Reliable and Safe Insulation in High-Voltage Inverter Applications

The market trends in high-voltage inverter applications such as wind turbines, renewable energy harvesting sites and industrial motor control applications require increasing working voltage levels and higher efficiencies. These trends are driving the use of 1700V intelligent power modules (IPMs) or IGBTs to meet these requirements. The reliable and safe insulation between low-voltage and high-voltage subsystems are key requirement for these designs. **Hakan Uenlue, Field Applications Engineer, Avago Technologies, Boeblingen, Germany**

In wind turbines and other renewable energy harvesting systems, converting and feeding energy from the generator to the grid requires high-voltage converters. When insulating the high-voltage subsystem from the low-voltage side (e.g., MCU, PWM generator), both the internal and external construction of the component plays an important role. A new intelligent optocoupler from Avago Technologies, the ACNV4506 (Figure 1), addresses insulation concerns in these systems. The device is available in a 500mil DIP10 package and has external insulation coordinates (creepage and clearance) of 13mm, which meets the IEC60664-1 standard. Moreover, it provides a minimum 2mm internal clearance - or Distance Through Insulation (DTI) - to offer designers extra flexibility for applications where high minimum internal clearances are required.

Figure 1: The ACNV4506 addresses insulation concerns high-voltage inverters for renewable energy applications

Interfacing a conventional 1700V IPM or IGBT

Figure 2 illustrates conventional 1700V IPM circuitry for industrial motor control. In this example, six ACNV4506 optocouplers are used for insulation of driving signals to high and low side IGBTs in an IPM. A seventh ACNV4506 device can be used for brake signal isolation. For additional signaling, such as fault feedback, additional optocouplers can be employed.

The IPM in Figure 2 uses inverted logic; when the input is high, the IGBT turns off and when the input is low, the IGBT turns on. The ACNV4506 optocoupler has an open collector output. Therefore, before the MCU and input side of the IPM is powered up; the optocoupler output logic level is high, which holds IGBT at OFF state. For certain families of IPMs, all three high-side floating power supplies (i.e., VCC_UH,

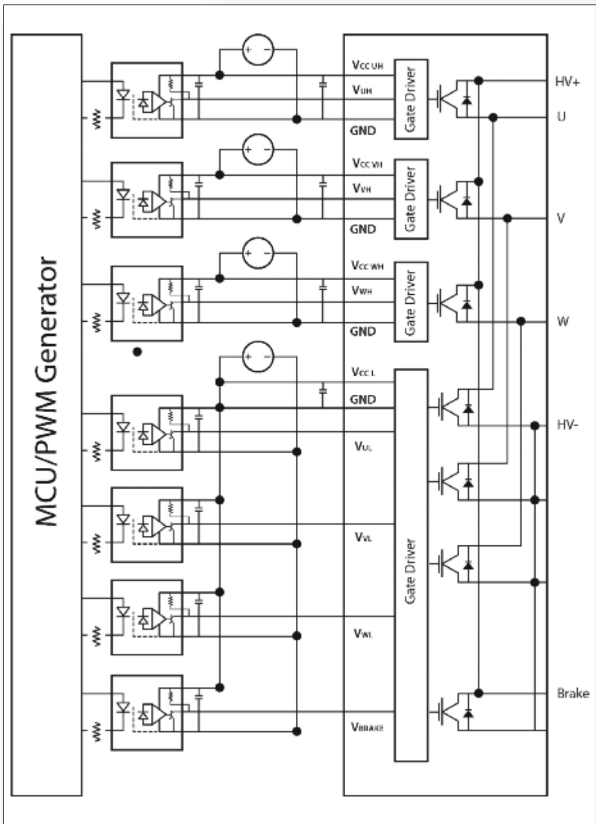


Figure 2: Interfacing MCU and IPM through ACNV4506 optocoupler

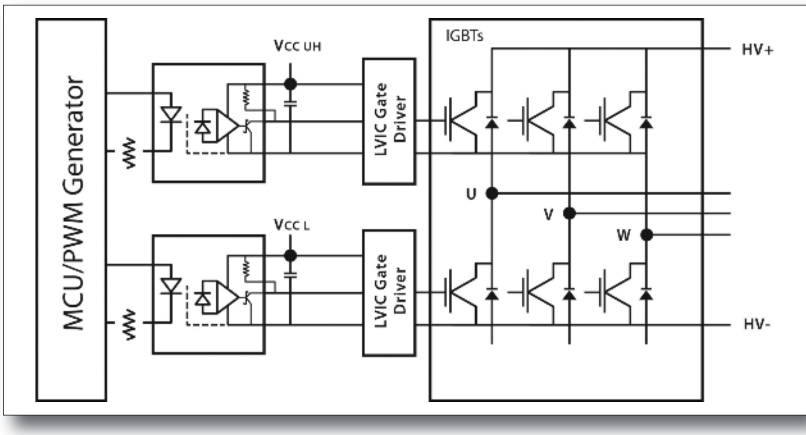


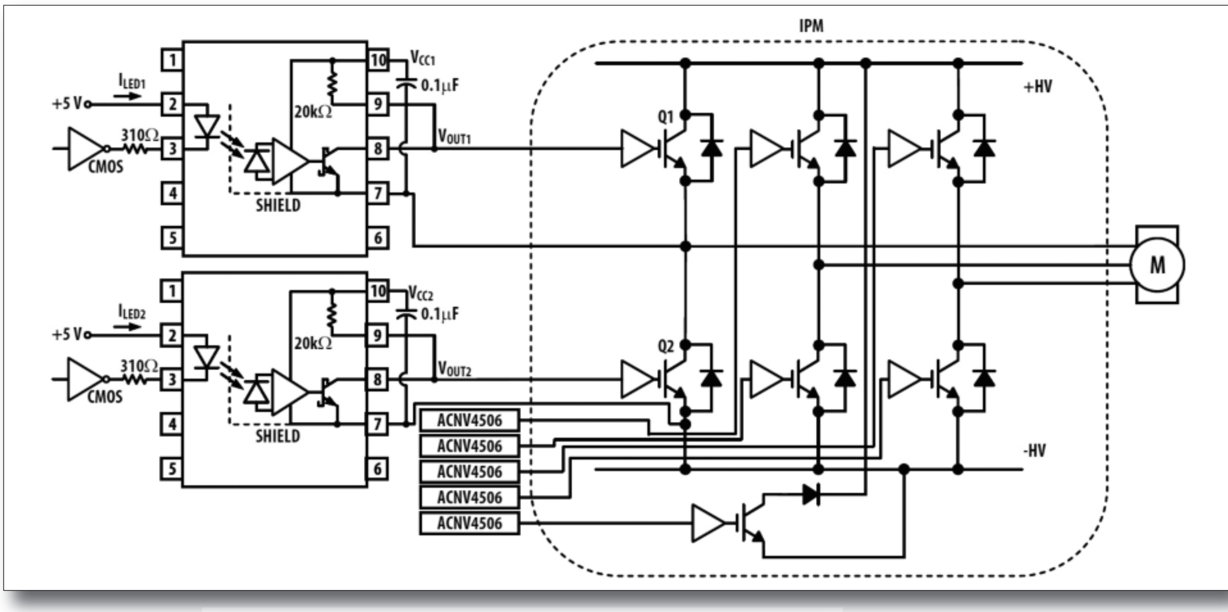
Figure 3: Insulation of IGBTs and their discrete gate drivers via an ACNV4506 optocoupler

VCC_VH, VCC_WH) and the low-side power supply (i.e., VCC_L), can have 15V. In other words, IPM inputs logic high is 15V.

The interface signal level calculations for output high level can be done according to the following equation

$$V_{OH} = V_{cc} - (R_L \times I_{OH})$$

where R_L is the pull up resistor needed for output transistor, and I_{OH} is the output transistor leakage current. For error-free driving of IPM inputs, a similarly matching resistor value can be found from this formula. For a 15V power supply and 50μA leakage current (maximum value for an ACNV4506 device, over -40°C to 105°C ambient temperature range), a 20kΩ pull resistor would be appropriate. In this case no external component should have to be used, as 20kΩ resistor is already included in the device's package (between pin 7 and 8). If a 5V power supply is used, a 3kΩ resistor would be appropriate and an external component for that purpose can be employed.



ABOVE Figure 4: Typical application circuit with recommended LED driver circuitry for best CMR performance

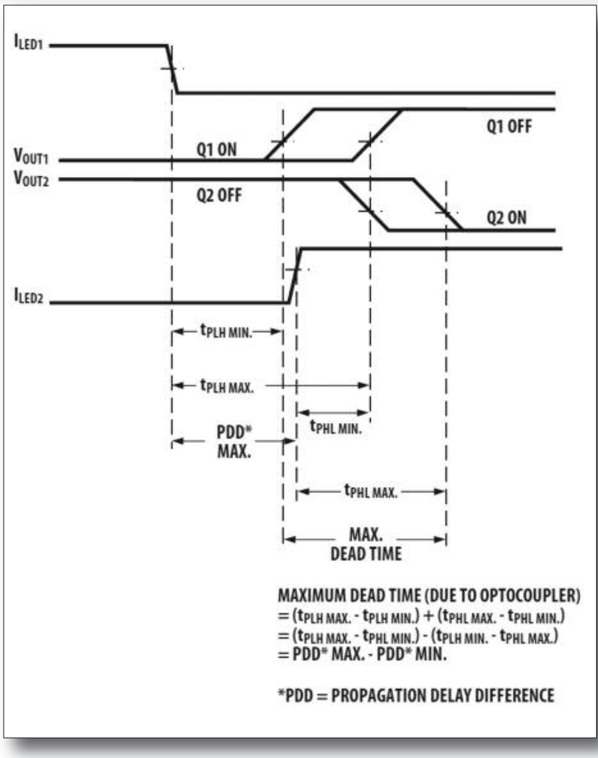


Figure 5: Waveforms for deadtime calculation

If gate drivers are not integrated into the power module, the ACNV4506 device can interface with gate drivers as shown in Figure 3. For respectively lower power modules, the discrete transistors can be used for driving IGBT gates and the ACNV4506 optocoupler can do the interfacing and insulation.

In some types of IPMs, where HVICs are integrated to gate driving stage, a low-voltage circuit can control high-voltage power devices through level shifting process. With this technology, all gate driver input circuits can be connected to one power supply, which enables input logic compatible from 5V to 20V. In this case optocouplers are used mainly to achieve electrical safety isolation between the low-voltage and high-voltage segments of the system.

Isolation of common mode transients

As isolation property, optocouplers are used to help prevent high-voltage transients from one side of the system to the other. There are two kinds of sources for such types of short-term unwanted signals:

- System internal sources (e.g., transients caused by switching IGBTs at high voltages), and
- system external sources (e.g., lightning pulses coupled to the system).

In addition to the external and internal construction of an optocoupler, an optically transparent faraday shield placed on detector IC helps to provide a robust Common Mode Rejection (CMR) of the component. For the best CMR performance, LED driving circuitry as shown in Figure 4, is recommended for designs. Using this approach, a minimum CMR of 30kV/µs at 1.5kV common mode voltage can be achieved.

Timing characteristics and further calculations

A typical application circuit for three-phase power converters or motor drivers can be seen in Figure 5. One of the unwanted effects in half-bridge versions of such IGBTs is to have both power transistors ON at the same time. Any overlap of these two devices (shown as Q1 and Q2 in Figure 4) will result in large currents flowing through these transistors between the high- and low-voltage rails. Therefore, in order to avoid possible complications caused by overlapping, designers should ensure appropriate signal timings so that both transistors will never be active at the same time. As a result, there will be a period of time in each signal cycle in which both transistors will be OFF. Since none of IGBTs are utilized, during this window of time, this causes possible limitations in efficiency of the overall system. To minimize this deadtime, the designer must consider the propagation delay characteristics of the optocoupler as well as the IPM IGBT gate drive circuit. When considering only the timing characteristics of the optocoupler, it is important to know maximum and minimum turn-on (T_{PHL}) and turn-off (T_{PLH}) propagation delay time specifications and propagation delay differences (PDD) between any two components.

Zero deadtime occurs when Q1 turns off at the same time point Q2 turns on. This is achieved when the signal to turn on Q2 is delayed by (T_{PLHmax} -T_{PHLmin}) from the turn off time-point of Q1. However, this method does not indicate what the maximum deadtime will be. In a very unlikely scenario, this occurs when one component with the fastest TPLH and other with the slowest T_{PHL} are in the same half bridge. The maximum deadtime in this case is equivalent to the difference between the maximum and minimum propagation delay difference specifications, as shown in Figure 5. For the ACNV4506 device, the maximum deadtime (only due to optocoupler) is (450ns - (-150ns)=600ns) in the temperature range of -40°C to 105°C.

Conclusions

IPMs or IGBTs used in high-voltage inverter applications need to meet the trends for increasing reliability and safety. Designers can achieve electrically safe insulation of controllers of 1700V IGBTs or IPMs using optocouplers, such as the ACNV4506 device, which has continuous working voltage level of 2268Vpeak. They can also help isolate unwanted disturbances or transients, due to the component's high CMR performance. With output specification of up to 30V, this optocoupler can be used to help isolate the wide range of 1700V IPMs with different supply voltages.

Literature

[1] ACNV4506 Datasheet (AV02-2483EN, Avago Technologies)

[2] Application Note 5401: Optocouplers Isolated Circuit for IPMs and Gate Drivers