Study Committee C4

Power system technical performance

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EMC Simulation Method for Multi-Level VSC HVDC Converters

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Motivation

- There is an ever-increasing demand on the radio frequency spectrum.
- With the increased presence of inverter-based resources it is important that power systems continue to comply with norms and regulations on Electromagnetic (EM) emissions.
- This paper presents an improved method for predicting EM emissions from MMC HVDC converters. The method is based on [1].

Method

- Main assumptions
  - EM emissions are generated by time-varying voltages across cell terminals.
  - Currents circulating in cells during commutations can be neglected.
  - Adjacent cells are assumed to give identical impulse responses and are aggregated into clusters.
- Method overview (Figure 1)
  - Impulse response estimation using 3D EM simulations
  - Estimation of high-resolution cluster voltages
  - Interpolation, windowing and convolution
  - EMI receiver model
- 3D EM modelling
  - Sub-resolution modeling of wires and bus-bars
  - Detailed models of converter valves (Figure 2)
  - Hybrid equipment models (transformers, reactors, etc.)
  - Screening (thin-aperture models, surface transfer impedances, etc.)

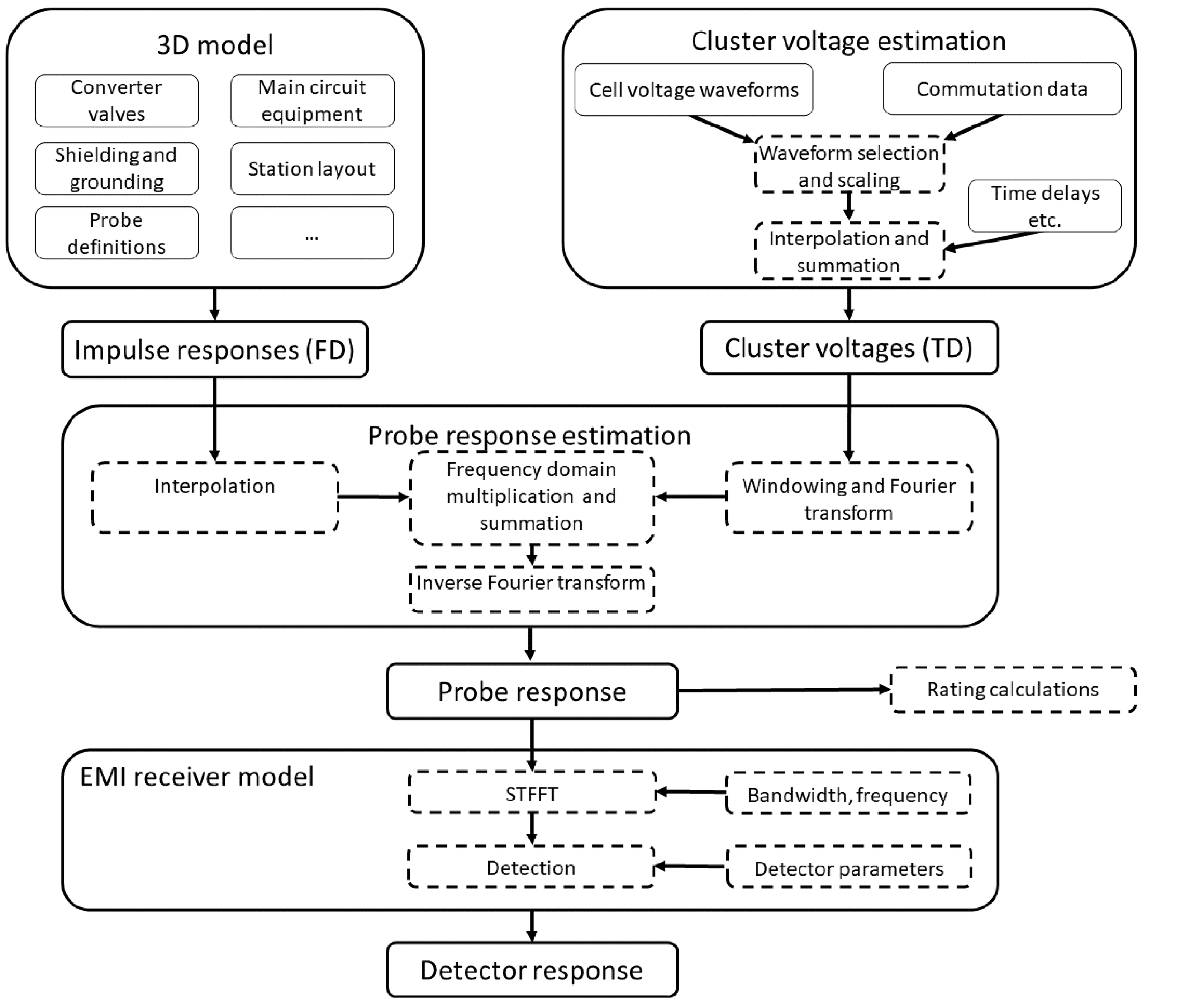

Figure 1. Overview of EMC simulation method. TD and FD are acronyms for time domain and frequency domain, respectively.

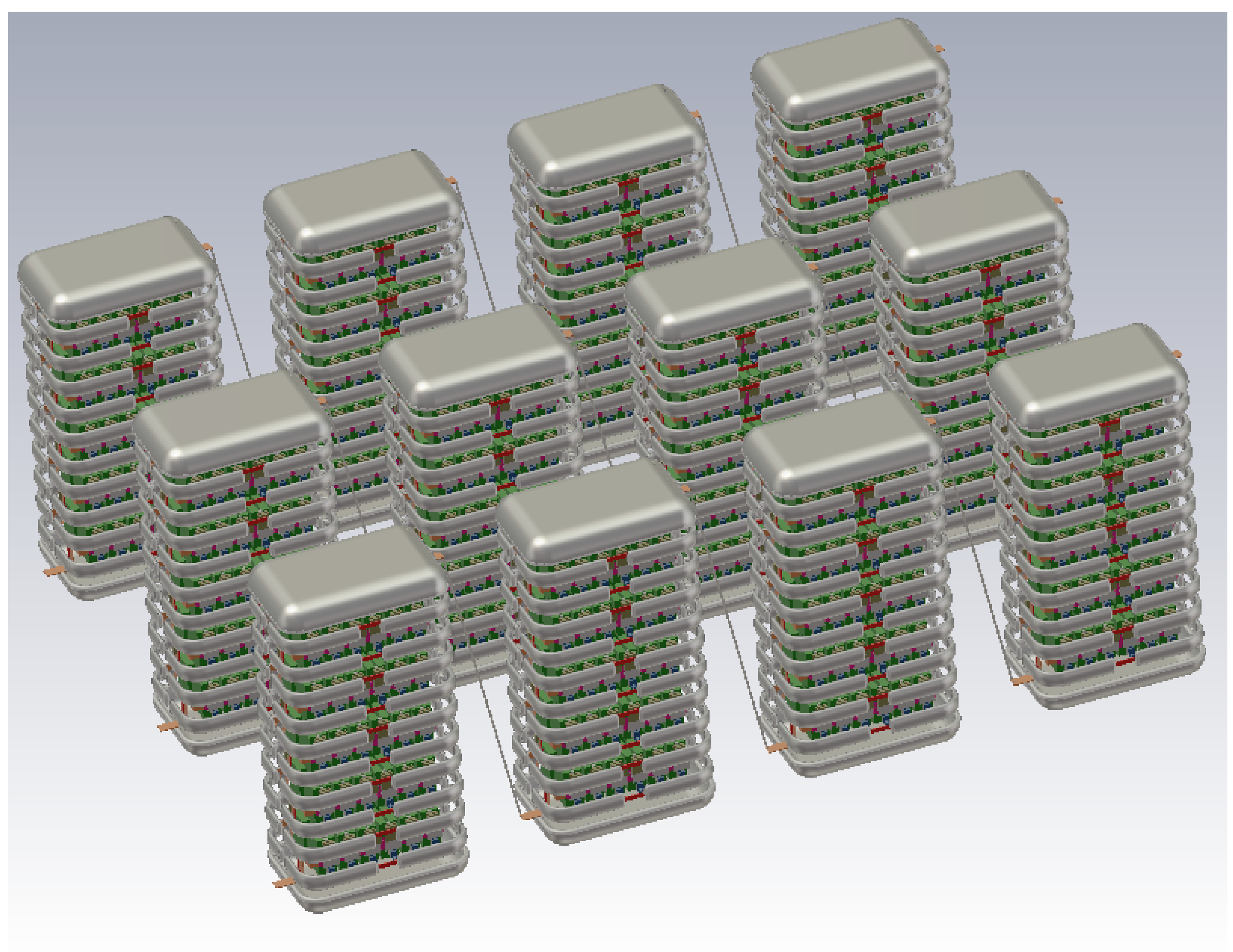

Figure 2. Example of 3D electromagnetic model of converter valves

[1] D. Cottet et al., "Electromagnetic modelling of high voltage multi-level converter substations," 2018 IEEE International Symposium on Electromagnetic Compatibility and 2018 IEEE Asia-Pacific Symposium on Electromagnetic Compatibility (EMC/APEMC), Suntec City, Singapore, 2018, pp. 1001-1006

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Method, contd.

- Hybrid equipment models
  - Combining 3D models and circuit descriptions for accurate equipment models.
  - Models based on measurements, simulations and physical understanding.
  - Example (Figure 3): hybrid models for large reactors [2].

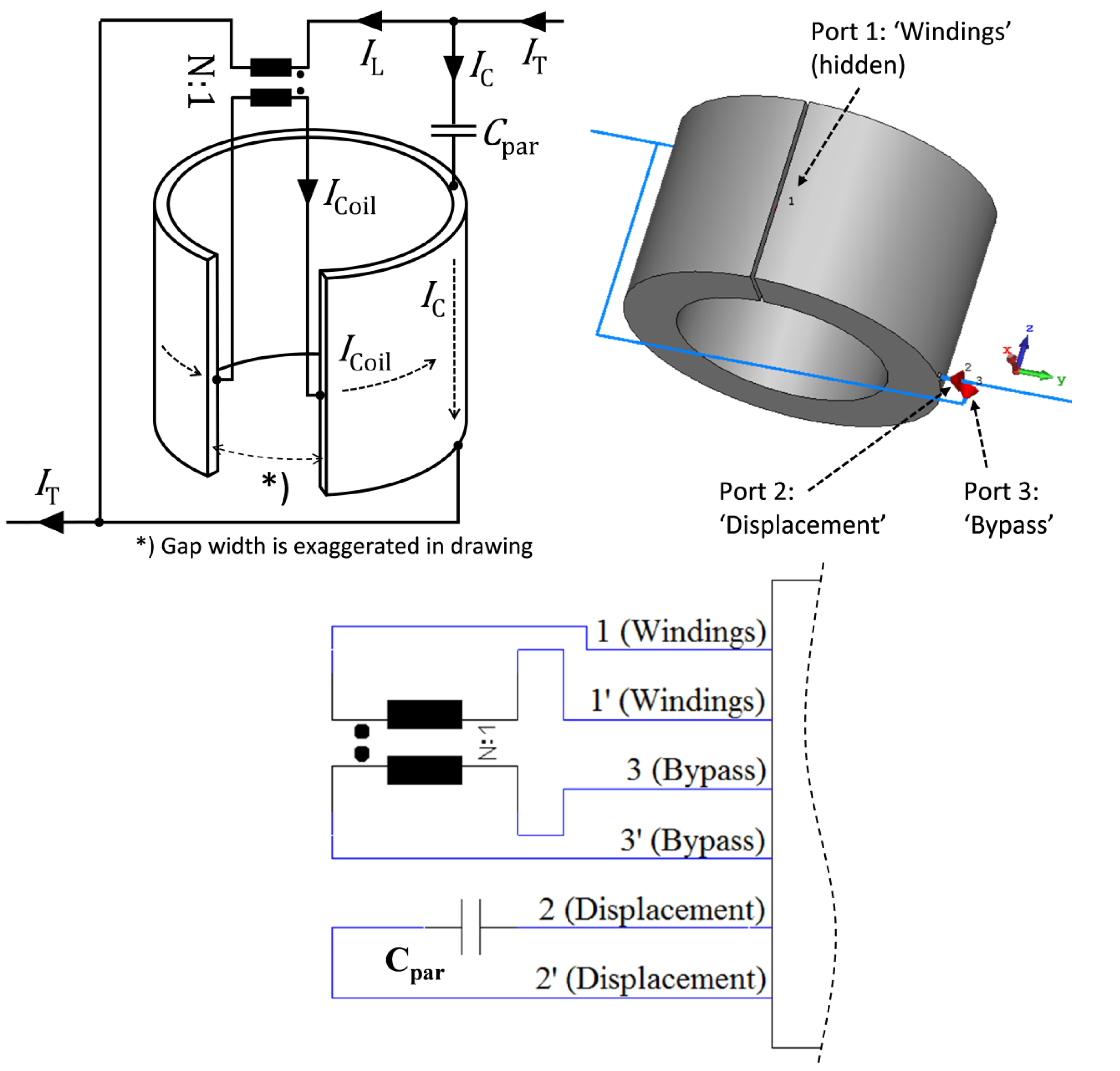

Figure 3. Principle of hybrid reactor model (top left), 3D view of reactor implementation (top right), and schematic view (bottom).

- Cluster voltage estimation (Figure 4)
  - Commutation data from steady state system simulations.
  - Measurements of individual cell voltage waveforms during commutations (database for different conditions).
  - Time delays (hardware delays, blanking time, etc.).

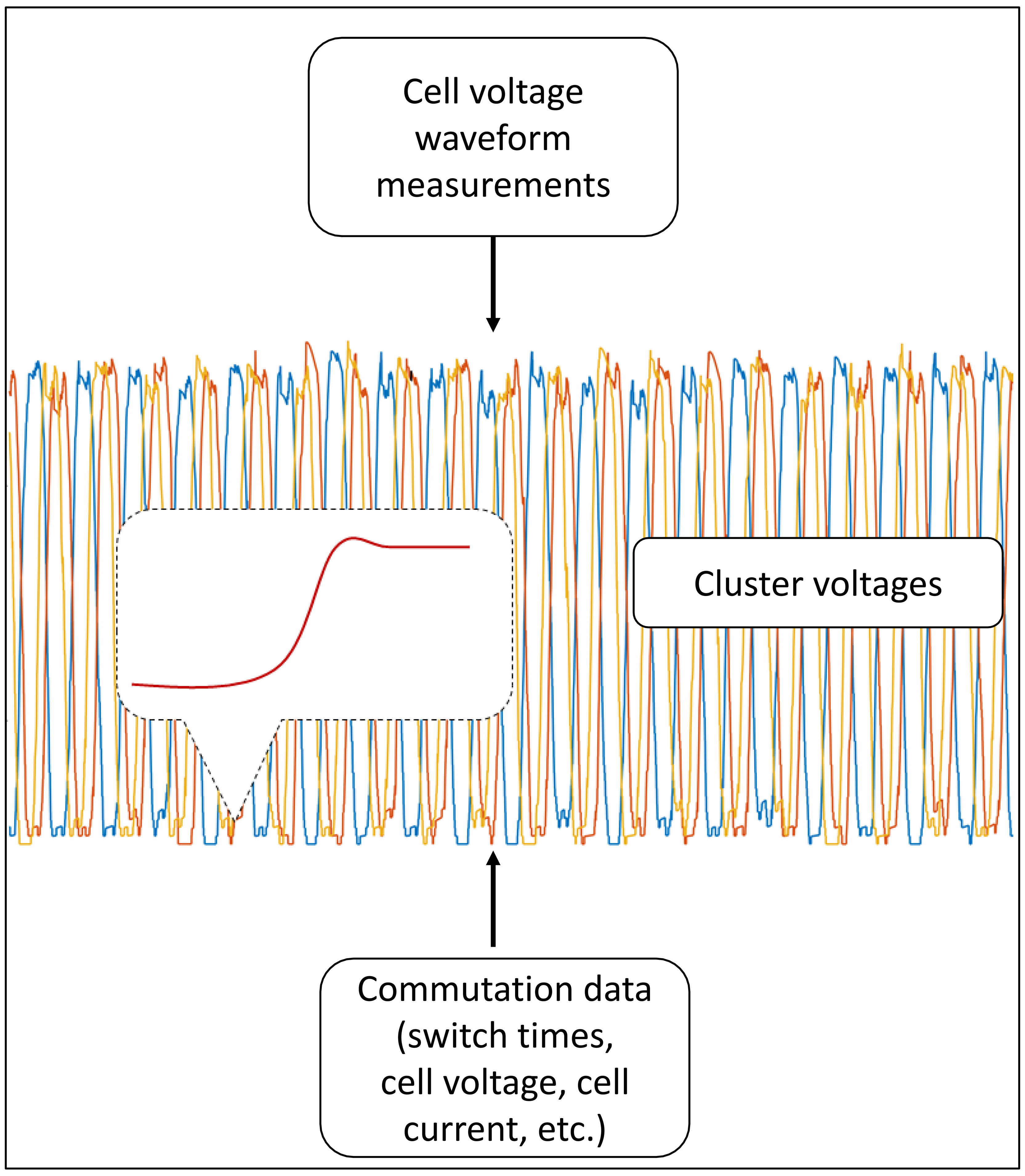

Figure 4. Illustration of cluster voltage estimation. Cell voltage waveform measurements and commutation data and combined into cluster voltages. The cluster voltages have a very high level of detail for each voltage step as illustrated by the close-up of a (generic) cell voltage waveform.

- EMI receiver model
  - Numerical EMI receiver model based on short time fast Fourier transform (STFFT).
  - Peak (PK), Quasi-Peak (QP), Root-Mean Square (RMS), Average (AV) detectors.
  - 9kHz – 150kHz (Band A), 150kHz – 30MHz (Band B).
  - Validated against CISPR 16-1-1.

[1] D. Cottet, et al., "Hybrid Model for Air Core Reactors in EMC Simulations of High Voltage Converter Stations," 2019 Joint International Symposium on Electromagnetic Compatibility, Sapporo and Asia-Pacific International Symposium on Electromagnetic Compatibility (EMC Sapporo/APEMC), Sapporo, Japan, 2019, pp. 429-432, doi: 10.23919/EMCTokyo.2019.8893727.

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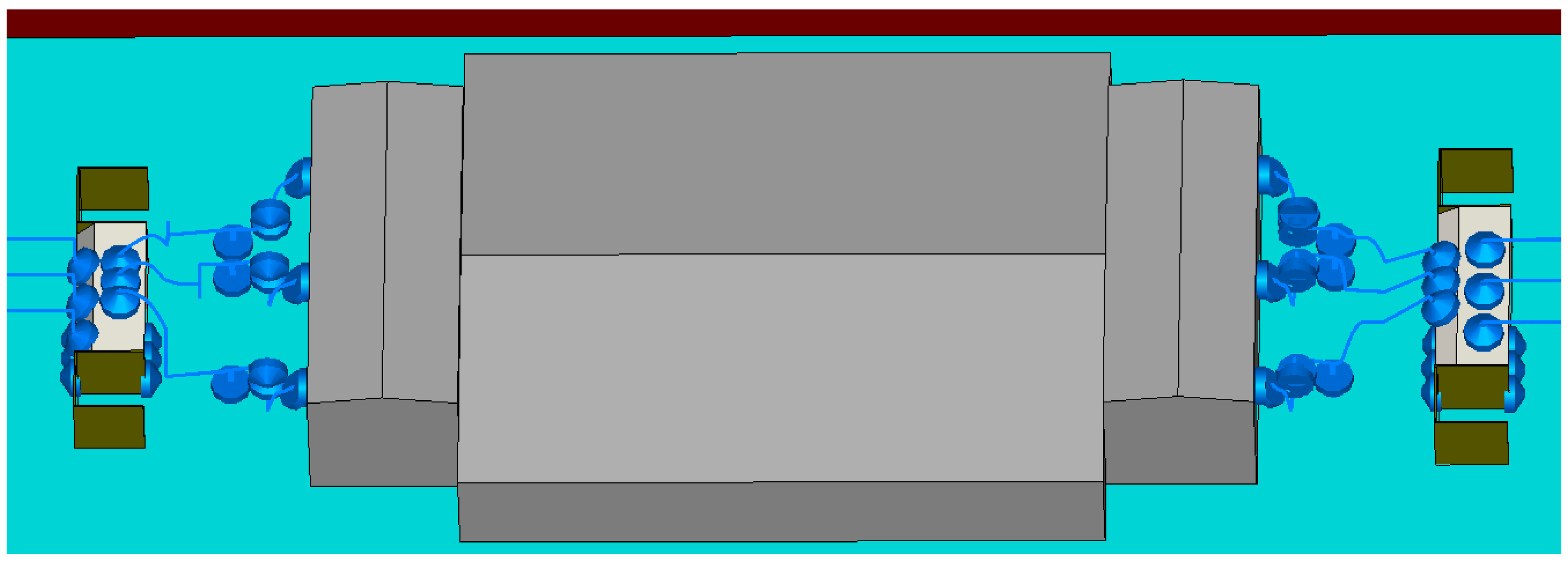

Figure 5. Screenshot of 3D EM model of a back-to-back HVDC converter station. Blue cones represent lumped circuit models embedded in the 3D model.

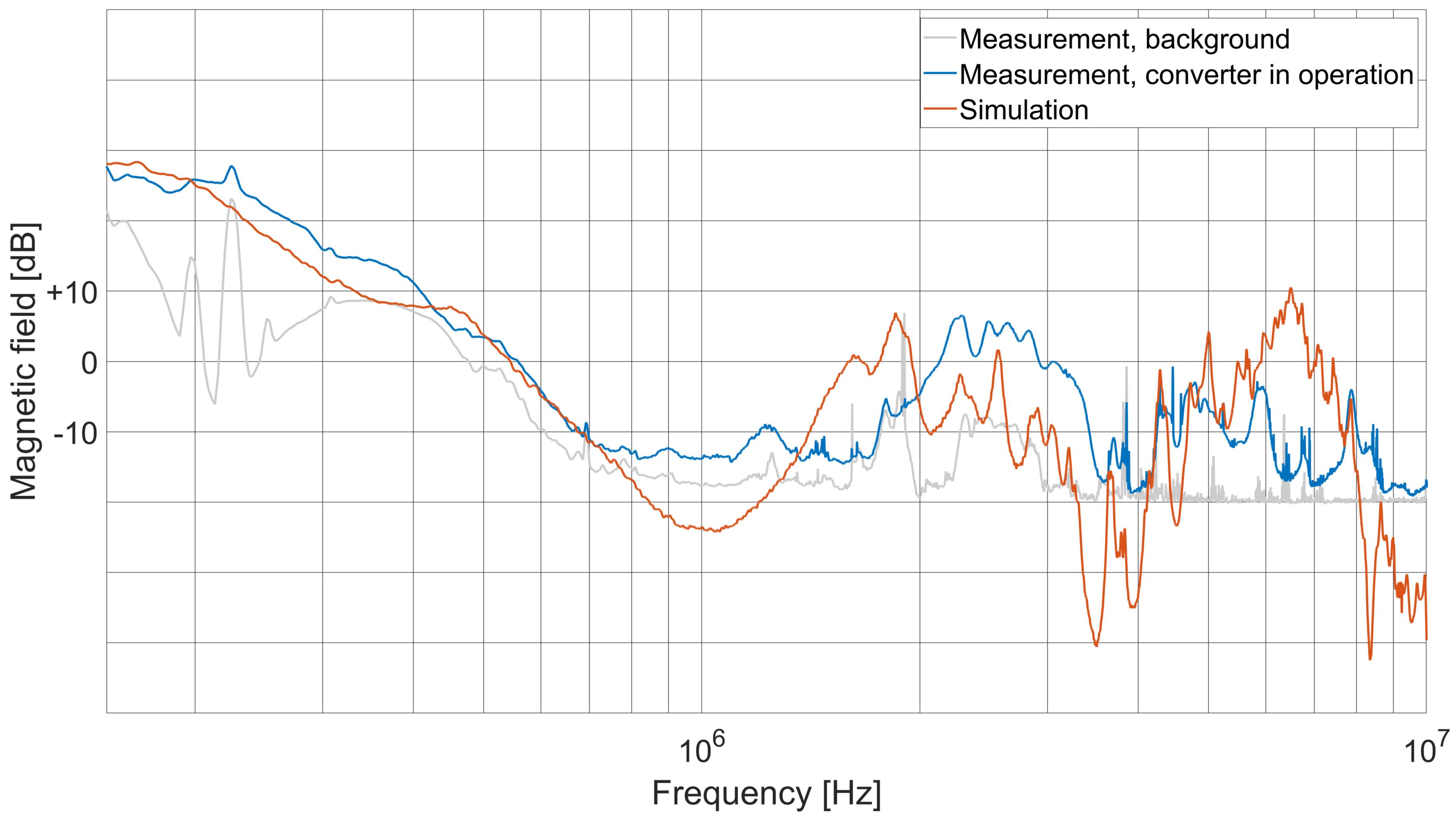

Figure 6. Simulated magnetic fields about 80 m from the converter station depicted in Figure 4

Experimental Validation

- Validation of proposed method using measurements from a back-to-back HVDC converter station.
- The 3D EM model of converter station is shown in Figure 5.
- Measured and simulated magnetic fields at a position 80 m from the converter are shown in Figure 6. A broadband agreement of ±5 dB is observed up to about 3 MHz.
- Qualitative agreement between measurement and simulations up to 10 MHz.
- For higher frequencies there is a qualitative agreement between simulations and measurements, but the method is not able to accurately predict absolute field levels.
- Simulated electric field distribution at 5 MHz is shown in Figure 7. A complex field distribution involving the full converter station is observed.
- Previous validation results on equipment and system level published in e.g. [1].

Discussion

- Estimation errors above 3 MHz are partly explained by a lack of accurate cell voltage waveform measurements in this frequency range. Other contributing factors are reduced accuracy in equipment models and underestimated system losses.
- Estimation errors presented in this paper are in line with previous results [1].

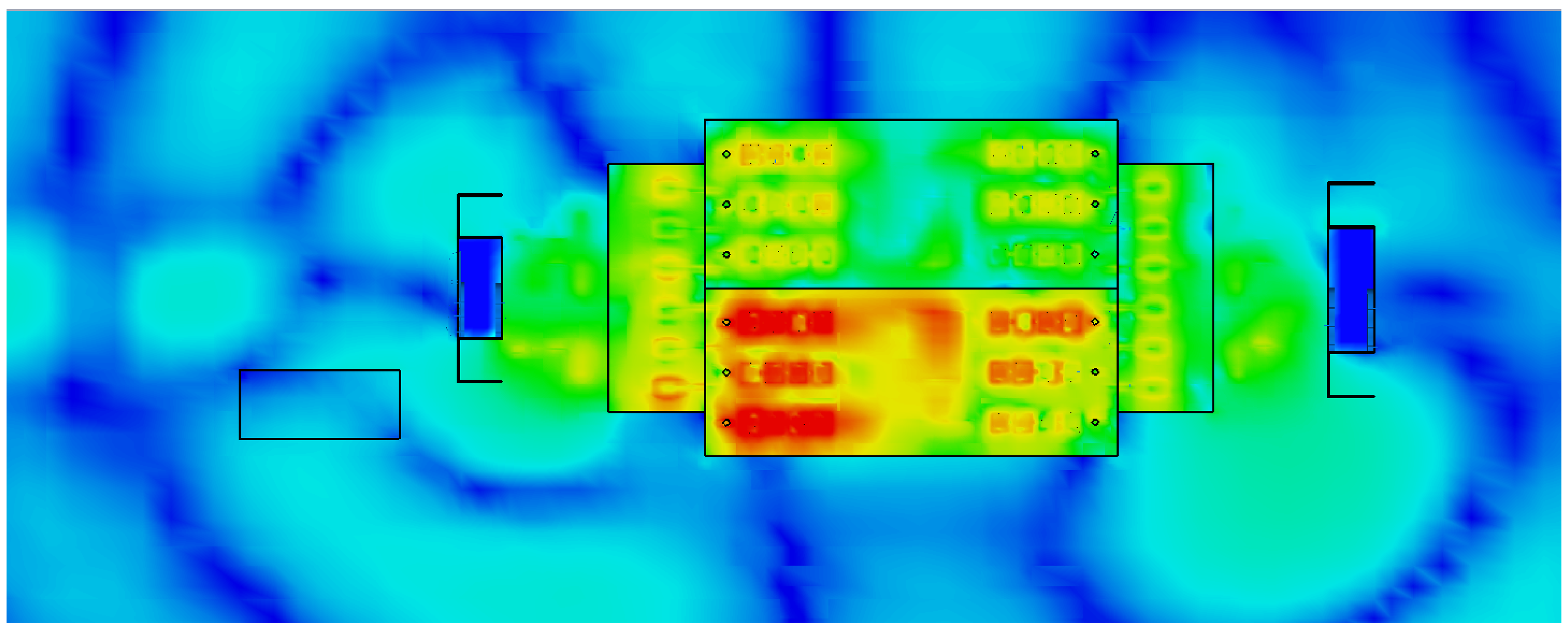

Figure 7. Electric field distribution at 5 MHz for the back-to-back converter station. A single impulse voltage source, placed in the lower left part of the converter, was used to generate the fields shown in the figure.

Conclusions

- A description of an improved simulation for prediction of EM emissions from HVDC converter has bee presented. The method is a continuation of the work presented in [1].
- Good broadband agreement between simulations and measurements provide experimental support for the simulation method.
- The accuracy and level of detail provided by the simulation method is invaluable for design of efficient and cost-effective mitigation measures for EM emissions.

[1] D. Cottet et al., "Electromagnetic modelling of high voltage multi-level converter substations," 2018 IEEE International Symposium on Electromagnetic Compatibility and 2018 IEEE Asia-Pacific Symposium on Electromagnetic Compatibility (EMC/APEMC), Suntec City, Singapore, 2018, pp. 1001-1006