

# Permanent Magnet Synchronous Motors (PMSM). Parameters influence on the synchronization process of a PMSM

J. Rais<sup>1</sup>, M. P. Donsión<sup>2</sup>

<sup>1</sup> Department of Electromechanics and Power Electronics  
Faculty of Electrical Engineering Plzeň., The University of West Bohemia in Pilsen  
Univerzitni 8; 306 14 Pilsen; Czech Republic  
phone: +420 776 8605232, fax:+420 37 7634301, e-mail: jrais@sduents.zcu.cz,

<sup>2</sup> Electrical Engineering Department, Vigo University, Spain  
Campus of Lagoas Marcosende, 36310 Vigo (Spain),  
IEEE, EA4EPQ and AEDIE member, donsion@vigo.es

## 1. Brief introduction

Permanent magnet synchronous motors are increasing applied in several areas such as traction, automobiles, robotics and aerospace technology. The power density of permanent magnet synchronous motor is higher than one of induction motor with the same ratings due to the no stator power dedicated to the magnetic field production. Nowadays, permanent magnet synchronous motor is designed not only to be more powerful but also with lower mass and lower moment of inertia.

We can't use typical model d-q. This model is uncoupled, linear and has constant parameter, applied to salient pole synchronous machines. It may be inadequate for accurate modeling characteristics prediction of permanent magnet synchronous motor of interior type. It leads below to important errors when we evaluate machine performance or calculate the control circuits.

The behavior of permanent magnet synchronous motor of the interior type can be rather different than expected using the conventional two axis theory. It is necessary to establish new models for this case. We must take into account the magnetic flux redistribution along the rotor iron placed between the magnets and the air-gap.

We must into account the required accurate of the results also the reliability of testing procedures for determination of the machine parameters, when we develop permanent magnet synchronous motor model.

The conventional methods of testing for determination of synchronous machine parameters can not be applied in the case of permanent magnet machine. And this is why we use test procedures, which are differing from the classical methods applicable to wound field synchronous machines.

### Key words:

Permanent Magnet Synchronous Motor, DQ model, Electromagnetic torque, Voltage Source Inverter, PWM

## 2. DQ model for PMSM

Equations for electric circuit:

$$U_1^S = R_s I_1^S + \frac{d\Psi_1^S}{dt} \quad (2.1)$$

where top index  $S$  is variable in the stator coordinate system.

Now we can define coupled magnetic flux  $\psi$ :

$$\Psi_1^S = \phi_F \cdot e^{j\theta} + L_s \cdot I_1^S \quad (2.2)$$

magnetic flux  $\Phi_F$  is excited by permanent magnets in rotor and it transforms to stator coordinates. Both equations are transformed to coordinate system DQ, which is rotating same radian frequency like rotate magnetic field:

$$U_1^R = R_s I_1^R + \frac{d\Psi_1^R}{dt} + j\omega\Psi_1^R \quad (2.3)$$

$$\Psi_1^R = \phi_F + L_s I_1^R$$

Now we can write equation in DQ form:

$$u_d = R_s i_d + \frac{d\Psi_d}{dt} - \omega \cdot \Psi_q \quad (2.4)$$

$$\Psi_d = L_d i_d + \phi_F$$

$$u_q = R_s i_q + \frac{d\Psi_q}{dt} + \omega \cdot \Psi_d \quad (2.5)$$

$$\Psi_q = L_q i_q$$

The stator flux linkage is

$$\Psi_S = \sqrt{\Psi_d^2 + \Psi_q^2} \quad (2.6)$$

Electromagnetic torque of motor is deduced from equation:

$$M_E = \frac{3}{2} \cdot p_p \cdot J_m \{ \psi_1^* \cdot I_1 \}$$

$$M_E = \frac{3}{2} \cdot p_p \cdot (\Psi_d i_q - \Psi_q i_d) = \frac{3}{2} \cdot p_p \cdot [\phi_F + (L_d - L_q) i_d] i_q \quad (2.7)$$

### 3.1. A Voltage Source Inverter (VSI) applied to a PMSM

When the machine has low value of resistance of stator winding, its behavior will change, even if it is small change direct-axes impedance. If the direct-axes impedance is very small or very high, the synchronous machine will not reach synchronism. The more we get nearer to up interval, where the machine can reach

synchronism, that the time of standstill of speed and torque is longer (fig. 1). It takes few seconds, and that is why we can't use this machine in practice. Machine with low value of resistance of stator winding has less loss in the winding.

When value of resistance of stator winding raises, the machine can reach synchronism, even the machine has low value of direct-axes impedance.

When we raise again value of resistance of stator winding, the interval of direct-axis impedance, where the machine can reach synchronism, will decrease. If the value of resistance is very high and inductance very small, the machine can't reach synchronism.

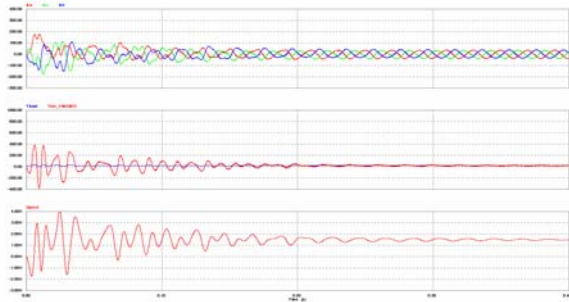


Fig. 1  $R_s=0.3\Omega$ ,  $L_d=0.01 H$  (Currents of the three phases charts for case, PMSM torque and constant load torque, PMSM speed versus time)

### 3.2. A Voltage Source Inverter (VSI) controlled by a Pulse Width Modulation (PWM) applied to a PMSM

When we use a voltage source inverter (VSI) controlled by a pulse width modulation (PWM) applied to a PMSM, the values direct-axes impedance and resistance of stator winding haven't so big influence on the behavior of machine. Other way, when we used only VSI applied to a PMSM, the values had big influence on the behaviour of machine.

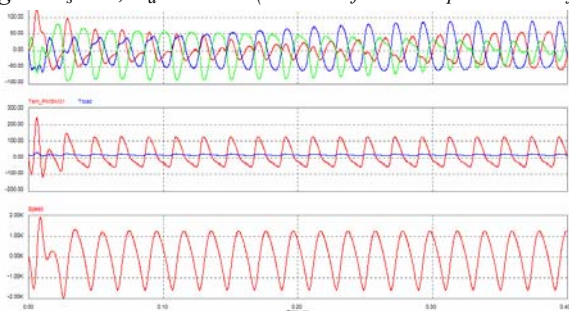
### 3.3. A Voltage Source Inverter (VSI) with supply cable applied to a PMSM

We neglected inductive reactance and resistance of supply cable in the previous measurements (VSI, VSI controlled by PWM). We took this supply like ideal in these cases. This means, that the resistance and inductive reactance are zero. Ideal wire doesn't exist in the practice. Every wire has its impedance.

When we use short cable (10m,  $R=0,0469\Omega$ ,  $X_L=0,00099\Omega$ ), we can observe, that this small impedance of system hasn't influence on the PMSM. Machine has same influence like case with ideal wire.

We use cable length 3km for last measurement. This cable has resistance  $14,097\Omega$  and inductive reactance  $0,2997\Omega$  (0,93mH). This impedance is so high, that it is problem to get the machine to synchronism (fig 2). PMSM can reach synchronism only when we use values  $R_s=0,3\Omega$  and  $L_d=0,01H$ .

Fig. 2  $R_s=1\Omega$ ,  $L_d=0.01 H$  (Currents of the three phases charts for



case, PMSM torque and constant load torque, PMSM speed versus time)

### 3.4. Influence quality of supplied electricity on the behavior of PMSM

In these measurements we deal with Influence of quality of supplied electricity on the behavior of PMSM. Quality parameters are many. We choose voltage asymmetry, voltage variations and network frequency for our measurements. This is task for VSI, which should watch on the quality for supply of machine.

## 4. Conclusions

The conclusion of VSI applied to PMSM is: When value of resistance of stator winding raises, the machine can reach synchronism, even the machine has low value of direct-axes impedance. When we raise again value of resistance of stator winding, the interval of direct-axis impedance, where the machine can reach synchronism, will decrease. If the value of resistance is very high and inductance very small, the machine can't reach synchronism. When we increase stator winding resistance and d-axis inductance, we can observe, that the current form VSI decreases up to 50%. Advantages of this control are his simplicity and his absence of PWM.

It is very difference, when we use VSI controlled by PWM applied to a PMSM, because in this case the values of stator winding resistance and direct-axes impedance haven't so big influence on the behavior of PMSM.

When the impedance of circuit is so high, it is problem to get the machine to synchronism. PMSM can reach synchronism only when we use values  $R_s=0,3\Omega$  and  $L_d=0,01H$ .

We simulated change of network frequency. This change hasn't influence on the behavior of PMSM, because the inverter can make right frequency for supply of machine. If we use pulse rectifier instead of ordinary diode rectifier, we would eliminate influence on the voltage variation and the motor would reach synchronism in all case even will be higher undervoltage. The last experiment shows, that two-phase supplied id impossible.

All four measurements show, that when the machine has good design, so it can reach synchronism in most adverse operational situation.

## References

- [1] Motores Sinchrones de Imanes Permanents, Manuel Pérez Donsión, Manuel A. Fernández Ferro, 1990 Universidade de Santiago de Compostela
- [2]Elektrické pohony pro dynamicky náročné aplikace, Martin Diblík, 2006 Technická univerzita v Liberci
- [3]Permanent Magnet Synchronous Machine Model for Real-time Simulation A. B. Dehkordi, A. M. Gole, T. L. Maguire 2005, International Conference on Power System Transients in Montreal
- [4]Direct Torque Control of a Permanent Magnet Synchronous Motor, David Ocen, 2005 Stockholm