International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 02 Issue: 08 | Nov-2015 www.irjet.net p-ISSN: 2395-0072

A Review of Analysis and Design of EMI Filters for Power Electronic Converters

[1]K.MANJULA, B.E., [2]S.BHUVANESWARI, M.E., (Ph.D).,

[1] *PG Scholar, Department of EEE, Dr. M.G.R Educational & Research Institute, Chennai, India,*

[2] *Research Scholar, Dr. M.G.R Educational & Research Institute, Chennai, India,*

Abstract:

This paper deals with the literature review of analysis and design of EMI filters used in power electronic converters. In modern days the usage of Laptops, Computers, Cellular phones, SMPS, electric drives etc., have been increased tremendously. The power electronic converters are mainly used for supplying dc source to these equipments. The power electronic circuits or converters pollute the power system by injecting electromagnetic interference (EMI) noise. This paper is focused on the EMI sources and types of EMI noise, need for EMI filters, Types of EMI Filters, Steps followed in EMI / EMC measurement and analysis, designing of EMI filters for power electronic converters and EMI reduction methods.

Index Terms: Electromagnetic interference (EMI) filter, Electromagnetic Compatibility (EMC), SMPS.

1. Introduction

In the era, the power electronics circuits, converters and power supplies etc., are widely used for the various fields of applications in industrial, commercial, domestic, aerospace and military. High power quality was obtained by active power factor correction (PFC) circuits. The good EMC design for power converter was mainly based on the analysis of EMI noise generated and its propagation paths. Many researchers have reported EMC analysis of different converter topologies used in power converters and SMPS. Different methods adopted for reducing the EMI noise levels by means of EMI input filter at the source-side, improved switching schemes [5], soft-switching techniques [6], employment of fast switching devices [7], [8], optimal layouts. Either Passive or Active EMI input filters were used in the power converter circuits and/or SMPS. Passive EMI filters are commonly used to increase EMI noise attenuation due to low cost and no need for control circuit or components. The passive components could introduce additional volume and cost to the overall power converter system design. The interaction of EMI filters components and power converter stages introduce the system instabilities and degradation of the main electrical functionality [10], [11].

The authors reported the parasitic cancellation techniques using PEEC boundary integral method (PEEC-BIM) was implemented in an EMC simulation tool GeckoEMC and then verified by the transfer function and impedance measurements of the L–C and C–L–C filter circuits [1], [11]-[14]. Most of the EMI input filters are affected due to self and mutual inductance parasitic effects and placement of component in PCB. The frequency performance of EMI filters can be studied using PEEC based modeling and simulation tool.

The modeling and simulation approach gives a suitable design for building the final hardware prototypes because it is difficult and time consuming process. The EMI filters are designed in order to suppress undesirable electrical impulses, noise or disturbances in power lines, power supplies (SMPS) and power converters. The amplitude of interfering voltages on AC power lines is limited by EMI filters.

2. EMI Sources

The major sources of EMI in power electronics converters are dv/dt and di/dt during switching period. The conducted emission is a major issue in most of the power electronic systems and it is caused by

- Stray inductance of current loops causing high di/dt may create significant over voltage in power converters.

- Stray capacitive coupling between windings and a frame resulting high dv/dt may create significant leakage current in magnetic elements and electric motors
- Starting of AC/DC motors
- Fluorescent bulbs/ ballasts
- Light dimmers
- Microwave ovens
- Microprocessors
- Computers
- Switch-mode power supplies (SMPS)

Most of the electrical and electronic devices can generate and/or being affected by EMI. In SMPS, a high dc voltage was chopped or switched at a high frequency range from 50 kHz to 1MHz. Compared with linear power supplies, the efficiency of the high speed switching power supplies will be high and compact in size. But these high speed switching Power Supplies are major sources of EMI.

The high frequency switching devices can generate unwanted EMI. Most of the conducted EMI within switched mode power supplies originates from the main switching devices such as MOSFETs, transistors, and output rectifiers. The ultimate function of an EMI filter in the power supplies and electronic equipments is minimizing both internally and externally generated noises.

3. Types of EMI

Electromagnetic interference will be in the range of radio frequency. It is an electrical noise or disturbance which degrades the performance of the electrical and electronic devices by the way of an electromagnetic induction, electrostatic coupling, or conduction.

The types of EMI based on the source of generation,

- ***Man-made EMI:*** This type of EMI usually generated from other electronics circuits, although some EMI can arise from switching of large currents, etc.
- ***Naturally occurring EMI:*** This type of EMI can generated from natural sources such as cosmic noise, lightning and other atmospheric noises.

The types of EMI based on the period of interference

Continuous interference: This type of EMI generated in the circuit will be in the form of continuous signal.

Impulse noise: This type of EMI can be generated either man-made or natural causes such as switching action, lightning and ESD. This type noise will be in the form of impulse.

Types of EMI based on the bandwidth

- ***Narrowband:*** This form of EMI is generated due to inter modulation and transmitter distortion. The bandwidth of spurious signals frequency is narrow.
- ***Broadband:*** The broadband EMI can be generated by the manmade actions such as arc welding and natural source of Sun behind the satellite.

The erratic operation in power system, excessive ripple, or degraded regulation, which can lead to system level problems caused due to excessive conducted or radiated interference or noise. Input EMI filters are used to limit inrush current, and to reduce conducted susceptibility, and suppress spikes. The specifications for the allowable interference are generally driven by the power circuit specification electromagnetic interference (EMI) filters. In the Fig.1 shows the Common mode (CM) and Differential (transverse) mode (DM) Noise Currents measurements conducted in EMI filters
The frequency ranges of EMI noise were

1. 10kHz to 30MHz by conduction through wires
2. 30MHz to 1GHz by radiation [3].

Modes of conducted EMI noise are two types

- Common mode (CM) interference EMI noise present on the line and neutral referenced to safety ground.
- Differential (transverse) mode (DM) interference, EMI noise present on the phase line reference to the neutral.

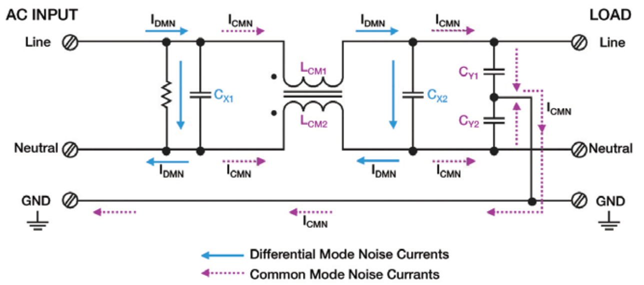


Fig.1. Common mode (CM) and Differential (transverse) mode (DM) Noise Currents

For the designing of EMI filters are based on the EMC requirements and standards. The International Electrotechnical Commission (IEC) and International

Special Committee on Radio Interference describe the EMC requirements with (CISPR22) and the conducted emission limits. The limits of conducted emission in the frequency range of 150kHz to 30MHz for class B digital devices are specified in the product standards EN55022.

4. Need for EMI Input Filter

All most all the power circuits contain an input electromagnetic interference (EMI) filter. The objective of the EMI filter was to reduce the interference caused either conducted or radiated from the power circuit. All ac/dc power supply circuits or systems may generate more electrical noise that cannot be filtered out by its internal filter. The EMI issues can be resolved only by introducing an additional EMI filters at the source side of the power supplies.

The EMI filters suppress the high frequency noise effectively in the following ways

1. Suppress the emission at its source end itself.
2. Make the coupling path as inactive.
3. Make the receiver less vulnerable to the emission.

The main challenges in designing a modern power electronic system are:

- Understanding of the EMI issues in power converters
- Analysis of switching transient in a power converter
- Consideration of an EMI at the beginning stage of design and compromise it with losses and low order harmonics
- Selection a proper topology and PWM technique
- Design of good magnetic elements such as inductors, transformers and electric machines
- Design of a power circuits layout with very low stray inductances

In multiple power supply systems working on the same ac power source, an unacceptable level of noise produced due to the small amount of noise which could not be filtered out by individual supply's internal EMI filter. The incoming noise in the form of a spike or burst of energy may be produced either by natural factors or human actions such as operating industrial control equipments like Solenoid valves, hydraulic actuators, large motors etc. External EMI fitters are essentially required in all of these cases, to reduce the electrical noise at considerable range.

Constraints / factors to be considered for the selection of EMI filters

1. EMC Standards
2. Case Size
3. I/O connections and mounting type
4. Safety agency approvals
5. Operating voltage
6. Operating current (ac or dc amps)
7. Leakage current
8. Isolation resistance
9. Withstand test voltages
10. High-voltage pulse or spike attenuation
11. Operating temperature range
12. DC resistance and insertion loss

5. EMI Filter Types

EMI filters usually two types, Passive and Active filters. Passive electronic components including capacitors and inductors would form the LC circuits. The unwanted EMI noise frequencies are greater than the normal signals frequencies. The EMI filter works by selectively blocking or shunting unwanted higher frequencies. The inductive part of the EMI filter is used to pass the low frequency and block the high frequency. The capacitive part of EMI filter is used to bypass or shunt unwanted high frequency noises. Thus the EMI filter considerably attenuates all unwanted internally and externally generated noise signals in the power electronic device.

Common solutions to meet EMC standards in power converters are using EMI filters [2]. The filters are designed and tuned after converter realization which results in a longer design time, a larger size and a higher cost [20]. The filtering is inevitable for achieving the further EMI reductions necessary to satisfy EMC regulations. It is desirable to implement cost effective suppression methods in order to reduce the filtering characterization before designing and implementing the filter. Many filtering solutions based on passive and active network approaches have been introduced [20] to attenuate conducted EMI. Presently the CM and DM filters are designed together by discriminating CM and DM noises for better performance.

Passive EMI filters [16], [18] are bulk in size and require multi stage LC circuits to achieve significant high frequency noise reduction. This results higher cost and larger size of the power converter. A typical passive EMI filter designed for the suppression of Common Mode (CM) is shown in Fig.2 and Differential Mode (DM) is shown in Fig.3. A standard typical π filter configuration of EMI filter is shown in Fig.4.

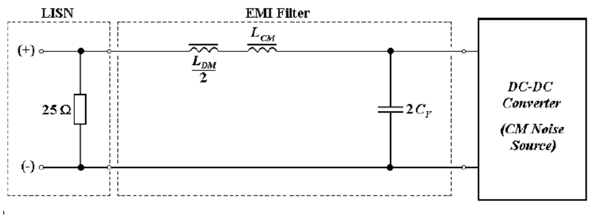


Fig.2 Equivalent circuit for CM

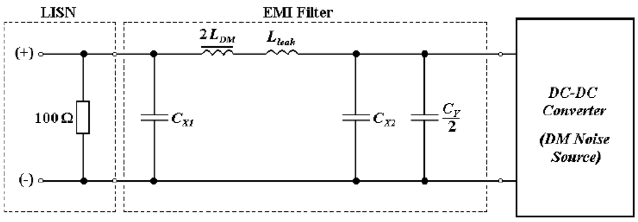


Fig.3 Equivalent circuit for DM

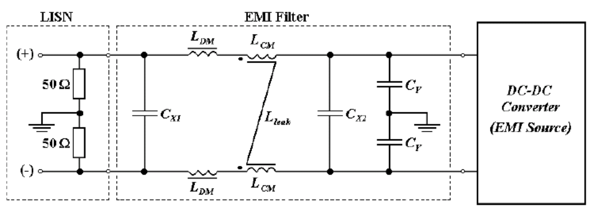


Fig. 4 A typical π filter configuration

Where,

LCM - Common-mode choke or inductor
LDM - Differential-mode choke or inductor
C_{x1}, C_{x2} - DM capacitors
C_y - CM capacitor

Active EMI filters [20] are designed with active components in addition to the passive elements to improve the low frequency attenuation. The Active EMI filter circuit is shown in Fig. 5. The main concept of Active EMI filter is based on sensing the noise current from the current transformer (CT), amplifying the same and then injecting back it as the compensation current through an RC branch connected to an operational Amplifier circuit.

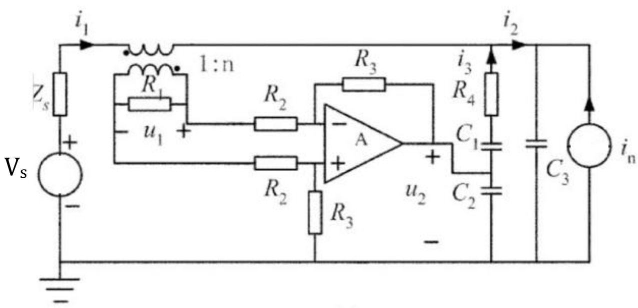


Fig.5 Active EMI Filter Circuit

6. Steps followed in EMI / EMC Measurement and analysis

An electromagnetically compatible system should satisfy the following conditions

1. It does not cause any interference to the other systems.
2. It is not vulnerable to emission from other systems.
3. It does not cause interference with itself.

The conducted EMI emission frequency ranges from 150 kHz to 30MHz as per the EMC standards. EMI emissions are measured by using Spectrum analyzer and electronic device are tested with a line impedance stabilization network (LISN) for EMC compliance

Measure and analyze the conducted EMI and Switching frequency ranges in power Electronic converters.

- Design line filter circuit to attenuate the conducted EMI noise.
- Optimizing the filter design for the attenuation of conducted EMI.
- Design line filters for single phase SMPS circuit.
- Comparison of filters design for two wire and three wire input SMPS.
- Use of near field probes to find the source of EMI

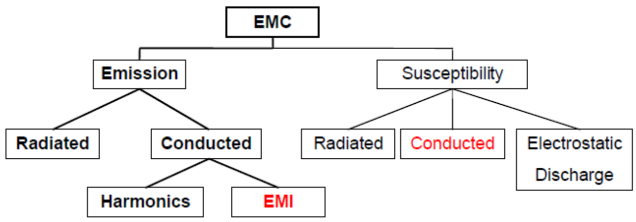


Fig.6 Hierarchical diagram for conducted EMI / EMC measurement

A typical schematic diagram for conducted EMI measurement for filter design system was shown in the Fig.6. The line impedance stabilization network (LISN) is mainly used to provide stabilized impedance to conducted emissions. LISN ensures the normal power flow required for the equipment under test (EUT). The main function of LISN is that it provides a low impedance path from the power source side and a high impedance path from load side at the power line frequency. The EMI Filter Circuit block represents the test equipment, passive filter components, end connectors and coaxial cables having characteristic impedance of 50Ω used for connecting test equipment and the measurement equipment. To match the 50Ω output impedance of the measurement equipment, 50 Ω resistors are either added onto the PCB layout.

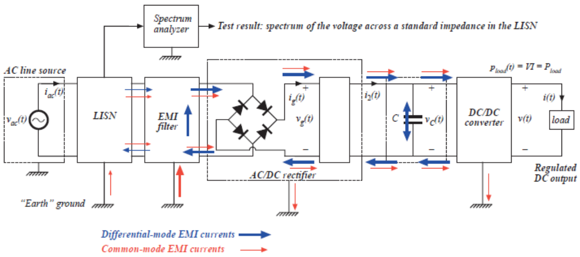
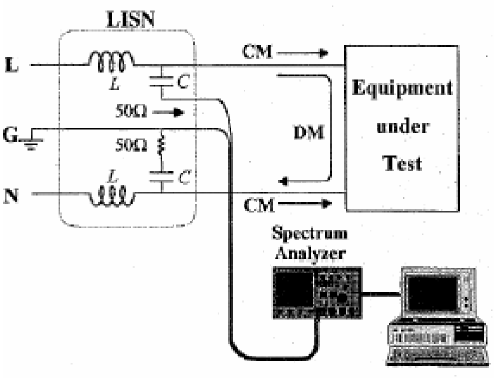


Fig.7 Typical schematic diagram for conducted EMI / EMC measurement



(a)

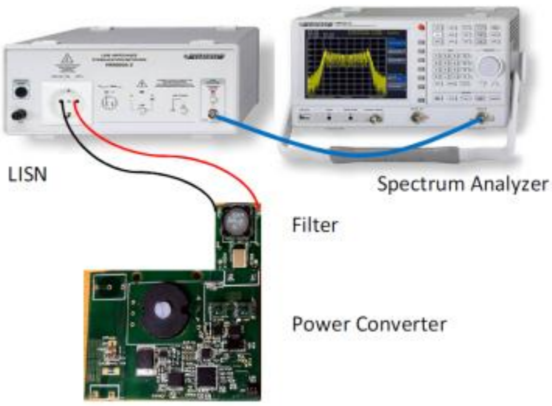


Fig.8. a & b Experimental setup for EMI measurement

The EMI meter used to measure the EMI noise or disturbances with input impedance of 50Ω. The LISN act as buffer network used for following purpose

- Interfacing between power source and test device
- Passing only the dc or ac power to the test sample
- Restricting the test equipment electromagnetic noise entering the power bus
- Blocking the power mains RF from coupling into the test sample

A LISN is connected in between the test equipment and the power line in order to present known impedance to the power line terminals over the frequency range of 150kHz to 30MHz. One LISN is connected in the hot side of the power line, and another one is connected in the neutral side of the power line.

The measurements were carried out using two LISN circuits as shown in Fig.7 and 8. Noise levels were measured separately for line and neutral. The DM noise current flows through two 50Ω resistors in series, resulting in 100Ω total load. The CM EMI current, the two 50Ω resistors are in parallel, resulting in 25Ω total load for the CM noise. The CM noise presents in the line and neutral having same magnitude and direction to the ground wire. AC power routed through the LISN to the test equipment. The measurement of impedance is standardized by LISN. An isolated Radio Frequency signal output to a spectrum analyzer, provides a plot of the conducted emissions coming from the test equipment.

7. Designing of EMI Filters

EMI Filter design procedure

A good design of EMI filters must satisfy the EMC standards.

1. Measurement of the base line (i.e without filter) common mode EMI noise spectrum, V_{CM} in dB and differential mode EMI noise spectrum, V_{DM} in dB of the test equipment.

2. Calculate the CM noise attenuation V_{reqCM} in dB and DM noise attenuation V_{reqDM} in dB using the equations (1) and (2)

$$V_{reqCM} = V_{CM} - V_{limit} + CF \longrightarrow (1)$$
$$V_{reqDM} = V_{DM} - V_{limit} + CF \longrightarrow (2)$$

Where,

V_{CM}, measured in dB
V_{DM}, measured in dB
V_{limit} in dB is the required conducted EMI limit specified in CISPR22 (EN55022) class B standard
CF - Correction factor, dB.

The typical value for correction factor taken as +6dB is added to Equations (1) and (2) because both the measured CM noise and DM noise to minimize the error occurred [10].

3. Calculate the minimum corner frequency of second order LC filter for CM and DM noise attenuation requirements.

A typical EMI filter design circuit model as shown in Fig.9 and the design of EMI filter flowchart as shown in Fig. 10.

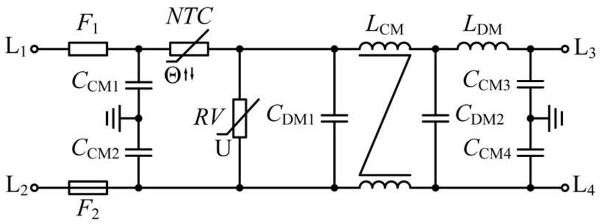


Fig.9. EMI Filter design circuit model

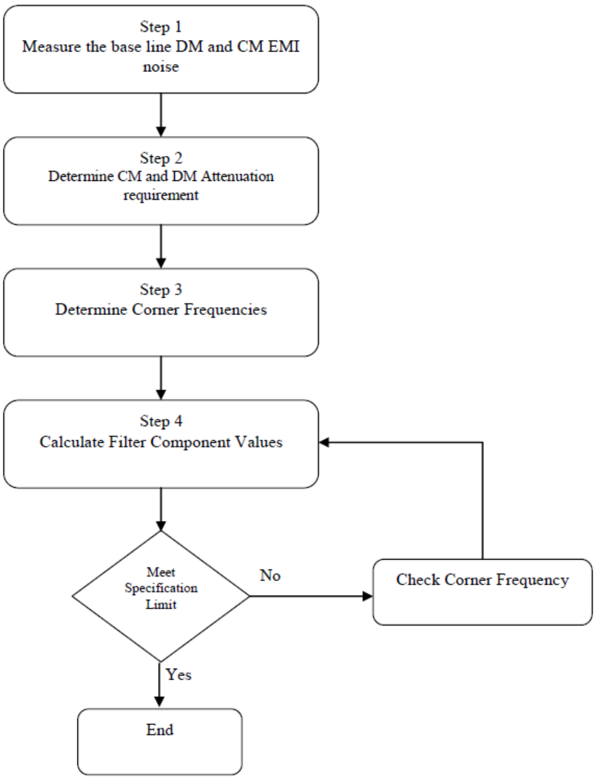


Fig.10. EMI Filter design flowchart

8. EMI Reduction Methods

There will be so many EMI reduction methods are used in power converters. These EMI reduction methods use an additional elements [5]–[7] and different control techniques [9]–[18] for switching of the power converters. EMI reduction techniques are mainly applied to the power or control sections, Hence the EMI reduction techniques are classified in to two sections such as the methods in the power section and the methods in the control section. The most popular EMC techniques such as grounding and shielding can be used in both Power and Control sections. The Control section methods are implemented based on two concepts: 1. varying the switching frequency 2. Improving ate circuitry. Decreasing the rate of change Voltage and current with respect you time will increase the switching time and results increased losses. It is tradeoff between losses and EMI to determine the switching time. The other methods also used to reduce stray inductance and capacitance of a power electronic system using a better layout, interconnection and configuration.

9. Conclusion

The EMI noise sources, types and need for EMI filters in power electronic converters, measurement of EMI/ EMC compliance or standards thoroughly reviewed. The typical EMI filter design procedure and EMI reduction techniques were also analyzed in this paper. Source current in double inductor Boost converter using EMI filters at the input was not discussed in the previous literatures. Based on the literature survey modeling and simulation of an EMI filter at the input of double inductor Boost converter to reduce the EMI level work is proposed. The simulation studies on single inductor Boost converter and double inductor boost converter system with and without an EMI filters will be performed in the future.

References:

[1] Ivana F. Kovaˇcevi´c, Thomas Friedli, Andreas M. Muesing, 3-D Electromagnetic Modeling of EMI Input Filters ", *IEEE Transactions on Industrial Electronics, Vol. 61, No. 1, pp. 231-242 January 2014,*

[2] M. N. Yazar, "Civilian EMC standards and regulations," *IEEE Trans. Electromagn. Compat.*, vol. 21, no. 1, pp. 2–8, Feb. 1979.

[3] F. Lin and D. Chen, "Reduction of power supply EMI emission by switching frequency modulation," *IEEE Trans. Power Electron.*, vol. 3, no. 1, pp. 132–137, Jan. 1994.

[4] L. Rossetto, S. Buso, and G. Spiazzi, "Conducted EMI issues in a 600-W single-phase boost PFC design," *IEEE Trans. Ind. Appl.*, vol. 36, no. 2, pp. 578–585, Mar./Apr. 2000.

[5] K. Mainali and R. Oruganti, "Conducted EMI mitigatin techniques for switch-mode power converters: A survey," *IEEE Trans. Power Electron.*, vol. 25, no. 9, pp. 2344–2356, Sep. 2010.

[6] S.P. Weber, E. Hoene, S. Guttowski, J. John, and H. Reichl, "Predicting parasitics and inductive coupling in EMI-filters," in *Proc. IEEE 21st Annu. Appl. Power*

Electron. Conf. Expo., Mar. 2006, vol. 1, pp. 1157–1160.

[7] M. L. Heldwein, “EMC filtering of three-phase PWM converters,” Ph.D. dissertation, Power Electron. Syst. Lab., Swiss Federal Inst. Technol., Zurich, Switzerland, 2007.

[8] H. Chung, S. Y. R. Hui, and K. K. Tse, “Reduction of power converter EMI emission using soft-switching technique,” *IEEE Trans. Electromagn.Compat.*, vol. 40, no. 3, pp. 282–287, Aug. 1998

[9] E. Hoene, “EMC in power electronics,” in *Proc. 5th Int. Conf. Integr.Power Syst.*, Mar. 2008, pp. 1–5.

[10] Nidhal Y. Nasser, “Practical Approach in Designing Conducted EMI Filter to Mitigate Common Mode and Differential Mode Noises in SMPS”, *Journal of Engineering an d Development,* Vol. 16, No.1, March 2012 ISSN 1813- 7822.

[11] I. F. Kovacevic, T. Friedli, A. Muesing, and J. W. Kolar, “PEEC-based virtual design of EMI input filters,” in *Proc. IEEE Energy Convers. Congr. Expo.*, Sep. 2011, pp. 1935–1941.

[12] I. F. Kovacevic, T. Friedli, A. Muesing, and J. W. Kolar, “Electromagnetic modeling of EMI input filters,” in *Proc. 7th Int. Conf. Integr. Power Syst.*, Mar. 2012, nos. 38–47, pp. 1–9.

[13] I. F. Kovacevic, T. Friedli, A. Muesing, and J. W. Kolar, “A full PEEC modeling of EMI filter inductors in frequency domain,” presented at the COMPUMAG Conf., Sydney, Australia, 2011.

[14] I. F. Kovacevic, A. Muesing, and J. W. Kolar, “An extension of PEEC method for magnetic materials modeling in frequency domain,” *IEEE Trans. Magn.*, vol. 47, no. 5, pp. 910–913, May 2011.

[15] C. Jettanasen, F. Costa, and C. Vollaire, “Common-mode emissions measurements and simulation in variable-speed drive systems,” *IEEE Trans.Power Electron.*, vol. 24, no. 11, pp. 2456–2464, Nov. 2009.

[16] S. Wang, F. Lee, W. G. Odendaal, and J. D. Van Wyk, “Improvement of EMI filter performance with parasitic coupling cancellation,” *IEEE Trans.Power Electron.*, vol. 20, no. 5, pp. 1221–1228, Sep. 2005.

[17] J. Ekman. (2003). Electromagnetic modeling using the partial element equivalent circuit method. Ph.D. dissertation, Department of Computer Science and Electrical Engineering/EMC Center, Lulea University of Technology, Lulea, Sweden,

[18] T.S. Tran, G. Meunier, P. Labie, and J. Aime, “Comparison of FEMPEEC coupled method and finite-element method,” *IEEE Trans. Magn.*,vol. 46, no. 4, pp. 996–999, Apr. 2010.

[19] A. Domurat-Linde and E.Hoene, “Analysis and reduction of radiated EMI of power modules,” in *Proc. 7th Int. Conf. Integr. Power Electron. Syst.*,Mar. 2012, pp. 1–6.

[20] B. Stube, B. Schroeder, E. Hoene, and A. Lissner, “A novel approach for EMI design of power electronics,” in *Proc. Design. Autom. Test Eur.*, Mar. 2008, pp. 170–175.