The Influence of Commercial PC Switched Mode Power Supply Interference on the PRIME PLC Performance

The Influence of Commercial PC Switched Mode Power Supply Interference on the PRIME PLC Performance

Waseem El Sayed [1,2], Paolo Crovetti [3], Piotr Lezynski [1], Robert Smolenski [1], Amr Madi [1,2,4] and Flavia Grassi [4]

[1]Institute of Automatic Control, Electronics and Electrical Engineering, University of Zielona Gora, Poland

[2]Electrical Engineering, Mathematics & Computer Science (EEMCS), University of Twente, Enschede, The Netherlands

[3] Department of Electronics and Telecommunications Torino, Politecnico di Torino, Torino, Italy.

[4]Department of Electrical Engineering, Politecnico di Milano, I-20133 Milano, Italy

w.wafiksaadelsayed@utwente.nl, paolo.crovetti@polito.it, p.lezynski@iee.uz.zgora.pl, r.smolenski@iee.uz.zgora.pl, amr.madi@ieee.org flavia.grassi@polimi.it

*Abstract*__**In the last few decades, the use of power converters is essential in the smart grid environment. Consequently, this leads to the presence of a high-level of conducted electromagnetic interference between the smart grid elements. This paper study the effect of two power converter modulation techniques: Normal convention modulation and spread-spectrum modulation, on the performance of the Power Line Communication (PLC) signal. The paper presents a practical implementation of the system and discusses the results for different operating scenarios.**

Keywords— Electromagnetic Interference (EMI) – Electromagnetic Compatibility (EMC) – Random modulation (SSM) – Power Line Communication (PLC)

I. Introduction

Nowadays, the interest in using green sources of energy like solar and wind energies [1], [2] increases due to the bad impact of using fossil fuel on the environment. Furthermore, the rapid increase in technological inventions helps in creating a smart grid environment to raise grid efficiency and reliability.

The use of smart meters in the grid is one of the common good approaches considered in the smart grid environment to monitor (sometimes control) the load consumptions in the system, most of the smart meters utilize Power Line Communication (PLC) protocols in sending the data to the main concentrators, as it uses the same grid infrastructure without adding much hardware to the system [3]. However, the smart meter communication may be interrupted by the conducted Electromagnetic Interference (EMI) in the system [4]. In the residential and commercial environment, usually, the main source of the conducted EMI in the electrical circuits is the switching of the power converters utilized by the loads in the grid such as the PCs, printers and televisions Switched Mode Power Supplies (SMPSs)[5], in addition to the LED lamps rectifiers [6].

The EMI problems in the communication system appear when the converter switching frequency or its harmonics lay in the same frequency bandwidth of the communication system [7]. Instead of utilizing EMI Filters, a lot of researches was conducted to provide the Spread Spectrum modulation techniques (SSM) as a mitigation solution for the higher amplitude of the noise in the context of the Electromagnetic Compatibility (EMC) standards [8]. The SSM provides a decrease in the amplitude of the generated noises from the converters by spreading the power spectral density (p.s.d) of the signal on a wider bandwidth instead of higher amplitude in one specific frequency in convention modulation [9].

Thus, Intense research activity is oriented to study the influence of the converter modulation types on the communication system. In [10]–[12], the effect of different modulation techniques on serial communication protocols RS-232 and RS-485 has been studied. In [13], [14], the influence of the spread-spectrum technique modulated interference on the digital communication channel (I^2C) were addressed. Also, the effect of the convention modulation on the Power line Related Intelligent Metering Evolution (PRIME) PLC was introduced in [15]. All the studies show that despite the advantage of the SSM techniques in decreasing the noise amplitude, they could also cause more or similar problems as the convention modulation to the communication systems.

This paper focuses on the influence of two commercial PC SMPSs on the PRIME PLC performance. The paper is divided as follows, Section II introduces the PLC theoretical background, beside the difference between the convention modulation and SSM. Section III presents the hardware connection of the used setup, and the discussion of the results is presented in Section IV, the conclusion of the work is given in Section V respectively.

II. Application Background

A) *The Power Line Communication channel in the presence of switching noises*

The PLC can be divided into two types: Narrowband (NB-PLC) and Broadband (BB-PLC), The NB-PLC typically works at a range of 3 kHz to 500 kHz and BB-PLC works at a range of 1.8MHz to 250MHz [3], in this paper, we will focus on NB-PLC. A lot of industries developed PLC solutions based on the standards (CENLEC, ARIB…..etc), G3-PLC has been developed by the G3-PLC Alliance, and The industry specifications PRIME by the PRIME Alliance. Most of the PLC protocols use the Orthogonal Frequency Division Multiplexing (OFDM) with advanced channel coding like forward error correction (FEC) codes to assure the robustness of the communication. However, as the NB-PLC frequency range overlaps with CISPR A standard frequency range, a lot of noises could affect the PLC performance. Based on [16], [17], the main types of noise effect in PLC channel can be

This paper is part of a project that has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No 812391 – SCENT.

divided into four types: Background Noise, Narrowband Noise, Periodic Impulsive Noise, and Asynchronous Noise, each type caused by a different reason. In the context of the communication framework, the Shannon-Hartley equation could be used for evaluating the PLC channel capacity to confirms the behavior of the PRIME PLC system in the presence of noises [14]. The Shannon-Hartley equation calculates the maximum allowable data transmission rate over a communications channel in noise existence, especially, in the communication systems featuring advanced channel codings like FEC codes adopted like G3-PLC and PRIME. The capacity of the PLC channel is expressed as:

$$\mathrm{C_{PRIME}} = \int_{B_{min}}^{B_{max}} log_2\left(1+\frac{S_{PLC}(f)}{N(f)}\right) df \qquad (1)$$

where B_{min} and B_{max} are the borders frequencies of the PLC bandwidth channel, $S_{PLC}(f)$ is the power spectral density of the PLC signal and $N(f)$ is the total noise power spectral density. Consequently, the capacity loss percentage $\mathrm{C_{Loss}}$ could be calculated as:

$$\mathrm{C_{Loss}}(\%) = \frac{C_0 - C_{PRIME}}{C_0} \times 100\,\% \qquad (2)$$

where C_0 is the calculated capacity of the PLC channel in a noise-free case, i.e. only including the AWGN.

B) Convention modulation Vs Spread-spectrum modulation

In standard Pulse Width Modulation (PWM) switching strategy, switching harmonics usually occur at fixed and well-defined integer multiples of the switching frequency, which of course sometimes exceed the allowable range from the EMC standards [18]. As a result, the engineers went towards the SSM as a solution to pass the EMC compliance tests. The basic concept is to spread the power of the spectrum to several frequencies, changes instantaneously with the time within the accepted range of frequency borders [9] as shown in Fig.1. Based on [8], the SSM approaches could randomize the switching frequency and/or the duty cycle, in all cases, the power of the signal is decreased according to the modulation spreading depth settings to fulfill the standards.

In this paper, the Shannon-Hartley equation was used to evaluate the performance of the PRIME PLC in the presence of EMI generated due to high-frequency switching converters which in our case are the PC SMPSs as explained in the next sections.

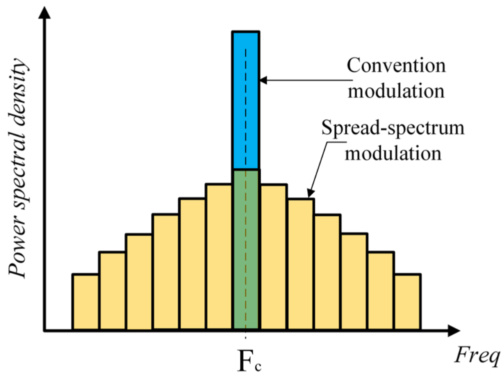

Fig. 1. Sketch to show the difference between a convention and spread spectrum modulation

III. Experimental Setup Discerption

The experimental testbed was built to emulate the communication between one smart meter and the main concentrator as a point to point communication. The communication was established out of two Texas Instrument PLC modems (TIDA-00192 PLC Docking Board), both cards are programmed to work using the PRIME protocol, they are connected through one single-phase cable, the sent data information are shown in Table I. The LISN is used to terminate the wiring at a well-defined impedance at RF (typically 50ohm) and also to decouple it from external disturbances. On the same line between the two PLC modems, two identical commercial PC SMPSs are connected in one of the sockets at the sending terminal, the electrical parameters of the utilized converters are presented in Table II. Besides, both SMPSs are modified to work with convention modulation and SSM by the means of an external Atmega48 microcontroller, each converter was connected to resistive load at 12 V and consumed 1 A, the circuit connection is shown in Fig.2.

TABLE I. PLC Test Assumptions

Type of PLC communication standard	PRIME
Data size	50 bytes
Physical layer	OFDM
Modulation	DBPSK
The nominal bitrate	0 to 128 kbit/Sec
Total sent frames	1373
The time between each frame	0.4 sec
The medium	The cable of length 42 m

TABLE II. SMPS Specifications

Parameter	Value
Power	
AC Input Voltage	220 ~ 250V
DC Output Voltage	12V- 5V
The output Current	40A
Switching Frequency	28 kHz

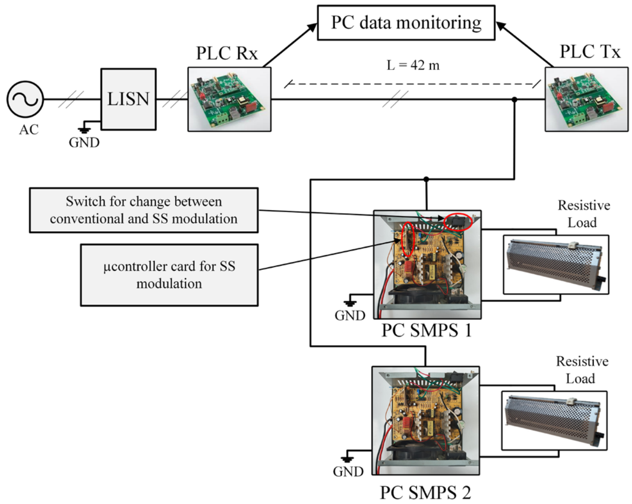

Fig. 2. Connection diagram

The PRIME protocol differential mode voltage spectrum in case of no-load connected to the line is shown in Fig.3, as the PRIME works with the OFDM, the communication bandwidth is between is 47 kHz (from 42 kHz and 89 kHz), the amplitude of the signal is 86 dBuV using the Average detector (AV)and IFBW = 200 Hz. Moreover, Fig.4 shows the differential mode voltage spectrum in case of connecting both converters at the transmitting terminals (at 0 meter from the transmitting modem) at the same measuring conditions in Fig.3, the figure shows the difference between the convention modulation and the SSM, the SSM provides a degradation in the spectrum amplitude of almost 10 dBuV at the main switching frequency of 28 kHz.

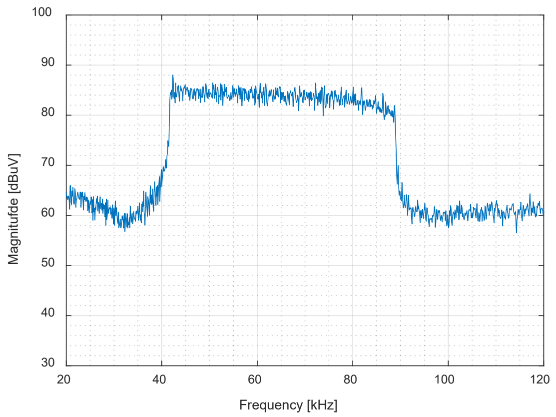

Fig. 3. PLC spectrum, Average detector, IFBW = 200 Hz

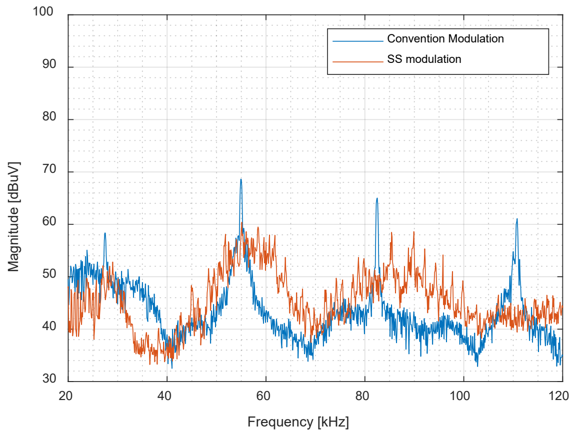

Fig. 4. The Differential voltage spectrum of 2 SMPS measured from the PLC receiving terminal with Average detector and IFBW = 200 Hz

IV. Results Discussion

The performance of the PRIME PLC protocol could be evaluated based on the Frame Error Rate (FER) parameter; it is a ratio of the broken frames to the total sent frames.

Fig.5 shows the FER percentage of both modulation convention modulation and SSM. It was noticed that the SSM has greater influence over the convention modulation which is opposite to the expected from the EMC standard point of view, the difference between the FER in the case of convention modulation and SSM is almost 15%. This confirms that despite the decrease in the spectrum amplitude provided by the SSM to fulfill the EMC standards, the SSM causes more problems for the communication systems. Table III shows the average bps in both cases of modulation, communicate data rate of flow in case of the convention modulation is higher than in case of SSM by 141 bps.

Fig.6 shows the histogram of the waiting times between frames in the three operation scenarios: noise-free case and in case connecting the SMPSs with convention modulation and SSM, the results show that in the noise-free case, 100 % of the sent frames reach the receiver at the reference scheduled time (0.4 sec), which was the configured time between each frame due to the absence of the converters in the circuit. In contrast, due to the connection of the SMPSs in the PLC Line, the time taken to send some frames exceeds the reference time value. In the case of using convention modulation, 83% of the frame data reach the receiver at the reference scheduled time, and the rest of the frames were delayed or destroyed due to the noise generated by the converters in the channel. Besides, in the case of SSM, 72% of the frame data were received at the reference scheduled time, and the rest of the frames were delayed or destroyed due to the noise generated by the converters in the channel.

TABLE III. PLC performance in case convention modulation and SSM

2-Converters with Convention Modulation		2-Converters with SSM	
Total time (sec)	**Average bps**	**Total time (sec)**	**Average bps**
886	619	1149	478

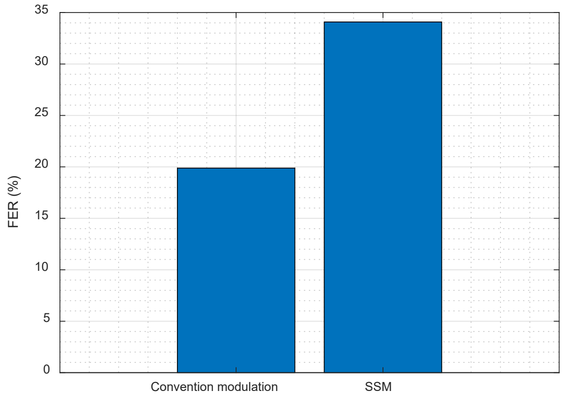

Fig. 5. The FER percentages in both case of modulation at connecting the converters at the sending PLC modem.

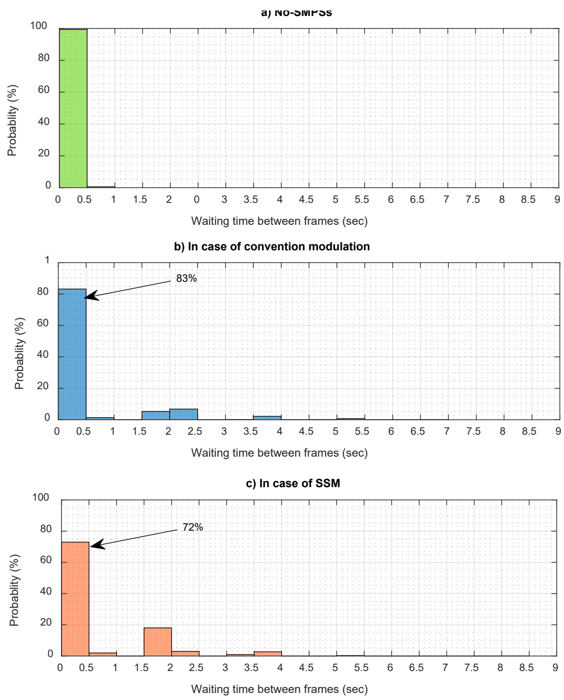

Fig. 6. The histogram of the time taken by the frames to reach the receiver a) in the noise-free case, b) in case of convention modulation and c) in case of SSM

Fig. 7 shows the calculated channel capacity of the PLC channel in the presence of the converters with convention modulation and SSM, as well as, the EMI noise-free case. The calculated channel capacity in the noise-free case is equal to 800 kbit/Sec, which is just an upper bound of the achievable bit rate in the communication channel, on the other hand, both types of modulation EMI noise influenced the calculated channel capacity, the capacity of the channel decrease to be in the range of 600 kbit/Sec in case of convention modulation, while in SSM the channel capacity equal to 500 kbit/Sec. Fig.8 shows the percentage of channel capacity loss in case of EMI noise modulated by convention and SSM, it seems clear that the SSM provides more problems to the communication channel rather than in the case of convention modulation, the C_{Loss} = 26% in the case of convention modulation, while it is equal to 37% in the case of SSM.

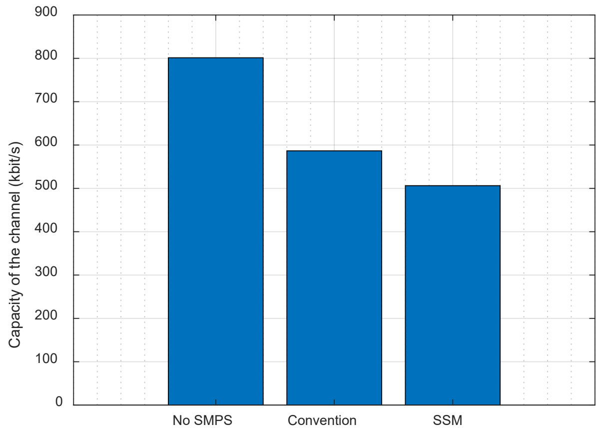

Fig. 7. The channel capacity calculations in case of a) NO no converters, b) 2 converters work with DetM, and c) 2 converters work with SSM

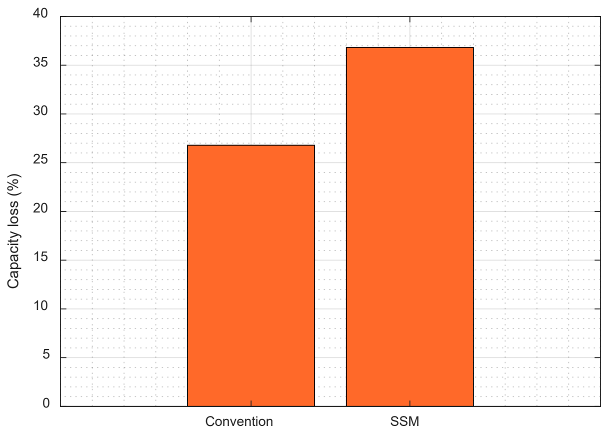

Fig. 8. The FER with various distances between the converters and the sending PLC board

V. CONCLUSION

This paper dealt with the influence of the two commercial PC SMPSs (as a source of EMI) on the PRIME communication system performance, which is commonly used in smart metering applications. The experimental tests result concerned the impact of changing the modulation type of the SMPSs within the same electrical grid line utilized by the PLC modems. The results show that convention modulation had a lower impact on communication performance than in the case of spread-spectrum modulation (SSM). Despite the decrease in the noise level provided by the SSM, the spreading of the signal to several frequencies increase the probability of destroying some of the OFDM subcarriers. Furthermore, the results were confirmed by applying the channel capacity calculation using the Shannon-Hartley equation, the achievable channel capacity in the case of convention modulation is more than in the case of SSM. The investigation has revealed that the problems of the EMI are not always related to the amplitude of the noise spectrum, but also it is related to the noise spreading criteria of the spectrum. This provides powerful insights to be considered in the future EMC and communication standards.

ACKNOWLEDGMENT

This paper is part of a project that has received funding from the European Union’s Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No 812391 – SCENT.

REFERENCES

[1] D. Roggo *et al.*, “Electromagnetic interferences in smart grid applications: A case study with power line communication smart meters and PV energy generation,” *CIRED - Open Access Proc. J.*, vol. 2017, no. 1, pp. 607–611, 2017.

[2] A. Hebala, W. Wafik, Walid.M.A.Ghoneim, and Hamdy A. Ashour, “Experimental Analysis of a Prototype Low Speed PMSG Unit With Different Loading Conditions,” in *2018 Twentieth International Middle East Power Systems Conference (MEPCON), Cairo University, Egypt*, 2018, pp. 1134–1139.

[3] C. Cano, A. Pittolo, D. Malone, L. Lampe, A. M. Tonello, and A. Dabak, “State-of-the-art in Power Line Communications : from the Applications to the Medium,” *IEEE J. Sel. Areas Commun.*, vol. 8716, no. c, pp. 1–19, 2016.

[4] B. Ten Have, T. Hartman, N. Moonen, and F. Leferink, “Inclination of Fast Changing Currents Effect the Readings of Static Energy Meters,” in *EMC Europe 2019 - 2019 International Symposium on Electromagnetic Compatibility*, 2019, pp. 208–213.

[5] S. Lanzisera, A. R. Weber, A. Liao, D. Pajak, and A. K. Meier, “Communicating power supplies: Bringing the internet to the ubiquitous energy gateways of electronic devices,” *IEEE Internet Things J.*, vol. 1, no. 2, pp. 153–160, 2014.

[6] M. A. Wibisono, N. Moonen, and F. Leferink, “Interference of LED Lamps on Narrowband Power Line Communication,” in *2020 IEEE International Symposium on Electromagnetic Compatibility & Signal/Power Integrity (EMCSI)*, 2020, pp. 219–221.

[7] Waseem El Sayed; Hermes Loschi; C.L. Lok; Piotr Lezynski; Robert Smolenski, “Prospective Analysis of the effect of Silicon based and Silicon-Carbide based Converter on G3 Power Line Communication,” in *2020 International Symposium on Electromagnetic Compatibility - EMC EUROPE*, 2020.

[8] Y. Lai, S. Member, and Y. Chang, “Novel Random-Switching PWM Technique With Constant Sampling Frequency and Constant Inductor Average Current for Digitally Controlled Converter,” *IEEE Trans. Ind. Electron.*, vol. 60, no. 8, pp. 3126–3135, 2013.

[9] H. Loschi, P. Lezynski, R. Smolenski, D. Nascimento, and W. Sleszynski, “FPGA-Based System for Electromagnetic Interference Evaluation in Random Modulated DC / DC Converters,” *Energies 2020*, vol. 13, no. 2389, pp. 1–14, 2020.

[10] J. Bojarski, R. Smolenski, P. Lezynski, and Z. Sadowski, “Diophantine equation based model of data transmission errors caused by interference generated by DC-DC converters with deterministic modulation,” *Bull. POLISH Acad. Sci. Tech. Sci.*, vol. 64, no. 3, pp. 575–580, 2016.

[11] R. Smolenski, J. Bojarski, A. Kempski, and P. Lezynski, “Time-Domain-Based Assessment of Data Transmission Error Probability in Smart Grids With Electromagnetic Interference,” *IEEE Trans. Ind. Electron.*, vol. 61, no. 4, pp. 1882–1890, 2014.

[12] K. Li, Y. Xie, S. Member, F. Zhang, and Y. Chen, “Statistical Inference of Serial Communication Errors Caused by Repetitive Electromagnetic Disturbances,” *IEEE Trans. Electromagn. Compat.*, vol. PP, pp. 1–9, 2019.

[13] F. Musolino and P. S. Crovetti, “Interference of Spread-Spectrum Switching-Mode Power Converters and Low-Frequency Digital Lines,” in *2018 IEEE International Symposium on Circuits and Systems (ISCAS)*, 2018, p. 5.
[14] F. Musolino and P. S. Crovetti, “Interference of Spread-Spectrum Modulated Disturbances on Digital Communication Channels,” *IEEE Access*, vol. 7, pp. 158969–158980, 2019.
[15] A. Llano, I. Angulo, P. Angueira, T. Arzuaga, and D. De Vega, “Analysis of the Channel Influence to Power Line Communications Based on ITU-T G . 9904 (PRIME),” *Energies 2016*, vol. 9, no. 39, pp. 1–16, 2016.
[16] M. Korki, N. Hosseinzadeh, S. Member, and T. Moazzeni, “Performance Evaluation of a Narrowband Power Line Communication for Smart Grid with Noise Reduction Technique,” *IEEE Trans. Consum. Electron.*, vol. 57, no. 4, pp. 1598–1606, 2011.
[17] L. Di Bert, P. Caldera, D. Schwingshackl, and A. M. Tonello, “On Noise Modeling for Power Line Communications,” in *2011 IEEE International Symposium on Power Line Communications and Its Applications On*, 2011, pp. 283–288.
[18] F. Pareschi, R. Rovatti, and G. Setti, “EMI reduction via spread spectrum in DC/DC converters: State of the art, optimization, and tradeoffs,” *IEEE Access*, vol. 3, pp. 2857–2874, 2015.