Overview of Power Electronics for Hybrid Vehicles

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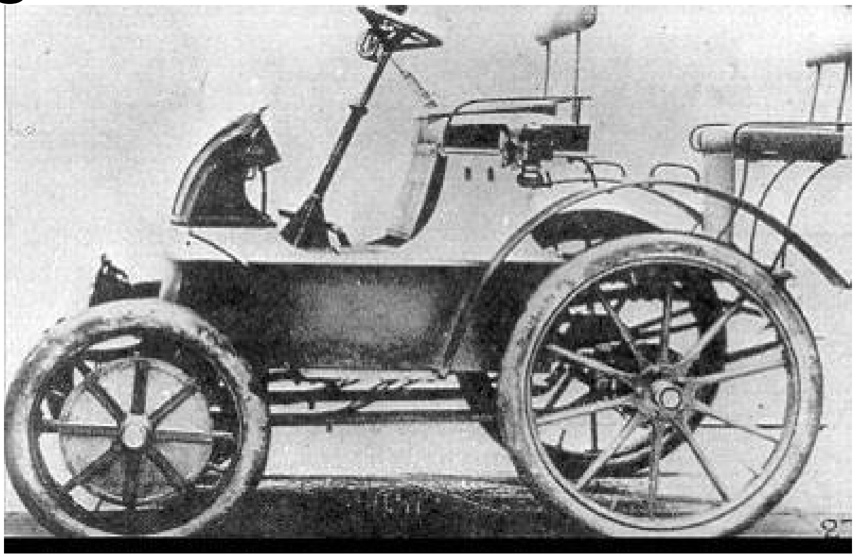
Overview

- 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.

www.freefoto.com



www.hybridvehicle.org

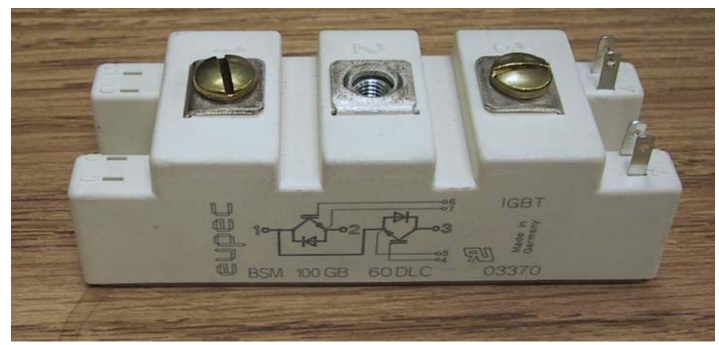
Quick History

- Revival for cars in the 1970s.
- Power electronics and drives reached the necessary level of development early in the 1990s.
- Major push: DoE Hybrid Electric Vehicle Challenge events from 1992-2000.

eands.caltech.edu

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

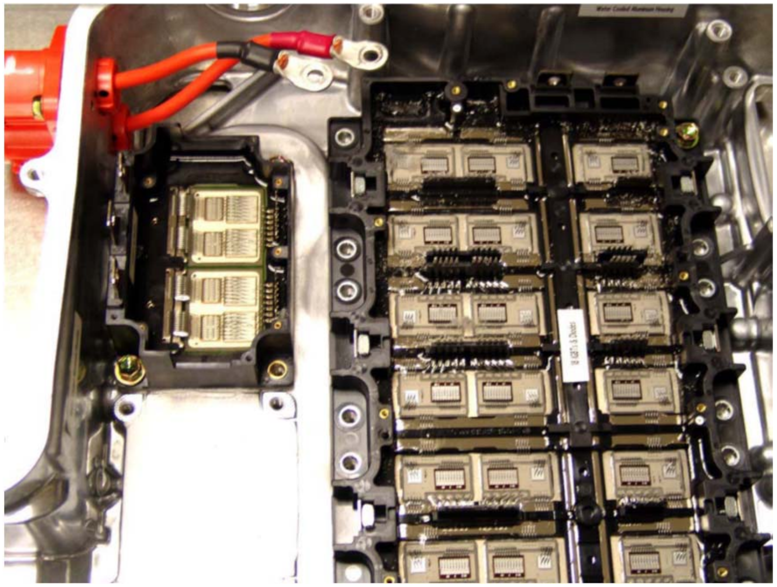
- Charger in the case of a plug-in

Traction Inverter

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

Traction Inverter

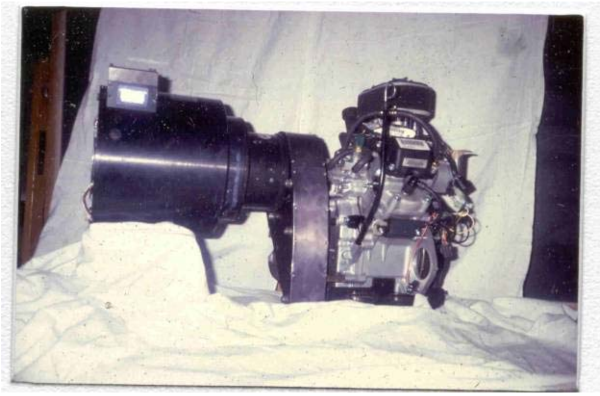
- Voltage ratings: ~150% or so of bus rating
- Currents: linked to power requirements
- The configuration is inherently bidirectional relative to the dc bus.
- Field-oriented controls provide for positive or negative torque.



C. C. Chan, “Sustainable Energy and Mobility, and Challenges to Power Electronics,” Proc. IPEMC 2006.

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

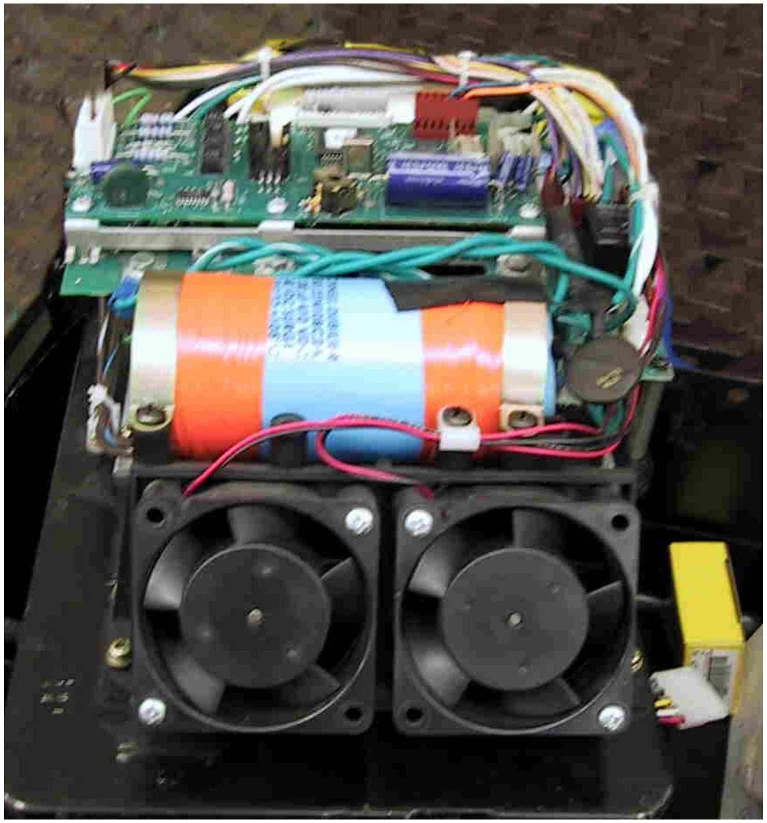
- In some architectures, the battery connection is indirect or has high-power interfaces.
  - Ultracapacitor configurations
  - Boost converters for higher voltage
  - Braking energy protection

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

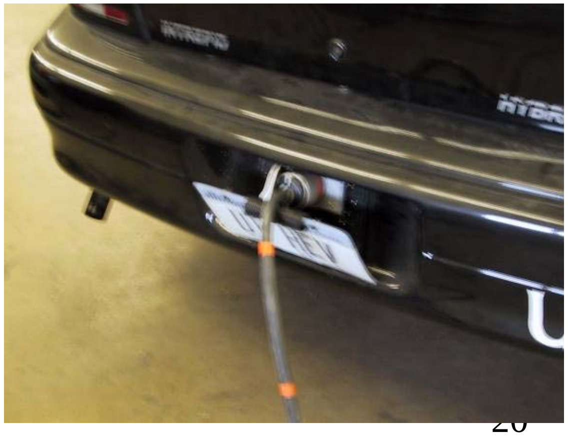
- Traction power in excess of 120 kW.
- Current requirements tend to govern package size.
- If this is all electric:
  - Requires about 500 A peak motor current for a 300 V bus.
  - About 300 A for a 500 V bus.
- Generator power on the order of 40 kW.

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.

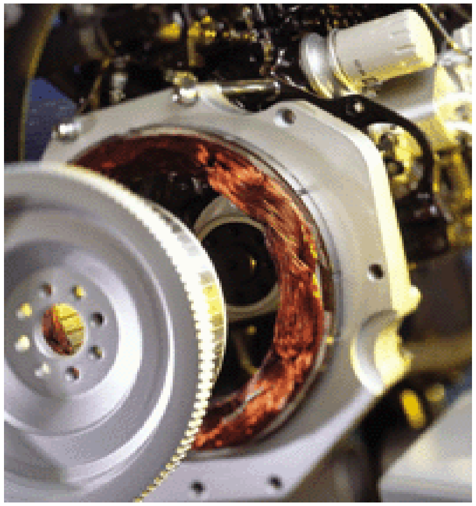
Architectures

- 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: ½ I, ½ 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

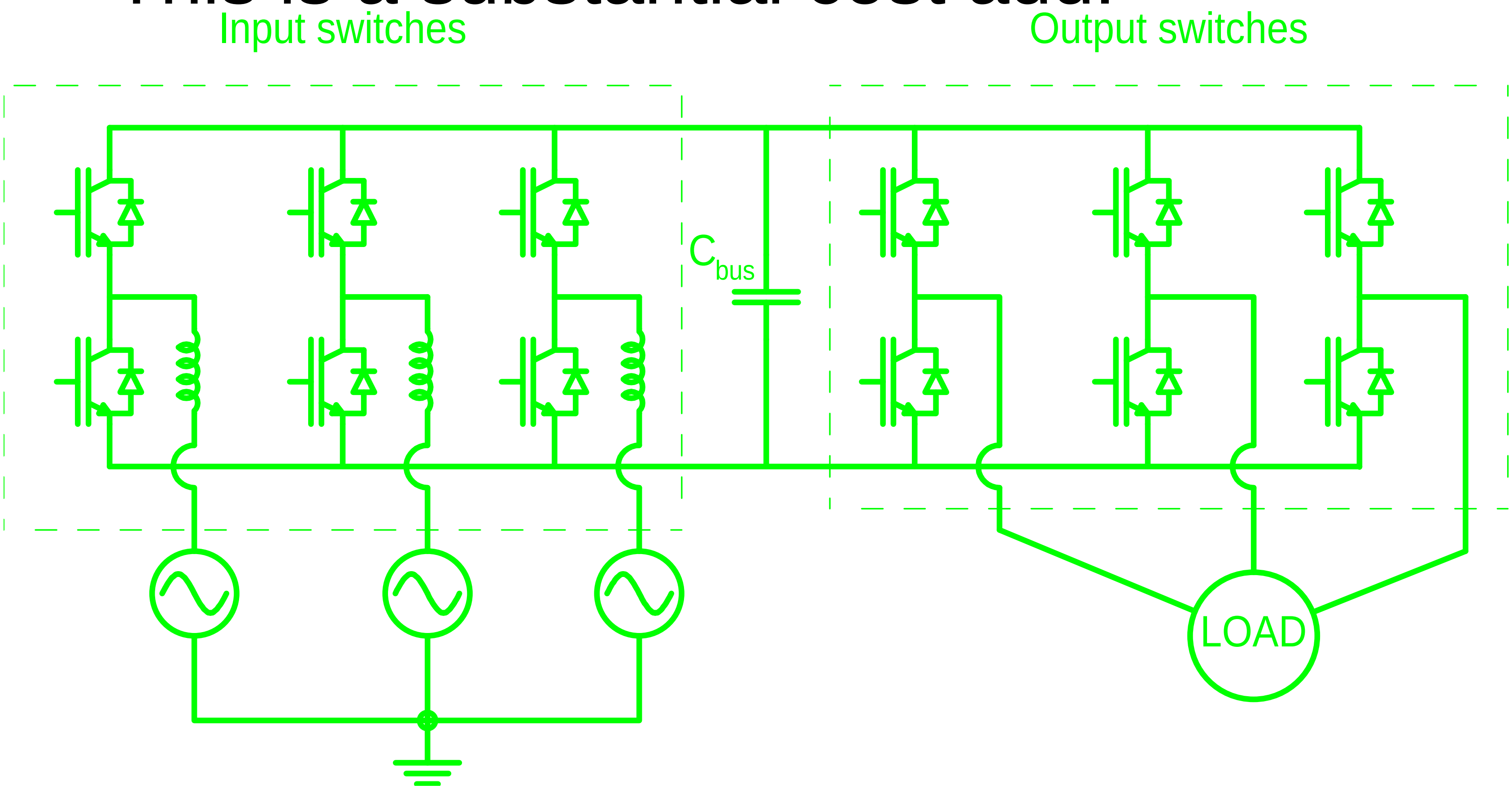
- More direct high battery voltage is likely to have advantages over boost converter solution.
- Battery voltages to 600 V or even 700 V have been considered.
- Within the capabilities of 1200 V IGBTs.

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.

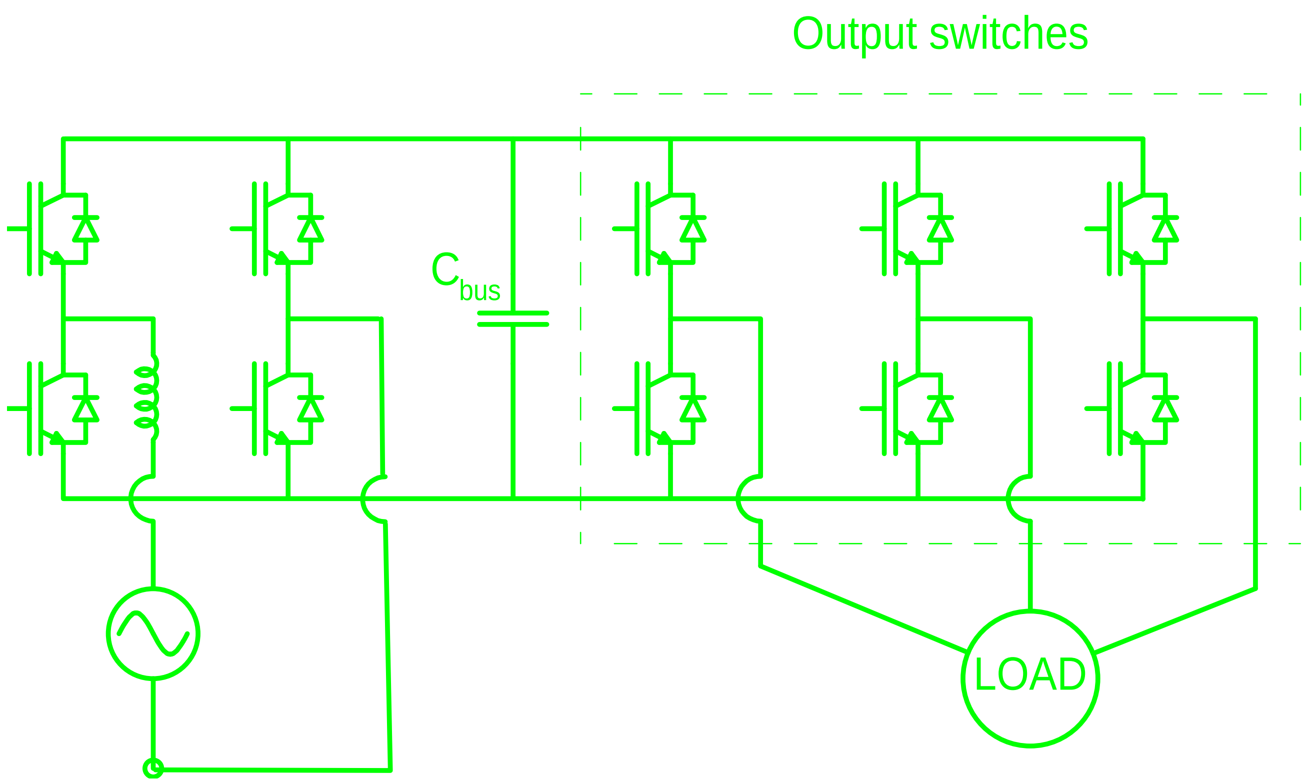
Impact of Plug-In Hybrids

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



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!