Is Your IGBT Gate-Driver Power Supply Optimized?

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ABSTRACT

Insulated Gate Bipolar Transistors (IGBTs) are used in high current three-phase AC motors. This application report discusses the theory and requirements of gate-drive power supply for IGBTs. It also discusses the isolation requirements and calculation of correct amount of IGBT drive power.

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1 Overview

Many people are familiar with low-power DC motors because they are seen everywhere on a daily basis. What may not be seen as much are all of the larger AC industrial motors working behind the scenes to automate the assembly of automobiles or to lift the elevators that are ridden in every day. These high-power motors are driven by electronics with very different requirements and with much higher current. Three-phase inverters are used for variable-frequency drives that control the speed of AC motors and for high-power applications. IGBTs are used in half-bridge configuration for each phase of the three-phase inverters. The high-side and a low-side IGBT switch of the half-bridge are used to apply positive and negative high-voltage DC pulses, respectively, to the motor coils in an alternating mode. A single, isolated gate driver IC drives the gate of each IGBT and galvanically isolates the high-voltage output from the low-voltage control inputs. The collector of the top (high-side) IGBT is connected to a very high voltage DC bus. The emitter of that IGBT floats relative to earth ground to maintain the transistor's V_{CE} within its specified limits. This in turn requires use of an isolated gate driver in order to isolate the low-voltage PWM inputs from the control circuit from the high voltages of the IGBT. Isolated gate-drivers are also used to control the bottom (low-side) IGBTs.

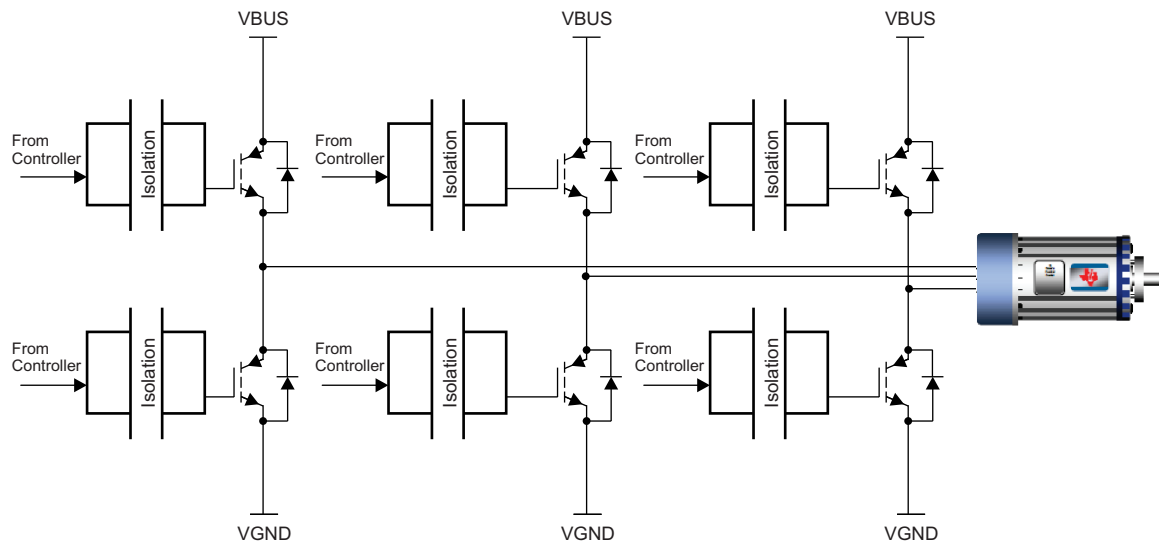Figure 1 shows typical configuration in an industrial motor drive.

Figure 1. Typical Configuration of an Industrial Motor Drive

An IGBT gate driver IC has to perform a multitude of functions simultaneously. During the IGBT turn-on, the gate capacitance is charged and, upon reaching the IGBT threshold voltage (V_{GE_on}), the reverse transfer capacitance (called Miller capacitance) is also charged. To turn off the IGBT, the gate capacitance has to be discharged and, once the threshold voltage (V_{GE_off}) is reached, the reverse transfer capacitance also needs to be discharged. Theoretically, the turn-on and turn-off voltages have to at least cross the threshold level, but practically, these values have to be replaced by other voltages more relevant to the application. Typically, IGBTs are turned on with a positive gate voltage of nominally 15 V.

Normally 0 V applied to the gate is enough to turn off the IGBT. However, to prevent voltage changes (dV_{CE}/dt) across the Miller capacitance (due to the turning on of the opposite IGBT in the half bridge) from turning the gate of the OFF IGBT back on, a large negative voltage (-8 V to -15 V) is often applied to the V_{EE} of the gate driver IC. It is very important to select the control voltage correctly.

2   Selecting the Correct Control Voltage

When a positive control voltage (higher than the threshold) is applied between gate and emitter, the IGBT turns on. Due to the IGBT trans-conductance, the collector current is a function of the gate-emitter voltage. There is also a dependency on the saturation voltage. In other words, the higher the gate-emitter voltage, the higher the possible collector current and the lower the resulting saturation voltage. To achieve the lowest possible conduction losses, which are determined by $V_{CEsat} = f(I_C, V_{GE})$, it is desirable to work with rather high positive control voltage. On the other hand, it should be noted that a high gate-emitter voltage may allow a high short circuit current should that fault occur. Therefore, a compromise needs to be found between the conduction losses during normal operation and the maximum short circuit current in case of a fault. IGBT manufacturers specify the characteristic value for gate voltage as 15 V, which is the most common value. The absolute maximum value should not be exceeded; otherwise internal damage to the driver IC may occur as well as destructively high current may result during short circuit.

In case of switching off with 0 V, parasitic turn-on can happen due to either of the following two reasons:

* Due to the feedback effect of the Miller capacitance. (The main cause of this is the voltage change between collector and emitter when the other IGBT in the half bridge is turned on or off).
* Due to the feedback effect of the Emitter stray inductance. (The main cause of this is the change in load current di_L/dt).

By applying a negative control voltage, the IGBT is turned off and the gate voltage required to turn the IGBT back on is much higher than can be achieved by the Miller effect described earlier. Depending on the application, turn-off voltages in a range -5 V to -10 V is very common. The main reasons are:

- Lower required driver power, which is directly proportional to the voltage lift from the negative to the positive gate voltage.
- Availability of driver IC. Many driver ICs are developed on CMOS or BiCMOS technology, which only provides a limited blocking capability of maximum 30 V between positive and negative supply voltage. Taking supply voltage tolerances into account and sufficient safety margin to the maximum voltage limits, the usual negative gate voltages proved by the V_{EE} power rail are in the range of -5 V to -10 V.

Section 3 provides more details on isolation requirements and Section 4 explains the calculation of correct IGBT drive power.

3   Isolation Requirements

For any industrial motor drive, potential separation of the input circuit (low-voltage) and the output circuit (high-voltage) has to be ensured. The low-voltage side interfaces with the control electronics, whereas, the high-voltage side is connected to the IGBTs. The separation is necessary, because the emitter potential of the upper IGBTs is switched between the DC+ and DC- potential of the DC-bus, which can range in the hundreds or thousands of volts. Depending on the application, the corresponding standards for clearance and creepage distance have to be observed as well as compliance with the test voltages. Some typical standards observed are: IEC60664-1, IEC60664-3, IEC61800-5-1, and EN50124-1.

In the simplest case, it may be sufficient to separate only the upper IGBTs of a half-bridge from the lower IGBTs. This is generally possible if the microcontroller is also referenced to the DC- potential. A subsequent separation of the interconnection to the user interface is advised or required, depending on the application. This is mostly to apply basic isolation from noise and common-mode ground effects. In high-power applications, separation takes place at every IGBT, each driver with its own power supply, as shown in Figure 2.
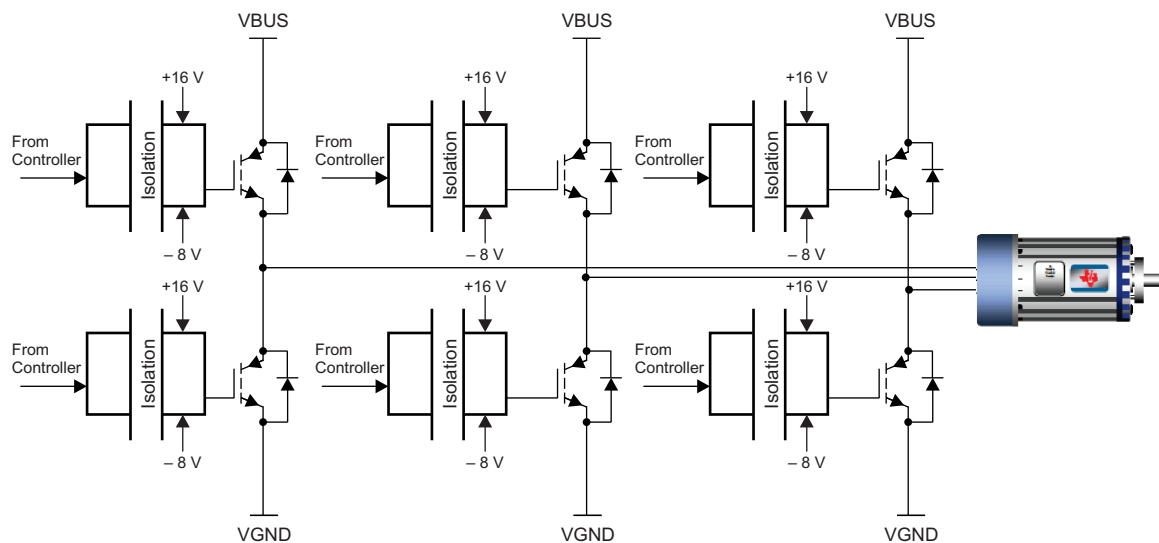

Figure 2. Three-Phase Inverter With Isolated Gate-Drive (all gate-drivers are powered with individual isolated power supplies) [1]

The complexity for the power supply can be simplified for those switched that have their emitter on DC-potential, as shown in Figure 3.
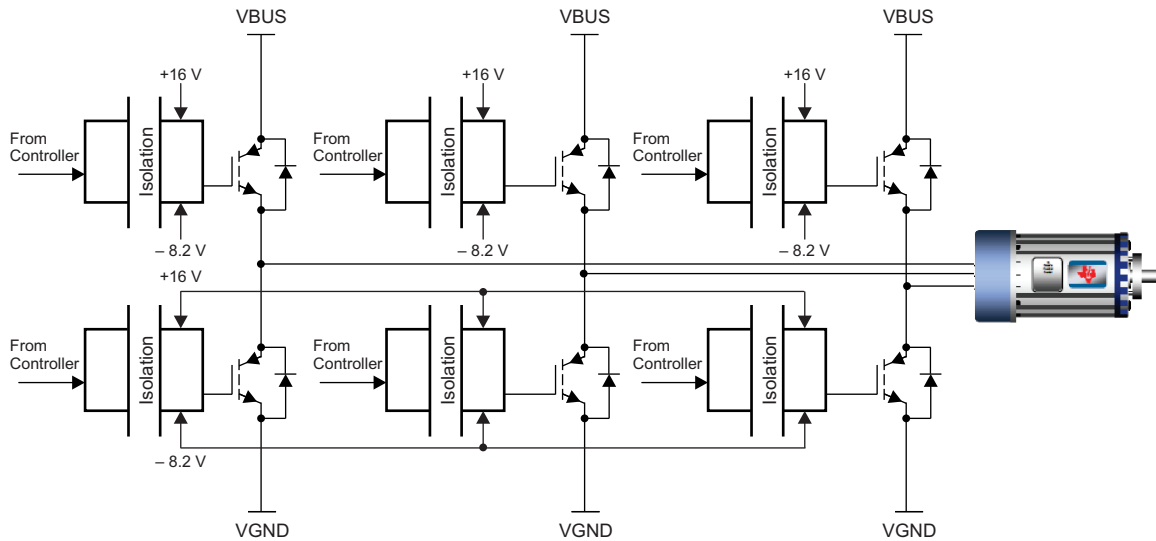

Figure 3. Three-Phase Inverter With Isolated Gate-Drive (lower gate-drivers are powered with a common power supply) [2]

4   Calculation of IGBT Drive Power

While driving an IGBT, the transition between the two gate voltage levels requires a certain amount of power to be dissipated in the loop among the gate driver, gate resistors and IGBT. Equation 1 is typically known as "drive power - P_{DRV}." This drive power is calculated from the gate charge Q_{GATE}, the switching frequency f_{IN} and actual driver output voltage swing ΔV_{GATE}.

$$P_{DRV} = Q_{GATE} * f_{IN} * \Delta V_{GATE} \tag{1}$$

If there is an external capacitor C_{GE} present (auxiliary gate capacitor), then the gate driver also needs to charge and discharge this capacitor, as shown in Figure 4.
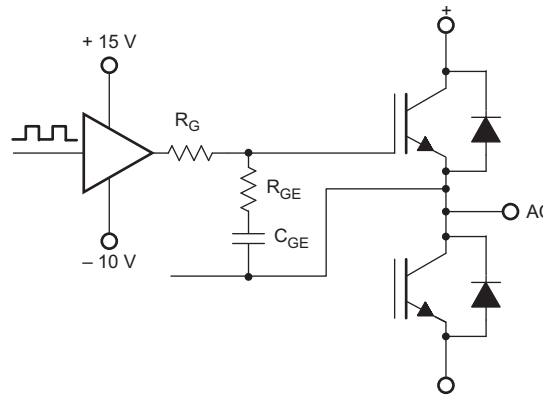

Figure 4. IGBTs With Gate Drive Circuitry for Gate Power Calculation

The value of R_{GE} is not influencing the required drive power as long as C_{GE} is fully charged and discharged during one cycle. Equation 2 shows the required drive power value.

$$P_{DRV} = \left(Q_{GATE} * f_{IN} * \Delta V_{GATE} \right) + \left(C_{GE} * f_{IN} * \Delta V_{GATE}^2 \right) \tag{2}$$

Note that the drive power does not depend on the value of the gate resistor or the duty cycle as long as the switching transition goes from fully on to fully off and back. Also, these equations are true in non-resonant gate drives. This is the total drive power required by the IGBT but the gate driver that is driving the IGBT also consumes some power. This power consumption should be added to get the final value for gate drive power.

$$P_{DRV} = (Q_{GATE} * f_{IN} * \Delta V_{GATE}) + \left(C_{GE} * f_{IN} * \Delta V_{GATE}^2\right) + P_{driver}$$

(3)

5   References

1. *Isolated IGBT Gate-Drive Push-Pull Power Supply with 4 Outputs Design Guide* (TIDU355)
2. *Reinforced Isolated IGBT Gate-Drive Flyback Power Supply With Eight Outputs Design Guide* (TIDU411)

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