Technical White Paper

Design Priorities in EV Traction Inverter With Optimum Performance

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ABSTRACT

This technical white paper explores key system trends, architecture, and technology for traction inverters. The devices and technologies used to enable traction inverters, including isolation, high-voltage domain, and low-voltage domain technology, are also covered. Finally, the document focuses on the system engineering concepts and designs to accelerate traction inverter design time.

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1 Introduction

The traction inverter is the heart of an electric vehicle (EV) drivetrain system. As such, the inverter plays a vital role in increasing the adoption of EVs worldwide. The traction motor provides excellent torque and acceleration by converting DC power from the batteries or generator to AC power to power traction drive motors such as permanent magnetic machines (PMSM), induction motors (IM), externally excited synchronous motors (EESM), and switched reluctance motors (SRM). A traction inverter also converts recuperation energy from the motor and recharges the battery while the vehicle is coasting or braking.

There are several key design priorities and trade-offs to consider when measuring the performance of the traction inverter:

- Functional safety and security – Functional safety design usually follows ISO 26262 or an e-safety vehicle intrusion-protected applications process that includes safety diagnostics; system-level failure mode and effects analysis; failure modes, effects, and diagnostic analysis; and a hardware security module (HSM).
- Weight and power density – The wide band-gap switch and powertrain integration are the key technologies enabling high-power density inverter design. The inverter power density target of OEMs continues to, for example, 100 kW/L in the US market by 2025. The use of SiC enables 800-V DC bus voltage, reduce the current rating and wiring harness. An MCU with fast control loop enables the use of high-speed, lighter motor, and powertrain integration such as an inverter integrated with DC-DC converters.
- Efficiency – System efficiency includes traction inverter efficiency, motor efficiency, and inverter efficiency in regenerative braking mode.
- Performance and reliability – Performance of the inverter system is measured through motor torque control, a current-sensing loop, and the motor torque transient response. Reliability includes power module reliability, motor reliability, and isolation, and so forth.
- System cost – Apart from the electric machine and wiring harness, the main components include:
  - EMI filter
  - DC link capacitor
  - Busbar
  - MCU and control electronics
  - Power modules and drive stage electronics
  - Current sensor
  - Inverter housing and cooling

2 Architectures and Trends

The architecture of a traction inverter varies with vehicle type. Plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs) have a three-phase voltage source inverter topology, with power levels in the 100- to 500-kW range. The battery pack can either directly connect to the inverter DC input or a DC/DC boost converter can be used to step up the battery voltage and supply the inverter with a controlled DC voltage.

The two-level inverter is the most common power converter used in electrified vehicles and in the industry, with the power range of tens of kilowatts up to hundreds of kilowatts. Usually, the switching frequency is in the range of 5 kHz to 30 kHz, Currently, three-level inverters are becoming more popular because the inverters offer higher power capability (beyond 300 kW), higher efficiency, and lower harmonic distortion and allow the use of a smaller electromagnetic interference (EMI) filter. Among many topologies, neutral point clamped and T-type neutral point clamped (TNPC) are the most competitive designs. Figure 2-1 illustrates an example of a three-level TNPC inverter.

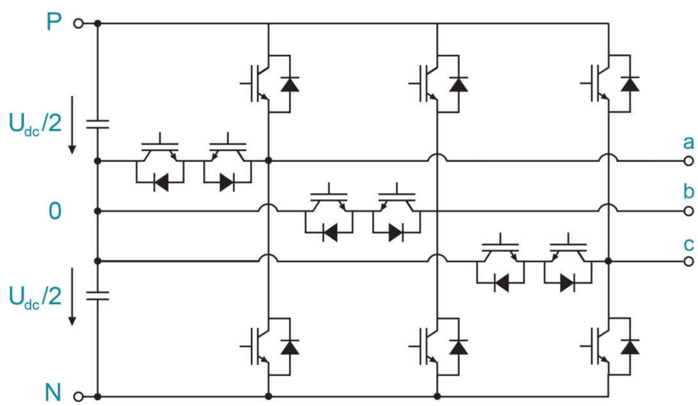


Figure 2-1. Three-Level T-Type Inverter

A second trend is a dual-motor architecture. As early as in 2012, Tesla introduced the Model S, a rear-wheel drive, full-size luxury sedan with a range of up to 426 km with the 85-kWh battery pack. In 2014, Tesla announced an all-wheel drive version of the Model S with an electric motor on both the front and rear axles. Since then, dual inverters have been implemented by various OEMs such as the Chevy Volt PHEV, Toyota Prius HEV, and Cadillac CT6 PHEV.

A third trend improving system integration is the implementation of e-axles, which combine the power electronics, electric motor, and transmission in a compact system housing. E-axles improve motor performance because this design can achieve higher torque and top speed, for example 20-k RPM. Better cooling and a coil winding structure improve power density and motor efficiency.

Other trends in traction inverter features include:

- Increasing power levels and Automotive Safety Integrity Levels (ASILs) (100 kW to 500 kW, ASIL C to ASIL D)
- Shifting towards 800-V technology with increased switching transient voltages
- Easily adjusting the gate-drive strength to reduce overshoot, optimize efficiency, and reduce EMI
- Employing an inductive position-sensing technology instead of a resolver to reduce costs
- Integrating active discharge into a Gate driver integrated circuit (IC) to reduce costs and save space

3 Key Technology to Enable Traction Inverters

A traction inverter requires *isolation technology*, technology implemented on the low-voltage domain, and technology implemented on the high-voltage domain. TI's capacitive isolation technology, found in isolated gate drivers, digital isolators, isolated analog-to-digital converters, and solid-state relays, incorporates reinforced signal isolation in a capacitive circuit that uses silicon dioxide for the dielectric. Figure 3-1 shows an example of a traction inverter system. The isolation barrier (red dotted line) separates the low-voltage domain and high-voltage domain.

In the low-voltage domain, a microcontroller (MCU) generates pulse-width modulation (PWM) signals to the power switches. The MCU runs the sensing and speed control in a closed loop, and handles host functions to fulfill mandatory hardware and software security and safe code execution requirements. Additionally, implementing a safe power-tree keeps the MCU and critical power rails from losing power. A power-management integrated circuit (PMIC) or system-basis chip connected to the 12-V car battery powers the MCU. The MCU interfaces with the analog front end of the resolver or a Hall-effect sensor.

Key functions in the high-voltage domain include:

- Power switches – usually silicon carbide (SiC) or insulated gate bipolar transistor (IGBT) based power modules, which are controlled by isolated gate drivers with protection and monitoring capabilities
- Isolated gate drivers – an isolation device allows data and power transfer between high- and low-voltage units, while preventing hazardous DC or uncontrolled transient current flowing from the high-voltage domain
- Bias supplies – a galvanically isolated power supply which takes the input from low-voltage side and generates the gate drive voltage to the power switches
- Isolated voltage and current sensing – to sense the DC link voltage and motor-phase current and makes sure that the correct torque is being applied to the motor
- Active discharge – to discharge the DC bus capacitor voltage to a safe voltage. Active discharge is required for the type of motors that can generate back-electromotive force (EMF). United Nations regulation No. 94 of the Economic Commission for Europe of the United Nations requires that the DC bus capacitor voltage drop to a safe voltage (60 V) in less than 5 s. Additionally, diagnostic circuitry is included to perform self-tests on critical functions to prevent system failure.

The inverter control and safety scheme also varies with vehicle type. For example, a permanent magnet synchronous motor (PMSM) can be leveraged because the PMSM has high efficiency, low torque ripple, and a large speed range. PMSMs often use pace vector PWM control, also known as field-oriented control. Controlling the stator current in the way that creates a stator vector perpendicular to rotor magnetics generates torque. Updating the stator currents keeps the stator flux vector at 90 degrees to the rotor magnets at all times. Other popular motor types in PHEVs and BEVs include induction motors, externally excited synchronous machines, and switched reluctance machines.

To reduce the costly rare earth materials permanent magnet, the externally excited synchronous motors (EESM) is growing as not only a secondary axle but also primary axle movers for the vehicle. The goal in using this motor is to reduce cost - for example, 100-kW peak power requires about 1.5 kg magnets, and to reduce the efforts in manufacturing and maintenance. EESM machine types include conductive EESM and inductive EESM (iEESM). Commercial vehicles using EESM include the Toyota Prius, Chevrolet Bolt EV, Ford Focus Electric, VW e-Golf, BMW iX3, and so forth.

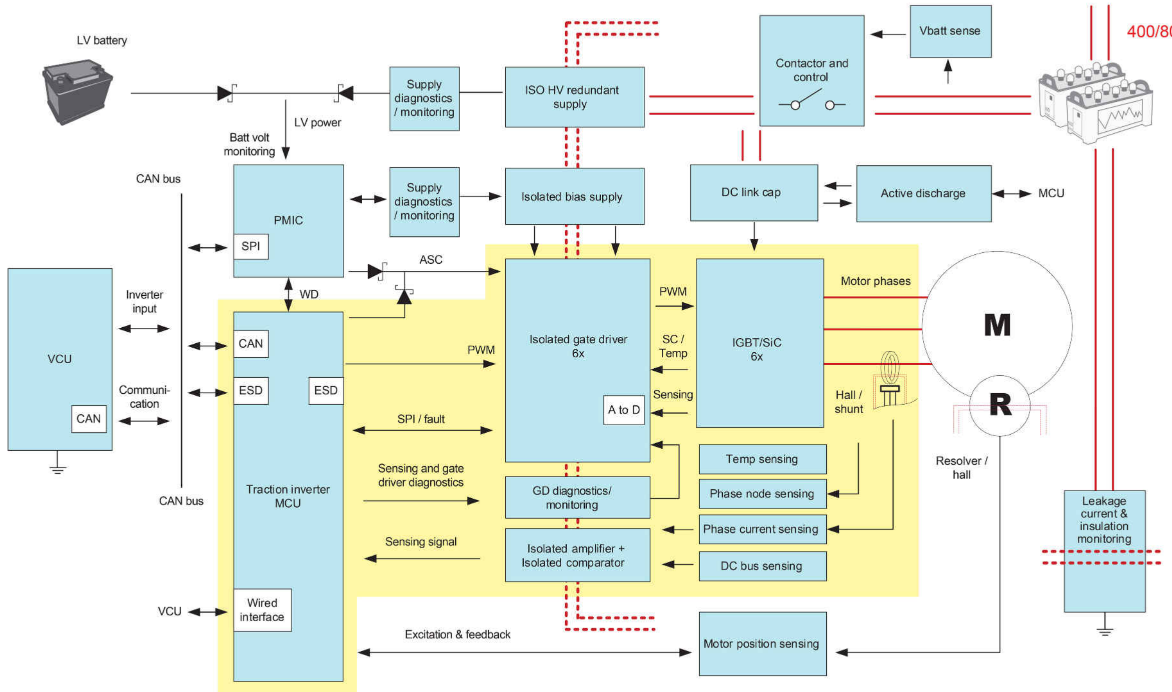


Figure 3-1. Traction Inverter System Block Diagram

4 Microcontroller

With the inverter architecture and specifications defined, the next step is to select the MCU. TI offers a strong portfolio of *Microcontrollers* for HEV and EV applications including the Arm® Cortex® R5F based Sitara family and the high-performance C2000™ MCU family with real-time control capability and fast control loop.

4.1 Sitara Family

The Sitara MCU family is an Arm-based architecture which incorporates ASIL-D functional safety, Evita-full Hardware Security Module (HSM), and AUTOSAR support in addition to real-time control capabilities. The Arm Cortex-R5F cluster in the *Sitara MCU family* includes up to 4-cores. Surrounding the core are accompanying memories such as L1 cache and tightly-coupled memories (TCM), standard Arm CoreSight™ debug and trace architecture, integrated vectored interrupt manager (VIM), ECC aggregators, and various other modules. The accelerator for real-time control inherits the classic C2000 control modules. The accelerator includes: analog-to-digital converter (ADC), analog comparator, buffered digital-to-analog converter, enhanced pulse width modulator (EPWM), enhanced capture, enhanced quadrature encoder pulse, fast serial interface, sigma delta filter module, and crossbar. Other benefits include: Flexible lockstep options for split safety decomposition, Hardware Security Module (HSM), CAN-FD support with AUTOSAR. A Traction inverter system block diagram controlled by AM2634-Q1 is shown in Figure 4-1.

The Code Composer Studio™ software project folder includes traction inverter demonstration codes. The resolver loop is implemented as follows: one PWM channel is set to trigger updates for a resolver excitation signal through direct memory access and a digital-to-analog converter (DAC) at higher frequencies, while three other PWM channels create an inverter signal and generate an ADC SOC. The resolver excitation signal is aligned from the DAC to the desired phase for ADC samples. Multiple ADC units can share the same System on Chip (SOC).

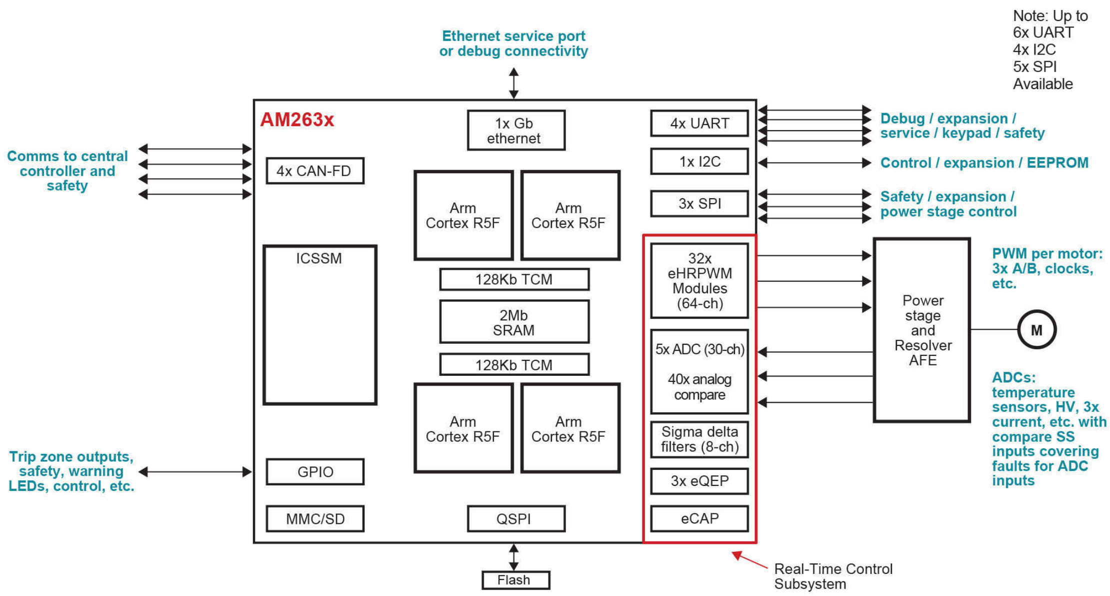


Figure 4-1. Traction Inverter System Block Diagram With the AM2634-Q1

4.2 C2000 Family

The *TI C2000 MCU* family has been delivering the leading real-time control performance in digital power and motor control applications for more than 2 decades. These MCUs integrate flash memory, an Analog-to-Digital Converter (ADC), a Digital Signal Processor (DSP), and Pulse Width Modulation (PWM) units and are very successful; such as the TMS320F28003x and TMS320F2837x. The C2000 family features range from standalone inverters up to full powertrain integration including: Traction Inverter, Onboard Charger (OBC), High Voltage DC-DC Converter, Battery Management System (BMS), Heating Ventilation, and Air Conditioning (HVAC), with the upcoming F29x family capable of delivering hundreds of Millions Instructions Per Second (MIPS).

TI C2000 MCUs include the following features to help accelerate control algorithms for traction inverters:

- A state machine-based 32-bit floating-point control law accelerator capable of independent code execution from the main DSP core field-oriented control
- Support for 32-bit floating point operations or 64-bit floating point on some devices in this family
- A trigonometric math unit (TMU) that provides intrinsic instructions to support common trigonometric math functions common in transforms and torque loop calculations. Significant cycle count reductions are possible using the TMU-based instructions. Figure 4-2 shows the improvement through TMU for the *traction inverter control algorithm*.
- Reduced cycle count for both Viterbi and cyclic redundancy check operations found in complex math equations

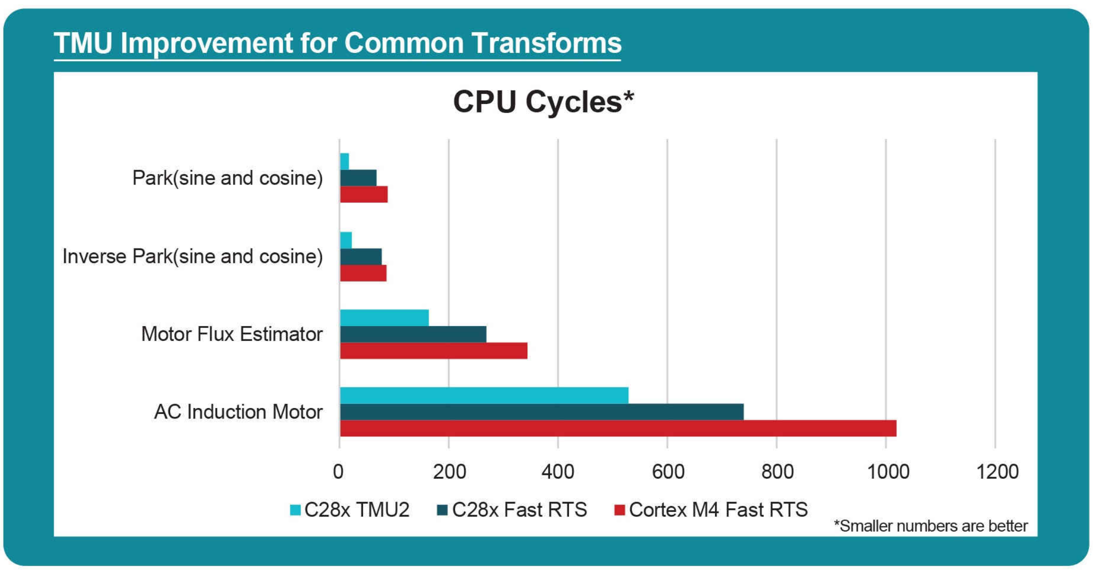


Figure 4-2. TMU Improvement for Traction Inverter Control

5 Isolated Gate Drivers

TI gate driver isolation – up to 5.7 kV_{RMS} – helps protect against electric shock while offering higher working voltages, and wider creepage and clearance for improved system reliability. There are two major isolated gate driver families: the smart driver UCC21750-Q1 family and the safety driver UCC5870-Q1 family. The UCC21750-Q1 family includes protection features for the power modules in traction inverters such as fast overcurrent and short-circuit detection, shunt current-sensing support, fault reporting, active Miller clamp, input and output-side power supply undervoltage lockout detections. An isolated analog-to-PWM sensor facilitates easier temperature or voltage sensing.

The *UCC5870-Q1* driver family includes the following features:

- *Functional Safety-Compliant*, isolated, single-channel gate driver, supporting up to 1-kV_{RMS} working voltage and longer than 40 years isolation barrier life, as well as providing low part-to-part skew, and >100 V/ns common-mode noise immunity (CMTI)
- A high 30-A peak drive strength for minimizing power switching losses and removes the buffer circuit on the drive circuit, thus reducing cost.
- A temperature sensor to monitor the temperature of the power module and allow operation up to a certain temperature limit, helping support a wide operating range
- Has a Miller clamp to prevent false turn on and enables switches to be switched as fast as needed to achieve efficiency targets

Figure 5-1 and Figure 5-2 show the 30-A drive strength of the UCC5870-Q1 and a competing device under the following test conditions:

- Vcc2 – Vee2 = 23 V
- $R_{gon} = R_{goff} = 0\ \Omega$
- Load capacitance = 1 µF

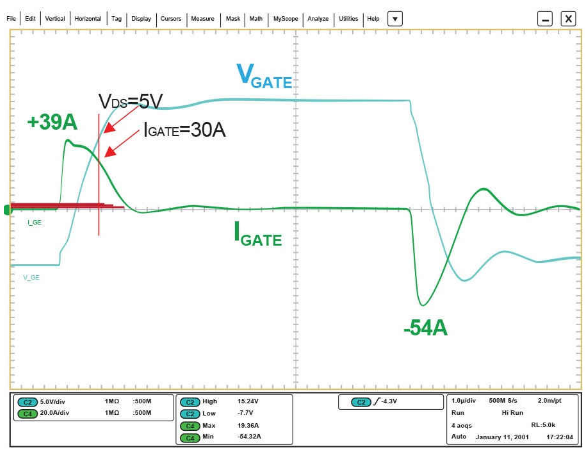


Figure 5-1. UCC5870-Q1 Gate Drive Strength

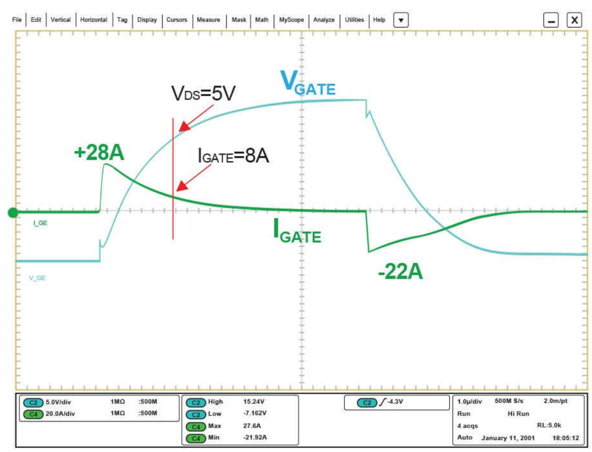


Figure 5-2. Competing Device Gate Drive Strength

One way to improve the traction inverter efficiency and reduce EMI is to adjust the gate-drive output for controlling the slew rate, thereby changing switching speeds under varying conditions such as temperature, load, and voltage. For example, when depleting the battery voltage, the transient voltage (dv/dt) is naturally smaller, and the gate-drive output can be adjusted to push the switch to transition faster.

Figure 5-3 and Figure 5-4 illustrate an adjustable gate-drive implementation based on the UCC5870-Q1. Figure 5-3 shows the design diagram, while Figure 5-4 shows the design board, which is connected to the XM3 half-bridge power module family from Company WolfSpeed.

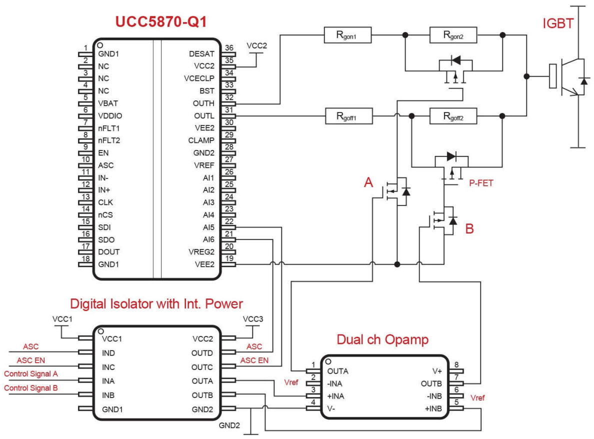


Figure 5-3. UCC5870-Q1 Design Diagram With an Adjustable Gate-Drive Implementation

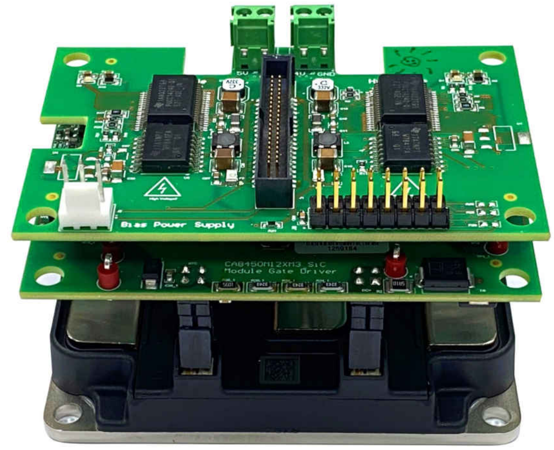


Figure 5-4. UCC5870-Q1 Design Board With an Adjustable Gate-Drive Implementation

Figure 5-5 and Figure 5-6 show the double pulse testing waveforms. The average switching dv/dt speed of rising edge increased from 4.6 kV/µs to 21 kV/µs. The average switching dv/dt speed of the falling edge increased from 3.8 kV/µs to 13.5 kV/µs.

Both of the following images were collected with a double pulse testing waveform under an 800-V bus.

Figure 5-5. Weak Drive With a 5.5-Ω Gate Resistor

Figure 5-6. Strong Drive With a 0.5-Ω Gate Resistor

Table 5-1 shows the switching energy comparison between weak drive (5.5-Ω gate resistance) and strong drive current (0.5-Ω gate resistance), under a 400-V bus voltage.

Table 5-1. Switching Energy Comparison Under a 400-V Bus Voltage

Parameter	Weak Drive (5.5-Ω Gate Resistance)	Strong Drive (0.5-Ω Gate Resistance)
Drain-to-source voltage	400 V	400 V
Drain-to-source current	200 A	200 A
Turn-on energy	2.364 mJ	893 µJ
Turn-off energy	2.12 mJ	898 µJ
Drain-to-source voltage (V_{DS}) overshoot	88 V	150 V

Table 5-2 shows the switching energy comparison between weak drive and strong drive current, under 800-V bus voltage.

Table 5-2. Switching Energy Comparison Under a 800-V Bus Voltage

Parameter	Weak Drive (5.5-Ω Gate Resistance)	Strong Drive (0.5-Ω Gate Resistance)
Drain-to-source voltage	800 V	800 V
Drain-to-source current	400 A	400 A
Turn-on energy	2.03 mJ	1.124 mJ
Turn-off energy	2.0 mJ	1.245 mJ
Drain-to-source voltage (V_{DS}) overshoot	120 V	230 V

6 Low-Voltage Bias Supplies

In traction inverters, the *low-voltage bias supplies* usually connect to a low-voltage source such as the 12-V battery and power the gate driver. TI provides various solutions: including converters with integrated field-effect transistors (FETs) and integrated magnetics, converters with integrated FETs and external magnetics, and controllers with external FETs and external magnetics.

The UCC14240-Q1 isolated DC/DC converter module delivers 1.5 W of output power at ambient temperatures of 105°C, and provides ±1.3% output voltage regulation. The device has basic and reinforced isolation versions and greater than 150 V/ns common-mode transient immunity performance. Figure 6-1 shows the image of (EVM) board of UCC14240-Q1 which is in a low-profile, 3.5-mm, wide body SOIC integrated package.

The UCC25800-Q1 device is an inductor-inductor-capacitor resonant converter with ultra-low EMI emission. This device allows the design to utilize a transformer with higher leakage inductance, but much smaller parasitic primary-to-secondary capacitance and protection features such as adjustable overcurrent protection, input overvoltage protection, overtemperature protection, and protection from pin faults.

The SN6507-Q1 is a high-frequency push-pull transformer driver with integrated MOSFETs, and duty cycle control which enables wide input voltage range. The device integrates a controller and two 0.5-A NMOS power switches that switch out of phase. This device also includes programmable soft start, spread spectrum clocking and pin-configurable slew rate control.

The LM2518x-Q1 family are primary-side regulated (PSR) flyback converters with integrated power switches and the ability to operate over a wide input voltage range of 4.5 V to 42 V. The isolated output voltage is sampled from the primary-side flyback voltage, eliminating the need for an optocoupler, voltage reference, or third winding from the transformer for output voltage regulation. Boundary conduction mode (BCM) switching enables a compact magnetic design and better than ±1.5% load and line regulation performance.

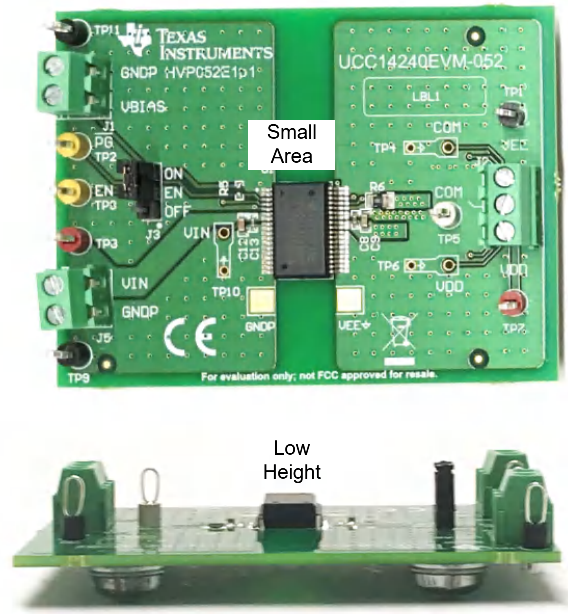


Figure 6-1. UCC14240-Q1 EVM Board

7 High-Voltage Bias, Redundant Supply

A traction inverter system often requires a high-voltage power supply, which converts power from the high-voltage battery and connects to the low-voltage side creating a redundant power path and increasing safety. This high-voltage power supply can be required to start up when the input voltage is as low as 50 V, and also must able to operate as high as 1 kV for an 800-V battery. A low start-up voltage can occur after a vehicle crash or if a traction inverter malfunction results in a separation of the high-voltage battery. The motor starts rotating and acts like a generator, which induces a non-controlled voltage into the DC bus. To control the voltage so that the voltage does not exceed 50 V (touch safe), the auxiliary power supply has to turn on and power up safety-relevant circuits that can discharge the DC link caps (active discharge) or actively short circuit the motor.

TI offers various reference designs to fulfill this requirement:

1. Texas Instruments, *UCC28C5y-Q1 EVM: 40V – 1kV Input, 15Vout, 40W PSR flyback*
2. Texas Instruments, *TIDA-01505 – Automotive 40-V to 1-kV input flyback reference design supporting regenerative braking test*
3. Texas Instruments, *PMP22288 – 15-W flyback reference design for automotive inverter power*
4. Texas Instruments, *PMP10200 – Ultra-Wide Input Voltage Range PSR Flyback Converter Reference Design*

8 DC Link Active Discharge

Every EV traction inverter requires a DC link active discharge as a safety-critical function. The discharge circuit is required to discharge the energy in the DC link capacitor under the following conditions and requirements:

- In an emergency situation or during repairs, the voltage in the system must be safe to touch in less than 2 s
- At vehicle *key-off*, the DC link capacitor must remain discharged
- System-level safety requirement ASIL D
- Shall be able to operate independently from the MCU, in case of MCU failure

TI has several active discharge designs targeted for different system-level requirements:

- Power transistor on, off control using the *TPSI3050-Q1*. The TPSI3050-Q1 reinforced isolated switch driver has an integrated 10-V gate supply that can drive the discharge power switches with no need for a secondary bias supply.
- Controlled PWM using the AFE539F1-Q1 device. The AFE539F1-Q1 smart AFE has built-in nonvolatile memory for PWM and custom waveform generators. The device has added programmability and logic which eliminates the need for software filling the gap between DAC-based circuits, MCU-based circuits, and entirely discrete circuits. Figure 8-1 and Figure 8-2 show a design block diagram and testing waveforms.

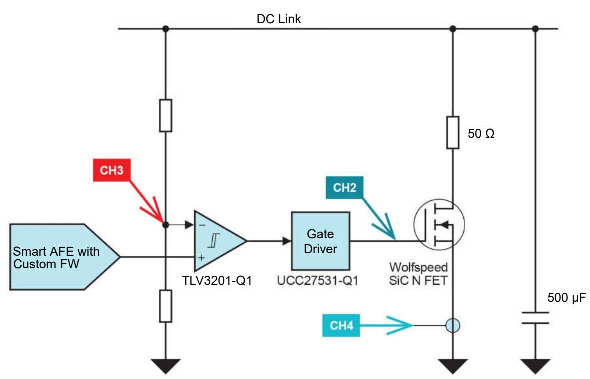
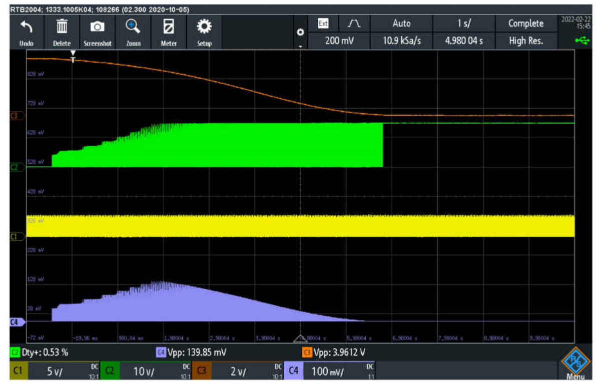


Figure 8-1. DC Link Active Discharge Based on the Smart AFE



CH1: AFE539F1-Q1 output
CH2: Gate driver (UCC27531-Q1) PWM output
CH3: DC link voltage after resistive divider
CH4: SiC FET drain-to-source current

Figure 8-2. Testing Waveforms

- Discharge through the power stage by linear biasing or PWM-based pulsed-linear switching on the power module to constitute a short circuit. TI's isolated gate driver with tri-state capability enables active discharge through a power module using discrete analog circuits. The discharge profile is mirrored to a current source reference across a capacitor, where a 100-µA constant current sink is representing 1-A constant discharge current. A gate voltage regulator regulates the gate-to-source voltage and drives the power module into the linear region.
- Energy discharge through the motor winding. Dividing a winding-based discharge into multiple stages is possible. These stages include a rapid discharge stage or a bus voltage regulation stage. Generating large d-axis current quickly reduces the DC link energy, while the q-axis current must be at zero. Fast loop control from TI's Sitara or C2000 MCU and *safety* isolated gate driver include Serial Peripheral Interface (SPI) programmability, Six ADC channels provides a reliable and smoothly controlled discharge.

9 Motor Position Sensing

A motor rotor position sensor measures the angular position of the rotor shaft. Motor position sensors are very important for speed feedback loop control meeting safety requirements in EV applications. For position control, the sensors enable a known (safe) position, motor speed and the positions throughout motion, and also provides feedback to the torque control loop.

A variable reluctance resolver sensor implements the principle of a rotating transformer. The transformer has a single primary winding and two secondary windings positioned at a right angle from each other. Applying an excitation voltage (V_{EXC}) to the primary winding (generated through an excitation amplifier such as TI's *ALM2403-Q1* or *TAS5431-Q1*) results in current that generates the magnetic flux (Φ). The flux distributes through secondary windings with respect to the rotor angle (Θ) and induces VSIN and VCOS accordingly. The feedback signals are converted from differential signals to the single-ended output for the ADC. A safety MCU calculates Θ from the voltage ratio on the *resolver* secondary windings.

The inductive position sensors implement magnet-free technology that can be used for high-speed motor position sensing. The sensors use the principle of eddy currents to detect the position of a metallic target that is moving above a set of coils. The position sensor interface IC converts the input signals from the RX coils into differential sine and cosine output signals, processed from the MCU.

10 Isolated Voltage and Current Sensing

Traction inverter systems use *isolated sensors* for voltage and current measurements such as DC link voltages and motor phase currents. TI's AMC1311B-Q1 and AMC1351-Q1 isolated amplifiers and AMC1305-Q1 isolated-modulator-based designs help to achieve high accuracy, high bandwidth, low latency, and low temperature drift for isolated current and voltage sensing. The product family offers both basic and reinforced isolation ratings. The silicon dioxide-based capacitive isolation barrier supports a high level of magnetic field immunity.

11 System Engineering and Reference Designs

TI's system engineering teams are dedicated to develop optimized system designs from TI's broad product portfolio, thereby helping customers to accelerate their system design cycle. Some previously-developed reference designs are detailed the following list:

- TIDM-02009:

  The TIDM-02009 is an ASIL D safety concept-assessed, high-speed traction, bidirectional DC/DC conversion reference design.

  This reference design demonstrates control of the HEV or EV traction inverter and bidirectional DC-DC converter with a single TMS320F28388D real-time C2000 MCU. The traction control uses a software-based resolver to digital converter (RDC) driving the motor to a high speed up to 20,000 RPM. The DC-DC converter uses peak current mode control (PCMC) techniques with a phase-shifted full-bridge (PSFB) topology and synchronous rectification (SR) scheme. The traction inverter stage uses a silicon carbide (SiC) power stage, driven by the UCC5870-Q1 smart gate device. A PCMC waveform is generated using the state-of-the-art PWM module and built-in slope compensation in the comparator sub-system (CMPSS). An ASIL decomposition based functional safety concept for the system was assessed with TÜV SÜD to demonstrate system-level safety integrity up to ISO 26262 ASIL D for representative safety goals.

- PMP22817:

  The PMP22817 is an automotive SPI-programmable gate driver and bias supply with integrated transformer reference design.

  This reference design provides isolated-bias supply and isolated-gate driver for power switches in traction inverters. Both the bias power and driver provide the high isolation needed for 800-VDC bus application. The isolated bias provides 24 VDC both the +15-V and –5-V gate-drive biases. The isolated driver provides the high currents needed to rapidly turn on and off these high-power switches and offers advanced protection features. The PMP22817 design also provides a tested DC-DC single-ended primary-inductor converter SEPIC off automotive battery voltage (6 V to 42 V including surge and dips) to provide the regulated 24 V.

- TIDA-01527

  The TIDA-01527 is a discrete resolver front-end reference design with a C2000™ microcontroller and ±0.1° accuracy.

  This reference design is an excitation amplifier and analog front end for resolver sensors. The design implements only discrete components and standard operational amplifiers on a 1-in-2 printed circuit board (PCB). The provided algorithm and code example uses a C2000 microcontroller (MCU) LaunchPad™ Development Kit with the TMS320F28069M MCU for signal processing and angle calculation. The reference design uses a remarkable, scattered-signal processing method. This method improves the system accuracy by 250% while maintaining hardware costs and complexity to a reasonable level.

12 Conclusion

The automotive traction inverter is trending towards 800-V technology, high-power density (towards larger than 50 kW/L), high efficiency (> 99%), and high safety (ASILD) requirements. TI technology and devices, such as MCUs, isolated gate drivers, isolated bias supplies, safety PMICs, active discharge, position sensing, isolated voltage, and current sensing help enable high-performance and safe traction-inverter systems with enhanced reliability and low cost.

13 References

For more detailed information on the advantages that C2000 brings to the real-time signal chain, including SW benchmarks, see the *Real-time Benchmarks Showcasing C2000™ Control MCU's Optimized Signal Chain* application note.

For more Smart AFE information, see the *What is a smart DAC?* technical article.

See the *Addressing high-voltage design challenges with reliable and affordable isolation technologies* white paper.

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