

Push-pull converter simplifies isolated power supply design in HEV/EV systems

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Introduction

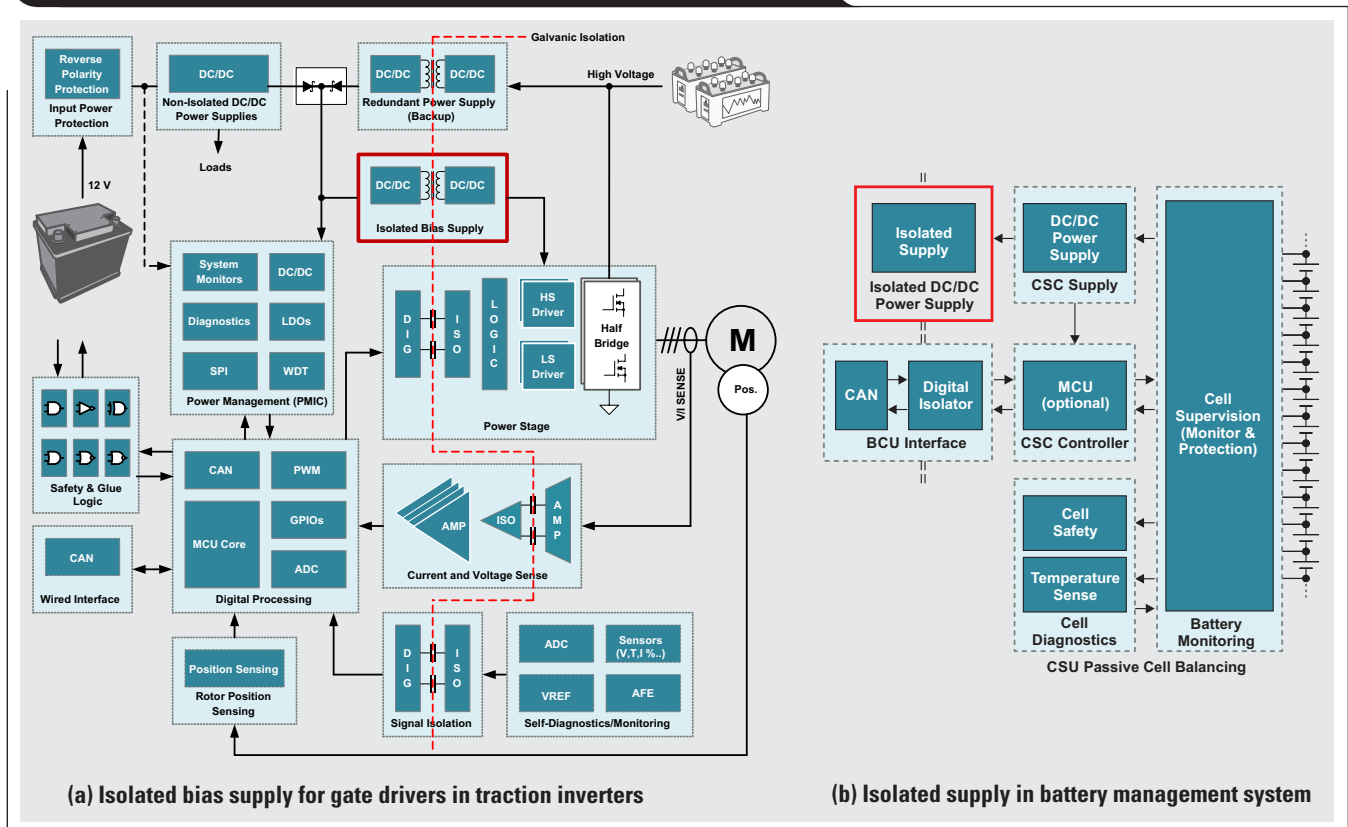
With the rapid growth of hybrid electric vehicles (HEVs) and full EVs, the need for galvanic isolation in automotive applications has also grown. Galvanic isolation is used in starter generators, battery-management systems, onboard chargers and traction inverters to separate high-voltage circuits from low-voltage circuits. Isolation is necessary in these applications for electrical safety, as well as for the protection of sensitive circuitry under fault conditions.

Along with signal isolation via digital isolators, isolated gate drivers, isolated transceivers, isolated amplifiers and isolated delta-sigma modulators, automotive systems also need power isolation. For example, Figure 1a shows an automotive subsystem with isolated gate drivers in traction inverters that requires an isolated power supply to

generate bias voltages. Figure 1b shows where an isolated power supply is also necessary to provide power to an isolated controller area network (CAN) interface in battery management systems (BMS).

Of the various power topologies available for power isolation, the push-pull converter has some advantages that make this topology particularly attractive for automotive applications. This article explores a few salient features of the push-pull topology and explains its performance and design benefits. Also discussed is the use of push-pull converters to provide the bias voltage for isolated insulated gate bipolar transistor (IGBT) gate drivers in traction inverters, for which this topology is particularly a good fit.

Figure 1. Isolated power supplies used in automotive systems



Benefit No. 1: Simplicity

Figure 2 shows the operation of a push-pull converter. The converter uses transformer action to transfer power from the primary side to the secondary side, as opposed to other topologies like the flyback, which store energy in an inductor in one phase of the switching cycle and transfer it to the load in the second phase.

Two switches—Q1 and Q2, operating in alternate cycles—provide the switching needed for transformer action, with a dead time in the middle to prevent short-circuiting the primary. The transformer action regulates the output voltage in a feed-forward manner, and the output voltage is determined primarily through the transformer turns ratios. If the input supply is well regulated, the output supply is also fairly well regulated, without needing analog feedback and loop stabilization. Flyback converters need an optocoupler-based analog feedback.

The push-pull topology is thus a very simple one, requiring only rectifier diodes and bypass capacitors in addition to the transformer and power switches, and no additional design verification for loop stabilization.

Benefit No. 2: Efficiency

The push-pull converter uses transformer action to transfer the load from the secondary to the primary. One or the other of the primary switches is on for the entire duration of the switching cycle, except for the dead time. The result is that the peak current through both the power switches and the transformer windings is only slightly higher than the load current compared to other topologies. Lower peak currents result in lower conduction losses (which are proportional to the square of the current), leading to higher efficiency.

Benefit No. 3: Low emissions

In isolated DC/DC converters, the net AC current flowing across the barrier is the main cause of electromagnetic emissions (see Figure 3). There is always parasitic or undesirable capacitance between the windings of the transformer (C_{PAR1} and C_{PAR2}) from side 1 to side 2. Voltage transitions across this parasitic capacitance result in current flowing across the barrier. Since there is no conductive path between the two isolated grounds, the current path is completed through a longer parasitic path through the air, creating a radiating loop. Another way to look at this is to treat the isolated DC/DC converter as a dipole antenna.

Reducing net common-mode current across the barrier is the key to reducing electromagnetic emissions. Symmetric switching helps with that. Single-ended topologies like flyback and forward converters are asymmetric by construction. Double-ended topologies such as half bridge and full bridge are not completely symmetric, since they either use complementary drive (P-channel metal-oxide semiconductor [PMOS] and N-channel MOS [NMOS]) switches or level translation to drive the high-side switch.

Figure 2. Push-pull converter and operation

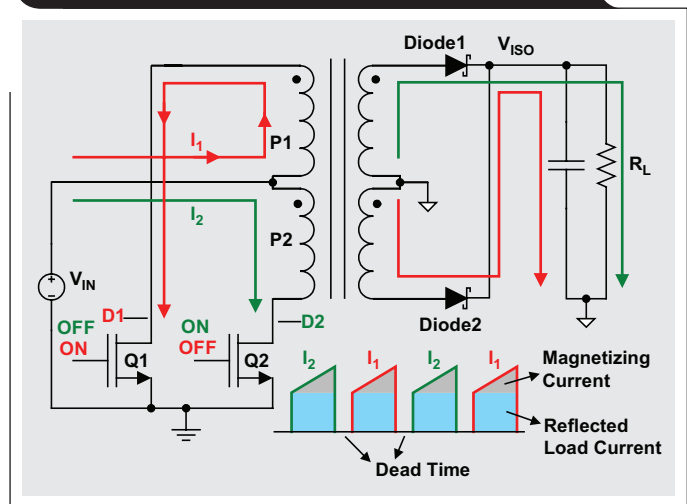
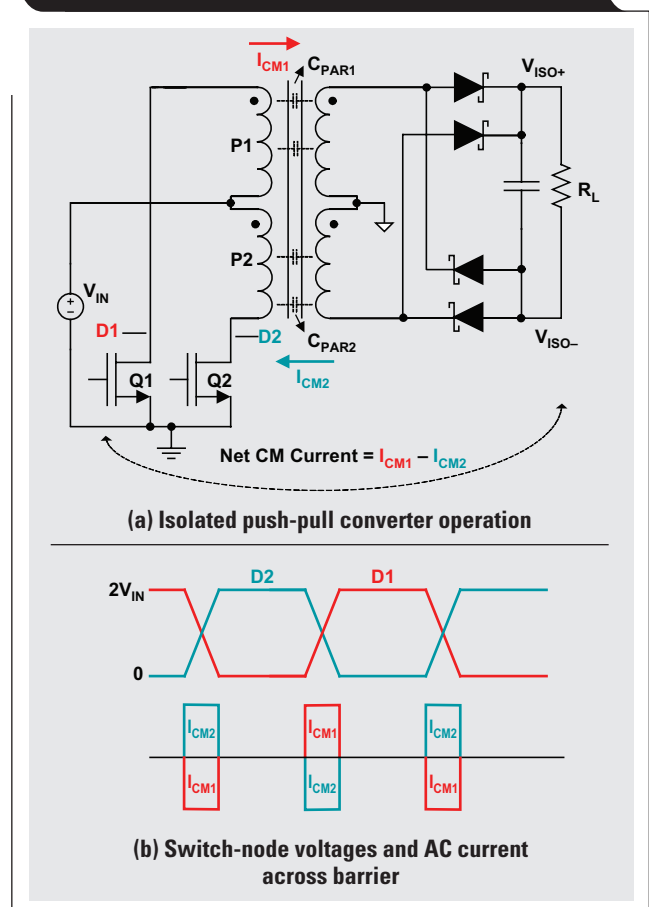


Figure 3. AC currents across the isolation barrier result in electromagnetic emissions



The push-pull topology, on the other hand, is inherently symmetric through the use of two identical low-side switches, a transformer with a center-tapped primary and secondary, and full-bridge rectifier diodes. (For additional symmetry, Figure 3 shows a full-bridge rectifier compared to the half bridge shown in Figure 2.)

The center-tapped primary in the push-pull topology, with the two primary windings strongly coupled to each other, forces the drain voltage of D1 and D2 to be exactly complementary. This is true even if switches Q1 and Q2 follow break-before-make switching with dead time. The complementary voltage transitions result in the current through C_{PAR1} exactly canceling the current through C_{PAR2} , resulting in net-zero common-mode current across the barrier. This unique feature of push-pull transformers is one of the reasons why they have extremely low radiated emissions.

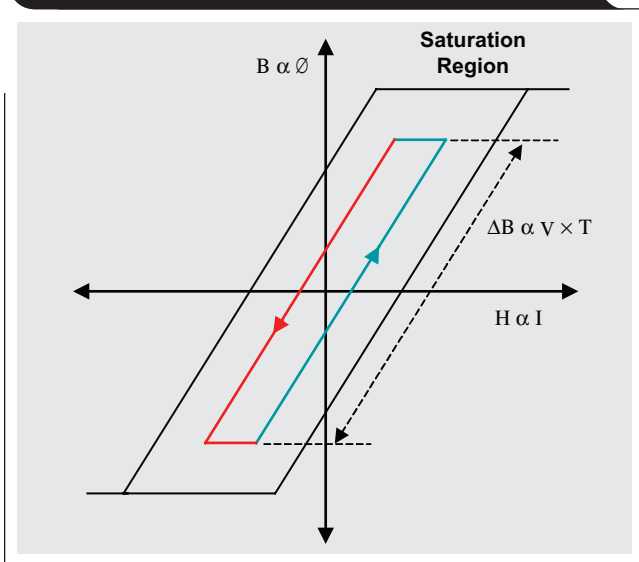
Lower peak current in the push-pull topology also results in lower inductive noise when currents are interrupted—another reason for lower emissions.

Benefit No. 4: Easier transformer choice and smaller transformers

Push-pull topologies use transformer action to transfer power, so the inductance of the transformer windings is not a major design consideration. A wide range of primary and secondary inductance is acceptable as long as the desired turns ratio is well controlled. The magnetizing inductance of the primary does result in current buildup every cycle, so a larger magnetizing inductance improves efficiency. Also, minimizing the leakage inductance is important to reduce emissions. Thus, while transformer design does have an impact on efficiency and emissions, the important aspects of output voltage and loop stability are independent of inductance value.

In the push-pull topology, the flux buildup in the core of the transformer in one phase is canceled in the other phase. This results in a two-quadrant or bipolar operation, as shown in Figure 4. Both the magnetic field strength (H) and magnetic flux density (B) will reverse in polarity and cross zero every cycle. Thus, the magnetic core is used efficiently, resulting in the ability to use smaller and cheaper transformers.

Figure 4. Flux buildup in the transformer core

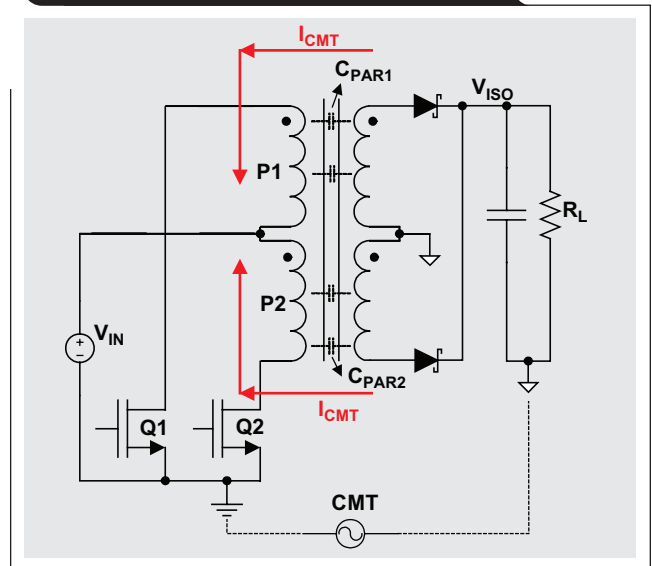


Benefit No. 5: Better immunity

Isolated systems are subjected to common-mode transients that appear as an AC voltage difference between the two grounds. These could be coupled disturbances such as electrical fast transients or electrostatic discharge, or transients caused by switching the high-side field-effect transistor (FET) in an inverter.

As shown in Figure 5, the common-mode transients result in common-mode current injected to the primary side. The two closely coupled primary windings do not allow common-mode voltage buildup. The flux generated by the current flowing in one primary coil cancels the flux generated in the second coil, resulting in a low-impedance path to the primary supply. This prevents the common-mode current from overloading primary switches Q1 and Q2, therefore avoiding a disruption in the operation of the power supply.

Figure 5. Common-mode transients in an isolated power supply



Using the push-pull topology in automotive applications

Automotive applications benefit from design simplicity, since simplicity also translates to reliability. The requirements on electromagnetic emissions and transient immunity are more stringent in automotive applications than in industrial equipment. A lower form factor is important because space is at a premium, as is reducing unnecessary weight in the car. When used to generate the bias voltage for an IGBT gate drive, the isolated power supply has to withstand high common-mode transient voltages due to IGBT switching. For all of these reasons, the push-pull topology is an excellent fit for automotive applications.

Figure 6. Push-pull converters generate isolated bias voltages for IGBT gate drivers

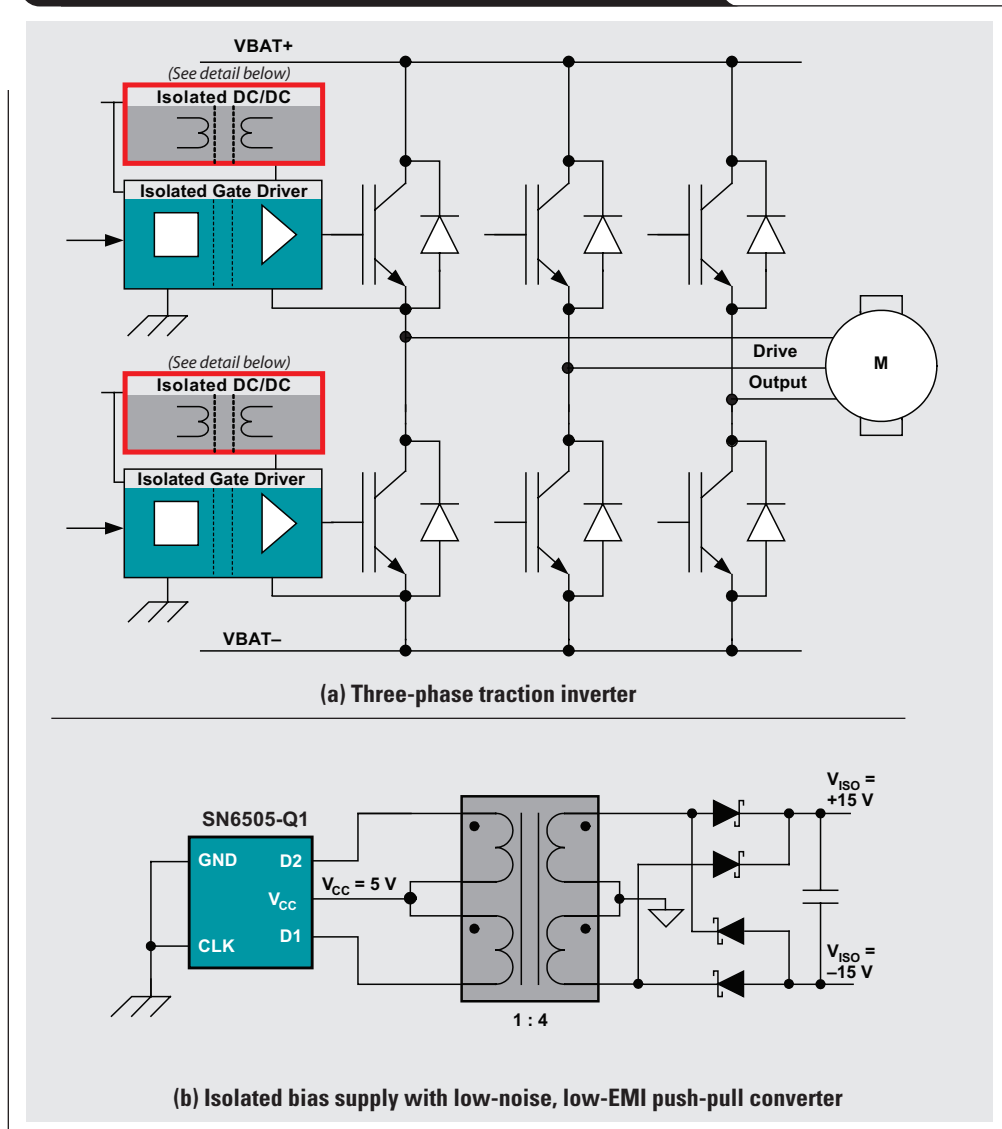


Figure 6 shows the use of push-pull converters (such as the Texas Instruments SN6505-Q1) to generate an isolated power supply for isolated IGBT gate drivers in a three-phase traction inverter. Each of the six IGBTs has a separate power supply in order to provide greater redundancy and simplify routing. The full-bridge rectifier can generate +15 V and -15 V to turn the IGBTs on and off. A similar approach is possible for onboard chargers as well.

Conclusion

The push-pull topology’s inherent benefits of simplicity, efficiency, low emissions, high immunity and small solution size are valuable for automotive applications. Semiconductors that integrate two switching FETS provide the additional benefits of lower emissions and fault protection.

Related Web sites

Product information:

SN6505B-Q1

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Isolated bias supply example in a traction inverter

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