PERFORMANCE COMPARISON OF SVPWM AND HYSTERESIS CURRENT CONTROL FOR DUAL MOTOR DRIVES

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Performance Comparison of SVPWM and Hysteresis Current Control for Dual Motor Drives

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Abstract- **Dual motor drives fed by single inverter are purposely designed to reduced sizes and cost with respect to single motor drives fed by single inverter. This paper presents the speed responses behavior of Dual Permanent Magnet Synchronous Motor (PMSM) driven base on two different PWM control schemes, which are Space Vector Pulse Width Modulation (SVPWM) and Hysteresis Current Controller. These two techniques are compared for wide range of speed and for variation of load. MATLAB/Simulink has been chosen as the simulation tools. The comparison between SVPWM controller and Hysteresis Current Controller for Dual PMSM fed by single inverter is presented. Both techniques show satisfactory speed regulation for a wide range of speed either with load, no load or variation of load.**

***Keywords*—** **Dual Motor Drives, Single Inverter, SVPWM, Hysteresis Current control**

I. Introduction

In many applications, one motor is controlled by one converter. These systems are called SMSC, single machine single converter system [1]. Multi machine systems (MMS) are more and more used for industry today. Those systems allow to extend the field of high power applications or to increase their flexibility, mechanical simplicity and safety operating. However, it includes a lot of power switches which are large in size, costly and bulky. The high cost and large size need of the inverter make such dual inverter, dual motor drive configurations economically less competitive. Therefore, the need for dual motor drives fed by single inverter is rising consequently to reduce sizes and cost with respect to the single motor drives, either in industrial or in traction application.

But, the reduction number of power electronics switches and other components will results the paralleling of the drives systems. If the load torque for each motor is still the same, there is no speed changes will be encountered because every motor will have the same behavior [2] . On the other hand, a variation of load on one of the motors will create perturbations on the electrical part and perhaps , a malfunctioning of the system. For this type of disturbance, a control drive is needed to compensate the disturbance in order to make the system back to its origin. After several reading, an average technique has been selected to overcome the loss of adhere of the motor. The technique is average of the mean of phase current.

Generally MMSC can be divided into two main categories, which are master-slave and mean control system [3]. In Master-Slave scheme, one motor which is selected as the master is directly control. The motor with the highest load is set as the master motor and the other one is slave motor, which has the same applied voltage, same electric pulsation and also the same speed [4]. Then the behavior of slave motor will be ignored. In some conditions, the performance of slave motors may not acceptable [3].

Whereas in mean control, there are several techniques have been applied . One of them is average of current [5], [6]. In this scheme, the control system is basically similar to that of a single machine. And the machine internal parameter such as flux, do not show desirable behavior. The second technique is averaging over the parameters of the equivalent circuit at steady state [7]. But in the case of motor parameters are not similar, some of the results, may not be not acceptable. The other techniques are the averaging the voltage space vector [3], [8]. Through this technique, for each motor, a single motor controller was applied, and then a reference voltage is obtained for each machine. In view of the fact that an inverter can only provide one reference voltage vector, thus a vector average is taken over the motor reference voltages, and the result is generated by the inverter. Besides, there are other technique such as mean and differential torque [5], [6] and the Optimum torque over current ratio [9].

II. Modulation Technique

To drive a motor, a modulation technique needs to be used in order to generate pulses with certain rules and goals through supplying DC voltage for the inverter. Basically, modulation technique can be classified into two types, which are voltage control and current control [10]. Voltage control modulation can be divided into three types of Pulse Width Modulation (PWM). The first type is six step PWM, the second is sinusoidal PWM and the third is Space Vector PWM also known as SVPWM. Besides, for current control, there are two techniques used, which are hysteresis current controller and delta modulation [7].

The pulse width modulation (PWM) makes the inverter output the waveforms which are made up of many pulses with certain rules and goals through supplying DC voltage for the inverter. Since it is the task for DC/AC switching mode to produce a sinusoidal AC output voltage, therefore, to control the flux linkage and frequency with ease, PWM is the essence in adjusting the speed drive systems. Among many forms of PWM, the SPWM and SVPWM are the most common form [6], the former is more familiar and the latter becomes mature promptly especially in the middle and high power systems.

A. SVPWM (Space Vector Pulse Width Modulation)

Space vector PWM (SVPWM) refers to a special technique of determining the switching sequence of the inverter power switches for obtaining variable output voltage which is defined spatially. Compared with the former three phase sinusoidal modulation (SPWM) method, SVPWM has advantages of lower current harmonics and possible higher modulation index. This technique has a wide linear modulation range without using distorted modulation and it also guarantees that only one switch changes at any time.

Figure 1 shows the basic configuration of SVPWM for Dual PMSM drives. Firstly, the speed controller estimates the torque through current, i_q*, then, two current controller will convert the i_q* and i_d* signals to voltages (V_q*, V_d*). These voltages are then transformed to α-β model by inverse Park's transformation. Then, using inverse Clark's equation, V_α* and V_β*, are converted to three phase voltages, V_a, V_b, V_c. These signal are used to generate SVPWM pulses before they can be used to drive a PMSM. Since it is dual motor, the average of d-q voltages ($V_{d,A}$*, $V_{q,A}$*, $V_{d,B}$*, $V_{q,B}$*) for both motors are calculated in order to be transform to three-phase voltages. As a feedback, three phase current output, need to be transform back to DQ model by using Clark's and Park's equations. Then, the actual i_d and i_q will be compared with the references current before proceed again by the current controller.

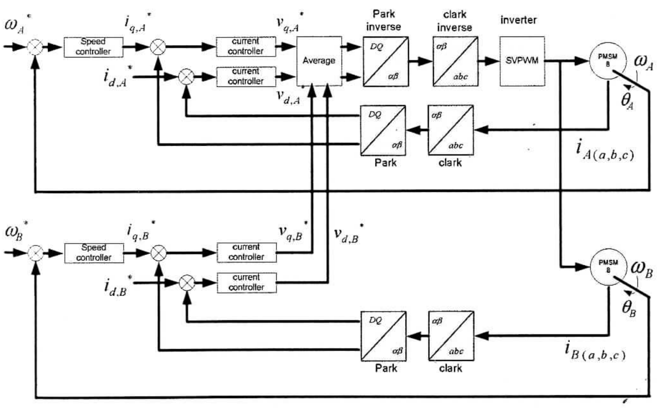


Fig. 1. SVPWM for Dual PMSM drives configuration

TABLE I
TRANSFORMATION SUMMARY FOR COORDINATE SYSTEM IN FIELD ORIENTED CONTROL

Park's equation : a,b,c → α,β	Inverse Park's equation : d,q → α,β
$i_\alpha = i_a$ $i_\beta = \frac{1}{\sqrt{3}}.i_a + \frac{2}{\sqrt{3}}i_b$ $i_a + i_b + i_c = 0$	$i_\alpha = i_d.\cos(\theta) - i_q.\sin(\theta)$ $i_\beta = i_d.\sin(\theta) + i_q.\cos(\theta)$
Clark's equation : α,β → d,q	**Inverse Clark's : α,β → a,b,c**
$i_d = i_\alpha.\cos(\theta) + i_\beta.\sin(\theta)$ $i_q = -i_\alpha.\sin(\theta) + i_\beta.\cos(\theta)$	$i_a = i_\alpha$ $i_b = -\frac{1}{2}.i_\alpha + \frac{\sqrt{3}}{2}.i_\beta$ $i_c = -\frac{1}{2}.i_\alpha - \frac{\sqrt{3}}{2}i_\beta$

B. Hysteresis Current Controller

The basic structure of the dual PMSM drives with hysteresis current control in the stationary reference frame and with PI speed controller is shown in Figure 2. Three independent hysteresis current controllers in the three phase a,b,c reference frame are applied in this scheme. In high performance servo drives, hysteresis current controllers are used to ensure that the actual currents flowing into the motor are as close as possible to the current references.

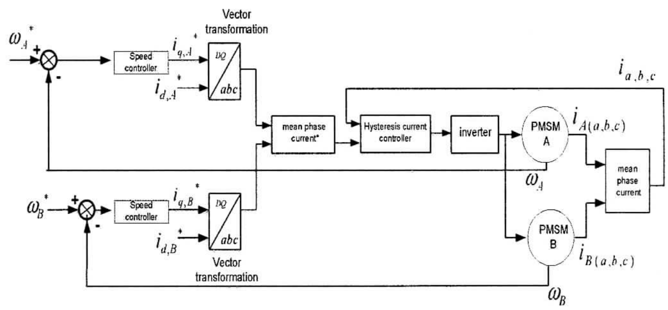


Fig. 2. Hysteresis Current Control for Dual PMSM configuration

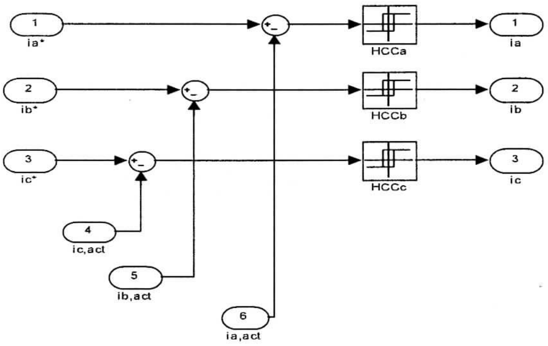


Fig.3. Hysteresis Current Control

Figure 3 shows the block diagram for hysteresis controller in order to produce the output signal. The actual phase currents (i_a, i_b, i_c) are compared with reference phase current (i_a*, i_b*, i_c*) using three independent comparator in hysteresis controller. The logic condition for six inverter switches is chosen by the output of the comparator [1].

When the phase "a" current is smaller than (i*-Δi), where Δi is the hysteresis band, the output of the comparator is "1", the "a" phase will be connected with the positive track of DC link. In contrast, if the phase "a" current is bigger than (i*- Δi), the output of the comparator will become "0", and the "a" phase will connected to the negative track of DC bus. A similar procedure exists in the other legs. The reason that this is called a hysteresis controller is that the leg voltage switches to keep the phase current within the hysteresis band. The phase currents are, therefore, approximately sinusoidal in steady state.

The smaller the hysteresis band, the more closely do the phase currents represent sine wave. Small hysteresis band, however, imply a high switching frequency, which is a practical limitation of the power device. Increased switching frequency also implies increased inverter losses.

III. Mathematical Model

The simulated machine is a smooth air gap PMSM without any damping circuits in the rotor. The rotor field is constant and created by permanent magnets and the e.m.f are considered as sinusoidal. The simplified electric equations for motor "A" can be presented as below [5]:

$$v_A = Ri_A + L\frac{di_A}{dt} + jp\omega_{r,A}\psi_{r,A} \quad (1)$$

$$T_A - T_{L,A} = J\frac{d\omega_{r,A}}{dt} \quad (2)$$

$$with\ T_A = \frac{3}{2}p\Im m\{i_A\psi_{r,A}\}$$

$$\omega_{r,A} = \frac{d\theta_A}{dt} \quad (3)$$

Where;

ω_r : Motor Angular velocity,
Ψ_r : Rotor flux,
T : Electrical torque,
T_L : Load torque,
J : Moment of Inertia.
θ : Instantaneous angular position

The model of the motor "B" can be derived from (1) to (3) by changing the subscript "A" to "B".

With the assumptions, motor "A" and motor "B" are equal in all parameters but have different loads. The space vectors of the rotor fluxes, $\psi_{r,A}$ and $\psi_{r,B}$ are equal in magnitude and its instantaneous position θ_A and θ_B respectively in the stationary frame. Consider a rotating reference frame d,q whose direct axis "d" is along the direction of $(\psi_{r,A}+\psi_{r,B})/2$ and its instantaneous angular position is $\theta=(\theta_A+\theta_B)/2$. Based on this reference, the electromagnetic torque of the motors "A" and "B" can be expressed as:

$$T_A = \frac{3}{2}p.\psi_{r,A}.i_{qA} \quad (4)$$

$$T_B = \frac{3}{2}p\psi_{r,B}.i_{qB} \quad (5)$$

And the average of the current and torque are as follows:

$$i_\Sigma = \frac{i_A + i_B}{2} \quad (6)$$

$$T_\Sigma = \frac{T_A + T_B}{2} \quad (7)$$

IV. Simulation Results

Averaging of Dual PMSM drives simulation has been done by using MATLAB/Simulink with referring the control strategy shown in Figure 1 and Figure 2. Quantities observed are speed responses for both motors for variation of speed and different loads.

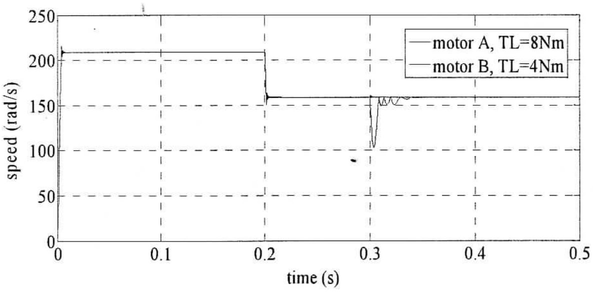
The first technique simulated is depicted in Figure 1. This simulation uses the average of phase current as the input for the hysteresis current controller. In contrast with SVPWM technique, Hysteresis uses actual current feedback from the motor to be compared with reference current, while in SVPWM, no current feedback needed. This method ensures that the actual currents flowing into the motor as close as possible to the current references.

The second control technique analyzed in this paper is synthesized by the control diagram of Figure 2. This control strategy is based on the generation of two different sets of reference currents $(i_{d,A}*, i_{q,A}*, i_{d,B}*, i_{q,B}*)$. These current are converted to three-phase current $(i_{a,b,c})$ by using vector transformation. Average of these three-phase reference currents are calculated before compared with actual phase current through hysteresis current controller. The current controllers are able to evaluate the expected voltage of motor "A" and "B".

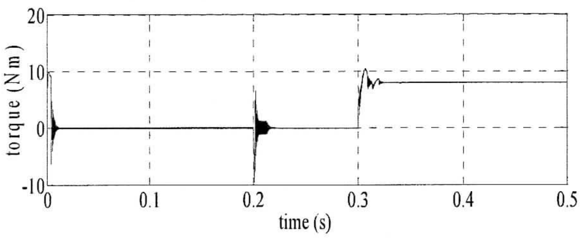
TABLE II
SPECIFICATIONS OF MOTOR

No	Motor Specifications	Value
1	Rated Torque	8 Nm
2	Rated Speed	209 rad/s
3	Inertia	0.0006329 kgm^2
4	Resistance	0.9585 Ω
5	Inductance	0.00525 H
6	Magnet Flux	0.1827 Vs
7	DC link Voltage	300 V

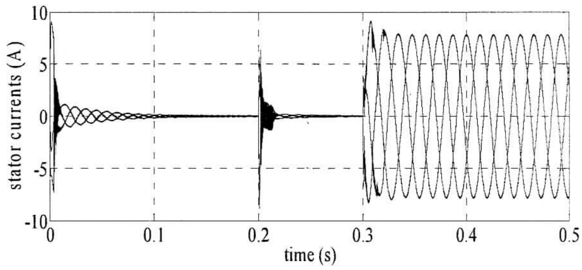
The relevant parameters of the motors are listed in TABLE II. Both motors have the same specifications and applied for both SVPWM and Hysteresis Current Control Technique. The transient responses of the drives for SVPWM and Hysteresis Current Controller are shown in Figure 4 to Figure 7.



(a) Speed response for motor A and motor B (SVPWM)

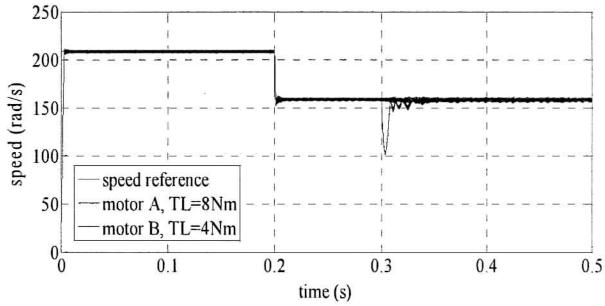


(b) Torque response for motor A (SVPWM)

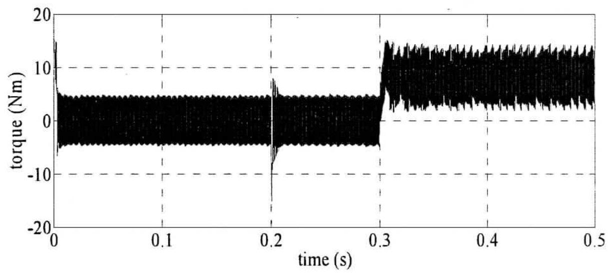


(c) Stator current for motor A (SVPWM)

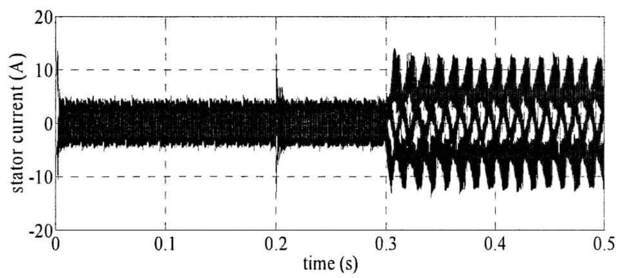
Fig.4. Transient responses for SVPWM method, (a). Speed response for motor A and motor B, (b) Torque response for motor A. (c) Stator current for motor A



(a) Speed response for motor A and motor B (Hysteresis Current Controller)



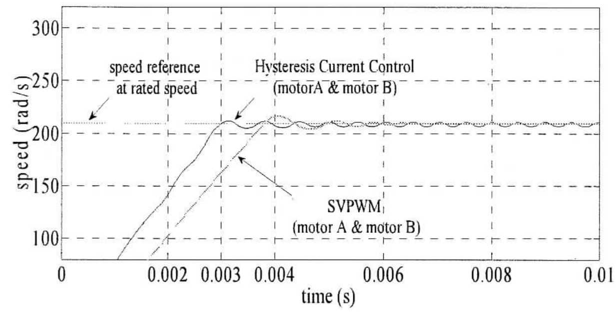
(b) Torque response for motor A (Hysteresis Current Controller)



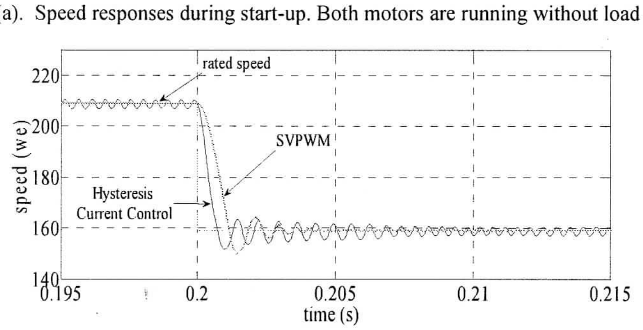
(c) Stator current for motor A (Hysteresis Current Controller)

Fig. 5. Transient responses for Hysteresis Current Control method (a). Speed response for motor A and motor B, (b). Torque response for motor A, (c). Stator current for motor A

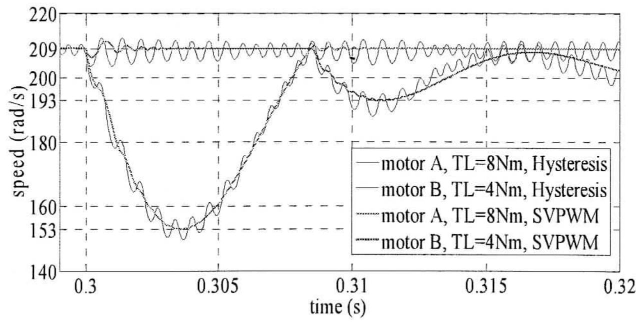
Fig.4. and Fig.5. show the transient response during start-up at t=0s, speed reduction about 50Nm (209rad/s to 159 rad/s) at t=0.25s and load variation at t=0.3s for SVPWM and Hysteresis Current Control method respectively. From t=0s until t=0.3s, the systems are running without load. At t=0.3s, motor "A"s are given 8Nm which is the rated torque, and motor "B"s are given 4Nm, which is half of the rated torque. The systems show that both techniques follow well the speed reference command. Although, both techniques show a little undershoot during load variation at t=0.3s, they manage to get to their reference speed after several millisecond. From these figures also, it can be observed that the output with SVPWM technique has low torque ripple and low current distortion as well as persistent for the rest of the system.



(a). Speed responses during start-up. Both motors are running without load



(b). Speed responses during reduction of speed about 50Nm



(c). Speed responses during load variation at rated speed (TL= torque load)

Fig.6. Comparison of Speed responses for motor A and motor using SVPWM and Hysteresis Current Control method – Close-up view.

Fig.6s, show the close-up view for both motor A and motor B, using both method, SVPWM and Hysteresis Current Control at rated speed. Fig.6(a). proves that, although Hysteresis Current Control method gives more ripple, it achieve steady state faster than SVPWM method. Their settling time are 0.3ms and 0.38ms respectively. Fig. 6(b) shows, the behavior of Hysteresis method achieve the steady state faster than SVPWM similar when the reduction of speed is applied to the system at t=0.2s. Speed responses for both motors and both techniques during load variation at t=0.3s are depicted on Figure 6(c). Both methods for motor A, which given more load, TL=8Nm) experience the same undershoot which is about 44 rad/s (209rad/s to 153 rad/s). But Hysteresis Current Control speed response shows more ripple compared to SVPWM method. For motor B, which given less load (TL=4Nm), the reduction speed due to load disturbance is about 16Nm (209rad/s to 193rad/s). This figure also prove that, the motor with higher load will experience higher undershoot, and the lighter load will get better performance.

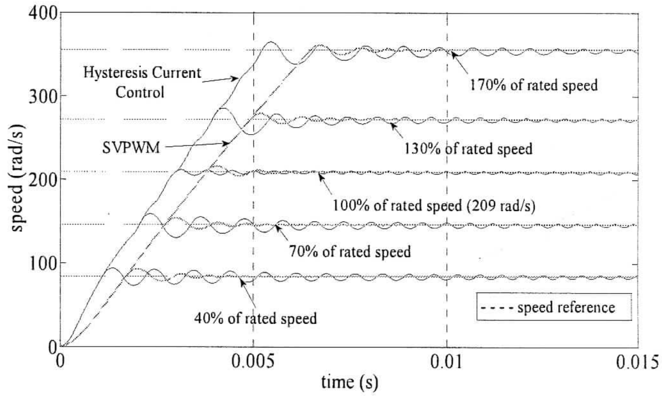


Fig.7. Speed responses for motor A and B using SVPWM and Hysteresis Current Controller during start-up

Fig. 7. shows the speed behavior for both SVPWM and Hysteresis Current Control methods during start-up. Obviously, that Hysteresis Current Controller method reaches the steady state faster than SVPWM method for all cases, but as can be observed, SVPWM produced fewer ripples than Hysteresis method. Also noted that, the optimize controller is at rated speed condition, where the magnitude of the ripple is lower that other cases.

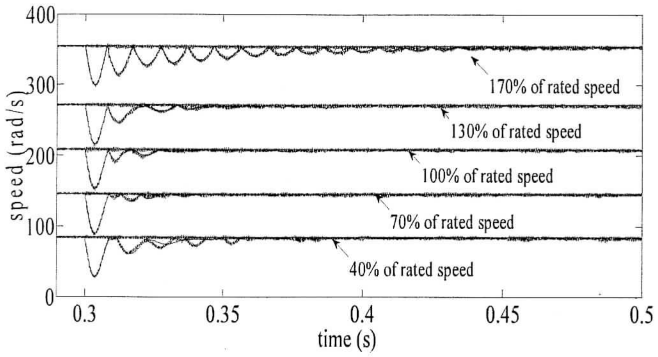


Fig. 8. Speed responses for motor A and B by using SVPWM and Hysteresis Current Controller during load variation

Fig.8. illustrate the behavior of motor A and motor B using SVPWM and Hysteresis Current Control during load variation at t=0.3s. Motor "A"s are given 8Nm torque load and motor "B"s are given 4Nm torque load. Both methods show good responses due to wide range of speed. As can be seen, both methods are stable from 50% to 170% of rated speed. But the oscillation for rated speed condition is having fewer undershoot compared to lower and upper of rated speed condition. The worst case is at 170% of rated speed, where the oscillation last for more than 0.1 second. And the minimum speed that can be applied is at 40% of rated speed. Below than that, the response shows the unacceptable behavior.

V. Conclusion

The comparison between SVPWM controller and Hysteresis Current Controller for Dual PMSM fed by single inverter is presented. Both techniques show acceptable speed regulation for a wide range of speed either with load, no load or variation of load. For overall, output with SVPWM has low torque ripple and low current distortion compared to Hysteresis Current Controller. In other way, Hysteresis Current Control technique can reach the speed demand faster than Space Vector Pulse Width Modulation (SVPWM) technique, but it has more oscillation before it comes to steady state. For variation of load testing, both controller techniques manage to stabilize the system within the acceptable duration. Both techniques also show that they can be applied from range of 40% to 170% of rated speed.

References

[1] Z. Li and S. Fengchun, "Torque control of dual induction motors independent drive for tracked vehicle," in *2008 10th Intl. Conf. on Control, Automation, Robotics and Vision*, 2009, pp. 68-72.

[2] Y. He, *et al.*, "A comparative study of space vector PWM strategy for dual three-phase permanent-magnet synchronous motor drives," in *Applied Power Electronics Conference and Exposition (APEC), 2010 Twenty-Fifth: Annual IEEE.*, 2010, pp. 915-919.

[3] H. Mohktari and A. Alizadeh, "A new multi-machine control system based on Direct Torque Control algorithm," in *The 7th International Conference on Power Electronics, EXCO 2007*, 2008, pp. 1103-1108.

[4] D. Bidart, *et al.*, "Mono inverter dual parallel PMSM-structure and control strategy," in *34th Industrial Electronics Annual Conference , 2008, IECON 2008*, 2009, pp. 268-273.

[5] M. Acampa, *et al.*, "Optimized control technique of single inverter dual motor AC-brushless drives," in *Universities Power Engineering Conference, 2008, UPEC 2008*, 2008, pp. 1-6.

[6] M. Acampa, *et al.*, "Predictive control technique of single inverter dual motor AC-brushless drives," in *Proceeding of the 2008 International Conference on Electrical MAchines*, 2008, pp. 1-6.

[7] P. Kelecy and R. Lorenz, "Control methodology for single stator, dual-rotor induction motor drives for electric vehicles," in *Power Electronics Specialist Conference, 1995, PESC'95*, 1995, pp. 572-578.

[8] J. Wang, *et al.*, "Comparative Study of Vector Control Schemes for Parallel-Connected Induction Motors," in *power Electronics Specialist Conference, 2005, PESC 05, IEEE 36th*, 2006, pp. 1264-1270.

[9] D. I. A.Del Pizzo, I.Spina, "Optimum Torque/Current control of dual PMSM single VSI Drive," *15th International Symposium on Power Electronics-Ee 2009, Novi Sad, Republic of Srbia,* October 28th-30th ,2009 2009.

[10] C. Mitsui, *et al.*, "Efficiency study of adjustable speed drive with dual motor connection," in *Power Engineering Conference,2007, IPEC 2007*, 2007, pp. 555-558.