Technical Article

Enabling automotive designers to increase power-density and reliability with LLC topology

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Automotive power designers have to choose topologies and controllers to meet standards for Automotive Safety Integrity Levels defined by International Organization for Standardization 26262, in addition to meeting specifications such as form factor and efficiency. Traditionally, designers used simple analog pulse-width modulation (PWM) controllers configured in a half-bridge topology. But for systems that require advanced protections or higher efficiency, PWM controllers may not be sufficient.

The latest hybrid or electric vehicles (EVs) need higher power density, light load performance, and better reliability to maximize range and safety, leading designers to explore novel architectures for powertrain systems such as auxiliary, redundant, distributed and zone modules. To reduce emissions, manufacturers of motorcycles, golf carts, forklifts, and even lawn mowers are investing in higher voltage battery packs, electrified models, and charging infrastructure. Light electric vehicle (LEVs) designers need products that deliver high power density without sacrificing cost or reliability.

The inductor-inductor-capacitor (LLC) topology can offer better efficiency and electromagnetic compatibility (EMC) caused by inherent resonance and zero voltage switching (ZVS) compared to a PWM controller-based half-bridge converter. But despite the benefits that the LLC topology can offer – including minimal standby power and low audible noise – EV manufacturers have been hesitant to use the LLC topology because the limited operating input voltage range. Automotive DC/DC converters need a wide input, output voltage support, or both, in order to maintain performance during cold-crank, transient or crash-related events.

Technological innovations in LLC controllers such as UCC25661(Q1) are enabling new use cases for the LLC topology in automotive and EV charging applications. In EVs, the LLC topology may be used for the redundant, auxiliary, zone module, or key off power supplies. For LEVs, the LLC topology can be used for the on-board DC/DC converter or the off-board charger/adapter. In ach of these applications, high efficiency and minimum size are necessary to maximize vehicle range and save cost, especially if there are multiple LLC converters distributed throughout the vehicle as show in the zone modules in Figure 1.

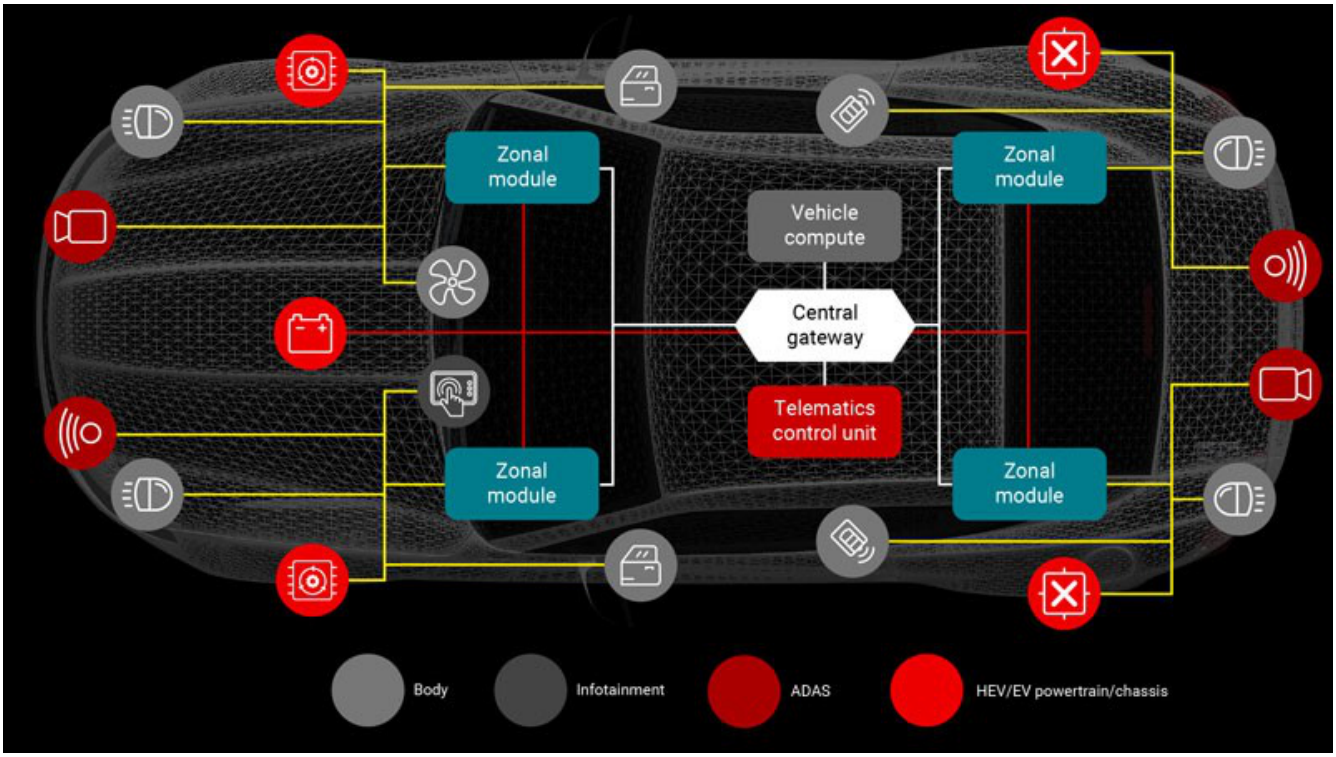

Figure 1. Zone architecture

Enabling higher power density in automotive systems using the LLC topology

Magnetic components typically dominate the size and weight of an isolated power supply. The size is inversely proportional to the switching frequency, because less energy needs to be stored or delivered per switching cycle at a fixed output power.

The 750kHz resonant frequency in the UCC25661-Q1 LLC controller can help shrink both the size and weight of magnetic components, which helps save costs and improve reliability. The distribution of many LLC converters throughout a vehicle multiplies the benefits of using smaller, lighter magnetic components.

PWM controllers may support high-frequency operation, but their hard switching means that it can be challenging to comply with EMI limits such as those specified in Comité International Spécial des Perturbations Radioélectriques (CISPR) 25 without a bulky EMI filter. LLC controllers are inherently soft switching because they have a resonant tank in the power stage. Therefore, the LLC topology generates less conducted EMI and switching losses than a hard-switched half-bridge toplogy.

Figure 2 illustrates the difference between hard switching and soft switching (ZVS).

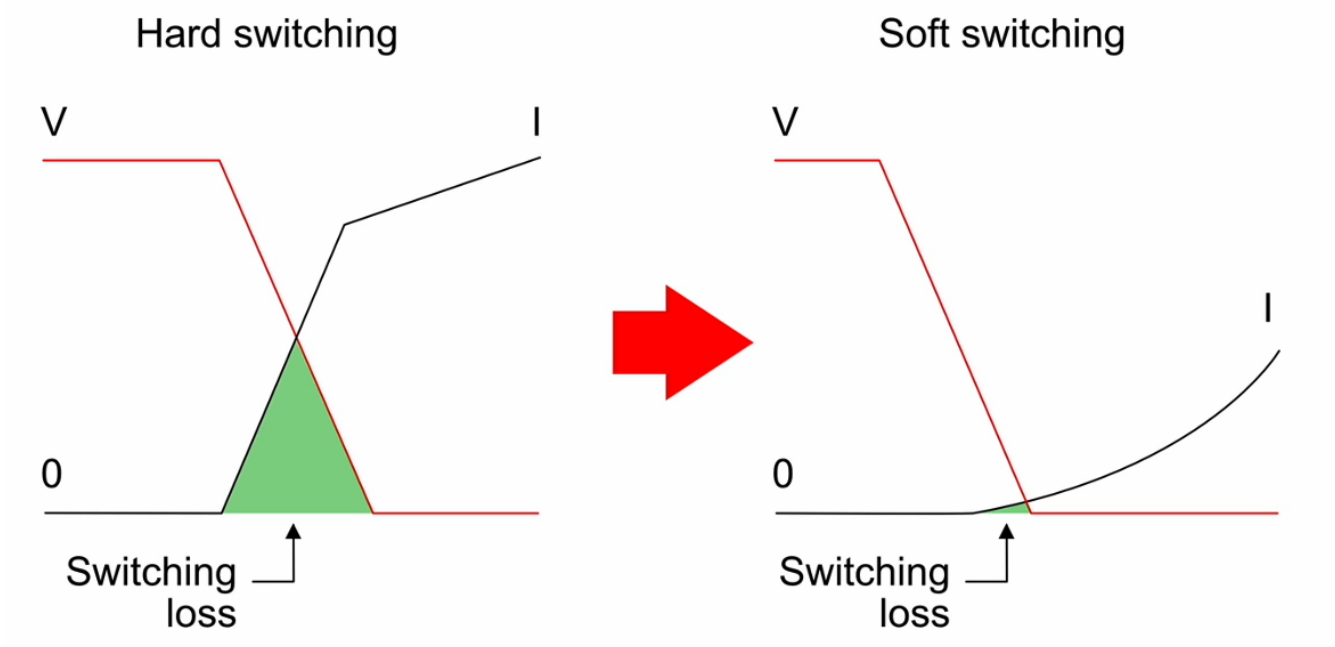

Figure 2. Example waveform of a switching event for a half-bridge PWM controller vs. an LLC controller

Unlocking new use cases with IPPC

The UCC25661-Q1 LLC controller includes TI's input power proportional control (IPPC) to support wide output-voltage applications such as battery charging (light EV adapters, charging stations or auxiliary supplies). IPPC also supports wide input voltage applications for battery-powered DC/DC systems in EVs. LEVs are migrating from lower voltage battery packs between 12V to 36V up to higher voltages like 48V and even higher than 96V to maximize range.

Wide output-voltage range support enables engineers to design LLC converters that avoid entering burst mode when the battery voltage is low, protecting battery longevity. IPPC also reduces development time when tuning burst-mode performance stability. IPPC in the UCC25661-Q1 surpasses the traditional limits of LLC control laws by substantially reducing the switching frequency used by the controller to deliver power. This removal enables engineers to avoid unwanted overload protection in battery applications, both on- and off-vehicle.

IPPC also helps deliver power more efficiently when power factor correction is disabled without triggering the overload power limit. Mixed burst mode not only minimizes audible noise but also improves light- and no-load performance, which is important to prevent draining the battery.

The UCC25661-Q1 comes with powerful protection features such as pre-bias startup, soft start, and capacitive region avoidance which all enable a highly reliable power-supply design.

Simplify and protect your power-supply unit with integrated features

The UCC25661-Q1's self-adaptive soft-start feature stabilizes and slowly ramps its supply voltage, allowing the capacitor connected to the VDD pin to fully charge before startup and protecting the power supply from excessive inrush current.

Depending on the load condition, power converters using LLC controllers may operate in the capacitive or resonant region. Operating in the capacitive region may cause catastrophic damage to the power stage. While most LLC controllers can stop operating after detecting capacitive region operation, the UCC25661-Q1 has capacitive region avoidance to terminate the gate drive, preventing damage.

Conclusion

EVs depend on advancements in isolated power-supply topologies such as the LLC topology and control methodologies such as IPPC to define DC/DC converters that enable next-generation architectures. Isolated DC/DC converters based on the UCC25661-Q1 LLC controller can deliver more power efficiently in the same or smaller form factor while maintaining performance.

Additional resources

- Read these application notes:
  - UCC25661x-Q1 Family 750kHz Wide VIN/VOUT Range LLC Controller Optimized for Light-Load Efficiency Data Sheet.
  - UCC25661x Selection Guide.
- Check out these reference designs:
  - Universal Input, 500W Constant Current and Constant Voltage E-Bike Charger Reference Design.
  - 750W Offboard Charger for Light Electric Two-Wheeler Reference Design.

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