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Methodology for sizing by optimization of an electric drive considering a multiphysics approach

Robin THOMAS*, Laurent GERBAUD*, Hervé CHAZAL* and Lauric GARBUIO*

** Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab, 38000 Grenoble, France*

E-mail: robin.thomas@g2elab.grenoble-inp.fr, laurent.gerbaud@g2elab.grenoble-inp.fr

Abstract. The paper describes a modelling and solving methodology of a {static converter – electric motor – control} system for its sizing by optimisation, considering the dynamic thermal heating of the machine. A co-simulation is set up for the steady state electrical system aspects and the transient thermal aspects. The simulators are coupled through a master-slave relationship with adapted time step management. A sizing by optimisation example of this system is carried out.

Keywords: electric drive, induction motor, methodology, multiphysics modelling, sizing by optimisation

INTRODUCTION

Electric drives are sophisticated systems made of components of different nature: power electronics static converter, electrical machine and control. The sizing by optimisation of these multiphysics and multidynamics systems raises complex modelling and solving issues. Thus, the paper presents a methodology for the modelling and solving of a {static converter – squirrel cage induction motor – control} system for its sizing by optimisation, considering the dynamic heating of the machine.

STUDIED PROBLEM ANALYSIS

The presented problem consists in finely sizing the components of the studied electric drive, in particular the electrical machine (from the electromagnetic viewpoint) considering its dynamic thermal heating. The system is sized at electrical steady state operating points exceeding the continuous operating limits of the machine, i.e. in the classical thermally limited area of operation. Thus, temperature thresholds are imposed and short operating times with high thermal constraints are studied to characterize thermal transients / response times.

In order to optimise the sizing of these systems, the choice of the optimisation algorithm (stochastic, deterministic) impacts directly the modelling method and the simulation tools used (computation time, derivatives...). Considering these constraints, the dynamic simulation of a multiphysics problem can be carried out:

- using one global solver but with a total simulation time imposed by the slowest dynamics (i.e. the thermal dynamics), possibly leading to an unacceptable computation time cost for optimisation problems due to the large gap between the physical dynamics (milliseconds compared to seconds). A common solution is to transform the dynamic thermal constraint into a static constraint [1]. However, this is not relevant for our case: the study of thermal dynamics and the crossing of temperature thresholds (critical limits) ;
- using a co-simulation with several solvers dedicated to the different physical dynamics.

This last solution is chosen and the use of commercial solvers is possible. However, they often have the disadvantage of being locked, leading to:

- limited driving capacity. Yet, in order to limit the computation time (regardless of the chosen optimisation method), it is essential to be able to detect when temperature thresholds are crossed (or steady state is reached) and to stop the simulation at that time, avoiding unnecessary computations ;
- inability to access or compute the exact derivatives, requiring the use of less accurate finite differences.

Thus, an open solver is developed for that purpose [2] and it enables to:

- control the co-simulation process and implement temperature thresholds and steady-state detection ;

- implement the exact derivatives computation of the sizing parameters of the models, where possible, to enable the use of deterministic optimisation algorithms. Otherwise, finite differences are used.

This solver is used in two simulators, to deal with the electrical system performances on one part and the thermal heating of the machine on another part. A specific methodology is set up to co-simulate these simulators.

METHODOLOGY FOR MODELLING THE MULTIPHYSICS SYSTEM

Sub-models are developed for the electromagnetic sizing, for the dynamic thermal behaviour of the machine and for the dynamic behaviour of the electrical system. The two dynamic simulators (machine and electrical system; thermal heating of the machine) use Runge-Kutta method (order 4 or more) with an adaptive time step [2] to solve dynamically the state systems of the global electrical and the thermal circuits. The dynamic electrical system simulator is encapsulated in the dynamic thermal simulator, which acts as the master for the time step management in order to synchronize the two solvers (cf. Figure 1).

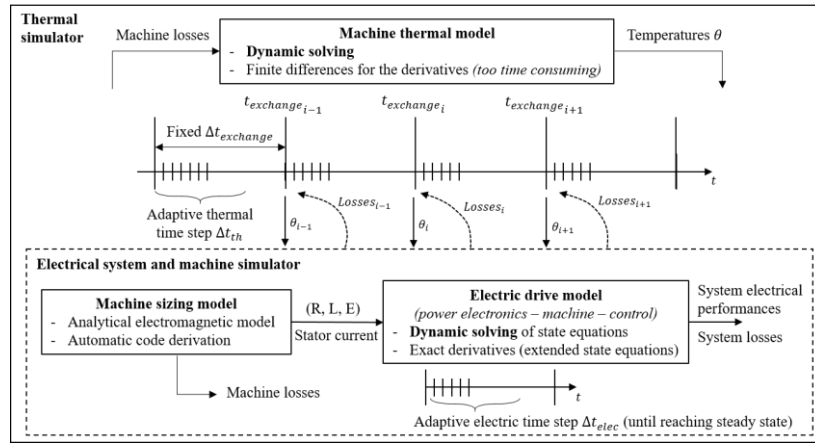


Figure 1: architecture of the system sizing model and co-simulation principle

For the co-simulation methodology, the thermal simulator calls on the electrical system simulator at fixed exchange time steps to re-evaluate the machine losses considering the temperature evolution. Then, the electrical system is solved on a few periods to reach the electrical steady state. The thermal simulator stops when a temperature threshold is crossed or steady state is reached. The full paper will develop these aspects.

SIZING BY OPTIMISATION

Two optimisation of the sizing of the system are carried out. The first considers only the electrical system and the machine (without thermal aspects), to size the power electronics. The optimisation is performed in several minutes, using SQP algorithm. The second optimisation study considers the full system (electrical system and thermal heating of the machine), to size the power electronics and the machine. The optimisation is carried out using a Genetic Algorithm, taking several days. Indeed finite differences are currently used to compute the thermal model derivatives and are too time consuming to use SQP algorithm. The full paper will develop these aspects.

CONCLUSIONS

The paper presents a multiphysics modelling and solving methodology of an electric drive considering the machine dynamic heating. The implementation of this methodology and its application to a sizing by optimisation case will be presented in the final paper.

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