Standardization of Human Exposure Assessment for Low-Frequency (Below 30 MHz) WPT systems (IEC/IEEE 63184)

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ABSTRACT: Vehicle electronation has raised compliance concerns regarding the vehicle EMC performance below 30 MHz. One of the compliance concerns is the human exposure against the electromagnetic fields from electric vehicle (EV) which installs wireless power transfer system (WPT). The International Electrotechnical Commission (IEC) Technical Committee 106 (TC106), in collaboration with the Institute of Electrical and Electronics Engineers International Committee on Electromagnetic Safety (IEEE ICES) TC 34, published IEC/IEEE 63184, "Assessment Methods of the Human Exposure to Electric and Magnetic Fields from Wireless Power Transfer Systems – Models, Instrumentation, Measurement and Computational Methods and Procedures (Frequency Range of 3 kHz to 30 MHz)", in February 2025. This paper introduces the assessment method defined in IEC/IEEE 63184, using the exposure scenario of the WPT system which is installed on EV. It also presents a study on the spatial averaging method, as defined in IEC/IEEE 63184 for non-uniform exposure assessment, which was discussed during the standardization process.

KEY WORDS: wireless power transfer, human exposure, electric vehicle

1. INTRODUCTION

The automotive industry has been working towards carbon neutrality, with the goal of eliminating CO_2 emissions throughout the entire lifecycle of a vehicle. One of the critical approaches in achieving carbon neutrality is the development of electric vehicles (EVs), which are seen as a key solution for reducing emissions throughout a vehicle's lifecycle(1). The EV uses some high voltage components including a rear inverter and motor for driving and the AC-DC convertor for charging system. These high voltage components impact to the vehicle EMC performance below 30 MHz because the frequencies of the switching and harmonics currents is caused below 30 MHz for charging and driving. In addition to the challenges related to EMC performance, human exposure to electromagnetic fields has been growing concerning, especially in the context of wireless power transfer (WPT) for EVs.

There are two types of international guidelines and standards published by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and Institute of Electrical and Electronics Engineers (IEEE) International Committee on Electromagnetic Safety Technical Committee 95 for human exposure(2)(3)(4). The two international guideline specifies different limit levels of magnetic fields and electric fields and the electric fields which induced in the body. In this paper, the limit level of the magnetic field is called "reference level" and the limit levels of the electric field induced in human body is called "basic restriction". The automotive industry needs to choose and satisfy guidelines.

The International Electrotechnical Commission (IEC) Technical Committee 106 (TC106) publishes international standards on measurement and calculation methods to assess human exposure to electric, magnetic and electromagnetic fields from 0 Hz to 300 GHz for compliance assessments. IEC Joint Working 63184 in collaboration with IEEE ICES TC 34 (JWG63184), published IEC/IEEE 63184 which defines the assessment methods of the human exposure to electric and magnetic fields generated from WPT system in the frequency range from 3 kHz to 30 MHz on Jan, 2025(5).

This paper introduces the assessment method which is prescribed in IEC/IEEE 63184 using exposure scenario of the WPT system installed on vehicle and the study of the spatial averaging method which was discussed in JWG 63184.

2. HISTORY OF STANDARDS OF WPT FOR HUMAN EXPOSURE

IEC TC 106 has established several working groups (WGs) to prepare international standards for measurement and calculation methods to assess human exposure to electric, magnetic, and electromagnetic fields since 1999. WG9 in TC106 was established for addressing methods for assessment of WPT related to human exposures in 2015, and published IEC Technical Report (TR) 62905 in 2018 and TR 63377 in 2022. These standards outline the exposure assessment methods for WPT systems, focusing on frequencies up to 10 MHz and between 30 MHz and 300 GHz, respectively[6][7]. For human exposure of the WPT systems below 30MHz, IEC TC106 WG9 was established for the WPT exposure assessment methods in 2015 and published IEC TR 62905 in 2018. In 2018, IEC TC106 PT 63184 was established, which became IEC Joint Working Group (JWG) 63184 in collaboration with ICES TC34 in IEEE, and published IEC Publicly Available Specification (PAS) 63184 in 2021 and IEC/IEEE 63184 as a dual-logo standard in 2025.

For WPT system in the frequency range from 30 MHz to 300 GHz, IEC TC106 WG9 also published IEC TR 63377 in 2022 and IEC/IEEE JWG63480 was established to prepare an international standard in 2022.

Fig. 1 shows the publication history of above WG9 and IEC JWG 63184.

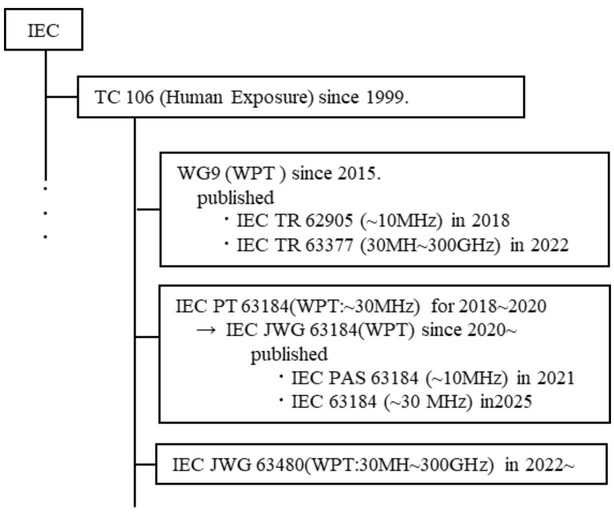


Fig. 1 Configuration and Publication History of Standards of WPT System for Human Exposure

3. Overview of IEC/IEEE 63184

This section shows the overview of IEC/IEEEss 63184. This paper mainly focusses on the assessment procedures for the WPT system (below100 kHz) installed on EV, which is defined in Annex I of IEC/IEEE 63184[5].

3.1. Scope

IEC/IEEE 63184 defines methods to assess human exposure to electric and magnetic fields which is generated WPT systems with electromagnetic human exposure guidelines (i.e., ICNIRP 1998, 2010 and IEEE Std C95.1). The frequency range is from 3 kHz to 30 MHz. This standard focuses on exposures from stationary and inductive WPT system. This standard does not consider the cardiac implantable electrical device.

3.2 Assessment procedures for WPT system installed on EV

This section shows the whole assessment procedures for WPT system installed on EVs. The whole assessment flowchart is shown in Fig. 2[5]. IEC/IEEE 63184 addresses the assessment procedures for evaluating both direct effects against internal electric field, current density and SAR, and indirect effects against contact currents of electromagnetic fields generated by WPT systems.

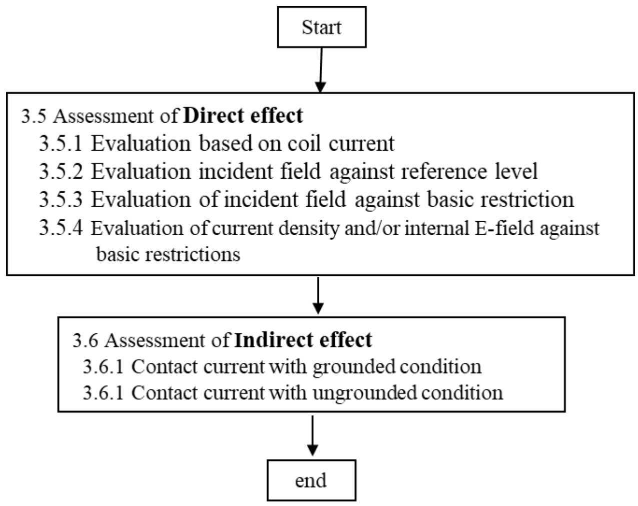


Fig.2 Assessment Flowchart

3.3 Definition of volumes for exposure assessment

Annex I of IEC/IEEE 63184 defines three regions based on anticipated user positions, as referenced from IEC 61980-3 (8): Region 1 refers to the volume under a vehicle or mimic plate, Region 2 corresponds to the volume outside it, and Region 3 represents the volume inside it. These definitions apply to both assessments of vehicles and vehicle mimic plates which is used for assessing component-level WPT systems, is also referenced from IEC 61980-3.

Although IEC/IEEE 63184 defines the exposure assessment of proximity detection sensor considerations for Region. 1, this paper will explain the exposure assessment of the WPT system installed on vehicles in Region. 1 and 2.

3.4 Condition for WPT system installed on EV

The coil offset between the transmitting coil and receiving coil of the WPT system should be determined by measurement or specifications provided by the device manufacturer. The transfer efficiency should be maintained at more than 80% at the above offset, which is referenced from IEC 61980-3[8].

3.5 Assessment procedure of Direct Effect

This section explains the assessment procedures of direct effects. The direct effect is biological effect resulting from exposure of the human body to electric or magnetic fields generated from WPT system in free space.

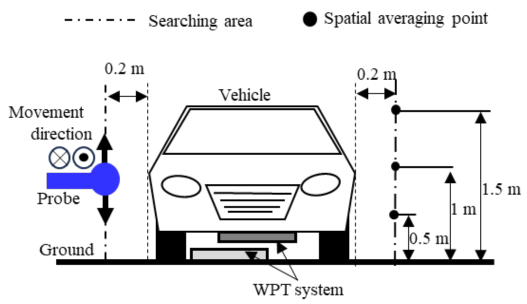
3.5.1 Evaluation based on coil current.

The evaluation based on coil current compares the measured coil current with the calculated maximum permissible coil current of the WPT system. The maximum permissible coil current can be calculated by the formula based on Bio-Savart equation and the applicable reference level which is explained in Annex A in IEC/IEEE 63184[5].

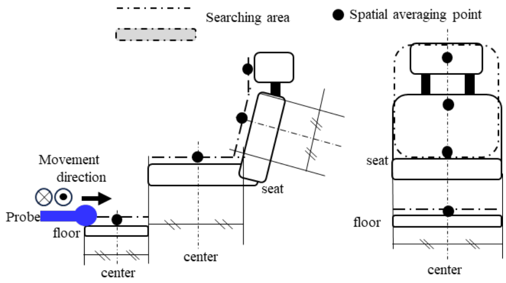
3.5.2 Evaluation of incident field against reference level

The evaluation of incident field against reference level compares the measured magnetic and electric field with the reference level. There are two methods for measuring the magnetic fields: searching for the maximum magnetic field and using the spatial averaging for local exposure. When spatial averaging is permitted in the guidelines or regulations we apply, we can choose either one[5]. In this section, we present two example cases in Region. 2 and 3 in this section to explain them in detail. The first method involves searching for the maximum magnetic and electric field levels in Region 2, at 0.2 m from the vehicle as shown in Fig. 3 (a). The second method involves the use of spatial averaging at 0.2 m from the closest accessible point and at three points (0.5 m, 1 m, 1.5 m) in height, as shown in Fig. 3 (a) [5].

For the evaluations in Region 3, the methods to search for the maximum magnetic and electric field levels and use the special averaging show in Fig. 3 (b).



(a)



(b)

Fig. 3 Measurement area in (a) Region. 2 and (b) Region. 3[5]

3.5.3 Evaluation of incident field against basic restriction

The evaluation of the incident field against basic restrictions compares the internal electric field and current density which are derived by multiplying the magnetic field by the coupling factor *k,* with basic restriction. Two methods to evaluate the incident fields using the coupling factors defined in IEC/IEEE 63184[5].

First method is to estimate the coupling factor from the localized scenarios. In case of WPT system installed on EV in IEC/IEEE 63184, the two values of the coupling factors are defined for ICNIRP 2010 and ICNIRP 1998 according to the analysis result [9]. Second method is to estimate the coupling factor based on the generic gradient source model method (GGSM). The GGSM can calculate the coupling factor from the measured normalized local B-field gradient[10]. In case of WPT system installed on EV in IEC/IEEE 63184, the lowest gradient of B-fields is determined at the point where the maximum magnetic field is obtained.

The internal electric fields can be calculated from multiplying the magnetic field by the coupling factor *k* as explained in the previous sentences.

3.5.4 Evaluation of current density and/or internal E-field against basic restrictions

The evaluation is to calculate the internal electric field or SAR for comparison with basic restrictions by simulation using anatomical human models[5]. The basic restrictions on human exposure are specified in terms of peak spatial average SAR, whole-body average SAR, averaged current density on a surface, peak spatial average E-field in a cubical volume, peak spatial average E-field along a line and maximum local E-field. We can choose the above the quantities depending on the frequency of the WPT system, exposed body parts and the applied national regulations.

3.6 Assessment procedure of Indirect Effect

This section explains the assessment procedures of indirect effects. The indirect effect is biological effect via a physical contact with the electrode or other source of current[(5)]. When the compliance assessment considering contact currents is needed according to the guidelines or regulations we apply, the assessment of the indirect effect is needed. The assessment flow for indirect effect is shown in Fig. 4. The following two conditions which causes contact currents flowing in human body are assumed in IEC/IEEE 63184[(5)].

(i) Human touches grounded metal plate near WPT system

(ii) Human touches ungrounded metal plate near WPT system

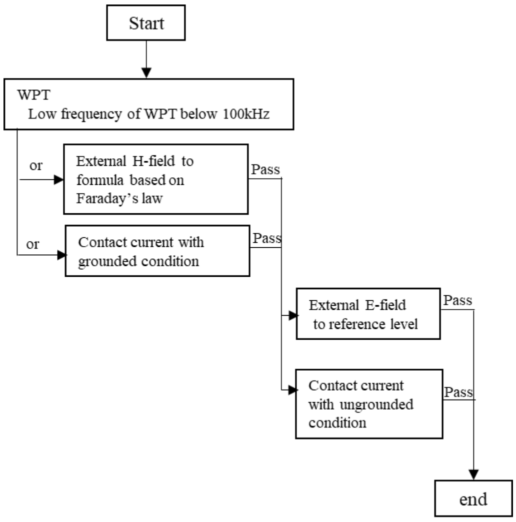
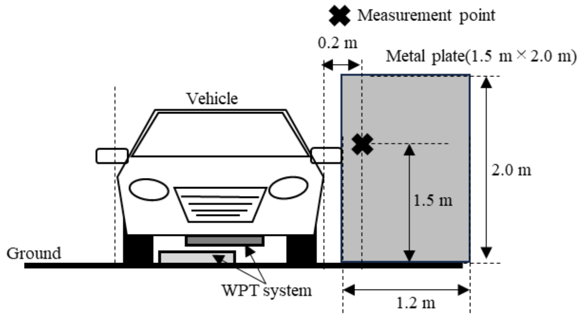


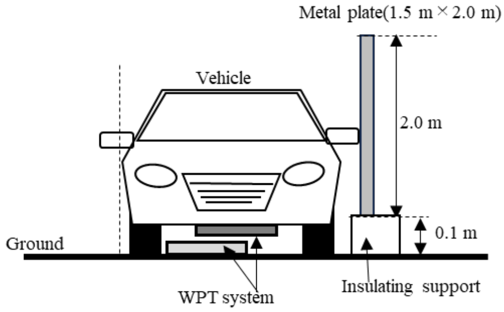
Fig. 4 Flow chart of indirect effect[(5)]

The contact current under the condition (i) is caused by Faraday's law. We can calculate the contact current from the maximum magnetic fields obtained in Sec. 3.5.2 by the formula based on Faraday's law. On the other hand, the maximum electric field obtained in Sec. 3.5.2 can be compared with the reference level for the assessment under the condition (ii).

The contact current also can be measured, directly. The measurement layouts of the condition (i) and (ii) are shown in Fig. 5. For the assessment of the condition (i), the grounded metal plate should be placed at the maximum magnetic field location obtained in Sec. 3.5.2 as shown in Fig. 5 (a). The plane of the metal plate should be placed normal to the vehicle body surface, and the distance between the vehicle body and the grounded metal plate should be determined by the surface of body or body part edge. The measurement position is defined as shown in Fig. 5 (a). For the assessment of the condition (ii), the ungrounded metal plate should be used, and the unground metal plate should be placed on a non-conductive at 100 mm above the ground shown in Fig. 5 (b). then the contact current can be measured.



(a)



(b)

Fig. 5 Measurement layout of contact current of (a) grounded condition and (b) ungrounded condition. [(5)]

4.Techical discussion of EV use case in JWG 63184

In this chapter, we introduce the technical issue which was discussed in JWG 63184. JWG 63184 mainly discussed the points of the special averaging explained in Sec. 3.5.2 using the coupling factor.

4.1 Description of Coupling factor

The compliance with a coupling factor is used in the technical issue to analyze human exposure to non-uniform fields at low frequencies. The coupling factor defined in IEC 62233[(11)] is derived using the following equation:

$$a_c = \left(\frac{E_{max}}{H_{max}}\right) / \left(\frac{E_{\mathrm{BR}}}{H_{\mathrm{RL}}}\right) \quad (2)$$

where $Emax$ is the internal electric field in the human body. E_{BR} is the basic restriction prescribed in the ICNIRP or IEEE guidelines. $H_{\max}$ is the spatial maximum magnetic field. Some studies evaluate the coupling factor for WPT system[(9)(12)(13)(14)]. We can evaluate whether the method is conservative based on the value of the coupling factor. For example, In the case of the coupling factor below 1, specifically 0.1, this indicates that the internal electric field is equivalent to the basic restriction when the magnetic field is ten times the reference level. On the other hand, in case of the coupling more than 1, it means that the internal electric field is more than that of the basic restriction when the measured magnetic fields is the same value as the reference level.

4.2 Study of the special averaging method using coupling

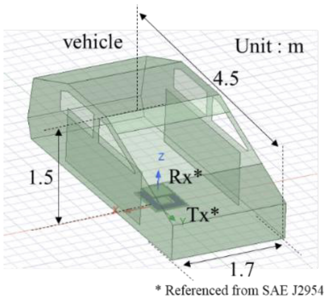
This section shows the study of the spatial averaging method for magnetic field leakage from a wireless power transfer system in EVs using the coupling factor, which was published in MDPI[14].

4.2.1 Simulation model

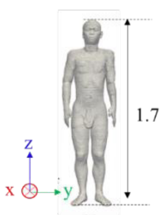
The spatial averaging in Region. 2 and 3 described in Fig. 3 (a) were conducted in this study. We will explain the study of the spatial averaging at Region.2 in this paper. The simulation model is shown in Fig. 6. The model of WPT system is referenced from SAE J2954 (Fig. 6 (a)) and the transmitting power is 3.7 kW the frequency of the WPT system is 85 kHz[15][16]. The study considered two vehicle body materials, including iron and carbon fiber-reinforced plastic (CFRP). The relative permittivity, permeability, and conductivity values for iron and CFRP were 1, 4000, and 10.3×10^6 S/m and 1, 1, and 0.25×10^6 S/m, respectively.

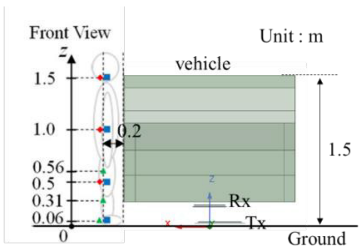
The standing human model is an anatomical human body model TARO developed at the National Institute of Information and Communications Technology (NICT), and the between the center the human body and the vehicle body is 0.2 m. as shown in Fig.6 (b) and (c). The height and mass of the model is 1.7 m and 65 kg, respectively. The number of tissues considered in TARO is 51. The voxel resolution of the human model was set at 2.0 mm.

ANSYS HFSS was used for calculating the magnetic fields and SPFD method is used for calculating the internal electric fields.



(a)





(b) (c)

Fig. 6 Simulation Model of (a) vehicle and WPT model, (b) human model and (c)

4.2.2 Point of averaging method

This study defines the three definitions of the points of the averaging method as shown in Table.1. The 2nd definition is the definition of IEC/IEEE 63184. This study calculates the averaged magnetic fields at the points described in Table.1.

Table1. Definitions of points of averaging method[14]

Definitions	Height from the ground [m]
1. IEC TR 62905	0.5, 1.0, 1.5
2. IEC/IEEE 63184	0.06, 0.5, 1.0, 1.5
3. Every 25 cm from maximum point	0.06, 0.31, 0.56

4.2.3 Simulation Results

The simulation results of the coupling factor show in Fig. 7 in case that the iron or CFRP was used for the vehicle body. For ICNIRP guideline, the coupling factors of all these definition in Table. 1 have the value below 1. On the other hands, for IEEE guideline, the coupling factor of the 1st definition in Table. 1 has the value more than 1. The coupling factor against IEEE is larger value than that of ICNIP guideline because the reference level defined in ICNRP is less than that of IEEE. Therefore, the points of the averaging method of the 2nd definition which is defined in IEC/IEEE 63184 is conservative. From these results, we also find that the confirmation of the coupling factor is needed when the limits of the reference level and the basic restriction defined in the other standards.

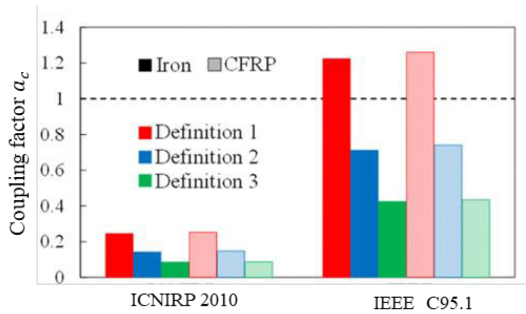


Fig.7 Calculation results of coupling factors[14]

5. CONCLUSIONS

This paper explained the standardization of human exposure assessment for low-frequency below 30 MHz.

Firstly, we introduce the history of standards of WPT for human exposure. IEC TC 106 already published technical reports of the assessment procedure of WPT, IEC TR 62905 below 30 MHz and TR 63377 above 30 MHz, respectively, and the international standards IEC/IEEE 63184 for the WPT below 30MHz. JWG 63480 was established for the international standardization of IEC/IEEE 63480 in 2022 and started to discuss it.

Second, this paper shows the outline of IEC/IEEE 63184 using the EV use case, there are two assessments of comparison for the reference level and the basic restriction against indirect effects and comparison for the contact current against direct effects, respectively.

Finally, we introduce the technical issue which was discussed in IEC/IEEE JWG 63184, which primarily focused on the points of the special averaging explained in Sec. 3.5.2 using the coupling factor.

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