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ADVANCES IN APPLICATION OF SILICON CARBIDE FOR HIGH POWER ELECTRONICS

GVSETS

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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Outline

- Overview of SiC Advantages
- Prototype 150kW DC/DC Converter Description
- Initial Test Results / Requirements Compliance
- Test Plan / Schedule
- Conclusions
- Acknowledgements

SiC Advantages

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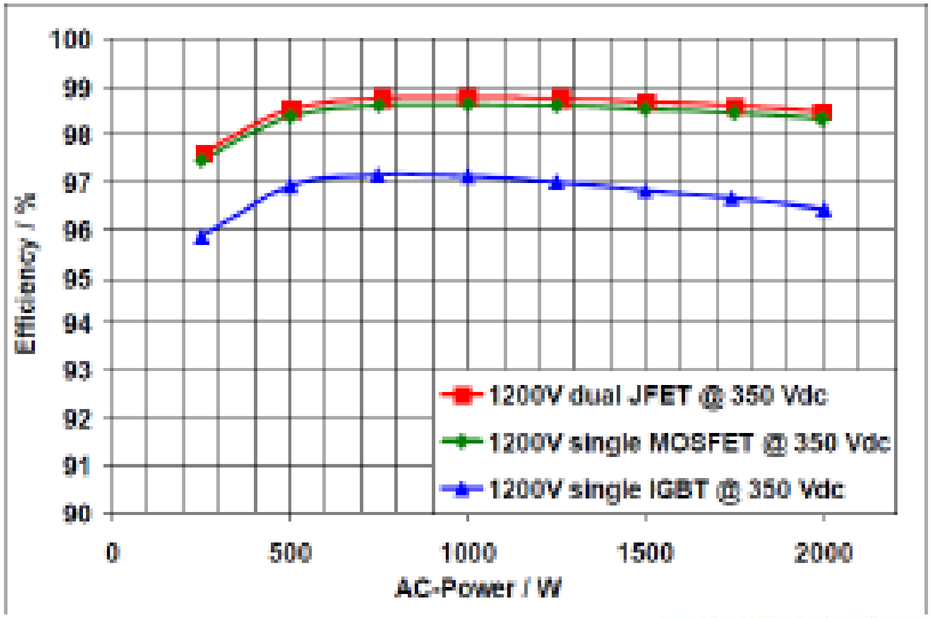
- Size, Weight & Performance Improved from Silicon:
  - Lower switching losses = substantially less waste heat
  - Higher operational switch junction temperatures = higher allowable coolant inlet temperature
  - Better thermal conductivity = better peak power capability
  - Higher switching frequencies = smaller capacitors & magnetics
  - Better radiation hardness = potentially simpler EMI/EMC design



System Advantages of SiC

- Cooling System Options
  - Increased top tank temperature allows:
    - Reduced radiator frontal area
    - Reduced cooling fan speed (proportional to fan power^3)
  - Reductions to sizing (flow, pump, power) of the power electronics circuit
- Integration Flexibility
  - Integration locations previously inhospitable for power electronics placement
- However: Cost currently a significant disadvantage

Vehicle System Designers Can Balance These Advantages for Significant System Improvements

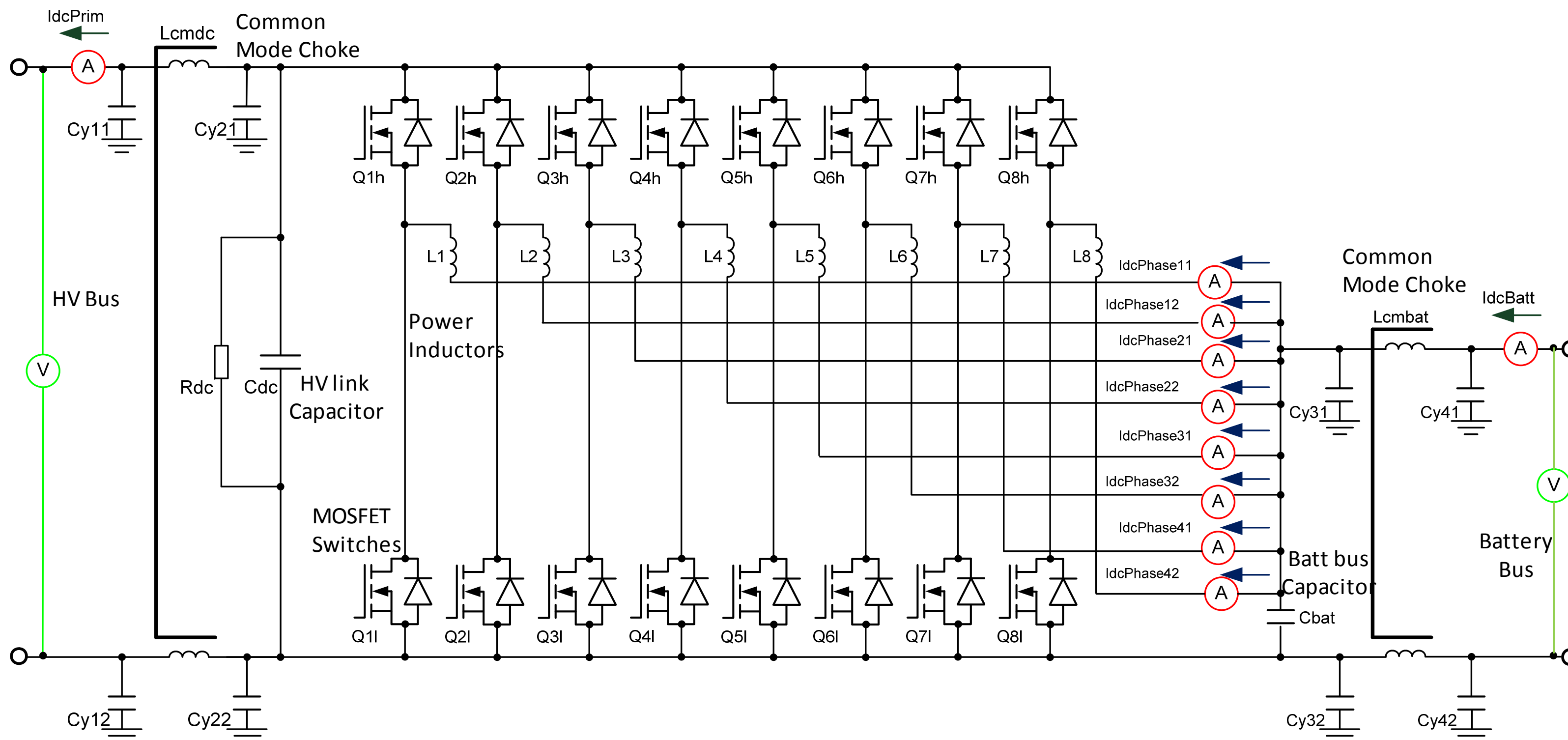
Prototype 150kW DC/DC Converter

- Bi-Directional 150kW Unit
  - 180kW Peak for 20s (discharge)
  - 100°C Coolant Inlet
  - 90°C Ambient
  - Full-SiC MOSFET half-bridges
  - Fiber optic communication interface
  - 3.35 kW/liter, 1.8 kW/kg continuous ratings
- High Voltage Conversion
  - Galvanically isolated gate driver with gate voltage & over current monitoring, minimal recovery time, & failure memory
  - 580-640Vdc propulsion bus
  - 300-530Vdc “battery” bus
  - 1200V, 100A switches
  - 40-50kHz frequency used

Prototype 150kW DC/DC Converter Architecture

VEA VEHICLE ELECTRONICS AND ARCHITECTURE

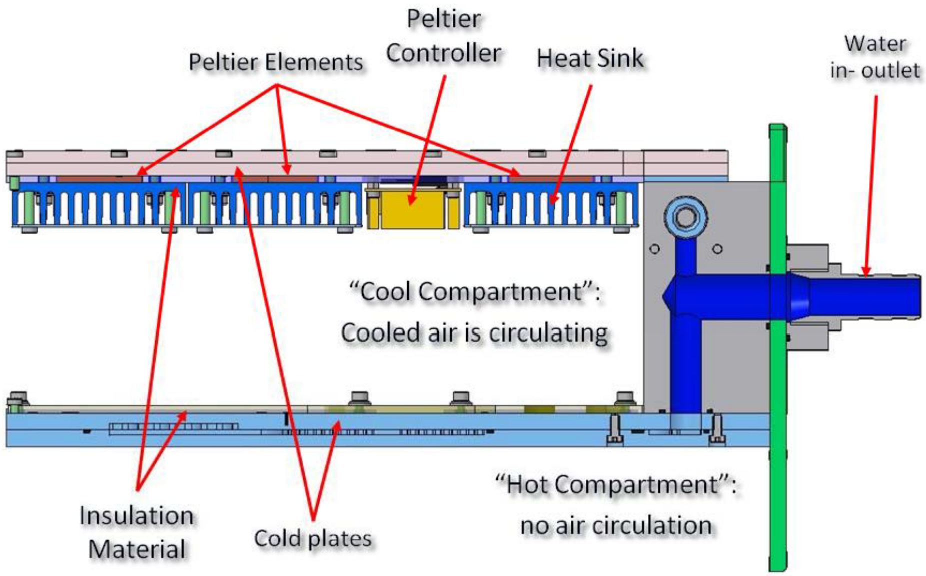
- Bi-Directional
- Eight power phases with 45° phase shift (4x2)
- Individual power chokes
- Dual compartment layout (hot & cool)



Key Design Challenges

VEA VEHICLE ELECTRONICS AND ARCHITECTURE

- Two compartment design
  - Minimize development of new high-temp control electronics (scope, budget constraints)
  - Maintain a lower operating temperature for these items
  - Peltier heat pump power supply
  - Peltier heat pump controller (to improve part-power efficiency)



This development area retains significant room for future power density improvements as high temperature components become more readily available

Key Design Challenges (Cont.)

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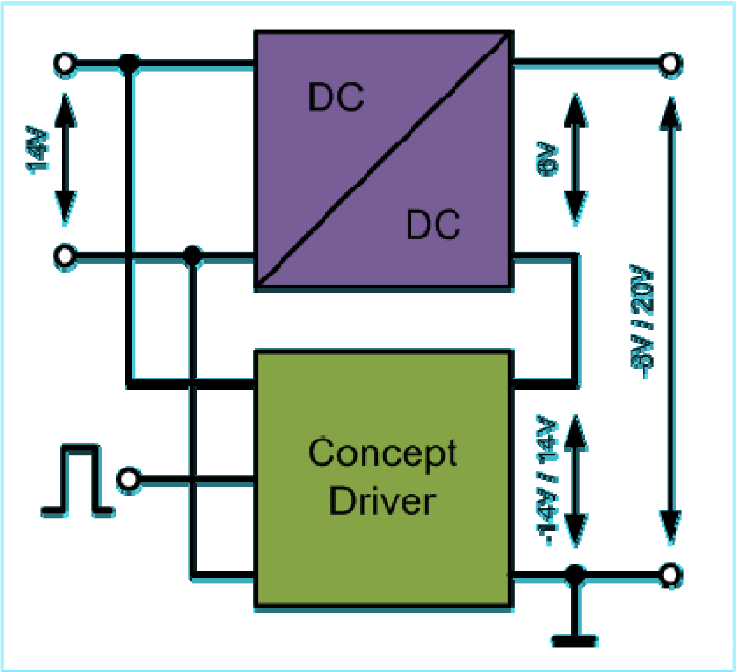
- Gate driver design
  - Must reside with switches in high-temperature compartment
  - Small board-mounted DC converters remain temperature sensitive – cool compartment
    air circulated
  - On/Off driver voltages of -8/+20 reduce conduction losses without need for adjustable output
  - Separate sub-circuit gate drivers used to avoid parallel issues associated with MOSFETs



Initial Test Results (1 of 4)

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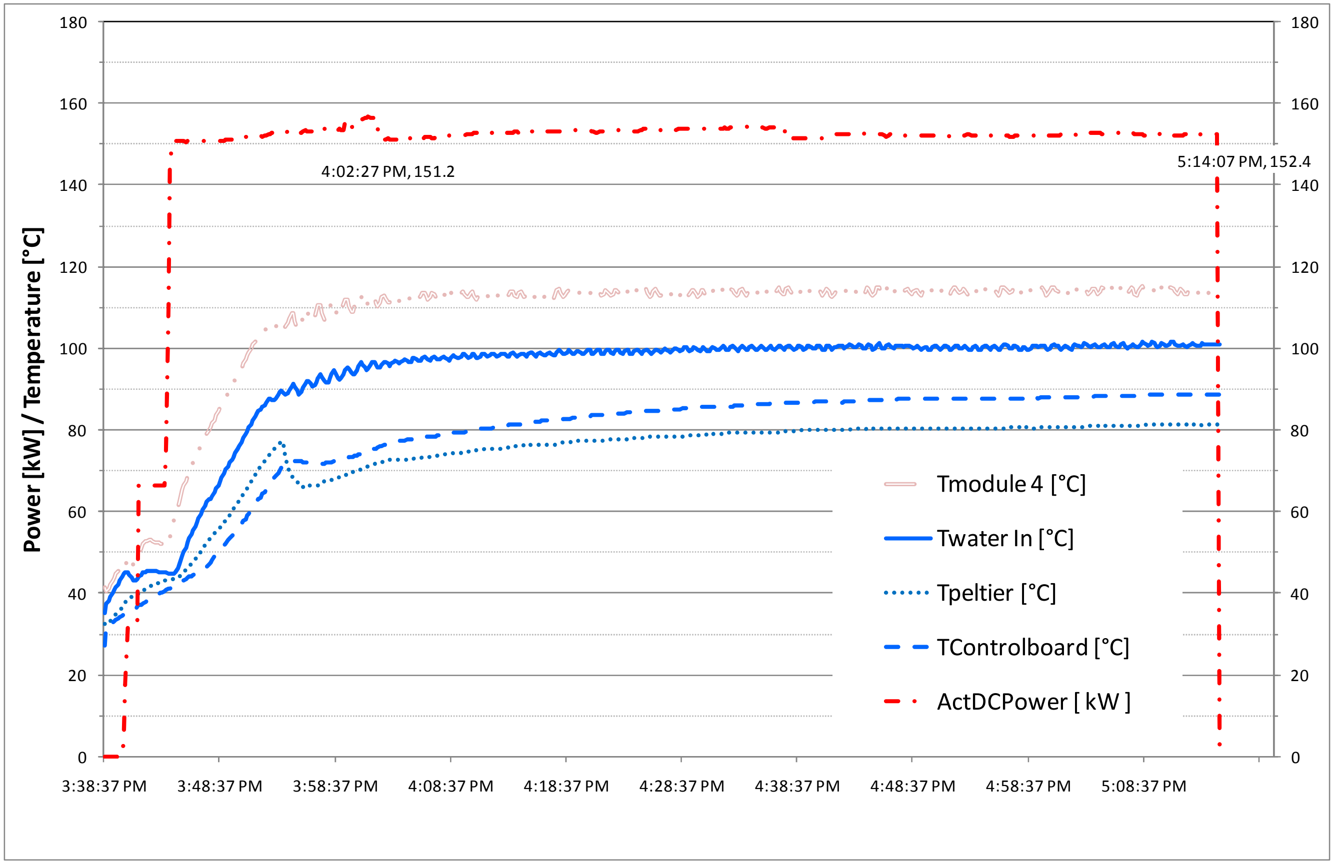
Goal: 150kW Power, Up-Convert, 90°C ambient, 100°C coolant



Continuous power goal met

Initial Test Results (2 of 4)

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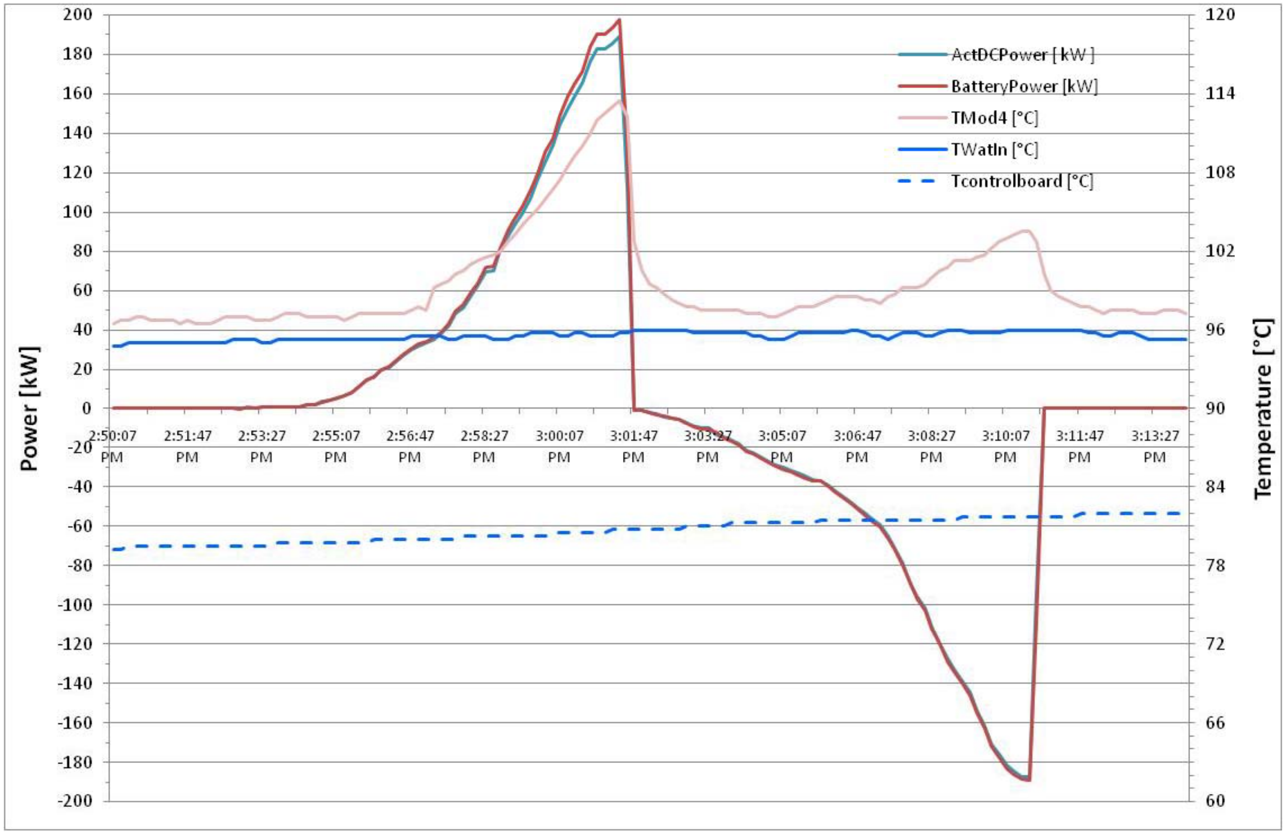
Goal: 180kW Peak Power, 90°C ambient, 100°C coolant



Peak power goal met, charge & discharge

Initial Test Results (3 of 4)

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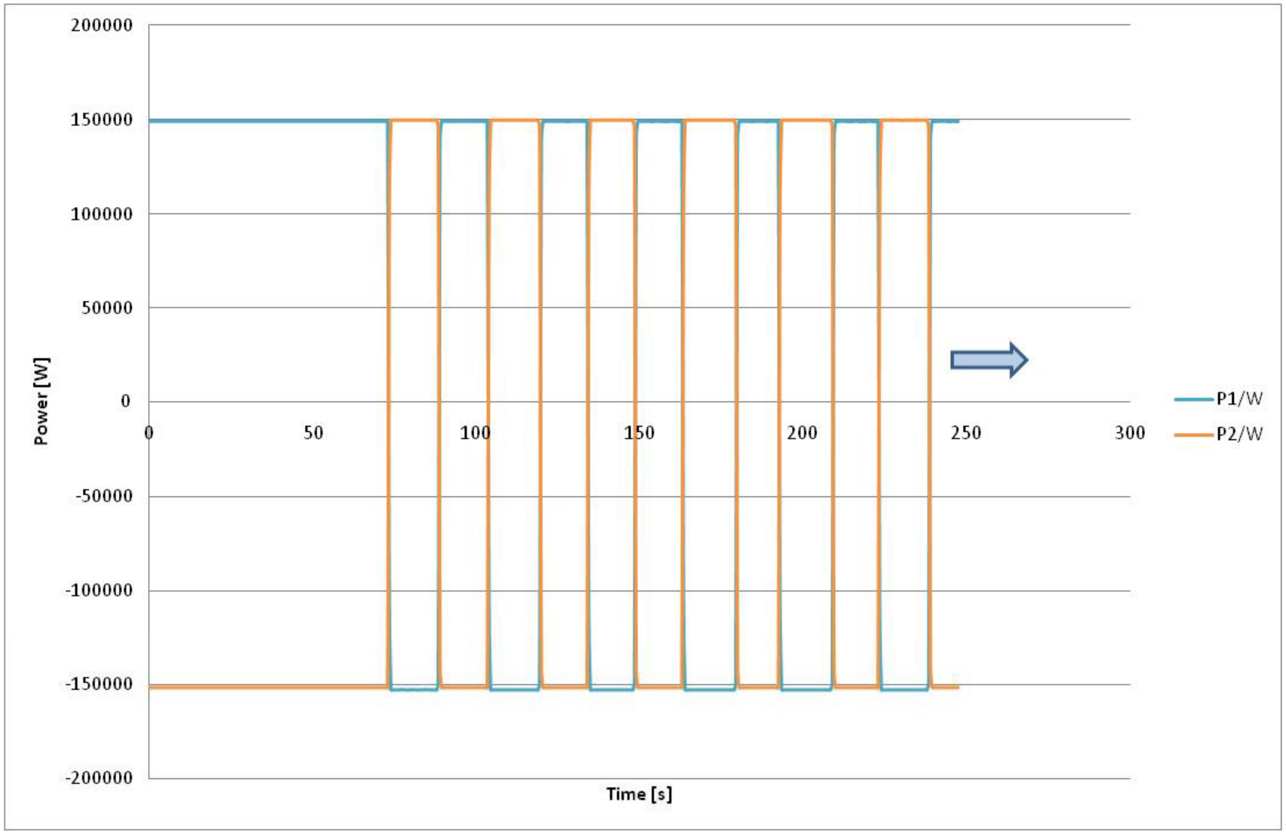
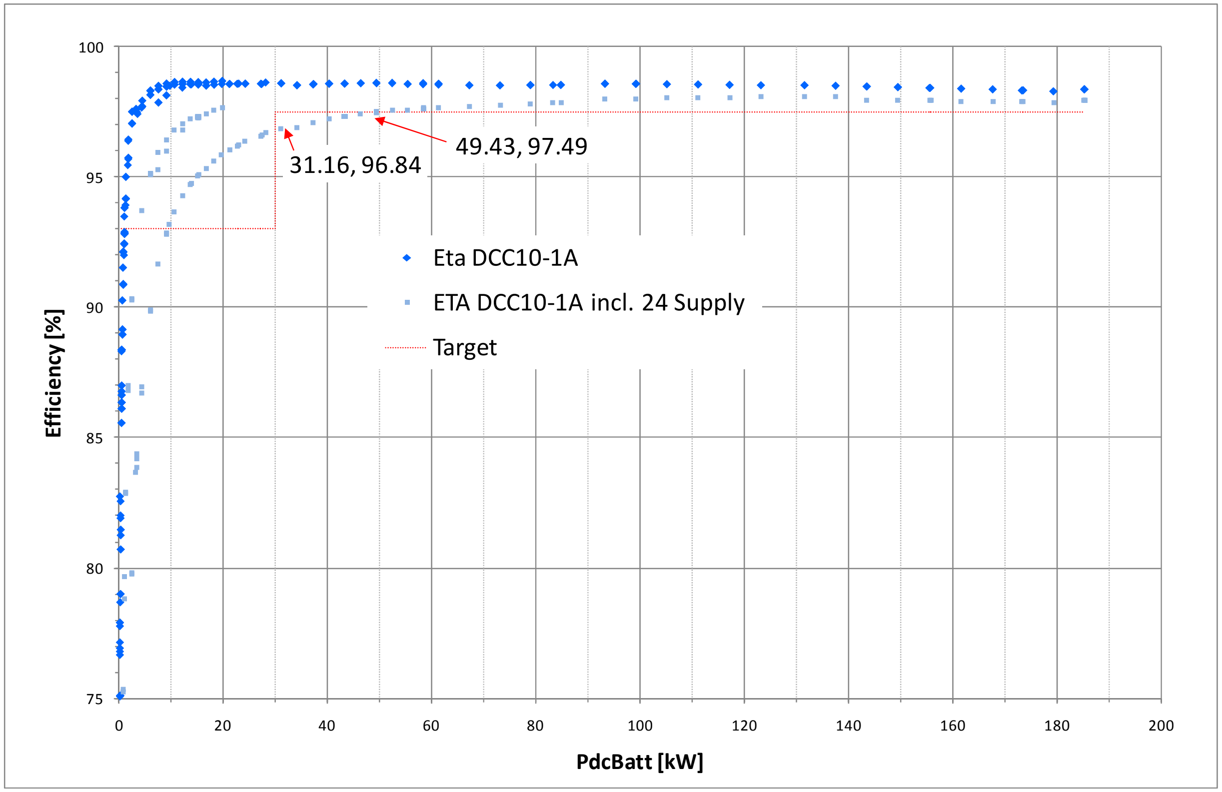
Goal: Buck/Boost 150kW toggle, 90°C ambient, 100°C coolant



150kW Buck/Boost toggle goal met

Goal: Buck/Boost efficiency, 90°C ambient, 100°C coolant

Shown with and without Peltier heat pump power supply



All efficiency targets met for P>2kW, without Peltier power supply

Requirements Compliance

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- ✓ 150kW continuous operation
- ✓ 180kW discharge operation for >20s
- ✓ Voltage maintained within high & low side ranges
- ✓ 100°C coolant inlet full power operation
- ✓ 90°C ambient full power operation
- ✓ ≤12.5 liter/min & ≤172kPa ΔP
- ✓ ≥93% efficiency, 2-30kW*
- ✓ ≥97.5% efficiency, 30-180kW*
- ✓ <45 liters
- ✓ 3.3kW/liter (continuous 150kW rating)
- X 81kg (goal 75kg) – due to added cooling complexity

*For lower temperatures when the Peltier cooling system is not operating

Ambitious Goals – Significant Achievements

Test Plan / Schedule

- Acceptance testing is underway at TARDEC labs
  - Verify steady-state operation up to 150kW and up to 100°C coolant inlet temperature
  - Verify peak operation at 180kW up to 100°C
  - Perform 150kW load cycling: +/-150kW in 15sec intervals for 30 minutes at 100°C coolant inlet temperature
  - Perform load-step testing to evaluate step response of DCC10
- Further testing is planned with TARDEC's Hybrid Electric Reconfigurable Moveable Integration Testbed (HERMIT) to evaluate the DCC10's performance in a real vehicle environment under typical operating conditions

Conclusions

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- Power electronics designs are achievable with high temperature coolant and elevated ambient temperature
- The biggest drawback of this design has been the need for the Peltier cooling system, which can use up to 600W to cool the low-temperature electronics
- High temperature alternatives have been identified for many of the devices that currently reside in the cool compartment of the DCC10
- An improved design eliminating the need for the Peltier system would keep the efficiency of the next generation of converter above 98% down to about 10kW

Questions?

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VEHICLE ELECTRONICS AND ARCHITECTURE

- Additional questions can be directed to:

Brian DeBlanc

L-3 Combat Propulsion Systems

Brian.deblanc@l-3com.com

231-855-0999

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