32nd Electric Vehicle Symposium (EVS32)
Lyon, France, May 19 - 22, 2019

Comparison of Full H-bridge and cascaded Multilevel H Bridge Inverter for WEVCS

Valentin RIGOT[1], Zariff MEIRA GOMES[1], Jihen SAKLY[1], François COLET[1]

[1]*VEDECOM, 23bis Allée des Marronniers 78000 Versailles, France,* jihen.sakly@vedecom.fr

Summary

An H-bridge inverter is employed in typical Inductive Power Transfer (IPT) For EV systems as the primary side power supply. Because of constraints related to power electronics devices and their costs, this inverter may not be suitable for high power Wireless Electric Vehicle Charging System (WEVCS). In this paper, A high-frequency cascaded multi-level inverter which is suitable for high power applications is proposed. Total Harmonic Distortion (THD) analysis for the H-Bridge and the (CHB) is done based on simulations and experimental validations obtained with a 3kW prototype system. Results demonstrates the effectiveness of the proposed topology choice. This approach can be useful also for high power (WEVCS).

Keywords: EV, inductive charger, wireless charging, inverter, BEV.

1 Introduction

Today, charging technology for EV is based mainly on plug in and charge the vehicle batteries using an onboard charger. The problem with the conductive charging of EV is the gauge cables which are difficult to handle and may cause hazards [1]. Besides that, it needs a wide charging network be installed to facilitate the adoption. An alternative technology to charge an EV, referred to as wireless power transfer (WPT) has been investigated. (WEVCS) can be a promising alternative technology to charge the (EVs) without any plug-in requirements [2, 3]. The advantages of wireless charging are, safety, convenience, and a fully automated charging process [4].
The (WEVCS) is based on inductive power transfer. It consists mainly of two components: the first is placed on the track including the AC/DC and DC/AC converter dedicated to providing (HF) High Frequency AC to feed the coupler primary coil and the second part mounted underneath the (EV) is composed of the coupler secondary coil, a rectifier and DC/DC converter to charge the (EV) Battery.
Optimization of power systems with the use of Multi level inverters has been extensively researched [5, 6]. The main advantages were low Total Harmonics Distortion (THD), less switching losses and low leakage current [7, 8]. Multilevel converters are increasingly being used in medium and high-power application because of their high operation ratings like the god output voltage profile and reduced stress across the power switches. There are three main multilevel converters in literature: Diode Clamped Converter, Flying Capacitor Converter, and the cascaded H-Bridge Converter (CHB). The CHB is widely used mainly because of its modularity and good relation between the number of switches and levels generated.

In order to enhance overall (WEVCS) efficiency, compensation capacitors are added in series on both transmitter and receiver part of the system [9, 10]. In this paper, to ameliorate the power transfer, we propose to evaluate the Total Harmonic Distortion (THD) of a multilevel topology namely Cascaded H-Bridge (CHB) in comparison with the 2 levels H-Bridge converter used as a DC/AC in the proposed (WEVCS). PSIM and LTSPICE simulations are done for the (WEVCS). FFT analyses of output voltage are carried out and 2L-H-Bridge and nL-CHB (n= 3, 5, 9) were studied and compared. Experimental validation was carried out on a 3 kW Wireless Power transfer (WPT) prototype with a DC/AC 5L-CHB developed at VEDECOM. The obtained results demonstrate the effectiveness of the proposed (WEVCS)

2 Proposed WEVCS

Figure 1 shows a typical WEVCS. A reactive power compensation is required on the primary and secondary side to maximize the efficiency [9, 10]. These capacitors can be connected in series or in parallel to the primary and secondary coils. There are four compensation topologies: series-series (SS), parallel-series (PS), series-parallel (SP), and parallel-parallel (PP). In this work, (SS) topology is chosen because it offers a constant current and voltage for the battery [11].

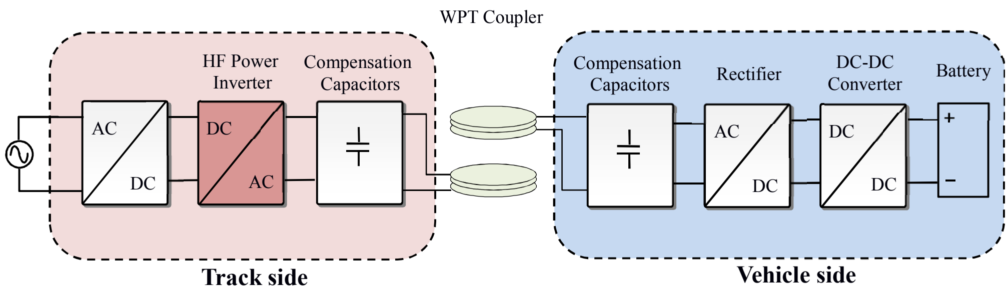

Figure 1: Typical Wireless Power Transfer System for EVs

The proposed WEVCS system is based on Cascaded H-bridge converter as HF DC/AC converter. It consists of a first part on the track with eight primary coils of the coupler fitted each one with a DC/AC converter. The second part includes secondary part of the coupler and a remote access robot is used to emulate the EV. The mobility of robot can be used also to characterise the power transfer with different coil, magnetic ferrite shapes and displacement scenarios.

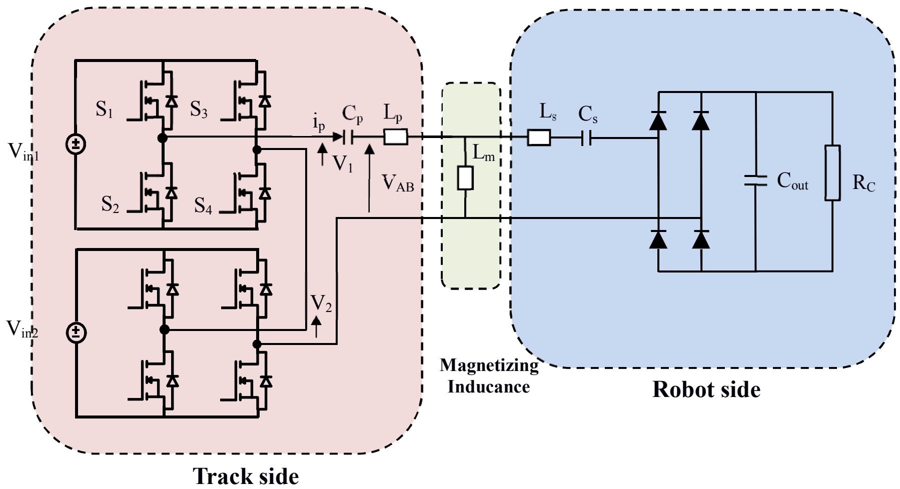

Figure 2: Proposed WEVCS

3 Cascaded H Bridge converter

In cascaded H Bridge converter topology (CHB), several H Bridge modules are connected in series to provide multilevel output voltage. When the DC link capacitor have different voltage values, it is possible to achieve more levels than when the DC link voltage levels are the same. In the proposed topology, the DC voltage for the two H-Bridge is the same.
Cascaded H Bridge converter requires several isolated dc supplies which make it suitable converter of distributed generation supplies i.e. power from batteries, fuel cell, photovoltaic cell can be united together. Figure 3 shows the inverter output voltage waveform V_{AB} for 5L-CHB with the phase shift modulation technique. The inverter phase voltage of nL-CHB is given as:

$$v_{AB} = \sum_{k=1}^{\Pi} v_k \quad (1)$$

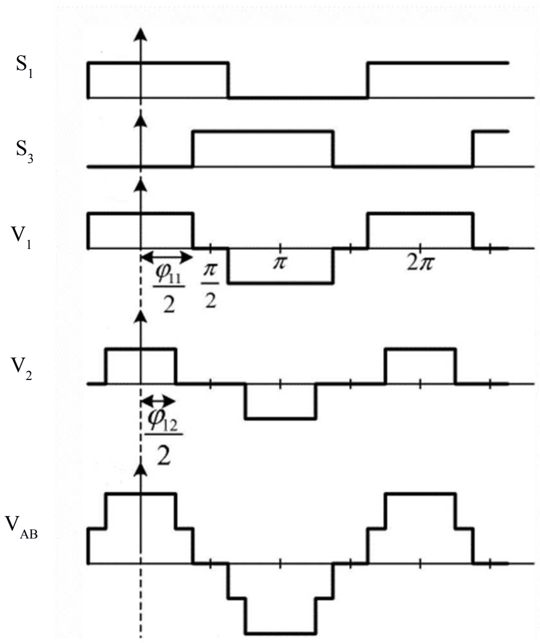

Figure 3: Phase modulated voltage for 5L-CHB

4 Modelling and analysis

The aim of this work is to evaluate the output voltage and current of the HF-converter.

The H-Bridge and the CHB are simulated using LTSPICE and PSIM with a resistive load. In the first tests, the THD of voltage V_{AB} at the primary side of the coil. This test has been done in the same conditions for both topologies: H Bridge and 5L- CHB. The voltage output waveform for H-Bridge and CHB are shown, respectively, in Figure 3(a) and 3(b). In the CHB inverter, the output voltage becomes smoother and more sinusoidal. The DC input voltage is 60V. It can be seen that for Voltage Total Harmonic Distortion noted THD_V, the amplitude for all order harmonic are attenuated as shown in Figure 4.

For experimental tests and simulations, we have chosen the Total harmonic distortion parameter defined by THD_F which is the RMS value of the sum of all harmonic components ($V_{h,rms}$ for voltage) to a specified order (N) to the RMS value of the fundamental component ($V_{1,rms}$ for voltage,) Equation 2 is the formulas for voltage THD used in experimental tests:

$$v_{THD-F} = \frac{100\sqrt{\sum_{h=2}^{N} v_{hrms}^{2}}}{v_{1rms}} \tag{2}$$

Other simulations were done also for three and nine levels CHB. It can be concluded, as presented in Figure 5, that by moving from three to five levels, the THD_V decreases with 13,5% and for nine levels, it steps down with 8.09% in comparison with five levels. Therefore, in order to guarantee the best compromise between the inverter THD_V and number of levels, we choose the 5L-CHB.

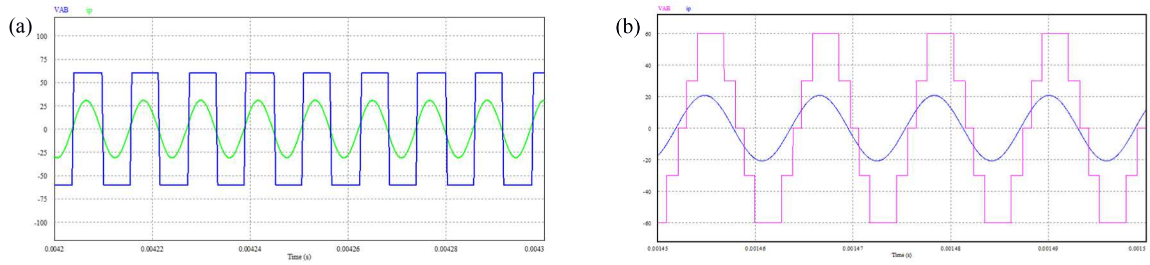

Figure 4: Waveforms of the output voltage V_{AB} and current i_p for (a) H-Bridge (b) CHB topology

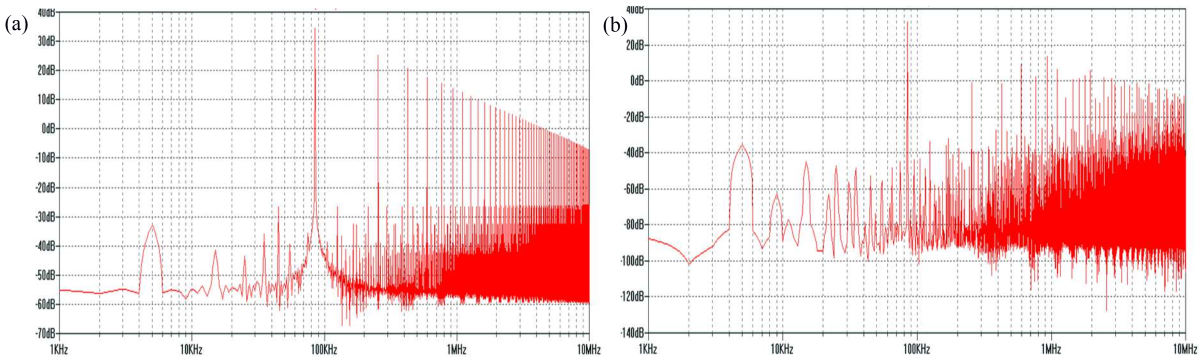

Figure 5: Harmonic spectrum of DC/AC output voltage V_{AB} for (a) H-Bridge (b) CHB topology

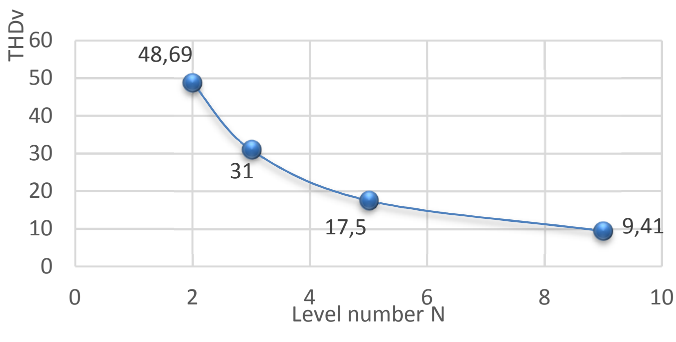

Figure 6: THD_V =f (N) curve

5 Experimental Validation

A 3-kW prototype DC/AC 5L-CHB converter topology (Figure 7) was constructed, and an experimental setup was designed and set up as shown in Figure 8 at the charging systems workshop. Table 1 gives the specifications of the system. The switching frequency is taken to be 85 kHz. The experiments of a load variation were examined to confirm the suitable operation of the system. Figure 9 shows, respectively, the waveforms of the voltage V_{AB} and the current i_p of the 5L-CHB.

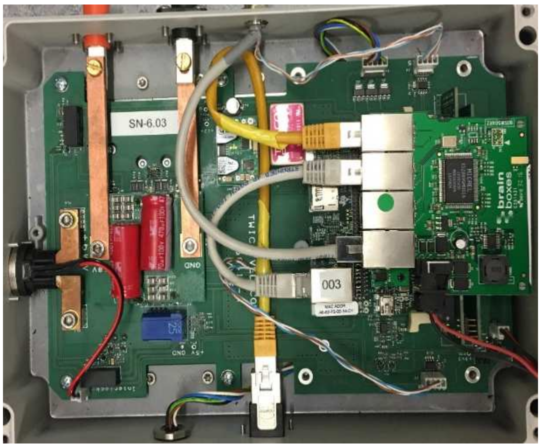

Figure 7: 3 kW HF DC/AC converter prototype

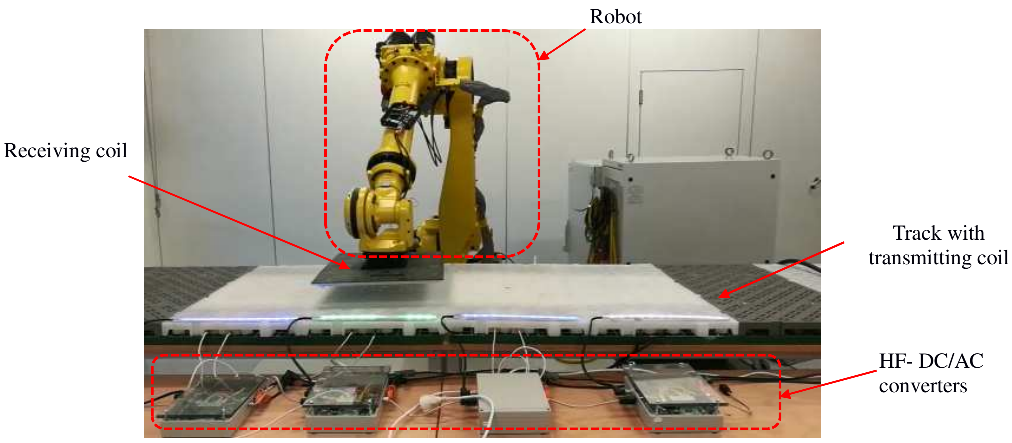

Figure 8: VEDECOM 3 kW Dynamic Wireless Electric Vehicle Charging System (D-WEVCS)

Table 1: Specification of the proposed WEVSC

Parameter	Value
DC input voltage	60 V
Primary inductance	60 µH
Secondary inductor	60 µH
Coefficient coupling	0.15
Resonant capacitors	66 nF
Power range	0-3 kW
Switching frequency	85 kHz

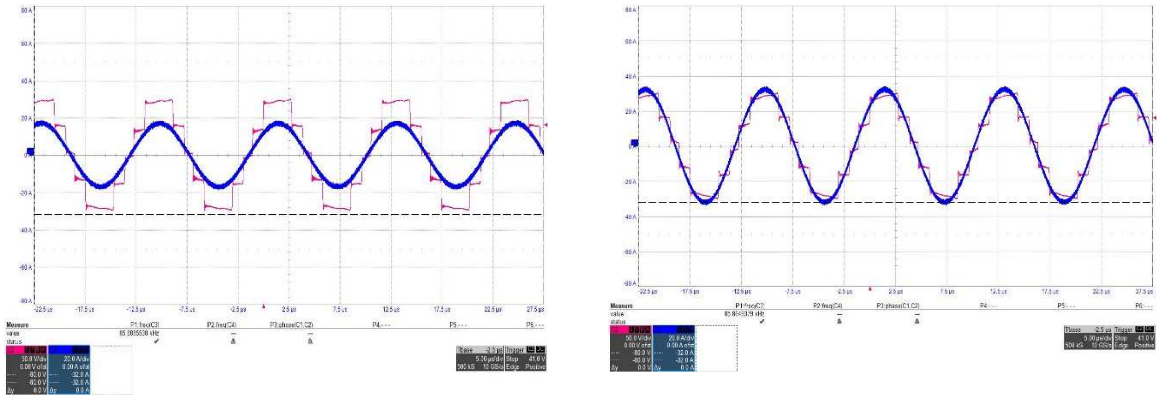

Figure 9: Experimental results of output voltage V_{AB} and current i_p for 5L-CHB topology with different load

It should be noted that the comparison between the two topologies is done at the same conditions namely power, current, voltage and fundamental voltage component. For instance, for input power of 900 W, THD_{VF} for H Bridge and 5L-CHB was, respectively, 45,33% and 24,22%.

Figure 10 presents the harmonic spectres of the primary and of the inverter output voltage, with an operating frequency is equal to the resonance frequency i.e. 85 kHz. We can observe that the third order harmonic is important for the two topologies. It also clear that the odd order harmonics are attenuated using the 5L-CHB.

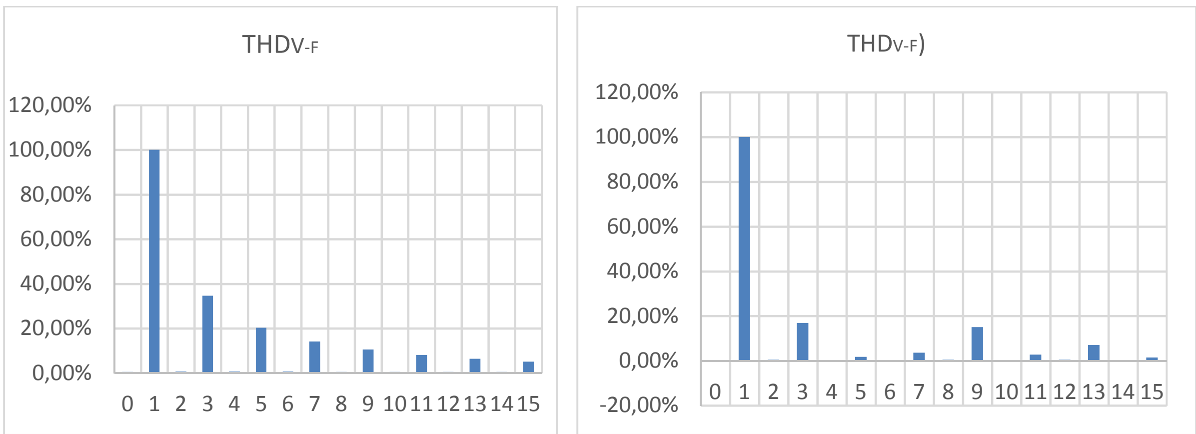

Figure 10: THD_V Histogram of the Magnitudes RMS (% fundamental) = f (Harmonic order) (a) H- Bridge (b) 5L-CHB Topology

6 Conclusion

A cascaded multilevel converter namely (CHB) based IPT system has been proposed not only to improve the output power quality but also to facilitate then the use of (CHB) for high power (WEVCS). A 3 kW (WEVCS) prototype is built at VEDECOM and performances assessment are in progress also to evaluate efficiency and interoperability of the system. A THD comparison between H-Bridge and (CHB) is presented in this paper using results from simulations and experimental validations. Total Harmonic Distortion was examined by the simulation of the nL-CHB converters. Both experimental and simulation results are done for 5L-CHB and H-Bridge and prove the interest of Multilevel inverter for wireless power transfer.

References

[1] M. Chinthavali and O. C. Onar, “Tutorial on wireless power transfer systems,” *in Proc. IEEE Transp. Electrific. Conf. Expo (ITEC)*, Dearborn, MI, USA, Jun. 2016, pp. 1–142

[2] Z. Zhang, H. Pang, A. Georgiadis, and C. Cecati, “Wireless Power Transfer - An Overview,” *IEEE Trans. Ind. Electron.*, vol. 1, no. c, 2018.

[3] D. Patil, M. K. McDonough, J. M. Miller, B. Fahimi, and P. T. Balsara, “Wireless Power Transfer for Vehicular Applications: Overview and Challenges,” *IEEE Trans. Transp. Electrif.*, vol. 4, no. 1, pp. 3–37, 2017.

[4] M. Yilmaz and P. T. Krein, “Review of battery charger topologies, charging power levels, and infrastructure for plug-in electric and hybrid vehicles,” IEEE Trans. Power Electron., vol. 28, no. 5, pp. 2151–2169, May 2013.

[5] L. Baruschka and A. Mertens, “Comparison of cascaded h-bridge converters and modular multilevel converters for the use in medium voltage grid connected battery energy storage systems,” vol. 21, no. June, pp. 6–9, 2011.

[6] J. Rodriguez *et al*., "Multilevel Converters: An Enabling Technology for High-Power Applications," in *Proceedings of the IEEE*, vol. 97, no. 11, pp. 1786-1817, Nov. 2009.

[7] G. Singh and V. K. Garg, “THD analysis of cascaded H-bridge multi-level inverter,” *4th IEEE Int. Conf. Signal Process. Comput. Control. ISPCC 2017*, vol. 2017–January, pp. 229–234, 2018.

[8] A. Gohari, E. Afjei, H. Torkaman and A. Mosallanejad, "Minimizing switching losses in cascaded multilevel inverters by proper switching array selection," *2018 9th Annual Power Electronics, Drives Systems and Technologies Conference (PEDSTC)*, Tehran, 2018, pp. 432-436.

[9] E. R. Joy, B. K. Kushwaha, G. Rituraj, and P. Kumar, “Analysis and comparison of four compensation topologies of contactless power transfer system,” *2015 4th Int. Conf. Electr. Power Energy Convers. Syst. EPECS 2015*, 2015.

[10] C. Panchal, S. Stegen, and J. Lu, “Review of static and dynamic wireless electric vehicle charging system,” *Eng. Sci. Technol. an Int. J.*, vol. 21, no. 5, pp. 922–937, 2018.

[11] W. Zhang and C. C. Mi, “Compensation topologies of high-power wireless power transfer systems,” *IEEE Trans. Veh. Technol.*, vol. 65, no. 6, pp. 4768–4778, 2016.

Authors

Valentin Rigot was born in Le Mans, France, in 1995. He received the Engineer degree in energy and mastering degree in system control from the Ecole Nationale Supérieur d’Ingénieurs de Poitiers, Poitiers, France, in 2018. Since 2018, he has been working as a PhD student for the institute for energy transition VEDECOM with the laboratory GEEPS. His research subject is Power DC/DC converters for charging electrical vehicle and integration of innovative components.

Zariff Gomes was born in Campina Grande, Brazil, in 1989. He received the Dipl. Eng, and the M.Sc degree in Electrical Engineering from the Federal University of Paraíba, João Pessoa, Brazil, in 2013 , 2015. Since 2017, he has been a research engineer on innovative charging systems of Electrical Vehicle with the institute for energy transition VEDECOM, Versailles, France. His current research interests include Static and Dynamic Wireless Power transfer, Real-Time Embedded Systems and Power Converters.

Jihen Sakly was born in Monastir, Tunisia, in 1988. She received the Dipl. Eng, the M.Sc and Ph.D. degree in electrical engineering from the Ecole Nationale d'ingénieurs de Tunis-Université de Tunis El Manar,Tunis, Tunisia, in 2012 , 2013, 2018.
Since 2018, she has been a research engineer on innovative charging systems of Electrical Vehicle with the institute for energy transition VEDECOM, Versailles, France. Her current research interests include Static and Dynamic Wireless Power transfer, V2G/V2H power converters, control design related to automotive systems and its performances improvement.

François Colet received Engineering degree from the Institut Polytechnique de Grenoble, France, in 1990. He is currently the Innovative Charging System Project Manager at Institut VEDECOM, Versailles, France and Groupe Renault, France. His research interests include communication protocols (ISO/IEC 15118, OCPP, IEC 6311 etc.), standardisation of grid codes for V2X technology, bidirectional onboard chargers for EVs.