

INTRODUCTION

At high power, inverters or converters typically use 'bridge' configurations to generate line-frequency AC or to provide bi-directional PWM drive to motors, transformers or other loads. Bridge circuits typically include IGBTs or MOSFETs including SiC and GaN, as 'high side' switches, whose emitters/sources are switching nodes at high voltage and high frequency. Therefore, the gate drive PWM signal and associated drive power rails, which use the emitter/source as a reference, have to be galvanically isolated from ground. Additional requirements are that the drive circuit and associated power rails should be immune to the high 'dV/dt' of the switch node and have a very low coupling capacitance. In many instances, the bridge circuit requires safety agency-rated isolation from the control circuitry and therefore the drive circuit isolation barrier must be robust and show no significant degradation over the design life time due to partial discharge effects.

The MGJ series of DC-DC converters is designed to provide optimum drive voltages and isolation for these 'high side' gate drive circuits.

CHOOSING MGJ SERIES OUTPUT VOLTAGE VARIANTS

Positive Voltage

The positive power rail voltage for the gate drive circuit should be high enough to ensure full saturation/enhancement of the power switch without exceeding the absolute maximum voltage for its gate. The MGJ series has options for +15V, +18V, +19V or +20V to suit various devices, with other voltage options available. For example, IGBTs and standard MOSFETs will be fully ON with 15 V drive but typical SiC MOSFETs may need closer to 20V for full enhancement.

Negative Voltage

For the off-state, 0 V on the gate can be adequate for all devices. However, a negative voltage typically between -5V and -10V enables rapid switching controlled by a gate resistor. The on-state gate threshold for IGBTs is a few volts, typically 5V but SiC and GaN can be as low as a little over a volt. A consideration also is that any emitter inductance L between a switch and the driver reference, (point 'x' in Figure 1), causes an opposing gate-emitter voltage when the switch is turning off. While the inductance may be small, just 5nH would produce 5V at a di/dt of 1000A/ μ s which is not unusual. 5nH is just a few millimetres of wired connection. An appropriate negative drive ensures that the gate-emitter off-voltage is always actually zero or less. The MGJ series offers -2.5V, -5V, -8.7V, -9V, -10V and -15V depending on variant, with other voltage options available. A negative gate drive also helps to overcome the effect of collector/drain to gate 'Miller' capacitance which works to inject current into the gate drive circuit on device turn-off. When an IGBT is driven off, the collector-gate voltage rises and current of value $C_m \cdot dV_{ce}/dt$ flows through the Miller capacitance into the gate to emitter/source capacitance C_{ge} and through the gate resistor to the driver circuit. See Figure 2. The resulting voltage V_{ge} on the gate can be sufficient to turn the device on again with possible shoot-through and damage. Driving the gate to a negative voltage mitigates this effect. IGBTs and all types of MOSFETs exhibit the same effect.

Figure 1

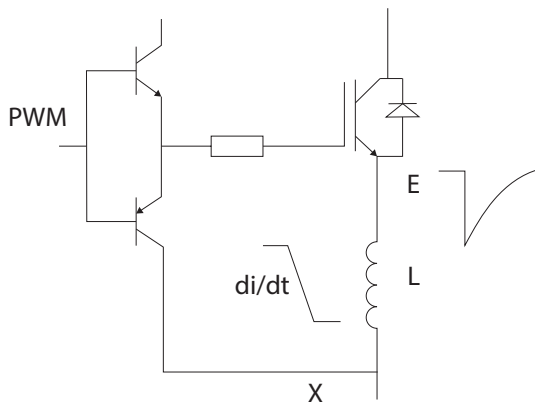


Figure 1. With stray inductance L , on switch-off, negative di/dt produces a negative voltage on the emitter, opposing the turn-off voltage.

Figure 2

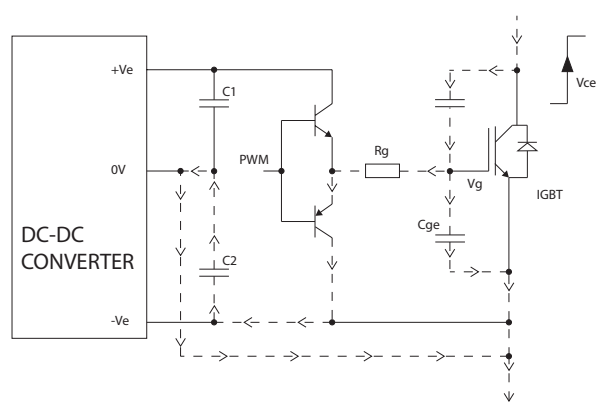


Figure 2. Current through 'Miller' capacitance opposes switch off.

GATE POWER REQUIREMENTS

In each switching cycle, the gate of an IGBT/MOSFET must be charged and discharged through R_g in Figure 2. If the IGBT data sheet provides a gate charge curve then the power (P) dissipated which must be provided by the DC-DC is:

$$P = Q_g \times F \times V_s$$

Where Q_g is data sheet charge for a chosen gate voltage swing, positive to negative, of value V_s and F is frequency. Note that this power is dissipated in the internal gate resistance of the device and external series resistance R_g . If the data sheet does not provide a charge curve but just a Q_g value at specific gate voltages, the value of Q_g at other gate voltage swings can be approximated by multiplying by the ratio of the actual versus data sheet voltage swings. For example IGBT device FZ400R12KE4 from Infineon has a Q_g value of $3.7\mu\text{C}$ with $\pm 15\text{V}$ gate voltage swing (30V total). For a swing of $+15/-10\text{V}$ (25V total) gate charge approximates to:

$$Q_g = 3.7e^{-6} \times 25/30 \approx 3.1 \mu\text{C}$$

At 10 kHz this requires gate drive power of:

$$P_g = 3.1e^{-6} \times 10e3 \times 25 \approx 0.78 \text{ W}$$

With derating and allowing for other incidental losses, a 1W DC-DC converter would be suitable such as Murata MGJ1 series. Figure 3 shows power required at various switching frequencies up to gate charge values of 5 micro coulombs for a total gate voltage swing of 25V and the corresponding suitable Murata DC-DC converter series. Different voltage swings produce proportionally different power requirements. A calculator tool is available, please refer to the final section of this application note.

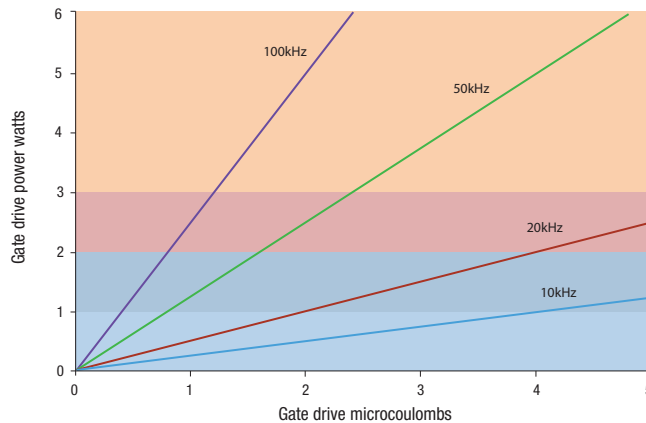


Figure 3. Gate drive power versus gate charge and switching frequency

Average Current Requirements

The average current into the gate capacitance must be zero over each switching cycle therefore the average charge and discharge current in each switching cycle must be the same, given by $\pm P_g \div V_s = \pm 31\text{mA}$ in our previous example.

Peak Current Requirements

The peak current I_{pk} , required to charge and discharge the gate is a function of V_s , gate resistance of the IGBT/MOSFET R_{int} and external resistance R_g .

$$I_{pk} = V_s \div (R_{int} + R_g)$$

Our example IGBT device FZ400R12KE4 has $R_{int} = 1.9$ ohms so with a typical external resistor of 2 ohms and a swing of 25V, a peak current of over 6A results. This peak current must be supplied by 'bulk' capacitors on the driver supply rails as the DC-DC converter does not have sufficient value of output capacitors to supply this current without significant 'droop'. Of course the gate driver itself must be rated for these peak current values as must the gate resistors.

GATE POWER REQUIREMENTS (Continued)

Bulk Capacitance Values

For our example, total gate drive energy E added and removed per cycle is given by:

$$E = Q_g \times V_s = 75 \mu\text{J}$$

The bulk capacitors C1 and C2 in Figure 2 on the +15 and -10V rails supply this energy in proportion to their voltages so the +15V rail supplies 45μJ. If we assume that the bulk capacitor on the +15V rail should not drop more than a small fraction of the rail, say 0.5V each cycle then we can calculate approximate minimum capacitance (C) by equating the energy supplied with the difference between the capacitor energies at its start and finish voltages, that is;

$$45 \mu\text{J} = \frac{1}{2} C (V_{\text{init}}^2 - V_{\text{final}}^2)$$

$$C = (45e-6 \times 2) \div (15^2 - 14.5^2) \approx 6.1 \mu\text{F}$$

Although the -10V rail supplies about a third of the energy, it requires the same capacitor value for 0.5V drop as this is a larger percentage of the initial value. In practice the voltage drop may be affected more by the ESR and ESL of the capacitor. For example an ESR of 0.1 ohm would drop more than 0.5V peak at our peak current of 6A. High performance capacitors should therefore be chosen, often necessitating large can sizes to achieve the low ESR, giving many times the minimum capacitance value. However, maximum capacitances as noted in the DC-DC data sheet should not be exceeded.

Note that any driver IC used for the gate PWM signal may specify a higher minimum capacitance necessary for correct operation.

DC-DC CONVERTER CONSIDERATIONS

Symmetrical Loading requirements

The MGJ series of DC-DC converters has been designed specifically for gate drive applications where the gate is fully charged and discharged each PWM switching cycle. This corresponds to equal positive and negative average and peak currents whatever the positive and negative drive voltages. If the outputs are loaded with unequal currents, for example by extra protection circuitry, the voltages may not remain within the expected tolerances.

DC-DC Regulation

The absolute values of gate drive voltages are not very critical as long as they are above the minimum required for switch enhancement, comfortably below breakdown levels and dissipation is acceptable. The DC-DC converters supplying the drive power therefore may be unregulated types such as MGJ1 or MGJ2 series if the input to the DC-DCs is nominally constant. Unlike most applications for DC-DCs however, the load is quite constant when the IGBT/MOSFET is switching at any duty cycle. Alternatively the load is close to zero when the device is not switching. Simple DC-DCs often need a minimum load otherwise their output voltages can dramatically increase, possibly up to the gate breakdown level. This high voltage is stored on the bulk capacitors so that when the device starts to switch, it could see a gate overvoltage until the level drops under normal load. A DC-DC should be chosen therefore that has clamped output voltages or very low minimum load requirements.

DC-DC Converter Start-up and Shutdown

IGBTs/MOSFETs should not be actively driven by PWM signals until the drive circuit voltage rails are at correct values. However, as gate drive DC-DCs are powered up or down, a transient condition might exist where devices could be driven on, even with the PWM signal inactive, leading to shoot-through and damage. The DC-DC outputs should therefore be well behaved on power-up and down with monotonic rise and fall. A primary referenced on-off control as featured in MGJ3 and MGJ6 series can enable sequencing of power-up of the DC-DCs in a bridge reducing the risk of shoot-through. MGJ1, MGJ2, MGJ3 and MGJ6 series all have monotonic rise and fall times. See Figure 4 example.

DC-DC CONVERTER CONSIDERATIONS (Continued)

Figure 4

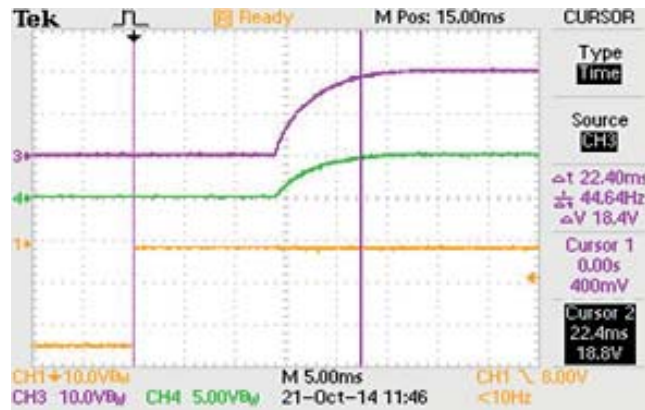


Figure 4. Typical output rise waveforms of MGJ3/6 configured with 20V and 5V outputs

DC-DC converter coupling capacitance

Isolated DC-DCs for ‘high side’ IGBT/MOSFET drives see the switched ‘DC-link’ voltage across their barrier. This voltage can be kilovolts with very fast switching edges from 10kV/μs upwards. Latest GaN devices may switch at 100 kV/μs or more. This high ‘dV/dt’ causes transient current through the capacitance of the DC-DC isolation barrier of value:

$$I = \frac{C \times dV}{dt}$$

So for just 20pF and 10kV/μs, 200mA is induced. This current finds an indeterminate return route through the controller circuitry back to the bridge causing voltage spikes across connection resistances and inductances potentially disrupting operation of the controller and the DC-DC converter itself. Low coupling capacitance is therefore desirable.

In some cases where an isolated DC-DC is being powered by another linear or switch mode converter the high transient current can cause an overshoot on the input to the isolated DC-DC. If this exceeds the maximum input voltage of the isolated DC-DC it can cause damage. In this case it may be necessary to use a zener diode across the input as protection.

MGJ1 and MGJ2 series have a typical capacitance of 3pF and MGJ3/6 have typically 15pF. Life tests show that the MGJ1 and MGJ2 series withstand >80 kV/μs at switched voltages in excess of 1kV and MGJ3/6 withstand >80 kV/μs at voltages in excess of 2.5kV. A common mode choke at the input to the DC-DC converter will reduce the displacement current caused by high dV/dt to still lower levels. Suitable common mode chokes can be found in the Murata 5000 series. See figure 6.

Figure 6

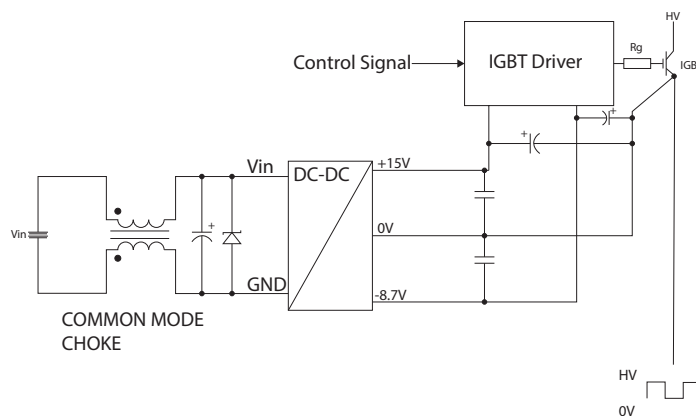


Figure 6. Common mode chokes reduce displacement current through the DC-DC converter.

DC-DC CONVERTER CONSIDERATIONS (Continued)

Converter Isolation

The high switched voltage expected across the MGJ series isolation barrier is withstood continuously by design but because the voltage is switched, the barrier can potentially degrade over time faster than with just DC by electrochemical and partial discharge effects in the barrier material. The DC-DC converter must therefore have robust insulation and generous creepage and clearance distances. If the converter barrier also forms part of a safety isolation system, the relevant agency regulations apply for the level of isolation required (basic, supplementary, reinforced), operating voltage, pollution degree, overvoltage category and altitude. Our gate drive DC-DC's are recognised or pending recognition to UL60950-1 for various basic and reinforced levels of protection which are generally equivalent to those in EN 62477-1:2012 which is an appropriate standard to apply for 'Power Electronic Converter Systems' where IGBTs and MOSFETs would commonly be used.

Recognition is also in place or pending to medical standard ANSI/AAMI ES60601-1. See product data sheets for latest recognition levels.

All DC-DC's recommended for gate drive applications have been evaluated and show no partial discharge effects at their recommended operating levels.

Temperature Ratings

It is advisable to place the IGBT/MOSFET driver and its DC-DC converter as close as possible to the switch device to minimise noise pick up and volt drops. This places the components in a potentially high temperature environment where reliability and lifetime can reduce. The MGJ series are particularly suited to this environment as they do not include components with temperature related wear-out mechanisms such as electrolytic capacitors and opto-couplers.

If the converter is providing a safety barrier, the user should also look for any conditions of use in the data sheet imposed by the safety agency. This would typically be a maximum operating temperature less than the maximum for non-safety barrier applications.

Paralleling MGJ Series Inputs

It is quite likely that multiple MGJ series converters could be used in one system, for example to provide power to three high-side switch drivers in a three phase inverter. If the inputs to the MGJ series converters are connected to the same power source, it is recommended that an LC filter be connected before each converter, as shown in Figure 7, to avoid noise coupling between the converters producing anomalous operation. A typical value of 10uH may be used rated at the current appropriate to the converter. Inductors from the Murata 2200 series for through-hole or 8300/8400/2900 series for surface mount would be suitable. A common mode choke incorporated to minimise dV/dt displacement current may have sufficient series mode inductance to provide the required filtering. An electrolytic capacitor is recommended to avoid the resonant overshoot that might occur with a low ESR capacitor such as a ceramic type.

Figure 7

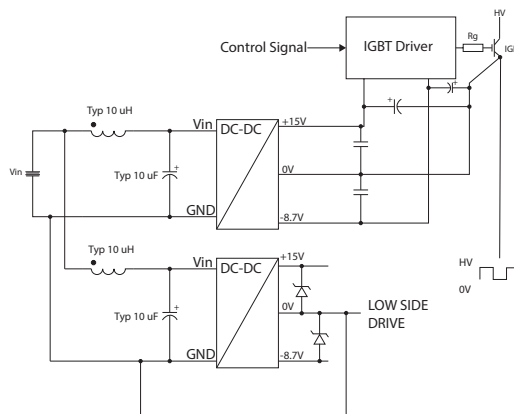


Figure 7. Paralleling MGJ converter inputs with filtering and anti-parallel diodes for non-isolated applications

MGJ Series In Non-Isolated Applications

It is possible that the MGJ series of converters may be used to power 'low-side' drives for IGBTs or MOSFETS as a convenient way of deriving the correct drive voltages even though isolation in the converter may not be necessary and is effectively bypassed. In this circumstance, it may be advantageous to fit reverse biased Schottky diodes across the converter outputs as shown in Figure 7 to avoid any possibility of significant reverse pre-bias voltages appearing on the converter outputs before they start up. Pre-bias voltages can cause anomalous start-up or even failure of DC-DC converters.

TYPICAL CONFIGURATIONS OF MGJ SERIES DC-DC CONVERTERS WITH IGBTs

Figure 8

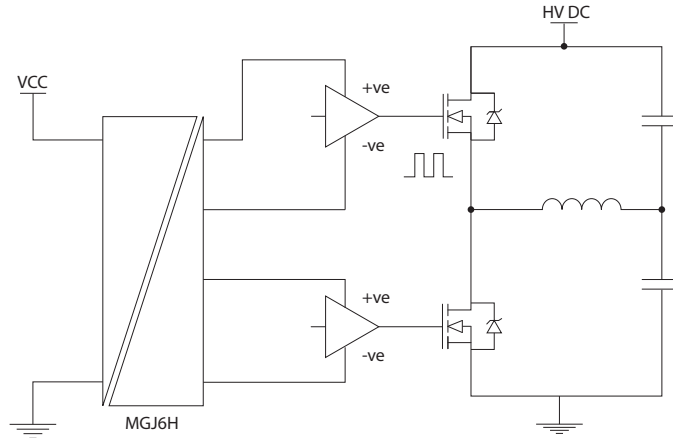


Figure 8. A single MGJ6H provides gate drive power for high and low side switches in a half bridge circuit. 3W per switch

Figure 9

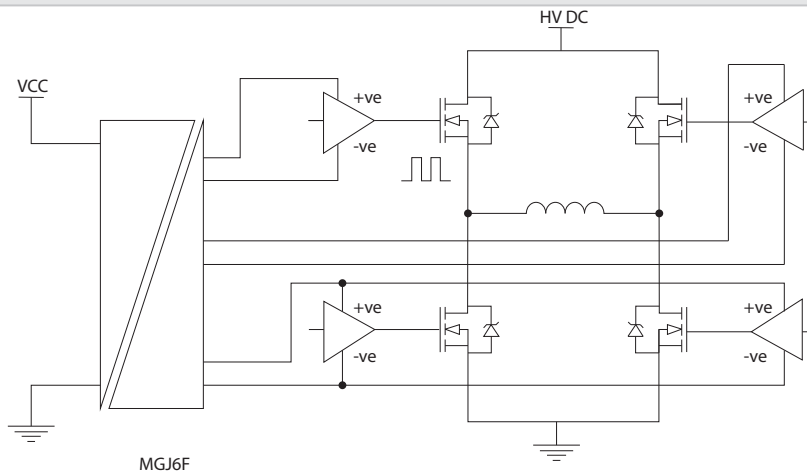


Figure 9. A single MGJ6F provides gate drive power for high and low side switches in a full bridge circuit. 1.5W per switch

Figure 10

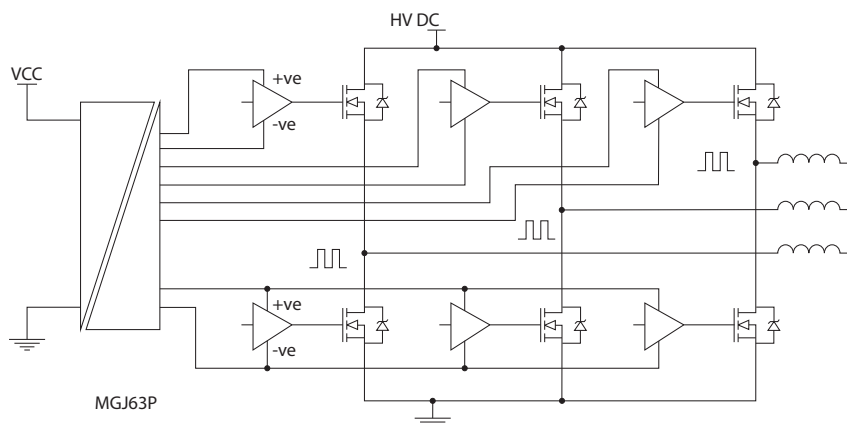


Figure 10. A single MGJ63P provides gate drive power for high and low side switches in a three phase circuit. 1W per switch

TYPICAL CONFIGURATIONS OF MGJ SERIES DC-DC CONVERTERS WITH IGBTs

Figure 11

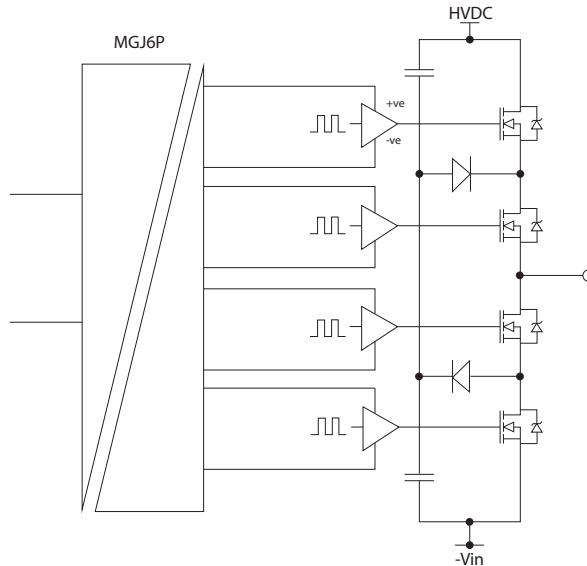


Figure 11. A single MGJ63P provides gate drive power for all switches in a leg of a three level inverter circuit. 1.5W per switch

Figure 12

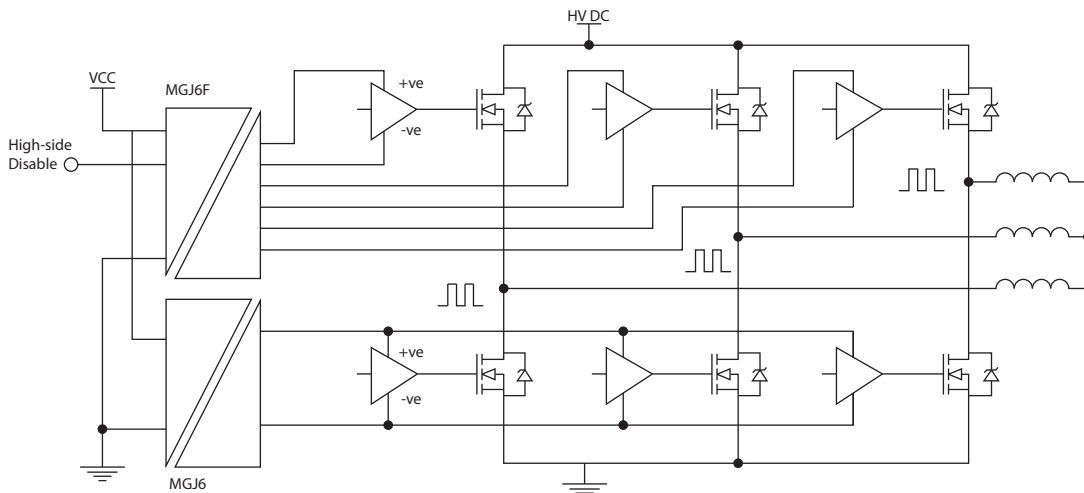


Figure 12. A single MGJ63F provides gate drive power for high side switches in a three-phase bridge with independent shut-down of high-side switch power. A single output MGJ6 provides gate drive power for all low side switches. 2W per switch.

MGJ Gate Drive SelectionTool

An excel based tool is available from Murata to enable selection of the appropriate MGJ series part number given bridge switching frequency, gate drive voltages, DC-DC input voltage, gate charge of chosen IGBT/MOSFET device and gate resistor.



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Refer to: <http://www.murata-ps.com/requirements/>

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