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How to Power SiC or IGBT Half Bridges in EVs

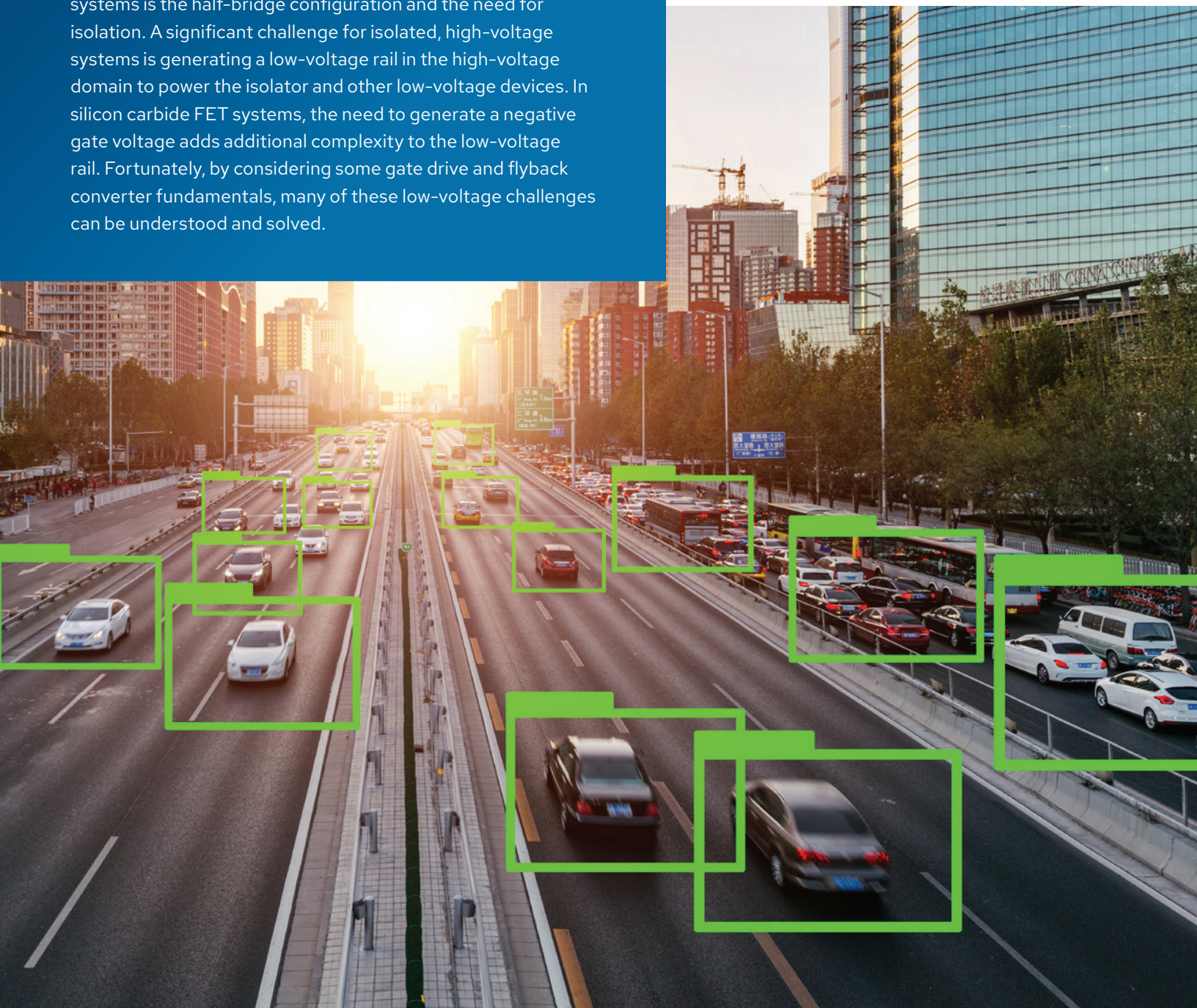
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Introduction

For over a century, vehicles have relied on fuel, pistons, and complex gearboxes to convert energy into mechanical motion. Today's electric vehicles (EVs) and hybrid electric vehicles (HEVs) rely on sophisticated electronics to convert electrical power into mechanical motion. This new class of vehicles uses high-voltage converters and traction inverters to manage power efficiently. Common to many of these high-voltage systems is the half-bridge configuration and the need for isolation. A significant challenge for isolated, high-voltage systems is generating a low-voltage rail in the high-voltage domain to power the isolator and other low-voltage devices. In silicon carbide FET systems, the need to generate a negative gate voltage adds additional complexity to the low-voltage rail. Fortunately, by considering some gate drive and flyback converter fundamentals, many of these low-voltage challenges can be understood and solved.



Immunity, Emissions, and Currents

Most high-voltage EV and HEV systems contain high-voltage, high-current switches (IGBTs or SiC FETs) schematically stacked one on top of the other to form a half bridge. Figure 1 shows a typical half-bridge configuration. In a half-bridge configuration, the center node (shown by the blue circle) is pulled to the positive or negative rail by turning on the high-side or low-side switch. In an EV or HEV system, these rails are typically referred to as the “dc link”, which can reach 400, 800, or even 1000 V in the latest EV designs. While the half-bridge configuration has many advantages, it requires special attention to the gate driver ground references in order to operate properly.

A FET fully turns on when the gate source voltage, V_{GS} , rises above a certain level, usually ~ 15 V for SiC FETs. Likewise, IGBTs turn on when the gate emitter voltage, V_{GE} , reaches a certain point. For simplicity, the remainder of this paper will refer to SiC FETs; however, the information generally applies to IGBTs as well. The purpose of a gate driver is to pull the gate voltage high enough to turn on the FET, and this is done by pulling the gate voltage to the V_{DD} rail of the driver. For example, if the low-side gate driver’s GND pin is tied to the negative rail, it simply pulls its gate pin to V_{DD} to turn on the low-side device. However, the high-side gate driver isn’t so simple because the high-side FET’s source is tied to the center node. As shown in Figure 2, the high-side gate driver’s ground cannot be tied to the negative rail (dc link -); otherwise, the output of the high-side gate driver will be referenced to the negative rail and cause a multitude of issues. For example, when the low-side FET is off, the source of the high-side FET is floating relative to the negative rail. The negative-rail-referenced high-side gate driver generates an unknown V_{GS} when it pulls the gate to its V_{DD} rail. As shown in Figure 2, the solution is to use two separate power supplies for the two gate drivers and tie the high-side gate driver’s ground to the source of the high-side FET. With both gate drivers on separate power rails and the ability to turn the two FETs on and off, the next step is to actually generate the two power supplies as efficiently and simply as possible.

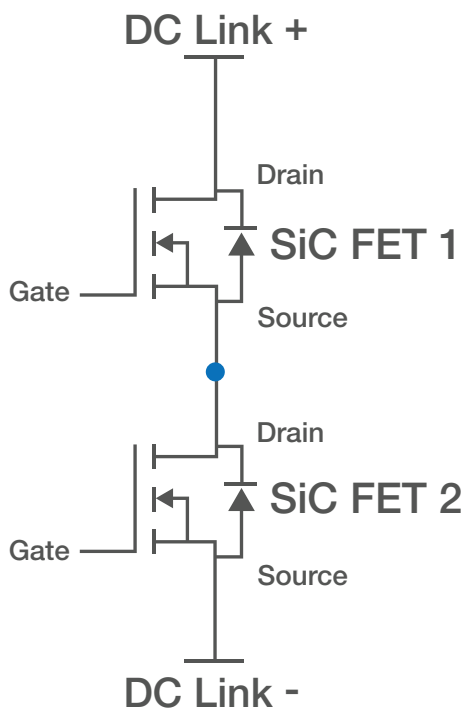


Figure 1 – SiC FETs in a Half-Bridge Configuration



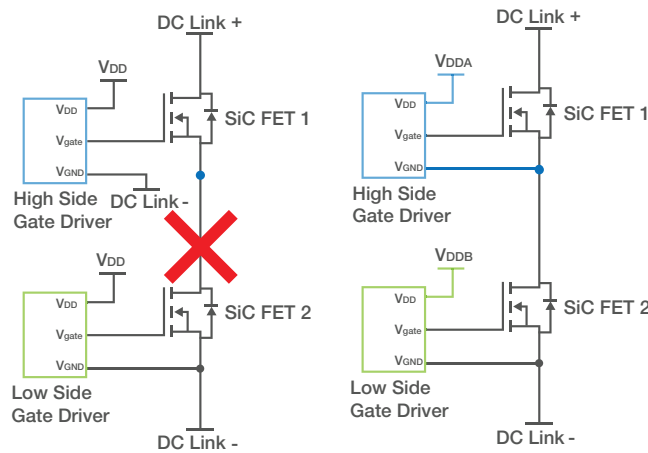


Figure 2 – Incorrect (Left) and Correct (Right) Gate Driver Connections

Generating Isolated Gate Driver Bias Supplies

Generating the low-voltage rails needed to power the isolated gate drivers often creates challenges in complexity and cost. Fortunately, most EVs today have a low-voltage (12 or 48 V) supply that runs throughout the vehicle. Using an isolated flyback converter, this low-voltage vehicle supply can be leveraged to create two isolated low-voltage rails for the gate drivers. Figure 3 shows a simplified diagram with the vehicle's 12 V rail powering both the primary and secondary sides of the isolated gate drivers. In this configuration, the flyback converter's transformer provides both the isolation across the main isolation barrier and the isolation between

the two low-voltage rails. The two low-voltage outputs are generated using two separate windings on the transformer. However, because they are coupled through the transformer, the dc-dc controller only directly regulates one of them. While this does cause the indirectly regulated output to have slightly worse performance, a suitable transformer design, with tight winding coupling, ensures cross-regulation and minimizes variation in the unregulated outputs. Overall, this dual output approach reduces board space and costs. In addition, this configuration can be leveraged to generate the negative gate voltage required by SiC FETs.

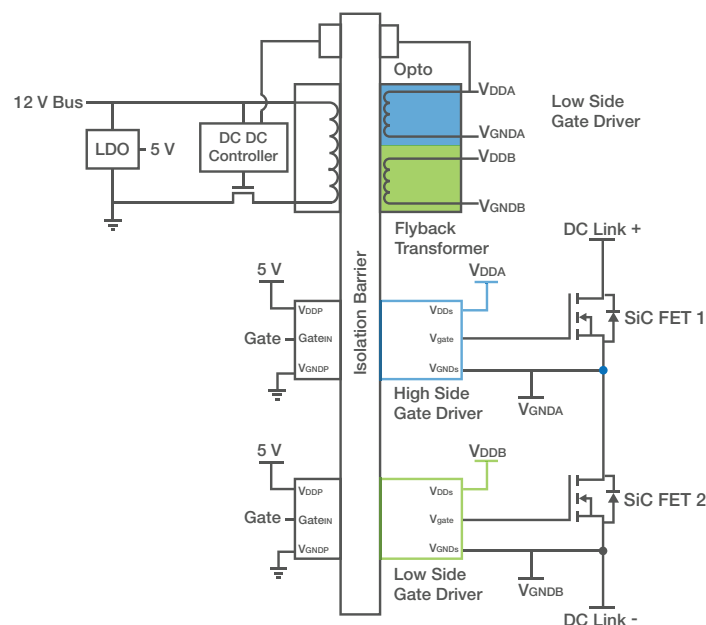


Figure 3 – Half Bridge with a Dual Output Flyback Converter for Powering the Isolated Gate Drivers

To generate the negative gate voltages, the transformer is further modified to add V_{MIDA} and V_{MIDB} taps to the two output windings. Figure 4 shows the half-bridge configuration modified to enable the negative gate voltages. The V_{MIDA} tap (highlighted in blue) creates a positive voltage relative to V_{GNDA} and a negative voltage with respect to V_{DDA} . The turns ratio between these outputs determines their relative voltages. Next, the high-side FET source is tied to V_{MIDA} while the gate driver remains referenced to V_{GNDA} . When the gate driver turns the high side FET off, it pulls the FET's gate to V_{GNDA} , and, because the FET's source is tied to V_{MIDA} , a negative gate voltage results, holding the SiC FET in the Off state. This also changes the gate-to-source voltage when the gate driver turns the high-side SiC FET on because it pulls the FET's gate to V_{DDA} . This same setup applies to the low-side gate driver (highlighted in green).

Skyworks' [Si828x](#) isolated gate driver and the [Si88xx](#) digital isolator families both include integrated dc-dc converters to reduce costs, board space, and complexity, and both eliminate the need for an optocoupler and feedback network by passing the feedback across the isolation barrier internally. Figure 4 illustrates a simplified half bridge using the Si828x's integrated dc-dc controller. The Si828x also includes a dedicated V_{MID} pin to sense the drain-to-source voltage across the SiC FET for desaturation detection. Skyworks offers two EVBs that quickly demonstrate the advantages of these two products. The [Si823Hx Gate Driver Board](#) shown in Figure 5 uses the Si88xx's dc-dc converter to generate all the necessary low-voltage rails needed to drive a half-bridge using the Si823Hx dual driver. The [Si828x SiC FET Half Bridge Reference Design](#) implements a design similar to the drawing shown in Figure 4, using the Si828x's dc-dc converter to generate the low voltage rails. Both designs demonstrate the dramatic reduction in board space, components, and costs possible with Skyworks' Si828x and Si88xx families.

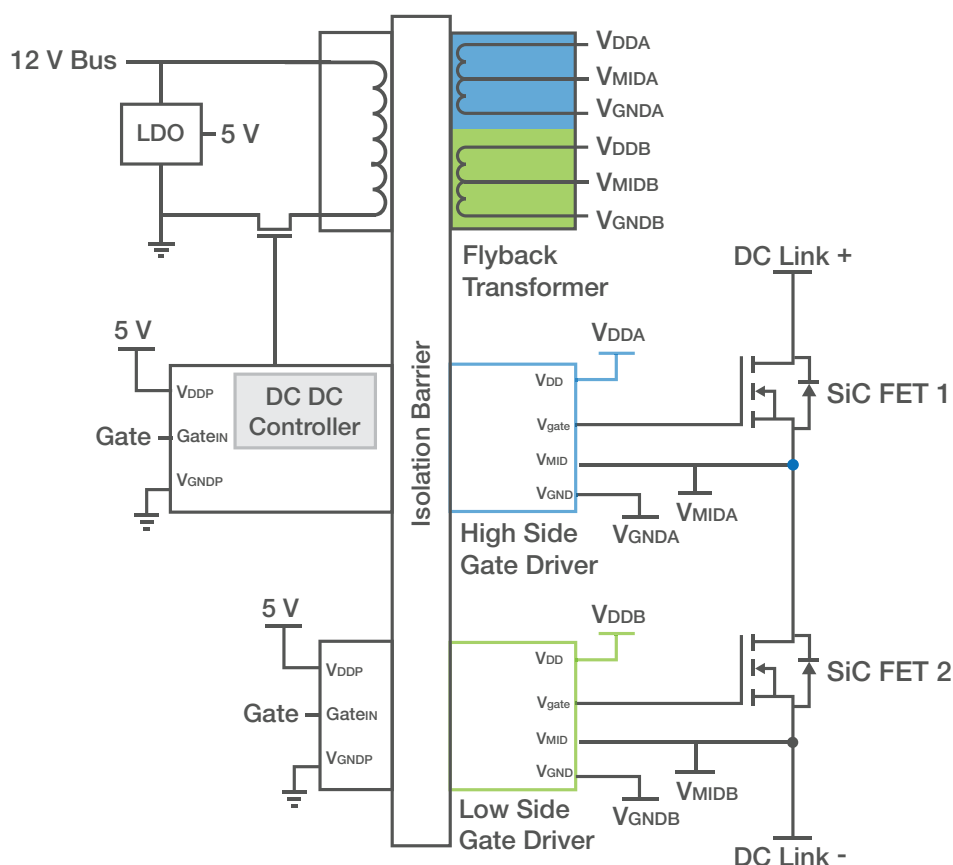


Figure 4 – V_{MID} Taps on the Flyback Transformer Generate the Negative Gate Voltage while the Integrated DC-DC Controller Reduces Costs and Board Space

Low-Voltage Architecture in Systems with Multiple Half Bridges

Many EV power conversion systems, such as the traction inverter, use multiple half bridges working together. In these systems, all of the low-side devices share a common dc link (a connection to their emitter) requiring only a single power domain for the low-side gate drivers. The high-side devices, however, each drive a different phase of the load, so separate power domains for the gate drivers are required. One common solution is to connect the low-side drivers to a single power domain and then use a single dc-dc converter to generate the additional high-side power rails, as shown in Figure 6. Unfortunately, this architecture typically leads to complex PCB designs and long traces and makes it difficult to achieve tight voltage regulation on all four output rails. It may also lead to noise from the high side coupling into the low side, as all of the rails share a single transformer. Breaking up the converter into multiple independent converters generally helps solve these issues, and, with Skyworks' integrated converters, this adds minimal board space without significant cost increases.

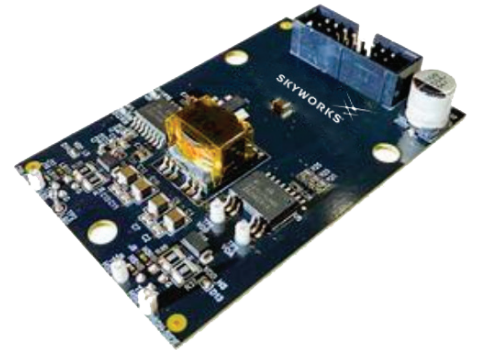


Figure 5 – Skyworks' Si823Hx Gate Driver Board

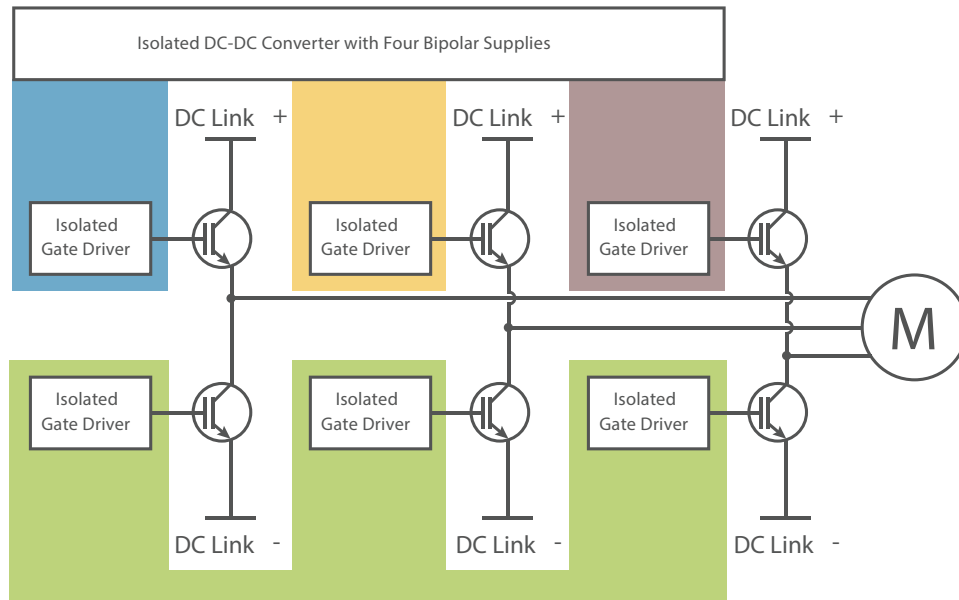


Figure 6. Inverter Design Using a Single DC-DC Converter



As shown in Figure 7, multiple independent converters generally simplify PCB layout, reduce trace lengths, and allow clean regulation to each low-voltage domain. This architecture also greatly reduces noise between the power domains—perfect for SiC-based systems with high switching frequencies. In addition, the converter design is reusable in other half-bridge configurations with fewer switches, such as full-bridge configurations. By leveraging the integrated converters on Skyworks’ isolation devices, this configuration strikes the right balance between complexity, cost, and performance.

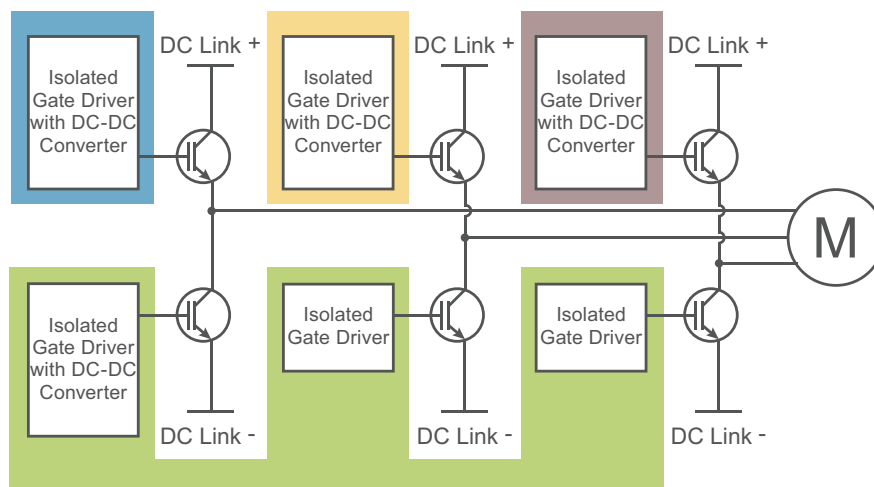


Figure 7. Three-Phase System Using Gate Drivers with Integrated DC-DC Controllers and Four Independent Power Domains

Half-bridge based power converters using SiC or IGBT switching devices rely on low-voltage rails to power the isolation and other low-voltage components used in the high-voltage domain. The integrated dc-dc converters in Skyworks Si88xx digital isolators and Si828x isolated gate drivers ease the design challenges of generating these power rails while reducing costs and board space. As EVs continue to become more sophisticated, designers will continue to rely on the half bridge to drive power converter innovations that improve efficiency, reduce weight, and ultimately make EVs mainstream transportation.





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Asa Kirby is a senior product manager at Skyworks where he manages isolation products that serve a wide range of industrial applications. Asa is trained as an electrical engineer and has worked with customers and products in the industrial automation and machine control market for more than a decade. Prior to joining Skyworks in 2017, Asa served as an Applications Engineer and Product Manager at National Instruments. Recently, Asa developed requirements for Skyworks's next generation of isolated gate drivers targeting the latest wide bandgap switch technology.

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