Annexe Scientifique et Technique

Proposition d’un sujet de thèse dans le cadre d’une collaboration   
Schneider Toshiba Inverter Europe SAS – Centre Automatique et Systèmes

# Context of the PhD thesis

Electric motors are the most important source of mechanical energy in the industry. They should be controlled, so that they rotate safely at the desired speed. For many years, it has been known that they can be properly controlled at medium to high speed using only the current sensors embedded in the drive [1, 2]. Such control laws have been implemented into industrial products.

However, controlling electric motors at low frequency or standstill remains a challenging task, because the observability of their state degenerates in this frequency range, when only motor current sensors are used. Operation in this frequency range is required for some industrial applications of electric motors such as lifts and cranes. To avoid using expensive and unreliable mechanical encoders, high frequency signal injection was proposed to recover observability at low speed for the Induction Motors (IM) [3, 4, 5], the Permanent Magnet Synchronous Motors (PMSM) [6, 7, 8] and the Synchronous Reluctance Motors (SynRM) [9, 10, 11]. It relies on the impact of a high frequency signal superimposed onto the control to obtain additional information on the system state. To determine the information gained by signal injection, a more accurate model of the motor, including magnetic saturation, is required. That is why signal injection is yet less used in industrial products.

# State of the art and experience of partners

STIE and CAS have been collaborating for almost twenty years on various aspects of motor modeling and control. In particular, they have recently developed together:

1. An energy-based approach for motor modeling, able to take into account magnetic (cross-) saturation and parasitic geometric saliencies; the produced models are well-suited for control and identification purposes [12, 13, 14, 15]
2. An original and rigorous analysis based on second-order averaging of the benefits of signal injection [7, 8, 15, 16, 17]. The method can accommodate any form of injected signals and blends well with a general model of magnetic saturation.

However, the situation is to date completely satisfying only for the PMSM. Indeed, the saturated model correctly describes the effect of signal injection on the measurements, while being valid for the fundamental wave [13]. Hence, signal injection can be used effectively to control the PMSM at low velocity or standstill [7, 8, 15]. On the contrary, obtaining a model allowing to convey both the fundamental wave and the HF injection effects on the SynRM and the IM remains a challenging task. For the SynRM, a model has been proposed which reproduces the effects of the fundamental wave and the HF injection, but it uses two different parameter sets [14], whereas a model able to reproduce the effects of HF injection on the IM is yet to be found. The literature proposes some models for the IM [15, 16, 17, 18] or the SynRM [19], but none of these models correctly reproduces the effects of HF injection on these motors.

Another issue with signal injection is that the ability to control the motor at low velocity comes at the price of a disturbed motor behavior. To avoid superimposing an additional signal on the control, which causes disturbances, a promising alternative is to use instead the perturbation of the current due to the realization of the voltage by Pulse Width Modulation (PWM) [22, 23]; we believe it is possible to extend our higher-order averaging analysis to this case. However, another problem arises in that context: a naive implementation of the idea requires the measurement of the current during the edges of PWM pulses, hence a fast and accurate Analog-to-Digital Converters (ADC); unfortunately, such an ADC is to date too expensive to be included even in a high-end commercial product. To overcome this problem, we have started to investigate an alternative approach relying on a ΔΣ-modulated-ADC and FPGA processing, which is compatible with the hardware of the recent STIE speed drives.

# Expected content of the thesis

This PhD thesis aims at:

1. Improving the models of electric motors, especially IMs and SynRMs, to account for HF injection effects. This will first require determining the predominant effect which causes the discrepancy between fundamental frequency and HF injection, which may involve designing Finite Element or Reluctance Network motor models
2. Controlling the motor using the perturbation due to the realization of the control voltages by PWM in the ΔΣ-modulated measurements, which involves designing advanced digital filters to be used in feedback loops
3. Investigating various applications of higher-order averaging for model identification, observer design (e.g. along the lines of [25]) and control

All the theoretical developments should be validated experimentally on the test benches available at STIE.

# Bibliography

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# Proposed planning

* Context (6 months)
  + Unsaturated and saturated motor models
  + Review of signal injection techniques
  + Discovery of test bench and experimental tools (including habilitation)
* Observation of motor state using ΔΣ-modulated measurement perturbation due to PWM (6 months)
  + Model of the algorithm
  + Implementation and test on a rapid prototyping test bench
* Low-speed sensorless control of electric motors using perturbation due to PWM (6 months)
  + Model of the algorithm
  + Implementation and test on a rapid prototyping test bench
* Electric motor modeling (6 months)
  + Review of existing motor models and motor modelling techniques
  + Identification of the required effects so that the motor model conveys the effects of HF injection
* Identification of the motor model (6 months)
  + Identification of the proposed model on a real motor (IM or SynRM)
  + Design of an automated procedure to obtain the parameters of the proposed model
* Redaction (6 months)