Designing the Reliable Driver for the Latest 450A/1.2kV IGBT

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Abstract

IGBT modules as the preferred power semiconductor device are used widely for industrial applications. The NX series with 6th generation IGBT using the latest CSTBT™ chip technology realizes high performance-cost ratio. This paper will summarize how to use CM450DX-24S for inverter applications with high reliability, which includes design details of driver circuit and solutions to connecting IGBTs in parallel.

1  Introduction of 6th generation IGBT

1.1 The advantages of CSTBT™ chip

The latest developed 6th generation CSTBT™ uses high energy injection into the CS layer, thin-wafer process, finer cells and structure optimization. Compared with 5th Generation CSTBT™, it provides the advantages of more than 10µs short circuit capacity and excellent paralleling characteristics suitable for practical application.

1.2 Positive temperature coefficient of saturation voltage of 6th generation IGBT

6th generation CSTBT™ chip employs the Light Punch Through (LPT) vertical structure, which is based on NPT structure and adds PT structure element. Taking Mitsubishi CM450DX-24S as an example, above approximate 120A, it has a positive temperature coefficient which makes it simple to connect several CM450DX-24S in parallel.

2  Design details of IGBT driver circuit

2.1 Galvanic isolation of DC/DC power supply according to different safety standards

The basic requirement of developing IGBT drivers is to ensure insulation voltage for product safety and user safety. A typical implementation of IGBT driver is shown in Fig. 1. The value
of insulation voltage for DC/DC power supply is determined by the safety standards of IEC61800-5-1 or EN50178 for industrial applications. But there is also a simple method to specify insulation voltage based on IGBT insulation voltage in the datasheets provided by IGBT manufacturers. According to design requirements, basic insulation or reinforced insulation needs to be selected firstly, and the main difference is that basic insulation only provides protection against electrical shock, but reinforced insulation provides protection against electrical shock and failsafe operation. Failsafe permits users to contact with product under fault condition. When developing IGBT driver for 450A/1.2kV IGBT, basic insulation can meet the insulation requirement what is defined by the section 4.2.3.2 of IEC61800-5-1:2003. The section 5.2.3.2.2 of value and type of test voltage specifies test voltage, and insulation voltage can be calculated according to the following equation:

\[ U_{iso} = U_0 + 1200V \]  
\[ \text{Eq.1} \]

(In TN and TT systems, \( U_0 \) is the r.m.s value of the rated voltage between a phase and earth; in three-phase IT systems, \( U_0 \) is the r.m.s value of the rated voltage between phases)

And we can also refer to the section 9.4.5.2.2 value and type of insulation test voltage of EN50178:1997, which requires insulation voltage according to the following equation:

\[ U_{iso} = 1.5 \times \frac{U}{\sqrt{2}} + 750V \]  
\[ \text{Eq.2} \]

\( U \) is the recurring peak value of the highest voltage appearing continuously at rated operation between any two live parts of the circuit of the electronic equipment.

For example, for a two-level inverter with the allowed input line voltage range of 323VAC to 528VAC, 1200V IGBT modules are selected based on a maximum DC-bus voltage, resulting from a three-phase rectified voltage plus a certain margin of the regenerated power of the load possibly feeding back to into the DC-bus. Referring to IEC61800-5-1, as the input voltage of DC/DC power supply is \(+15V_{DC}\), the input circuit of DC/DC power supply is defined as Circuit A, and the output circuit of DC/DC power supply connected to IGBT can be defined as Circuit C. If protection against direct contact is provided by supplementary insulation for Circuit C, basic insulation should be designed to meet isolation requirement. According to Eq.1, a \( U_{iso} \) of more than 1728VAC can meet isolation requirement. And according to Eq.2, a \( U_{iso} \) is more than 1542VAC. While the insulation voltage of CM450DX-24S is 2500VAC, so it could satisfy the requirement of basic insulation.

### 2.2 Selection of opto-coupler between IGBT and control signal according to \( V_{V_{\text{ORM}}} \) and \( V_{\text{ISO}} \)

To ensure the inverter system safety, a galvanic isolation is required between IGBT and control signal. When applying opto-coupler for circuit design, the parameters of \( V_{\text{ISO}} \) (momentary withstand voltage) and \( V_{\text{V_{ORM}}} \) (maximum working insulation voltage) are of
significant importance for circuits designers. The opto-coupler is basically certified through the safety standards of IEC60747-5-2 and UL1577. UL1577 rating of $V_{ISO}$ means that devices can survive and isolate transient (1min) voltage spikes within its respective requirements. This is only a momentary insulation withstand rating for one minute. The $V_{IORM}$ is specified by IEC60747-5-2 rating, which means that the voltage can continuously apply across the opto-coupler insulation barrier. When selecting the opto-coupler, major concerns for designers are $V_{IORM}$ and $V_{ISO}$ which are determined by the DC-bus voltage of inverter.

For example already described in chapter 2.1, a $V_{IORM}$ of 891$V_{peak}$ and a $V_{ISO}$ of 3750$V_{rms}$ or 5000$V_{rms}$ of opto-coupler in the datasheets provided by Avago can meet isolation requirement.

### 2.3 IGBT gate drives and protective measures

#### 2.3.1 Comparison of different push-pull drivers (totem-pole drivers)

![Fig. 2. Gate driver with $R_{G(on)}$ and $R_{G(off)}$ resistance separated by diode](image)

![Fig. 3. Gate driver with respective $R_{G(on)}$ and $R_{G(off)}$ resistance](image)

![Fig. 4. Gate driver with the use of MOSFETs](image)

Push-pull driver (totem-pole driver) with BJT or MOSFET is commonly used, which mainly has three types shown in Fig. 2, Fig. 3 and Fig. 4.

The configuration of Fig. 2 is recommended for a push-pull driver, but Collector-Emitter Voltage and Maximum Forward Bias Safe Operating Area need to be checked when selecting NPN and PNP transistor.
The configuration of Fig. 3 is not recommended for a push-pull driver, as the base-emitter of the transistor may have a breakdown under IGBT turned off or short circuit.

The configuration of Fig. 4 is sophisticated and we can apply MOSFET drivers and dual channel MOSFET to design push-pull driver, or apply level shifter and buffer to design. When selecting MOSFET, it's more preferable to select n-channel MOSFET than p-channel MOSFET, as the bulk resistance $R_{DSS\text{(on)}}$ between the drain and source of the MOSFET per chip size is lower compared to p-channel MOSFET resulting from the mobility of the hole and electron.

The configuration of Fig. 4 has several advantages over the configuration of Fig. 2 as follows:

- Providing a rail-to-rail output, as the voltage drop between drain and source of the MOSFET is nearly zero, we can set the output voltage of DC/DC power supply to 15V, or else the output needs to be set to more than +15V;
- Providing high gate currents for IGBT with high amplification gain and low control current compared to gate drives using BJTs, and it can also replace what several push-pull drivers with the use of BJTs are connected in parallel;
- Reducing the turn-on losses of the IGBT due to higher switching speed of MOSFET;
- Using respective turn-on and turn-off resistors, the possible shoot-through current can be limited from +15V to -10V, and switching characteristics of IGBT is easy to adjust according to requirements.

2.3.2. IGBT protective circuits

As below is an overview of IGBT gate protective circuits, there are three typical protective circuits as showed in Fig.5, Fig.6 and Fig.7.

![Gate clamping circuit](image1)

![Active clamping circuit](image2)
Gate clamping circuit is to protect IGBT gate, as well as to limit short circuit current; active clamping circuit is to limit $V_{CE}$ peak voltage at IGBT turned off; active miller clamping circuit is to prevent the parasitic turn-on of IGBT.

Gate clamping circuit is shown in Fig. 5, the circuit consists of Zener diode and fast Schottky diode. The function of Zener diode of $D_2$ is to limit the maximum gate-emitter voltage less than 20V, and fast Schottky diode of $D_1$ is to clamp the gate-emitter voltage to the value of the positive supply voltage plus the diode forward voltage, which has been proven extremely useful under short circuit.

Fig. 6 shows one type of active clamping, which is commonly used to protect IGBT from high voltage peak across collector-emitter of IGBT resulting from short circuit, overload current. For practical design, the maximum active clamping voltage is set based on the RBSOA diagram of CM450DX-24S, and the internal stray inductance of the module also need to be taken into account; TVS diodes connected in series is recommended for active clamping circuit.

Fig. 7 shows the type of active miller clamping which is used to prevent parasitic turn-on of the IGBT due to the miller capacitance in single power supply gate drivers (0 to +15V). Although this parasitic turn-on lasts a very short time, it can lead to larger losses in the IGBT and cause the temperature of IGBT chip to rise. Finally, the IGBT may be broken down by thermal runaway. This circuit has better use n-channel MOSFET to create a low-impedance path, as BJT has a higher voltage drop across collector-emitter.

3 IGBT driver design for parallel connection of IGBTs

Parallel connection of IGBTs is commonly used for higher power applications. Three CM450DX-24S connected in parallel could realize 250kW/380VAC inverter design. When using IGBTs connected in parallel, the following design tips need to be concerned:

- All the parallel connection of IGBTs are driven by the common driver;
- The length of twisted pairs or PCB tracks are identical;
Resistor tolerance should be less than 1%;
Inserting a emitter resistor in series with each emitter to force current balance is very important.

Fig. 8 shows two IGBTs in parallel connection. Due to parallel connection of IGBTs with different tolerances, the IGBTs have different switching speeds. The fast IGBT1 causes a higher \(\frac{di}{dt}\), and a higher induced voltage across the emitter stray inductances of L1 will occur. So a loop current flows through Re1, Re2 and L2 to L1. The gate voltage of IGBT1 \(V_{G1E1} = V_{CC} - V_{Re1}\) due to the voltage drop \(V_{Re1}\) across the Re1, and the gate voltage of IGBT2 increases up to \(V_{G1E1} = V_{CC} + V_{Re2}\). As a consequence, the current of two parallel IGBTs achieve symmetry. Based on application experience, the emitter resistor is recommended to select pulse power resistor and approximate 0.5 \(\Omega\) or 50% of the gate resistance.

![Fig. 8. IGBTs connected in parallel with the emitter resistors](image)

4 Conclusion

The most important requirements that a reliable IGBT driver for CM450DX-24S has to meet and perform simultaneously can be summarized briefly as follows:

a) An insulation voltage of 2500\(V_{AC}\) is recommended for DC/DC power supply as described in chapter 2.1;

b) A \(V_{IDORM}\) of 891\(V_{peak}\) and a \(V_{ISO}\) of 3750\(V_{rms}\) or 5000\(V_{rms}\) is recommended for opto-coupler as described in chapter 2.2;

c) Gate clamping circuit, active clamping circuit and active miller clamping circuit are commonly used to protect IGBT under abnormal condition;

5 References
