Operation of MMCs with Dynamic Temperature-Dependent Current Limits

Manchester Electrical Energy and Power Systems Workshop

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Outline

• Modular Multilevel Converter:
  – Structure and Control
  – Limits and Constraints
  – Electro-Thermal Model
  – Dynamic Temperature-Dependent Current Limits

• Case Study

• Results

• Conclusions & Future Work
Under power unbalance conditions, additional transmission capability might be necessary.
Modular Multilevel Converter

- Structure and Operation

![Diagram of Modular Multilevel Converter with examples of Half-Bridge, Clamp Double, and Full Bridge configurations.](image)
Modular Multilevel Converter

- Control (dq0 reference frame)

- Fixed limits set the maximum power contribution from the converter
- Must ensure that thermal limits are not exceeded
Modular Multilevel Converter

• Limits and Constraints
  
  – Besides electrical, semiconductors have strict thermal limits that must be respected;
  
  – A more robust control system must ensure that the necessary constraints are respected, **without limiting the transmission capacity**;
  
  – In this work a combined approach is proposed, where the current limits are sensitive to the temperature dynamics in the semiconductors.
Dynamic Temperature-Dependent Current Limits

\[
I_{\text{lim}}(T_J) = I^0_{\text{lim}} + k \left( T'^{\text{max}}_J - T_J \right)
\]

(a)

(b)
MMC Electro-Thermal Model

IGBT Module
Data Sheet

Curve Extraction

Curve Fitting (LS)

Thermal Description

Electrical Model

V

I

P_{Losses}

T_j

R_{th}^i

C_{th}^i

R_{th}^n

C_{th}^n

T_{case}

Z_{C-A}

T_{amb}

Heat Sink

Chip

Heat Flow
MMC Electro-Thermal Model

Dynamic Temperature-Dependent Current Limits
Case Study

System Data

<table>
<thead>
<tr>
<th>AC System Data</th>
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<tbody>
<tr>
<td>$V_{AC}$ (kV)</td>
</tr>
<tr>
<td>$f$ (Hz)</td>
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<thead>
<tr>
<th>MMC and DC System Data</th>
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<tbody>
<tr>
<td>$V_{DC}$ (kV)</td>
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<tr>
<td>#SM</td>
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<tr>
<td>$V_{cap}$ (V)</td>
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<tr>
<td>$f_{c}$ (Hz)</td>
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<thead>
<tr>
<th>IGBT Data</th>
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<tr>
<td>Model</td>
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<tr>
<td>$V_{CE}$ (V)</td>
</tr>
<tr>
<td>$I_{CE}$ (A)</td>
</tr>
</tbody>
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$\begin{align*}
T_{\text{max}}^J &= 85 \, ^\circ\text{C} \\
I_{\text{lim}}^0 &= 650 \, \text{A} \\
k &= 16.25 \, \text{A/}^\circ\text{C}
\end{align*}$
Results

I. Operational Quantities

System Dynamics:
- $P^*: 9.5 \rightarrow 11.4 \text{ MW (}1 \rightarrow 1.2 \text{ pu)} @ 6s$
- CLM activated @ 8s
- $P^*: 11.4 \rightarrow 9.5 \text{ MW (}1.2 \rightarrow 1 \text{ pu)} @ 13s$
Results

II. Dynamic Temperature-Dependent Current Limits

Extension of power transmission capability
+ Respect of electrical and thermal limits
= Seamless power support to an unbalanced grid
Conclusions & Future Work

I. Proposed strategy to control the current limits with sensitivity to semiconductors junction temperature;

II. Transmission capacity can be dynamically controlled, while respecting electrical and thermal constraints, enabling the support to grids with power imbalance;

III. Operation under fault conditions (not shown) was verified and confirms the validity of the proposed control;

IV. Experimental validation is on its way.
Thank you for your attention!