Semi-Analytical Nonlinear Model of Slotless Electrical Machines

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Introduction

The following incremental improvement of the current sheet model of slotless wound rotor electrical machines allows simultaneously to model both the rotation of the rotor field winding and the time-dependent stator armature windings currents. Additionally, an iterative scheme is introduced to take into account the magnetization of rotor and stator iron cores. The results are compared with those of a 2-D nonlinear finite element model.

Semi-analytical model: overview

The machine is divided into annular concentric air/iron subdomains. The windings are modeled by current sheets between two subdomains. Using the distribution of current via its Fourier series $K$, the magnetostatic vector potential $A$ can be inferred.

- Concentric current sheets (input):
- Nonlinear $B$-$H$ curve: $B = \mu(B) H$
- Magnetic vector potential (from Maxwell-Ampère: find $a$, $b$, $c$, $d$ via separation of variables):

Numerical model (2D FEM)

2D Finite Element Model built and solved in COMSOL Multiphysics using the AC/DC module with:
- A-formulation of Maxwell’s equations
- Magnetostatic problem:
- In the ferromagnetic material: $B = \mu(B) H$
- Solid conductor

Comparative results (10 MW, load example)

Load condition: 10 rpm, $I_r$ (rotor) = 502.74 kA, $I_q$ (stator) = -1.963 kA, $I_d$ (stator) = -1.530 kA

The results of the nonlinear analytical and FEM models are in close agreements.

Conclusion

The proposed model includes:
- simultaneously the rotor rotation and the 3-phase armature windings (new feature)
- an improved iterative scheme which resolves the iron nonlinear BH curve

This generic approach can be adapted to any slotless wound rotor machines including multiphase machines with multi-layer distributed or concentrated windings for rapid pre-design and optimization (6 times faster than FEM computation).

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