EMC Issues on Wireless Power Transfer

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***Abstract*—Wireless power transfer technology is expected to be one of key technologies to offer easy and safe power supply as well as battery charging and thus to contribute to smart community through various kinds of products, such as portable digital devices and electrical vehicles. This paper mainly focuses on EMC issues on wireless power transfer, including emission which may cause the interference to other radio equipment, immunity, and human body protection. The general overview on the EMC and relevant issues are shown. The current and ongoing effort of technological research, rule making, and international and regional standardization on EMC aspects of wireless power transfer are also described.**

Keywords—wireless power transfer, EMC, emission, immunity, human body protection, regulation, standardization.

I. INTRODUCTION

In 2007, Kurs et al. report their investigation on magnetic resonance wireless power transfer [1]. The article built a momentum for current research and development of wireless power transfer technologies.

Wireless power transfer technologies are expected to offer the following values:

- Convenience on power supply and battery charging, without connection and release of any cables.
- Safe and secure power supply: Especially for charging of EV (electric vehicle) or PHEV (plug-in hybrid electric vehicle) which requires high electric power, there will be no worry about electrification even under wet condition, because metal contact is not required. (Figure 1)
- Environmental friendliness in so-called smart transportation system: For example, Electric bus can enjoy frequent refresh wireless charging, without connection and release of charging cable, even at brief stops at terminals. These refresh charging enables to enlarge the operation time and distance of electric bus. Alternatively the number of loaded batteries can be reduced, and you can get better mileage and reduction of energy consumption by lighter weight of the electric bus.

As for the several watt class application of wireless power transfer to portable digital devices, so-called "Qi" which is promoted by Wireless Power Consortium (WPC) is typical. Qi uses electromagnetic induction technology, and operating frequency is 110 to 205 kHz.

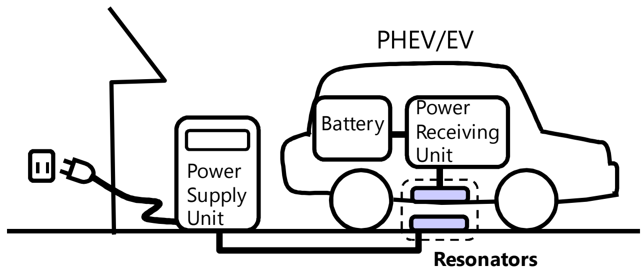

Fig. 1. Typical wireless PHEV/EV charger

Current target of Qi system is mobile device whose charging power is up to 5 watts, and various Qi products including cell-phone and charging jackets are sold in the market. The consortium intends the increase of transmission power to 120 watts. Other parties including PMA (Power Matters Alliance) and A4WP (Alliance for Wireless Power) are also active for other types of wireless power transfer system for portable digital devices. Several parties hope to use 6.78 MHz band, 13.56 MHz band and so on for operation frequency.

Meanwhile, the research and development of kilo-watt class wireless power transfer for PHEV/EV shows rapid advance. 3 to 7 kW class systems target light duty cars while several tens or hundreds kilo-watt class system are intended to apply to heavy duty vehicles such as bus. A forecast says that 3 to 4 million units in 2020 and 10 to 15 million units in 2030 will be sold. The discussion of operating frequency of the kilo-watt class wireless power transfer system is ongoing. The candidate bands seem to be included in 20 through 150 kHz.

Bi-directional wireless power transfer has already been investigated, and several pioneering experimental results were reported [2][3]. When these bi-directional technologies are realized, HEMS (Home Energy Management System) application using the batteries of PHEV/EV as home energy storage might be popular in coming smart community.

To the authors' knowledge, the general and wide overview throughout the various issues of wireless power transfer on EMC has not been reported yet. It would be very important to avoid interference to/from other radio products for wide deployment of the wireless power transfer technology to many potential applications which might contribute smart community. This paper intends to provide the general overview of the EMC issues on wireless power transfer, and to describe the most recent ongoing efforts of technological research to overcome the issues, rule making, and international or regional standardization on EMC aspects of wireless power transfer.

II. Overview of EMC and Relevant Issues on Wireless Power Transfer

Figure 2 shows a typical block diagram of wireless power transfer system. Note that radio transceivers are required on individual sides of the system, because the control signals between both sides are exchanged [4].

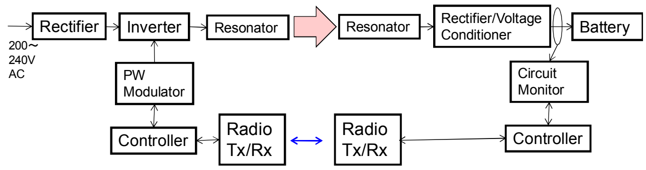

Fig. 2. Typical block diagram of wireless transfer system

In addition to usual conducted emission through AC lines of conductive charger, the new potential EMC problems of wireless power transfer systems would include the radiated emission from resonators carrying large current, and the undesired radiation from inverter or rectifier through resonators which includes higher order harmonics originated by switched waveform power signals.

Considering the above property, the following challenges are expected in rule making and standardizations:

1. Categorization of wireless power transfer equipment, i.e.it is regarded as an ordinary high-frequency-based equipment, or should be treated as a communication system which is usually subject to tighter restriction
2. Emission or interference to other radio equipment such as radio broadcasting receiver and radio controlled clock
3. Immunity to external noise and so on
4. Human body protection
5. Other aspects on safety such as heat generation
6. Standardization for international and regional interoperability

While Items 2, 3 and 4 are directly related to EMC, other challenges are also important considering the practical solution of EMC issues. The two following sections describe recent efforts to the above EMC issues.

III. Recent Efforts of Research and Rule Making on EMC of Wireless Power Transfer For Portable Digital Products

A. Guidelines for the use of wireless power transmission technologies from Broadband Wireless Forum Japan

In Japan, the Wireless Power Transmission Working Group of the Broadband Wireless Forum (BWF) has been active on many aspects on promotion of wireless power transfer [5]. Among many activities, the forum has released and updated "Guidelines for the use of wireless power transmission technologies". The most recent Edition 2 was released in 2013 [6]. The guideline also introduces relevant rules and notifications in annex as informative.

The guideline applies to wireless power transfer equipment meeting the following performance conditions:

- Transmission power does not exceed 50 W
- Power transmission distance does not exceed several meters
- Transmission frequencies: 10 kHz to 10MHz, 13.56 MHz band (ISM band), 27.12 MHz (ISM band), and 40.68 MHz (ISM band)

There is no restriction on the type of the equipment used or the power transmission method.

B. Emission or interference to other radio equipment

Based on the above guidelines by BWF, according to current regulation in Japan, if a wireless-power-transfer equipment is not a communication equipment and its high-frequency transmission power is 50 watts or less, an individual installation permission is not required. Even if the above requirements are met, if the equipment causes continuous and serious trouble to the functions of other radio equipment, the government authority can order necessary action to remove the trouble under Radio Act in Japan.

A 13.56-MHz wireless power transfer circuit using an inverter and fast switching devices to power receiving unit is reported in [7]. The evaluation shows that harmonics emissions can be reduced to -60 dB or less compared to the operating frequency power with a total efficiency of 67%.

In United States, permission by FCC through PBA (Permit but Ask) process is required. An article in KDB (Knowledge Database), 648474 D03 Handset Wireless Battery Charger（2012/03/01 v01r01）can be referred. In most wireless power transmission portions, Part 18 (18.305 for radiated emission, 18.307 for conducted emission) will be applied. When an ISM band is used, CISPR 11 Group 2 is usually applied on radiated and conducted emission, while CISPR 14-1, mainly for home appliances, or CISPR 22, mainly for information equipment may have to be referred. Additionally, if communication link which is not directly related to wireless power transfer is used in wireless power transfer frequency band, or other frequency is used for communication, Part 15 is applied to communication portion.

In EU countries, the wireless power transmission portion should meet:

- EN 61000-3-2 / IEC 61000-3-2 (Harmonic current emissions))
- EN 61000-3-3 / IEC 61000-3-3 (Voltage changes, voltage fluctuations and flicker),

while the following standards may consider in some cases:

- EN 61000-6-3 / IEC 61000-6-3 (Generic standards - Emission standard for residential, commercial and light-industrial environments)
- EN 55011 / CISPR 11 Group 2 (ISM band equipment)
- EN 55014-1 / CISPR 14-1 (Home appliances, etc.)
- EN 55022 / CISPR 22 (Information equipment)
- EN 300 330-1 (Induction loop using 9 kHz-30 MHz).

Meanwhile, the communication portion should meet EN 301 489-1 (Common technical requirements), while the following standards may consider in some cases:

- EN 301 489-17 (Bluetooth, Wireless LAN, Zigbee, etc.)
- EN 301 489-3 (Short range devices using 9kHz – 40GHz)

C. *Immunity*

The guidelines in BWF Japan do not have a description on immunity. As for FCC Part15 in US, 15.15 (general requirement) and 15.17 (Susceptibility to interference) describe the general statement on immunity, but does not show concrete test method.

The following standards for respective kinds of equipment will be applied in EU countries:

- EN 61000-6-1/IEC 61000-6-1 (Generic standards - Emission standard for residential, commercial and light-industrial environments)
- EN 55014-2 / CISPR 14-2 (Household appliances, etc.)
- EN 55024 / CISPR 24 (Information technology equipment).

D. *Human body protection*

The BWF guidelines say that wireless power transfer equipment should meet Radio-Radiation Protection Guidelines of TTC (Telecommunication Technology Committee) in Japan, and is recommended compliance internationally with ICNIRP guidelines [8] and IEEE/ICES standard [9]. Annex F in the BWF guidelines describes the brief summary of the above guidelines and standard.

Under the condition of power level is 50 watts or less, when the operating frequency is 10 kHz through 100 kHz, the above guidelines include the rules on stimulant effect, thermal action, and contact current. When the frequency is 100kHz through 10 MHz, the rule on induced current is added to the above three aspects. If the frequency is 10 MHz or more, the guidelines include the rules on thermal action, contact current, and induced current. You should note that measurement and evaluation methods are different between the TTC's Protection Guidelines and ICNIRP guidelines.

In US, FCC Part 1 (1.1307(c),(d), 1.1310) and FCC Part 2 (2.1091(mobile), 2.1093(portable)) will be referred. But the target frequency of current SAR evaluation system is 100MHz or more. There is a case of frequency below 100MHz which is permitted through the PBA process based on numerical simulation. It is noted that IEEE shows IEEE C95.1（3 kHz-300 GHz）and IEEE C95.6 (0-3kHz) as guidelines while they have difference in numerical limits from ICNIRP guidelines.

EC recommends 1999/519/EC (0-300GHz) on human body protection, while the ICNIRP guidelines are generally referred. The following measurement methods for respective kind of equipment are shown:

- EN 62311 / IEC 62311 (Default)
- EN 62233 / IEC 62233 (Household appliances, etc.)
- EN 62479/IEC 62479 (Low power electronic and electrical equipment, 10 MHz-300 GHz)
- EN 62209-2/IEC 62209-2 (hand-held and body-mounted wireless communication devices, 30 MHz-6 GHz)

E. *Other aspects on safety*

In the BWF guidelines, IEC60335 (Household and similar electrical appliances －Safety-) and IEC60950 (Information Technology Equipment － Safety-) are listed as general requirement. The guidelines described the following additional safety measures:

- Identification of reception sides and power transmission restrictions
- Measures to prevent metal pieces located in the path of the power transmission line or at the periphery of the equipment from overheating
- Safety measures to protect any human body that is located in the path, or at the periphery, of the power transmission line
- Safety measures for the location of reception equipment
- Safety measures against abnormal operation .

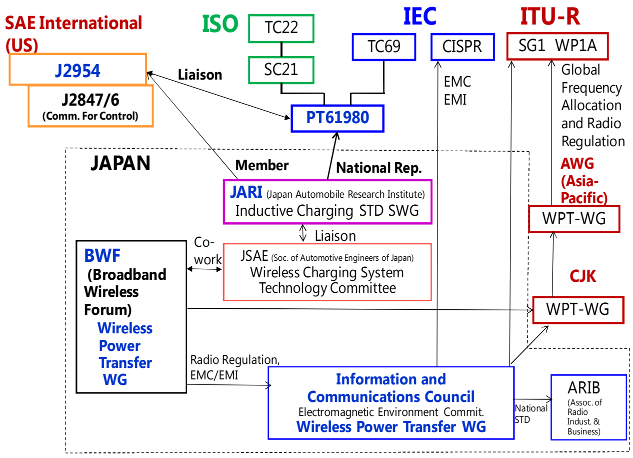

Fig. 3. International and regional bodies for discussion on standards and regulations on wireless charger for PHEV and EV

IV. RECENT EFFORTS OF RESEARCH AND RULE MAKING ON EMC OF WIRELESS POWER TRANSFER FOR PHEV/EV

The most of the researches, rule making, and standardization of wireless power transfer for PHEV/EV are still ongoing. Here we would like to describe the most recent efforts. Figure 3 shows that the relationship between the major international and regional bodies which are relevant to rule making and standardization.

In United States, Task Force J2954 of SAE International, which was formed in 2010, is active to discuss many aspects on wireless power transfer for PHEV/EV. For example, in November 2013, the members of the task force agree that 85-kHz band is chosen as operation frequency for light duty PHEV/EV wireless charging system.

A. *Emission*

As well known, it is quite difficult to magnetically shield the LF signal such as 85-kHz band. Typical and limited methods for magnetic shield might be categorized into two: the first is a current loop to reverse the magnetic field, and another is the enclosure made of high permeability magnetic material, such as ferrite. It should be noted that the latter using a lossy type of ferrite may lose the power transfer efficiency of the system, and is usually costly. Thus, the wireless charging system in LF band is desired to intrinsically have less emission.

SAE J2954 also discusses the rule and test method of emission from the inductive charging equipment. The draft has been based on FCC Part 18, and the task force additionally discusses the practical measurement at the shorter distance and how to convert the measured result to the equivalent value at the distance of 300 meters. J2954 additionally refers EN 300 330-1, EN 55011 (CISPR 11), and the relevant rules applied to "high-frequency-based equipment" in Japan as well.

2004/104/EC (Automotive EMC Directive) is the general rule in EU countries. Moreover, the set of EMC requirement on conductive charger for PHEV/EV is included in ECE R10-04. ECE R10-04 refers the practical standards such as:

- IEC 61000-3-2/12 (Harmonic current emissions)
- IEC 61000-3-3/11 (Voltage changes, voltage fluctuations and flicker)
- CISPR 12 (Radiated emission)
- CISPR 22 (Conducted emission).

Wireless charger should also meet the above set of standards for conductive charger. Additional rules especially for wireless charger are currently discussed in IEC PT 61980-1. The discussion so far refers EN 300 330-1, EN 55011 (CISPR 11), CISPR 16, CISPR 12, and so on.

B. Immunity

The draft of J2954 in SAE International describes several items relevant to immunity. In EU countries, 2004/104/EC (Automotive EMC Directive) and ECE R10-04 are also applied for immunity. ECE R10-04 refers the several practical rules on immunity, such as:

- ISO 11451-2 (Radiated EM immunity)
- IEC 61000-4-4 (Fast transient burst immunity)
- IEC 61000-4-5 (Surge immunity).

The additional items of standard draft for conductive charging of IEC61851-21-1 (On board), IEC61851-21-2 (Off board) referring

- IEC 61000-4-2 (ESD)
- IEC 61000-4-6 (Conducted Immunity)
- IEC 61000-4-8 (Power Frequency Magnetic Field Immunity Test)
- IEC 61000-4-11/34 (Power quality measurement),

will be also applied to wireless charger. IEC 61980-1 also discusses the additional items especially for wireless power transfer.

C. Human body protection

Tell et al. reported in [10] that none of the magnetic or electric fields measured either within or outside an electric bus during wireless charging exceeded the ICNIRP or the IEEE exposure limits for the general public [11][9]. The system operates at 20 kHz and a peak power of 60 kW.

Draft of SAE International J2954 also refers ICNIRP guidelines and IEEE standards. The current draft proposes that the access in the area near the radiators and underneath the vehicle should be prevented by an EMF Protection System, which may utilize physical means (e.g., barrier), and/or an organic object detection system which must detect organic object approach and control the field to a compliant level.

The recommendation 1999/519/EC (0-300GHz) and ICNIRP guidelines are also applied to kilo-watt class wireless power transfer system. IEC 61980-1 plans to discuss the measurement method.

D. Other aspects on safety

SAE J2954 and UL 2750 jointly discuss the safety aspect. The current discussion includes the temperature limit of equipment and foreign objects and the detection of foreign metal objects. The committee draft of IEC 61980-1describes the general requirement for safety, and SG1 of 61980 discusses the temperature limit as well. The general requirement on safety in the BWF guidelines is also applied for PHEV/EV wireless charger.

V. Conclusion

Most of portable digital devices, home appliances and、PHEV/EV will employ wireless power transfer, and these equipment are connected to power grid with energy management system such as HEMS. Current observation shows that regulation and rules on EMC emission and immunity are not so clearly specified. The early clarification of regulation and standardization are important aspects for future proliferation of wireless power transfer.

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