Application Report

SLAA672–July 2015

Analysis of Power Supply Topologies for IGBT Gate Drivers in Industrial Drives

Sanjay Pithadia, N. Navaneeth Kumar

ABSTRACT

This application report explains different parameters used for selecting the appropriate topology for powering Insulated gate bipolar transistor (IGBT) Gate-drivers in Industrial Motor Drives.

Contents

List of Figures

1 Introduction

IGBTs are considerably used in three phase inverters, which have numerous applications like variable-frequency drives that control the speed of AC motors, uninterruptible power supply, solar inverters and other similar inverter applications.

In these applications, sophisticated PWM control signals are required to turn the power-devices on and off, which at the system level may eventually determine, for example, the speed, position, and torque of the motor or the output voltage, frequency and phase of the inverter. These control signals are usually the outputs of a microcontroller, and are at low voltage levels such as 3.3 V or 5.0 V. The gate controls required by the IGBTs are in the range of 15 V to 20 V, and need high current capability to be able to drive the large capacitive loads offered by those power transistors. Not that only the gate drive needs to be applied with reference to the Emitter of the IGBT and by inverter construction, the Emitter node of the top IGBT swings between zero to the DC bus voltage, which is several hundreds of volts in magnitude. As the IGBT can float with respect to ground at the power stage, both the power supply and the gate circuitry should be isolated from the inverter ground. This gives room to a limited number of gate-driver configurations:

- Gate drivers with potential separation
- Gate drivers without potential separation

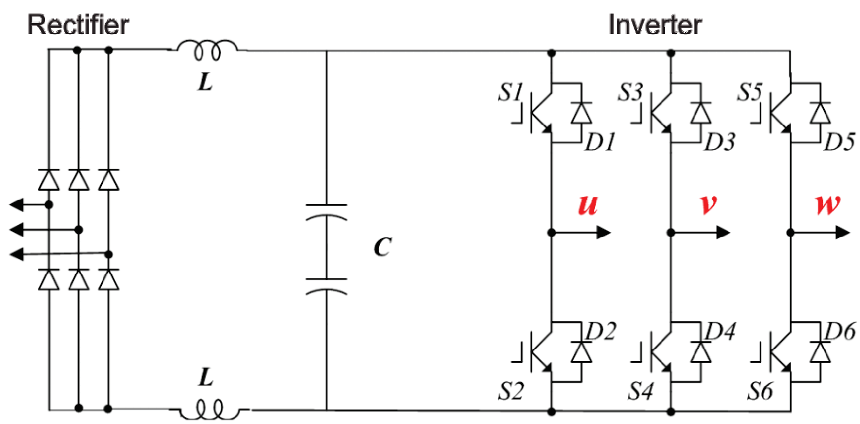


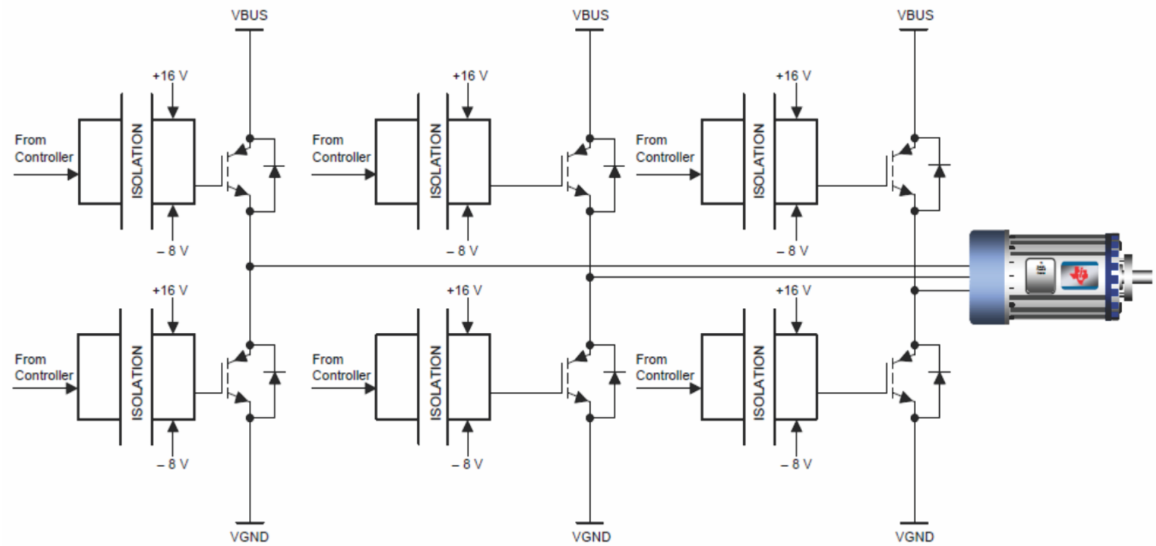
Figure 1. 3-Phase Inverter

2 Gate Drive Supply Voltages

2.1 Isolated IGBT Gate-Drivers

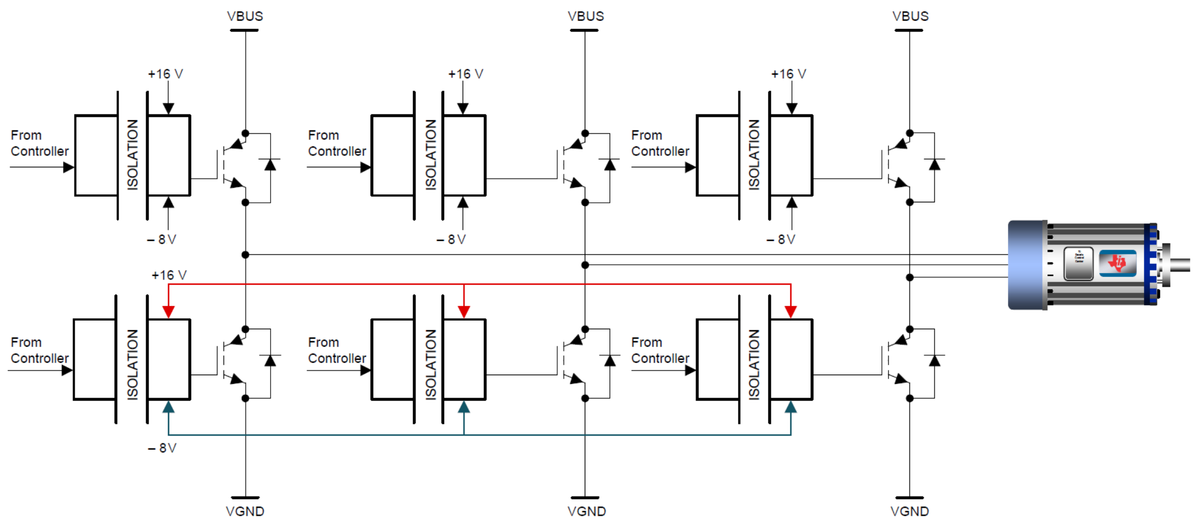
Three phase high power bridge inverters usually have dedicated isolated gate drivers for each IGBT to control the functioning of IGBT. In such a scenario, each driver has its own power supply as shown in Figure 2. During the conduction time, the gate–emitter voltage of the IGBT is held between 13.5 V and 16.5 V so that $V_{CE(sat)}$ is kept as low as possible to minimize conduction losses. During the off-state the IGBT gate emitter is normally held at a minimum of –5 V to ensure the device cannot be spuriously turned on.

For medium power applications, a common power supply can be used for the Bottom IGBT gate drive circuits but with separate capacitors for each power switch, where the emitter of the switch is connected to the ground of the corresponding capacitor. For this architecture, see Figure 3. Under certain conditions like using Gate drivers with miller clamp functionality, negative gate voltage can be avoided.



A All gate-drivers are powered with individual isolated power supplies.

Figure 2. 3-Phase Inverter With Isolated Gate-Drive



A Lower gate-drivers are powered with a common power supply.

Figure 3. 3-Phase Inverter With Isolated Gate-Drive

2.2 Powering IPMs

The intelligent power module (IPM), a kind of modularized device, is integrated by the IGBT and circuits that have the functions of signal processing, self-protection and diagnosis. It provides the advantages of small volume, light weight, simple design and high reliability. As the IPM's has short wiring between gate drive and the IGBT, and the power levels being small, making driving without reverse bias possible.

Many low power IPMs operate on single +15 V power supply and use boot strap-based gate drivers. In such case, it is sufficient to generate single +15 V with power capability to drive all six gate drivers. Figure 4 shows such example of an IPM.

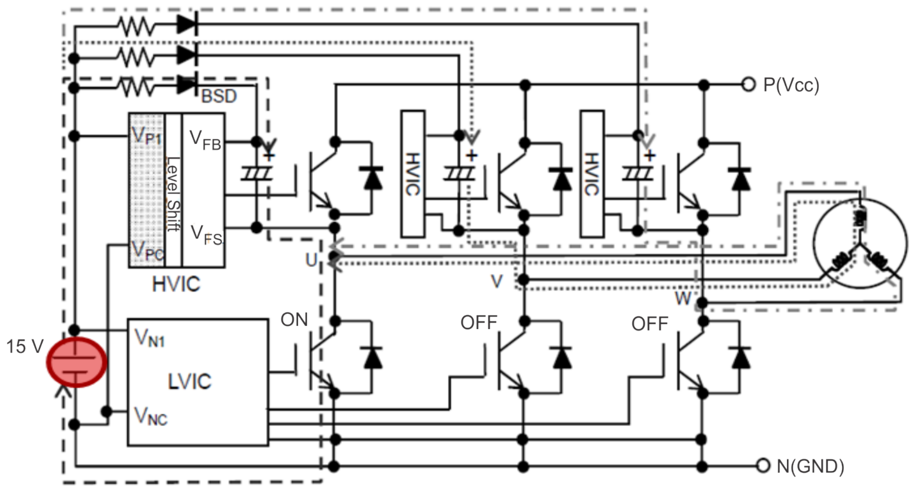


Figure 4. IPM Requiring Single +15 V Supply

Figure 5 shows IPM with individual pre-driver. This configuration necessitates four control power supplies, one supply for all the lower IGBTs and three individual supplies for the upper IGBTs with proper isolation circuit. Supply voltage of each pre driver is usually in the range of 13.5 V to 16.5 V with 15 V being typical value.

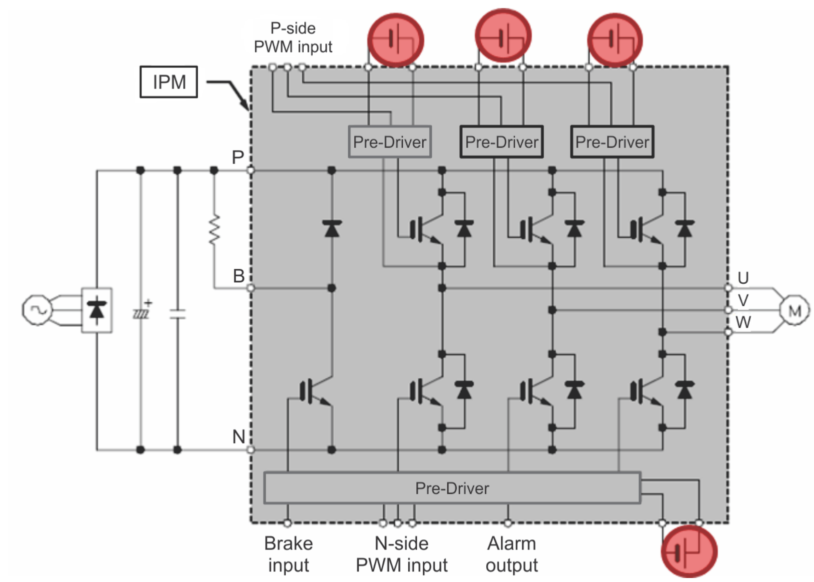


Figure 5. IPM Requiring Individual Power Supplies

2.3 Typical Power Supply Configurations in Industrial Drive

Variable-speed drive (VSD) consists of a power section, controller, User I/O, display, and communication blocks. The power section contains a rectifier, a dc link, inrush current limiting, and IGBT-based inverter. The main power supply (see Figure 6), either powered directly from ac mains or from DC link is used to generate multiple voltage rails which are required for the operation of all the control electronics in the drive including IGBT gate drive. Section 2.1 and Section 2.2 provided insights into 'how many' and 'what magnitude' of voltage rails is required to power IGBT gate drivers in different scenarios.

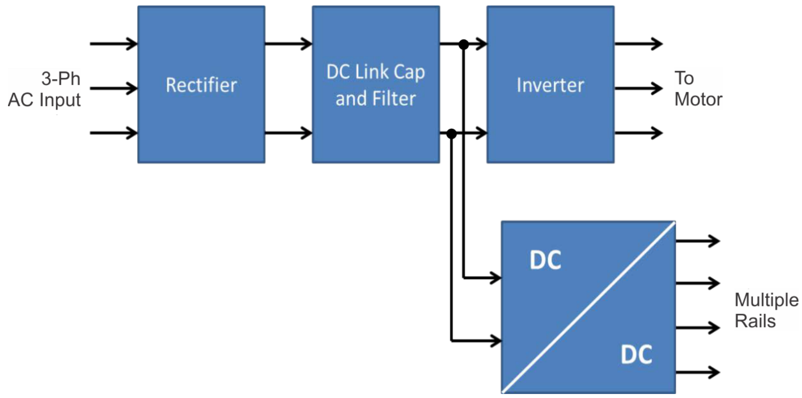


Figure 6. Generation of Multiple Rails in Typical Industrial Drive

Depending upon the input supply of the DC/DC converter (main power supply) and its output rail, there could be multiple options for generating gate drive supply voltages.

2.3.1 Configuration – 1

In this configuration, the IGBT gate-driver power supply is generated from +24 V rail coming from the main power supply as shown in Figure 7. The gate-drive power supply can use Flyback or Flybuck™ topology or Push-pull or Half-bridge. The isolated output of gate-drive power supply can be either +15 V or +15 V/-8 V rails to power the gate drivers.

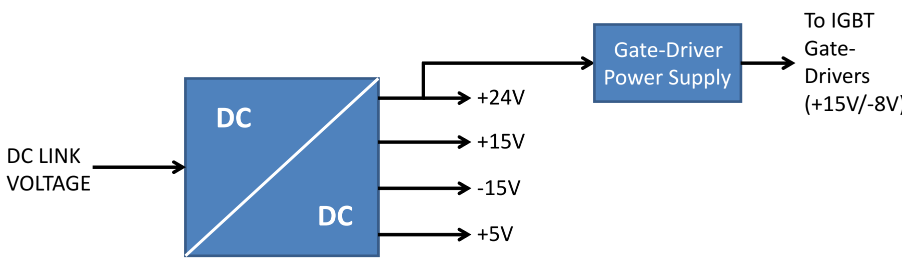
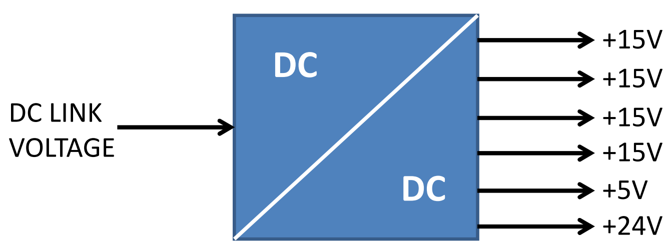


Figure 7. IGBT Gate-Drive Power Supply (+16 V and -8 V) Generated From +24 V Rail

2.3.2 Configuration – 2

Figure 8 shows another configuration in which all the rails (including the rails for IGBT gate-drivers) are generated using main power supply itself. It means that this configuration is cost competitive compared to the Configuration – 1. In such cases, the power supply topology can be Flyback.

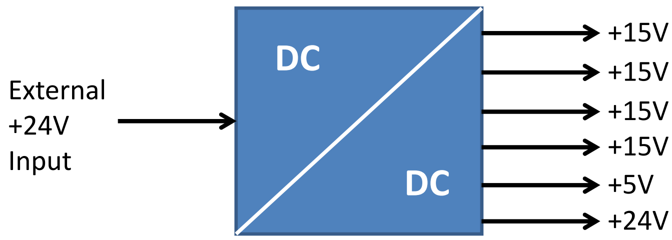


A All four +15 V rails are for powering gate-drivers.

Figure 8. IGBT Gate-Driver Rails Generated Using Mains Supply

2.3.3 Configuration – 3

There is a possibility that the main power supply is powered from external +24 V supply (see Figure 9) instead of from DC link voltage. This configuration uses single transformer similar to configuration 2 to generate all the rails (including the rails for IGBT gate-drivers). The power supply topology can be Flyback or Flybuck.



A All four +15 V rails are for powering gate-drivers.

Figure 9. IGBT Gate-Driver Rails Generated From External +24V Input

3 Selecting the Topology for the Gate-Drive Power Supply

The following section explains that some of the important design criteria are considered for selecting the topology for IGBT gate-driver power supplies.

3.1 Regulation of Available Input Source

The output of IGBT gate-drive power supply needs good regulation. The regulation of input supply voltage for the gate drive power supply decides the necessity of having feedback - open-loop or closed-loop topology. If the input source is regulated, then gate drive power supply without feedback can still provide reasonable regulated output. Possible topologies could be push pull and half bridge. If the input source is not regulated (or coming from some external source whose regulation is not known), a topology with feedback is more appropriate for such scenarios.

3.2 Type of PWM Controller

With reinforced isolation requirements, opto feedbacks are typically not recommended. Primary Side regulated Flyback controllers are cost-effective and eliminate use of opto-couplers and other feedback circuitry.

3.3 Isolation and Spacing

For any industrial motor drive, potential separation of the input circuit (low-voltage) and the output circuit (high-voltage) has to be ensured. Isolation levels are selected based on Pollution Degree, Overvoltage Category and Supply Earthing System.

Depending on the application, the corresponding standards for clearance and creepage distance have to be observed as well as compliance with the test voltages. One typical standard observed for Motor Drives is IEC61800-5. The Isolation level – ‘Reinforced’ or ‘Functional’ dictates the design of the transformer. Creepage, Clearances, number of transformer Pins – all play a vital role in design of the transformer. Reinforced isolation asks for bigger transformers and hence more space on the board compared to Functional isolation.

3.3.1 With Functional isolation – Single Transformer

The functional isolation is the isolation between conductive parts within a circuit, which is necessary for the proper functioning of the circuit, but which does not provide protection against electric shock. With functional isolation requirement the clearance and creepage are defined as:

- Primary to Secondary clearance = 3.2 mm
- $Secondary_1$ to $Secondary_2$ clearance = 2.2 mm
- Creepage distance = 4 mm

Considering these parameters, the board size can be very small. One of the examples design with basic isolation is TIDA-00199. The layout for TIDA-00199 is shown in Figure 10.

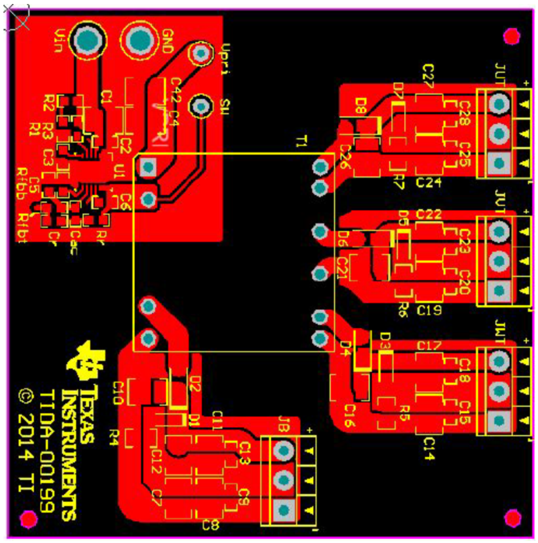


Figure 10. Basic Isolated Board With Single Transformer (Size: 62mm x 55mm)

3.3.2 With Reinforced Isolation – Single Transformer

With reinforced isolation requirement the clearance and creepage are defined as:

- Primary to secondary isolation = 7.4kV for 1.2/50 µs Impulse voltage
- Type test voltage: Primary to Secondary = 3.6kVrms, $Secondary_1$ to $Secondary_2$ = 1.8kVrms
- Primary to Secondary clearance = 8 mm
- $Secondary_1$ to $Secondary_2$ clearance = 5.5 mm
- Creepage distance = 9.2 mm

Considering these parameters, the board size can easily go up to 110mm x 90mm area. TI's TIDA-00182 design uses Flyback topology and is designed based on Reinforced Isolation. Figure 11 shows the layout of TIDA-00182 design.

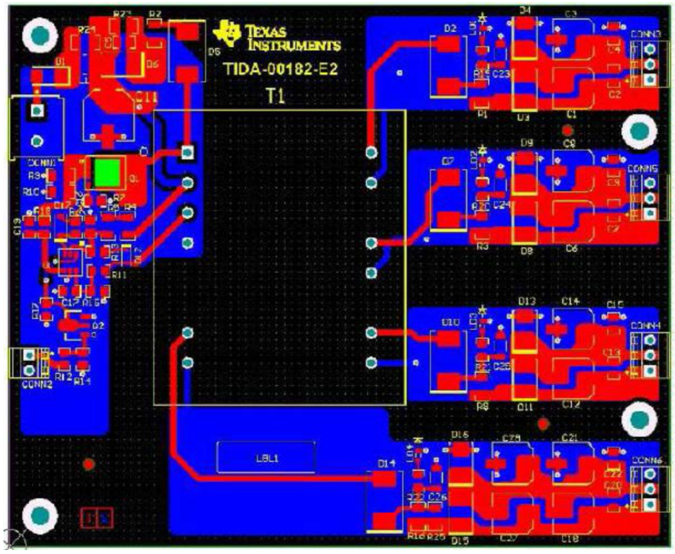


Figure 11. Reinforced Isolated Board With Single Transformer (Size 110mm x 90mm)

3.4 Operating Frequency

The operating frequency of the power supply decides the efficiency and the size of the power supply. Some topologies, like Push-Pull are not appropriate for high frequency operations because of transformer designs. For higher frequencies of more than 400 kHz, Flybuck or half bridge topologies are suggested. Selecting higher frequency is advantage while only functional isolation is required.

3.5 Modular structure

The placement of IGBT Module in the drive and the IGBT Module Pin-Out play an important role. Figure 12 shows an example layout of a mid-end drive where six isolated IGBT gate-drivers are used to drive one Power Module. It shows that the pinout of the IGBT power module is such that one transformer is required to power two reinforced isolated IGBT gate-drivers.

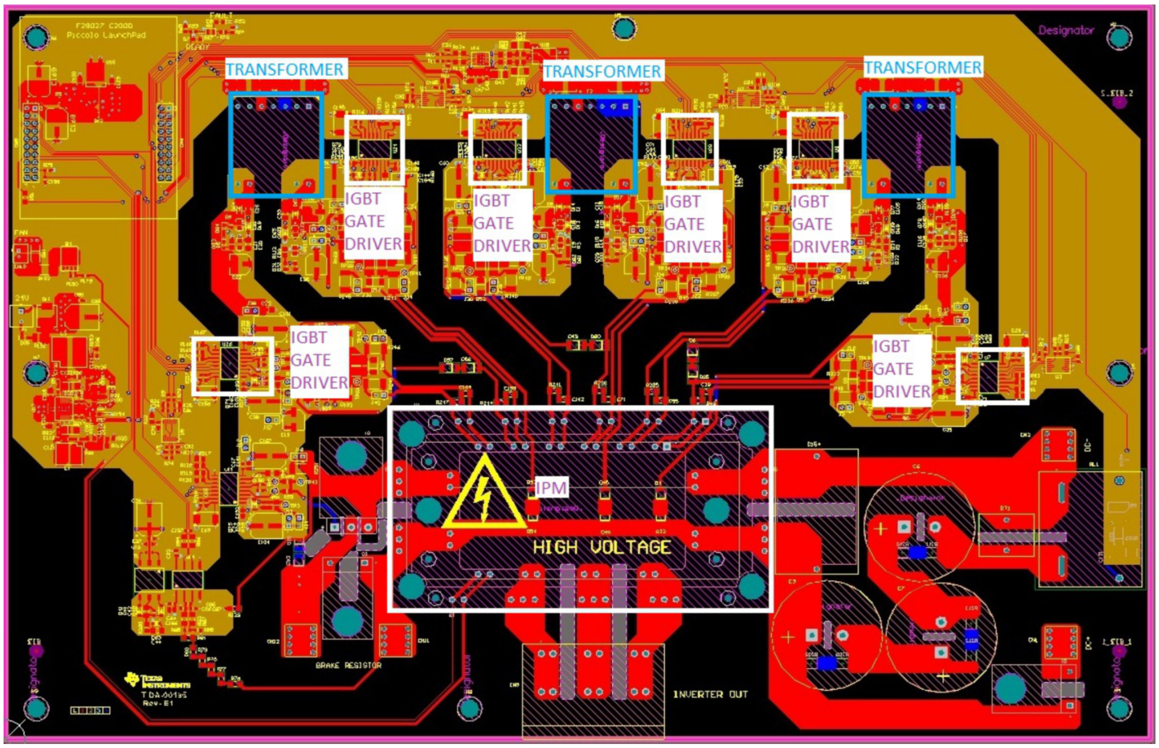


Figure 12. Six IGBT Drivers Driving Single Power Module

3.5.1 Single vs. Multiple Transformers

The use of single versus multiple transformers is dependent on the isolation required by the drive structure. If there are multiple transformers used to power each of the IGBT gate-drivers, it calls for the use of single or multiple PWM Controllers based on the selected topology. Push-Pull and half bridge topology allows multiple transformers to be connected in parallel to generate voltage rails required to power multiple IGBT drivers present in the inverter power stage. Flyback and Flybuck Topologies do not allow this because of their operation on the secondary side of the transformer.

4 Conclusion

The gate-driver power supply topology is dependent on multiple parameters. Based on the architecture of drive application, the choice varies. The number of components also plays an important role in deciding the topology. The Flybuck topology has low-component count and primary-side feedback, whereas, the Push-pull topology with open-loop configuration does not require feedback components but uses two switches on the primary side. All of the parameters help in finalizing the power supply topology for gate-drivers:number of transformers (based on the structure), availability of supply, type of IGBT module, isolation requirements.

5 References

- TIDA-00181: *Isolated IGBT Gate-Drive Push-Pull Power Supply with 4 Outputs* (TIDU355)
- TIDA-00182: *Reinforced Isolated IGBT Gate-Drive Flyback Power Supply With Eight Outputs* (TIDU411)
- TIDA-00174: *Isolated IGBT Gate-Drive Fly-Buck™ Power Supply with 4 Outputs* (TIDU478)
- TIDA-00199: *Wide-Input Isolated IGBT Gate-Drive Fly-Buck™ Power Supply for Three-Phase Inverters* (TIDU670)
- FUJI IGBT–IPM Application Manual
- DIPIPM Application Note - Mitsubishi Electric

IMPORTANT NOTICE

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265