The Impact of Different Operation Conditions on the Plasma Extraction Transit Time Oscillation in High-Voltage Insulated Gate Bipolar Transistor Devices

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Abstract. During the tailing current period when the bipolar device is turned off, plasma extraction transit time (PETT) oscillation will occur, and the electromagnetic interference caused by it will have a negative effect on the driver circuit and the surrounding electronic components. Therefore, it is necessary to investigate the factors that affect the characteristics of PETT oscillation. In this paper, the relationship between the characteristics of PETT oscillation and the operation conditions of high-voltage insulated gate bipolar transistor (IGBT) device is studied experimentally. When the DC link voltage, load current and gate driver resistance are changed, and the peak value and duration of PETT oscillation under different operation conditions are recorded. The results show that the PETT oscillation characteristics have a strong dependence on the voltage and current of IGBT device, as well as the gate driver resistance. The experimental results in this paper can provide the guidance for suppressing the PETT oscillation of high-voltage IGBT devices.

1. Introduction

With the continuous improvement of power system voltage levels, the application of high-voltage power electronic devices has become more extensive. To date, the voltage level of the IGBT used in the switching device can reach 3.3 kV or even higher. One big challenge that comes with it is the electromagnetic interference (EMI) problem. Electromagnetic interference in a high-voltage environment may damage sensitive electronic equipment due to overload, so sufficient attention should be paid to it. When the IGBT devices turned off, plasma extraction transit time (PETT) oscillation might occur, and its frequency can reach several hundred of megahertz, causing electromagnetic interference to the surrounding electronic equipment, which is harm to the requirements of EMC [1]. In order to suppress PETT oscillation, its characteristics and dependence on operation conditions need to be studied.

In 1997, the PETT oscillation was first discovered by Fuji Electric researchers [2][3]. Then, they pointed out that PETT oscillation is related to chip junction capacitance and circuit parasitic parameters. In 2003, Siemieniec found that the PETT oscillation frequency is related to circuit inductance [4][5][6]. After that, he set up experiments to study the characteristics of PETT oscillation under different voltages, currents, and temperatures. In 2009, Mitsubishi Electric researchers studied the PETT oscillation phenomenon of the high-voltage IGBT through simulation [7][8], focusing on the analysis of the internal carrier changes during the device oscillation, but their work lacked the study of external characteristics.
High-voltage IGBT devices are special in two aspects, one is that its requirements for packaging structure are different from those of medium and low voltage devices, and it is more sensitive to electromagnetic interference. Therefore, it is meaningful to study the PETT oscillation of high-voltage devices. Secondly, the internal semiconductor process parameters of high-voltage chips are different from those of medium and low-voltage chips. The operation conditions that affect PETT oscillation may be different. In this paper, the dependence of the PETT oscillation of high-voltage IGBT devices on operating conditions is studied through experiments. The experimental results can provide a reference for suppressing PETT oscillations.

2. Experimental platform

The equivalent circuit of the experimental platform is shown in Figure 1. The experimental principle is the double pulse test principle. The high-voltage DC power supply $V_{DC}$ charges the capacitor $C$. The turn-on and turn-off of IGBT is controlled by pulse trigger. The voltage required for the experiment can be changed by controlling the charging time of the capacitor $C$, the current required for the experiment can be achieved by changing the pulse width. The devices under test are two parallel NPT IGBTs, whose rated parameter is 3300 V/50 A. The gate drive resistance and can be easily replaced, so the impact of different driver conditions can be investigated.

There are four electrical quantities measured in the experiment. $V_{ce}$ and $V_{ge}$ are measured by setting up the voltage probes on the common collector and common gate of parallel IGBTs respectively. Set the Rogowski coil to measure the total current at the common source. There is a near-field probe which is 0.1 meters away from the tested IGBTs to measure the spatial oscillation signal. Fig. 2 shows the experimental setup.
3. The influence of different operation conditions on the PETT oscillation

This section analyzes the influence of different operation conditions on the PETT oscillation characteristics of high-voltage IGBT devices. The voltage in the experiment ranges from 900 V to 2200 V with an interval of 100 V; the current in the experiment ranges from 20 A to 100 A with an interval of 20 A, and the gate drive resistance in the experiment are 12 Ω, 20 Ω, and 30 Ω respectively. Experimental results show that changes in operation conditions will have a greater impact on the oscillation characteristics of PETT, and the definitions of the oscillation peak and duration time are displayed in Fig. 3.

3.1. The relationship between different operation conditions and PETT oscillation peak

The larger the PETT oscillation peak, the stronger the radiation interference, so it is hoped to reduce the PETT oscillation peak as much as possible. Fig. 4 shows the relationship between PETT oscillation peak value, voltage and current when the gate drive resistance is 12 Ω.
Figure 4. The relationship between PETT oscillation peaks, voltage and current when the gate drive resistance is 12 Ω.

As shown in Fig. 4, there is a positive correlation between the oscillation peak value and the current level as a whole. This positive correlation is very small while the voltage is lower than 1200 V, the oscillation peak hardly changes with the current when the current level reaches above 60 A; this positive correlation is obvious when the voltage is higher than about 1200 V, under the same voltage, the peak value of the oscillation increases with the current in the entire current range. In addition, when the current is less than or equal to 40 A, the PETT oscillation peak value increases with the increase of the voltage, and a turning point occurs at 1000 V; when the current is greater than 40 A, the oscillation peak value decreases with the increase of the voltage, and a turning point occurs at 1200 V. The 1200 V voltage seems to be a critical value. In the vicinity of this voltage, the rate of change of the oscillation peak value with the voltage will vary greatly.

Figure 5. The relationship between PETT oscillation peaks, voltage and current when the gate drive resistance is 20 Ω.
Fig. 5 and Fig. 6 shows the relationship between PETT oscillation peak value, voltage and current when the gate drive resistance is 20 Ω and 30 Ω, respectively. The oscillation peak value increases with the increase of the gate drive resistance. When the gate drive resistance changes, the correlation between the oscillation peak value, current and voltage does not change. The critical voltage mentioned earlier is still around 1200 V. It can be seen that the change of the gate resistance seems to only affect the magnitude of the oscillation peak value, and does not affect its change trend with voltage and current.

3.2. The relationship between different operation conditions and PETT oscillation duration time

The duration time of PETT oscillation reflects the length of the entire electromagnetic interference process. Fig. 7 shows the relationship between the PETT oscillation duration time, voltages, and currents when the gate drive resistance is 12 Ω. There is a good positive correlation between duration time and current level. In the entire voltage range, as the current increases, the duration time increases continuously. But when the current reaches more than 80 A, the increments in duration time will gradually decrease, and will turn to 0 in the end. The duration time decreases as the voltage increases, and this inverse correlation becomes more obvious when the current is greater than 40 A. The voltage value of 1400 V seems to be a critical voltage. When it is lower than this voltage, the change rate of the duration time with the voltage is relatively large. When it is higher than this voltage, the change...
rate of the duration time with the voltage suddenly decreases. The duration time may even increase in the opposite direction while the current is lower than 40 A.

![Figure 8](image1)

Figure 8. The relationship between PETT oscillation duration time, voltage and current when the gate drive resistance is 20 \( \Omega \).

![Figure 9](image2)

Figure 9. The relationship between PETT oscillation duration time, voltage and current when the gate drive resistance is 30 \( \Omega \).

Fig. 8 and Fig. 9 show the relationship between the PETT oscillation duration time, voltages, and currents when the gate drive resistance is 20 \( \Omega \) and 30 \( \Omega \). It can be seen that when the gate drive resistance becomes larger, it does not affect the positive correlation between the duration time and the current level, and the inverse correlation between duration time and voltage is more obvious in the entire current range. With the increase of the gate resistance, the change rate of the duration time with the voltage gradually tends to be the same, and there is no more sudden decrease.

4. Conclusion
- The peak value of PETT oscillation is strongly dependent on the operating conditions of the IGBT. There is a positive correlation between the oscillation peak value and the current level as a whole. Under low voltage, the positive correlation is small, and under high voltage, the positive correlation is strong. And there is a critical voltage. When the voltage is lower than this voltage, the oscillation peak value will decrease with the increase of the voltage. When the voltage is higher than this voltage, the oscillation peak value will first increase and then
decrease with the increase of the voltage. When the gate drive resistance increases, the PETT oscillation peak value increases, but the dependence on current and voltage does not change.

- There is a positive correlation between the duration time of the PETT oscillation and the current level. When the current level is high, the positive correlation weakens to zero. The duration time decreases as the voltage increases in the entire voltage range. The increase of gate resistance does not affect the correlation between duration time and voltage and current.
- In the EMC test of the IGBT device, more attention should be paid to the electromagnetic disturbance of the IGBT device under the condition of large current and larger gate resistance, and the influence of different switching modes on PETT oscillation characteristics needs to be further focused.

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