Design and Implementation of Magnetic Field Generator with 82 mT and 85 kHz Bandwidth

Keiji Wada1a), Yukihisa Suzuki1), Akira Ushiyama2), Shin Ohtani3), Kenji Hattori3), Atsushi Saito4), Satoshi Nakasono4), Satoshi Miyawaki5), Takashi Yanagisawa5), Yoshiya Ohnuma5)

1 Tokyo Metropolitan University, Hachioji, Tokyo, JAPAN
2 National Institute of Public Health, Wako, Saitama, JAPAN
3 Meiji Pharmaceutical University, Kiyose, Tokyo, JAPAN
4 Central Research Institute of Electric Power Industry, Abiko, Chiba, JAPAN
5 Nagaoka Power Electronics Co. Ltd., Nagaoka, Niigata, JAPAN

a) kj-wada@tmu.ac.jp

Abstract: This letter presents development of a magnetic field generator to evaluation of biological effects. The magnetic field generator has a frequency bandwidth of 85 kHz because it is intended for wireless power supply for electric vehicles. Furthermore, the generator is designed to operate for only one second, and can produce the induced magnetic field of 10 times compared to basic restrictions of the ICNIRP. By applying the magnetic field generator, it is possible to conduct a evaluation and verification of biological effect depending on electromagnetic fields for WPT systems of electric vehicles.

Keywords: biological effect, magnetic field generator, wireless power transfer

Classification: Electromagnetic Compatibility (EMC)

References

1 Introduction

In recent years, research and development of various wireless power transfer (WPT) system has been conducted. Although the power and frequency are different depending on applications, electromagnetic field based on wireless transmission frequency may be leaked into the space more than ever before. This may result in human beings exposed to electromagnetic environments in their daily lives. Especially, magnetic fields from low to intermediate frequency [1] band (1 Hz to 10 MHz) induce electric fields in their bodies getting close to values of the basic restrictions provided by the international guidelines [2], or the protection policy for the human body from effects of radio waves use in Japan [3].

The WPT systems using the 85 kHz frequency band for electric vehicles (EV) have been developed [4]. As usage in the 85 kHz frequency bandwidth, the WPT in the 10–100 kW output power is expected to be put into practical use. If human body and animal accidentally get very close to the WPT system for EV, the WPT system should be stopped as soon as possible for safety. However, in an actual WPT system, there is a time delay in stopping operation due to foreign object detection. Therefore, it is assumed that the human body is exposed to an 85 kHz magnetic field whose intensity exceeds the guidelines for a short period, such as less than one second. In such cases, it requires appropriate assessment of health effects. However, adequate scientific findings on the exposure scenario of intermediate-frequency magnetic field under these situations have never existed.

The authors have developed a magnetic field generator to evaluate biological effects at 85kHz [5]. This generator is capable of operating for one hour with 100 A and 20 mT. This generator achieved twice the whole body averaged induced electric field within a mouse, that is an experimental animal for the exposure target to 85kHz magnetic field compared to the basic restriction provided by ICNIRP guideline. As shown in the references [6][7], the circuit implementation has already been proposed for SiC-MOSFET based inverters. Because these inverters have current ratings of about 100 A, power device parallel connection implementations have never been discussed.

This letter presents a design and implementation of an magnetic field generator, which is based on a voltage-source inverter circuit, capable of producing a sinusoidal current of 85 kHz bandwidth and 82 mT. The output current of the magnetic field generator is set to 400 A, then it is to achieve 10 times the whole body averaged induced electric field within the mouse of...
the 85 kHz frequency band compared to the basic restriction. In other words, the magnetic field generator has an engineering value in that it can be used to evaluate and verify the ICNIRP guideline. The two challenges to realize the magnetic field generator for 400 A at 85 kHz are both the development of an inverter circuit and the implementation of a magnetic field generating coil. In this letter proposes the circuit implementation which is a single-phase full-bridge inverter circuit with four SiC-MOSFET modules are connected in parallel, that is the full-bridge inverter and DC-side capacitors were evenly arranged. As a results, the inverter can realize a large current flow and equal current sharing, simultaneously. In addition, the magnetic field generator based on a solenoid coil with high withstand voltage and low conduction loss were designed and developed. Furthermore, it is clear that the current value could be kept constant by 700 times repeating the operation for 1 second operation.

2 System Configuration

Fig. 1(a) shows the circuit diagram of the voltage source inverter with series LC resonant circuit, and Fig. 1(b) is a 3D image of the inverter circuit.

Herein, \( L \) is the inductance of the magnetic field-generating coil and \( C \) is the capacitance for a series resonance. The switching frequency of the inverter and the resonant frequency of the LC resonant circuit should be matched, and they are set to 82 kHz in this system. The output voltage \( v_{\text{INV}} \) of the inverter circuit produces a square wave of duty cycle 50%. Although the output sinusoidal current \( i_L \) flowed to the AC output side, the DC voltage source supplies only the loss of this circuit. To achieve simultaneous 85 kHz frequency bandwidth and large current flow to the coil, four SiC-MOSFET modules (CAS300M12BM2, Wolfspeed, Inc.) were used in parallel for the semiconductor power devices. The DC capacitors were placed on close to the parallelized devices. The semiconductor devices and DC capacitors were connected to form units, and the two units were placed facing each other to form a structure that allowed AC outputs to be placed as close as possible.

The magnetic field-generating coil is based on a solenoid air-core coil which is considered both magnetic flux density and resonant voltage. The terminal voltage of magnetic field generator coil will occur 22 kV when the current of 400 A and 85 kHz. To prevent dielectric breakdown of the coil, the terminal distance between the winding by adopting a one-layer winding structure. Litz wire was used to suppress the conduction loss from the coil winding due to the 85 kHz current. The inductor is fabricated by winding 21 turns of 3.6 mm diameter of the litz wire. A magnetic flux density of 82 mT can be generated at the center of the coil by 400 A and 82 kHz. The coil inductance was set to 36.9 \( \mu \)H; however, the wiring length has to be increased to maintain a safe distance between the coil and inverter. Therefore, the total inductance \( L \) for the resonance was 42 \( \mu \)H as it included the coil inductance and wiring inductance for connecting the inverter, capacitor, and coil. For the resonant capacitor \( C \), three 32 nF and 30 kV film capacitors
In magnetic field exposure, a 400 A sinusoidal current is applied for one second. Because the coil temperature rises of this experiment, an interval time of cooling both the coil and capacitor for 15 minutes is provided after each short-time magnetic field exposure.

3 Experimental Results

The switching frequency of the inverter was set to 82 kHz, and DC input voltage $V_{\text{DC}}$ is 410 V. The coil current $I_L$ of 400 A can be flowed to the AC output terminal. For DC input voltage source, four HX0600-12.5 (600 V, 12.5 A, 7.5 kW) (Takasago Ltd.) were used in parallel. Fig. 2 shows the experimental waveform rated at 400 A and 82 kHz. Fig. 2(a) shows the overall waveform for one second operation, and Fig. 2(b) shows the expanded waveform. The coil current $i_L$ was sinusoidal waveform due to LC resonance, and the output current $I_L$ of 400 A was obtained for one second. In this case, the apparatus power of this system was 164 kVA ($= 410 \, \text{V} \times 400 \, \text{A}$). Since
the input current was 50 A, the active power on the DC input side was 20.5 kW (=410 V × 50 A) during just one second.

Fig. 3 shows experimental results of the output RMS current values $I_L$ when the inverter was repeated one-second operations of 700 times. In this experiment, the inverter was operated every 15 minutes to fix the temperature at the beginning of the experiment, because the coil and capacitor temperatures rise one second operation. The DC voltage $V_{DC}$ was varied and adjusted so that the standard deviation due to fluctuations in the current value was about 1%.

4 Conclusion

This letter presents a magnetic field generator capable of generating a higher flux density at 82 mT in the 85 kHz frequency bandwidth and one second operation. In the proposed system, an output sinusoidal current of 400 A was achieved through 82 kHz. The generator can produce the induced magnetic field of 10 times the whole body averaged induced electric field within a mouse.
compared to basic restrictions of the ICNIRP guideline. Furthermore, it was clarified that the current can be output stably even after 700 operations. This means that the magnetic field generator can be used to conduct research on the evaluation of magnetic field exposure from WPT for EVs.

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