Application Note

AMC High-Side Power Supply Options

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ABSTRACT

With the increase in electrification, the need for accurate and cost-efficient isolated current sensing has grown significantly. This document shows the five most common high-side power supply options used for Texas Instruments' isolated shunt current sensing devices: AMC0300D, AMC0300R, AMC0306M05, AMC0306M25, AMC3301, AMC3302, AMC3306M05, AMC3306M25, and AMC131M03, which are all available in industrial and automotive versions.

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1 Introduction

Texas Instruments' AMC devices are a variety of isolated current and voltage sensing devices that are capable of withstanding high common-mode voltages. The integrated isolation barrier inherently separates a high-voltage side and a low-voltage side of a given device which each require an independent power supply. When determining an optimal high-side power supply for an AMC device and system, considerations may include cost, size, location, ease of use, isolation, and functional safety. This app note aims to summarize five recommended high-side power supply options for the seven main locations isolated current sensing is seen in high voltage power conversion. The high-side power supply options include three cost optimized power supply designs: transformer winding, gate driver supply with Zener diode, and gate driver supply with LDO and two simplified power supply designs: integrated DC/DC converter and discrete transformer. Then, this document outlines the seven main locations isolated current sensing in the rectifier, DC/DC, and inverter.

Table 1-1. High-Side Power Supply Options Comparison

	Cost Optimized Power Supplies			Simplified Power Supplies	
	Transformer Winding	**Gate Driver Supply with Zener Diode**	**Gate Driver Supply with LDO**	**Integrated DC/DC Converter**	**Discrete Transformer**
Cost	$$	$[1]	$[1]	$$	$$$
Size	++	++	+	+	+++
Ease of Use	++	+	++	+++	+++[1]
Isolation	N/A	N/A	N/A	+	++
Functional Safety	++	+	+	+++	++
System Requirements	Low cost option with greater functional safety.	Lowest cost option with less potential for overshoot.	Low cost option with stable output and lower noise.	Small footprint with great ease of use.	Most customizable with great ease of use.

1. Further differentiating factors included in System Requirements row.

2 Detailed Description

2.1 Cost Optimized Power Supplies

2.1.1 Transformer Winding

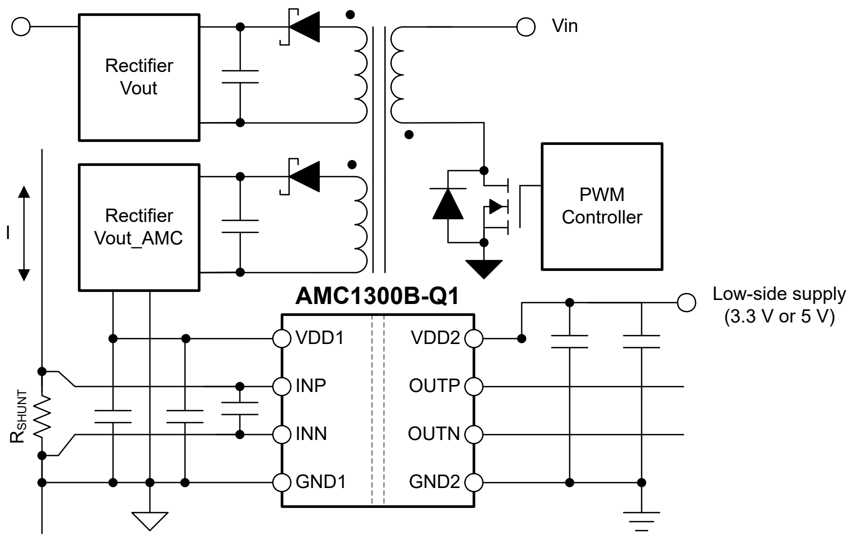

Figure 2-1. Transformer Winding Supply Schematic

Transformer winding power supplies are an efficient, low loss design. This design is made up of a primary winding and secondary winding. Each winding is made up of insulated copper conductors wound about a magnetic core. Current flows through the primary winding to create a magnetic field. The magnetic field is induced onto the secondary coil to create a voltage. This power supply option offers greater functional safety due to this architecture.

In flyback converters, transformer windings are selected to minimize energy losses and offer a cost-effective design. In DC/DC converters, which is covered later in the application note, transformer windings can be selected due to the ability to store and isolate power. This power can be extended to the high-side power of an AMC device as well. If not implemented well, however, transformer windings may pose EMI concerns. Therefore, carefully considering and designing with detail is imperative when opting for this power supply source. Design considerations can include wire-size selection, winding methodologies, and ferrite material. Consider Flyback transformer design considerations of efficiency and EMI | Video | TI.com as a resource for further information.

2.1.2 Gate Driver Supply with Zener Diode

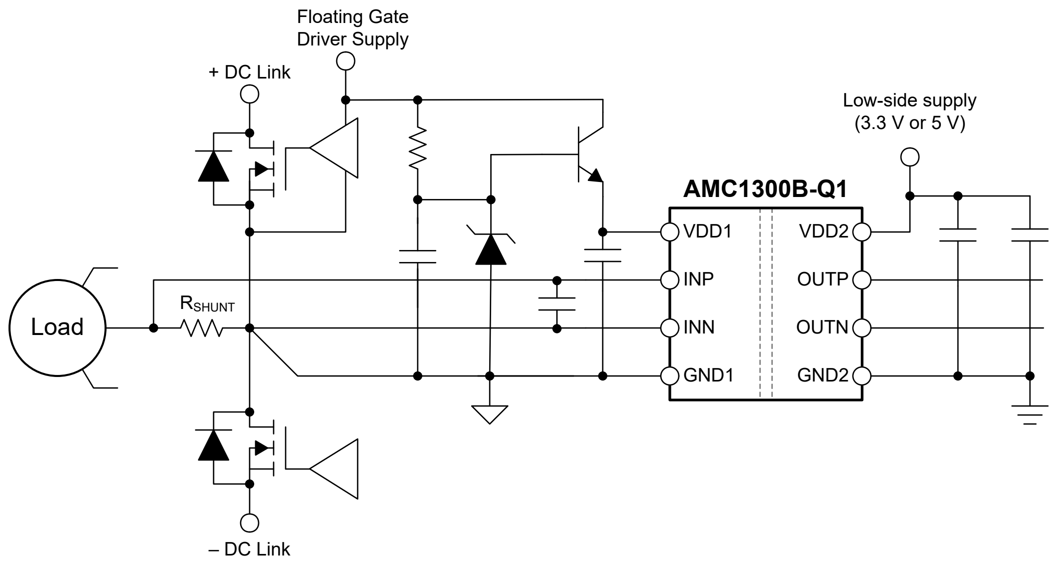

Figure 2-2. Gate Driver Supply with Zener Diode Schematic

Gate driver supplies are designed to control the switching of power devices and to serve as an interface between a low-power device and a high-power device. This allows faster switching times and minimizes the system's power losses improving overall efficiency. Isolated gate drivers promote safety as well by isolating the low-voltage and high-voltage circuit. Largely though, gate driver power supply options are utilized when a system prioritizes low cost. Two options are discussed in this application note, the first with a Zener diode and the second with an LDO. Pairing a gate driver supply with a Zener diode typically offers the lowest cost of the power supplies described in this application note.

In addition to motivating the lowest design cost, Zener diodes carry less potential for overshoot than the alternate gate driver supply option mentioned. Design consideration includes understanding that Zener diodes clamp at a certain voltage to be used which lessens the potential for overshoot. LDOs can see overshoot during startups with slower slew rates. This design requires understanding high-side gate driver current sensing locations. This involves simulating and fine tuning to adjust the size of the sensing resistor and capacitor to verify operation. This design procedure is often outlined in a given LDO datasheet or documentation.

2.1.3 Gate Driver Supply with LDO

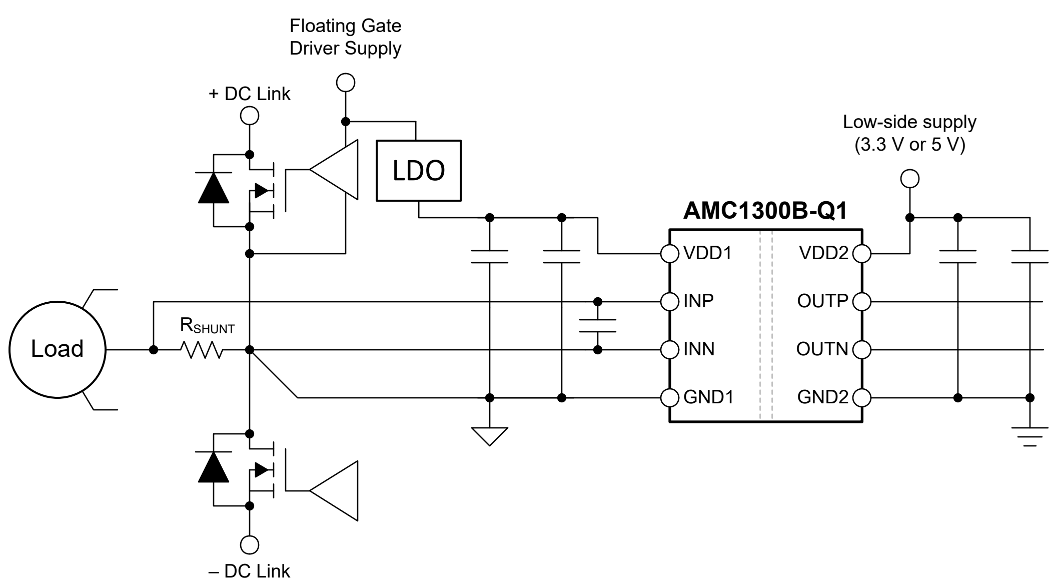

Figure 2-3. Gate Driver Supply with LDO Block Diagram

Corresponding to the previous power supply option discussed, the gate driver supply with LDO power supply design also includes a gate driver supply but with an LDO instead of a Zener diode. For similarly low-cost applications where it is crucial to provide stable voltage with low noise to the gate driver, an LDO may be favored to regulate the voltage. LDOs can help stabilize the power in conditions such as expected system voltage spikes or overheating.

LDOs offer better regulation than diodes do. They provide a more stable output voltage with fluctuating load or input current. LDOs are also preferred for applications where the input voltage and output voltage are only a small difference. When designing with an LDO, the additional voltage drop of the LDO needs to be considered too. This involves selecting resistor values to establish the output voltage at the AMC's necessary supply voltage. Including capacitors to counteract reactive input sources and improve transient responses are required steps in this design process with LDOs. As the schematic in Figure 2-3 shows, the isolated gate driver power supply is established after the DC link. This power supply option can be used in rectifier or inverter applications, which is covered later in the app note. Both of these applications include active switches that can benefit from the stable output of a gate driver supply. A gate driver with an LDO further reduces noise from the power supply helping bolster the stability of this power supply suitable for many applications.

The TLV709 is a good LDO option for many applications. This LDO can operate with 2.5V to 30V on the input which makes it preferred for many power supply rails that can source the gate driver. This device also has adjustable outputs, meaning with a simple resistive divider a user can establish the output voltage to be that of the high-side power supply – for example 3.3V or 5V for most AMC devices. This is demonstrated in the AMC-MOD-50A-EVM Evaluation Board. See the *Analog Input* section of the user's guide for more information.

2.2 Simplified Power Supplies:

2.2.1 Integrated DC/DC Converter Power Supply

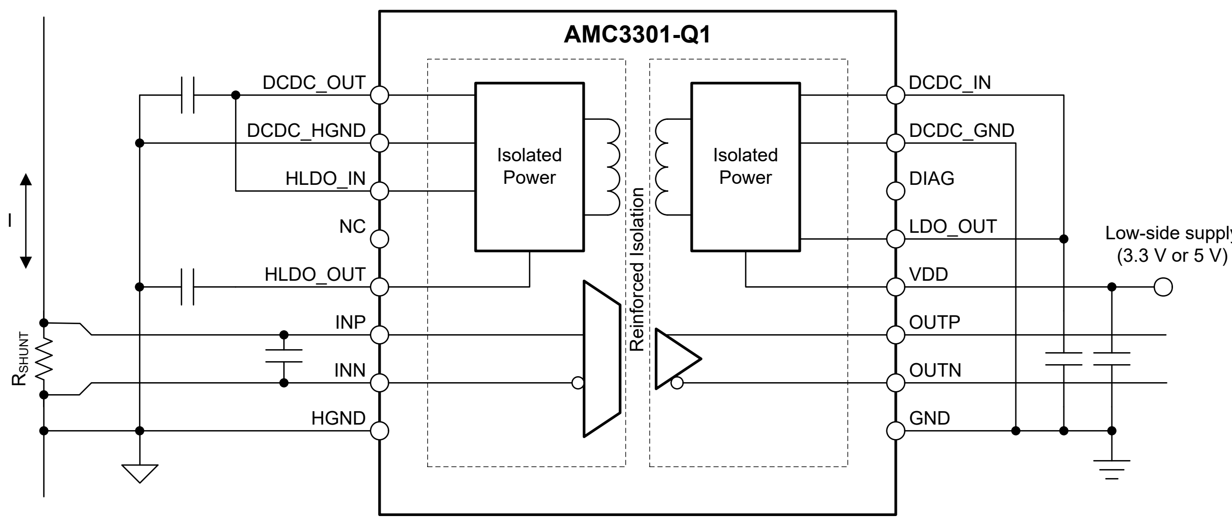

Figure 2-4. Integrated DC/DC Converter Supply Schematic

The integrated DC/DC converter power supply provides the highest ease of use amongst the five power supply options provided in this application note and contains a small footprint. The AMC33xx device family feature this power supply option and are an all-encompassing current or voltage sensing design. The family feature a fully integrated, isolated DC/DC converter that allows single-supply operation from the low-side power of the device to the high-side power of the device. This offers advantages in space constrained applications due to the limited need for external circuitry. Additionally, the integrated DC/DC converter offers diagnostic output to assist in monitoring that the device is operational and that the output voltage is valid. The diagnostic, DIAG, pin remains low until the high-side power is available. This facilitates in validating proper functioning of each power supply. Integrated DC/DC converters are useful in applications that prioritize power efficiency where only one power supply is available.

Figure 2-4 demonstrates a typical application schematic with the AMC3301-Q1 isolated amplifier. This device requires only very simple external circuitry. Namely, decoupling capacitors on the power pins on both the primary and secondary side, as well as a shunt or sensing resistor to frame the input to the device's full-scale input. Input filtering is recommended but not required depending on a given system and input source. The AMC3301EVM Evaluation Board EVM outlines the recommended design considerations and typical circuitry in more detail.

2.2.2 Discrete Transformer

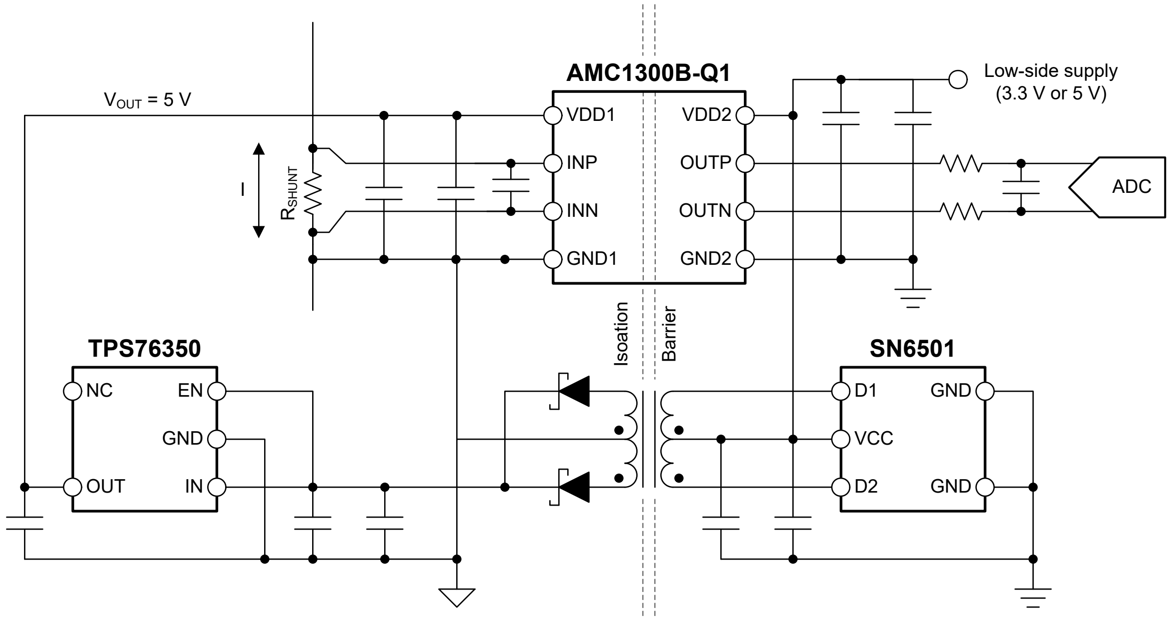

Figure 2-5. Discrete Transformer Supply Schematic

The discrete transformer power supply option also offers a simplified design compared to the cost optimized designs. A discrete transformer supply involves leveraging an isolated transformer and other individual components to source the high-side power from the same low-side power. This power supply option is often used with devices without an integrated DC/DC converter since the functionality of these designs are alike. Discrete transformers are highly customizable and consequently result in a higher BOM and PCB size than other options considered in this application note. However, designing a discrete transformer is simpler than other previously described design processes and is often considered for applications that require very clean signals.

The Figure 2-5 example schematic includes the AMC1300B-Q1 - an isolated amplifier, the SN6501 – a transformer driver, and the TPS76350 – an LDO, as well as additional passive components. This design works to use the low-side voltage supply of the amplifier to power the high-side supply by means of an isolation transformer and the transformer driver. The LDO once again stabilizes the power on the high-side. Following the typical schematic recommendations of the selected components is advised. This includes decoupling capacitors and diodes. This schematic example is largely straightforward and simple to follow, but consumes a large area of PCB.

Furthermore, an example discrete transformer power supply is included in the AMC1300EVM Evaluation Board. The SN6501 transformer driver preserves the isolation barrier by utilizing an oscillator and gate drive circuit to drive the power switches. The logic of the SN6501 translates this power safely between two switches. Diodes are required to source as much voltage to the output as possible. The SN6501 user's guide gives more information about these selections.

2.3 Isolated Current Sensing Locations in High Voltage Power Conversion

2.3.1 Introduction

In high voltage power conversion, there are three main systems: rectifier (AC to DC converter), DC/DC converter, and inverter (DC to AC converter). In those three systems, there are seven locations for isolated current sensing. This section discusses the best high-side power supply options for each sensing location and the recommended device from the isolated converters device family. Table 2-1 splits the high-side power supplies into two sections: gate driver present and no gate driver present. When a gate driver supply can be used, TI recommends using a gate driver design for the low-cost design. By leveraging the gate driver supply, it is possible to achieve a total design isolated current sensing cost that is lower than competing technologies such as hall, CT, and Rogowski, even when considering the external shunt resistor. When a gate driver supply can not be used, TI recommends using an integrated DC/DC supply option (AMC33xx devices) for a simple design.

Table 2-1. High-Side Power and Isolated Converter Device Selection

	Gate Driver Present	No Gate Driver Present	
High-Side Power Supply Design	**Gate Driver with LDO or Gate Driver with Zener Diode**	**Int. DC/DC Supply**	**Transformer Winding or Discrete Transformer**
Recommended Isolated Converter Device	AMC0300D (-Q1), AMC0300R (-Q1), AMC0302D (-Q1), AMC0302R (-Q1), AMC0306M05 (-Q1), or AMC0306M25 (-Q1)	AMC3301 (-Q1), AMC3302 (-Q1), AMC3306M05 (-Q1), AMC3306M25 (-Q1), or AMC131M03 (-Q1)	AMC0300D (-Q1), AMC0300R (-Q1), AMC0302D (-Q1), AMC0302R (-Q1), AMC0306M05 (-Q1), or AMC0306M25 (-Q1)

2.3.2 Rectifier (AC to DC Converter)

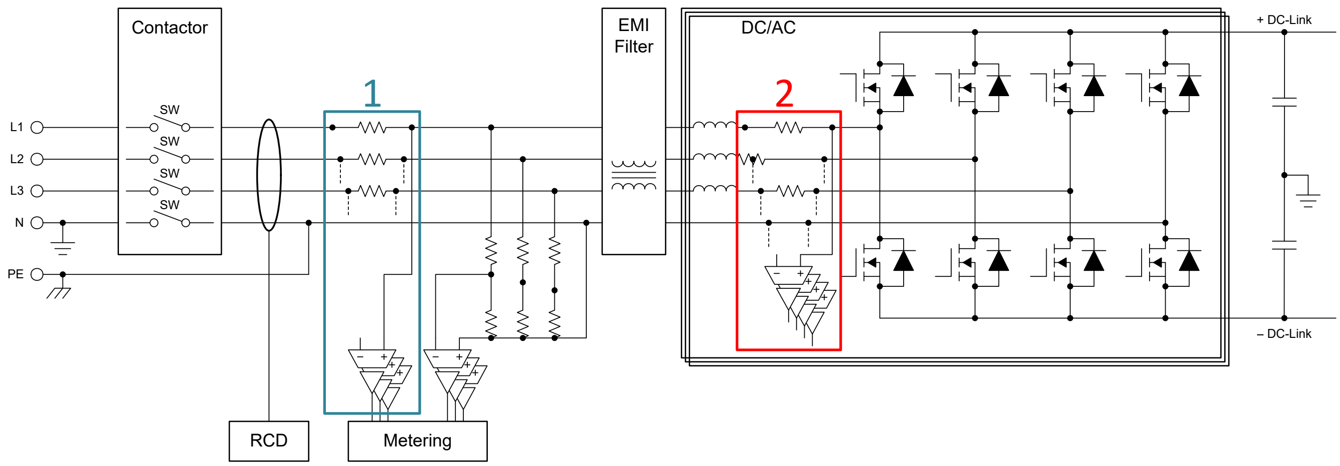

Figure 2-6. Rectifier Block Diagram (AC to DC Converter)

The rectifier is in charge of turning AC voltage into DC voltage. Isolated current sensing is needed in the rectifier to know the power going in and out of the system. Applications include the on-board charger (OBC) in automotive, motor drive, and metering applications. There are two isolated current sensing locations. The first location, indicated by the blue box in Figure 2-6 is in the Point of Common Coupling (PCC), which is before the EMI filter and after the contactor. The best choice is to use a no gate driver present design. The second location, indicated by the red box in Figure 2-6 , is in the Power Factor Correction (PFC) stage, which is after the EMI filter. The best choice is to use a gate driver present design using the high-side gate driver supply of each phase to power the corresponding device. Typically, only one isolated current sensing location is required in the rectifier, but with trends such as vehicle-to-everything (V2X), TI recommends having isolated current sensing in both locations due to bidirectional capabilities.

2.3.3 DC/DC

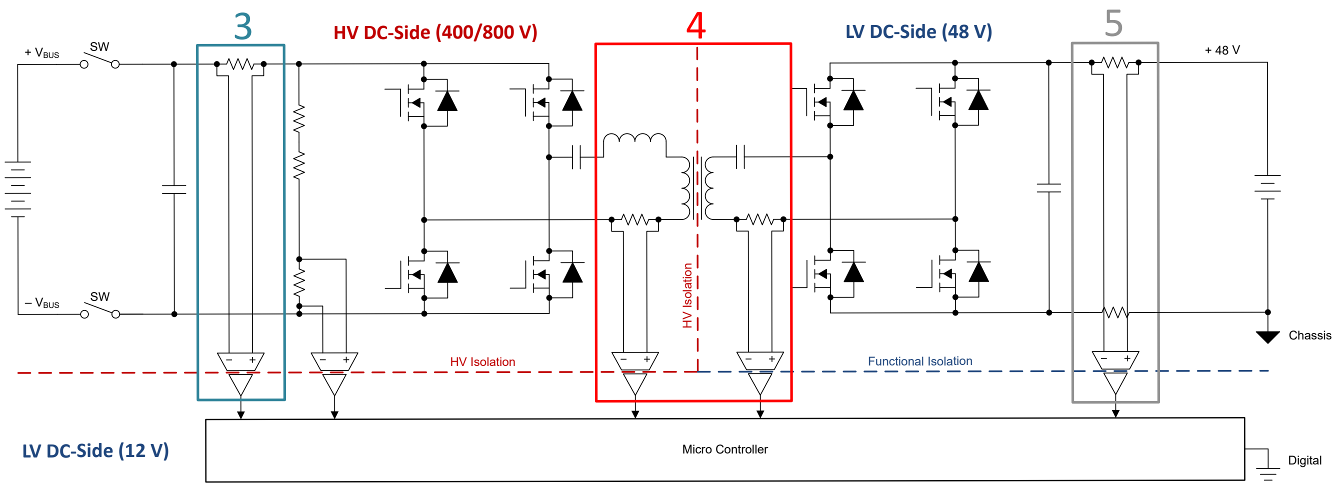

Figure 2-7. DC/DC Converter Block Diagram

The DC/DC converter is in charge of stepping down or up the voltage in a high voltage system. Most commonly, the converter takes the 400V or 800V from the battery and steps the converter down to 48V for low-voltage uses. Applications include the HVDC/HVDC or HVDC/LVDC converter in automotive and solar optimizer and maximum power point tracking (MPPT) in grid. There are three isolated current sensing locations. The first location, indicated by the blue box Figure 2-7, is the DC link. The best choice is to use a no gate driver present design. Accuracy in this location is not always a priority since the power coming out of the battery is measured accurately. If this is the case, it is common to have an isolated comparator such as the AMC23C12 for industrial applications and the AMC23C12-Q1 for automotive applications to sense if power is present. The second location, indicated by the red box in Figure 2-7, is the DC tank. The best choice is to use a no gate driver present design. Isolated current sensing done in this location is most commonly for over-current protection or zero cross detection. Again, TI recommends using the AMC23C12 for industrial applications and the AMC23C12-Q1 for automotive applications. The third location, indicated by the gray box in Figure 2-7, is the HV/LV DC/DC. The best choice is to use a no gate driver present design. One great resource is the AMC-AMP-50A-EVM, which is a simple design to evaluate isolated shunt current sensing for 50A applications.

2.3.4 Inverter (DC to AC Converter)

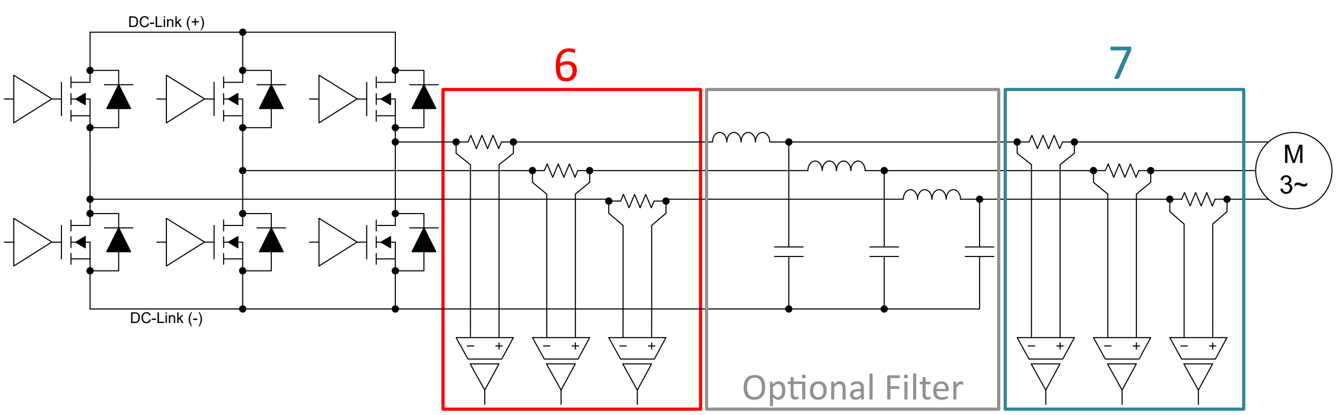

Figure 2-8. Inverter Block Diagram (DC to AC Converter)

The inverter is in charge of turning DC voltage into AC voltage. Isolated current sensing is needed in the inverter for motor control. Applications include the traction inverter or EESM for automotive and motor control for motor drive applications. The first location, indicated by the red box in Figure 2-8, is the traditional location, which is located before the optional filter. The best choice is to use a gate driver present design using the high-side gate driver supply of each phase to power the corresponding device. The second location, indicated by the blue box in Figure 2-8, is the sinusoidal location, which is located after the optional filter. The best choice is to use a no gate driver present design. The need for an optional filter can be more many reasons. First, the design can be used to reduce noise from nearby systems for applications where the motor and motor controller are not next to each other such as in factory automation. Second, the design can be used to reduce transient over-voltages due to switching in the power stage and potential damage to the motor windings.

3 Summary

Amongst the transformer winding, gate driver supply with Zener diode, gate driver supply with LDO, integrated DC/DC, and discrete transformer power supply options, building an efficient system can be modular. These different high-side power designs are highlighted in the seven main locations for isolated current sensing in power conversion. Based on system and project requirements, the optimal power supply can be determined and implemented using the isolated AMC devices from Texas Instruments.

4 References

1. Texas Instruments, *Design considerations for isolated current sensing*, analog design journal.
2. Texas Instruments, *Avoid Start-up Overshoot of LDO*, application note.
3. Texas Instruments, *Flyback transformer design considerations of efficiency and EMI | Video | TI.com*, video.
4. Texas Instruments, *AMC-MOD-50A-EVM Evaluation board*, evaluation board.
5. Texas Instruments, *AMC1300EVM Evaluation board*, evaluation board.
6. Texas Instruments, *AMC3301EVM Evaluation board* , evaluation board.