Dynamic Current Limits to Manage IGBT Temperature in Modular Multilevel Converters for HVDC Applications

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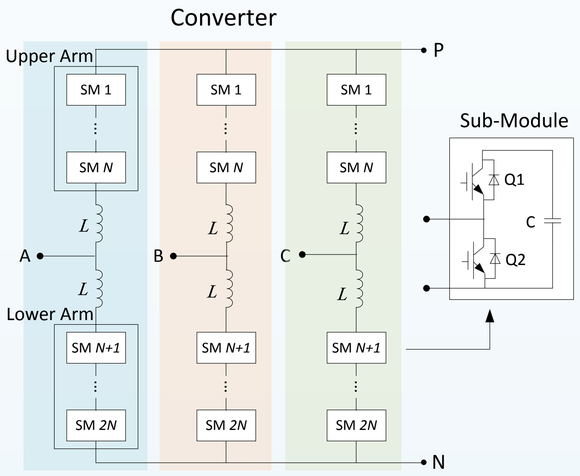
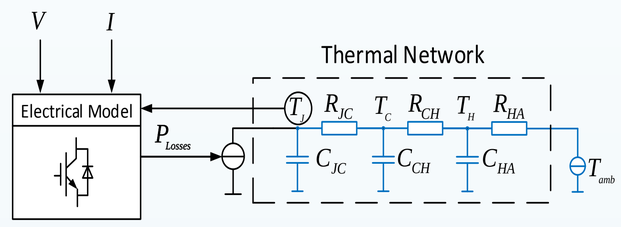
Research Background

- Modular Multilevel Converters (MMC) for HVDC applications, composed by thousands of IGBTs with a limited overload capability;
- IGBTs junction temperature must be tightly controlled for increased lifetime and reliability and a fixed current limit is implemented in the converter control system to avoid IGBT over-temperature stresses;
- Limited overload is particularly relevant when VSC-based multi-terminal DC grids are expected to provide power and frequency support to a distressed AC grid and temporary overload capability is not provided.





Electro-Thermal Model for Junction Temperature Estimation

Research Overview

- Conservative fixed limits are set low enough such that the maximum junction temperature of the semiconductor die in the IGBT modules is never violated, even under worst-case operating conditions (e.g. high system voltage and high ambient temperature)
- During other operating conditions (e.g. nominal system voltage and low ambient temperature), the limits prevent the full capability of the converter from being used to support the AC or DC grid.
- A combined electro-thermal model based on IGBT module information is used to provide an estimation of the junction temperature under any operating condition;
- We propose an additional control loop to extend the power transmission capability while keeping the temperature within safe limits by dynamically setting the current limit in response to the estimated semiconductor temperature:

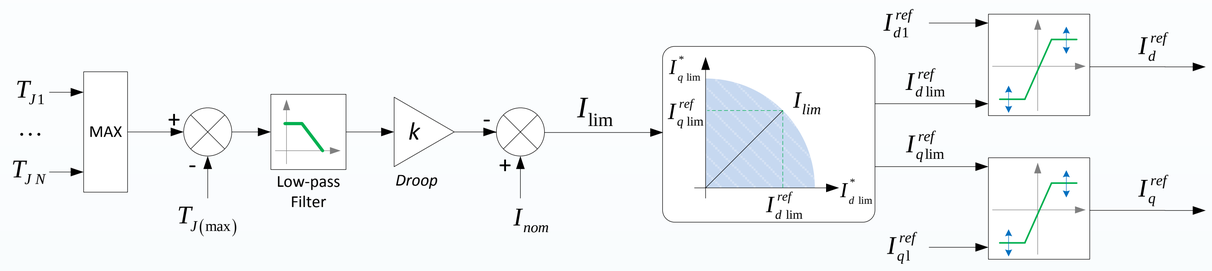
$$I_{lim}\left(T_J\right) = I_{nom} + k\left(T_{J(nom)} - T_J\right)$$

Where:

- T_J is the semiconductor junction temperature estimation;
- I_{nom} is the design (nominal) current limit of the system;
- $T_{J(nom)}$ is the nominal operating temperature of the IGBT module;
- k, defined in [A/°C], is the temperature-current droop constant.

- The proposed control scheme acts to enforce a current magnitude limit that ensures the electrical and thermal limits are kept within safe bounds;
- This offers the potential to extend the power transmission capability of the converter when semiconductor junction temperature is below the maximum limit, i.e. there is thermal headroom available.
- Only the absolute current limit is defined, as the individual current components limits are shared according to the control objective.

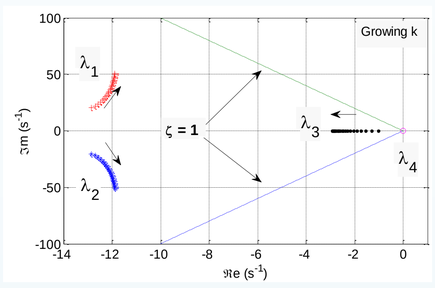
- A Half-Bridge MMC with 10 sub-modules per arm was considered;
- Converter fixed limits are defined at ±1.1 p.u. and the IGBT Module 5SNA 0650J450300 from ABB was used.



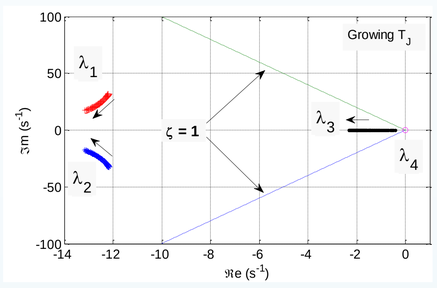
Calculation of Dynamic Temperature-Dependent Current Limits

Stability Analysis: Eigenvalues Sensitivity

Controller Gain Variation



Estimated Junction Temperature Variation



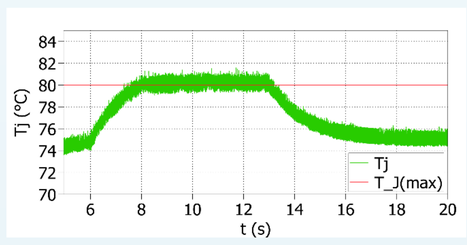
The Eigenvalues of the system show that the controller succeeds in keeping the junction temperature within the limit for a wide range of the gain *k* and under different operating temperatures.

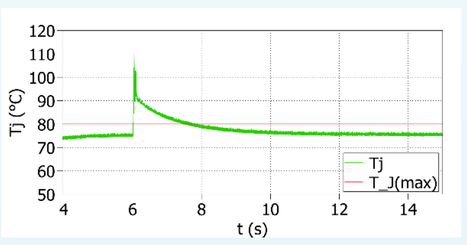
Simulation Results

Power Reference Change

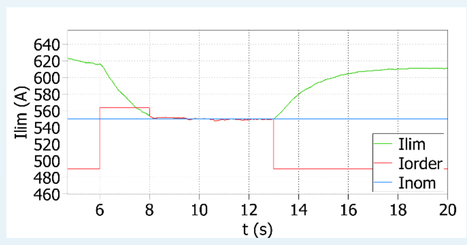
AC Phase-Ground Fault

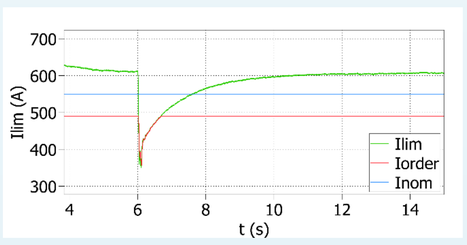
Junction Temperature Estimation



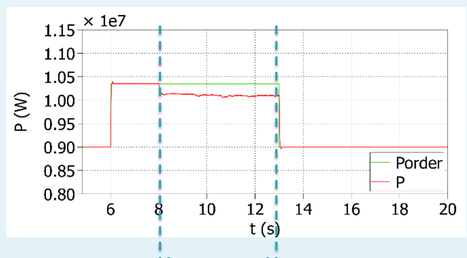


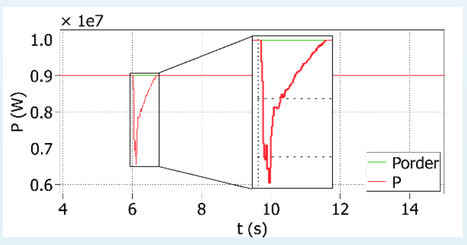
Current Limit





Active Power Order and Injected Power





Stability analysis and simulation results validate the capability of the proposed control method to extend the power transmission capacity in MMC-HVDC applications without violating the junction temperature of IGBT modules. The controller is able to cope with additional power order requests and capable of maintaining some power transmission capacity during fault conditions.

A test bed has been designed and experimental validation using a small-scale model or a converter will be performed at Cardiff University, where the problem of having a physical measurement of semiconductors junction temperature will be addressed.

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