Hochschule München University of Applied Sciences

Laboratory for Mechatronic and Renewable Energy Systems (LMRES)

# Reference Current Saturation Methods for Modular Multilevel Converters in HVDC Systems

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# Introduction

Motivation and problem statement

### Problem Statement

- Over-currents accelerate component aging due to thermal stress [1]
- Over-currents require oversizing of components during design phase

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- Over-current limiting strategies for fault currents well researched [2, 3]
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## Research gap

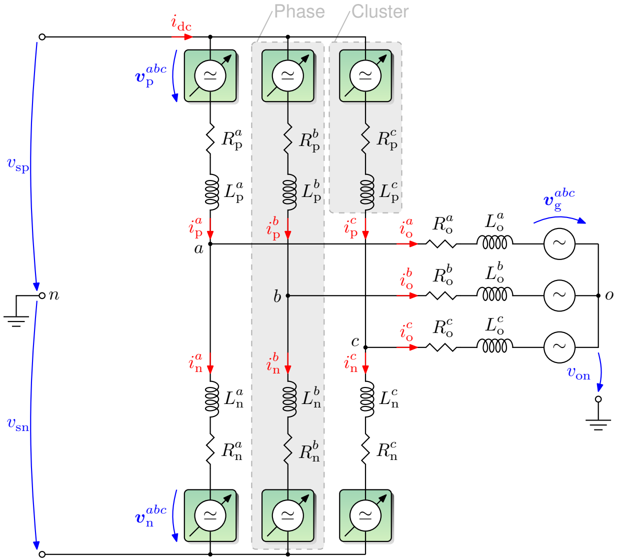
- Limited insight on how current limits relate to each other
- Current saturation only for grid currents, neglecting cluster and dc currents [4, 5]

# Reference Current Saturation

## Converter Modelling

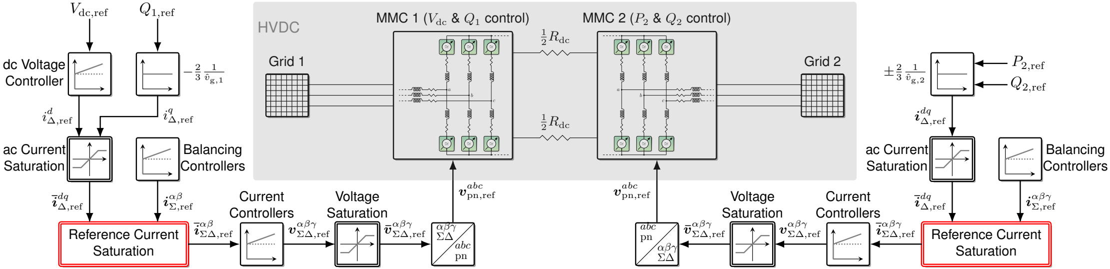
Three current types

| | |
|---|---|
| grid currents | $\boldsymbol{i}_{\Delta}^{\alpha\beta}$ |
| dc current | $i_{\Sigma}^{\gamma}$ |
| cluster currents | $\boldsymbol{i}_{\mathrm{pn}}^{abc}$ |



# Reference Current Saturation

## HVDC System



# Reference Current Saturation

## Current constraints

The physically motivated current constraints due to active and passive components are

### Current constraints

| | |
|---|---|
| grid current constraint | $\left\lVert \boldsymbol{i}_{\Delta,\mathrm{ref}}^{dq} \right\rVert_2 \leq i_{\mathrm{ac,max}}$ |
| dc current constraint | $\left\lvert i_{\Sigma,\mathrm{ref}}^{\gamma} \right\rvert \leq \frac{1}{3} i_{\mathrm{dc,max}}$ |
| cluster current constraint | $\left\lVert \boldsymbol{i}_{\mathrm{pn,ref}}^{abc} \right\rVert_\infty \leq i_{\mathrm{pn,max}}$ |

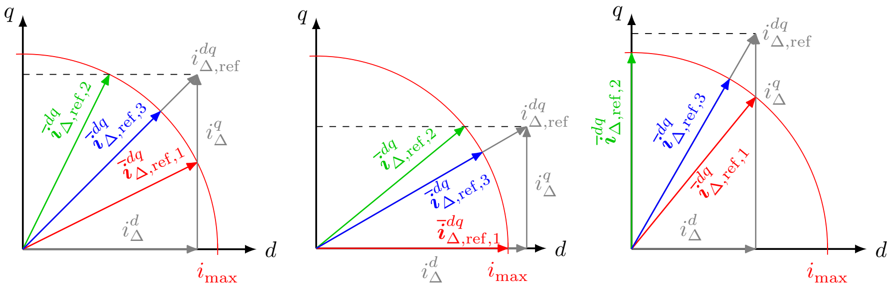
with the maximum allowable values

$$i_{\mathrm{dc,max}},\ i_{\mathrm{ac,max}},\ i_{\mathrm{pn,max}} > 0$$

# Reference Current Saturation

Grid current saturation

Vector diagrams of three different grid reference currents




Prioritization methods:

1. Prioritization of $d$-Component: $\bar{\boldsymbol{i}}^{dq}_{\Delta,\mathrm{ref},1}$
2. Prioritization of $q$-Component: $\bar{\boldsymbol{i}}^{dq}_{\Delta,\mathrm{ref},2}$
3. Prioritization of the Power Factor: $\bar{\boldsymbol{i}}^{dq}_{\Delta,\mathrm{ref},3}$

# Reference Current Saturation

## dc current saturation

Saturation of the dc current is achieved by clipping at its upper and lower bounds

$$\bar{i}^{\gamma}_{\Sigma,\mathrm{ref}} := \begin{cases} i^{\gamma}_{\Sigma,\mathrm{ref}}, & \text{if } \left|i^{\gamma}_{\Sigma,\mathrm{ref}}\right| \leq i_{\mathrm{dc,max}}, \\ \mathrm{sign}\left(i^{\gamma}_{\Sigma,\mathrm{ref}}\right) i_{\mathrm{dc,max}}, & \text{otherwise.} \end{cases}$$

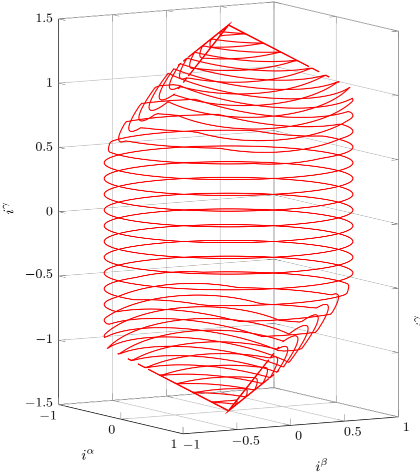
# Reference Current Saturation

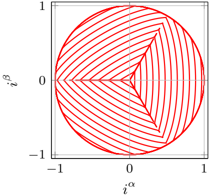
## Cluster current saturation – Two saturation concepts for a three phase system

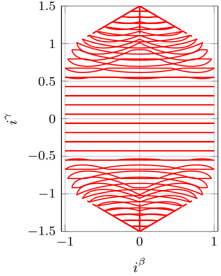
1. *abc* Saturation: Cluster currents are saturated elementwise

$$\bar{i}^{x}_{\mathrm{y,ref}} := \begin{cases} i^{x}_{\mathrm{y,ref}} & \text{if } |i^{x}_{\mathrm{y,ref}}| \leq i_{\mathrm{pn,max}} \\ \mathrm{sign}(i^{x}_{\mathrm{y,ref}})\, i_{\mathrm{pn,max}} & \text{otherwise} \end{cases}$$

with $x \in \{a, b, c\}$ and $\mathrm{y} \in \{\mathrm{p}, \mathrm{n}\}$



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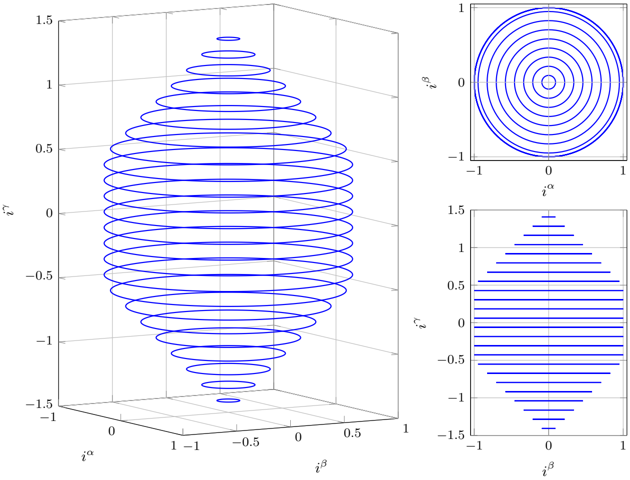
with $x \in \{a, b, c\}$ and $\mathrm{y} \in \{\mathrm{p}, \mathrm{n}\}$

2. $\Sigma\Delta$ Saturation: Cluster currents are saturated in their transformed coordinates

$$\|\boldsymbol{i}^{\alpha\beta}_{\mathrm{y}}\|_2 + |i^{\gamma}_{\mathrm{y}}| \leq i_{\max}$$



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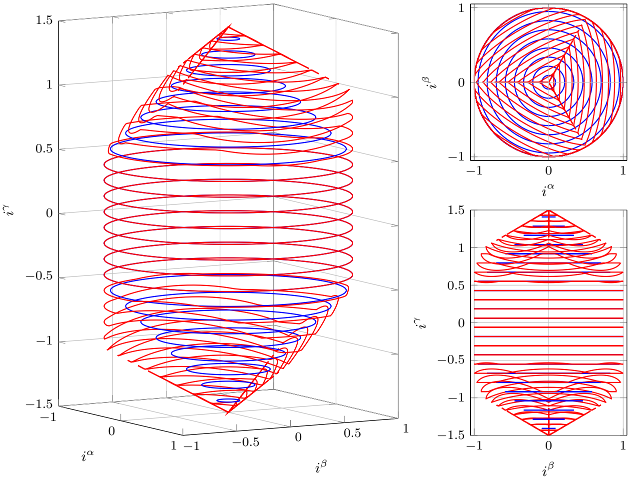

# Reference Current Saturation

## Cluster current saturation – Extension of the $\Sigma\Delta$ saturation to the MMC

Extension to the MMC currents by

- Applying the $\Sigma\Delta$ transformation
- Use of the triangle inequality

**Inequality constraint for cluster currents**

$$\|\boldsymbol{i}_{\Sigma}^{\alpha\beta}\|_2 + \frac{1}{2}\|\boldsymbol{i}_{\Delta}^{\alpha\beta}\|_2 + |i_{\Sigma}^{\gamma}| \leq i_{\mathrm{pn,max}}$$

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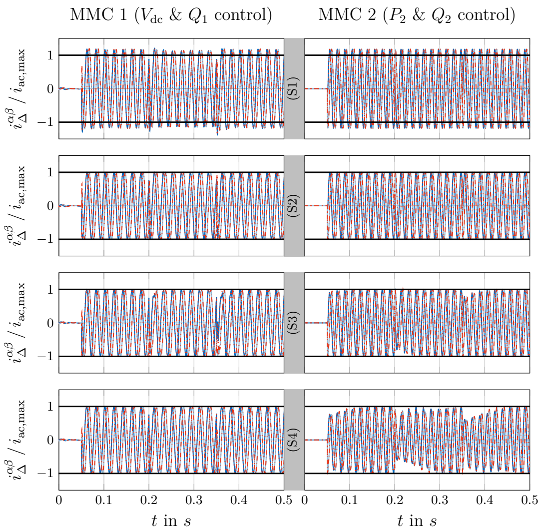
Prioritization depending on operating mode (Inverter/Rectifier) or grid operator demands.

# Validation and Simulation Results

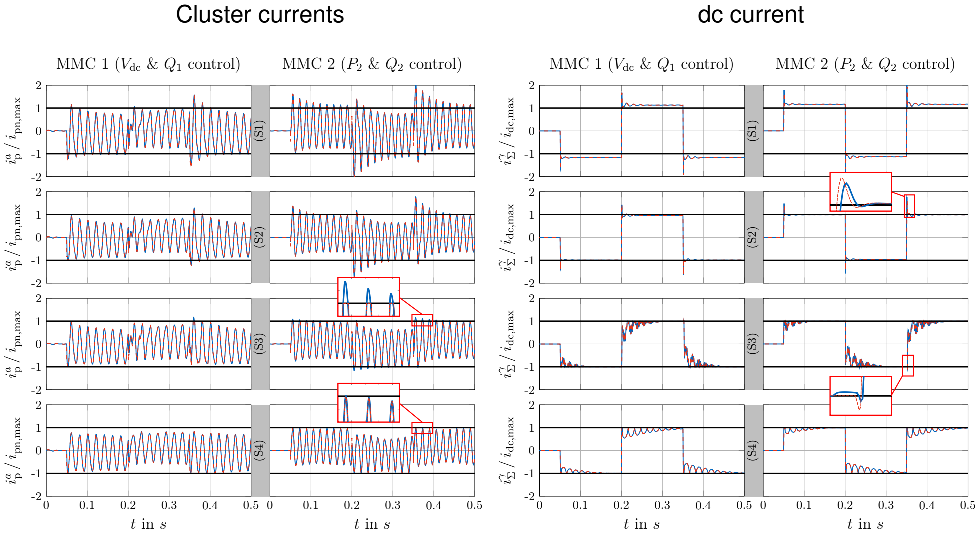
## Simulation scenarios and grid currents

- (S1): No reference current saturation strategies are applied.
- (S2): Only grid current saturation applied.
- (S3): Grid and dc current saturation, along with the $abc$ saturation, are applied.
- (S4): Grid and dc current saturation, along with the $\Sigma\Delta$ saturation, are applied.



# Validation and Simulation Results

## Cluster currents and dc current



# Conclusion

### Contribution

- Ensure operation within current limits (fully utilizing existing hardware) for all currents
- Saturation methods are easy to insert in conventional control algorithm

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### Future Work

- Experimental validation
- Address the nontrivial task of current prioritization at its limits using advanced control techniques (MPC)

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Preprint available on TechRxiv

# References I


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