ELECTRIC VEHICLES INTERNATIONAL CONFERENCE & SHOW

Powerful Advanced N-Level Digital Architecture for models of electrified vehicles and their components

Multi-level knowledge models of a permanent magnet synchronous machine

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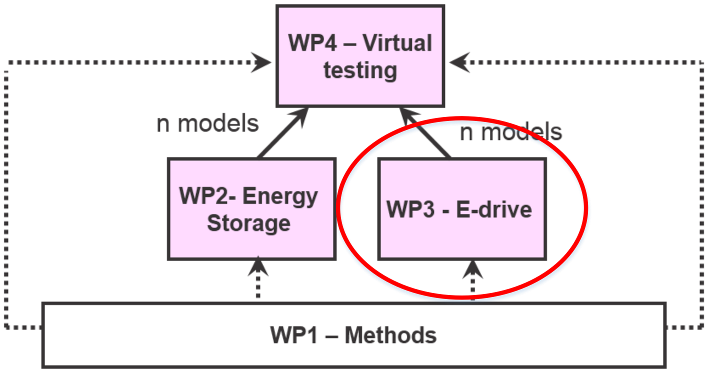
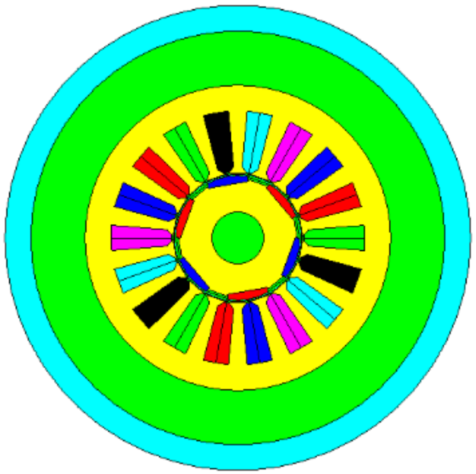
Outline

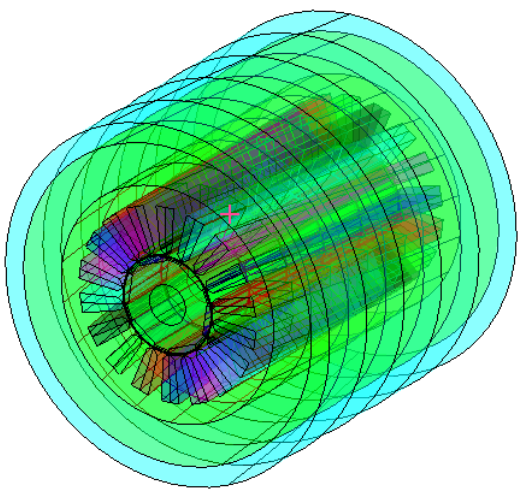
- Finite-element analysis of the PMSM;
- First-level analysis: saturation is neglected;
- Second-level analysis using Frozen Permeability method;
- Third-level analysis using Flux and torque maps
- Simulation models of the LEV propulsion system using Energetic Macroscopic Representation
- Results
- Conclusions

- Tools:
  - Flux Skew;
  - MATLAB/Simulink;



Finite-element analysis of the PMSM

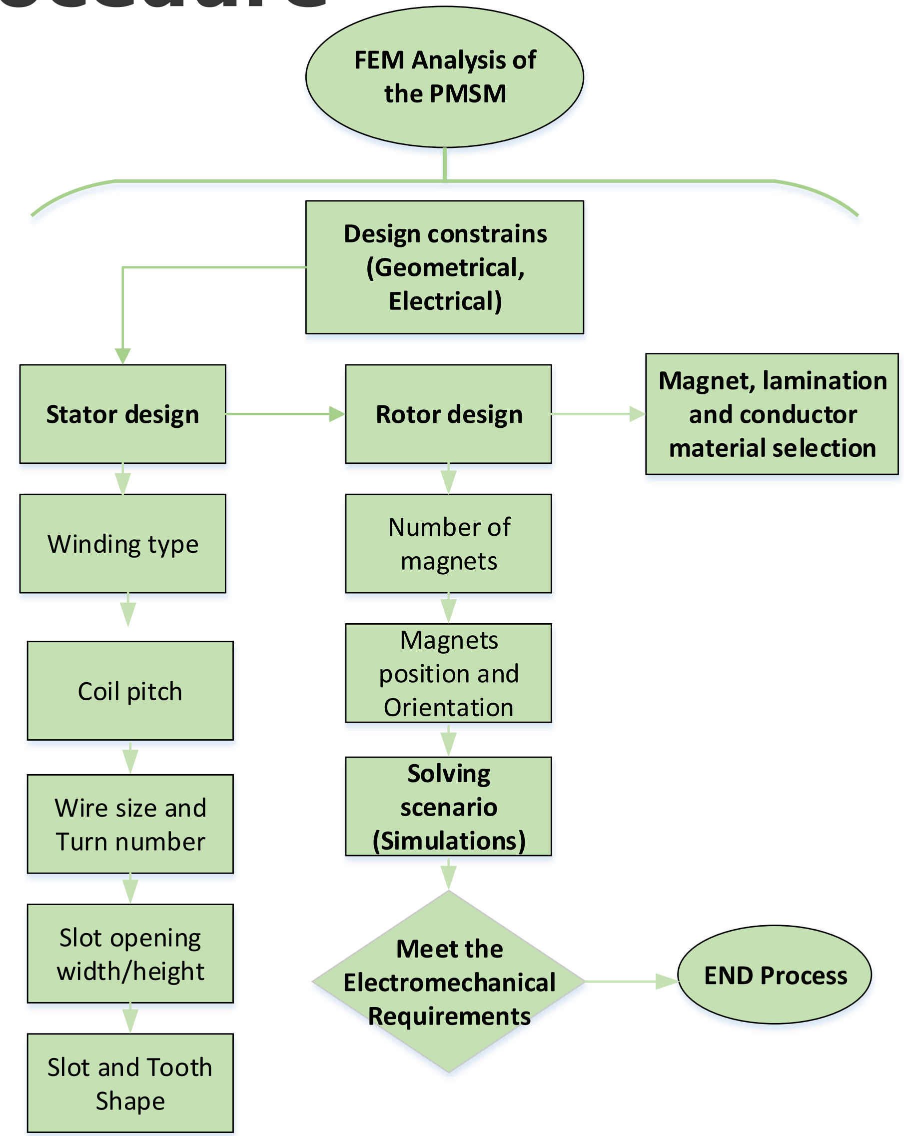




Electrical and geometric parameters

Dimension	Value	Unit
Stator slots	18	-
Number of phases	3	-
Nr. turns on the phase	48	-
Type of winding	Distributed	-
Length of the machine	160	[mm]
Diameter of the machine	118	[mm]
Rotor speed	2000	[rot/min]
Frequency	100	[Hz]
Rated current per phase	21	[A]
Mechanical power	2500	[W]
DC Voltage link	120	[V]

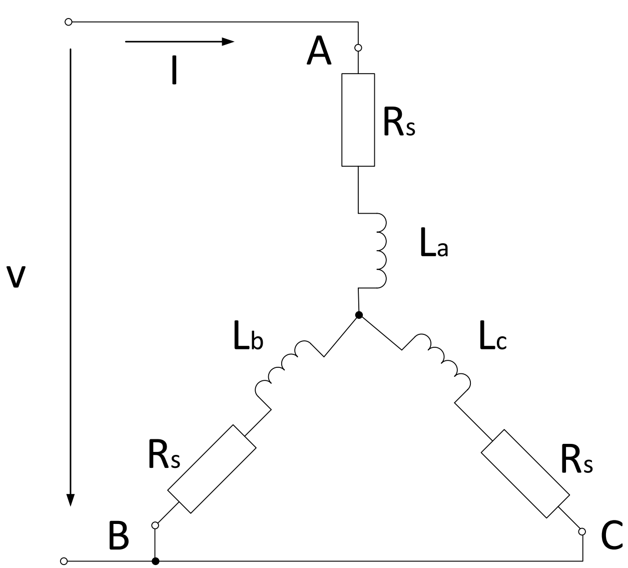
Design procedure

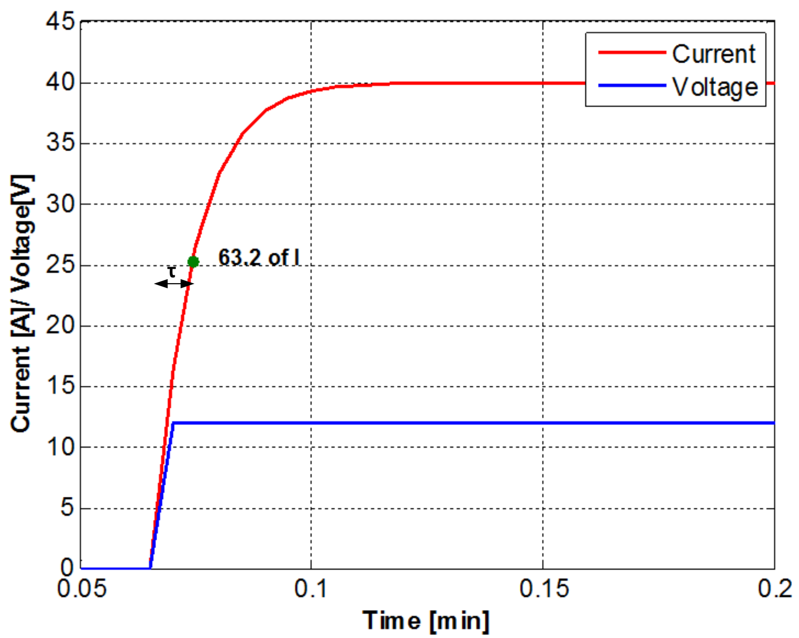


First-level analysis (Ld, Lq-constants)

Inductance measurement circuit

Current step response





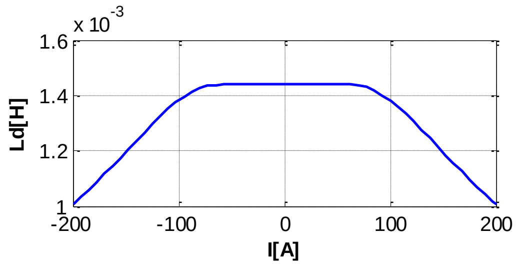
$$I_\tau = 63.2\% \cdot I \qquad \tau = \frac{L}{R}$$

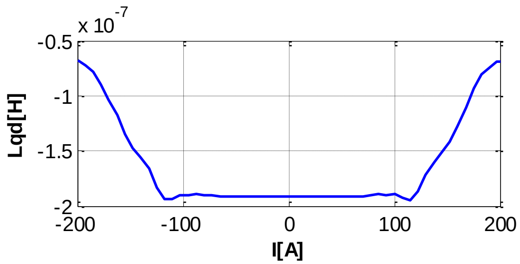
$$\mathrm{Ld} = \mathrm{Lq} = 0.002817\,[\mathrm{H}]$$

Second-level analysis using Frozen Permeability method

1. Inductances Ld and Lqd

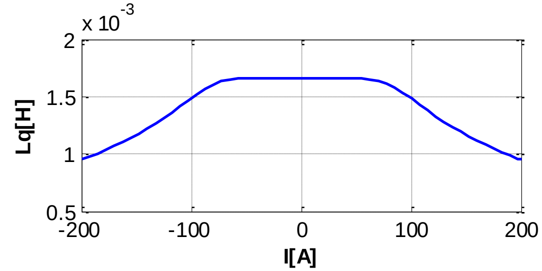
-the magnet flux is turned off by setting the magnet remanence to zero
-the current vector it's aligned with the d axis

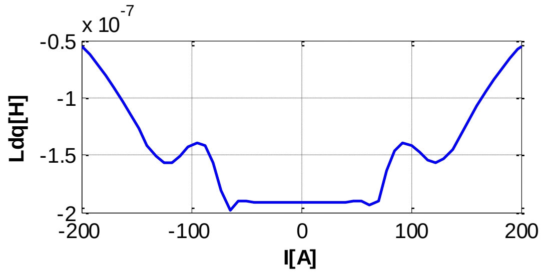




2. Inductances Lq and Ldq

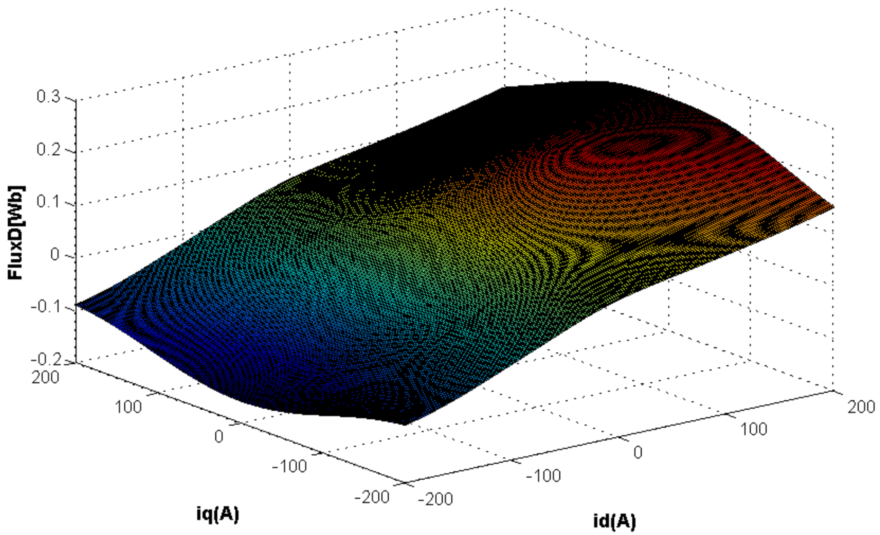
-the current vector it's aligned with the q axis



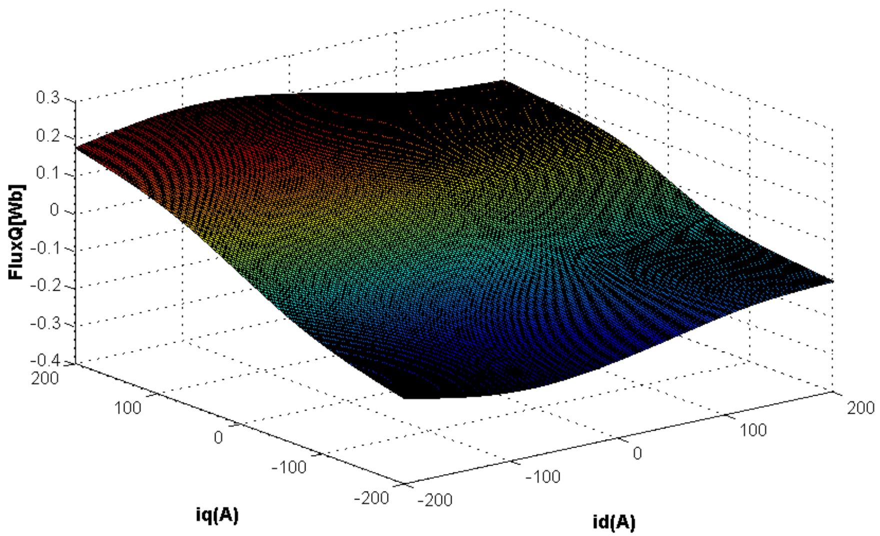


Third-level analysis using Flux and torque maps

Original flux-linkage map for d-axis(a) and q-axis (b) flux linkage



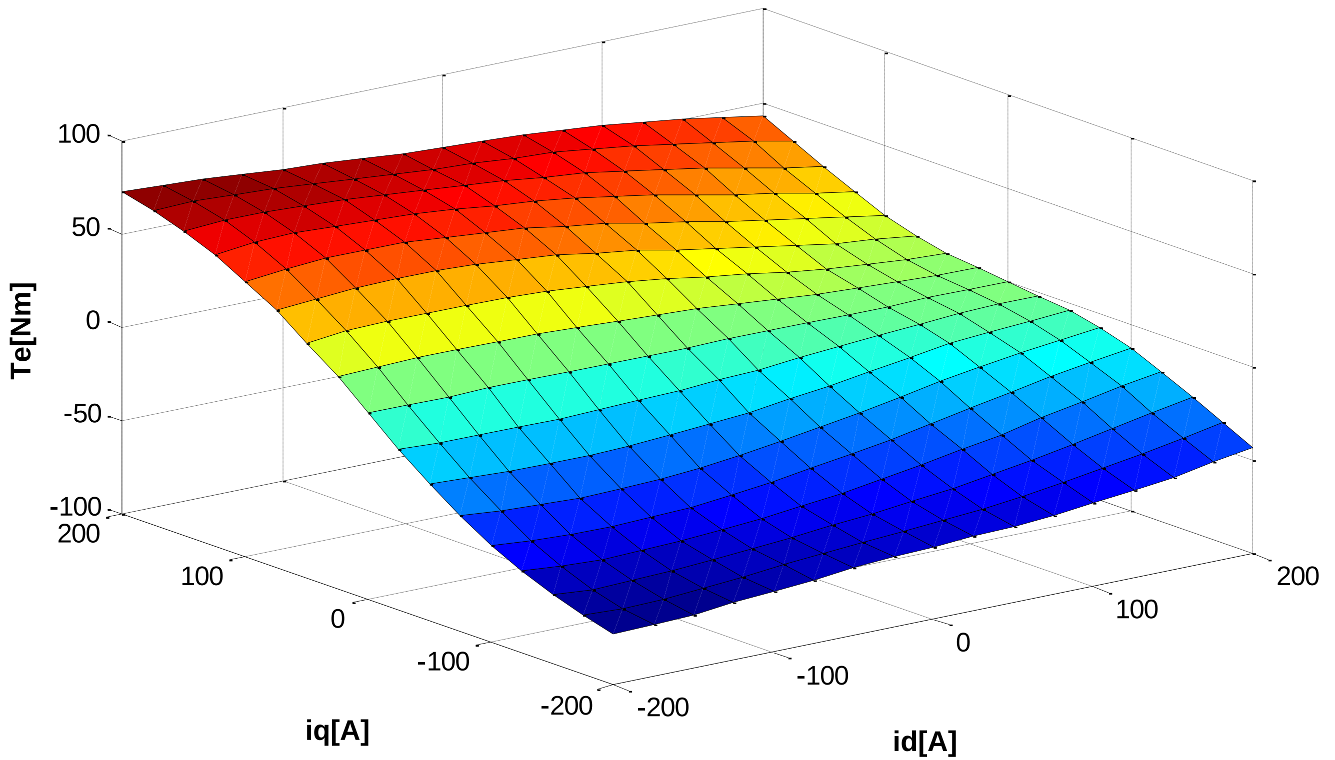
(a) d-axis



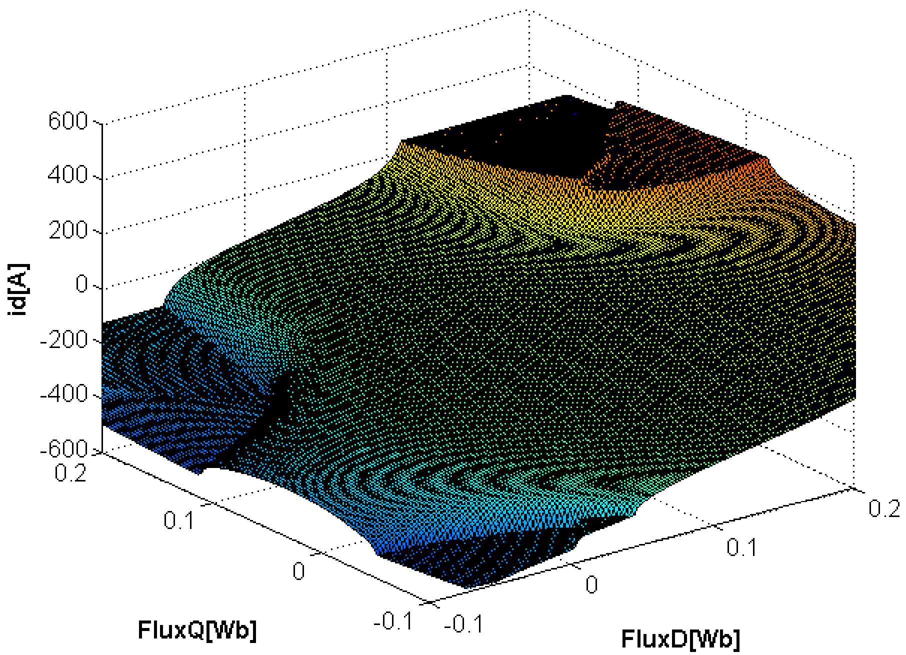
(b) q-axis

Third-level analysis using Flux and torque maps

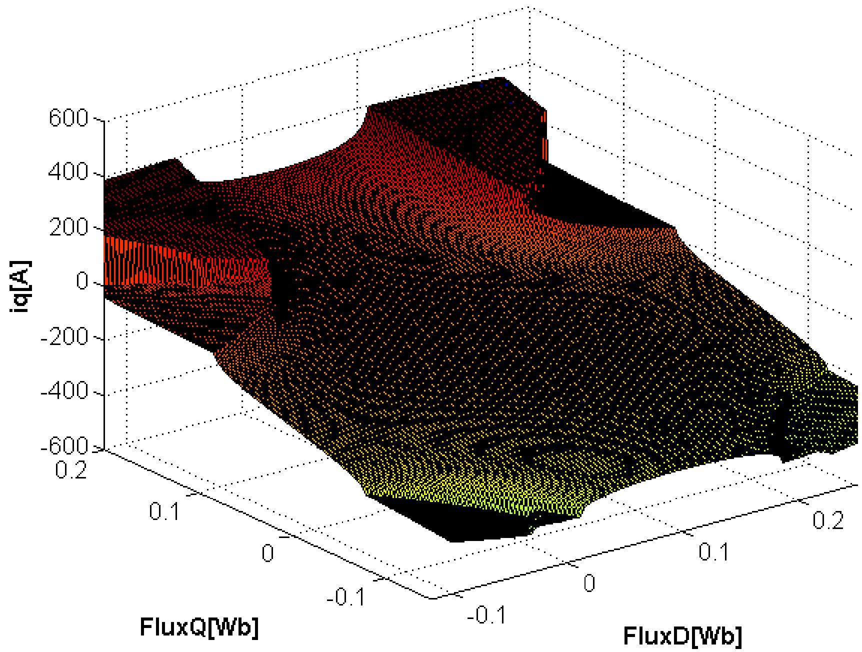
Original torque map for electromagnetic torque



Inverse flux map via intersection

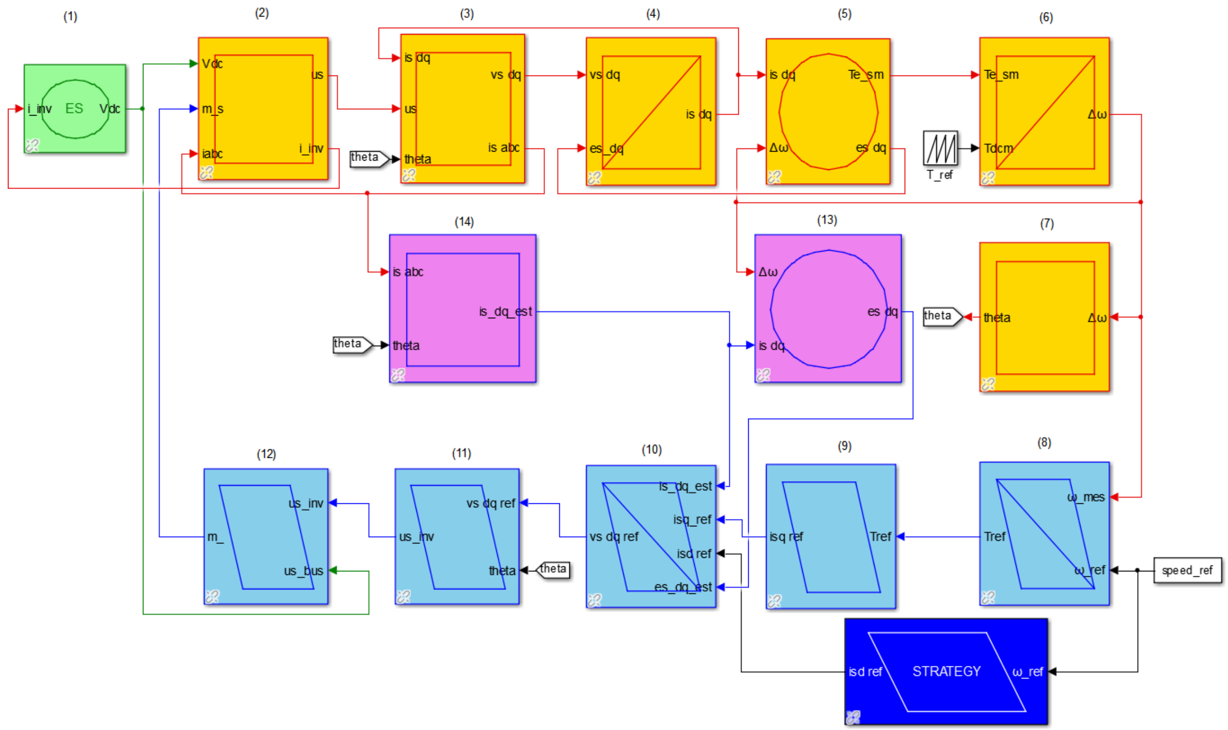


(a) d-axis



(b) q-axis

First simulation model of the PMSM (Ld=Lq=constant)



- (1) Electrical source; (2) Inverter; (3) Transformations; (4) Winding equations of the PMSM; (5-6) Electromechanical conversion
- (12) Estimation of the back emf; (13) Park Transformation.
- (8-10) FOC of the PMSM ; (16) Inverse Park Transformation; (17) Pulse Width Modulation

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Analytical model of the PMSM

$$di_{sd} = \frac{u_{sd} - R_s i_{sd} + \omega \cdot \Psi_{qs}}{L_d}$$

$$di_{sq} = \frac{u_{sq} - R_s i_{sq} + \omega \cdot \Psi_{ds}}{L_q}$$

$$\Psi_{ds} = \Psi_{md} + L_d \cdot I_{ds} + L_{dq} \cdot I_{qs}$$

$$\Psi_{qs} = \Psi_{mqd} + L_q \cdot I_{qs} + L_{qd} \cdot I_{ds}$$

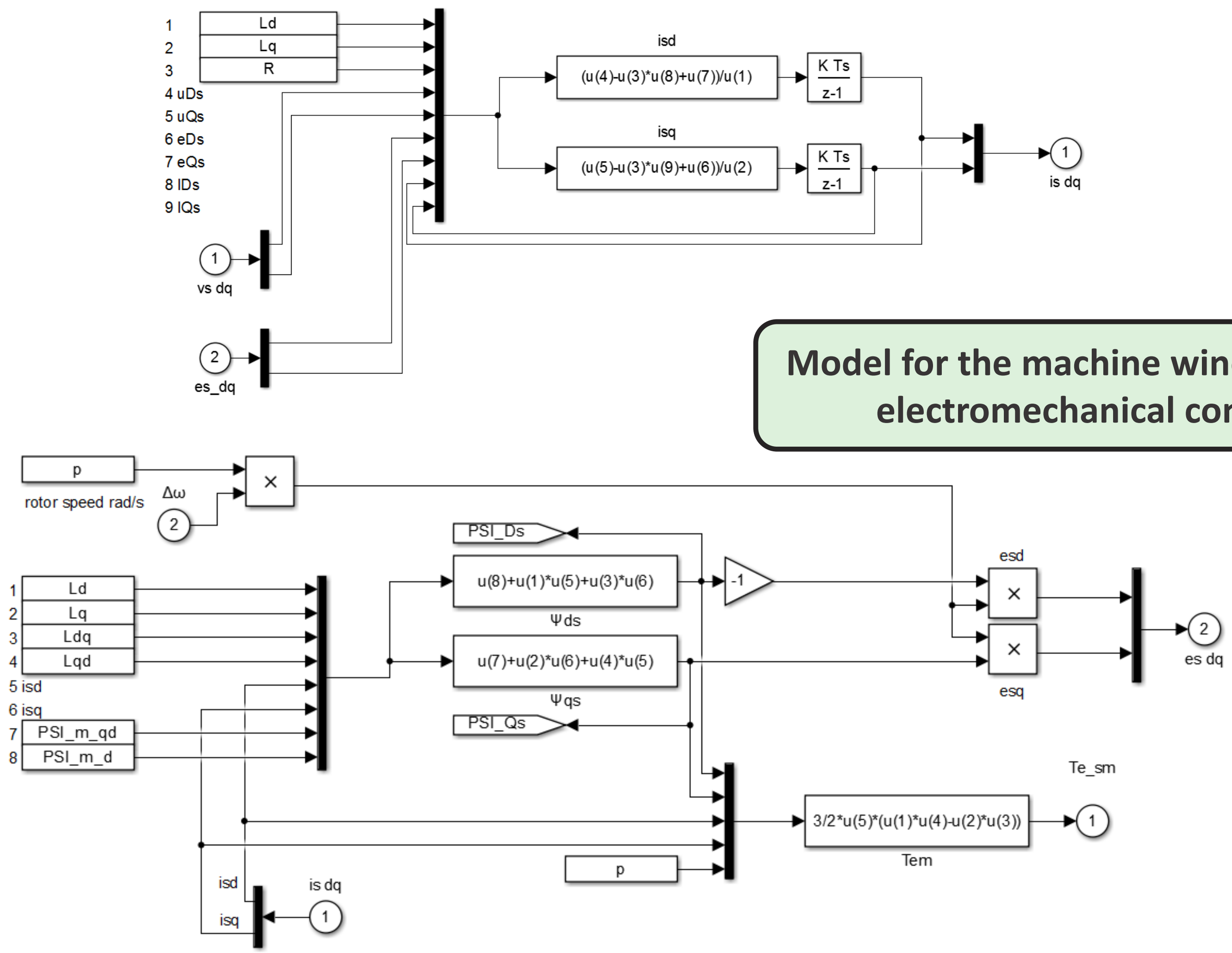
$$e_{sd} = -\omega \cdot \Psi_{ds}$$

$$e_{sq} = \omega \cdot \Psi_{qs}$$

$$T_{e\_sm} = \frac{3}{2} \cdot p \cdot (\Psi_{ds} \cdot i_{qs} - \Psi_{qs} \cdot i_{ds})$$

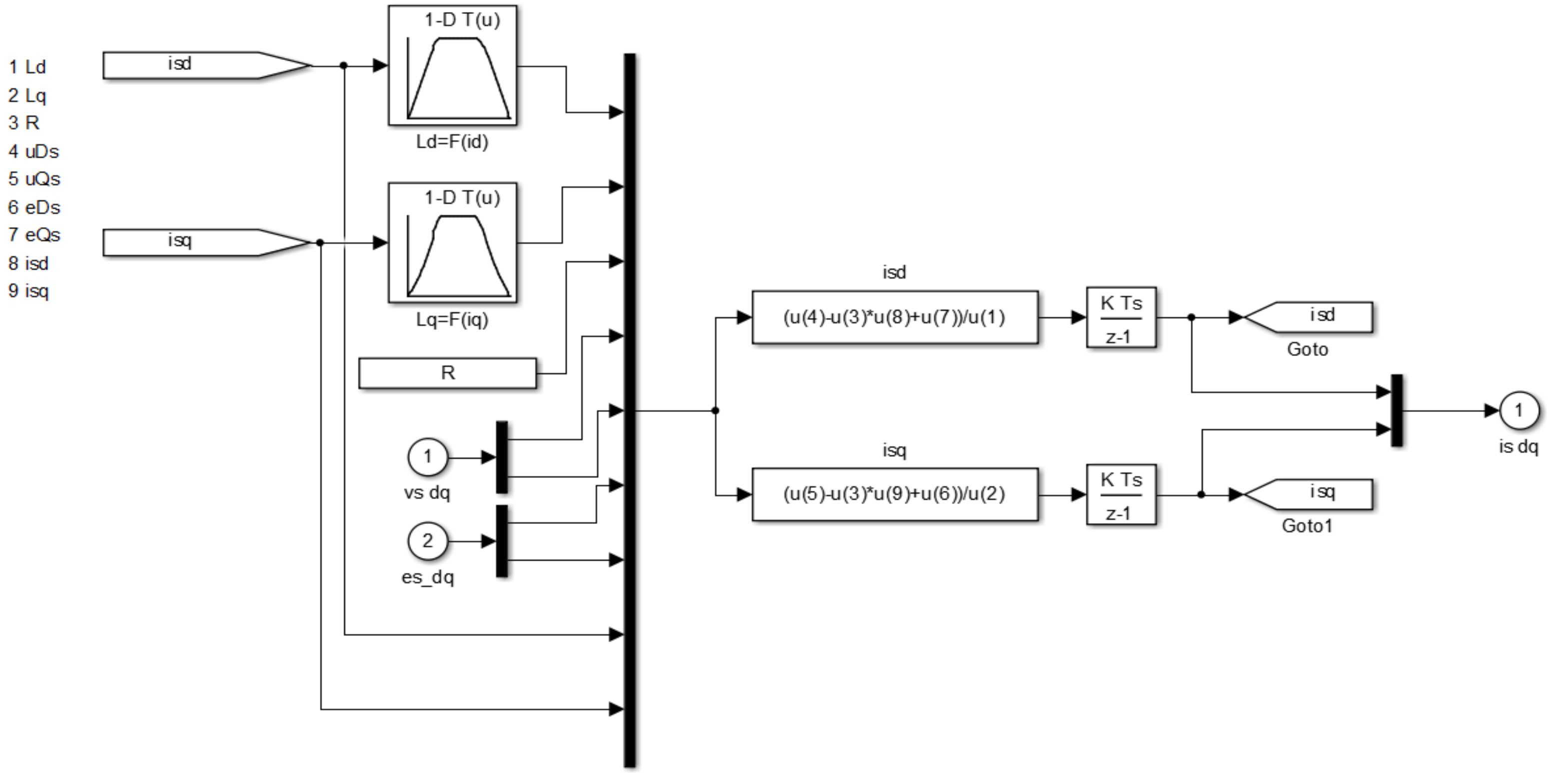
- **Ld=Lq=0.002817 [H];** Rs=0.2 [Ω]; Ψmd=0.1025 [Wb]; J=0.0048 [kg·m^2], B=0.006 [N·m·s], Ψmd=0,1025 [Wb], p=6, V_{dc} =120 [V] ;

Analytical model of the PMSM (Ld=Lq=constant)



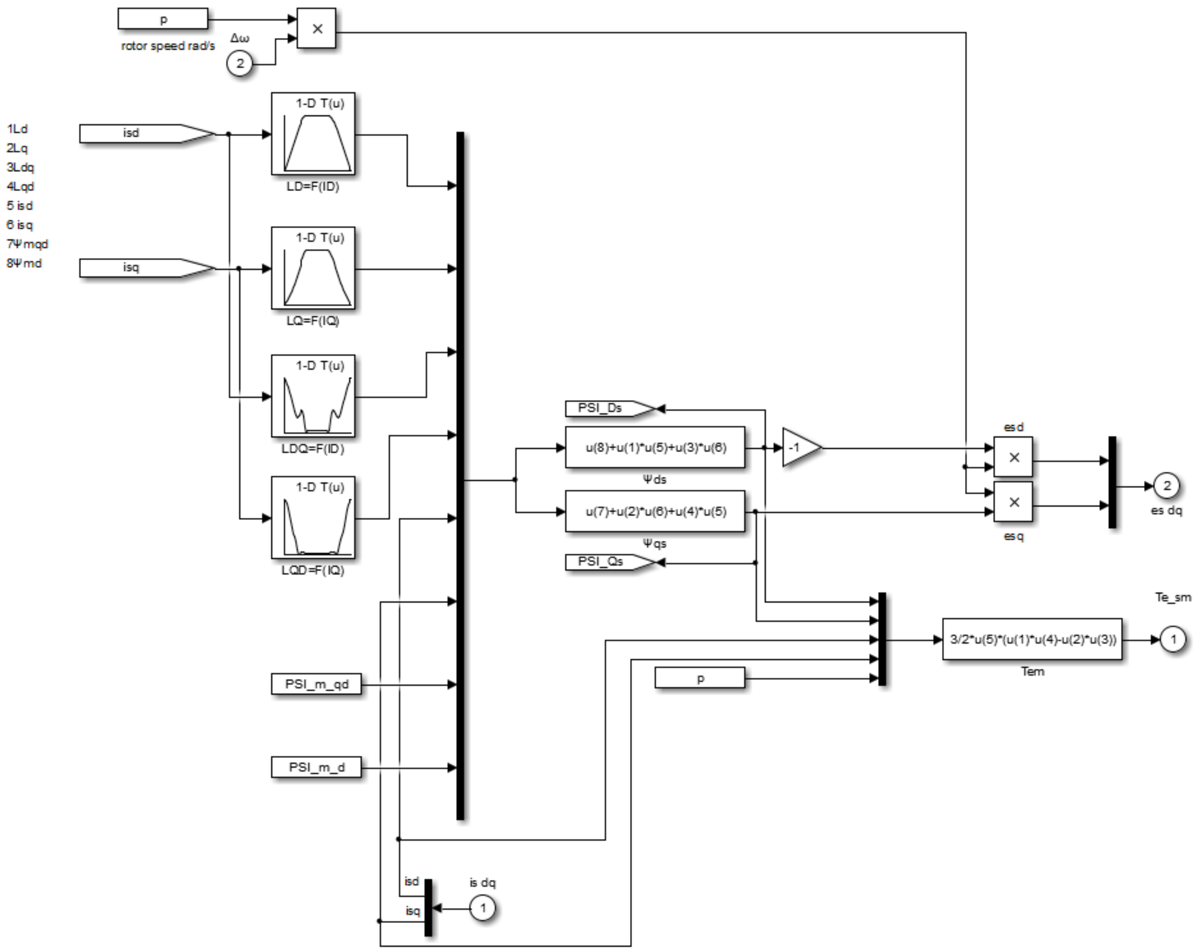
Model for the machine windings and the electromechanical conversion

Second simulation model (Frozen Permeability method)



- Rs=0.2 [Ω]; **Ψmd=0.1025 [Wb]; Ψmqd=0.00002673 [Wb];** J=0.0048 [kg·m^2], B=0.006 [N·m·s], Ψpm=0,015 [Wb], p=6, V_{dc} =120 [V].
- **Ld=f(isd); Lq=f(isq).**

Second simulation model (Frozen Permeability method)

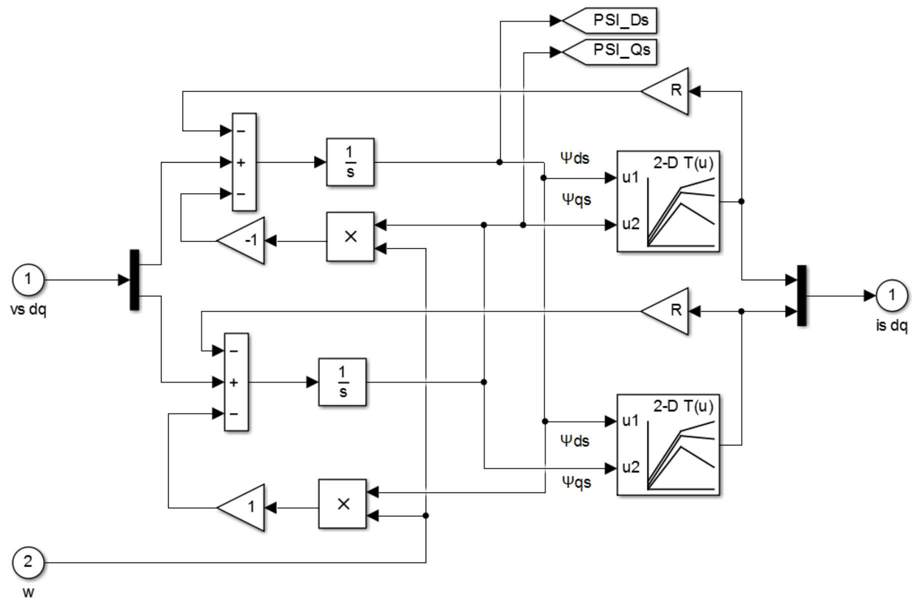


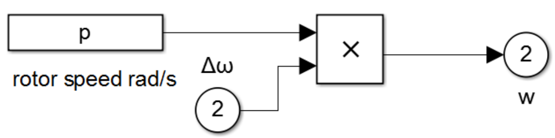
Third simulation model (Flux-linkage model)

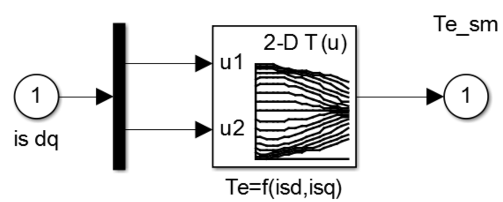
$$i_{sd} = h(\Psi_{sd}, \Psi_{sq})$$

$$i_{sq} = h(\Psi_{sd}, \Psi_{sq})$$

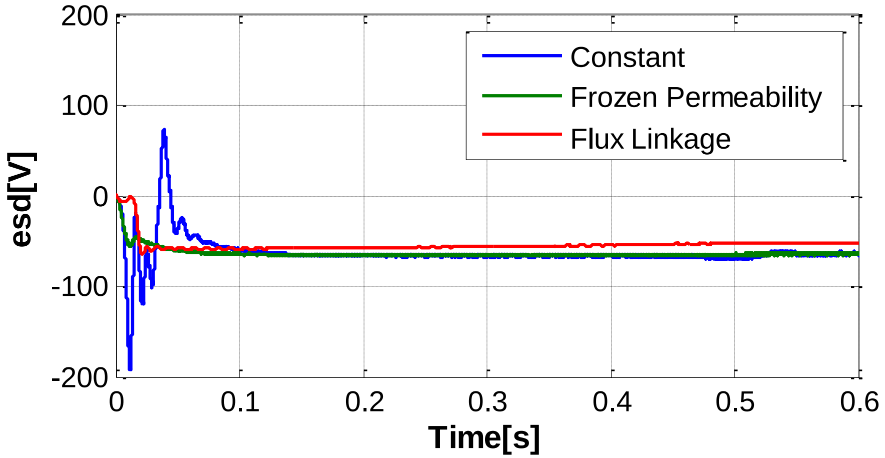
$$T_{em} = h(i_{sd}, i_{sq})$$

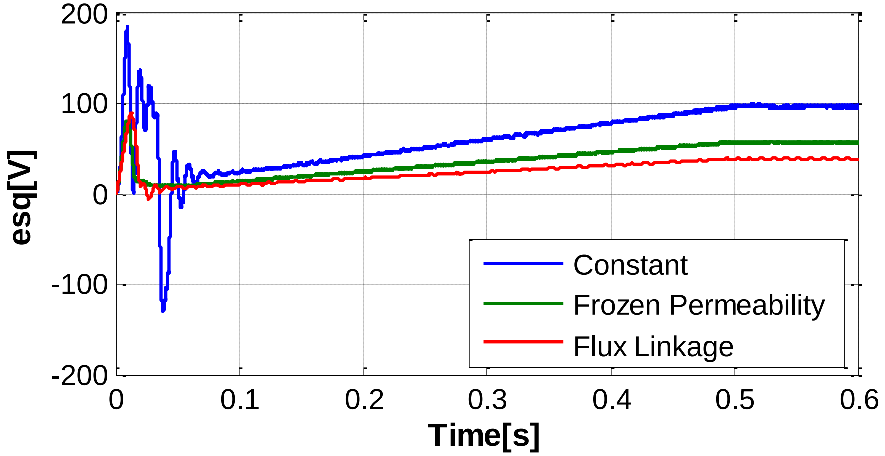




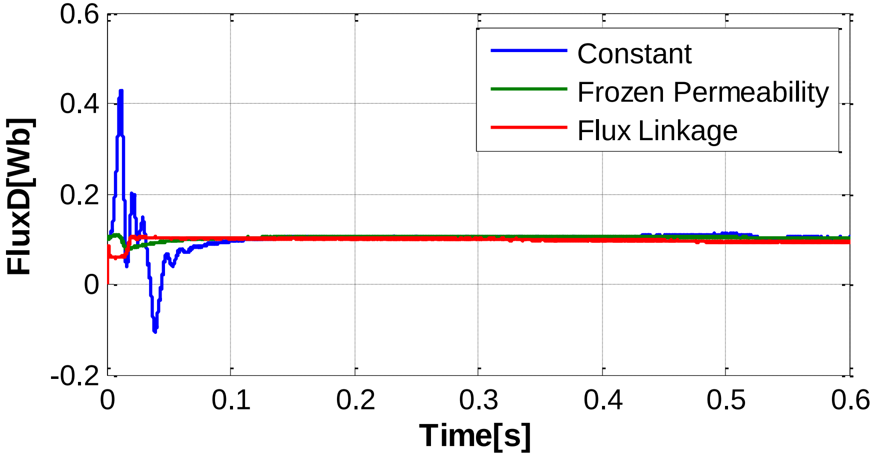


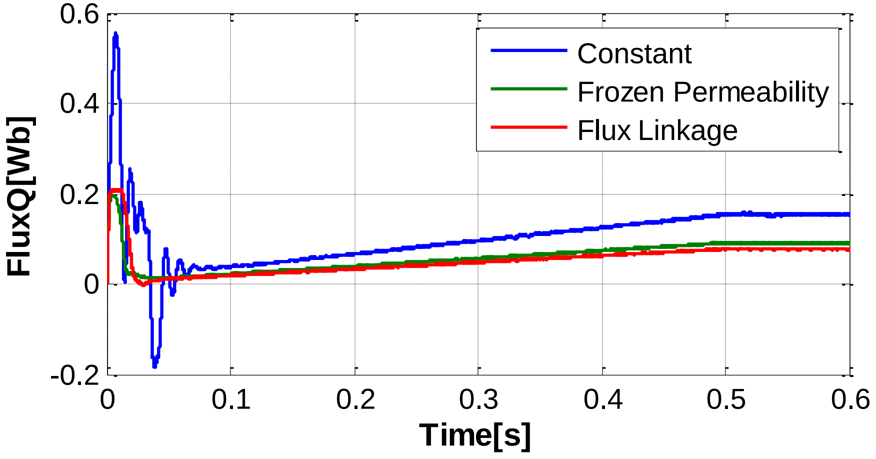
Simulation results



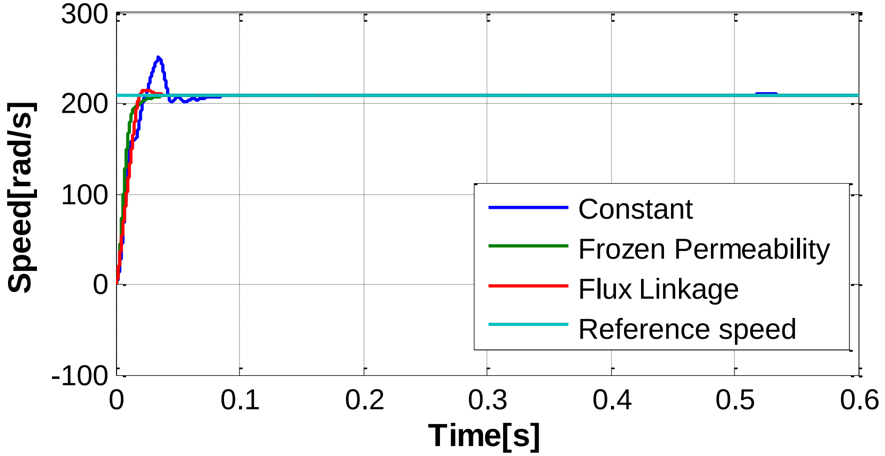


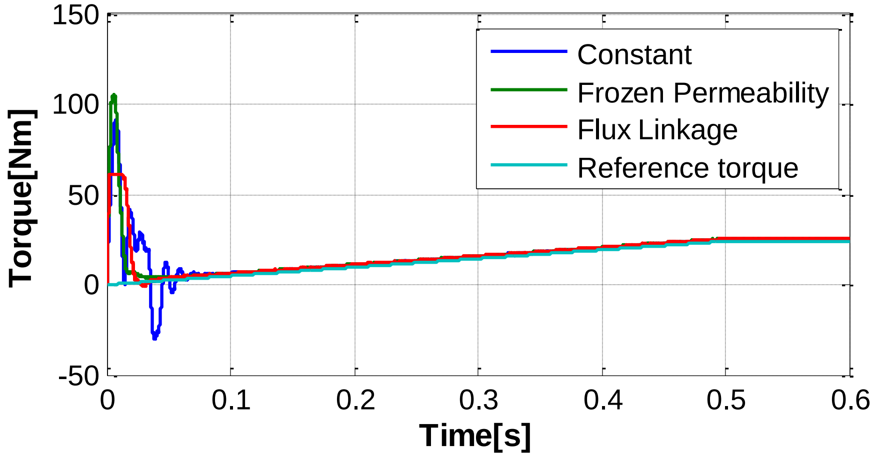
Simulation results





Simulation results





Conclusions

- A **FEM analysis** using Flux Skew was realized for a **PMSM** in order to obtain the required parameters for the model simulation.
- Three levels models using EMR organization were proposed, from the most accurate to the simple one for the study of the **LEV propulsion system**.
- The results showed that all the system models was able to follow closely the requirements in what concerned the load torque and the reference speed.
- From the flux response, it is observed that in the first level model, having all the **machine parameters constant** and fixed values, the **saturation was not considered**, therefore the flux presented higher values.
- An accurate analytical model as accomplished by **Flux-linkage model** is essential for operational characteristics analysis and high precision control.

End of presentation

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Thank you for your attention!

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