

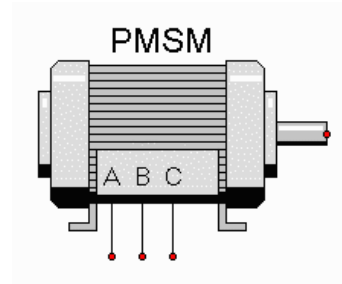
Permanent Magnet Synchronous Motor (PMSM)

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Description

A Permanent Magnet Synchronous Motor (PMSM) is constructed by fitting the magnet inside the rotor cage, which is necessary for induction starting. The PMSM are usually considered a linear device over its entire operating range of torque and speed, with practically linear speed-torque characteristic.

The main advantage of Permanent Magnet Synchronous Motors (PMSM) is the absence of the excitation winding. An important application area for the synchronous machine is large-scale power generation. In the majority of power stations synchronous machines operate as generators and their design depends on the rotational speed required. Multipole machines with salient poles are used for relatively slow rotation speeds whereas for higher speeds (for example gas turbine driven generators) the machines have lower pole numbers and cylindrical rotors - so-called turbo rotors. But such big machines are also employed in electrical drives for traction, rolling mills, mining etc. A special type is the Permanent Magnet Synchronous Machines (PMSM), which is often used for servo systems up to 100 kW.

The stator has usually cylindrical shape with slots on the inner surface where the stator windings are placed. In general the number of slots is large for distributed windings (typically 6 per phase). The stator is manufactured using laminated metallic sheets to minimize the eddy currents induced by the rotating flux. (figure 1).

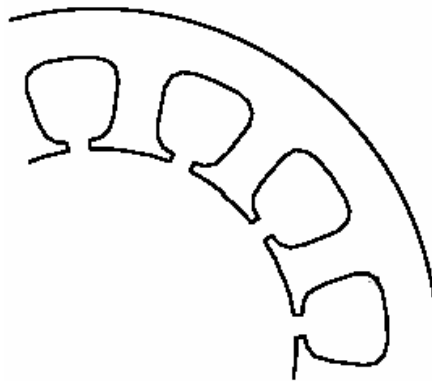


Figure 1. PMSM Stator.

The rotor of a permanently magnetized synchronous machine can have the magnets applied either on the rotor surface or buried deep into the rotor. The most common materials for the permanent magnets are Samarium-Cobalt and Neodymium-Boron Iron, which are very durable (resist to vibration and to relatively high temperatures) and allow high magnetic flux densities.

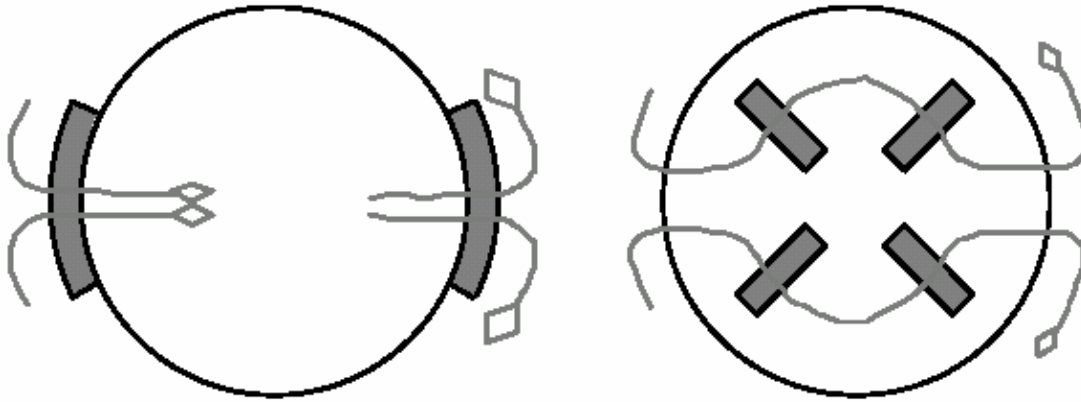


Figure 2. a) 2-pole rotor with outer magnets -- b) 2-pole rotor with inner magnets

This type of motors uses a permanent magnet to generate the magnetic field in which the armature rotates, the electrical circuit in the armature alone can model the motor. In this model R_s and L_s indicate the equivalent armature coil resistance and inductance respectively. The model for the electrical part is shown in figure 3.

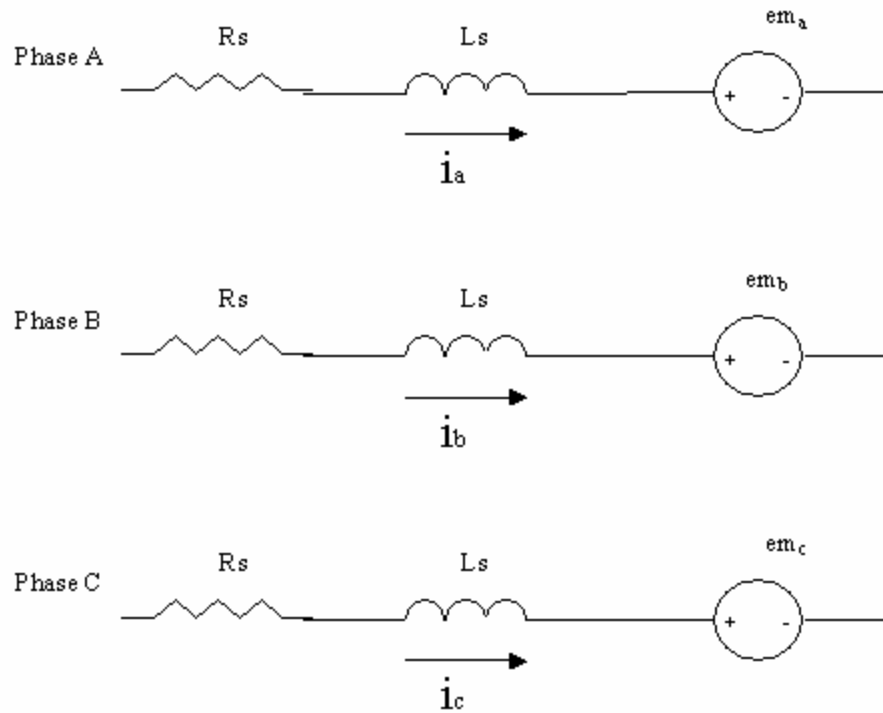


Figure 3. PMSM Armature Equivalent Circuit.

Validity Range and Limitations

The model is valid for both transition and steady state operation. For this model we assume that the magnetic flux is constant. The model does not account for the initial conditions in the inductor and capacitor.

Connections

There are four terminals in this model, three of which are electrical and one of them is mechanical. The electrical terminals are Labeled A, B, C, and the mechanical terminal is not labeled, and is located in the right hand end of the shaft.

Label	Description
A	Input Terminal for Phase A
B	Input Terminal for Phase B
C	Input Terminal for Phase C
(not labeled)	Mechanical Terminal

Adjustable Parameters

Name	Description	Valid Range	Default Value	Units
Rs	Stator Winding Resistance	$\geq 1.0e-6$	0.39	Ω
Ls	Armature Inductance	$\geq 1.0e-6$	0.000444	Henries
Ft	Frictional Coefficient	$\geq 1.0e-6$	0.0037	N.m/rad/s
J	Rotor Moment of Inertia	$\geq 1.0e-6$	0.0355	Kg.m.m
E _{max}	Maximum Electromotor Force	$\geq 1.0e-6$	1	V
Speed _n	Nominal Speed	$\geq 1.0e-6$	1	rad/s

Output Variables

Name	Description	Units
\dot{i}_A	Current in the Stator Phase A	Volts
\dot{i}_B	Current in the Stator Phase B	Amps
\dot{i}_C	Current in the Stator Phase C	Volts
ω	Angular Velocity	rad/s

Model Assumptions

All parasitic parameters and any device physics were ignored. All the terminal currents have their positive directions referred to flowing into the corresponding node. For this model we assume that the magnetic flux is constant.

Mathematical Description

From the circuit shown in figure 3 Kirchoff's voltage law lead to the followings equations:

$$V_A = (R_s * i_A) + \left(L_s * \frac{di_A}{dt} \right) + em_A \quad \text{Equation 1}$$

$$V_B = (R_s * i_B) + \left(L_s * \frac{di_B}{dt} \right) + em_B \quad \text{Equation 2}$$

$$V_C = (R_s * i_C) + \left(L_s * \frac{di_C}{dt} \right) + em_C \quad \text{Equation 3}$$

Where R_s indicate the equivalent armature coil resistance, L_s indicates the equivalent armature coil inductance, and em represent the back electromotor force. Analyzing the magnetic field in the motor, and realizing that the magnetic flux is constant, the following equations relating the torque t_m and the motor speed output ω to the supplied current and voltage.

$$em_A = K_A * \omega \quad \text{Equation 4}$$

$$em_B = K_B * \omega \quad \text{Equation 5}$$

$$em_C = K_C * \omega \quad \text{Equation 6}$$

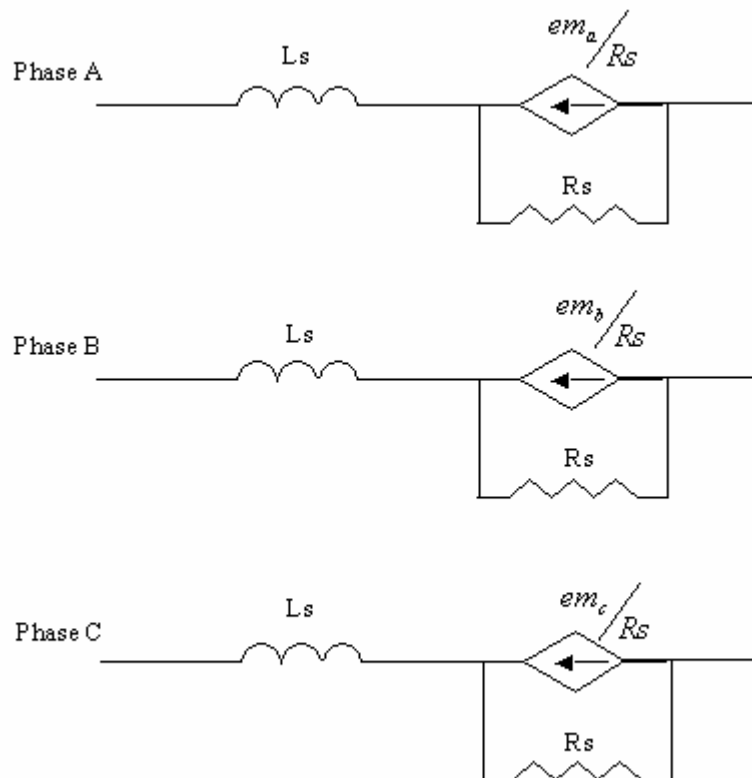
$$t_m = (K_A * i_A) + (K_B * i_B) + (K_C * i_C) \quad \text{Equation 7}$$

In addition to the electrical equations, the mechanical part that is the load effect must be considered as in equation 8 and 9. Where F_t is a frictional coefficient, and J is the inertia moment.

$$(K_A * i_A) + (K_B * i_B) + (K_C * i_C) = (F_t * \omega) + \left(J * \frac{d\omega}{dt} \right) \quad \text{Equation 8}$$

$$\frac{d\theta}{dt} = \omega \quad \text{Equation 9}$$

Finally the equivalent circuits for the PMSM are shown in figure 4.



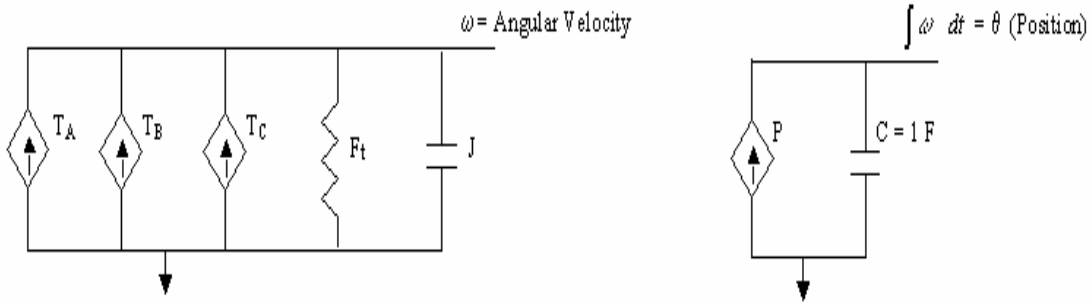


Figure 4. PMSM Equivalent Circuit.

The inductors are modeled with a dependent current source B_L in parallel with a conductance G_L

$$i_L(t) = -G_L * (V_4(t) - V_{out}(t)) - B_L(t-h) \quad \text{Equation 10}$$

$$B_L(t-h) = -G_L * (V_4(t-h) - V_{out}(t-h)) - i_L(t-h) \quad \text{Equation 11}$$

Where:

$$G_L = \frac{h}{2 * L}$$

$h = \text{Time Step}$

$L = \text{Inductor Value}$

The capacitor is modeled with a dependent current source B_C in parallel with a conductance G_C

$$i_c(t) = G_c * (V_{out}(t) - V_{ref}(t)) + B_c(t-h) \quad \text{Equation 12}$$

$$B_c(t-h) = G_c * (V_{out}(t-h) - V_{ref}(t-h)) + i_c(t-h) \quad \text{Equation 13}$$

Where:

$$G_C = \frac{2 * C}{h}$$

$h = \text{Time Step}$

$C = \text{Capacitor Value}$

Model Validation

This is only an ideal model and does not have a real counterpart, so the measured data for the real object is not available.

Example Application

The following test bench for the PMSM (figure 5), is designed for testing the electrical behavior of the machine. For this test the input terminal for phase A is connected to a square voltage source, the other two phases are connected to ground. And the mechanical part is connected to the ground too. The setting for the square voltage source and the PMSM are shown in figure 6.

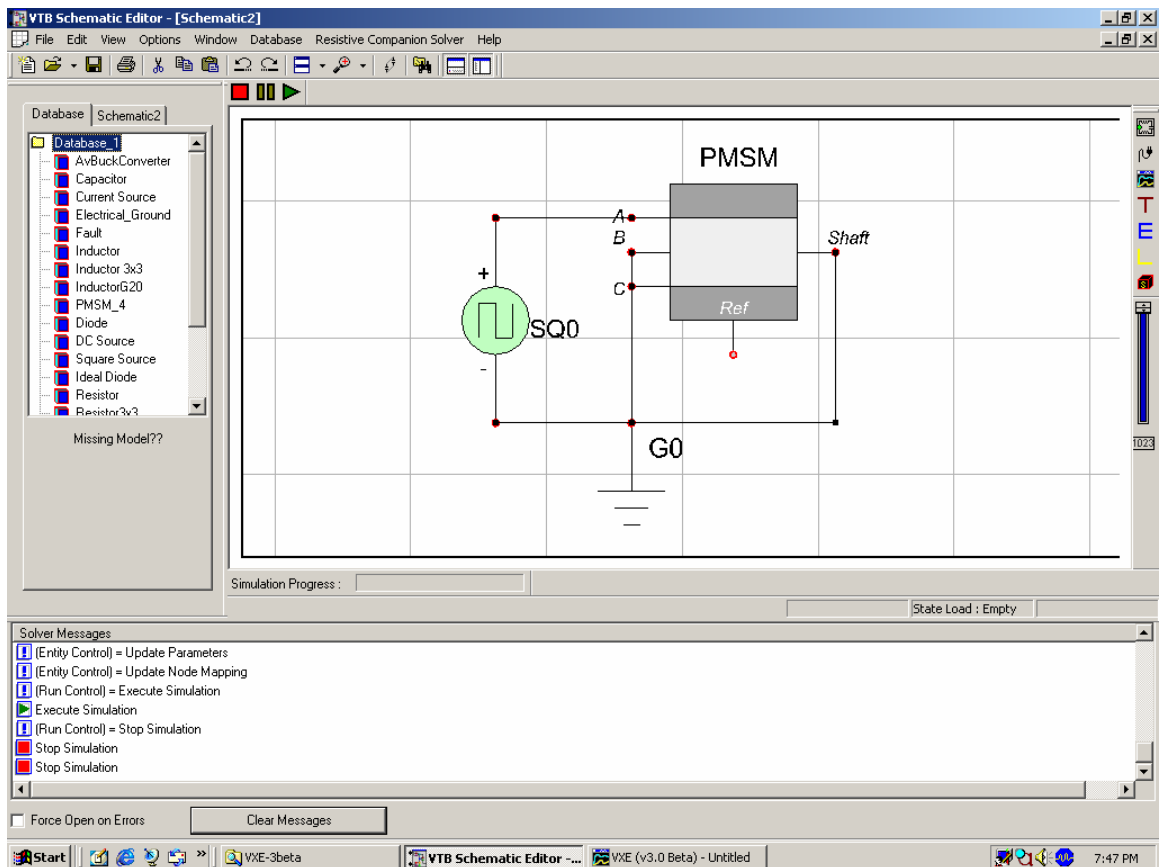


Figure 5. Test Bench for the PMSM.

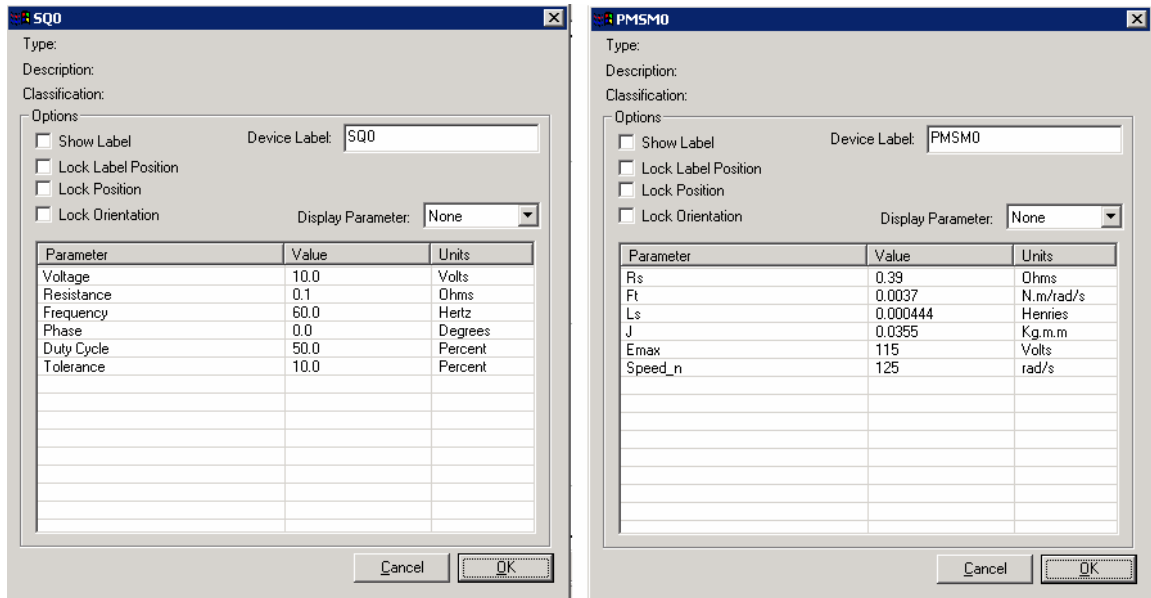


Figure 6. Settings for the Square Voltage Source and the PMSM.

In the figure below the simulation results are shown, the input voltage into the phase A, is the voltage generated by the square voltage source is shown in green in the figure 7, and the stator current in phase A is shown in red.

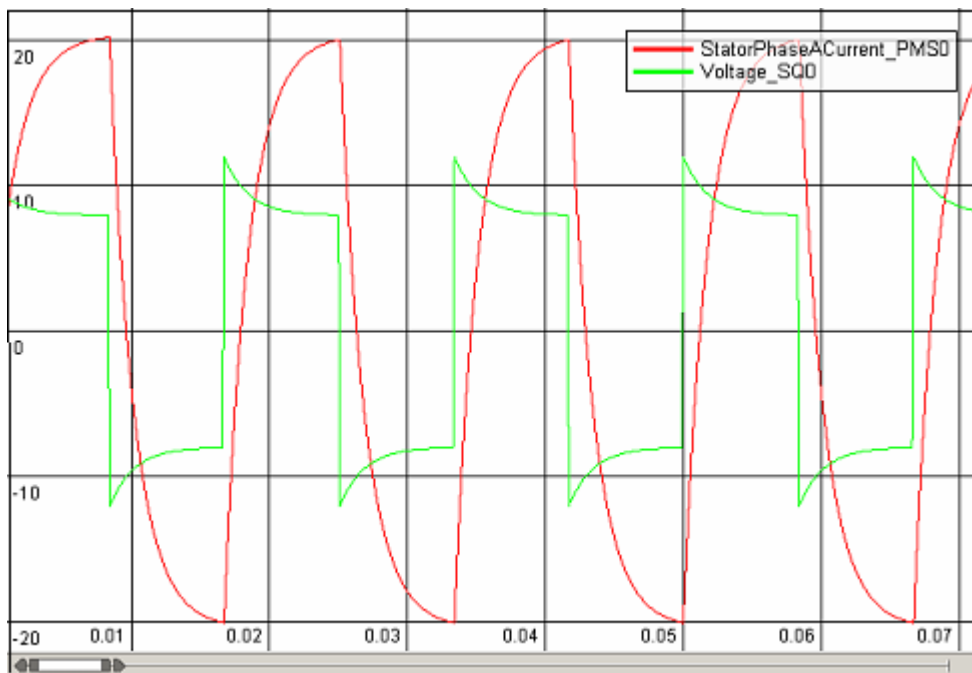


Figure 7. Simulation Results Current and Voltage signals for phase A.

Model Verification

References

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