# Identification of sensitive R-L parameters of a multiphase drive by a vector control

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***Abstract*—This paper focuses on an experimental method to determine the electric parameters of a seven-phase low-voltage multiphase drive. The drive is a belt driven starter-alternator for powerful cars with Hybrid Electrical Vehicles (HEV) functions. The resistive and inductive parameters are necessary to obtain the six characteristic time constants of the control modeling. Classical direct measurements lead to imprecise results because of very low values for the windings electric resistance (a few mΩ) and inductance (a few µH). Effects of the imprecision on the measurements are all the more important that time constants are obtained by a ratio of cyclic inductances by resistance, with cyclic inductances being a linear combination of seven measured inductances. The methodology for identification detailed in this paper is based on a stator current vector control, in a multi-reference frame. This methodology allows us to get directly these time constants. Numerous measurements allow the robustness of the method to be evaluated.**

## INTRODUCTION

Reducing petrol consumption and CO2 emission is now assumed to be one of the great new societal and economical issues. In this context, automotive suppliers as Valeo, offer new solutions to make cars less costly in terms of energy and less polluting. One of these solutions consists in adding electrical machines running with the classical Internal Combustion Engine (ICE) to make it work more efficiently; it is the principle of Hybrid Electric Vehicles (HEV) [1]-[2]-[3]. From a small ten years, several hybrid cars structures have appeared on the market. This paper deals with the cheaper one: the starter-alternator system [4]-[5]-[6]. This system is composed of a classical car generator, i.e. a claw pole synchronous machine, but with a Voltage Source Inverter (VSI) instead of the diode bridge; the claw-pole machine can then be used as motor. Starter-alternators already equip small cars, with a small ICE, as the Citroën C3, and are used to a unique function: the Stop-start function [5]-[6]. The major interest of this simple system concerns the limited extra cost for the final car. In order to extend the range of models equipped with a start-alternator or to extend the system capabilities, there is a need to increase its power. Previous works [7] show the interest of multiphase (with more than 3 phases) VSIs to improve the use of the DC-bus voltage. Moreover, the use of multiphase machines also enables the increase of torque density by using new windings [8]. It is thus possible to extend the power range, keeping the standard low cost low voltage level of 14V.

With the final objective to explore the capabilities of this kind of system, this paper focuses on the first difficulty: the determination of the control modeling parameters such as resistance, inductances and time constants. In a seven-phase machine with usual voltages, the determination of these parameters is already sensitive [9]. With the studied machine, this sensitivity is amplified because of the low values of resistance (a few mΩ) and inductances (a few µH) induced by the low voltage value of the DC-bus. The original methodology of identification presented in this paper lies on a vector control of the multiphase machine currents, in a multi-reference dq frame based on a generalized Concordia transformation [10]-[11]. In the first part of this paper, the 7-phase drive modeling in the multi-reference frames is introduced. In the second part, the methodology of identification is presented. In the last part, experimental results are discussed.

## I. MODELING THE 7-PHASE DRIVE IN A CONTROL FRAME

### A. Presentation of the 7-phase drive

*The drive:* it is composed of a 7-phase wye-coupled claw-pole synchronous machine with separate excitation. The machine is supplied with a Voltage Source Inverter (VSI). MOSFETS transistors (MOS) are used for the VSI switches. In normal operating modes (with high currents level), voltage drops of MOS are supposed to be a linear function of the current. The DC-bus voltage $V_{DC}$ is imposed by a 12V battery.

*The experimental set-up*: an experimental set-up has been developed in order to test control algorithms. It is described in Fig. 2. In this, the starter-alternator is directly mechanically connected to a brushless machine, used to simulate the ICE behavior. An electronic voltage source and an electronic load are used to replace the 12V battery. The whole system is managed using a dSPACE™ DS1006 control board.

### B. Classical modeling of the 7-phase synchronous machine in the stator frame

In the stator frame, the 7-phase synchronous machine is commonly modeled with the set of equations (1) and (2). In Fig.2, a classical scheme is used to introduce the common notations: $v_k$, as the phase "$k$" voltage, and $i_k$ this phase current. The position of the rotor is $\theta$ and the

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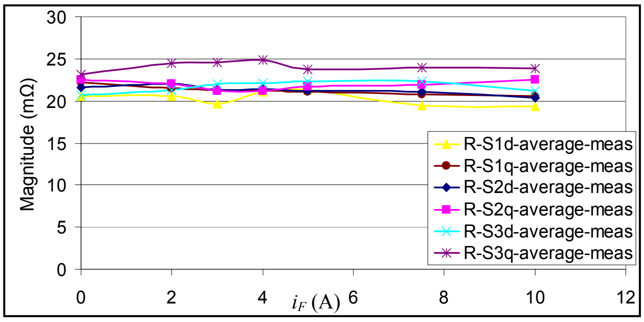


Figure 7. Evolution of the measured resistance in S1, S2 and S3, as a function of the excitation current

### C. *Measurement of the time constants*

Fig. 8 gives the evolution of the time constants measured in the three subspaces S1, S2, S3 (on d- and q-axes), as a function of $i_F$. These time constants (and so, the inductances) decrease while the excitation current increases. This is due to the evolution of the magnetic materials properties, which proves their non-linear characteristic. This magnetic state depends on the currents (phase currents and excitation current). Here, the characteristic is just given as a function of the excitation current at a specific operating point. The evolution of the time constant with the stator currents evolution is not given. Nevertheless, the same approach has been lead at other operating points, and at different rotation speeds. The same measurements can be established as described in this paper without any major difficulty. The presented results, at a null rotation speed, correspond to the easiest measurement, because of a good decoupling between the six axes.

Finally, another point must be observed with the results shown at this operating point, particularly in S1: the inductance on the d-axis is much different with the inductance on the q-axis. This is due to variable reluctance effects. For this machine, at this operating point, the reluctant effects affect mainly the S1 subspace. For the other S2 and S3 subspaces, the d- and q- inductive parameters are almost the same.

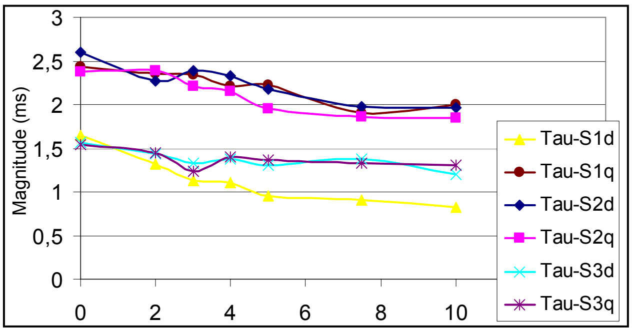


Figure 8. Evolution of the time constants measured in S1, S2 and S3, as a function of the excitation current

## CONCLUSION

In order to establish the control of a 7-phase starter alternator drive and to build virtual models, a good knowledge of its electrical parameters and time constants is needed. Due to the low voltage and the high number of phases of the studied drive, indirect determination of the time constants, using classical inductive measurements in the stator frame, implies uncertainties.

In this paper, an experimental methodology for identifying directly in the Concordia frame, in which are determined the cyclic inductances, has been presented. Numerous measurements have been carried out to prove its robustness. Moreover, this methodology allows us to take into account all parasitic resistances (of the MOSFET transistors and at electrical connections), which are not negligible in this low voltage automotive application: it is really the identification of the drive and not of the electrical machine that has been achieved.

The results have been given for a specific operating point, at null rotation speed. Nevertheless, the developed methodology has been also used at other operating points. Concerning more specifically the studied drive, the variations of the time constants with the excitation currents have been given, with a noticeable difference between the three characteristic subspaces S1, S2 and S3: only S1 subspace presents two different $L_d$ and $L_q$ cyclic inductances.

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