Overview of Power Electronics for Hybrid Vehicles

P. T. Krein

Grainger Center for Electric Machinery and Electromechanics
Department of Electrical and Computer Engineering
University of Illinois at Urbana-Champaign
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Overview

• Quick history
• Primary power electronics content
• Secondary power electronics content
• Review of power requirements
• Architectures
• Voltage selection and tradeoffs
• Impact of plug-in hybrids
• SiC and other future trends
Quick History

- Hybrids date to 1900 (or sooner).
- U.S. patents date to 1907 (or sooner).
- By the late 1920s, hybrid drives were the “standard” for the largest vehicles.
Quick History

• Revival for cars in the 1970s.

• Power electronics and drives reached the necessary level of development early in the 1990s.

Quick History

• Battery technology reaches an adequate level in late 1990s.
• Today: Li-ion nearly ready.

• Power electronics: thyristors before 1980.
• MOSFET attempts in the 1980s, expensive (GM Sunraycer)
• IGBTs since about 1990.
Primary Power Electronics Content

- Main traction drive inverter (bidirectional)
- Generator machine rectifier
- Battery or dc bus interface

- Charger in the case of a plug-in
Traction Inverter

• IGBT inverter fed from high-voltage bus.
• Field-oriented induction machine control or PM synchronous control.
Traction Inverter

- Voltage ratings: \( \sim 150\% \) or so of bus rating
- Currents: linked to power requirements
- The configuration is inherently bidirectional relative to the dc bus.
- Field-oriented controls provide for positive or negative torque.

Generator Rectifier

• If a generator is present, it can employ either passive or active rectifier configurations.

• Power levels likely to be lower than traction inverter.

• Converter can be unidirectional, depending on architecture.
Battery/Bus Interface

• In some architectures, the battery connection is indirect or has high-power interfaces.
  – Ultracapacitor configurations
  – Boost converters for higher voltage
  – Braking energy protection
Battery/Bus Interface

- With boost converter, the extra dc-dc step-up converter must provide 100% power rating.
- With ultracapacitors, the ratings are high but represent peaks, so the time can be short.
Secondary Power Electronics Content

• Major accessory drives
  – Power steering
  – Coolant pumps
  – Air conditioning
• Conventional 12 V content and interfaces
• On-board battery management
Major Accessories

• Approach 1 kW each.
• Typically operating as a separate motor drive.
• Power steering one of the drivers toward 42 V.
• Air conditioning tends to be the highest power – run from battery bus?
Conventional 12 V Content

• About 1400 W needed for interface between high-voltage battery and 12 V system.

• Nearly all available hybrids use a separate 12 V battery.

• Some merit to bidirectional configuration, although this is not typical.
On-Board Battery Management

• Few existing systems use active on-board battery management.
• Active management appears to be essential for lithium-ion packs.
• Active management is also required as pack voltages increase.
• A distributed power electronics design is suited for this purpose.
Power Requirements

• Energy and power in a vehicle must:
  – Move the car against air resistance.
  – Overcome energy losses in tires.
  – Overcome gravity on slopes.
  – Overcome friction and other losses.
  – Deliver any extra power for accessories, air conditioning, lights, etc.
Power Requirements

- Typical car, 1800 kg loaded, axle needs:
  - 4600 N thrust to move up a 25% grade.
  - 15 kW on level road at 65 mph.
  - 40 kW to maintain 65 mph up a 5% grade.
  - 40 kW to maintain 95 mph on level road.
  - Peak power of about 110 kW to provide 0-60 mph acceleration in 10 s or less.
  - 110 kW at 137 mph.
- Plus losses and accessories.
Power Requirements

• Traction power in excess of 120 kW.
• Current requirements tend to govern package size.
• If this is all electric:
  – Requires about 500 A peak motor current for a 300 V bus.
  – About 300 A for a 500 V bus.
• Generator power on the order of 40 kW.
Power Requirements

• For plug-in charging, rates are limited by resource availability.

• Residential:
  – 20 A, 120 V outlet, about 2 kW maximum.
  – 50 A, 240 V outlet, up to 10 kW.

• Commercial:
  – 50 A, 208 V, up to 12 kW.

• All are well below traction drive ratings.
Architectures

• Series configuration, probably favored for plug-in hybrid.
  – Engine drives a generator, never an axle.
  – Traction inverter rating is 100%.
  – Generator rating approximately 30%.
  – Charger rating 10% or less.
Architectures

• Parallel configurations, probably favored for fueled vehicles.
  – Inverter rating pre-selected as a fraction of total traction requirement, e.g. 30%.
  – Similar generator rating if it is needed at all.

Source: Mechanical Engineering Magazine online, April 2002.
Voltage Selection

• Lower voltage is better for batteries.
• Higher voltage reduces conductor size and harness complexity.
• Extremes are not useful.
• < 60 V, “open” electrical system with limited safety constraints.
• > 60 V, “closed” electrical system with interlocks and safety mechanisms.
Voltage Selection

• Traction is not supported well at low voltage. Example: 50 V, 100 kW, 2000 A.
• Current becomes the issue: make it low.
• Diminishing returns above 600 V or so.
• 1000 V+ probably too high for 100 kW+ consumer product.
• Basic steps governed by semiconductors.
Voltage Selection

- 600 V IGBTs support dc bus levels to 325 V or so. (EV1 and others.)
- 1200 V IGBTs less costly per VA than 600 V devices. Support bus levels to 600 V +.
- Higher IGBT voltages – but what values are too high in this context?
Voltage Selection

• First hybrid models used the battery bus directly.

• Later versions tighten the package with a voltage boost converter.

• Double V: $\frac{1}{2}$ I, $\frac{1}{2}$ copper, etc.
Voltage Tradeoffs

- Boost converter has substantial power loss; adds complexity.
- Cost tradeoff against active battery management.
- Can inverter current be limited to 100 A or less?
Voltage Tradeoffs

• More direct high battery voltage is likely to have advantages over boost converter solution.

• Battery voltages to 600 V or even 700 V have been considered.

• Within the capabilities of 1200 V IGBTs.
Impact of Plug-In Hybrids

• Need sufficient on-board storage to achieve about 40 miles of range.

• This translates to energy recharge needs of about 6 kW-h each day.

• For a 120 V, 12 A (input) charger with 90% efficiency, this supports a 5 h recharge.
Impact of Plug-In Hybrids

- The charger needs to be bidirectional.
- This is a substantial cost add.

Input switches

Output switches

Cbus

LOAD
Impact of Plug-In Hybrids

- Single-phase version.
Impact of Plug-In Hybrids

- Easy to envision single-phase 1 kW car-mount chargers.
- Bidirectional chargers could double as inverter accessories.
- Notice that utility control is plausible via time shifting.
Impact of Plug-In Hybrids

• Home chargers above 10 kW are unlikely, even based on purely electric vehicles.
• Obvious limits on bidirectional flow that limit capability as distributed storage.
SiC and Future Trends

• Power electronics in general operate up to 100°C ambient.
• HEV applications: liquid cooling, dedicated loop.
• Would prefer to be on engine loop.
SiC and Future Trends

- Si devices can operate to about 200°C junction temperature.
- SiC and GaN offer alternatives to 400°C.
- Both are high bandgap devices that support relatively high voltage ratings.
SiC and Future Trends

• More subtle but immediate advantage: Schottky diodes, now available in SiC for voltages up to 1200 V, have lower losses than Si P-i-N diodes.
Future Trends

• Fully integrated low-voltage drives.
• Higher integration levels for inverters ranging up to 200 kW.
• Better battery management.
Thank You!