \text{ if } i_b < i_b^{*} - \Delta i \quad (4)$$

$$S_{c1} = 1 \text{ and } S_{c2} = 0, \text{ if } i_c \geq i_c^{*} + \Delta i \quad (5)$$

$$S_{c1} = 0 \text{ and } S_{c2} = 1, \text{ if } i_c < i_c^{*} - \Delta i \quad (6)$$

The only drawback of the hysteresis controller is the uncontrolled frequency of switching which may damage the switches**.**

III. PWM CURRENT CONTROLLER

In the PWM Controller a high frequency saw tooth wave is generated in the order of several KHz. In this work saw tooth of 10 KHz is proposed. The current error of all the phases is compared with this saw tooth waveform. For phase a, if the current error is greater than saw tooth wave then a signal S_{a1}=1 and S_{a2}=0 is generated to ON the upper switch S_{a1} and OFF the lower switch S_{a2}. If the current error is smaller than saw tooth wave, then a signal S_{a1}=0 and S_{a2}=1 is generated to OFF the upper switch S_{a1} and ON the lower switch S_{a2}. Similarly, switch of phase b and phase c are ON and OFF simultaneously. This logic for a single phase is shown in Fig. 3 and given in Eq. 7-12, for all three phases. Number of PWM schemes like Sinusoidal Modulation PWM, Symmetric Sinusoidal Modulation PWM, Flat Top Modulation PWM, and Space Vector PWM are reported in literature [1-4], out of which basic PWM scheme is presented in this paper.

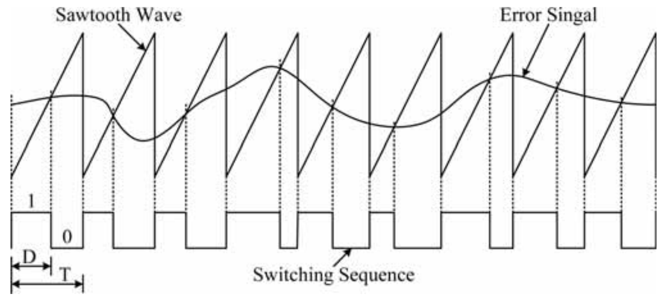


Fig. 3: Sequence generation using PWM Controller

$$S_{a1} = 1 \text{ and } S_{a2} = 0, \text{ if } \Delta i_a \geq m_s \quad (7)$$

$$S_{a1} = 0 \text{ and } S_{a2} = 1, \text{ if } \Delta i_a < m_s \quad (8)$$

$$S_{b1} = 1 \text{ and } S_{b2} = 0, \text{ if } \Delta i_b \geq m_s \quad (9)$$

$$S_{b1} = 0 \text{ and } S_{b2} = 1, \text{ if } \Delta i_b < m_s \quad (10)$$

$$S_{c1} = 1 \text{ and } S_{c2} = 0, \text{ if } \Delta i_c \geq m_s \quad (11)$$

$$S_{c1} = 0 \text{ and } S_{c2} = 1, \text{ if } \Delta i_c < m_s \quad (12)$$

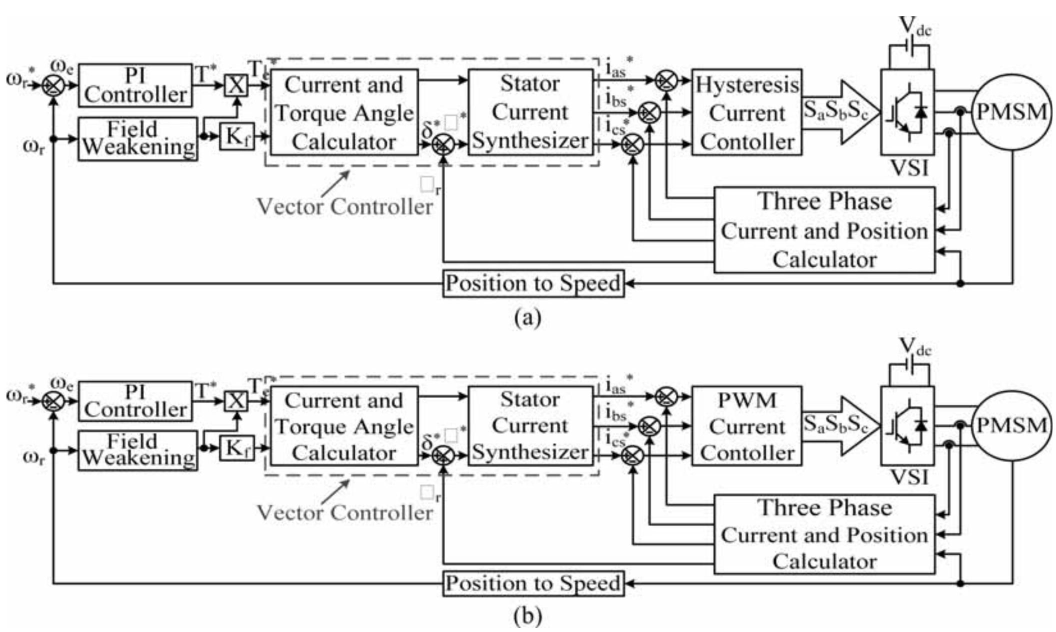


Fig. 4: Block diagram of PMSM Controller with (a) Hystersis Current Controller and (b) PWM Current Controller.

Where m_s represent the instantaneous value of saw tooth wave.

IV. SIMULATION MODEL

Simulation model of Vector Controlled PMSM drive has been shown in Fig. 5a and simulation of control scheme used in PMSM controller has been shown in Fig 5b. In this model a Constant DC source has been applied to VSI as it required perfect DC. Normally, this input DC voltage is achieved from AC mains using Diode Bridge Rectifier (DBR). This model is simulated for Hysteresis as well as PWM current controllers for PMSM drive parameters as given in Table 1 and Table 2.

V. RESULTS AND DISCUSSIONS

The obtained simulation results for Hysteresis and PWM controller are shown in Fig. 6a and Fig. 6b respectively, which clearly shows difference between these two controllers. PWM Controller minimize the current error effectively and produces the stator current similar to reference current, whereas hysteresis controller does not minimize the error effectively and have ripples in stator current and electromagnetic torque. On the other hand, the motor achieve its rated speed in 0.07 sec in case of hysteresis current controller and while in case of PWM current Controller it takes 0.13 sec to achieve its rated speed, which shows fast response of the hysteresis current controller.

This comparison shows that both the controllers have their own advantages over other, and still the competitor of each other. Therefore, careful selection is essential for various applications.

Table 1: Current Controller Parameters

S. No.	Current Controller	Kp	Ki
1.	Hysteresis	0.0320	3.3350
2.	PWM	0.0885	3.8035

Table 2: Motor Parameters

S. No.	Parameter	Symbol	Value
1.	Rated Torque	T	8 Nm
2.	Maximum Torque	T_m	10 Nm
3.	Voltage	V_{dc}	300 V
4.	Rated Speed	ω_r	2000 rpm
5.	Stator Phase Resistance	R_s	0.9585 ohm
6.	d-axis inductance	L_d	0.00525 H
7.	q-axis inductance	L_q	0.00525 H
8.	Rotor flux linkage	λ	0.1827 V.s
9.	Inertia	J	0.0006329 Kg.m2
10.	Friction factor	F	0.0003035 N.m.s
11.	Pole	P	8
12.	Field Weakening Gain	K_f	0.2

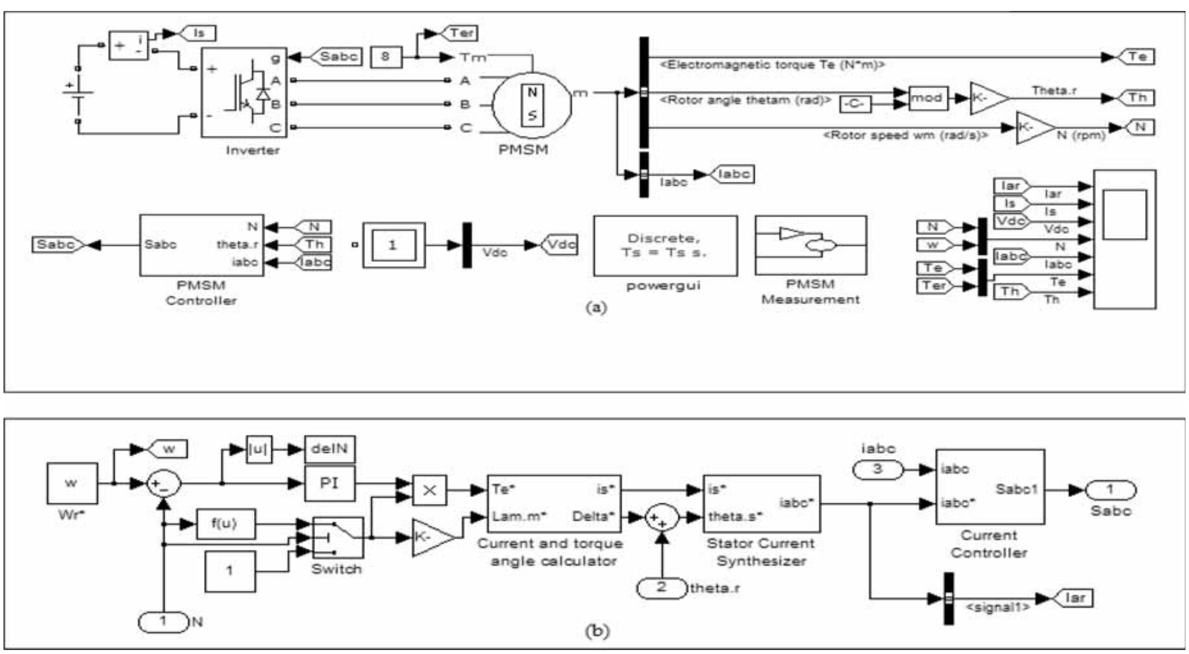
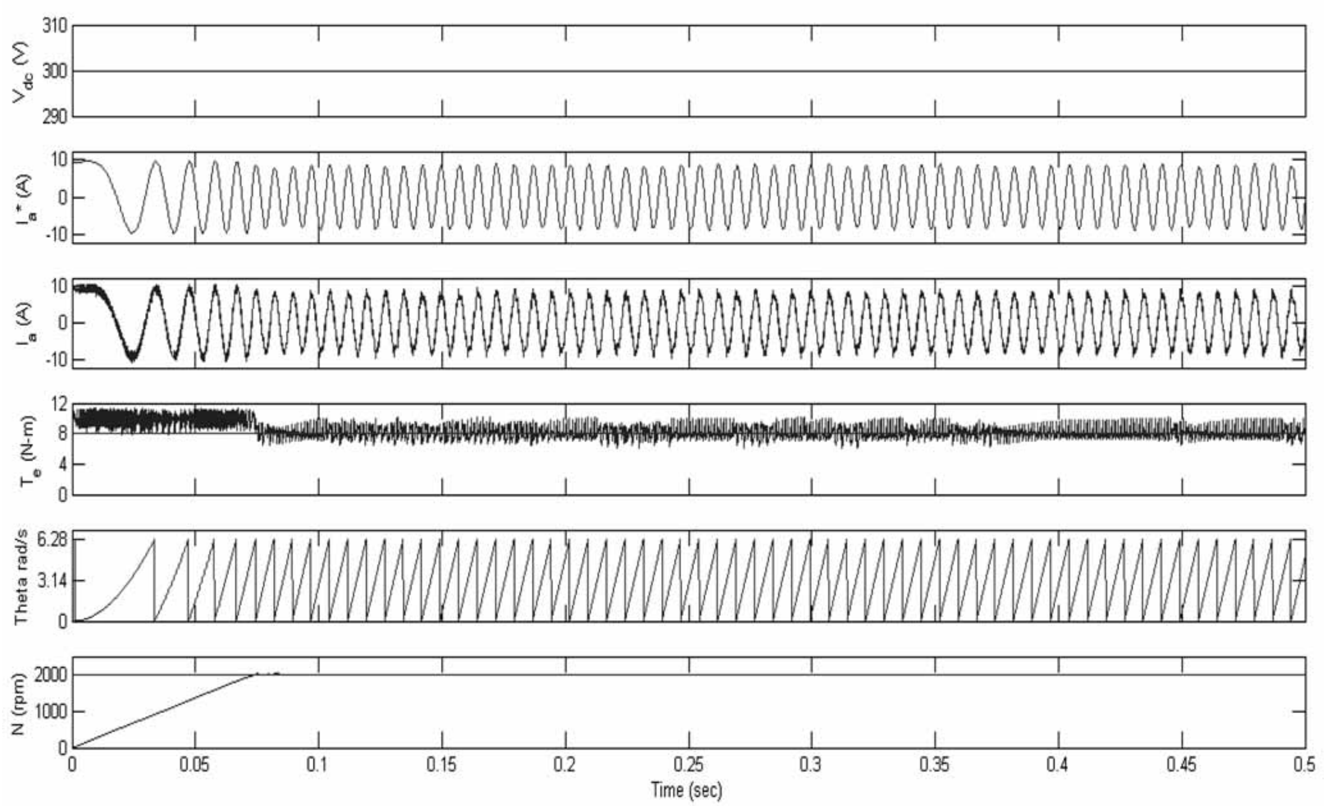
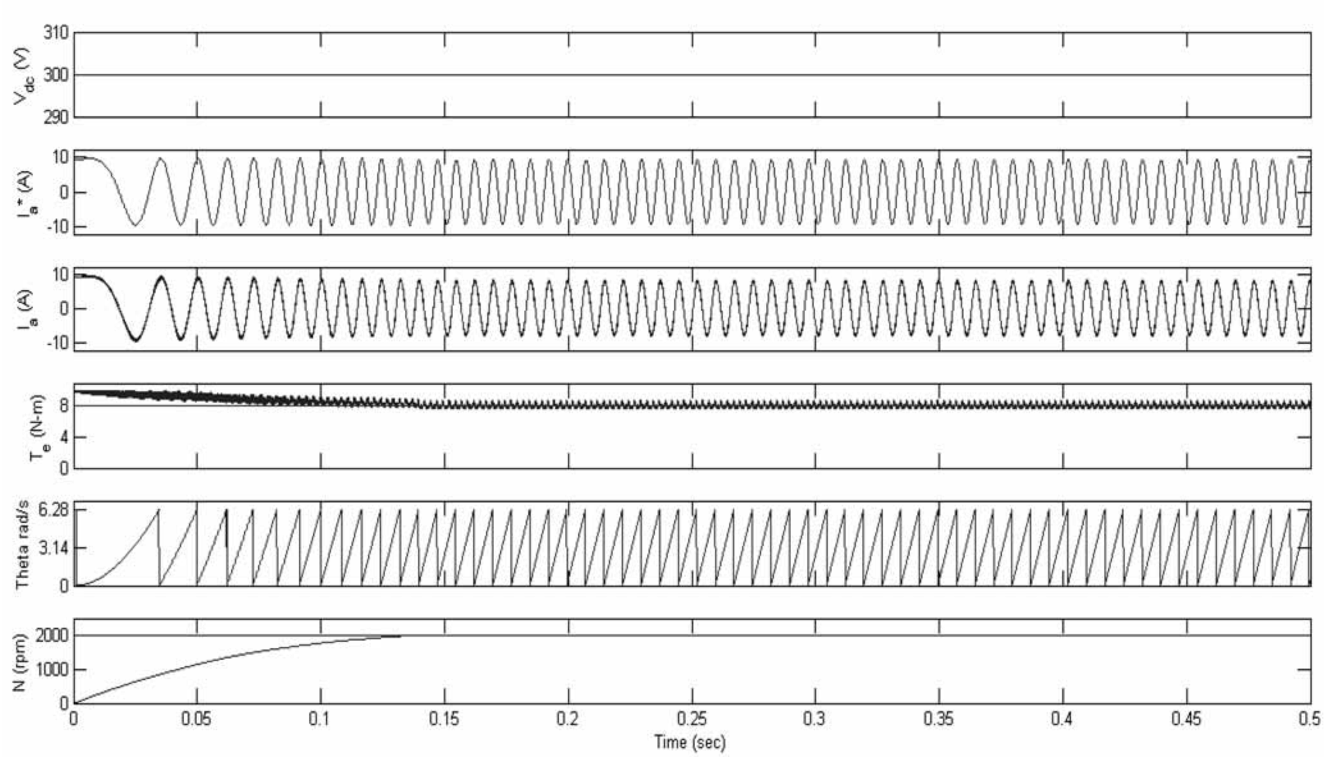


Fig. 5. Simulation model of (a) PMSM Drive and (b) PMSM Controller



(a)



(b)

Fig. 6: Simulation Results of Vector Controlled PMSM Drive with (a) Hysteresis and (b) PWM Current Controller

VI. CONCLUSION

A comparative analysis of Hysteresis current controller of constant hysteresis band and PWM current controller of 10 KHz sampling frequency has been presented for a vector controlled Permanent Magnet Synchronous Motor (PMSM) drive. The proposed controllers as well as the PMSM drive has been modeled and simulated in MATLAB/Simulink environment. The PMSM drive has been supplied through constant source. MATLAB simulation results of the drive for both the controllers have been presented for comparison. It is concluded that Hysteresis current controller makes the drive fast to achieve its rated speed while the PWM current controller reduces the ripples in the current and torque of the drive.

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