Motor and power control inverter designers share the common problem of isolating control and user interface circuits from dangerous power line voltages. The key elements of this are the basic requirements to prevent power line voltages from damaging control circuits, and more importantly, to protect the user from dangerous voltages. Systems must comply with safety requirements defined by international standards such as IEC 61800 and IEC 62109 that cover applications like motor drives and solar inverters. Standards primarily focus on compliance testing. How does the standards' compliance testing give freedom to the engineer? It guides the engineer regarding safety but how does it give freedom so the engineer has the option to choose the appropriate architecture, circuit, and components required to meet the target system specification, including standards compliance? These decisions are influenced by the capability of the circuits to deliver the required system performance in terms of efficiency, bandwidth, and precision while still meeting safety isolation requirements. The challenge in designing innovative systems is that the design rules developed for existing architectures, circuits, and components may no longer apply. Therefore, the engineer needs to invest time in carefully evaluating the capability of a new circuit or component to meet standards for EMC and safety. In some regions there is a more onerous burden because the engineer may be personally liable in the case of an injury resulting from the failure of a safety function on a system he designed. This article explores the impact of system architecture choice on the power and control circuit design and the implications on system performance. It will show how performance improvements in recently available isolation components are enabling alternate architectures to provide system performance improvements without compromising safety.

Isolation Architectures

The problem is that you need to safely control the flow of power from the ac supply to the load based on commands provided by the user. This problem is described in the high level motor drive system diagrams shown in Figure 1 of three power domains: command, control, and power. The safety constraint is that the user command circuits must be galvanically isolated from the dangerous voltages on the power circuit. The architectural decision is based on whether to place the isolation barrier between the command and the control circuits or place the isolation barrier between the command and the power circuits. This article explores the impact of system architecture choice on the power and control circuit design and the implications on system performance. It will show how performance improvements in recently available isolation components are enabling alternate architectures to provide system performance improvements without compromising safety.

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it between the control and the power circuit. The introduction of an isolation barrier between any circuits risks signal integrity and adds cost. The isolation of analog feedback signals is particularly challenging because the classical transformer approach rejects the dc signal component and introduces nonlinearities. Digital signal isolation is relatively easy at low speeds but much more challenging and power hungry at high speeds or when low latency is demanded. Power supply isolation is surprisingly challenging in systems with 3-phase inverters because of the multiple power domains connected to the power circuit. The power circuit has four different domains that need to be functionally isolated from each other: high-side gate drive and winding current signals need to be functionally isolated from the control circuit even though both may be referenced to ground power.

The nonisolated control architecture has a common ground connection between the control and power circuits. This gives the motor control ADC access to all signals in the power circuit. The ADC samples motor winding currents at the midpoint of the center-based PWM signals when they flow in low-side inverter legs. The drivers for the low-side IGBT gates may be a simple nonisolating type, but the PWM signal needs to be isolated from the three high-side IGBT gates with functional isolation or level shifting. The complexity introduced by isolation between the command and control circuits depends on the end application, but it typically involves using a separate system and communications processor. This is acceptable in home appliance or lower end industrial applications where a simple processor manages a front panel interface and sends speed commands over a slow serial interface. The nonisolated architecture is less common in high performance drives used in robotics and automation because of the high bandwidth requirements for the command interface.

The isolated control architecture has a common ground connection between the control and command circuits. This allows the very tight coupling between the control and command interface and allows the use of a single processor. The isolation problem shifts to the power inverter signals with a different set of challenges. The gate drive signals require relatively high speed digital isolation to satisfy inverter timing requirements. Magnetic or optically coupled drivers work well in inverter applications where isolation requirements are quite severe because of the very high voltages present. The requirements for the dc bus voltage isolation circuit are modest because of the low dynamic range and bandwidth demanded. Motor current feedback is the biggest challenge in high performance drives because high bandwidth, linear isolation is required. Current transformers (CT) are an obvious choice because they provide an isolated signal that can be easily scaled. CTs have nonlinearities at low currents and do not transmit the dc level but are used extensively in low end inverters. CTs are also used in high power inverters with nonisolated control architectures because current shunt losses become excessive. Open-loop and closed-loop Hall effect current sensors can measure dc, so they are more suitable for high end drives but suffer from offset. Resistive shunts provide a high bandwidth, linear signal with low offset but need to be matched with a high bandwidth, low offset isolation amplifier. Typically the motor control ADC directly samples the isolated current signal, but the alternative measurement architecture described in the next section shifts the isolation problem to the digital domain and provides significant performance improvements.

Inverter Feedback Using Isolated Converters

A common approach to improving the linearity of the isolation system is to move the ADC to the other side of the isolation barrier and isolate the digital signal. In many cases this uses a serial ADC combined with a digital signal isolator. The specific requirements of high frequency for motor current feedback combined with a fast response for drive protection steers the ADC selection to a \( \Sigma-\Delta \) type. The \( \Sigma-\Delta \) ADC has a linear modulator that converts the analog signal to a single bit stream,

followed by a digital filter that reconstructs the signal as a high resolution digital word. The beauty of this approach is that two different digital filters can be used; a slower one for high fidelity feedback and a second low fidelity fast filter for inverter protection. In Figure 2, winding shunts measure the motor winding currents and an isolating ADC transmits a 10 MHz data stream across the isolation barrier. The sinc filters present high resolution current data to the motor control algorithm, which calculates the inverter duty cycles needed to apply the required inverter voltages. A second lower resolution filter detects current overloads and sends a trip signal to the PWM modulator in the case of faults. The sinc filter frequency response curve illustrates how appropriate parameter selection enables the filter to reject PWM switching ripple from the current samples.
Power Supply Output Isolation

The common problem in both control architectures is the requirement to support multiple isolated power domains. This is more difficult if multiple bias rails are required in each domain. The circuit of Figure 4 efficiently produces +15 V and –7.5 V for gate drive and +5 V for powering an ADC, all in one domain using only one transformer winding and two pins per domain. This design makes it possible to use a single transformer core and bobbin to create dual-supply or triple-supply rails for four different power domains.

![Figure 4. Isolated power supply circuit for the gate driver and current feedback converter.](image)

About the Author

Aengus Murray is the Motor and Power Control Applications Manager for the automation, energy, and sensors unit at Analog Devices. He is responsible for the complete Analog Devices signal chain offering for industrial motor and power control. Dr. Murray holds a bachelor’s and doctorate’s degree in electrical engineering from University College Dublin in Ireland. He has over 30 years of experience in the power electronics industry and has also worked with International Rectifier, Kollmorgen Industrial Drives, and Dublin City University. He can be reached via email at aengus.murray@analog.com.