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Automated EMI Simulation Workflow for Frequency-Variable High Power DC/DC Converter for Aviation

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Abstract

Addressing the challenges of power electronic systems for more electric aircraft (MEA), an automated simulation-based workflow is introduced to predict conducted emissions (CE) of a multiphase frequency-variable bidirectional DC/DC converter. The workflow evaluates over 150 operating points (OPs), identifying critical electromagnetic interference (EMI) scenarios and defining necessary filter requirements. The analysis generates results for common mode (CM) and differential mode (DM) emissions, analyzing the different influences of system parameters such as switching frequency and output power on CE. These outcomes support the development of a highly optimized power electronic system and enable to design high-performance EMI filters, ensuring compliance with aviation standards.

1 Motivation

In order to achieve the specified climate targets in the aviation sector, increasing efforts are being made in the area of the MEA. With the European Union strategy for clean aviation aiming for entry into service by 2035 [1], new challenges arise for the performance of power electronic systems and their components (e.g. EMI filters) [2]. High-performance systems in the megawatt (MW) range are needed with low weight, compact size and high power density. Accordingly, measures must be taken during the design of power electronic systems to prevent unwanted interference emissions in order to ensure the specified safety requirements and robustness. The challenge here is to make an initial reliable prediction of the expected CE even before a first prototype of the power electronics system has been built. Knowledge of the emissions is necessary for designing the required EMI filter, which can then be integrated into the overall system during the design phase of the power converter to achieve the highest possible power density.

This paper examines a multiphase high-performance DC/DC converter for a MEA, which operates unidirectional as a boost converter at the fuel cell (FC) or bidirectional as battery interface converter to charge and discharge the battery system (cf. Fig. 1) [3, 4]. This DC/DC converter is operated at a variable switching frequency in order to achieve the highest possible efficiency across the

entire operating range. From these boundary conditions, the questions arise as to how it is possible to predict CE across the entire operating range at variable switching frequencies (cf. Fig. 2) and which insertion losses for CM and DM must the EMI filter achieve to meet the standards (e.g. DO-160) across all OPs. Even if the system were available, performing the necessary measurements of CE for such a DC/DC converter is very complex, requires special measuring equipment for this power range, and is very time-consuming.

Simulation based prediction of CE helps to define the filter requirements [5]-[7], assess the system OPs with critical EMI and starting with the filter design during the design phase of the power electronic system. This paper presents an automated EMI simulation workflow as a solution for a comprehensive evaluation of the expected CE for a five phase frequency-variable bidirectional DC/DC converter with 500 kW output power in a clean aviation application, aiming to define the filter requirements across the entire operating range of the system.

The paper is organized as follows. Section 2 provides an introduction to the multiphase DC/DC converter with boundary conditions and operating area. Section 3 elaborates on the methodology of the automated simulation-based workflow. Section 4 discusses the results with dependencies on the system parameters.

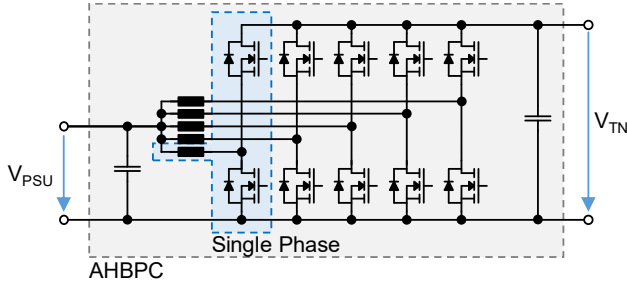


Fig. 1 Topology of the Aircraft Half Bridge Power Core (AHBPC) with five interleaved phases

2 Multiphase DC/DC Converter

The topology of the used system is hereafter referred to as Aircraft Half Bridge Power Core (AHBPC) and illustrated in Fig. 1. The AHBPC consists of five parallel phases, each implemented as a half-bridge topology. The maximum inductor current $i_{L,max}$ per phase is 150 A, which results in total of 750 A. The power supply side voltage V_{PSU} is in the range from 200 V (minimum FC) to 850 V (maximum battery) and the traction network voltage V_{TN} is in the range from 800 V (minimum but should be above nominal V_{PSU}) to 900 V (absolute maximum), here V_{TN} is set to 850 V. The system operates in Boundary Conduction Mode (BCM) with a variable switching frequency f_{sw} in the range of 20 kHz to 140 kHz and in Discontinuous Conduction Mode (DCM) with a fixed switching frequency f_{sw} of 140 kHz.

For our considerations the focus is on the BCM and DCM in boost mode operation, which is the most frequent use case in this application and the energy is converted from the power supply side (PSU) to the traction network (TN) side [3]. In Fig. 2 the 150 selected OPs are shown which are used to analyze EMI behavior over the entire operating area at $V_{TN} = 850$ V and $i_{L,max} = 150$ A with a maximum power of 120 kW per phase. The selected V_{TN} can be assumed to represent the worst-case scenario for CM disturbances in boost mode, since lower voltages result in lower interference levels. The DCM mode is colored in green and the BCM mode is shown in blue.

To gain a deeper understanding of the behavior of the AHBPC, we will first examine the influence of the switching frequency f_{sw} and the duty cycle δ on the converter behavior within the output power operating range for a single phase shown in Fig. 2.

Figure 3 illustrates the relationship between the selected OPs with different output powers and the variable switching frequency f_{sw} by showing the

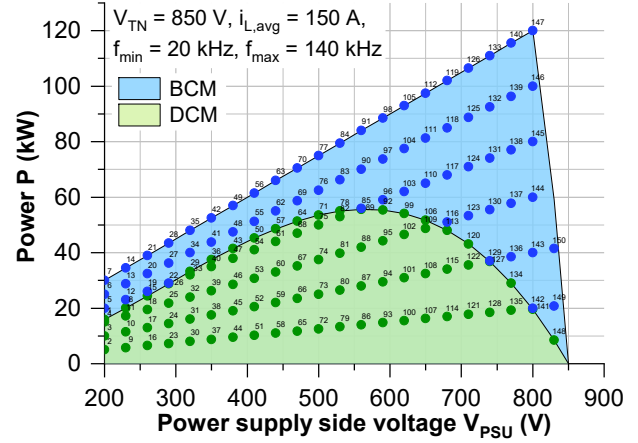


Fig. 2 Operating range of the AHBPC for a single phase with selected OPs (marked with numbers) and labelled BCM (blue) and DCM (green) areas

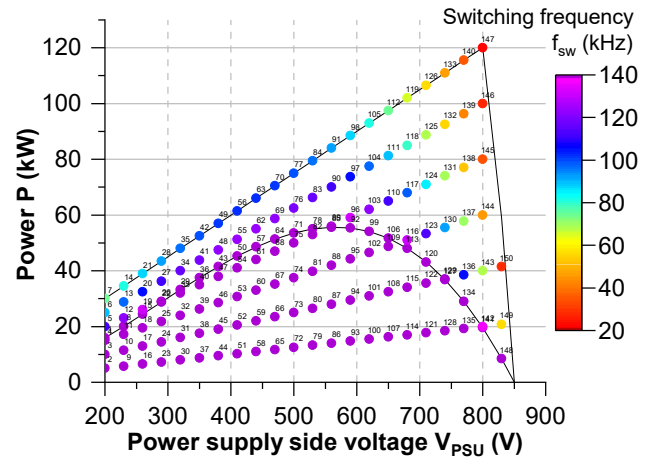


Fig. 3 Output power operating range of the DC/DC converter for a single phase plotted vs. PSU voltage; switching frequency f_{sw} for each selected OP (cf. Fig. 2) added as color-coded third parameter

switching frequency range as a third parameter in the output power curves. In DCM mode, the switching frequency is fixed at 140 kHz and the output power is set by specifying the duty cycle. In BCM mode, the switching frequency and duty cycle are adjusted so that a triangular current waveform without offset is achieved for each phase. This results in low switching frequencies lower 90 kHz for $V_{PSU} > 600$ V in order to reach high output power levels and, consequently, high phase currents $i_{L,avg}$.

In Fig. 4, the duty cycle δ is plotted as a second control parameter across the selected OPs in color-coded form. Unlike the switching frequency in Fig. 3, the duty cycle decreases monotonically over a wide range in Fig. 4, starting at low V_{PSU}

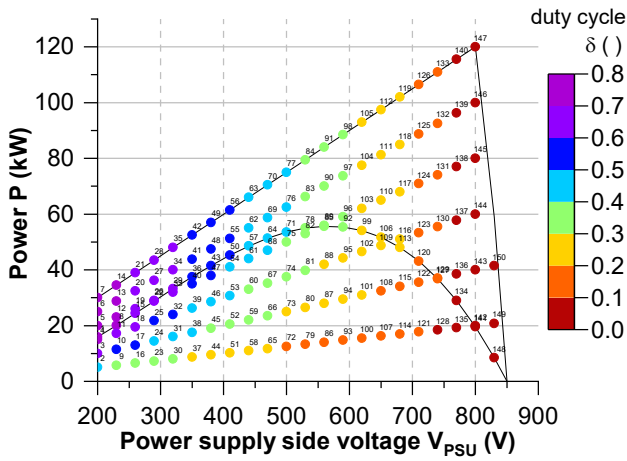


Fig. 4 Output power operating range of the DC/DC converter for a single phase plotted vs. PSU voltage; duty cycle δ for each selected OP (cf. Fig. 2) added as color-coded third parameter

values and continuing down to small duty cycles at $V_{PSU} = 850$ V.

3 Methodology and Design Workflow

In this chapter the methodology for the automated simulation-based design workflow including the description of the individual steps for the AHBPC is described. The workflow can be divided into three areas - modeling, automation, and prediction - and is broken down into a total of nine individual calculation and analysis steps (cf. Fig. 5). Selecting EMI-critical OPs in a frequency-variable system and manually simulating individual OPs can be cumbersome. With the automated EMI simulation workflow, graphical representations can be quickly generated across a wide range of OPs. Changes to converter parameters within the operating range can be implemented flexibly and evaluated rapidly. The goal is to provide a tool that supports EMI filter design and clarifies the dependencies of system parameters with regard to EMI.

3.1 Modelling

In the first part of the simulation-based workflow, the necessary CE simulation models are prepared (cf. Fig. 5). A functional electrical simulation that models the characteristic current and voltage waveforms at various OPs is a useful starting point. In our case, a double-pulse simulation for the AHBPC was available in LTspice. In Step 1, the system components are analyzed with the necessary, non-negligible parasitic properties. This

primarily concerns the power module used, the DC link, and the inductance of the buck-boost converter. The RF models and the parasitic properties of the components result from measurements performed on existing components (e.g., using an impedance analyzer (IA)) and from information in the datasheets of the selected components.

In Step 2, separate simulation models are set up based on the converter characteristics, divided between the EMI disturbance modes CM and DM [6]. The relevant converter and system components are included in the equivalent circuits according to the respective EMI disturbance modes and supplemented with the exciting V_{CM} and I_{DM} noise sources. The model also includes a line impedance stabilization network (LISN) in accordance with the applicable EMC standard, as well as coupling paths and the grounding concept at system level. For the early prediction of CE, the CM and DM equivalent circuits are designed such that, on the one hand, they include all necessary coupling paths and parasitic characteristics to ensure sufficient accuracy and, on the other hand, are kept as streamlined as possible so that the modeling and simulation time for the automated process can be minimized [5]-[7].

In total, we have developed one CM equivalent circuit and two DM equivalent circuits for evaluating the CE in the present AHBPC system. This is because, in the AHBPC system, the input and output terminals of the DC/DC converter are located on the same side of the converter housing and close to each other due to construction constraints [3]. Furthermore, the negative terminals are connected to each other, resulting in 3 available terminals (see Fig. 6). A tri-port approach is intended, combining the conventional input and output filters for the DC/DC converter into a single EMI filter to be developed. To define the filter requirements, the CM interference is analyzed across all three terminals, and the DM interference is analyzed on the TN side and on the PSU side, resulting in three equivalent models.

As previously mentioned, the CM and DM disturbance modes are modeled in the equivalent circuits using parameterizable V_{CM} and I_{DM} noise sources. To model the interference level with sufficient accuracy, the waveform of the noise voltage or current is modeled and simulated in the time domain. With knowledge of the switching frequency (and its harmonics) present at the evaluated OP, the `.four` directive implemented in LTspice is used for the subsequent automated calculation of the sought CE levels.

During the development process of the CM and DM simulation models, a limited verification was

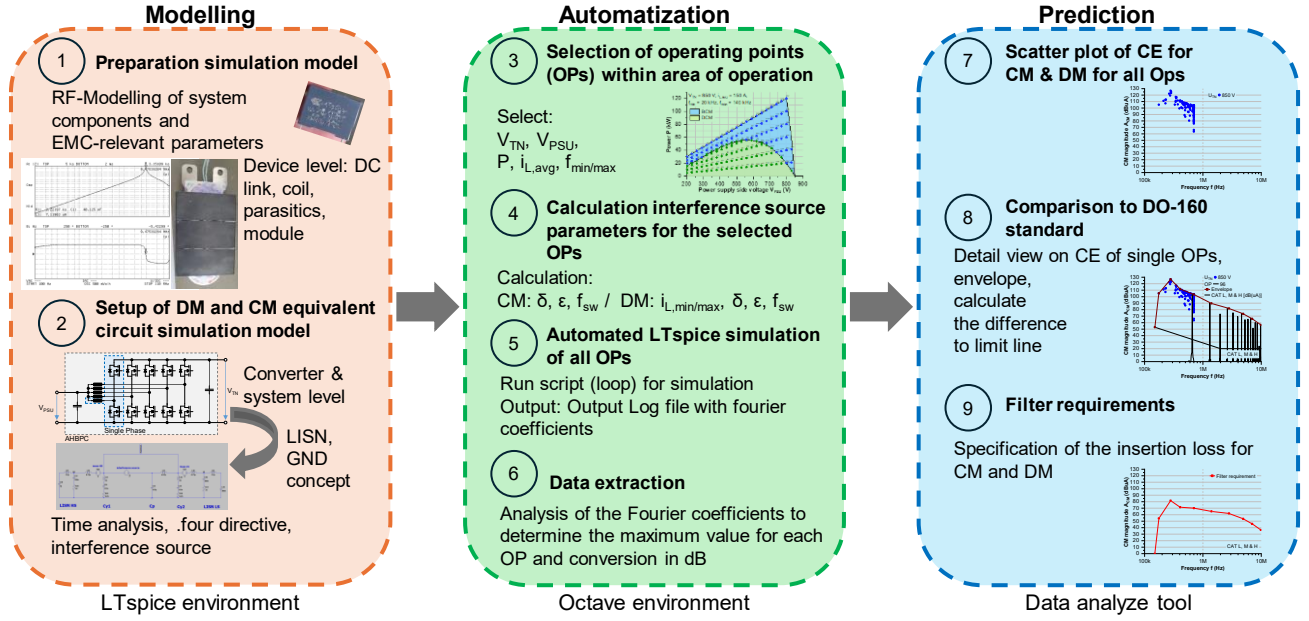


Fig. 5 Methodology of the automated simulation-based design workflow for prediction of CE and the definition of filter requirements

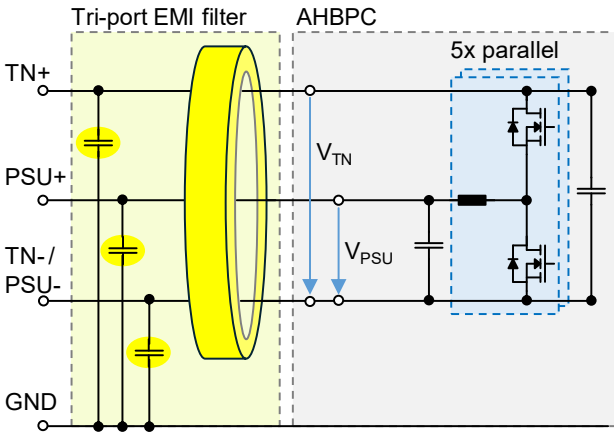


Fig. 6 Proposed topology of the tri-port EMI filter for the AHBPC

performed by comparing the simulation results with CE measurements of a first prototype with limited power and simplified control methods. The validation was performed only at low and medium output power levels at a few individual OPs, but showed good agreement with the simulated CE levels.

Through modeling of elements at the device, converter, and system level, as well as the setup of the CM and DM equivalent circuits including LTspice instructions and verification, the modeling step is done, and the simulation can now be embedded into the automatization environment.

3.2 Automatization

The second part of the workflow focuses on automating the simulation and evaluating them for various OPs (cf. Fig. 5). Step 3 defines the operating area by selecting the converter parameters: power P , input and output voltages V_{PSU} , V_{TN} , inductor average current per phase $i_{L,avg}$, switching frequency range $f_{min/max}$ and specifying the location and number of the OPs within this defined area, as shown in Fig. 2.

For each defined OP in Fig. 2, Step 4 uses the known equations for boost operation to automatically calculate the duty cycle δ and zero-current interval ratio ϵ for DCM mode (in CCM $\epsilon = 1$), the minimum and maximum inductor current $i_{L,min/max}$, and the switching frequency f_{sw} as a function of the specified parameters. The calculated values are used to parameterize the noise sources: the DC-link voltage, δ and ϵ , and the switching frequency are used as input variables for the CM noise source; the inductor current, the duty cycle, and the switching frequency serve as parameters for the DM noise source. To efficiently calculate these quantities, the input variables are organized as vectors, and the results are stored in matrix notation for the range of OPs.

In Step 5, the implemented script automatically triggers one simulation in LTspice for each defined OP based on the established result matrix. As a result, the script receives the simulated and extracted Fourier coefficients of the CM, DM-PSU,

and DM-TN noise currents, as determined by the Fourier Series in LTspice. These coefficients are then evaluated in Step 6 for each OP, and only the highest noise level is converted into decibel (dBuA) and stored in the result matrix. Coefficients below 150 kHz (start of the limit line) are not taken into account.

3.3 Prediction

In the third part of the workflow, the CE values for each defined OP are displayed graphically based on the simulation results obtained in the second part of the workflow (cf. Fig. 5). We have therefore decided to display only the highest interference level for each OP, since superimposing the noise spectrum of more than three OPs quickly becomes confusing, and such a representation is of little help in evaluating the noise of 150 OPs. Accordingly, Fig. 7 shows the highest CM interference level per OP in gray for all evaluated OPs, rather than multiple CM interference spectra; in addition, the CM interference spectrum for OP no. 132 is shown in blue as an example. The known literature focuses on single individual OP and thus on a fixed switching frequency of the system, as shown here in the example for OP no. 132. It is clear that, for a spectrum with only one OP, the levels are underestimated compared to the results of a frequency-variable system where all OPs are taken into account. By adding a color scale to the scatter plot, e.g. for switching frequency, effects of the DC/DC converter and its operating parameters on CE can be highlighted and will be discussed in the next chapter. Using the implemented script and the LTspice simulation, the frequency range under consideration is limited to frequencies below 1 MHz, since the maximum simulated interference level is restricted to the range between 150 kHz and the selected maximum switching frequency for five phases (see Fig. 7). However, the script offers the option of either including additional maximum values in addition to the highest simulated noise level per OP or using the order of the extracted Fourier coefficients (1st, 2nd, 3rd harmonics) for the OPs to cover the frequency range above 1 MHz. For the sake of clarity, this option has been omitted here.

The proposed DC/DC converter equipped with the developed EMI filter should meet the airborne equipment standard DO-160G section 21-4 for conducted RF emissions in category L, M & H. The permissible limits for all categories of this standard are shown in Fig. 8 and are defined in dBuA using the current measurement method.

In Step 8 of the proposed workflow, the envelope is derived from the individual simulated noise lev-

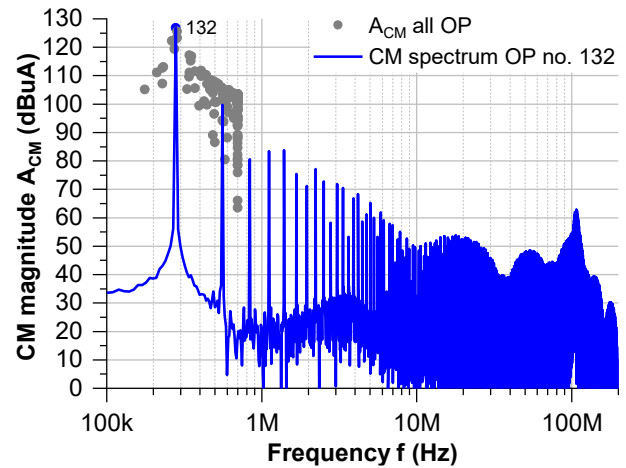


Fig. 7 Simulated CM interference scatter plot (gray) for all OPs and as example a single CM CE spectrum for OP no. 132 (blue)

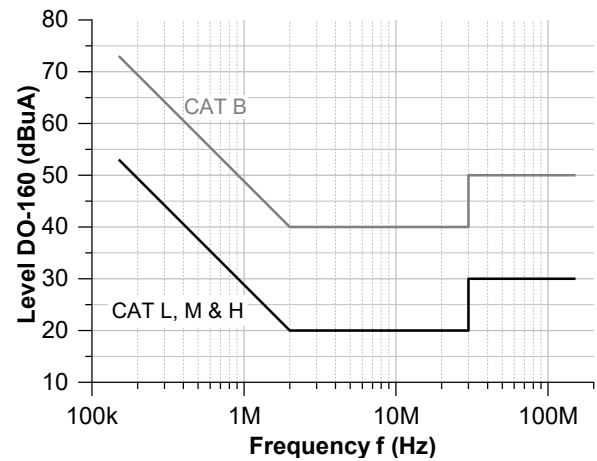


Fig. 8 Limit level for DO-160 standard, section 21-4, maximum level for power lines

els, and this curve is subtracted from the selected limit line to calculate the filter requirements. The corresponding plots will be discussed in Section 4. Finally, in Step 9 we can derive the required filter specifications regarding the insertion loss to be achieved for the CM and DM interference.

For EMI filter design, the frequency range under consideration up to 10 MHz is sufficient and EMI filter components can be dimensioned. Hence, the CE simulation model doesn't need to be able to predict the emissions in the MHz range above 10 MHz; moreover, it is not capable doing so, since EMI in the higher frequency range is primarily caused by inductive and capacitive coupling, which cannot be determined in an early prototype stage. It should also be noted that the later insertion loss of the designed EMI filter will not exactly match the curve shape specified in the filter re-

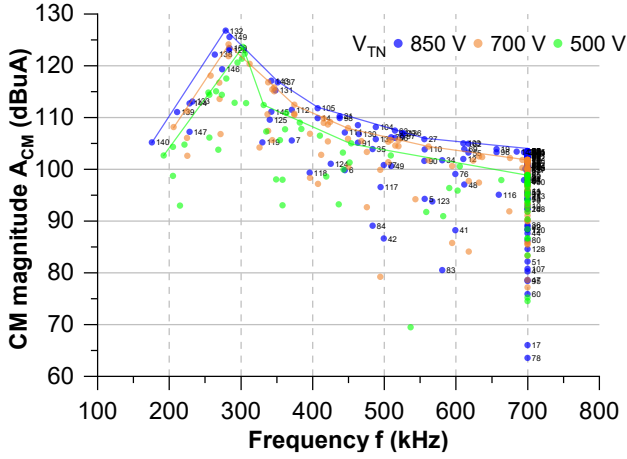


Fig. 9 Maximum CM magnitude A_{CM} for each selected OP of V_{TN} at 850 V in blue (cf. Fig. 2) an additional V_{TN} at 700 V (orange) and 500V (green) plotted vs. frequency; supplemented with their respective envelopes

quirements; rather, it is determined by the topology and filter component arrangement. The values of the filter components are determined by attenuation in the frequency range below 1 MHz and a little safety margin is most typically planned into the sizing of the EMI filter.

The workflow shown allows a system-related EMI filter design based on the early development status of the AHBPC. The authors are aware that the workflow described here loses some accuracy due to various simplifications, but provides a quick tool for the analysis of a frequency-variable system with many different OPs in a short time and at an early stage of development, allowing a rough estimation of the filter volume.

4 Results and evaluation

This section will take a closer look at the results which are generated in the third block of the workflow. The results distinguish between CM and DM.

4.1 Common mode interference spectra

In Fig. 9 the results of the simulated maximum CM magnitude A_{CM} for three different V_{TN} are shown for the operating area of the DC/DC converter. The individual numbered data points in blue for V_{TN} at 850 V correspond directly to the OPs selected in Fig. 2. The other two scatter plots are for V_{TN} values at 700 V (orange) and 500 V (green). Various V_{TN} values are taken into account to analyze the influence of the DC link voltage V_{TN} together with the power semiconductors on the CM interference

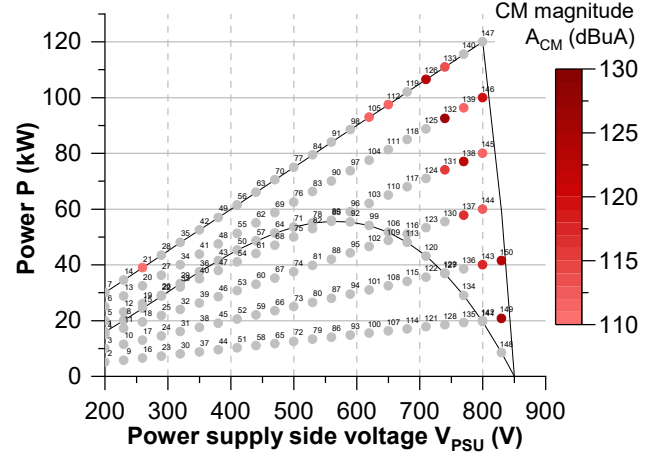


Fig. 10 Output power operating range of the DC/DC converter for a single phase plotted vs. PSU voltage; simulated CM magnitude A_{CM} above 110 dBuA for each selected OP (cf. Fig. 2) added as color-coded third parameter

spectrum. As shown by the blue values for V_{TN} at 850 V in Fig. 9, OPs with V_{PSU} larger than 700 V lead to the highest noise magnitudes. The CM magnitudes decrease with increasing frequency and this behavior can be described by the waveform of the CM noise source: The CM noise source is a trapezoidal voltage source with constant V_{TN} . A trapezoidal signal converted in the frequency domain attenuates by 20 dB per decade after its inflection point, as can be seen here. The envelopes of the individual scatter plots depending on V_{TN} show, that the CM noise levels depend significantly on the selected value for V_{TN} : as the DC link voltage V_{TN} decreases, the overall interference level drops across the frequency range under consideration. This is because the amplitude of the CM noise source is proportional to the applied voltage. It should be noted that CM CEs depend less on the converter parameters (switching frequency, duty cycle) themselves and more on the system configuration. Notable factors here include parasitic capacitance and inductance of the supply line, which influence the peak at 280 kHz.

In addition, the resulting simulated maximum CM magnitudes were superimposed on the selected OPs shown in Fig. 10. Within the resulting CM magnitude range of 60 dBuA to 130 dBuA, only the top third, starting at 110 dBuA, was highlighted in the color scale. It is easy to see that the maximum CM magnitudes do not occur at the maximum output powers, but rather at high V_{PSU} values and operation in BCM mode at low switching frequencies (cf. Fig. 3); about 78% of the OPs have CM magnitudes A_{CM} in the range of 90 dBuA to 110 dBuA.

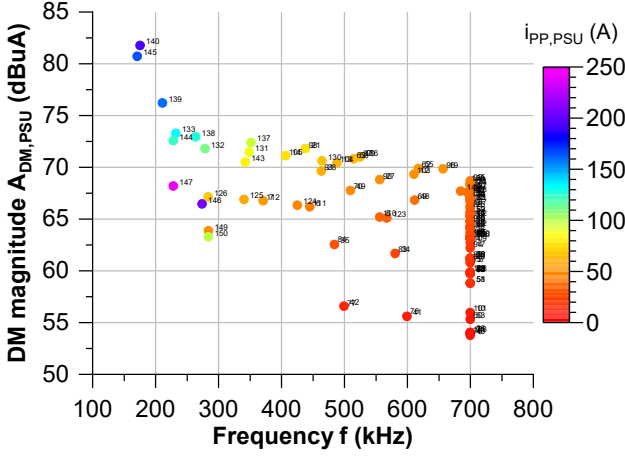


Fig. 11 Maximum DM-PSU magnitude $A_{DM,PSU}$ for each selected OP (cf. Fig. 2) plotted vs. frequency; input current ripple at PSU side $i_{PP,PSU}$ of the DC/DC converter added as color-coded third parameter

4.2 Differential mode interference spectra

In this section, we will now discuss the results of the two DM equivalent circuits on the TN side and on the PSU side as well as the influence of their five phase peak-to-peak (PP) currents on these results.

The noise sources in the DM equivalent circuits are current sources. It should be noted at this point that the waveforms of the DM noise sources in the time domain correspond to a triangle wave for the PSU side and a sawtooth wave for the traction network side.

To show the impact of the results, the simulated DM noise current were evaluated based on their peak-to-peak (PP) value from the superposition of the five phase currents and used for the illustration. The simulation results for the maximum DM magnitude at the PSU side $A_{DM,PSU}$ plotted vs. frequency are depicted in Fig. 11. As a third parameter the input current ripple of the five phases at the PSU side of the DC/DC converter is color-coded for each OP in a range from 0 A to 250 A. A continuous color scale across the frequency range is visible. In DCM operating mode, the simulated DM magnitudes of the AHBPC remain at 700 kHz throughout (which is five times the maximum switching frequency of 140 kHz) with values of up to 70 dBuA, covering below $i_{PP,PSU}$ values of 45 A.

For a more detailed analysis of $i_{PP,PSU}$ values between 45 A to 250 A the illustration in Fig. 12 is analyzed with the simulated maximum DM magnitudes $A_{DM,PSU}$ superimposed on the selected OPs. Within the resulting DM magnitude range of

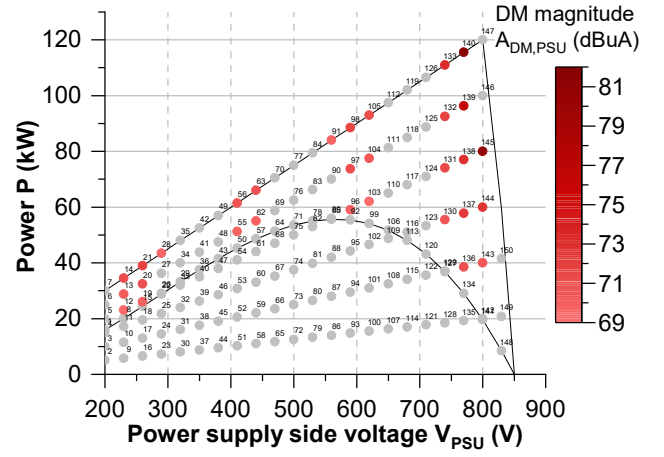


Fig. 12 Output power operating range of the DC/DC converter for a single phase plotted vs. PSU voltage; simulated DM magnitude $A_{DM,PSU}$ above 70 dBuA for each selected OP (cf. Fig. 2) added as color-coded third parameter

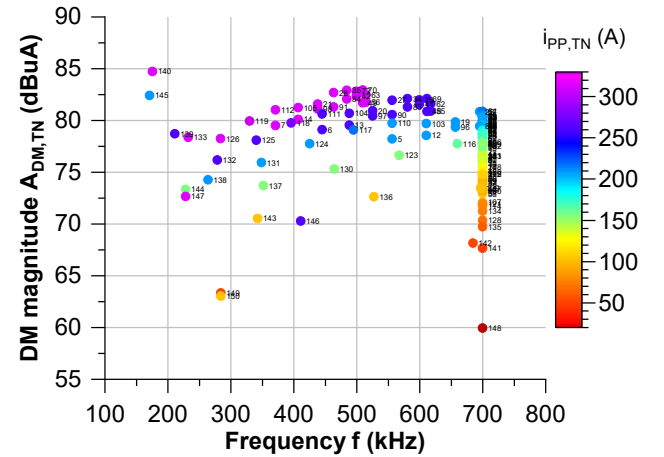


Fig. 13 Maximum DM-TN magnitude $A_{DM,TN}$ for each selected OP (cf. Fig. 2) plotted vs. frequency; output current ripple at the TN side $i_{PP,TN}$ of the DC/DC converter added as color-coded third parameter

50 dBuA to 85 dBuA, only the top 46%, starting at 69 dBuA, was highlighted in the color scale. Clusters of OPs can be identified, values below 650 V_{PSU} having an $i_{PP,PSU}$ of less than 100 A, and values above 650 V_{PSU} having values of $i_{PP,PSU}$ up to 250 A. Overall, 19% of the OPs have DM magnitudes $A_{DM,PSU}$ above 69 dBuA and are located in the BCM region.

In Fig. 13 the results of the simulated maximum DM magnitude at the TN side $A_{DM,TN}$ are plotted vs. frequency. As a third parameter the output current ripple of the five phases at the TN side of the DC/DC converter is color-coded for each OP in a range from 20 A to 330 A. In contrast to the results

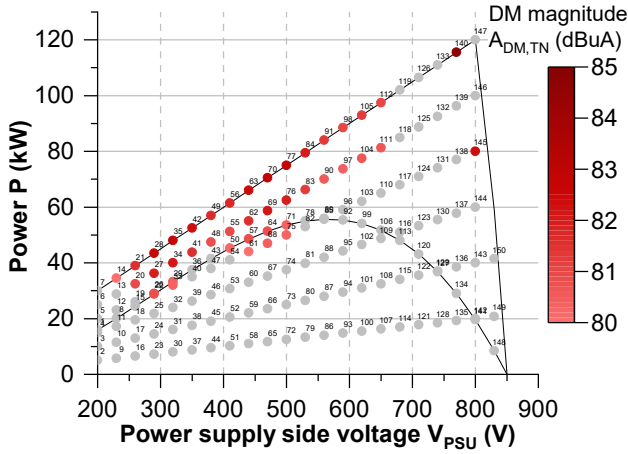


Fig. 14 Output power operating range of the DC/DC converter for a single phase plotted vs. PSU voltage; simulated DM magnitude $A_{DM,TN}$ above 80 dBuA for each selected OP (cf. Fig. 2) added as color-coded third parameter

in Fig. 11 for $A_{DM,PSU}$, the distribution of $A_{DM,TN}$ in Fig. 13 does not show a horizontal color gradient across the frequency range (x-axis), but rather a vertical color gradient along the interference level (y-axis).

In addition, the resulting simulated maximum DM magnitudes $A_{DM,TN}$ were superimposed on the selected OPs shown in Fig. 14. Within the resulting DM magnitude range of 60 dBuA to 85 dBuA, only the top 20% of the values, starting at 80 dBuA, were highlighted in the color scale. Approximately 28% of the OPs have DM magnitudes $A_{DM,TN}$ above 80 dBuA and are located in the BCM mode with single phase $i_{L,avg}$ currents between 100 A and 150 A. It is evident that the levels increase as the inductor current rises. Reducing the ripple current by a factor of two results in interference levels that are approximately 6 dB lower.

The simulation results and the presented workflow approach demonstrate that it is possible to identify the worst case CE across a wide operating range of the system. The automation allows quick adjustments of system parameters, enabling a focused analysis on specific sections of the operating area and facilitating the observation of influences and results.

4.3 Filter requirements for CM and DM

In this section, based on the previous results from the workflow in Section 4.2, we will discuss the resulting filter requirements for the tri-port EMI filter approach mentioned in Section 3.1. As noted there, we distinguish as before between CM, DM-PSU, and DM-TN.

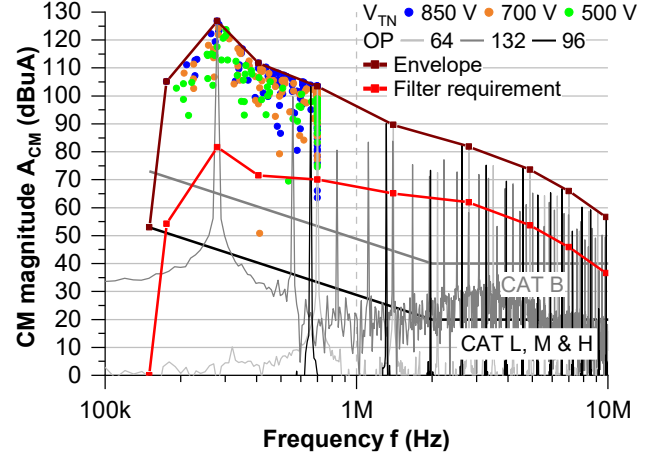


Fig. 15 Simulated CM magnitude A_{CM} for TN voltages 850 V, 700 V and 500 V; CE CM spectrum for OP no. 64, 132 and 96; envelope of the maximum interference levels compared with DO-160 limit lines, in special CAT L, M & H for CM filter requirement

The previous figures show scatter plots for a V_{TN} voltage of 850 V (blue), as specified in Fig. 2. This voltage defines the worst-case scenario for CM CE in boost mode. The following figures are extended to include lower V_{TN} voltages of 700 V (orange) and 500 V (green) for additional reference. In addition, the known limit lines of the DO-160 standard, as shown in Fig. 8, have been included.

To define the filter requirements (red), the highest requirement in CAT L, M, and H (black) is used and compared with the envelope (dark red). Potentially critical EMI OPs for filter design can be derived from the maximum difference of these curves. The CE spectrum of these OPs can enable prediction up to 10 MHz. Likewise, critical points on the limit line at the transition from the decreasing to the linear region should be examined more closely.

For the simulated results for CM and DM one single OP was analyzed in more detail for each. For completeness, however, all three CE spectra are shown in the graphs.

4.3.1 Common mode filter requirements

In Fig. 15 a significant peak in the CM scatter plot is observable, which is attributed to resonance with the cable model. OP no. 132 was selected because it exhibits the highest envelope levels. The spectrum of OP no. 132 decrease with increased frequency. For the CM part of the EMI filter design, critical values of 54 dB at 176 kHz and 82 dB at 279 kHz are observed, which significantly influence the determination of the EMI filter cutoff frequency and CM component values as CM choke or Y-capacitances.

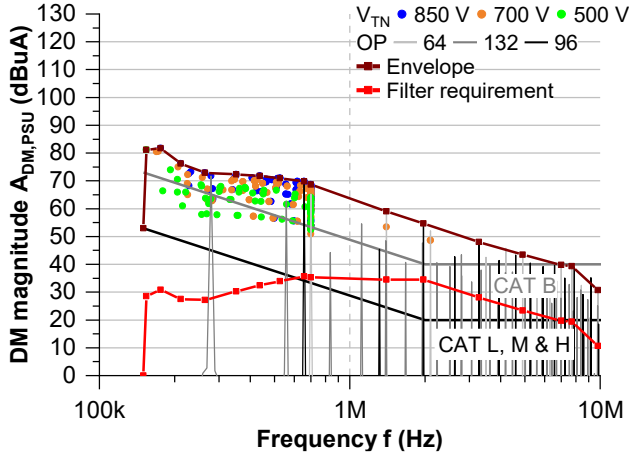


Fig. 16 Simulated DM-PSU magnitude $A_{DM,PSU}$ for TN voltages 850 V, 700 V and 500 V; CE CM spectrum for OP no. 64, 132 and 96; envelope of the maximum interference levels compared with DO-160 limit lines, in special CAT L, M & H for DM-PSU filter requirement

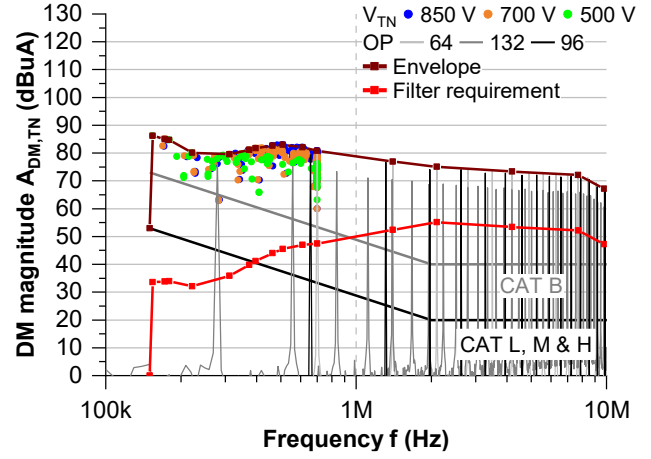


Fig. 17 Simulated DM-TN magnitude $A_{DM,TN}$ for TN voltages 850 V, 700 V and 500 V; CE CM spectrum for OP no. 64, 132 and 96; envelope of the maximum interference levels compared with DO-160 limit lines, in special CAT L, M & H for DM-TN filter requirement

4.3.2 Differential mode filter requirements

At frequencies close to the maximum switching frequency of 700 kHz, Fig. 16 shows an increase in the DM-PSU filter requirements (red). OP no. 96 was selected as the critical EMI OP because it has a first harmonic at 657 kHz, and its third harmonic is therefore at approximately 1.97 MHz, just before the linear transition of the limit line. It can be seen that the DM-PSU filter requirement in this range remains constant at about 35 dB. The DM-PSU spectrum of OP no. 96 decreases with 40 dB per decade at increased frequencies, due to the triangular wave noise source in the time domain mentioned at the beginning of Section 4.2.

As was already the case for DM-PSU (cf. Fig. 16), DM-TN also shows in Fig 15 an increase in filter requirements (red) at frequencies close to the maximum switching frequency of 700 kHz. OP no. 64 was selected as the critical EMI OP because, similar to the previous description, the third harmonic in the transition region of the limit line leads to a maximum difference of 55 dB. In contrast to DM-PSU, the spectrum for DM-TN does not appear to decrease with increasing frequency; the interference levels remain almost constant up to about 8 MHz. This is due to the sawtooth wave noise source in the time domain, which attenuates by only 20 dB per decade in the frequency domain. It thus becomes apparent that a high, constant DM filter attenuation of approximately 50 dB is necessary within a broad frequency range from 1 MHz to 10 MHz.

The DM components of the tri-port EMI filter must be designed separately due to their different char-

acteristics and noise levels in Fig. 16 and Fig. 17. This ensures that the filter is designed as optimally as possible and that the DM components such as DM chokes and Y-capacitors are selected to be as small as possible.

5 Summary and Outlook

This paper demonstrates an automated, simulation-based workflow for predicting CE in a multiphase, frequency-variable, bidirectional DC/DC converter designed for MEA. The approach comprises a three-block methodology: building CM and DM equivalent circuit models, automating the process with a script that generates more than 150 OPs, runs LTspice simulations, extracts Fourier coefficients, and identifies the highest interference levels (in dBuA) per OP, and predicting CE using envelope representations up to 10 MHz and deriving initial filter requirements. The workflow is readily extensible to other multiphase or frequency-variable DC/DC topologies and to additional operating modes. CM and DM interferences and their dependencies on the DC/DC converter parameters and the selected OP are examined. The goal is to define quantitative filter requirements for a passive tri-port EMI filter in the MW range enabling efficient and reliable filter development.

Looking ahead, the next steps include validating the inference results by measurements on a prototype to quantify discrepancies between simulation and measurement and to further calibrate the model. The model will be extended, such as para-

sitic couplings and layout-induced effects, to increase the robustness of filter decisions. Further publications will provide an overview of the sizing and development process of the passive filter as well as CE measurements to validate the shown workflow and effectiveness of the passive filter.

References

- [1] Clean Aviation Joint Undertaking, "Towards Disruptive Technologies for new Generation Aircraft by 2035", 2nd rev. SRIA 2024, Sep. 2024, <https://clean-aviation.eu/sites/default/files/2024-09/2024-Clean-Aviation-SRIA.pdf>.
- [2] Yuan, L., Zhang, J., Liang, Z., Hu, M., Chen, G., & Lu, W., EMI challenges in modern power electronic-based converters: recent advances and mitigation techniques. *Electronics*, 2023, vol. 4, doi: 10.3389/felec.2023.1274258.
- [3] M. Kerscher, N. Schmied, S. Matlok, B. Eckardt and M. März, "Application of Zero Over-voltage Switching in Switched Mode Power Supplies," 2025 Energy Conversion Congress & Expo Europe (ECCE Europe), Birmingham, United Kingdom, 2025, pp. 1-6, doi: 10.1109/ECCE-Europe62795.2025.11238468.
- [4] D. Menzi, L. Imperiali, E. Bürgisser, M. Ulmer, J. Huber and J. W. Kolar, "Ultralightweight High-Efficiency Buck-Boost DC-DC Converters for Future eVTOL Aircraft With Hybrid Power Supply," in *IEEE Transactions on Transportation Electrification*, vol. 10, no. 4, pp. 10297-10313, Dec. 2024, doi: 10.1109/TTE.2024.3375026.
- [5] S. Negri, G. Spadacini, F. Grassi and S. A. Pignari, "Prediction of EMI Filter Attenuation in Power-Electronic Converters via Circuit Simulation," in *IEEE Transactions on Electromagnetic Compatibility*, vol. 64, no. 4, pp. 1086-1096, Aug. 2022, doi: 10.1109/TEMC.2022.3165377.
- [6] S. Kadam, V. M. Iyer and S. Gulur, "Prediction and Mitigation of Common Mode Noise in a Four-Switch Buck-Boost Converter," *2024 IEEE International Communications Energy Conference (INTELEC)*, Bengaluru, India, 2024, pp. 1-6, doi: 10.1109/INTELEC60315.2024.10679018.
- [7] E. Rondon-Pinilla, F. Morel, C. Vollaïre and J.-L. Schanen, "Modeling of a Buck Converter With a SiC JFET to Predict EMC Conducted Emissions," in *IEEE Transactions on Power Electronics*, vol. 29, no. 5, pp. 2246-2260, May 2014, doi: 10.1109/TPEL.2013.2295053.