Identification of a 7-phase claw-pole starter-alternator for micro-hybrid automotive application

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INTRODUCTION
This study focuses on a specific 7-phase drive: a belt driven starter-alternator for powerful cars with Hybrid Electrical Vehicles (HEV) functions. This structure needs specific approaches to plan its electrical and mechanical behaviors and to identify the parameters needed for control purpose:

• A Finite Element Method (FEM) modeling of the claw-pole structure is used for the predetermination of the machine electromotive forces and of its torque. A comparison between the numerical calculation and experimental results is made;

• Resistive and inductive parameters of the drive are determined by an original experimental approach that takes into account each component of the drive: the battery, the VSI, and the machine.

7-PHASE STARTER-ALTERNATOR DESCRIPTION

Experimental inductive parameter measurements

1. Measurements in the stator frame:
For several excitation currents and several positions of the rotor:

A: Self inductances are classically measured imposing successively a step wave voltage to the seven phases

B: Mutual inductances are measured while Phase 1 current is controlled by the VSI at a sinusoidal reference (120Hz, 17A RMS current around 18A constant)

Induced voltages on the other phases are measured

Induced voltages are integrated: flux and inductances are then deduced

Average results (in µH, versus θ) are given for two excitation currents values (i_F = 0A and i_F = 5A):

\[ <\text{M}_{17}> \text{A}_{17} > <\text{M}_{16}> \text{A}_{16} > <\text{M}_{15}> \text{A}_{15} > <\text{M}_{14}> \text{A}_{14} > <\text{M}_{13}> \text{A}_{13} \]

\[ i_F = 0A \quad 45 \quad -7 \quad -3 \quad -7 \quad -3 \quad -7 \quad -3 \]

\[ i_F = 5A \quad 39 \quad -6.5 \quad -3 \quad -6.5 \quad -3 \]

2. Measurements in the generalized Concordia frame:

A: projection in the Concordia frame: measurement needed for control

\[ \begin{bmatrix} L_0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & L_{1d} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & L_{1q} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & L_{2d} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & L_{2q} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & L_{3d} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & L_{3q} \end{bmatrix} = [c]^{-1}[L_{ss}] \]

B: d-, q-currents control scheme:

C: cyclic inductances function of \( i_F \)

CONCLUSION
A mixed approach has been presented for the identification of a seven-phase starter-generator. The FEM modeling allows planning the main output values of the machine, as electromotive force and torque. This result is particularly interesting for the design step. A comparison with experimental results shows a good accuracy of the numerical model for the determination of these values. For parameters which are more characteristic of the whole drive such as time constants, it has been shown that the determination of inductances in the stator frame lead to uncertainties in the case of a very low voltage saturated machine.

An experimental approach using a vector control has been consequently proposed in order to obtain directly the required time constants for the design of the drive.