Research on electromagnetic disturbance characteristics of magnetic coupling resonant wireless energy transmission device and converter valve system

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Abstract. The IGBT device in the converter valve device will produce complex electromagnetic disturbance signals in the process of fast on and off, and the driving circuit is close to the device. In this paper, the wireless energy transmission system based on magnetic coupling resonance is used to replace the traditional driving power supply method, which makes the electromagnetic environment in the space where the driving circuit is located more complex. In this paper, firstly, the test is completed according to the relevant standards of the drive circuit, and then the electromagnetic simulation software is used to complete the modeling and simulation of the converter valve based on the wireless energy delivery system, which proves that the drive circuit can withstand the electromagnetic disturbance generated by the wireless energy delivery system and the converter valve, and there is no need to add additional shielding measures.

1. Introduction

The research on electromagnetic safety of wireless power transmission system has been widely carried out at home and abroad [1]. In this paper, the wireless power supply system is applied to the drive of converter valve for the first time. The driving circuit of converter valve is the only secondary circuit which is closest to the wireless power transmission system and IGBT devices, and the driving circuit is the core part to control the turn-on and turn off of IGBT module as well as the protection module of IGBT. When IGBT devices are working normally, serious electromagnetic disturbance will be generated. Whether the drive circuit can withstand the electromagnetic disturbance generated by the wireless energy transmission system and the IGBT device is turned on and off is the key to the normal operation of the converter valve, so it needs to be directed to the drive circuit [2]. The anti-jamming performance of the board in the wireless energy transmission system environment is simulated and studied [3].

In this paper, through the FEKO electromagnetic simulation software, based on IEC-61000-4 series standards for electromagnetic environment immunity of international electronic equipment for driving circuit, the excitation amplitude in the target frequency range is obtained from the disturbance source waveform of IGBT and wireless energy transmission device after Fourier transform, which is used as the disturbance source under current working condition for calculation. The simulation results show that the electromagnetic strength of the driving circuit is lower than the test strength, which proves that
the driving circuit can withstand the electromagnetic disturbance generated by the wireless energy transmission system and the converter valve without additional shielding measures[3].

2. Electromagnetic disturbance

2.1. Wireless energy delivery system
IGBT Series valve of wireless energy transmission system, the DC voltage of the valve body is 10kV, a total of 12 IGBTs are in series. The upper bridge arm is composed of 6 IGBTs in series, and the lower bridge arm is composed of 6 IGBTs in series. Each IGBT corresponds to a driving circuit, and the driving circuit is powered by the wireless energy transmission system. In this paper, a wireless energy transmission system is used to supply power for the driving circuit of IGBT. The power supply of the driving circuit is coupled by magnetic field, without direct physical contact [4]. Because the coil is coupled by magnetic field, the driving of IGBT may be affected.

2.2. IGBT device of converter valve
When the IGBT device is working normally, it will produce serious electromagnetic disturbance, and the disturbance mainly comes from the device itself and the surrounding environment, thereby forming electromagnetic disturbance. Due to the increase of switching frequency, it is the main source of high frequency electromagnetic disturbance [5].

3. EMC immunity test of driving circuit
This paper focuses on the EMC immunity performance of the drive board, so iec-61000-4 series standards are selected as the test basis:

| Standard       | Description                        | Level 1 | Level 2 |
|----------------|------------------------------------|---------|---------|
| IEC-61000-4-3  | Radio frequency electromagnetic field immunity | 80MHz-1000MHz | 800MHz-960MHz and 1.4GHz-2.0GHz |
| IEC-61000-4-8  | Power frequency magnetic field immunity | 100 | - |
| IEC-61000-4-10 | Magnetic field immunity of damped oscillation | 100 | - |

4. Simulation of electromagnetic disturbance

4.1. simulation model

![Figure 1. FEKO modeling diagram](image)
According to the converter valve system, in FEKO, including IGBT, drive system and wireless coil. In the modeling process, all metal objects in the valve are considered, and the size is the same as the actual structure. In order to be as close as possible to the actual situation, the wireless energy transmission device model adopts the multi turn metal coil model, as shown in Fig. 1.

4.2. Source of harassment
IGBT switch action will produce voltage and current with a very large rate of change. The high-frequency disturbance generated by it can reach tens of MHz, and the generated radiation disturbance can easily damage the stable operation of the drive board. In the primary side system of the wireless energy transmission system, the high-frequency inverter circuit inverts the DC power supply to the high-frequency AC power supply, and the radiation disturbance generated by the energy transmission coil will also affect the normal operation of the drive board. Therefore, it is necessary to consider the intensity of radiation disturbance near the drive board when the IGBT and the energy sending coil are operating.

In this paper, a current source is used as the excitation source. Firstly, the current waveforms of IGBT and wireless power transmission system are obtained, and then the excitation amplitude in the target frequency range is obtained by Fourier transform, and the excitation amplitude of the target frequency point is obtained as the excitation source by connecting the envelope lines of each peak value. Since the current waveform of IGBT includes rated operation condition and short circuit condition, the condition with larger amplitude at the target frequency point is selected as the simulation excitation. The spectrum analysis results of IGBT rated operation and short-circuit current and wireless power transmission system current are shown in Fig. 2.

![Figure 2. Spectrum analysis of short circuit current and wireless power transmission system current.](image)

4.3. Calculation area
For the electromagnetic field simulation of IGBT drive and wireless power supply coil unit in each layer, two measuring points are set in each layer, and the specific arrangement is shown in table-2.

![Figure 3. Examples of simulation points and simulation areas.](image)
Table 2. Layout of simulation measuring points

| Measuring point | Simulation area position |
|-----------------|--------------------------|
| P               | Drive board the geometric center of the upper surface of each layer, 30mm in front of the driver board of each layer |

5. Simulation result

5.1. RF electromagnetic field simulation

Test the frequency of 80MHz, 160MHz, 380mhz, 450MHz and 900MHz, and the excitation source is shown in table-3. The electric field intensity at each measuring point is shown in Figure 4.

Table 3. Determination of excitation source of radiated electromagnetic field

| Incentive source | Frequency /MHz | Current/dBA | Incentive source | Frequency /MHz | Current/dBA |
|------------------|----------------|-------------|------------------|----------------|-------------|
| IGBT short circuit condition | 80 | -44.6 | Wireless energy delivery system | 80 | -93.1 |
|                   | 160 | -51.3 |                               | 160 | -97.3 |
|                   | 380 | -58.6 |                               | 380 | -104.9 |
|                   | 450 | -60.5 |                               | 450 | -106.7 |
|                   | 900 | -68.3 |                               | 900 | -111.4 |

Figure 4. Calculation results of each measuring point under RF electromagnetic field

At 80MHz, the change trend of electric field intensity of each layer of F and P is similar, showing a peak at the 4th and 11th layers, but the electric field intensity of P is significantly greater than that of F. The maximum electric field intensity of P is 8.06v/m, while the maximum electric field intensity of F is only 2.40v/m. At 160MHz, the change trend of electric field intensity of the two measuring points is similar, but the maximum electric field intensity is at the seventh layer in the middle, the maximum electric field intensity of P measuring point is 1.78v/m, and the maximum electric field intensity of F measuring point is 1.09v/m. At other frequency points, the maximum electric field strength of the two measuring points is less than 0.50v/m due to the small excitation amplitude.

According to the test conditions shown in TABLE-1, the immunity performance of the drive circuit can reach 30V / m in the frequency band of 80mhz-1000mhz. The maximum electric field strength of each frequency point is summarized and compared with the standard. As shown in Figure 5, the electric field strength of different measuring points at P point above the driving circuit at 80MHz frequency point is the largest, but the maximum value is only 8.06v/m, which is far less than the tolerable strength of the driving circuit of 30V/m.
Figure 5. The electric field intensity of the fourth driving layer at 80MHz and the electric field distribution of the XZ section of the driving plate at each frequency point.

Because the measuring points can only represent the electric field intensity at the center of each driving geometry, not the maximum electric field intensity of the driving surface, it is necessary to study the electric field intensity distribution of the driving surface comprehensively. Among multiple frequency points of RF electromagnetic field, the maximum field strength of each measuring point is at the fourth layer under 80MHz, and the surface electric field strength distribution is shown in Figure 5. According to the calculation results, the maximum field strength is 17.94v/m, but it is still lower than the driving withstand value (30V / M). The upper left region of the driving surface is closest to the IGBT device, and the electric field intensity decreases gradually with the distance from the IGBT device. The minimum electric field intensity is 3.27v/m at the farthest distance from the IGBT device.

The electric field distribution of XZ section where the geometric center of the driving plate is located at different frequency points is shown in Figure 5. At 160MHz frequency, the electric field intensity at the middle end of the driving board space is larger than that at the upper and lower ends; at 80MHz, 380mhz, 450MHz and 900MHz frequency, the electric field intensity at the upper and lower ends of the driving board space is larger than that at the middle end. At five frequencies, the electric field intensity of the driving plate is far less than 30V / m.

Figure 6. Magnetic field strength of F measuring point in front of driving plate and P measuring point above driving plate
5.2. Simulation of power frequency magnetic field
The excitation amplitude at 50 Hz is shown in Table-4. Since the working frequency of the wireless power transmission system is 200kHz, the difference between the current component of the system at 50 Hz and the current component at 50 Hz under the rated condition of IGBT is more than 100 dB, so the simulation can only be carried out for the rated condition of IGBT.

| Incentive source | Frequency /MHz | Current/dBA |
|------------------|----------------|-------------|
| Rated working condition of IGBT | 50 | 49.01 |

Table 4. Determination Value of power frequency magnetic field excitation source

After calculation, the magnetic field intensity of each layer at 50 Hz is as shown in. Under the power frequency, the magnetic field intensity of P and F is similar, which first increases and then decreases. The magnetic field intensity of the upper space measurement point is significantly greater than that of the lower one, and the maximum value is in the fourth layer. The magnetic field intensity of P measuring point is greater than that of F measuring point, and the maximum value is 53.69a/m, which is less than the magnetic field intensity of 100A / M specified in the standard.

The magnetic field distribution cloud diagram of XZ section where the geometric center of the driving plate is located under the power frequency magnetic field is shown in Figure 7. The area with high power frequency magnetic field intensity of XZ section is near z = -200M. When the Z direction is from high to low, the magnetic field intensity decreases rapidly to 7.02a/m; when the X direction is from left to right, the magnetic field intensity also decreases.

The magnetic field intensity distribution of the fourth layer driving surface is shown in Figure 7. It is consistent with the electric field intensity distribution of the fourth layer driving surface at 80MHz. The magnetic field intensity of the driving surface at power frequency is the maximum near the IGBT device area, and decays rapidly with the increase of IGBT distance. The maximum field intensity is 92.37a/m, and the minimum field intensity is 32.56a/m. Since the maximum field strength is still less than the tolerable magnetic field strength (100A / M), and the field strength area above 85A / m only accounts for less than 2% of the whole driving surface area, it can be considered that there is no need to add additional shielding measures.

![Magnetic field distribution of XZ section](image1)

![Magnetic field distribution of upper surface of the fourth layer driver at 50Hz](image2)

Figure 7. Magnetic field distribution of XZ section where geometric center of driving plate is located under power frequency magnetic field.

5.3. Simulation of damped oscillating magnetic field
The model is simulated at frequencies of 100kHz, 200kHz and 1000khz, and the amplitude of excitation source at each frequency point is shown in Table 5.

| Incentive source | Frequency /MHz | Current/dBA | Incentive source | Frequency /MHz | Current/dBA |
|------------------|----------------|-------------|------------------|----------------|-------------|
| IGBT short circuit condition | 100 | 47.43 | Wireless energy | 100 | -26.86 |
| | 200 | 35.75 | delivery system | 200 | 11.64 |
| | 1000 | 9.39 | | 1000 | -30.48 |

Table 5. Selection of excitation source of damped oscillating magnetic field
The simulation results of damped oscillating magnetic field under different frequencies at the same test position are shown in Figure 8. At 100kHz, the magnetic field intensity of P and F is the largest. Under the frequency of 100kHz and 200kHz, the change of magnetic field intensity at P and F measuring points is basically the same. The magnetic field intensity at the upper part of the driving plate is greater than that at the lower part of the driving plate, and both reach the maximum at the fourth layer. At the frequency of 100kHz, the maximum magnetic field intensity of the measuring point above the driving plate is 44.67a/m. At the frequency of 1000kHz, the maximum value is only 0.56a/m due to the small excitation.

According to the test conditions shown in TABLE-1, the immunity performance of the drive circuit can reach 100A / m in the frequency band of 100kHz-1000MHz. Fig. 9 compares the maximum magnetic field strength and standard field strength at P and F measuring points under different frequencies. The maximum magnetic field strength at P measuring point is 44.67a/m at 100kHz frequency, which is still less than the tolerable strength of 100A / m of drive circuit.

As shown in FIG.9, the magnetic field intensity distribution characteristics of XZ section where the geometric center of the driving plate is located are basically the same at three frequencies. Near the
coil and the upper part of IGBT, the magnetic field intensity is larger and the lower part is smaller. With the increase of frequency, the magnetic field intensity of the space part of the driving plate decreases. Compared with 200kHz and 1MHz frequency points, the magnetic field intensity of the driving space at 100kHz frequency is greater, and the maximum magnetic field intensity is about 58.39a/m, which is less than the driving withstand magnetic field intensity of 100A / m.

As shown in Figure 9. Similar to the characteristics of the surface field intensity distribution of the driving circuit in the previous paper, the magnetic field intensity of the four layer driving surface is the maximum in the region close to the IGBT device at 100kHz, and decays rapidly with the increase of IGBT distance. The maximum field intensity is 77.02a/m, and the minimum field intensity is 27.58a/m. The maximum field strength is still less than 100A / m.

6. Conclusions
According to the standards, the relevant tests were completed and the following conclusions were obtained:

(1) In the RF electromagnetic field simulation, the maximum electric field intensity is 8.06v/m at the geometric center of the upper surface of the driving circuit at the frequency of 80MHz, and the overall electric field intensity of the upper surface at this frequency is far less than the withstand electric field intensity of the driving circuit (30V / M), so the radio frequency electromagnetic field during normal operation will not affect the normal operation of the drive;

(2) In the power frequency magnetic field simulation, the maximum magnetic field strength of the geometric center of the upper surface of the driving circuit is 53.69a/m, and the overall magnetic field strength of the upper surface is less than the power frequency magnetic field strength (100A / M). The power frequency magnetic field will not affect the normal operation of the drive;

(3) In the simulation of damped oscillation magnetic field, the maximum magnetic field intensity is 44.67a/m at 100kHz frequency point at the geometric center of the upper surface of the driving circuit, and the overall magnetic field intensity of the upper surface at this frequency is less than the power frequency magnetic field intensity (100A / M) that can be tolerated by the driving circuit;

(4) In addition, the field strength of each point in the simulation is the root mean square value of the three-dimensional component, and the component in each direction is less than this value, that is, the component in each direction is less than the driving withstand field strength. In conclusion, the drive circuit can work normally in this electromagnetic environment without additional electromagnetic shielding measures.

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