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MEAN AND DIFFRENTIAL TORQUE CONTROL USING HYSTERESIS CURRENT CONTROLLER FOR DUAL PMSM DRIVES

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ABSTRACT

The dual motor drives fed by a single inverter are purposely designed to reduce size and cost with respect to single motor drives fed by a single inverter. This paper presents the speed responses behavior of Dual Permanent Magnet Synchronous Motor (PMSM) driven by Mean and Differential Torque Control technique. The drive is simulated by using Hysteresis Current Controller. MATLAB/Simulink is chosen as the simulation tools. The performance of speed, current and torque responses for Dual Motor PMSM fed by a single inverter is presented. The applied technique shows satisfactory speed regulation for a wide range of speed either with load, no load or variation of load.

Keywords: *Dual Motor Drives, Single Inverter, Hysteresis Current Control*

1. INTRODUCTION

In many applications, one motor is controlled by one converter. These systems are called SMSC, Single Machine Single Converter system [1]. Nevertheless, Multi Machine Systems (MMS) are extensively used in industry today especially in the case of dual motor drives. This system allows the field of high power applications to be extended and their flexibility, mechanical simplicity and safety operating system to be increased. However, the system requires a lot of power switches which are costly and bulky. The high cost and large size needed by the inverter make such dual inverters, dual motors drive configuration is not favoritable economically. Therefore, the need for dual motor drives fed by single inverter is preferable to reduce size and cost with respect to the single motor drives, either in industrial or in traction applications.

However, the reduction number of power electronics switches and other components will result the paralleling of the drives systems. If the load torque for each motor is still the same, there is no speed changes 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.

Generally control of dual motor drives can be divided into two main categories, which are Master-Slave and Mean Control techniques. In Master-Slave technique, one motor which is selected as the master is directly controlled. The motor with the highest load is set as the master motor and the other is slave motor. Both motors have the same applied voltage, same electric pulsation and also the same speed [3]. The main advantage of this technique is that, only one set of sensor is needed since the choice of the master machine is based on “Enable” switch that select the master motor to be controlled. Then, the behavior of slave motor will be ignored. In some conditions, the performance of slave motors may not acceptable. This technique also has a magnetic induction effect especially for slave motor. This is because, for slave motor which is not been controlled, will induce more flux compared to the master motor.

Whereas in mean control, there are several techniques are applied. One of them is average of

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current [4] - [6]. In this technique, the control system is basically similar to that of a single machine. Reference [4] uses average of phase current technique. Even though the technique is capable to stabilize both motors during the unbalanced load condition, the results show higher ripple, large undershoot and long time taken for both motors to recover after load disturbance. Reference [5] uses averaging technique for motors parameters and averaging the voltage space vector. However, the paper only report on speed changes without any load changes tested on the system. The first Direct Torque Control (DTC) method is implemented in dual motor drives is applied in [6]. It also uses averaging over the motors parameters in order to produce an equivalent circuit. But this technique produces insignificant results if the parameters are not similar.

Other than averaging technique, [7] had introduce mean and differential torque technique for Induction Motor. The control technique is based on orienting the stator current vector relative to the mean rotor magnetizing current vector (or rotor flux vector) in order to achieve the desired mean torque and differential torque. The mean and differential values of the current space-vectors and the torque are introduced in order to evaluate the mismatch between the mean and differential values of the currents and torques for the unbalanced loads.

From this basis, [8] – [11] had adapted the mean and differential torque topology in dual PMSM drives. These researches have proven that this topology gives better response for dual PMSM drives especially during the load variation. But, through observation, the techniques which applied in [8]-[11] are only tested under one operating condition, which according to this current paper, may not enough to represent the behavior of dual Motor Drives fed by a single inverter. Reference [8] illustrates "torque control based" by using hysteresis current controller as the Pulse Width Modulation (PWM) technique to feed the inverter. In the case of unbalanced load, the speed responses are sufficient enough to compensate the transient during load changes. Predictive Current Controller is applied in [9], which also uses mean and differential torque topology. The difference between [8] and [9] is the usage of SVPWM instead of hysteresis current controller. [10] and [11] use optimum torque over current ratio to minimize the resultant armature current needed to obtain an assigned resultant motor torque, when the load is unbalance.

This current paper presents the effectiveness of the Mean and Differential Torque Control technique by using Hysteresis Current Controller under a wide range of speed including forward and reverse operations.

2. 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 [12]. 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 [9], the former is more familiar and the latter becomes mature promptly especially in the middle and high power systems.

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 Fig. 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.

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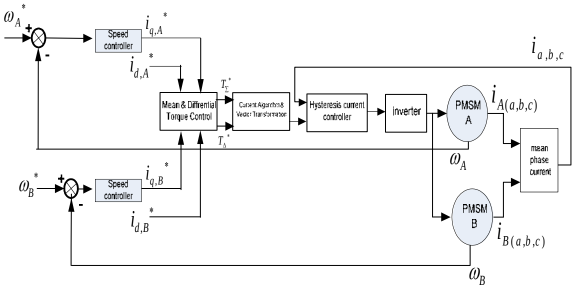

Fig. 2. Hysteresis Current Control for Dual PMSM configuration

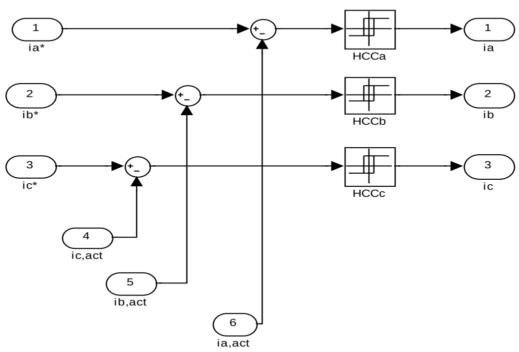

Fig.3. Hysteresis Current Control

Fig.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 Direct Current (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.

3. 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 electric magnetic force (e.m.f) is considered as sinusoidal. The simplified electric equations for motor "A" [8], can be presented as below:

$$v_A = Ri_A + L\frac{di_A}{dt} + jp\omega_{r,A}L_s i_A + jp\omega_r \psi_{r,A} \tag{1}$$

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

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

$$\omega_{r,A} = \frac{d\theta_A}{dt} \tag{3}$$

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.

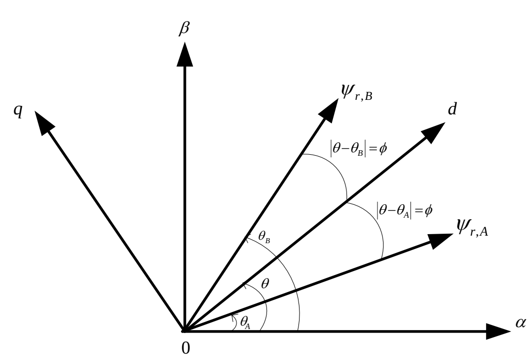

Fig.4. Reference system for dual motor drives (adapted from [8])

where:

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$\psi_{r,A}$, $\psi_{r,B}$: rotor fluxes space vector
θ_A, θ_B : instantaneous rotors position

Based on Fig.4, the electromagnetic torque of the motors "A" and "B" can be expressed as:

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

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

Stator current space vector with respect to the stationary phase magnetic axes is defined as:

$$i_s = i_s e^{j\phi}$$

Since the flux produced by permanent magnets has been assumed to be constant, the electromagnetic torque can be varied by changing the magnitude and the phase of the stator current. Thus, a constant torque is obtained if the quadrature axis component of the stator current space vector is kept constant and the max torque per Ampere of stator current is obtained if the torque angle is 90^0. This corresponds to the application of imaginary axis only for the above stator current equation.

Control of Mean and Differential Torque

Mean and differential torque control is introduced by [7] to overcome the mismatch between mean and differential values for torque and current due to unbalance load as depicted in Fig.5.

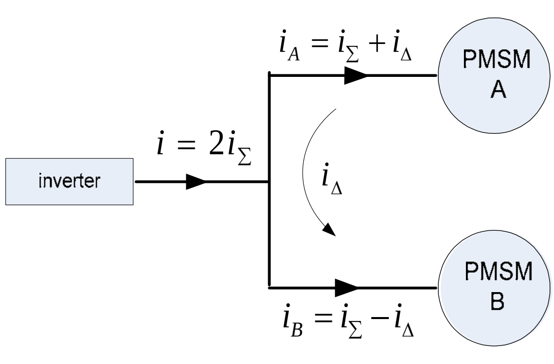

Fig.5. : Basic Configuration for Dual Motor Drives fed by single inverter

Reference [8] had introduced the usage of:

"Σ" = mean value
"Δ" = differential value

The mean and differential expressions for current and the torque space-vectors are as follows:

$$i_\Sigma = \frac{i_A + i_B}{2} \quad ; \quad i_\Delta = \frac{i_A - i_B}{2} \quad (7)$$

$$T_\Sigma = \frac{T_A + T_B}{2} \quad ; \quad T_\Delta = \frac{T_A - T_B}{2} \quad (8)$$

substituting eq. (7),(8) and (9) into (4) and (5) yields,

$$\begin{aligned} T_\Sigma &= \frac{3}{(2)(2)} p\psi_r[(i_{q,A}\cos\phi + i_{q,B}\cos(-\phi)) + \\ &\quad (i_{d,A}\sin\phi + i_{d,B}\sin(-\phi))] \\ &= \frac{3}{2} p\psi_r[i_{q,\Sigma}\cos\phi + i_{d,\Delta}\sin\phi] \end{aligned} \quad (9)$$

$$\begin{aligned} T_\Delta &= \frac{3}{(2)(2)} p\psi_r[(i_{q,A}\cos\phi - i_{q,B}\cos(-\phi)) + \\ &\quad (i_{d,A}\sin\phi - i_{d,B}\sin(-\phi))] \\ &= \frac{3}{2} p\psi_r[i_{q,\Delta}\cos\phi + i_{d,\Sigma}\sin\phi] \end{aligned} \quad (1$$

In order to improve steady state and transient performances, the speed control can be achieved by carrying out the evaluation of the current reference values $i_{d,\Sigma}$ and $i_{q,\Sigma}$ as follows;

$$i^*_{d,\Sigma} = \frac{1}{\sin\hat{\phi}}\left[\frac{2}{3p\psi_r}T^*_\Delta - \hat{i}_{q,\Delta}\cos\hat{\phi}\right] \quad (11)$$

$$i^*_{q,\Sigma} = \frac{1}{\cos\hat{\phi}}\left[\frac{2}{3p\psi_r}T^*_\Sigma - \hat{i}_{d,\Delta}\sin\hat{\phi}\right] \quad (12)$$

which " ^ " subscript represents the actual values for the motor parameters. These $i_{d,\Sigma}$ and $i_{q,\Sigma}$ are then transformed into three-phase current, $i_{a,b,c}$ using vector transformation.

4. SIMULATION RESULTS

The Dual Motor Drives is simulated using MATLAB/Simulink under forward and reverse operations for wide range of speed. The relevant parameters of the motors are listed in TABLE 1.

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Both motors have same specifications and applied for Hysteresis Current Control technique.

TABLE I
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 drives is given 209rad/s as the speed reference value at t=0s. After 0.2s, both motors are tuned to reverse operation, having -209rad/s as the speed reference. At t=0.7s, both motors are given forward operation again, so that, at t=0.9s, the load variation can be applied. The transient responses of the drives are shown in Figure 6 to Figure 12.

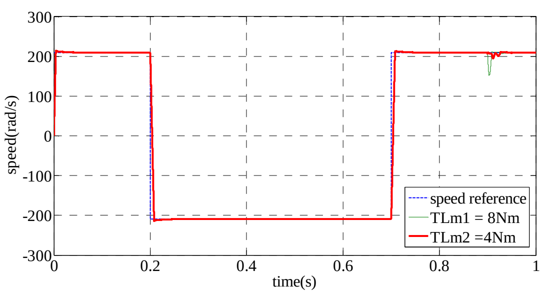

Fig.6. Speed response at rated speed (forward and reverse operations), and load tested at rated torque

Fig.6 shows that the dual motor drives running at rated speed (209rad/s) for forward operation and (-209rad/s) as the reverse operation. At t=0.9s, motor "A" is given 8Nm load torque and motor "B" is given 4Nm load torque as the loads variation testing.

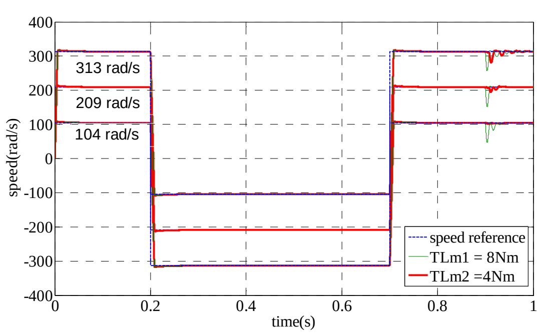

Fig.7. Speed responses for wide range of speed

Fig.7 represents the speed responses from 50% of rated speed (104rad/s), 100% of rated speed (209rad/s) and 150% of rated speed (313rad/s). This figure proves that this system is stable for wide range of speed.

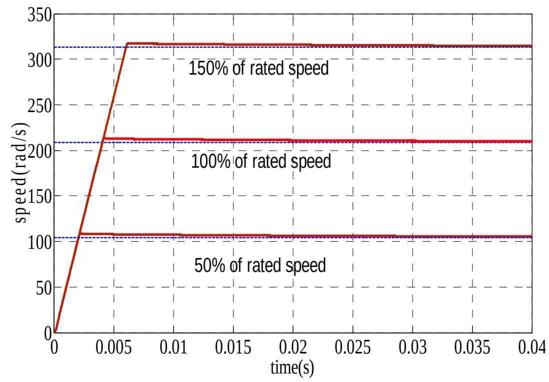

Fig.8. Speed responses during start-up

Fig.8 shows the close-up view for speed responses during start-up condition. This figure shows that, for higher speed, it requires slightly more time to achieve steady state condition compared to lower speed.

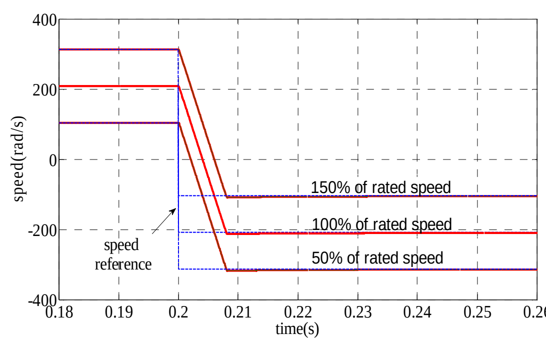

Fig.9. Speed responses during reverse operation

Fig.9 shows the speed responses during reverse operation. This figure proves that this system is capable to handle reverse operation and requires less than 20miliseconds to achieve steady state operation.

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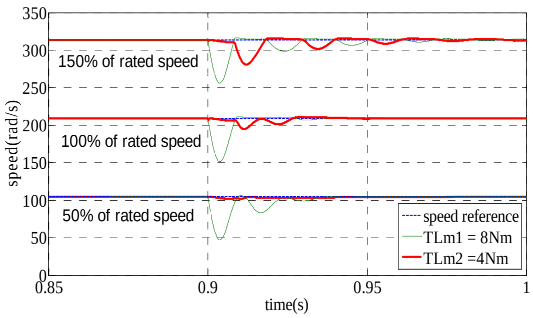
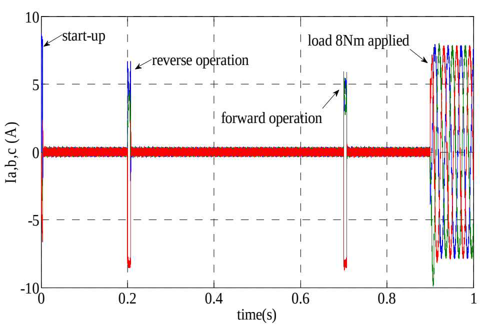


Fig.10. Speed responses during load variation

Fig.10 represents the speed responses during load variation. Motor “A” is given 8Nm, which is rated torque value, and motor “B” is given 4Nm which is 50% of rated speed. For all three speed conditions, motor “A” which is given the higher load, experiences the same undershoot which about 58rad/s reduction from the reference speed. But, for motor “B”, which has lower load, experience different oscillation depends on speed applied to the motor. The higher speed applied will create more oscillation, and the lower speed applied will give smaller disturbance to the motor. This figure also concludes that, this technique able to stabilize the unbalance load condition for both motors.

(a)



(b)

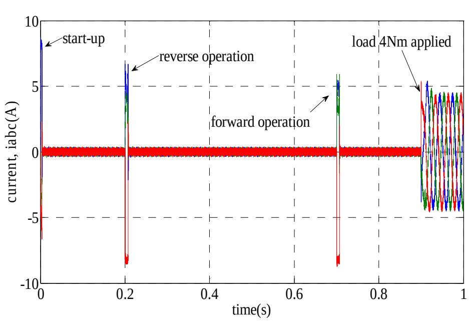
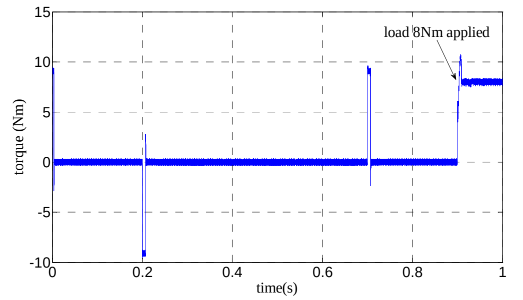


Fig.11. Three-phase current, ia,b,c (a)for motor A, (b)for motor B

(a)



(b)

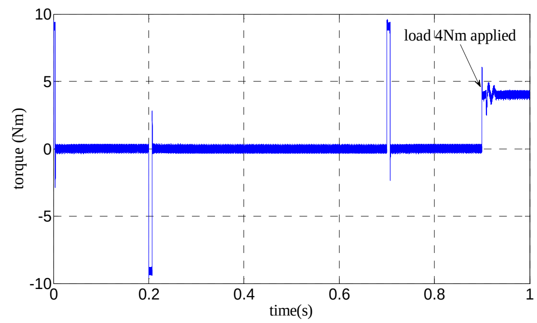


Fig.12. Torque responses (a)for motor A, (b)for motor B

Fig.11 and Fig.12 represent the three-phase current and torque responses for motor “A” and “B” respectively. These figures show that motor with higher load, produce higher current, while the motor with lighter load, produce lower current.

5. CONCLUSION

This paper presents the speed responses behavior of Dual Permanent Magnet Synchronous Motor (PMSM) driven by Mean and Differential Torque Control technique. This technique shows good speed regulation for wide range of speed either with no load or variation of load.

6. ACKNOWLEDGEMENT

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