Voltage Space Vector Averaging Technique for Two PMSMs Connected in Parallel

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***Abstract*—Application of numerous motors driving by only a one inverter attract more interest since several motors can be connected in parallel and only driven by one three-phase inverter. The benefit is that it will give more impact on cost performance, lightness and compactness. In this project, we focus on driving two PMSMs connected in parallel using only one three-phase inverter. Both voltage space vector of the two motors are average in order to achieve the synchronisation between these two motors even their load are different. Furthermore, the speed for both motors was controlled by using field oriented control method. This drive system has been designed and then simulated by Matlab/Simulink software. This drive system has been tested at various speeds under balanced and unbalanced load conditions.**

***Index Terms*—parallel connected drive, permanent magnet synchronous motor, voltage space vector averaging technique**

I. Introduction

Nowadays more industrial which use multi motor in their application such as in traction and industrial application are changeover to multi motor single controller (MMSC) because it give more advantages compare than multi motor multi controller system [1]. Multi inverter and multi motor drive systems are not very practical because of the size of the inverter is large and cause a high cost to the drive system. So, this type of dual motor drive with multiple inverters is the great selection of the drive if the factor of size and cost is the priority beside of their performance. Consequently, two motor connected in parallel and share their three leg inverter as depicted in Fig. 1 is frequently use because it resolve the problem where the expenditure and space are the important criteria to take into account [2]. By applying this configuration, the voltage order for both motors is same. Likewise with the velocities, it will be equal, when the load torque applied to the both motors is same.

Many researches have been carried out with this configuration but using an induction motor [1]-[5]. However, the researches mentioned above are not focused on the permanent magnet synchronous motor type. PMSMs are used when the high speed application is needed. In vehicle propulsion application, PMSM is become popular compare to other motors because it gives exceptional efficiency and produce better power density as well as their operation are silent [6].

Two methods can be implementing with the multi motor single controller named, the mean control and master-slave system [7].

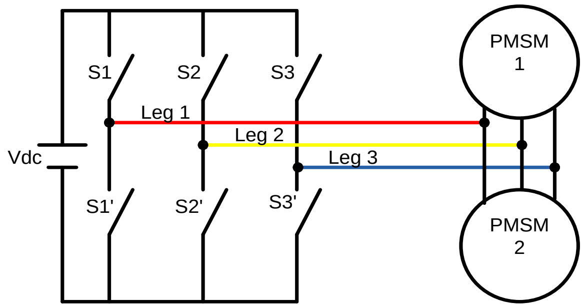

Figure 1. Parallel connected PMSM with three leg inverter.

By applying master-slave method, both motors must be set as a master or a slave depend on the size of the load connected to them. Master motor should have the highest amount of load torque compare to the slave motor. In this method, the performance of the slave motor is not acceptable and all it behaviors can be neglected because they are not important [7].With this configuration, the quantity of speed, applied voltage and electric pulsation for master and slave motor are identical [8]. Several techniques can be used in mean control method such as average of current, averaging over the parameters of the equivalent circuit at steady state, averaging the voltage space vector, mean and differential torque, and optimum torque over current ratio[1], [9]-[11]. The control system of this scheme is approximately similar to the single machine system.

Previous researchers have focused on design the drive system for two induction motor connected in parallel and fed to a single inverter. They also have done on sensorless control strategy applied to that system.

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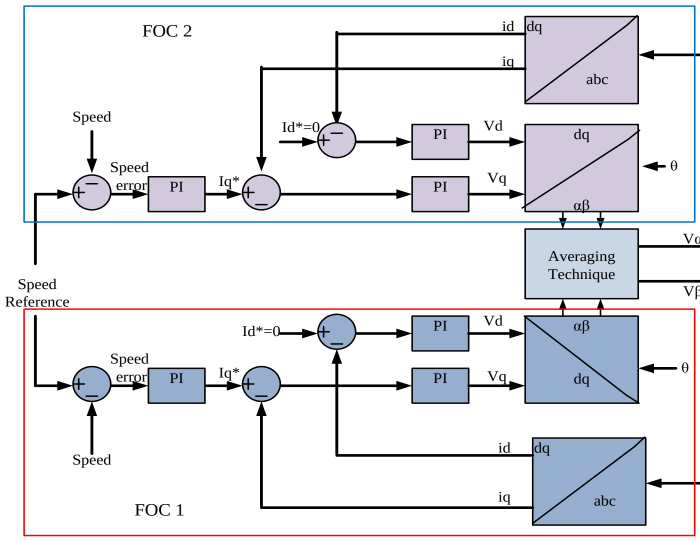

Figure 2. Field oriented control schematic diagram.

Some of the research works have done controlling the two parallel connected PMSM [8]-[14]. In [11], the research work has focused on the performance of the dual motor drive by applying an averaging method. The results proved that the averaging technique can be used even if the load is varied. In [12], the designed based on the microprocessors which are digital signal processor and complex programmable logic drives. The authors discussed synchronization techniques which are parallel synchronous control, and parallel synchronous control with compensation master-slave synchronous control applied to three multi motor.

All the researchers mentioned above have done their work on designing two PMSMs connected in parallel with a speed sensors attached at the motor. On the other hand, this research has been conducted on controlling the two PMSMs connected in parallel and using only a single three phase inverter and applies a sensorless control strategy which is a model reference adaptive system. In order to maintain an equal speed on both motors although if their loads are different, a voltage space vector averaging technique is applied to the system. The system has been tested through simulations by using Matlab/Simulink software by means of provide the both motors with various speed and torque conditions.

II. Model of PMSM in Mathematical Equation

The PMSM model is based on the d-q rotating reference frame. The stator voltage equations and flux equations are given by:

$$v_{d\_1} = R_1 i_{d\_1} + L_{d\_1}\frac{di_{d\_1}}{dt} - \omega_{r\_1}\psi_{q\_1} \quad (1)$$

$$v_{q\_1} = R_1 i_{q\_1} + L_{q\_1}\frac{di_{q\_1}}{dt} - \omega_{r\_1}\psi_{d\_1} \quad (2)$$

$$\psi_{d\_1} = L_{d\_1} i_{d\_1} + \psi_{pm\_1} \quad (3)$$

$$\psi_{q\_1} = L_{q\_1} i_{q\_1} \quad (4)$$

The developed motor torque is given by;

$$\tau_{e\_1} = \frac{3}{2}\left(\frac{P}{2}\right)\left(\psi_{d\_1} i_{q\_1} - \psi_{q\_1} i_{d\_1}\right) \quad (5)$$

The mechanical torque equation is given by:

$$\tau_{e\_1} = \tau_{L\_1} + B_1\omega_{m\_1} + J_1\frac{d\omega_{m\_1}}{dt} \quad (6)$$

Because of the two motors is identical, the mathematical model for both motors are same from (1) to (6). The subscript notation “1” is referring to motor 1 and subscript notation “2” is referring to motor 2. Table I list the symbol used in this project.

TABLE I. Symbol

Symbol	Quantity
v_{d_1}	Stator’s d- axis voltages
v_{q_1}	Stator’s q- axis voltages
i_{d_1}	Stator’s d -axis currents
i_{q_1}	Stator’s q -axis currents
R_1	Stator resistance
L_{d_1}	d- axis stator inductances
L_{q_1}	q- axis stator inductances
ψ_{d_1}	d- axis stator magnetic flux
ψ_{q_1}	q- axis stator magnetic flux
ψ_{pm_1}	Rotor’s permanent magnet flux
τ_{e_1}	Electromagnetic torque
τ_{L_1}	Load torque
P	No of poles
B_1	Vicious friction
ω_{m_1}	Mechanical speed
J_1	Moment inertia

III. Voltage Space Vector Averaging Technique

There are two popular techniques used in order to maintain the synchronisation of the two or numerous motors connected in parallel named the mean control and master- slave control methods.

Current averaging, averaging over the parameters of the equivalent circuit at steady state, averaging the voltage space vector and the mean and differential torque are the methods under the mean control. Applying this method, the system for this scheme is approximately similar to the single motor system.

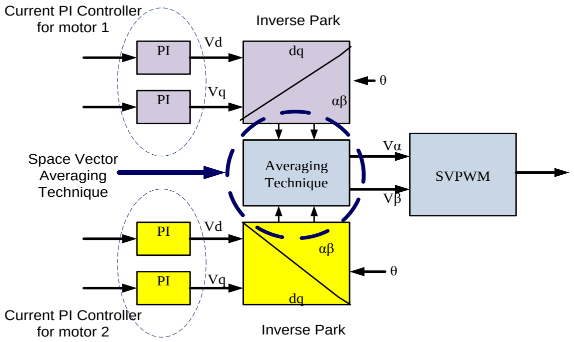

Figure 3. Block diagram of averaging technique.

In this project, the voltage space vector averaging technique is chose so that the speed between two motors are synchronise. By referring to Fig. 3, output current from PI controllers for each motor are converted into stator voltage vector using inverse park transformation. These stator voltage vectors for both motors are then averaged by using the equations (7) and (8). This process is reflected into phasor diagram as shown in Fig. 4. Afterwards, the average stator voltages are sent to space vector pulse width modulation (SVPWM) in order to switch on and off the inverter.

$$V_{avg} = \frac{1}{2}\left(V_{d1} + V_{d2}\right) + \frac{1}{2}\left(V_{q1} + V_{q2}\right)j \tag{7}$$

$$\theta_{avg} = \frac{1}{2}\left(\theta_1 + \theta_2\right) \tag{8}$$

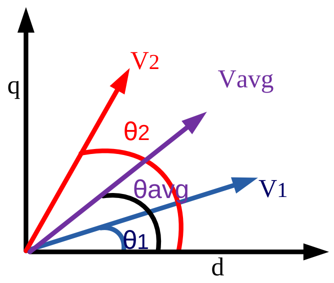

Figure 4. Phasor diagram.

IV. Field Oriented Control

Fig. 2 shows the overall design of the drive system for this project. In this project, speed of the both motors is control by using field oriented control (FOC) method. By employing this method, the q-axis stator current will control the motor torque whereas the d-axis stator current is set to be zero. This type of vector control consists of important elements which are q-axis and d-axis PI current controllers, speed PI controller, park and clarke transformation and the three phase inverter driver. Space vector pulse width modulation has been adapted to the inverter unit as portrayed in Fig. 2.

Park transformation is used to convert the phase currents to d-q current components to achieve a complete decoupling of torque (i_q) and flux (i_d). Based on equation (3), if d- axis current, i_d is set to zero, and the d-axis flux linkage is fixed such that:

$$\psi_{d\_1} = L_{d\_1} i_{d\_1} + \psi_{pm\_1} \tag{9}$$

It yield, the electromagnetic torque by the following equation:

$$\tau_{e\_1} = \frac{3}{2}\left(\frac{P}{2}\right)\left(\psi_{d\_1} i_{q\_1}\right) \tag{10}$$

V. Results and Discussions

Analysis was done by testing the system by various speed and load conditions to observe the behavior of the system. Both motors are identical, so that the parameters are equal as listed in Table II.

TABLE II. Parameters of PMSM

Parameters	Values
Resistance per phase (Ω)	2.88
d- axis inductances (mH)	8.5
q- axis inductances (mH)	8.5
Speed (rpm)	3000
No of poles	4
Magnetic flux (Vs)	0.18
Inertia (kg.m^2)	1 x 10^{-3}
Torque (Nm)	1.5
Speed (rpm)	3000

A. Case A: Equal Load and Unvarying Speed

In this analysis, the step changes in the load for both motors were same as illustrates in Fig. 5. At starting, the load torque for both motors was set to zero. Then, at 0.2 s, the load was increased to 1 Nm. As illustrated in Fig. 6, it demonstrated that both motors follow the command speed at 500 rpm even, at 0.2 s the speed dropped momentarily but return back to their steady state value at 500 rpm at 0.23 s.

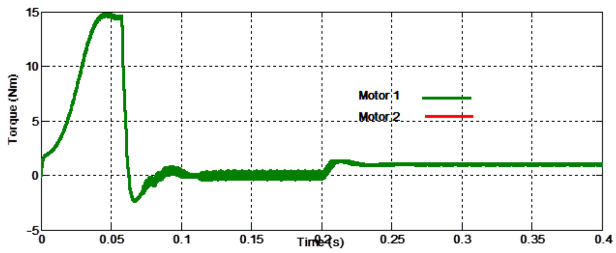

Figure 5. Torque response.

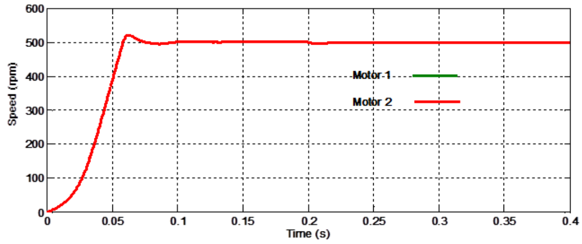

Figure 6. Speed response.

B. Case B: Unequal Load and Unvarying Speed

In this case, the system was tested by applying the motor with different amount of motor load torque while the motor speed for both motors are equal and maintain constant at 500 rpm.

Both motors were given the equal load torque at starting which is 1 Nm. Then, the load torque for motor 2 was increased to 2 Nm at 0.2 s as represent in Fig. 7. Both motors torques preserve their actual reference load torque. By referring to Fig. 7, it shows that the motor torque produced high oscillation during starting, before it reached their set point value. As a result, there has been a speed oscillation occur in the system as depicted in Fig. 8.

As shown in Fig. 8, it can be obviously illustrated that the speed of motor 1 dropped momentarily but later retrieval to their steady state value of 500 rpm at 0.35 s. There was an overshoot of speed on the motor at starting but, reached their steady-state value at 0.07 s.

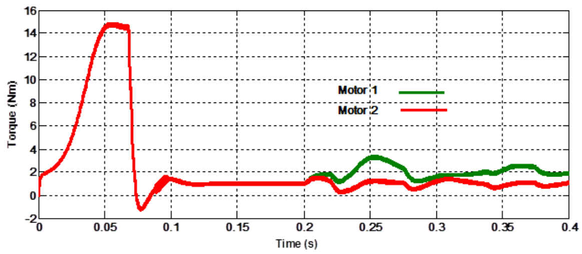

Figure 7. Torque response.

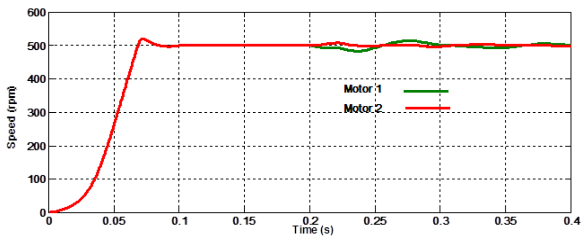

Figure 8. Speed response.

C. Case C: Unequal Load and Varying Speed

In this case, the speed was varied at different value with unequal load torque. Motor 1 and Motor 2 were given an identical load torque at starting, which is 1 Nm. At 0.2 s, the load torque for motor 2 was increased to 2 Nm. By referring to Fig. 9, it is clearly shows that the both motors torque follow their common load torque. Initially, the motor runs at speed of 500 rpm. Afterwards, at 0.15 s the motor speed was decreased to 400 rpm at time equal to 0.15 s. and the speed was increased abruptly to 600 rpm at 0.3 s. It's clearly shown that both motors followed their speed command as shown in Fig. 10.

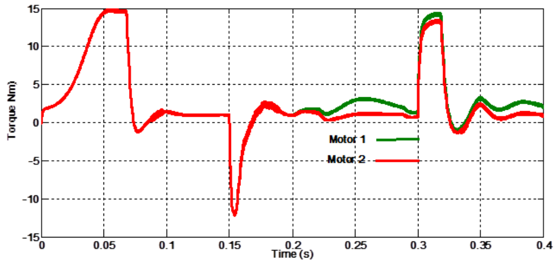

Figure 9. Torque response.

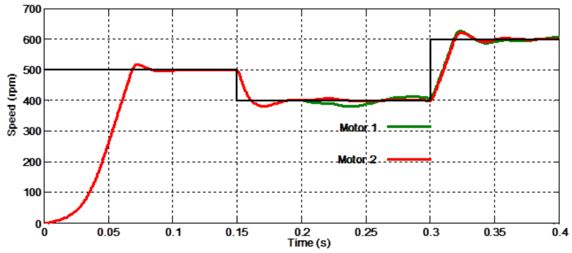

Figure 10. Speed response.

VI. CONCLUSION

From the results obtained, it demonstrate that voltage space vector averaging technique can be used to maintain the speed synchronization between two PMSMs connected in parallel even their loads are differ.

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REFERENCES

[1] P. M. Kelecy and R. D. Lorenz, "Control methodology for single inverter, parallel connected dual induction motor drives for electric vehicles," in *Proc. 25th Annual IEEE Power Electronics Specialists Conference, PESC '94 Record*, vol. 2, 1994, pp. 987–991.

[2] Y. Matsumoto, C. Osawa, T. Mizukami, and S. Ozaki, "A stator-flux-based vector control method for parallel-connected multiple induction motors fed by a single inverter," in *Proc. Applied Power Electronics Conference and Exposition, APEC '98., Thirteenth Annual*, 1998, vol. 2, pp. 575–580.

[3] H. Kawai, Y. Kouno, and K. Matsuse, "Characteristics of speed sensorless vector control of parallel connected dual induction motor fed by a single inverter," in *Proc. Power Conversion Conference, PCC-Osaka 2002*, vol. 2, 2002, pp. 522–527.

[4] K. Matsuse, Y. Kouno, H. Kawai, and S. Yokomizo, "A speed-sensorless vector control method of parallel-connected dual induction motor fed by a single inverter," *IEEE Trans. Ind. Appl.*, vol. 38, no. 6, pp. 1566–1571, 2002.

[5] Y. Matsumoto, S. Ozaki, and A. Kawamura, "A novel vector control of single-inverter multiple-induction-motors drives for Shinkansen traction system," in *Proc. Sixteenth Annual IEEE Applied Power Electronics Conference and Exposition*, 2001, vol. 1, pp. 608–614.

[6] "Some special operation modes of synchronous machine systems at constant speed and variable speed," in *AC Machine Systems*, Springer Berlin Heidelberg, 2009, pp. 166–266.

[7] H. Mohktari and A. Alizadeh, "A new multi-machine control system based on direct torque control algorithm," in *Proc. 7th Internatonal Conference on Power Electronics*, 2007, pp. 1103–1108.

[8] D. Bidart, M. Pietrzak-David, P. Maussion, and M. Fadel, "Mono inverter dual parallel PMSM-structure and control strategy," in *Proc. 34th Annual Conference of IEEE Industrial Electronics,* 2008, pp. 268–273.

[9] M. S. D. Acampa, A. D. Pizzo, D. Iannuzzi, and I. Spina, "Predictive control technique of single inverter dual motor AC-brushless drives," in *Proc. 18th International Conference on Electrical Machines*, 2008, pp. 1–6.

[10] C. Mitsui, S. Tu, Taufik, and M. Anwari, "Efficiency study of adjustable speed drive with dual motor connection," in *Proc. Power Engineering Conference*, 2007, pp. 555–558.

[11] J. M. Lazi, Z. Ibrahim, M. H. N. Talib, and R. Mustafa, "Dual motor drives for PMSM using average phase current technique," in *Proc. 2010 IEEE International Conference on Power and Energy (PECon)*, 2010, pp. 786–790.

[12] Y. F. Wu, W. Chen, Q. W. Chen, and R. H. Du, "Design of dual-PMSM synchronous control drive," in *Proc. 2011 6th IEEE Conference on Industrial Electronics and Applications (ICIEA)*, 2011, pp. 1702–1706.

[13] N. L. Nguyen, M. Fadel, and A. Llor, "Predictive torque control-a solution for mono inverter-dual parallel PMSM system," in *Proc. 2011 IEEE International Symposium on Industrial Electronics (ISIE)*, 2011, pp. 697–702.

[14] J. M. Lazi, Z. Ibrahim, M. Sulaiman, I. W. Jamaludin, and M. Y. Lada, "Performance comparison of SVPWM and hysteresis current control for dual motor drives," in *Proc. 2011 IEEE Applied Power Electronics Colloquium (IAPEC)*, 2011, pp. 75–80.

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