

# Prediction and Optimization of Near Magnetic Field Produced by Interconnections of Multi-cell Converters

Glauber de Freitas Lima, Fabien Ndagijimana, Yves Lembeye,

Jean-Christophe Crebier

### ▶ To cite this version:

Glauber de Freitas Lima, Fabien Ndagijimana, Yves Lembeye, Jean-Christophe Crebier. Prediction and Optimization of Near Magnetic Field Produced by Interconnections of Multi-cell Converters. PCIM Europe digital days 2021; International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management, May 2021, Online, France. pp.895-902. hal-03352406

# HAL Id: hal-03352406 https://hal.science/hal-03352406

Submitted on 23 Sep 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Prediction and Optimization of Near Magnetic Field Produced by Interconnections of Multi-cell Converters

Glauber de Freitas Lima<sup>1</sup>, Fabien Ndagijimana<sup>1</sup>, Yves Lembeye<sup>1</sup>, Jean-Christophe Crebier<sup>1</sup>

<sup>1</sup> Univ. Grenoble Alpes, CNRS, Grenoble INP, G2Elab, France

Corresponding author: Glauber de Freitas Lima, glauber.de-freitas-lima@grenoble-inp.fr

#### Abstract

This paper consists on developing a generic modeling routine for the prediction and optimization of the near magnetic radiated emission produced by Differential Mode Current (DMC) in the interconnections of multi-cell converters, more precisely Power Converter Arrays (PCAs) in 2D. The PCAs are based on associations of Dual Active Bridges (DAB) Conversion Standard Cells (CSC) for low and medium power applications. They are built, assembled and interconnected based on PCB technologies. An algorithm based on Biot-Savart law and the physical and electrical configurations of a PCA is provided to develop generic models. Then, a comparison between the proposed algorithm and experimental results of a setup mimicking the equivalent loops are presented with two different measurement technologies, validating the theoretical results qualitatively and quantitatively. The methodology can be applied to spatially characterize the emitted near field produced from CSC's interconnections and to develop rules and guidance to minimize it.

## 1 Introduction

The benefits of multi-cell converters for high power and / or high voltage applications are well described in the literature [1]. Splitting of voltage and / or current ratings in any of the following configurations: input-series output-parallel (ISOP), input-series output-series (ISOS), input-parallel output-series (IPOS) or input-parallel outputparallel (IPOP), the global converter can be optimized regarding efficiency, power density, Electromagnetic Interference (EMI) signature and even costs, considering lower rated components and reduced cooling needs [2]-[3].

As presented in [4]-[6], the same benefits of multicell topologies plug-and-play can also be found in low / medium, power / voltage applications. It is shown how a precise characterization of CSCs can be used to predict the characteristics of PCAs based on the implementation of numerous CSCs, as illustrated in Fig. 2 (a). For convenience, the notation PCA<sub>LxC</sub>, is used throughout this paper, in which L and C are the number of lines and columns that composes the PCA, respectively. Fig. 2 (a) presents an example of PCA4x2 composed of low power and low voltage DAB CSCs operated at approximately 250 kHz, designed and manufactured in volume in previous works [6].

Regarding EMC, currently, power converter qualification techniques rely mostly on post prototyping EMC standard compliances. The implementation of PCAs can be seen, therefore, as an important opportunity to predict and / or to optimize the EMI signature of any electrical assembling configuration, thanks to the use of standard elements, such as CSC's filtering and interconnecting routing, as illustrated in Fig. 1. This may significantly increase the speed of power electronics converter design and industrialization, leading to a revolutionary power electronic design automation (P-EDA) [6]-[7].









Fig. 2: (a) (Left side) A 800W step up DC/DC PCA<sub>4x2</sub> (IPOS) prototype (bottom view) highlighting the input (red) output (blue) current sending paths; (Right side) a 100W 20V/5A DC/DC DAB CSC prototype (bottom and top view); (b) Near field produced by a PCB that mimics the interconnections of a PCA<sub>4x3</sub>.

## 2 EMI Characterization

As the typical switching frequencies of power converters are continually increasing with the adoption of WBG devices with very high *di/dt* and *dv/dt*, the modelling of their conducted and radiated emissions becomes very important for standard compliance and self-immunity.

Specifically, the EMI radiated models of power converters [8]-[21], are important approaches for prediction of EMC compliance [22], human exposure [23] and safe converter performance. They can be separated into far field [8]-[11] and near field [9]-[20]. According to [10], they are differentiated by a distance r between the observation point and the radiation source: far field is defined when  $r >> \lambda/2\pi$ , whereas near field is defined when  $r < \lambda/2\pi$ , where  $\lambda$  is the wavelength. The far field, not treated in this paper, is the one that concerns EMC compliances, e.g. CISPR 16-4-2, that defines limit values for the harmonic spectrum ranging from 30 MHz to 40 GHz. The source of the far field is mostly predominant from Common Mode Currents (CMC), usually on the very high frequency range, flowing across the input and output cables [8], and are directly proportional to the length of the conductors [11].

The near field are produced by current loops, therefore, mostly predominant from *di/dt* of DMC, rather than CMC, being directly proportional to the area of the current loop [11]-[12]. While, currently, the near magnetic field cartography [24], is not required on the EMC compliance standards, it is an effective way for diagnosing [20] and

characterizing [16]-[18] spatially the sources of radiation produced by power converters and its correlation with the electrical parameters of the power converter itself. Indeed, due to the short distance, peripherals of a PCA nearby its near field sources, such as driver boards and their paths, sensors, signal conditioning devices and filters are susceptible of undesirable couplings, causing malfunctioning [11] and performance degradation in analog signals [21]. In addition, trendy topics such as Internet of things (IoT) [25] using magnetically coupled communication technologies (NFC, QiWPC, RFID, WCT...) requires more complex and detailed knowledge of the emitted near field to avoid interferences. Therefore, the prior knowledge of the near field helps defining the good location and possible shield needs of the peripherals contained in a PCA.

Finally, there exists transformation formulas that co-relates the far field from near field measurements [26].

#### 2.1 At DAB CSC level

As it is presented in [27], the DAB converter can produce high DM harmonic distortion amplitudes multiple of the double of the switching frequency, depending on operating points and design choice. Therefore, even though it is not on the scope to characterize the EMI signature at the cell level, it is important to understand the harmonic content produced, specifically treated here, by the DAB CSCs.

A single DAB CSC can be summarized into three inner loops between the input and output DC link

capacitors: the two H-bridge commutation cell loops and the AC link loop. The inner loops produce higher harmonic levels over a wider band of frequency, as the DC link capacitors provides attenuation. However, the fixed area of each inner loop are small enough compared the PCA's outer loop areas, that increases with the number of CSCs contained in the PCA. This means that, with the increasing number of CSCs composing a PCA, the near magnetic emission are supposed to exist mostly due to the PCA's interconnections. Neglecting the inner loops, the DAB CSCs are then modeled as DM current sources in parallel to their DC link capacitors, as presented in Fig. 1.

Indeed, depending on the way the CSC interconnects loop are physically implemented, large interconnecting loops can be produced building up the converter configuration, as it will be seen throughout this paper.

#### 2.2 At PCA level

For compliance with CISPR 22 (EN 55022) Class A or B standard (conducted emission), a filter design optimization for DMC of a PCA made out of several DAB CSCs associations is described in [28]. It is pointed out that distributed filters among CSCs, together with a globalized filter at PCA scale, are recommended for systematically mitigating DMC EMI regardless of the electrical configuration of the PCA. If the DMC filter optimization of PCAs is proven effective using mostly a centralized filter, large High-Frequency (HF) current harmonics may circulate in the interconnection among CSCs (see the bars marked in red and blue on Fig. 2 (a)), either acting as a typical unintentional antenna or creating harmful mutual magnetic induction couplings. Such phenomenon may impose difficulty for EMC compliance and the good operation of the converter. With respect to HF differential current paths, the PCA presents large outer loops, made up of the CSC's interconnection (bus bars).

In [12], it is verified that the bus bars of SiC Power Modules are the ones affecting the most on the near field, mostly on the *z*-axis; and it is shown how such predicted field can be used to find the needs of locally shielding or immunizing sensitive devices. As it is discussed in the reference, guidance is already presented: firstly, dynamic current balancing (that can be improved with circuit symmetry and distributed driving approaches), useful therefore for parallel conceptions (ISOP, IPOP, IPOS); and, secondly, physical interleaving of positive and negative bus bars.

The different possible combinations to close PCA's interconnection loops, and therefore, different geometric loop combinations, can directly influence the resulting near field. Four possible combinations are the object of discussion presented here. For simplification purposes, the discussion presented throughout this paper makes some electrical neglects and assumptions:

- CMC harmonics are neglected, meaning that either each CSC has a CM filter on its input and output that entirely suppress CMC, or that, at the observed frequency band, CM harmonics are negligible
- Thus, resulting only in DM currents (which can be partially filtered locally or from a centralized point of view). If only centralized filter is assumed, all the DM harmonics are circulating in the PCA interconnections. If partially locally filtered, less harmonics are circulating in the loops;
- All CSCs are considered identical and supposed to generate the same conducted emission contents. Besides, the CSC presents a rotational symmetry, due to the DAB topology inherited feature as well as due to a PCB routed purposely designed;
- The series and parallel connections are inserted on the same paths. Notice, however, that parallel connections will increase the current ratings, and therefore, larger near magnetic field emission;
- The phase-shifts between input and output harmonic currents are neglected;
- Magnetic elements and MOSFETs switching cells radiated emissions are ignored. In practice this means that these components are locally shielded, or that superposition theorem can be further applied;
- Only outer interconnecting loops are considered, meaning that inner loops are small enough for not considering their effects, or that superposition theorem can be further applied;
- Frequency dependent and parasitic effects are not evaluated. Such scenario for the DAB is roughly approximatively for operation within the ZVS region and an optimized layout is assumed.
- No mutual coupling between input and output currents is computed, and its effect is neglected; This means that the loops are considered to be fed by independent current sources;

With respect to the loops, simplification statements that allow meaningful results are also assumed.

Fig. 3 is an example of the loop patterns present on an ISOS  $PCA_{4x3}$  that summarizes the following list of assumptions, rules and conclusions:



- Fig. 3: (a) Example of the assumed input (red) and output (blue) current sending paths of typical ISOS PCA<sub>4x3</sub>;(b) The equivalent resulting interconnect loops by connecting through the PCA's left-hand (path A); (c) The equivalent resulting interconnects loops by connecting through the PCA's right-hand (path B).
- Only 2D segments on predefined orthogonal paths are allowed;
- Even though multiple segments occupy same position or cross by, no short-circuit is produced. This can be interpreted that, in practice, the segments are located only close enough at in any plane;
- Opposite magnetic fields due to opposite current directions very close to each other will cancel out the resulting near magnetic field emission;
- There are only 2 returning path options available. The returning path A – through the PCA's left-hand side, and the returning path B – through the PCA's right-hand side;
- Thus, forming 2 patterns of current loops, larger or smaller rectangular shape, depending on the input and output current paths (see Fig. 3 (b) and (c)), which their sizes can be expressed with respect to PCA's characteristics;
- All the DMCs must return to their origin points. The point *a*<sub>1</sub>, for input DMC and *a*<sub>2</sub> for output ones;
- Specifically, a returning path A causes a larger loop for the input current and a smaller loop for the output current, while a returning path B causes smaller loop for input current and larger one for output current;
- Each CSC can be positioned only vertically, and they can only rotate 180° over the *z*-axis, keeping their electrical and physical characteristics unaltered;

# 3 Magnetic field produced by interconnections with respect to PCA architectures

In Fig. 4, it is presented a simple algorithm [29] for prediction and optimization of near field due to PCA's interconnections based on Biot-Savart law [30]-[31] inspired by the use of coordinate transformations [32], highly used for example on computer graphics. It is possible to express analytically the magnetic field of a set of finite wires that have any directions or lengths over the PCA plane. Such method can also be identified as a PEEC method [13],[32] in which the need of subdivision into smaller elements is not necessary, as in a FE, and, therefore, quicker to generate results.





In Fig.5, it is presented the theoretical results of the four loop combinations of a PCA<sub>4X3</sub>  $\pi$ : z = 10 mm, indicating that B<sub>1</sub>A<sub>2</sub> combination are the least harmful by a factor *k* of approximately 3 compared to what seems to be the worst case A<sub>1</sub>A<sub>2</sub>. Indeed, the higher this distance, the higher this factor is.



**Fig. 5:** Module of the magnetic field (*z*-component) results produced by all four-loop combinations of a PCA<sub>4x3</sub> over the plane  $\pi$ : *z* = 10 mm: (a) A<sub>1</sub>A<sub>2</sub>; (b) B<sub>1</sub>B<sub>2</sub>; (c) A<sub>1</sub>B<sub>2</sub>; (d) B<sub>1</sub>A<sub>2</sub>. The input (red segments) and output (black segments) current sending paths as well as the CSCs (black rectangles) are presented for visualization. The circles represent the locations of the calculated average magnetic field values in A/m.

#### 4 Experimental EM Cartography

An experimental setup was built with a PCB mimicking the four possible loop combinations, terminated with a 50 Ohms resistor and connected to two synchronized outputs of a signal generator set at a sinusoidal 20 Vpp - 5 MHz, resulting in circulating currents of approximately 200 mA. In Fig. 6 (a), it is presented the layout of the PCB traces, highlighted by circles indicating the physical adaptions needed to overcome unrealistic theoretical assumptions above mentioned. As

portrayed in Fig. 6 (b), two measuring methods were used: one using a H10 EMC near-field probe from Tekbox and another one using EM-Scanephone V1 from Luxondes. In Fig. 6 (b) it is portrayed the setup using plexiglas sheet located above the PCB in order to maintain the equipment well parallel at desired fixed distances.

Luxondes



Fig. 6: (a) Layout of the PCB for the tests; (b) Setup for the near field cartography: Tekbox and Scanephone.



**Fig. 7:** Module of the measured magnetic fields (*z*-component) produced by all four loop combinations of a PCA<sub>4x3</sub> over the plane  $\pi$ : *z* = 10 mm: (a) A<sub>1</sub>A<sub>2</sub>; (b) B<sub>1</sub>B<sub>2</sub>; (c) A<sub>1</sub>B<sub>2</sub>; (d) B<sub>1</sub>A<sub>2</sub>. The input (red segments) and output (black segments) current sending paths as well as the CSCs (black rectangles) are presented for visualization. The circles represent the locations of the measured magnetic field over the plane using a H10 probe. Values inside the plotting are corresponding to the actual measured magnitudes converted into A/m.



**Fig. 8** Module of the measured magnetic fields (*z*-component) produced by all four loop combinations of a PCA<sub>4x3</sub> over the plane  $\pi$ : *z* = 10 mm: (a) A<sub>1</sub>A<sub>2</sub>; (b) B<sub>1</sub>B<sub>2</sub>; (c) A<sub>1</sub>B<sub>2</sub>; (d) B<sub>1</sub>A<sub>2</sub> using Scanephone.

At distance of 10 mm of the PCB, the near field probe was connected to an oscilloscope. At total, 35 measurements, as seen on the white circles, were performed for each combination. Their values in volts were computed and converted into mA/m according to the antenna factor AF<sub>th</sub> of 48.86 db A/m.V at 5 MHz found in practice through a TEM calibration. The location of the measurements were strategically set to allow better interpolation results. A simple linear

interpolation function on Matlab was used, providing accurate quantitative results regarding magnitude and shape compared to theoretical plotting.

For the Scanephone, the accounted distance was 15 mm and the measurements are presented in Fig. 8, presenting good results as well. Such approach allowed analyzing the experimental results in a more qualitative way, compared to previous method.

# 5 Conclusion

In this work, an algorithm and methodology for comparing the near field radiated emissions caused by PCA's interconnections assembled in four different ways has been proposed and validated experimentally with 2 different measurement methods. Such algorithm, based on simplifying assumptions and rules, is a straightforward approach that allows not only verification, but also spatial and magnitude near field emission optimization with respect to the filtering distribution, peripherals placement and needing shield. The methodology is simple to follow and to run on optimization processes, avoiding heavy simulations, as in FEMs, or cosimulations. The theoretical and practical results suggest that the current paths on a PCA may be very impactful not only on the near emission, but also the far field emission, as the notion of opposite current rule on close seaments is still maintained. For future studies. the complexification of the algorithm with respect to parasitic and frequency dependent effects, current density, accurate physical routings, increase of degree of freedom in a 3D direction, and other radiating sources will be updated according to the needs verified in practice.

## 6 Acknowledgment

This research work has been carried out with the co-funding support FRI Booster Mamaatec from Auvergne Rhône Alpes state in France in the frame of European Union FEDER program. The authors would like to thank Jalal Alaa Eddine for the H10 Tekbox EMC probe calibration, indispensable for the accurate results.

### 7 References

- M. Kasper, D. Bortis, and J. Kolar, "Scaling and Balancing of Multi-Cell Converters," in Proc. of the International Power Electronics Conference (IPEC), 2014.
- [2] M. Kasper, C. Chen, D. Bortis, J. W. Kolar and G. Deboy, "Hardware verification of a hyper-efficient (98%) and super-compact (2.2kW/dm3) isolated AC/DC telecom power supply module based on multicell converter approach," 2015 IEEE Applied Power Electronics Conference and Exposition (APEC), Charlotte, NC, 2015, pp. 65-71, doi: 10.1109/APEC.2015.7104333.
- [3] T. A. Meynard, H. Foch, P. Thomas, J. Courault, R. Jakob and M. Nahrstaedt, "Multicell converters: basic concepts and industry applications," in IEEE Transactions on Industrial Electronics, vol. 49, no. 5,

pp. 955-964, Oct. 2002, doi: 10.1109/TIE.2002.803174.

- [4] A. G. Andreta et al., "A High Efficiency and Power Density, High Step-Up, Non-isolated DC-DC Converter Based on Multicell Approach," CIPS 2018; 10th International Conference on Integrated Power Electronics Systems, Stuttgart,Germany, 2018,pp.1-5.
- [5] T. Lamorelle, A. Andreta, Y. Lembeye, J. -. Crébier and J. Podvin, "Design level power electronics building block: Industrial framework for DC-DC conversion," 2018 IEEE International Conference on Industrial Technology (ICIT), Lyon, 2018, pp. 670-675, doi: 10.1109/ICIT.2018.8352258.
- [6] Andreta, A.; Lavado Villa, L.F.; Lembeye, Y.; Crebier, J.C. A Novel Automated Design Methodology for Power Electronics Converters. Electronics 2021, 10, 271. <u>https://doi.org/10.3390/electronics10030271</u>
- [7] A. J. Marques Cardoso, "Power Electronics Design Methods and Automation in the Digital Era: Evolution of Design Automation Tools," in IEEE Power Electronics Magazine, vol. 7, no. 2, pp. 36-40, June 2020, doi: 10.1109/MPEL.2020.2988077.
- [8] J. He, Z. Guo and X. Li, "Mechanism Model and Prediction Method of Common Mode Radiation for a Nonisolated Very-High-Frequency DC–DC Converter With Cables," in IEEE Transactions on Power Electronics, vol. 35, no. 10, pp. 10227-10237, Oct. 2020, doi: 10.1109/TPEL.2020.2978278.
- [9] Y. Zhang, S. Wang and Y. Chu, "Analysis and Comparison of the Radiated Electromagnetic Interference Generated by Power Converters With Si MOSFETs and GaN HEMTs," in IEEE Transactions on Power Electronics, vol. 35, no. 8, pp. 8050-8062, Aug. 2020, doi: 10.1109/TPEL.2020.2972342.
- [10] B. Zhang and S. Wang, "A Survey of EMI Research in Power Electronics Systems With Wide-Bandgap Semiconductor Devices," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 8, no. 1, pp. 626-643, March 2020, doi: 10.1109/JESTPE.2019.2953730.
- [11] Y. Zhao et al., "The radiated EMI noise modeling and features analysis on the basis of Smart Grid Equipments," 2014 International Symposium on Electromagnetic Compatibility, Gothenburg, 2014, pp. 1199-1202, doi: 10.1109/EMCEurope.2014.6931086.
- [12] B. Zhang, H. Zhao and S. Wang, "Near Magnetic Field Emission Analysis for IGBT and SiC Power Modules," 2020 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI), Reno, NV, USA, 2020, pp. 411-416,doi: 10.1109/EMCSI38923.2020.9191684.
- [13] J. Aime et al., "Prediction and measurement of The magnetic near field of a static converter," 2007 IEEE

International Symposium on Industrial Electronics, Vigo, 2007, pp. 2550-2555, doi: 10.1109/ISIE.2007.4375009.

- [14] Z. Ariga and K. Wada, "Analysis and evaluation of near field noise voltage on power electronics circuits," 2009 International Conference on Power Electronics and Drive Systems (PEDS), Taipei, 2009, pp. 1014-1019, doi: 10.1109/PEDS.2009.5385836
- [15] C. Labarre and F. Costa, "Circuit Analysis of an EMI Filter for the Prediction of its Magnetic Near-Field Emissions," in IEEE Transactions on Electromagnetic Compatibility, vol. 54, no. 2, pp. 290-298, April 2012, doi: 10.1109/TEMC.2011.2159563.
- [16] C. Labarre, F. Costa and J. Ecrabey, "Correlation between the near magnetic field radiated by an EMI filter and its electric working," 2010 IEEE Vehicle Power and Propulsion Conference, Lille, 2010, pp. 1-5, doi: 10.1109/VPPC.2010.5729189.
- [17] Æ. Labarre, F. Costa, O. Aouine and J. Ecrabey, "Modelling and analysis of the magnetic field radiated by a three phased inverter," 2010 IEEE International Symposium on Industrial Electronics, Bari, 2010, pp. 927-932, doi: 10.1109/ISIE.2010.5637100.
- [18] O. Aouine, C. Labarre and F. Costa, "Measurement and Modeling of the Magnetic Near Field Radiated by a Buck Chopper," in IEEE Transactions on Electromagnetic Compatibility, vol. 50, no. 2, pp. 445-449, May 2008, doi: 10.1109/TEMC.2008.922794.
- [19] V. Ardon, J. Aime, O. Chadebec, E. Clavel, J. Guichon and E. Vialardi, "EMC Modeling of an Industrial Variable Speed Drive With an Adapted PEEC Method," in IEEE Transactions on Magnetics, vol. 46, no. 8, pp. 2892-2898, Aug. 2010, doi: 10.1109/TMAG.2010.2043420.
- [20] Y. Chen, X. Pei, S. Nie and Y. Kang, "Monitoring and Diagnosis for the DC–DC Converter Using the Magnetic Near Field Waveform," in IEEE Transactions on Industrial Electronics, vol. 58, no. 5, pp. 1634-1647, May 2011, doi: 10.1109/TIE.2010.2051939.
- [21] A. Virdi, P. Salunkhe, D. Choudhary and T. Mahadik, "Enhancement of PCB Design for Radiated Immunity Compliance in Analog Signal Measurement," 2018 15th International Conference on ElectroMagnetic Interference & Compatibility (INCEMIC), Bengaluru (Bangalore), India, 2018, pp. 1-4, doi: 10.1109/INCEMIC.2018.8704577.
- [22] R. Redl, "Power electronics and electromagnetic compatibility," PESC Record. 27th Annual IEEE Power Electronics Specialists Conference, Baveno, Italy, 1996, pp. 15-21 vol.1, doi: 10.1109/PESC.1996.548553.
- [23] IEEE Approved Draft Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic and

Electromagnetic Fields, 0 Hz to 300 GHz," in IEEE PC95.1/D3.5, October 2018 , vol., no., pp.1-312, 25 Jan. 2019.

- [24] N. Sivaraman, K. Jomaa and F. Ndagijimana, "Three dimensional scanning system for near-field measurements," 2017 11th European Conference on Antennas and Propagation (EUCAP), Paris, 2017, pp. 2866-2.
- [25]X. Li and L. Da Xu, "A Review of Internet of Things— Resource Allocation," in IEEE Internet of Things Journal, doi: 10.1109/JIOT.2020.3035542.
- [26] H. Chen, T. Wang, L. Feng and G. Chen, "Determining Far-Field EMI From Near-Field Coupling of a Power Converter," in IEEE Transactions on Power Electronics, vol. 29, no. 10, pp. 5257-5264, Oct. 2014, doi: 10.1109/TPEL.2013.2291442.
- [27]G. de Freitas Lima, Y. Lembeye, F. Ndagijimana and J. -C. Crebier, "Modeling of a DAB under phase-shift modulation for design and DM input current filter optimization," 2020 22nd European Conference on Power Electronics and Applications (EPE'20 ECCE Europe), Lyon, France, 2020, pp. P.1-P.10, doi: 10.23919/EPE20ECCEEurope43536.2020.9215851.
- [28] T. Lamorelle, Y. Lembeye and J. Crebier, "Handling differential mode conducted EMC in modular converters," in IEEE Transactions on Power Electronics.
- [29] G. de Freitas Lima, Y. Lembeye, F. Ndagijimana and J. -C. Crebier, "Un algorithme simple pour la prediction du champ magnétique proche et l'optimisation des interconnexions des réseaux de convertisseurs de puissance," Symposium de genie electrique (SGE 2020), France. Manuscript submitted for publication.
- [30] Misakian, Martin. (2000). Equations for the Magnetic Field Produced by One or More Rectangular Loops of Wire in the Same Plane. Journal of Research of the National Institute of Standards and Technology. 105. 10.6028/jres.105.045.
- [31] J. H. Kim, B. H. Choi, H. R. Kim and C. T. Rim, "2-D Synthesized Magnetic Field Focusing Technology With Loop Coils Distributed in a Rectangular Formation," in IEEE Transactions on Industrial Electronics, vol. 66, no. 7, pp. 5558-5566, July 2019, doi: 10.1109/TIE.2018.2869362.
- [32] Vjosa Shatri, Ruzhdi Sefa, Lavdim Kurtaj, "Partial Element Equivalent Circuit (PEEC) Toolbox for MATLAB,integrating FastCap2 and FastHenry2 to Calculate Partial Elements, and Multisim or LTspice for circuit simulation", Proceedings of the 12th WSEAS International Conference on Systems Theory and Scientific Computation (ISTASC '12), Istanbul, Turkey, August 21-23, 2012.