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ABSTRACT

Methods and Algorithms for Power Devices Losses Behavioral Modeling

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Power electronics is since decades in the focus of very important technology innovations, as the characteristics and the performances of power supplies can severely condition and limit the performances of the system to be fed. In almost all the applications there is the demand to increase as much as possible the ratio between the maximum power the power supplies can deliver and their volume, defined as the power-density while, at the same time, the cost must be as reduced as possible. For this reason, electronic system designers have the task of finding, in a reasonable time, ever better performing solutions, choosing the best semiconductor devices and magnetic components.

The attention of this thesis has been on the modeling of power losses of magnetic components and semiconductor devices, considering that they have the biggest impact on the system efficiency. The model classically adopted are usually calculated in different conditions from the operative conditions, require long time simulations, need the knowledge input variables that cannot be easily measured and have coefficients difficult to be identified. For this reason, the aim of this thesis has been to investigate a general approach to identify power losses models of devices, obtained from experimental data. In particular, sufficiently accurate and at the same time simple and intelligible loss model are desired.

The approach adopted is based on Genetic Programming (GP), that is an evolutionary method able to return output models, in order to minimize a given fitness function that is a metric of the quality of the solution. The goal of the algorithm has been to obtain models accurate, but at the same time simple and intelligible for the user. These two desired conditions are often conflicting, being complicated models usually accurate and simple models usually inaccurate. For this reason, a Multi Objective (MO) approach, returning a Pareto Front composed non-dominated solutions, has been adopted. Moreover, the GP has been modified to return parametric functions, having the same structure, but different coefficients for all the devices to characterize. In this way, it is supposed to have a more general model, that is sufficiently good for all the devices.

To reduce the variability typical of evolutionary approaches, and to obtain more reliable solutions, more runs of the GP have been done and only the solution that repeat themselves on more than one run have been considered. Furthermore, some metric have been introduced to select the best model from all the models present on the Pareto Front.

Several case studies have been considered for both semiconductor and magnetic components:

The method has been applied to the identification of power losses of IGBTs for Induction Cooking applications. In this kind of systems the prediction of power losses is really important to maximize efficiency and avoid damages to the devices. The uncertainty of the load, depending on the position and the kind of pot, makes the conditions difficult to be predicted and very variable. Input variables representing the current waveforms and the system operative conditions have been adopted to take in account this load variability. Two Device Under Test (DUTs) with different snubber capacitor (affecting the switching losses) have been considered and the results have been validated with all different conditions and load, obtaining a good approximation in the training set range.

Then, the GP method has been tested on a simulated training set on SMPS, to test the method also in this application and to verify if the obtained model can generalize. Different devices having different dynamic and static characteristics have been used as DUT. A with Gaussian noise has been added to emulate measurement noise. The results present an error near to the Gaussian noise standard deviation, as expected, but with the same structure for all the device. The obtained model has been fit to a new device training set, having intermediate characteristics with the other ones, and the error is similar to the other devices, indicating a good generalization capability of the model.

Finally, the method has been applied to partially saturated inductor, in order to identify a model able to consider the saturation effects, and with input variables measurable. The algorithm has been tested on three inductors having different Inductance vs current behaviors and different parameters. The obtained models present a term valid in not saturated conditions multiplied with a power term that takes in account the saturation effects when the current gets higher.

Generally, the obtained models are simple, accurately fit the measured experimental data, and have input variables that can be easily measured and estimated, differently to other models that require the knowledge of physical parameters to be used, often not included in the data-sheets of the devices. Moreover, the solutions are repeatable and the GP tree's structure adopted guarantees a physical meaning of the models.

This approach can have two different applications: the obtained laws can be easily loaded on embedded systems. In fact, the models are simple, and not present too many coefficient, requiring a small amount of calculation and a low memory consumption. In this way, the power losses can be estimated and predicted in real time, once the system variables are changed, allowing the adoption of appropriate control techniques to avoid damages to the devices or to maximize the system efficiency. On the other hand, this approach could be adopted by power devices manufacturer, to provide loss model more accurate and more easily adoptable by the designers. Systems allowing to easily characterize power inductors are already available, while it would be interesting for semiconductor manufacturer make automatic measurement to characterize their devices.