Junction temperature control for more reliable power electronics

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I. Tutorial Objectives

1) Introduce the topic of power modules reliability.
2) Describe the concept of active reliability control.
3) Explain the thermal modeling and temperature sensing approaches.
4) Explain the implementation of the active thermal control methods.

The target audience are PhD students in power electronics or engineers from the industry that are working towards the realization of highly reliable power electronics converters.

The **learning outcome** is the capability to implement active thermal control strategy tailored to the target application.

II. Topic Outline

Power semiconductor modules are built of different layers of copper and substrate to ensure electrical insulation on one hand and a good thermal conductivity on the other hand [1]. For the electric connection between chips and terminals, aluminum bond wires are typically used [2], although copper has been recently introduced.

Variations of the ambient temperature and power variations create cyclic heating and cooling processes, also called thermal cycles. The thermal cycle magnitude is the most critical parameter for the scale of the aging [3].

A. Active Thermal Control Basics

Failures in power electronics impact safety in operation and cause downtimes, giving extra cost for the operators of the system [4]. In order to increase lifetime and improve reliability of power electronic modules, improvements in the connection technology and assembly of the modules have been done. Active thermal control is a new concept recently introduced to regulate power losses and control the thermal stress, **it has started from industry [5] as an optimized thermal management for a better utilization of the semiconductor**. The general principle is to vary temperature related control variables of the system to influence its junction temperature in order to prevent damages caused by thermal cycling [6].

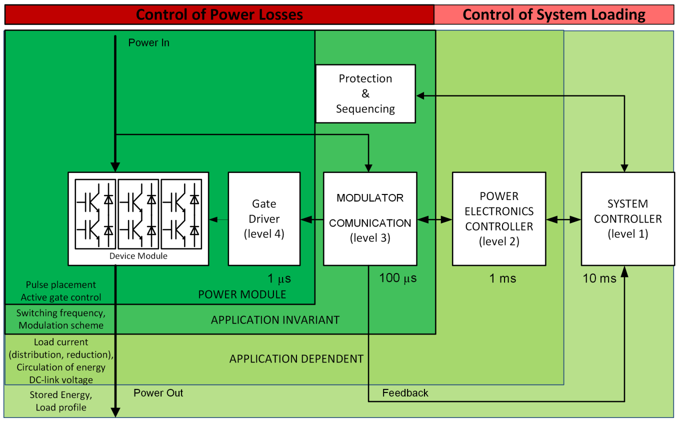
There are several possibilities to implement active thermal control, as sketched in Figure 1a. Since the thermal behavior is changed via the control, there are as many possibilities as the control layers and variables. The lowest level is the gate driver, that can be used directly to influence the losses of the power devices. Also modified modulation patterns can be employed to this aim.

The converter control level generates the reference signals for the modulator and in this case active de-rating can be performed, or modification to some control variables (DC link, switching frequency) can be realized without altering the normal converter's operation. At the highest level there is system control, where the presence of multiple power converters can be exploited to alter the losses distribution or to create additional losses without affecting the main converter's goal.

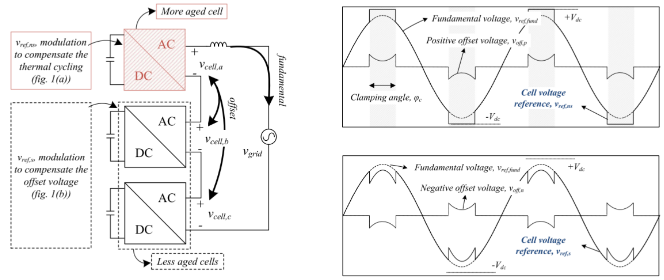
B. Junction temperature estimation and sensing

To enable an effective active thermal control for reliability purpose, the junction temperature must be measured/estimated. The use of optimized models is a cost-effective solution [7]. The problem of extracting the thermal parameters can be solved by using appropriate techniques [8].

With the development of power electronics and the importance of the diagnostic, active gate driving techniques have been rediscovered in the recent years. Although the gate driver can be used to perform active thermal control, for example by modifying the driving voltage to change the switching and conduction losses [9], more feature can be incorporated, as the junction temperature measurement [10].



(a) Classification of temperature control method.



(b) Advanced modulation for thermal control of CHB converter (left), modulation signal for the unloaded cell (top right) and loaded one (bottom right) [11].

Fig. 1: Active thermal control possibilities.

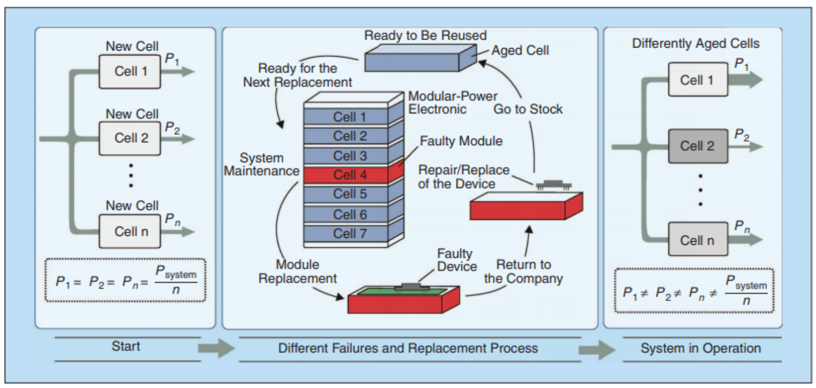


Fig. 2: A repairable system in operation: commissioning with new cells and different wear-out due to varied cell aging, replacement, and repair. The resultant aging conditions of each cell in the system are indicated in gray. [15].

C. Advanced Modulation for ATC

From the modulation control level, possibilties have been explored related to modular converters. In [11], a discontinuous modulation for Cascaded H-Bridge (CHB) converter is adopted with the aim of relieving a deteriorated cell from excessive damage. This is shown in Fig. 1b, where the clamped cell sees its switching loss reduced, while the modulation index distortion is compensated for by the remaining cells. Further optimization [**?**] allow for a reduction in the overall THD during this operation mode. The method of modifying the switching frequency can also be applied to non-modular converters [12].

A combined thermal/voltage balancing modulation has also been applied to Modular Multilevel Converters [13]. Predictive control with the aim of including the reliability as a controller variable has also been explored in [14].

D. The Power Routing

Power routing is an advanced control scheme applied to modular power converters, where the power processing is shared unevenly, taking into account the residual lifetime of the individual cells. Fig. 2 shows this concept applied to a repairable system, where all cells have inherently different residual lifetime. By modifying the power processing, different reliability targets can be obtained.

The application of this technique could extend to the planning and delaying of the maintenance [16], having tremendous effects on the overall cost of ownership of a power electronics system.

Applications where the power routing has proved to give a better lifetime control are electrical drives , smart transformer distribution [17] and aerospace transportation [18].

III. Tutorial Outline

1) Introduction to reliability of power semiconductors and systems.
2) Overview of junction temperature measurement methods .
3) Introduction to Active Thermal Control.
4) Different categories of Active Thermal Control.
5) Active Thermal Control Design and Application.
6) Evaluation of the Active Thermal Control potential for lifetime extension.
7) Discussion

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