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Survey on Standards and Regulations for Wireless Charging of Electric Vehicles

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***Abstract*—In the next decades, the number of electric vehicles (EVs) for private use is predicted to increase considerably. Charging the EVs through wireless power transfer (WPT), i.e. wireless charging, has the potential to shorten charging duration of EVs batteries through dynamic charging and it would also improve the safety of static charging in case of wet weather conditions. From 2015, standards and regulations have been released such that common constraints can be defined. Therefore, it is essential to be aware of these regulations before designing an EV wireless charging system, such that it can become an actual application. This paper focuses on the available regulations and standards on EVs charging through WPT. These regulations are explained individually and then, they are compared and discussed mainly in terms of the electromagnetic compatibility (EMC) and exposure of humans to the radiated magnetic field limits. To gain a better understanding, a quantitative and qualitative interpretation of these limits is also given.**

***Index Terms*—Electric vehicles (EVs), electromagnetic compatibility (EMC), electromagnetic field (EMF) human exposure, regulations, standards, wireless power transfer (WPT).**

I. Introduction

In a society that is pointing towards a sustainable future, the number of electric vehicles (EVs) for private use is predicted to increase considerably [1]. However, there are still some doubts about the use of EVs on a large scale, primarily related to the energy storage. The battery technologies currently used in EVs have as main concerns duration, charging time, size, weight and price, and these variables influence each other in terms of performance. As an example, the duration of a journey with only one charge can be enlarged by increasing the battery size. However, this would make both the charging time and the price of the resulting battery increase as well. Another possible solution could be charging the EV's battery while it is in motion, which is called dynamic charging. The dynamic charging is widely used in public transportation via overhead cables, but it would be unfeasible in case of private EVs. Therefore, the need for wireless charging becomes evident in this case. EVs wireless charging is also essential in static conditions, if completely autonomous vehicles are considered. Since these vehicles are driver-less, they should be charged fully automatically without people involved. Moreover, wireless charging is also safer than the plug-in one, because it does not require the users to touch any conductive part that might become dangerous especially in case of wet weather conditions. Wireless charging of EVs is possible through wireless power transfer (WPT). WPT consists of the transfer of energy without any physical connection in between the transmitter and the receiver. Depending on their configuration, different transfer technologies can be used [2]. As an example, microwave and infrared power transfer technologies are used generally for low power applications, and they work at frequencies equal or greater than GHz. Another commonly used technology is the electromagnetic power transfer, that can be either capacitive or inductive. The capacitive power transfer consists of coupled metal plates that work together with time-varying electric fields. However, the method used the most in EVs charging is the inductive power transfer, in which coupled coils transfer power using time-varying magnetic fields. To compensate the coils' inductive power, capacitors can be added either in series or in parallel to the coils. Both the transmitter and the receiver become then resonant circuits and, to enhance the efficiency of the power transfer, they are tuned to the same resonant frequency. This kind of inductive power transfer is known as *magnetic resonant* coupling [3]–[5].

In the last decade, extensive research on WPT for EVs charging has been conducted, which covers many different aspects. As an example, coils design, compensation capacitors, control strategies, topologies, communication methods are covered by many papers and patents have been published regarding both static and dynamic EVs charging. Because of this increasing interest, standards and regulations have been released from 2015 such that common constraints are set to guarantee interoperability and safety. On top of this, physical limits also restrict the development of WPT for EVs charging. These can be due to the fixed dimensions of the vehicle, that needs to be taken into account during the design. On the other hand, physical limits can also be the intrinsic limitations of components which depend on the chosen power level, allowed frequency range and required speed of both control and communication systems. All these limits are constraints in the research on this technology. Therefore, there are still many scientific and engineering challenges to make this application efficient within all those constraints.

This paper focuses on the available standards and regulations of WPT for EVs charging which are IEC 61980-1, ISO 19363 and SAE J2954. These are explained singularly in Section II. In Section III, they are compared for what concerns

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electromagnetic compatibility (EMC) and human exposure to fields' radiation. A quantitative and qualitative interpretation is also proposed. Finally, in Section IV, conclusions on the available standards and regulations on WPT for EVs are given.

II. Available Standards and Regulations

The three publicly available standards and regulations are here explained, listed in chronological order of publication.

A. IEC 61980-1

Electric vehicle wireless power transfer (WPT) systems - Part 1: General requirements

This is an European standard released as fist edition in July 2015 by the International Electrotechnical Commission (IEC) [6]. Its stability date is 2019, and the second edition is expected to be published on the 30^{th} March 2020. IEC 61980-1 is the first part of the IEC 61980 series that only focuses on general requirements. Moreover, in 2017, both the second and third parts were also expected to be published. They treat specific requirements respectively for communication and magnetic field power transfer. However, they have not been published yet.

IEC 61980-1 concerns generic aspects of WPT such as use cases, electrical safety, electromagnetic compatibility (EMC), and electromagnetic field (EMF) exposure, which are common for all the possible power transfer technologies:

- Inductive power transfer, including magnetic resonance;
- Capacitive power transfer;
- Microwave power transfer (1-300 GHz);
- Infrared power transfer (300 GHz-400 THz).

The transfer power classes, efficiency, interoperability and communication are not specified here, but they are going to be part of the specific requirements for each transfer technology. The installation of the WPT charging system could be either ground mounted (in-ground, on-ground or over-stand), vertical surface mounted or on-roof mounted. The system can be design either for indoor use, outdoor use or industrial areas exposed to pollution and/or severe condition. Environmental tests must be executed to asses the WPT system compliance to IEC 61851-1 and ISO 19363.

EMC limits are defined in this standard, which are essential constraints for the development of this technology. Both immunity and disturbance requirements are specified, and each of them treats conducted and radiated perturbations. The immunity requirements refers to IEC 61000-4. On the other hand, the disturbance requirements are divided into two groups depending on the frequency range. The low frequency (LF) range comprehends frequencies lower than 150 kHz, and it is regulated by IEC 61000-3 which sets limits for harmonics, voltage fluctuation and flicker. In the LF range, the radiated limits are not specified. The radiated disturbances of the WPT system are regulated by CISPR 11 only in the radio frequency (RF) range that goes from 150 kHz to 1 GHz. Since the WPT system is classified as an equipment of group 2 and therefore,

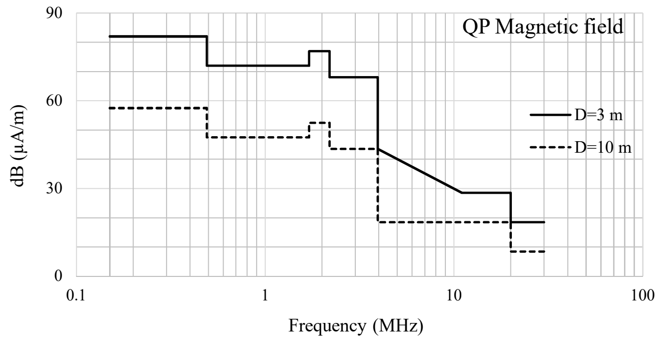

Fig. 1. IEC 61980-1 limits of the magnetic field strength from 150 kHz to 30 MHz, for both class A and B equipments (CISPR 11 Group 2 Class A).

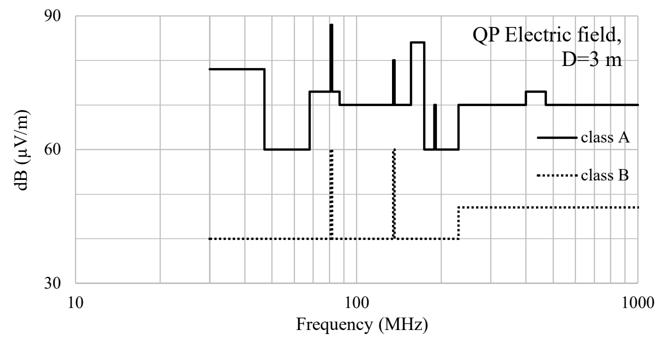

Fig. 2. IEC 61980-1 limits of the 30-1000 MHz electric field strength for both class A and B equipments, at 3 meters distance (CISPR 11 Group 2).

it needs to be compliant to the group 2 limits. Moreover, depending on the environment in which the WPT system is supposed to be used, that can belong to two different classes. Class A equipments are suitable for any environment other than residential, and class B equipments are suitable for residential and domestic environments. After this classification, the limits of the radiated disturbance field strength are defined considering both the magnetic and the electric components of the field. In the RF range from 150 kHz to 30 MHz, limitations are proposed only for the magnetic component at both 3 and 10 meters distance from the equipment under test. These limitations are shown in Fig. 1 in terms of quasi-peak (QP) magnetic field and, according to IEC 61980-1, they are valid for all kind of WPT systems independently from their environmental class A or B. It is interesting to point out that the limitations in Fig. 1 are equivalent to the ones of group 2 class A equipments in CISPR 11 [7]. Therefore, below 30 MHz, higher levels of radiated disturbances are tolerated for WPT systems in residential environments and it can be still considered for class B environments if all the other disturbance limit of class B are satisfied. On the other hand, in the frequency range from 30 MHz to 1000 MHz, limitations are proposed only for the electric component of the field, and these limitations at 3 meters distance are reported in Fig. 2 for both classes. The limitations at 10 meters distance have the same trend of the ones in Fig. 2 shifted down of 10 dB. On top of these limitations, the WPT system must be also compliant to other requirements when it is operating with the EV. In particular, the standby and active mode must also be tested according to ISO 11451-2. The radiated disturbances of the WPT with the EV must be compliant to CISPR 12 in the range 30-1000 MHz, to provide protection for broadcast transmitters and receivers used in residential environments [8]. These limits are similar to the ones in Fig. 2 class B, but they do not include the two peaks. EMF restrictions for human exposure are also treated in this standards. In case there are not specific local or national regulations, the limits shall be compliant to the International Commission of Non-Ionizing Radiation Protection (ICNIRP) Guidelines 1998 or 2010, which are discussed in Section III-B1.

B. ISO/PAS 19363:2017

Electrically propelled road vehicles - Magnetic field wireless power transfer - Safety and interoperability requirements

This is an intentional intermediate specification released as first edition in January 2017 by the International Organization for Standardization (ISO), from which the International Standard ISO/DIS 19363 is currently under development. This specification is intended to be compatible with the IEC 61980 series [9]. In particular, ISO/PAS 19363 treats magnetic field power transfer for car passengers and light duty vehicles, in stationary and unidirectional applications. An example of a WPT system structure is shown in Fig. 3. The whole transmitter system is called ground assembly (GA) and the receiver one is called vehicle assembly (VA). The WPT technology chosen is inductive power transfer, using magnetic resonance. The GA and the VA are coupled through their respective coils and they use wireless communication.

This specification not only has common parts with IEC 61980-1, but also aligns with several characteristics of SAE TIR J2954 published in May 2016. To guarantee interoperability between WPT systems from different manufacturers, four power classes and three Z-classes are defined in this specification. The power level and the interoperability are provisionally defined for each power class and need to be confirmed in IEC 61980-3 which is under development. The Z-classes defined based on the clearance between the VA coil and the ground, the offset tolerances, the minimum target efficiencies, the nominal operating frequency and its tuning range are defined as in SAE TIR J2954. Since ISO/PAS 19363 has many similarities with the TIR from SAE, it is reasonable to assume that the final version of ISO 19363 will be also harmonized with the updates of SAE J2954 from April 2019. For lack of space, the definitions of power classes, Z-classes and operating frequency range are introduced in Section II-C according to the latest SAE J2954 RP, since it is the most updated regulation.

For what concerns EMC, ISO/PAS 19363 refers to CISPR/D which is currently under development. For EMF human exposure, this document refers to the Guidelines of ICNIRP 2010 for general public and, for human with implanted medical devices (IMDs)/pacemaker, it refers to AAMI/ISO 14117-2012 Annex M. These regulations are going to be discussed in Section III-B1 and III-B2. Moreover, this intermediate

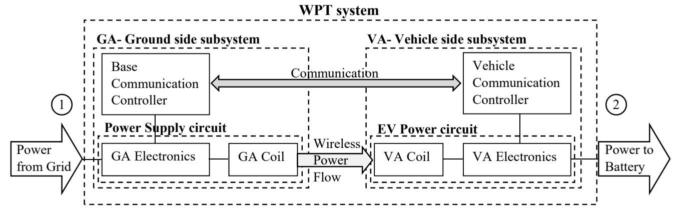

Fig. 3. Example of WPT system structure proposed by ISO/PAS 19363.

TABLE I
POWER CLASSES, EFFICIENCY AND INTEROPERABILITY FOR LD EVS.

			WPT power classes			
			WPT1	WPT2	WPT3	WPT4
		Maximum input (kV A)	3.7	7.7	11.1	22
Interoperability			VA			
	GA	WPT1	✓	✓	✓	✗
		WPT2	✓	✓	✓	✗
		WPT3	✓	✓	✓	✗
		WPT4	✗	✗	✗	✓

✓ = required ✗ = TBD

specification is focusing also on the communication, in which it is defined the required parameters to be sent and the steps to be followed in a chronological order for ensuring a safe WPT transfer. The communication defined in all the parts of ISO 15118 is valid for both conductive and WPT charging.

C. SAE J2954 RP

(R) Wireless Power Transfer for Light-Duty Plug-In/ Electric Vehicles and Alignment Methodology

This an International recommended practice (RP) released by the Society of Automotive Engineers (SAE) which provides specific guidelines and technical references for the design of a WPT charging systems for EVs. The first edition has been published in May 2016 as technical information report (TIR) [10] and it has been revised in November 2017. The second edition SAE J2954 RP has been published in April 2019 [11] as an evolution of TIR J2954 based on experimental interoperability data and it will be standardized in the future after receiving more data. A second version SAE J2954/2 is also under development, which targets Heavy-Duty EVs and higher power levels for the WPT charging.

SAE J2954 presents technical guidelines for Light-Duty EVs (<4545 kg) which works using stationarity and unidirectional WPT charging. This WPT system is designed for EVs compliant to J1772 plug-in charging, such that the battery management system could be modified to allow both charging technologies. The WPT system schematic is equivalent to the one from ISO 1936, shown in Fig. 3. The power classes and Z-classes are defined as shown in Table I and II, respectively. There are four power classes depending on the maximum input power (Volt Ampere) and the interoperability between the classes is well-defined. The first three classes also have a minimum target efficiency of 85% at perfect alignment of the coils, 80% at offset positions and 75% when the coils belong to different power classes. The fourth power class is still in its early stages of definition

TABLE II
Z-CLASSES AND INTEROPERABILITY FOR LD EVS.

				Z-classes		
				Z1	Z2	Z3
	VA Coil-ground clearance range (mm)		from	100	140	170
			to	150	210	250
Interoperability				VA		
	GA	Z1		✓	✗	✗
		Z2		✓	✓	✗
		Z3		✓	✓	✓

✓ = required ✗ = N/A

TABLE III
OFFSET TOLERANCES.

Direction	Value
ΔX	$\pm$75 mm
ΔY	$\pm$100 mm
ΔZ	Zmax, Zmin $\in$ Z-class
Roll, Pitch, Yaw	$\pm 2^\circ$, $\pm 2^\circ$, $\pm 3^\circ$

and it will be further elaborated in the future editions. The efficiency is calculated with the measured power at points (1) and (2) in the schematic of Fig. 3. The efficiency test must be performed at three reference battery voltages of 280 V, 350 V, and 420 V with the output power at its maximum rated deliverable level. The efficiency test must be perform when the WPT is warmed up at a stable temperature. Multiple misalignment positions must be evaluated in any directions including the rotational misalignment. On the other hand, the three Z-classes in Table II are not defined as fixed numbers, but as ranges in definite intervals such that the system works when the EVs is both fully loaded and unloaded, and independently of the tires' pressure. By now, SAE J2954 only considers the case in which the GA coils is mounted above the ground, which makes the actual air gap between the coils lower than the distance specified by the Z-class. The amount of relative positions between the GA and VA coil can be infinite, but the nominal position is considered to be one that gives the maximum coupling at the target Z distance while their surfaces are parallel. From this nominal position, there are three possible degrees of freedom for the VA coil respect to the GA one which are: the direction of the travel called X, the direction perpendicular to the travel called Y, and the distance between the coils called Z. Moreover, the VA coils surface could also perform a rotation around any of these three axes. After the EV is parked in the designed spot, it is very unlikely that the VA coil is perfectly aligned with the GA one. Therefore, the system must allow some offset tolerances in all the directions, which values are shown in Table III. All these definitions have the aim to ensure both electric and magnetic interoperability between coils with different topologies and produced by different manufactures. To achieve so, SAE J2954 RP defines more guidelines respect to the previous TIR, e.g. the relation between maximum coupling and alignment of coils with different topologies is explained in detail. In the Appendices, reference designs of both the GA and VA coils are defined for testing their interoperability, which cover the first three power classes and all the Z-classes. The nominal operating frequency of the WPT system is 85 kHz, with a tuning band of 79-90 kHz. It needs to be pointed out that the lower limit of the frequency range of both the previous SAE TIR and ISO 19363 is 81.38 kHz, which has been changed to 79 kHz in this RP.

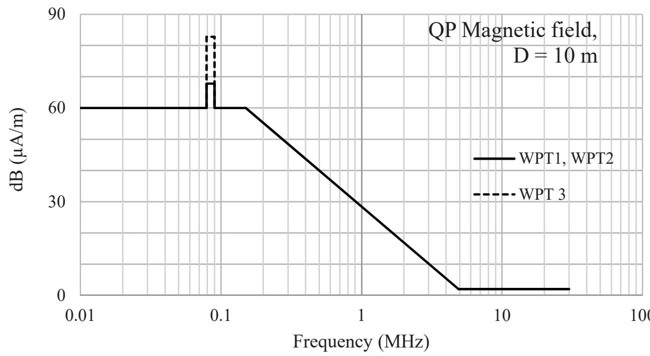

Fig. 4. SAE J2954/1 proposed limits for the radiated disturbances in residential environments below 30 MHz, for WPT1, WPT2 and WPT3.

EMC limits are also recommended in this TIR, classifying the WPT system below 30 MHz as in FCC part 18. Considering the entire system (WPT system + EV), the limits of the radiated disturbances at 10 meters distance are plotted in Fig. 4. In the allowed frequency range 79-90 kHz, the radiated field at both WPT1 and WP2 is limited to 67.8 dB. On the other hand, at WPT3, it is limited to 82.8 dB and, in case sensitive equipments are present in the environment, this limit is lowered of 15 dB. In the previous SAE TIR, there was not distinction in the limits of different power levels and in the allowed frequency range the limit was set to 100 dB. Moreover, this RP is the only regulation that defines limits for EMC radiated disturbances below 150 kHz, which is not the case in IEC 61980 and ISO 19363. EMC limits are also specified at components level, and they can be used as a first evaluation before their integration into the WPT system. However, only the vehicle level measurements are the ones that determine the compliance to the regulations. In this RP, the EMF exposure of both humans and IMD/pacemaker is treated extensively. For what concerns the general public, the Guidelines of ICNIRP 2010 are used as references and they are discussed in Section III-B1. On the other hand, the EMF limits for human with IMD/pacemaker are stricter according to AAMI/ISO 14117-2012 Annex M, and these are discussed in Section III-B2.

Foreign object detection (FOD) is also treated in this specification. In particular, if a foreign object is detected on the surface of the GA coil, the process is either not started or stopped in case it was already running. On the other hand, in case the object is not detected, the temperature of the surface must be monitored and the process can continue in case that temperature does not exceed the limits of UL 2750 ($\approx 80\,^\circ$C). The tests to be executed with thirteen sample objects are either temperature rising or ignition test. In this RP, the concept of living object protection (LOP) is also introduced.

In particular, LOP must ensure that both a living object is properly detected within certain boundaries and the protection system reacts fast enough such that the radiated field is not harmful. For what concerns communication, this RP relies on SAE J2836/6, J2847/6 and J2931/6. The communication is important to ensure enough alignment between GA and VA coils. A minimum required alignment technology is defined which uses low power excitation. This works with a low current that flows in the GA coil which induces a signal on the VA coil. The communication system is active during the entire charging process from the pairing stage until the end of charge, monitoring anomalies and checking the alignment.

III. Comparison and discussion

The three available standards and regulations on EVs charging through WPT have been discussed in Section II. Since they defines constraints on the same application, it is reasonable that they agree with each other. However, it is interesting to compare these regulations for what concerns EMC and EMF human exposure to verify at which extend they agree.

A. EMC

To guarantee the unperturbed operation of electronic devices in the surrounding of the WPT charging system, EMC limits are imposed by standards and regulations, without taking into account the safety limits for humans. Fig. 5 compares the EMC limits of the QP magnetic field strength in dB, at a distance of 10 meters. According to SAE J2954 RP, in the operating frequency range 79-90 kHz the field limit peaks up to 82.8 dB. This higher field value is allowed because the operating frequency range is chosen on purpose for this application, which means that the radiated field at this frequency would not interfere with the operation of any other electronic device. It is reasonable to assume that the amount of radiation allowed in the operating frequency range would be determined by the EMF human exposure limits. This assumption is discussed and evaluated in Section III-C. On the other hand, the limit proposed by IEC 61980-1, which is equivalent to CISPR 11 Group 2 Class A, goes from 150 kHz to 30 MHz because CISPR 11 does not give limits for the radiated disturbance in the range 9-150 kHz. Therefore, this limit applies only to field radiations caused by the higher-order harmonics which is greater than the relative one proposed by the SAE RP.

B. EMF human and IMD/pacemaker exposure

To guarantee that EMF radiations are not dangerous of the EV passengers and for the people in the surrounding, limits for the EMF are defined taking into account both the intensity and the frequency of the radiated EMF. An high-frequency EMF could interfere with some biological functions inside the human body in case its intensity is relatively high, because it can induce an electric field and currents in the body's tissues. Therefore, it is important to ensure that these have an intensity within the safety limits for humans. Measurements at different misalignments must be performed, such that the worst-case measurement can be recorded and compared with the regulations. The SAE RP defines limits for the EMF in three regions respect to the EV with the WPT system.

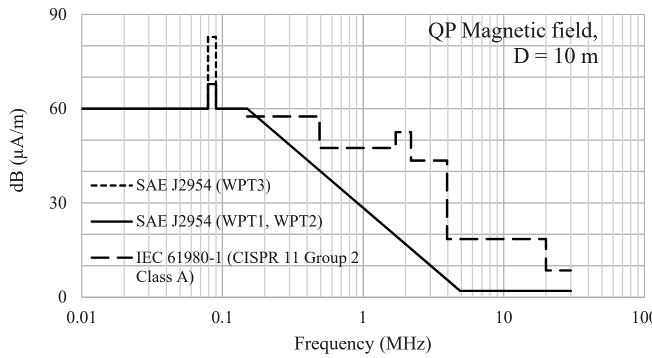

Fig. 5. Limits of the magnetic field strength at 10 meters distance.

TABLE IV
Reference levels for general public exposure in the frequency range 3 kHz-10 MHz (rms values). [12]

Electric field strength - E	**Magnetic field strength - H**	**Magnetic flux density - B**	**Contact current**
83 V/m	21.5 A/m	27 μT	0.2*f(kHz) =17 mA @85 kHz

- Region 1: area between the GA and VA coils.
- Region 2: area around the vehicle, with a height
- Region 3: area inside the vehicle.

Limits for region 1 are not specified because the area underneath the vehicle is considered not accessible to people and covered by LOP. SAE RP also suggests detail guidelines to asses the compliance to EMF exposure, including models the human body and they relative position respect to the car. This is a evolution compare to both the previous SAE TIR and ISO 19363 that are less specific and in which the region 2 is divided into two parts by the height of 70 cm. According to IEC 61980-1, the EMF assessment is divided in different regions and the measurements are performed with a probe at 20 cm distance from the EV, while the current level ranges from the 50% to 100% of the rated power. However, the SAE RP is just considered as a reference in the next sections because it is the most recent among the other regulations.

1) ICNIRP Guideline 2010 for general public: ICNIRP has studied extensively the biological effects of EMF on the human tissues, depending on both the fields intensity and frequency. Therefore, in the ICNIRP Guidelines 2010, *basic restrictions* on the maximum allowed EMF inducted inside the human body are defined for different tissues. However, since it is impossible to measure directly the EMF inside the body, *reference levels* are defined for the EMF outside the human body, such that if these conservative levels are met also the limits inside the body would be within the basic restrictions. The reference levels for general public exposure are shown in Table IV, for the frequency range of interest 3 kHz-10 MHz. These guidelines apply to both regions 2 and 3, but they do not necessarily preclude the interference with IMDs.

2) AAMI/ISO 14117-2012 Annex M for IMD/pacemaker: In Table V, stricter limits are defined such that the WPT system's radiation is safe for a wider range of people.

TABLE V
LIMITS FOR IMD/PACEMAKER EMF EXPOSURE (RMS VALUES). [11]

Region	Magnetic filed strength - H	Magnetic flux density - B
3, 2	11.9 A/m	15 μT
	from 79 to 90 kHz	

Even if the rms values of the field are reported in Table IV and V, the peak values are considered as normative limits. These EMF limits concern only the operating frequency range, because the contribution of higher harmonics can be neglected if their amplitude is at least 30 dB below the fundamental.

C. EMC and EMF: Quantitative and qualitative interpretation

Table IV and V clearly show the limits of the EMF exposure in the allowed frequency range. However, it is difficult to evaluate them without using any other term of comparison. For gaining a better understanding of their meaning, they are compared first with another radiation phenomenon and, after this, with the EMC limits in Fig. 5.

The most tangible example is to consider the natural magnetic field of the Earth as a term of comparison. According to [13], the magnetic flux density of the geomagnetic field varies in the range 30-70 μT, depending on the distance of a certain location from the geomagnetic poles. This natural magnetic field can be considered to be static and, consequently, its frequency is 0 Hz. Therefore, the geomagnetic field does not interfere with the human biological function inside the body, because it has low intensity and it is static. On the other hand, the magnetic field produced by the WPT system for EVs charging is time-varying, which means that it is potentially able to induce an electric field and currents inside the human body. However, these are negligible in case their intensity is kept at a low level. To achieve so, in Table IV and V, the radiated magnetic field by the WPT system has the same order of magnitude of the geomagnetic one. Moreover, the limits of EMF human exposure to the magnetic filed strength and flux density are expressed, respectively, in A/m and μT. Nevertheless, the EMC magnetic field limits in Fig. 5 are expressed in $\mathrm{dB}_{(\mu\mathrm{A/m})}$ which makes it difficult to directly compare them to the human exposure limits. Assuming that the limits of Table V are taken as reference, the magnetic flux density must be within 15 μT in the allowed frequency range, which intensity is less than the typical value of the geomagnetic field. This value can be transformed in $\mathrm{dB}_{(\mu\mathrm{A/m})}$ to be able to compare it directly to the EMC limits. The procedure is divided into two steps. Firstly, the magnetic flux density is converted in magnetic field strength (see Table V) and then, its peak value is converted in $\mathrm{dB}_{(\mu\mathrm{A/m})}$ as in (1).

$$20 \cdot \log\Big(\frac{\overbrace{\sqrt{2} \cdot 11.9 \cdot 10^6 \mu\mathrm{A/m}}^{\text{peak value}}}{\mu\mathrm{A/m}}\Big) = 144.52 \ \mathrm{dB}_{(\mu\mathrm{A/m})} \quad (1)$$

According to (1), the amount of magnetic field allowed in the surrounding of the vehicle is 144.52 dB considering the most conservative case. From Fig. 5, in the same frequency range, the EMC limit recommended by the SAE RP is up to 82.8 dB at a distance of 10 meters from the vehicle. This limit seems to be reasonable since it is lower than the limit for human exposure. However, it would be interesting to derive the value of the magnetic field in the surroundings of the vehicle knowing that at 10 meters distance its value is 82.8 dB, and evaluate if that value would be still lower than 144.52 dB.

IV. CONCLUSION

From 2015, standards and regulations on EVs charging through WPT have been released. Currently, the available ones are IEC 61980-1, SAE J2954 RP and ISO/PAS 19363:2017 which have many common points. However, they are not entirely in agreement in terms of EMC. From Fig. 5, it is clear that the limits currently adopted by IEC 61980-1 are on average 15 dB larger than the ones in SAE J2954. Since the human exposure to magnetic fields is also well-regulated in the operating frequency range 79-90 kHz, it would be convenient to define EMC limits for that frequency range that also ensure a safe magnetic field around the vehicle for the humans. Therefore, the next step is to analyze the propagation of the magnetic field which depends on the coils' topology. Concluding, wireless charging is a technology still in its early stages and new regulations are now under development. In the future, other aspects will also be regulated such as dynamic, vehicle-to-grid and higher power level wireless charging.

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