Multi-level simulation suited for lifetime estimation of critical power electronic devices

Michal Frivaldsky, Pavol Spaník, Peter Drsgona, Michal Pridala
University of Zilina, Faculty of electrical engineering, Department of mechatronics and electronics
Univerzitna 1, 010 26 Zilina, Slovakia, e-mail: michal.frivaldsky@fel.uniza.sk

Abstract – The paper deals with proposal of multi-level simulation, suited for the evaluation of lifetime of critical electronic devices (electrolytic capacitors). The aim of this issue is to have imagination about the expected operation of complex and expensive power electronic systems, when the failure of the most critical component occurs. For that reason, various operational conditions and various physical influences must be considered e.g. mechanical, humidity, electrical, heat stresses, where nonlinearities are naturally introduced. Verification of the proposal is given, whereby lifetime estimation of electrolytic capacitor operated in DC-DC converter during various operational conditions is shown.

I. GENERAL INFORMATION

The paper describes multi-level simulation design, as well as possible practical application areas. Proposal for target application (DC-DC converters) is initially considered. At first the individual simulation modules are presented. Consequently necessary settings for simulation data exchange between individual modules are described together with description of relevant physical phenomena. Finally verification of the proposed multi-level simulation system is done, whereby lifetime estimation of electrolytic double layer capacitor operated in DC-DC converter during various operational conditions is being shown.

II. MULTI-LEVEL SIMULATION DESIGN

As was initially mentioned, during operation of any electronic system, various physical phenomena influence system behavior (Fig. 1). Practically it is very difficult to determine the impact of these physical processes experimentally due to necessity of long-running measurements, or due to requirements on special measuring equipment (testing chambers etc.).

Fig.1. Physical influences on electrical components during operation

Possible way how to investigate previously described issues is multi-level simulation design, where various electronic and non-electrical processes can be considered (Fig. 2).

It is well known that electrolytic capacitors act as most critical component when talking about lifetime. Proper operational conditions (electrical, thermal, etc…) can contribute to extension of these parameters. Almost proposed system (fig. 2) enables to investigate/or define proper operational characteristic in order to determine/ or define expected component lifetime.

III. IMPLEMENTATION AND RESULTS

For design of electrical systems, we decided to use sub-packages from OrCAD 16.6 software:

- Capture/analog or mixed A/D – schematic editor with high number of integrated.
- Pspsie A/D – a simulation substructure of OrCAD that models real electrical behavior of a circuit. It is possible to simulate mix of analog and digital devices.

For design of multiphysics models we used COMSOL. The advantages of this software:

- CAD import module for simulation of more complex geometries
- predefined equations for nonlinear problems (e.g. thermal, magnetic, ambient, mechanical)

For control of co-simulations and for data analysis, we decided to use Matlab:

- m-file - post processing of results, evaluation of convergence, determination of optimal parameter settings.

Fig.2. Proposal for multi-level simulation

We have designed multi-level simulation for determination of lifetime of electrolytic capacitor in DC-DC converter (Fig. 3). The simulation model considers these physical phenomena:
Electrical - with given parameters of voltage stress, current ripple stress and with possibility of definition of nonlinear component behavior (e.g. temperature dependence of capacitor’s ESR).

Thermal with given parameters like ambient temperature, air velocity and with variable parameter like component temperature (electrical dependence).

In order to provide precise multi-level simulation, it is required to design precise simulation models for selected modules. Therefore very accurate thermal simulation model was developed in COMSOL [1], and consequently implemented into circuit simulator of SLPS interface (Matlab – OrCAD) [2].

Fig. 3 is showing initial testing model, where lifetime of electrolytic output capacitor of DC-DC converter can be investigated in dependency on ambient temperature, on output power of converter as well as on other electrical/non-electrical variables (input voltage variations, humidity, air pressure etc.)

Nominal values are:
- Output voltage = 400 Vdc
- Output power = 800 W
- Switching frequency = 100 kHz
- Capacitance of output capacitor = 4.7uF

Simulation results from Fig. 3 are shown on Fig. 4. It can be seen that dynamic response can be also investigated. The steady-state values of required variables are consequently transferred into deterministic algorithm. Based on computed variables (fig. 3), the mathematical – prediction algorithm serves for determination of component’s lifetime [3],[4]. The computation is implemented into multi-level supervisor, which is Matlab – Simulink. Estimation of lifetime is based on known datasheet values (expected lifetime, maximal operational temperature, maximal allowed ripple current, maximal voltage etc...), and actual operational conditions from multi-level simulation model (actual ambient temperature, actual ripple current, actual component temperature, and actual voltage stress).

After several runs of simulations, during which critical operational parameters vary, the lifetime in dependency on given parameters can be plotted (fig. 5). It must be mentioned here, that this dependency also considers other sub-dependencies, like nonlinearity of capacitor ESR, temperature dependency of capacitor core, current ripple dependency etc...

Fig.5. Estimated lifetime for investigated capacitor in dependency on ambient temperature and output load of converter

IV. SUMMARY

At this point we would like to conclude, that design of multi-level simulation can be helpful in the case of complex and expensive electrical systems investigation, where experimental testing of various physical phenomenons is very time-consuming, or costly.

REFERENCES