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PARAMETERS INFLUENCE ON THE CONTROL OF A PMSM

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Abstract : ***In this paper we apply a two axis model for accurate representation of the characteristics of permanent magnet synchronous motors of the interior type. For a 3-phase PMSM, we'll use a voltage source inverter (VSI) with six power transistors with independent switching. We'll use a PSIM software with Matlab for check, by simulation, some parameters influence about start process.***

1. Introduction

In recent years, compact and high efficiency synchronous motors have been designed using high energy PM in the rotor. Particular interest has been shown in those motors with permanent magnet mounted inside the steel rotor core, which is known as interior permanent magnet (IPM) synchronous motor, like the SIEMOSYN motor, with rotor inner magnets. This configuration produces a number of significant effects on the motor's operating characteristics.

Permanent magnet synchronous motors (PMSM) are being manufactured and used increasingly in low to medium power range applications due to their inherent advantages. There is a great deal of opportunity to enhance their merits by design optimization, thus reduce production costs and improve performance of the motors.

The PMSM is a rotating electric machine where the stator is a classic three phase stator like that of an induction motor and the rotor has surface-mounted permanent magnets. In this respect, the PM Synchronous motor is equivalent to an induction motor where the air gap magnetic field is produced by a permanent magnet. The use of a permanent magnet to generate a substantial air gap magnetic flux makes it possible to design highly efficient permanent magnet motors

PMSM motors are being increasingly used in different industry sectors in new applications or as alternatives to induction motors in current applications. This is due to their many advantages including high efficiency, compactness, fast dynamics and high torque to inertia ratio. Interior permanent magnet (IPM) motors with extra features of mechanical robustness, capability of flux weakening and high speed operation are particularly suitable as variable speed drives.

A PMSM is driven by sine wave voltage coupled with the given rotor position. The generated stator flux together with the rotor flux, which is generated by a rotor magnet, defines the torque, and thus speed, of the motor. The sine wave voltage output have to be applied to the 3-phase winding system in a way that angle between the stator flux and the rotor flux is kept close to 90° to get the maximum generated torque. To meet this criterion, the motor requires electronic control for proper operation.

The lack of excitation control is one of the most important features of permanent magnet motors, as a consequence, the internal voltage of the motor rises proportionally to the rotor speed, and when the motor is working at constant horsepower mode its power factor becomes leading.

2. PMSM Model

The equations of the permanent-magnet synchronous machine are:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & R_s & 0 \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \lambda_a \\ \lambda_b \\ \lambda_c \end{bmatrix} \tag{1}$$

where v_a, v_b, v_c, and i_a, i_b, i_c, and λ_a, λ_b, λ_c, are the stator phase voltages, currents, and flux linkages, respectively, and R_s, is the stator phase resistance. The flux linkages are further defined as:

$$\begin{bmatrix} \lambda_a \\ \lambda_b \\ \lambda_c \end{bmatrix} = \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \lambda_{pm} \cdot \begin{bmatrix} \cos(\theta_r) \\ \cos\left(\theta_r - \frac{2\pi}{3}\right) \\ \cos\left(\theta_r + \frac{2\pi}{3}\right) \end{bmatrix} \tag{2}$$

where θ_r is the rotor electrical angle, and λ_{pm} is a coefficient which is defined as:

$$\lambda_{pm} = \frac{60 \cdot V_{pk} / k_{rpm}}{\sqrt{3} \cdot \pi \cdot P \cdot 1000} \tag{3}$$

where V_{pk} / K_{rpm} is the peak line-to-line back emf constant, in V / K_{rpm} (mechanical speed) and P is the number of poles.

The stator self and mutual inductances are rotor position dependent, and are defined as:

$$L_{aa} = L_{sl} + L_0 + L_2 \cdot L_2 \cdot \cos(2\theta_r) \tag{4}$$

$$L_{bb} = L_{sl} + L_0 + L_2 \cdot \cos\left(2\theta_r + \frac{2\pi}{3}\right) \tag{5}$$

$$L_{cc} = L_{sl} + L_0 + L_2 \cdot \cos\left(2\theta_r - \frac{2\pi}{3}\right) \tag{6}$$

$$L_{ab} = L_{ba} = -\frac{L_0}{2} + L_2 \cdot \cos\left(2\theta_r - \frac{2\pi}{3}\right) \tag{7}$$

$$L_{ac} = L_{ca} = -\frac{L_0}{2} + L_2 \cdot \cos\left(2\theta_r + \frac{2\pi}{3}\right) \tag{8}$$

$$L_{bc} = L_{cb} = -\frac{L_0}{2} + L_2 \cdot \cos(2\theta_r) \tag{9}$$

where L_{sl} is the stator leakage inductance. The d-axis and q-axis inductances are associated with the above inductances as follow:

$$L_d = L_{sl} + \frac{3}{2} L_0 + \frac{3}{2} L_2 \tag{10}$$

$$L_q = L_{sl} + \frac{3}{2} L_0 - \frac{3}{2} L_2 \tag{11}$$

The developed torque can be expressed as (equation 12):

$$T_{em} = \frac{P}{2} \cdot L_2 \cdot \begin{bmatrix} i_a & i_b & i_c \end{bmatrix} \cdot \begin{bmatrix} \sin(2\theta_r) & \sin\left(2\theta_r - \frac{2\pi}{3}\right) & \sin\left(2\theta_r + \frac{2\pi}{3}\right) \\ \sin\left(2\theta_r - \frac{2\pi}{3}\right) & \sin\left(2\theta_r + \frac{2\pi}{3}\right) & \sin(2\theta_r) \\ \sin\left(2\theta_r + \frac{2\pi}{3}\right) & \sin(2\theta_r) & \sin\left(2\theta_r - \frac{2\pi}{3}\right) \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} - \frac{P}{2} \cdot \lambda_{pm} \cdot \begin{bmatrix} i_a & i_b & i_c \end{bmatrix} \cdot \begin{bmatrix} \sin(\theta_r) \\ \sin\left(\theta_r - \frac{2\pi}{3}\right) \\ \sin\left(\theta_r + \frac{2\pi}{3}\right) \end{bmatrix} \tag{12}$$

The mechanical equations are:

$$J \cdot \frac{d\varpi_m}{dt} = T_{em} - B \cdot \varpi_m - T_{load} \tag{13}$$

$$\frac{d\theta_r}{dt} = \frac{P}{2} \cdot \varpi_m \tag{14}$$

where B is a coefficient, T_{load} is the load torque. The coefficient B is calculated from the moment of inertia J and the mechanical time constant τ_{mech} as below (equation 15).

$$B = \frac{J}{\tau_{mech}} \tag{15}$$

Using the *d–q* transformation, the voltage equations of a PM machine in the rotor reference frame are as follows:

$$v_d = R_s i_d + \frac{d\lambda_d}{dt} - \varpi_e \lambda_q \tag{16}$$

$$v_q = R_s i_q + \frac{d\lambda_q}{dt} + \varpi_e \lambda_d \tag{17}$$

where $\lambda_d = L_d i_d + \lambda_m$, $\lambda_q = L_q i_q$ and the stator flux linkage is $\lambda_s = \sqrt{\lambda_d + \lambda_q}$.

3. PMSM VSI Parameter influence

A PM Synchronous motor is driven by sine wave voltage coupled with the given rotor position. The generated stator flux together with the rotor flux, which is generated by a rotor magnet, defines the torque, and thus speed, of the motor. The sine wave voltage output have to be applied to the 3-phase winding system in a way that angle between the stator flux and the rotor flux is kept close to 90° to get the maximum generated torque. To meet this criterion, the motor requires electronic control for proper operation.

It has been shown that the electromagnetic torque in a PM machine can be regulated by controlling the magnitude and angle of the stator flux linkage or load angle δ. This can be performed by applying the proper output voltage vectors of an inverter to the machine. We have used a voltage source inverter (VSC), like we can see at figure 3, for observe the parameters influence.

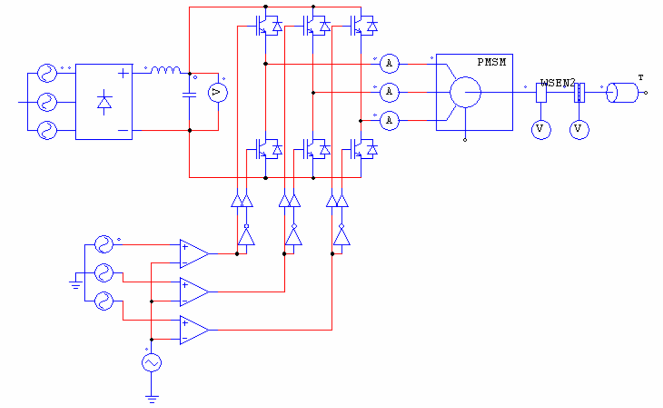


Fig. 3. A voltage source inverter (VSI) applied to a PMSM

If we use a PSIM software with Matlab for check, by a time-step simulation, R_S and Ld parameters influence, we obtain:

Case 1: Figures 4 and 5. PMSM: Rs=0.3Ω, Ld=0.0027 H.

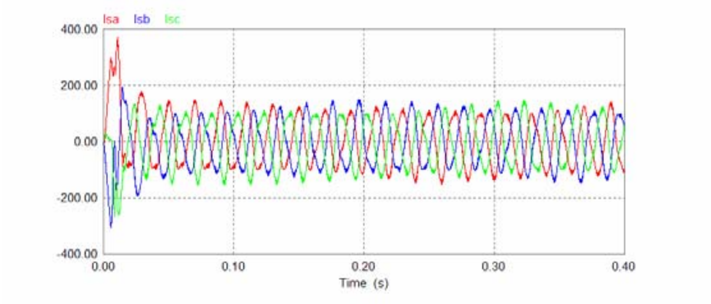
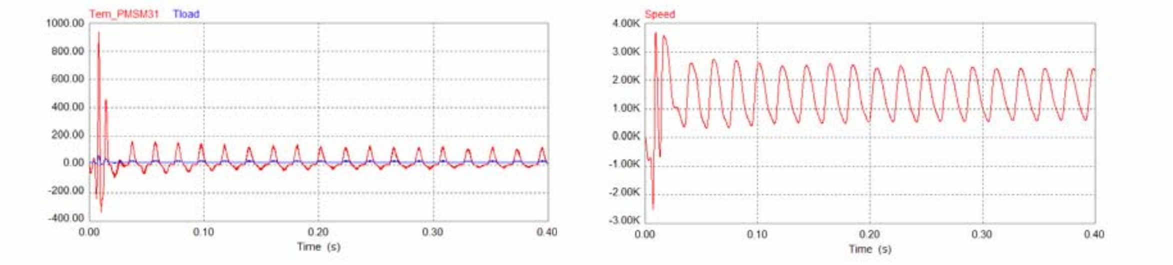


Fig.4. Currents of the three phases charts for case 1



(a) (b)

Fig. 5. (a) PMSM torque and constant load torque and (b) PMSM speed versus time for case 1.

Case 2: Figures 6 and 7. PMSM: Rs=2Ω, Ld=0.0027H.

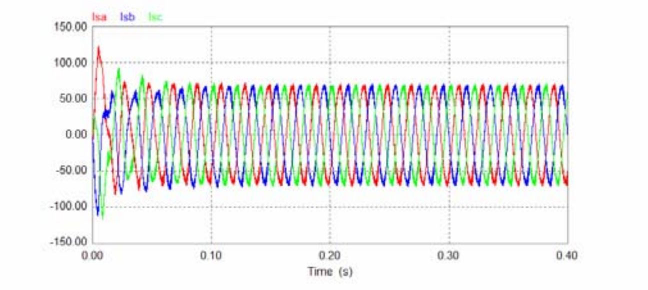
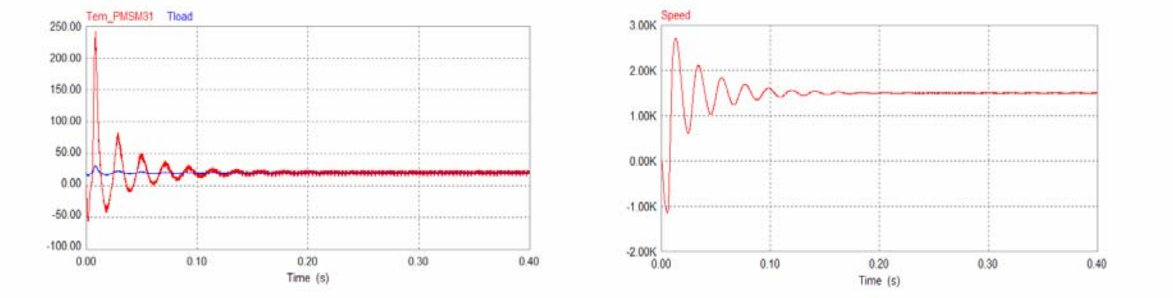


Fig. 6. Currents of the three phases charts for case 2.



(a) (b)

Fig. 7. (a) PMSM torque and constant load torque and (b) PMSM speed versus time for case 2.

Case 3: Figures 8 and 9. PMSM: Rs=2Ω, Ld=0.03H.

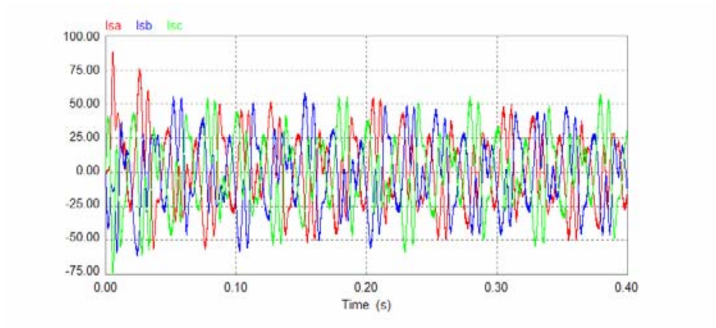
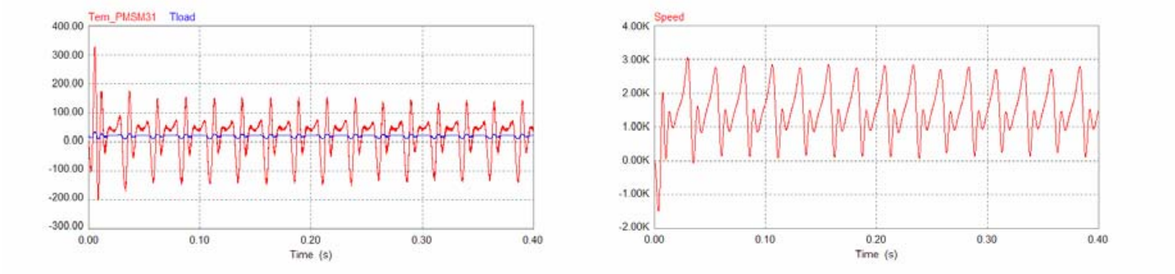


Fig. 8. Currents of the three phases charts for case 3.



(a) (b)

Fig. 9. (a) PMSM torque and constant load torque and (b) PMSM speed versus time for case 3.

Case 4: Figures 10 and 11. PMSM: Rs=4Ω, Ld=0.0027 H

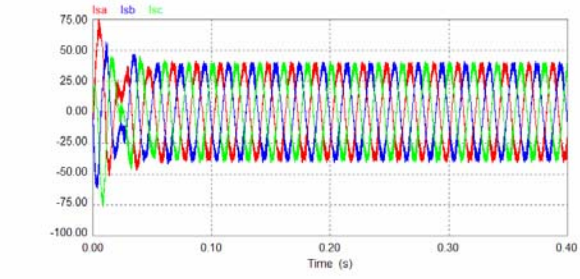
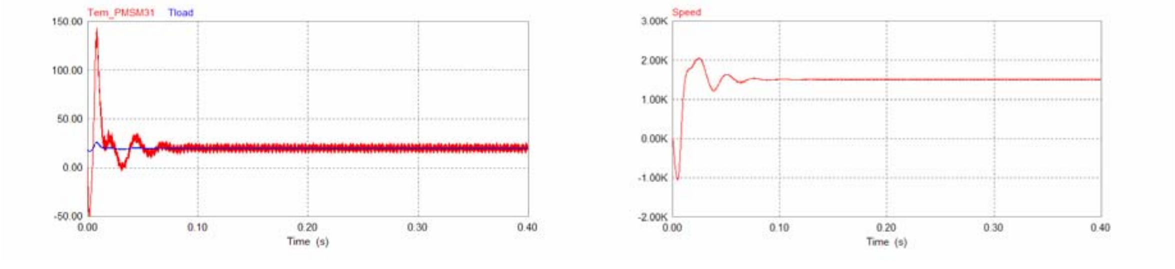


Fig. 10. Currents of the three phases charts for case 4.



(a) (b)

Fig. 11. (a) PMSM torque and constant load torque and (b) PMSM speed versus time for case 4.

If we compare the cases 1, 2 and 4 we can conclude that for the same Ld value the synchronization with a VSI it is not possible with a very low stator resistance (case 1) but from a minimum value of R_S if we increase this R_S value (just the double), 2 and 4 cases, the synchronization is also possible. For the same R_S value, 2 and 3 cases, the synchronization is not possible if we increase to much the Ld inductance, from 0,0027 H to 0,03 H.

For all the four studied cases we have considered constant the following parameters of the PMSM, LOAD , SUPPLY and DC link:
PMSM: Lq=0,0067H, Vpk=198,67V/krpm, Moment of inertia=0,00179 kg*m^2, Time constant=10 s
LOAD: Constant Torque=20 N*m, Moment of inertia=0.0001 kg*m^2

SUPPLY and DC link: Line-line rms V=556 V, L=0.001 H, C=0.0005 F, Initial Cap. Voltage=750 V

Control Strategies

The performance of a PMSM are strongly dependent of its control. Direct torque control (DTC) is considered as one of the best alternatives for motor drive designers in order to get a fast torque response; especially when torque control instead of speed or position control, is the control objective. Besides high torque dynamics, it is well known for being robust to motor parameters change, except stator resistance [1] and no need of complicated coordinate transformation and pulse width modulation (PWM). A major problem associated with the DTC is the big torque and flux linkage ripples because of the use of two simple two-value hysteresis controller for the stator flux linkage and the torque and a 60º angular region based signal for choosing the space voltage vector applied to the stator windings, which is so crude that none of this space voltage vectors generated by the VSI could offer a precise control of the torque and the stator flux linkage at the same time [10].

4. **Conclusions**

We have applied in this paper a model for accurate representation of the characteristics of permanent magnet synchronous motors.

For a 3-phase PM Synchronous motor, a standard 3-phase power stage is used. The power stage utilizes six power transistors with independent switching. The power transistors are switched in the complementary mode. The sine wave output is generated using a voltage source (VSI). We have used a PSIM software with Matlab for check, by simulation, R_S and Ld parameters influence on the start process. At the same manner we can check the influence of others PMSM parameters.

For further work, one can obtain by simulation the influence of PMSM parameters by using a new system control with PWM. With PWM surely the influence of the parameters will be different. A powerful processor such a DSP controller enable enhanced real time algorithms and controls power switching inverter and generate high resolution PWM outputs.

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