Bi-directional dc-dc Converter

Including Vehicle System Study to determine Optimum Battery and DC Link Voltages

Dr. Abas Goodarzi
Email: abas@ushybrid.com

Phone: 310-212-1200

Organization: US Hybrid Corporation

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Project Duration: FY2007 to FY2010

Project ID # apep**_06_goodarzi**

Overview

US Hybrid
Mobile Energy Technologies

Timeline

- Project start date: October 2007
- Project end date: December 2010
- Percent complete: 50%

Budget

- Total project funding:
  - DOE share: $1,113,691
  - Contractor share: $668,732
- Funding received in
  - FY08: $593,279
  - FY09: $280,000

Barriers

Barriers addressed

- Low cost (≤ $75 /kW)
- MTBF 10,000 hours.
- High inlet and ambient temperatures (> 105 °C)
- High efficiency (> 95 %)
- High power density (65 W/in3)

Partners

- University Of Illinois-Chicago
- Project lead: Dr. Abas Goodarzi

Objectives

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Reduce the cost of PHEV system

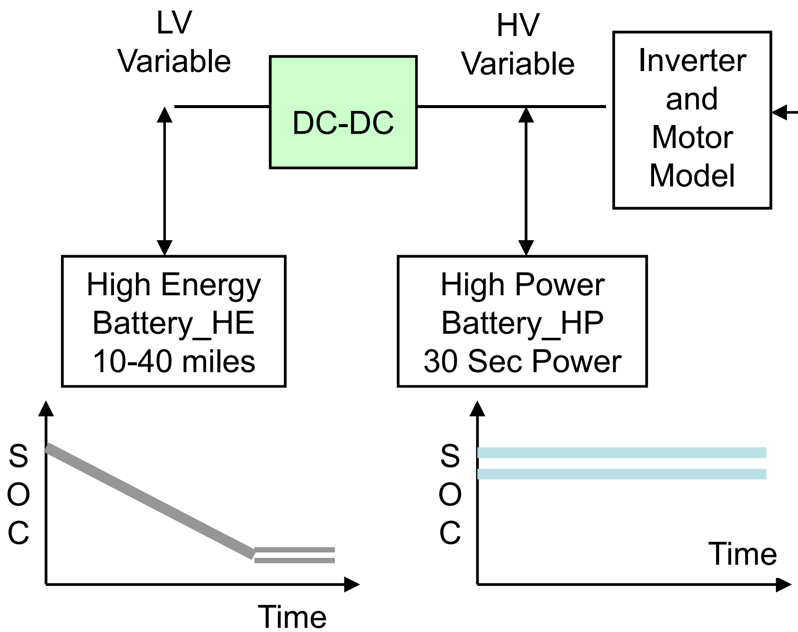
Perform System level modeling to determine optimum operating voltages and Design a bi-directional dc-dc converter and fabricate a 5kW POC unit to demonstrate the following;

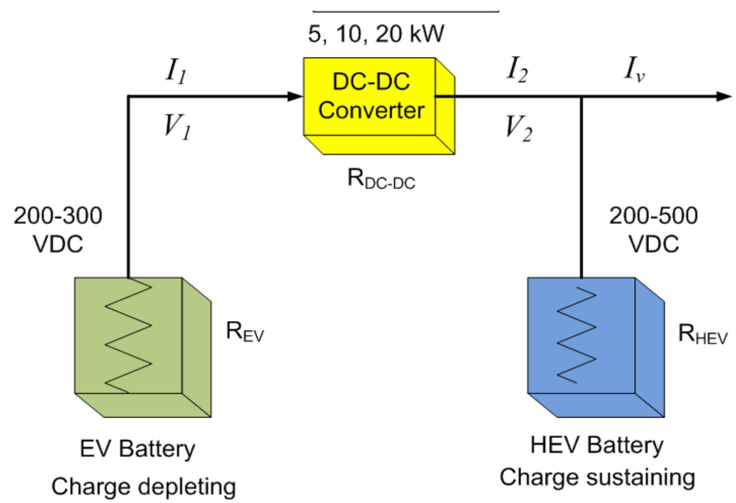
- **High inlet and ambient temperatures (> 105 °C)**
- **High efficiency (> 90 %)**
- **High power density (20 – 50 W/in3)**
- **Low cost (≤ $75 /kW)**

Milestones

1. Define the Vehicle level performance Index determination, objectives and optimize the system operation voltages.
2. Summarize the potential Energy Storage supplier and Technologies for 2010 implementations.
3. Define the system dynamics requirements for the Bi-directional dc-dc converter.
4. Model the power and the integrated magnetic components.
5. Design the SIC converter and determine the performance.
6. Design the Si converter and determine the performance.

Approach





To reduce life cycle cost of PHEV we propose dual battery system with bi-directional dc-dc.

- The Vehicle performance and handling is not compromised as the battery is operating in low SOC after charge depletion operation mode.
- The Battery energy capacity can be fully utilized, enhancing the EV only range for the size of battery.
- The battery system life cycle for the charge depletion battery is based on the charge cycles, while the HEV battery life cycle is for power cycling at higher SOC band of operation.

Technical Accomplishments

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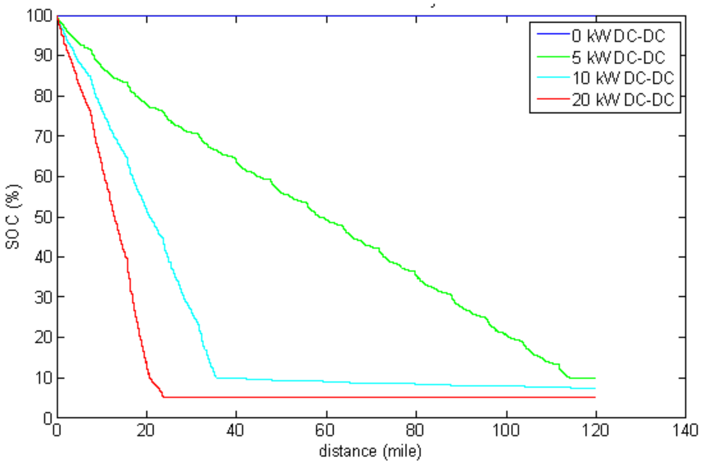
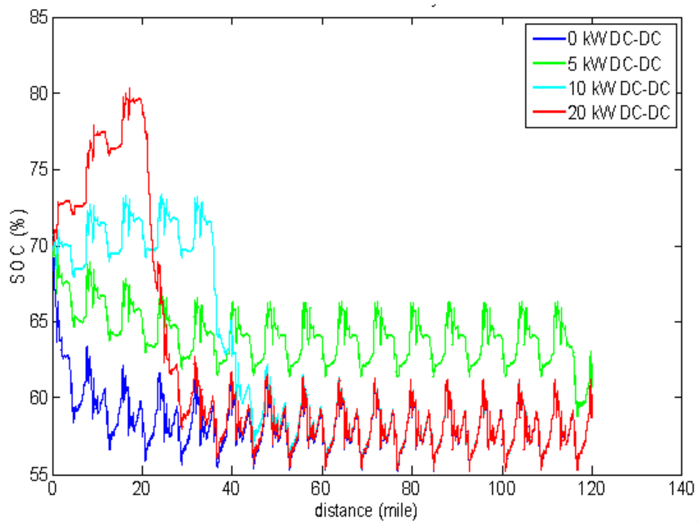
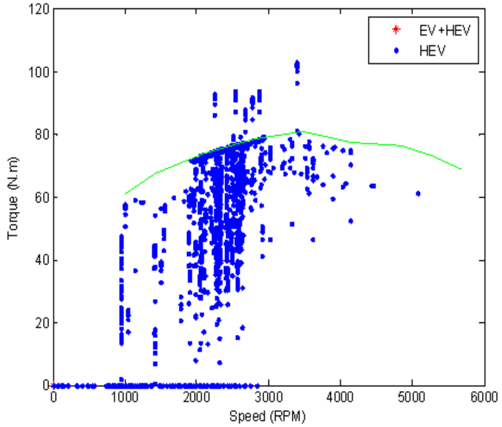
Vehicle System Modeling

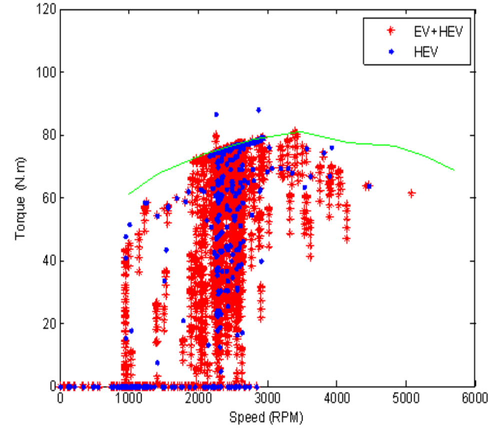




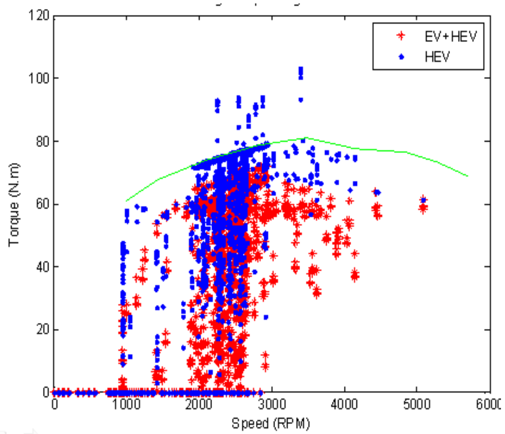
P_{DC-DC}=0 kW



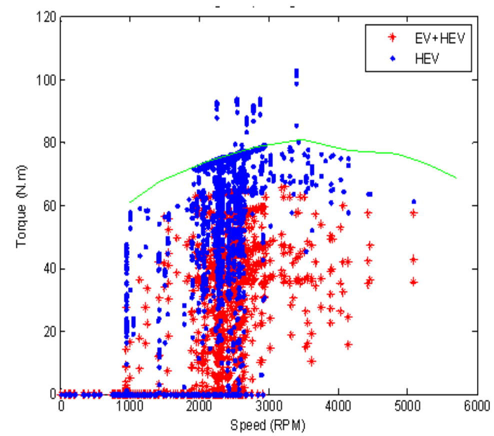
P_{DC-DC}=5 kW



P_{DC-DC}=10 kW

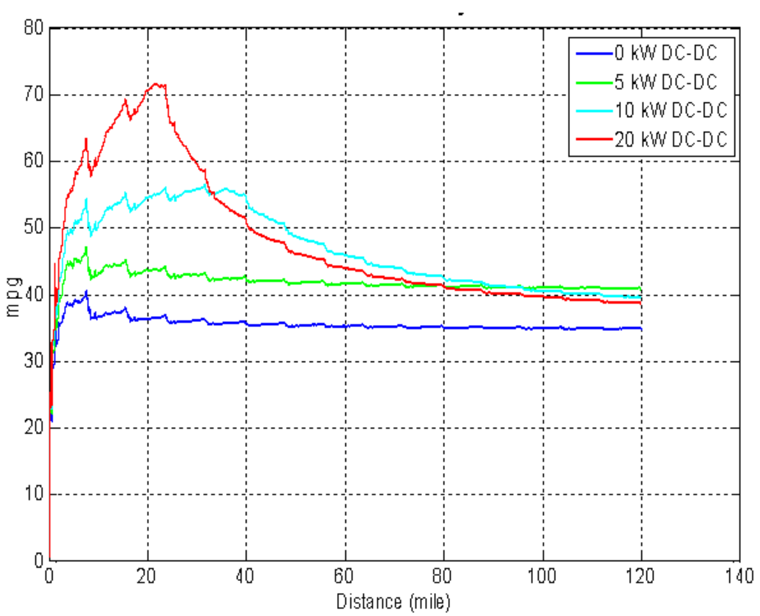


P_{DC-DC}=20 kW

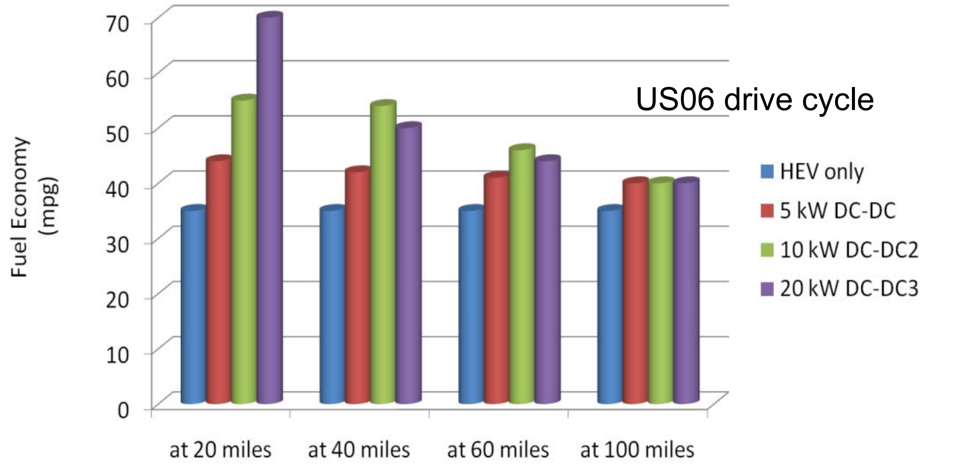


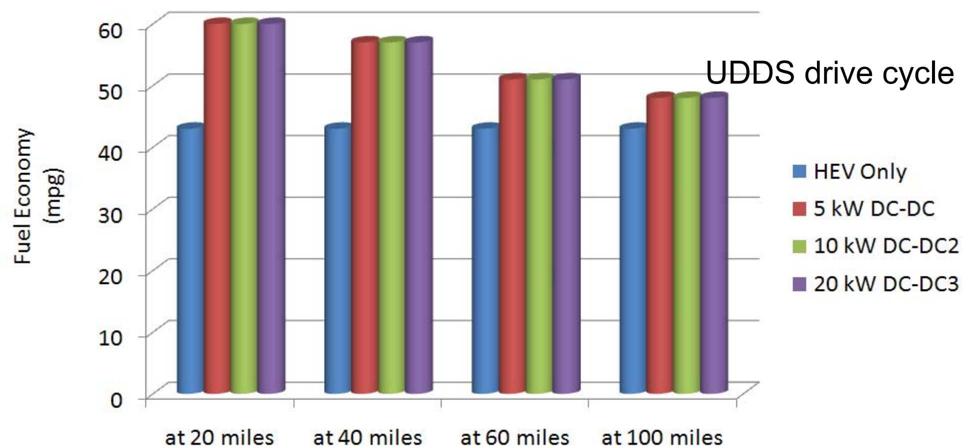
Technical Accomplishments

Vehicle System Modeling



Fuel Economy MPG vs. miles driven (US06 drive cycle)





dc-dc sizing

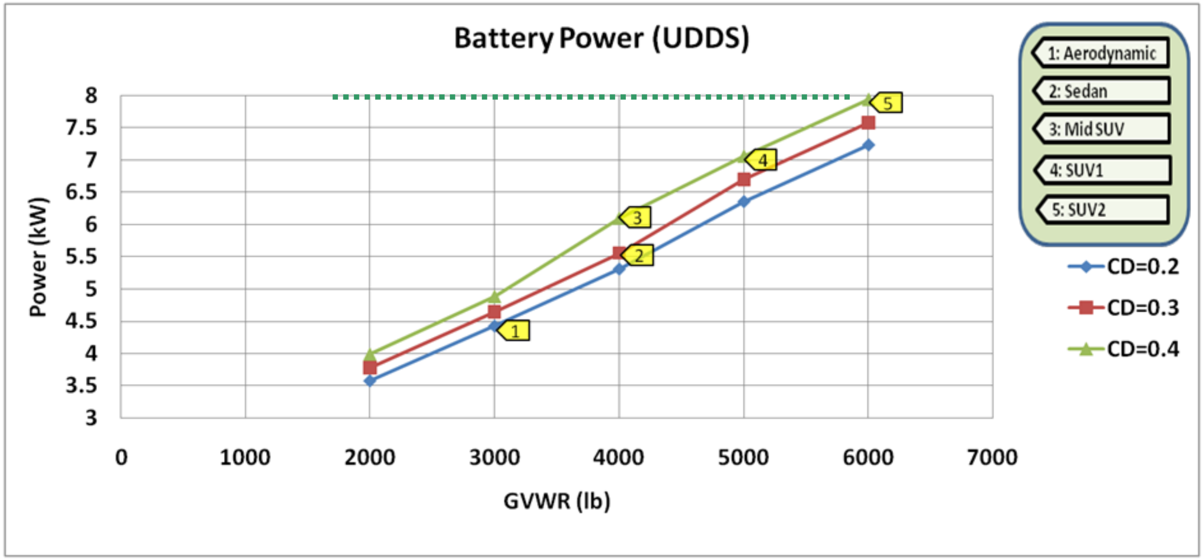
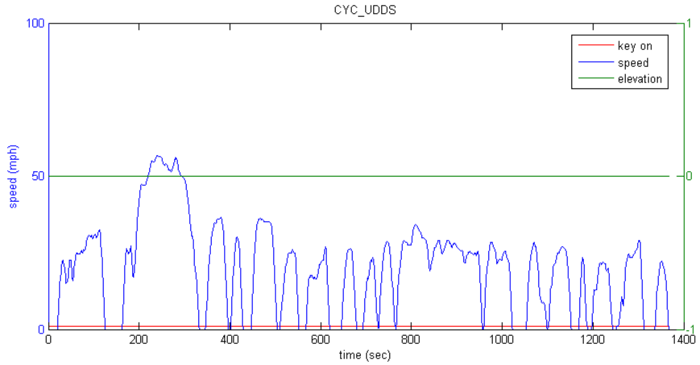
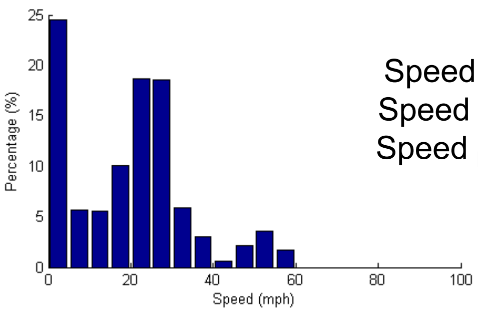


Fig. 4: Battery power requirement for electric vehicle (EV) (UDDS drive cycle)

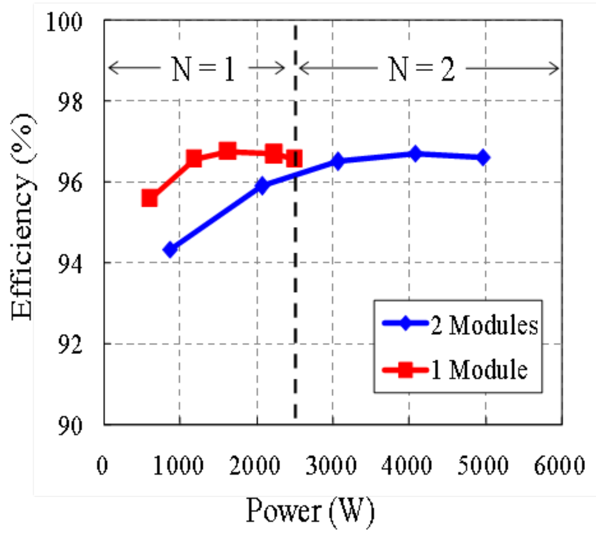


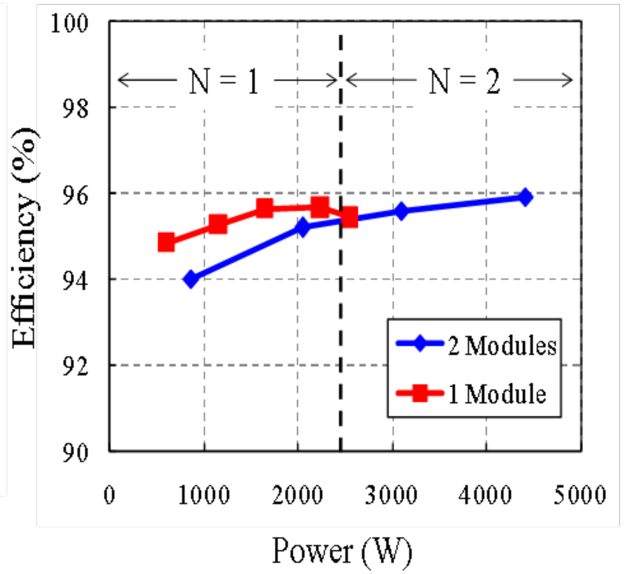


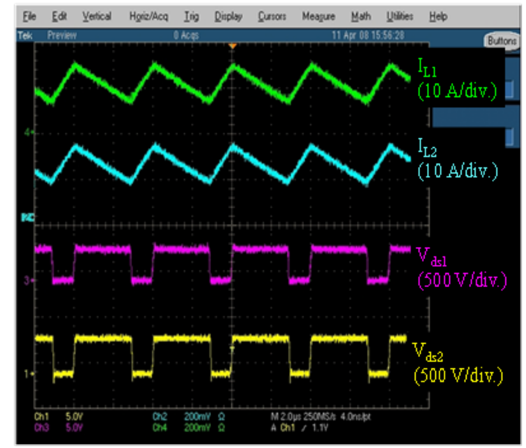
Speed $_{max}$=56.7 mph
Speed $_{ave}$=19.58 mph
Speed $_{RMS}$ =24.5 mph

Fig. 2: Urban Dynamometer Driving Schedule (UDDS)

SIC based dc-dc performance



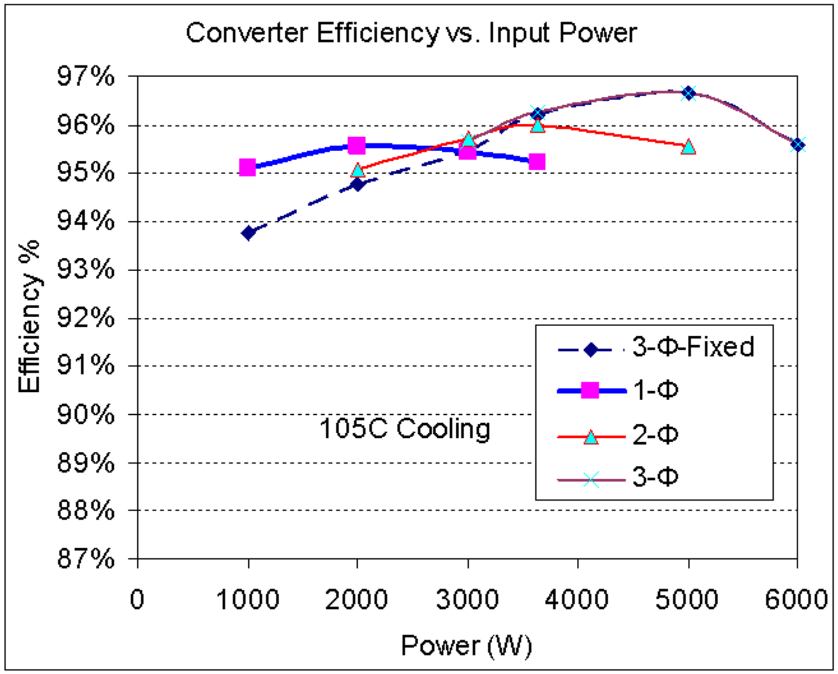


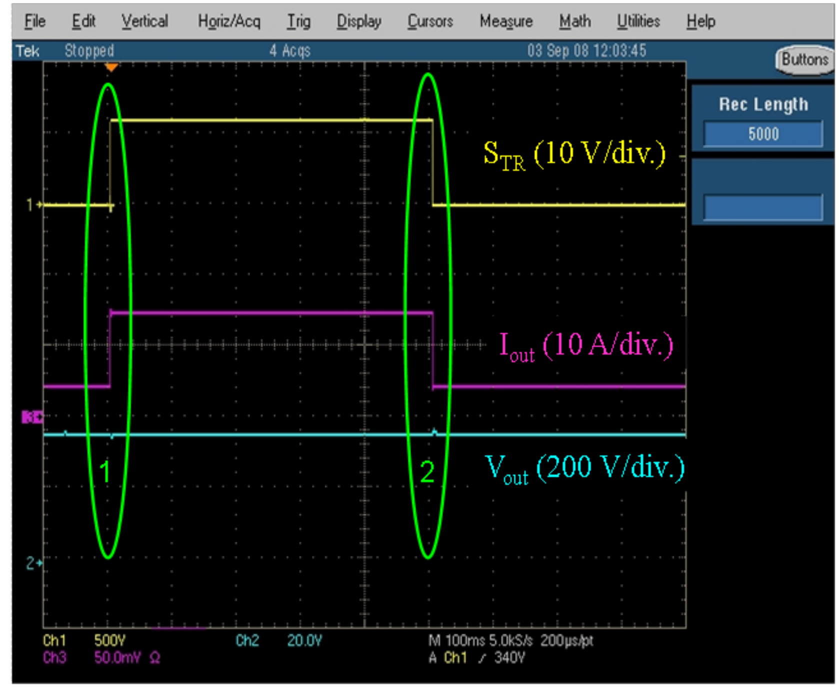


(a)	(b)
Variation of efficiency of the bidirectional dc/dc converter at 140 °C case temperature for; (a) V_{in} = 250 V, (b) V_{in} = 200 V. Clearly, dynamic power management by switching the number of modules (as the load varies) is an effective method to increase the efficiency at lower loads.	

Input currents of the two converter modules for V_{in} = 250 V, V_{out} = 350 V, and T = 105 °C for P = 5000 W. Switching Frequency of 250kHz each

SI based dc-dc performance





MOSFET converter operating at 50 kHz, Vin=200V and Vout=350V.

Fast Dynamic response 100ms/div.

Phase-I summary

Phase-I summary:

- Vehicle level performance, component Optimization and hybrid control system completed. Dual battery system can increase the efficiency by 13%-18%.
- SIC and SI based converters and critical components have been modeled and simulated.
- SIC and SI converter components performance has been validated by actual test data.
- Dc-dc converter sizing has been modeled and determined.

Phase I recommendations:

We recommend an 8kW dc-dc converter to meet the SUV class vehicles driving at UDDS, which is most typical of urban driving for PHEV application.

Project tasks for FY09

The Milestones of Phase II are as follows:

I. To design, develop and complete performance validations of the production intent prototype high power density power 8 kW bidirectional dc/dc boost converter. Vin=150V-300V, Vout=300V-500V and meets a DOE cost target of $75/kW

II. To demonstrate a power-conversion efficiency of 95% or more at a junction temperature of 130-150 oC corresponding to an inlet coolant temperature of 105 oC

III. To realize a power density of at least 1kW/l and a specific power of at least 0.8 kW/kg by operating the multi-phase converter at a modular switching frequency of 100 kHz.

IV. To realize a current loop bandwidth of 20 kHz and higher.

Project tasks for FY09 Cont.

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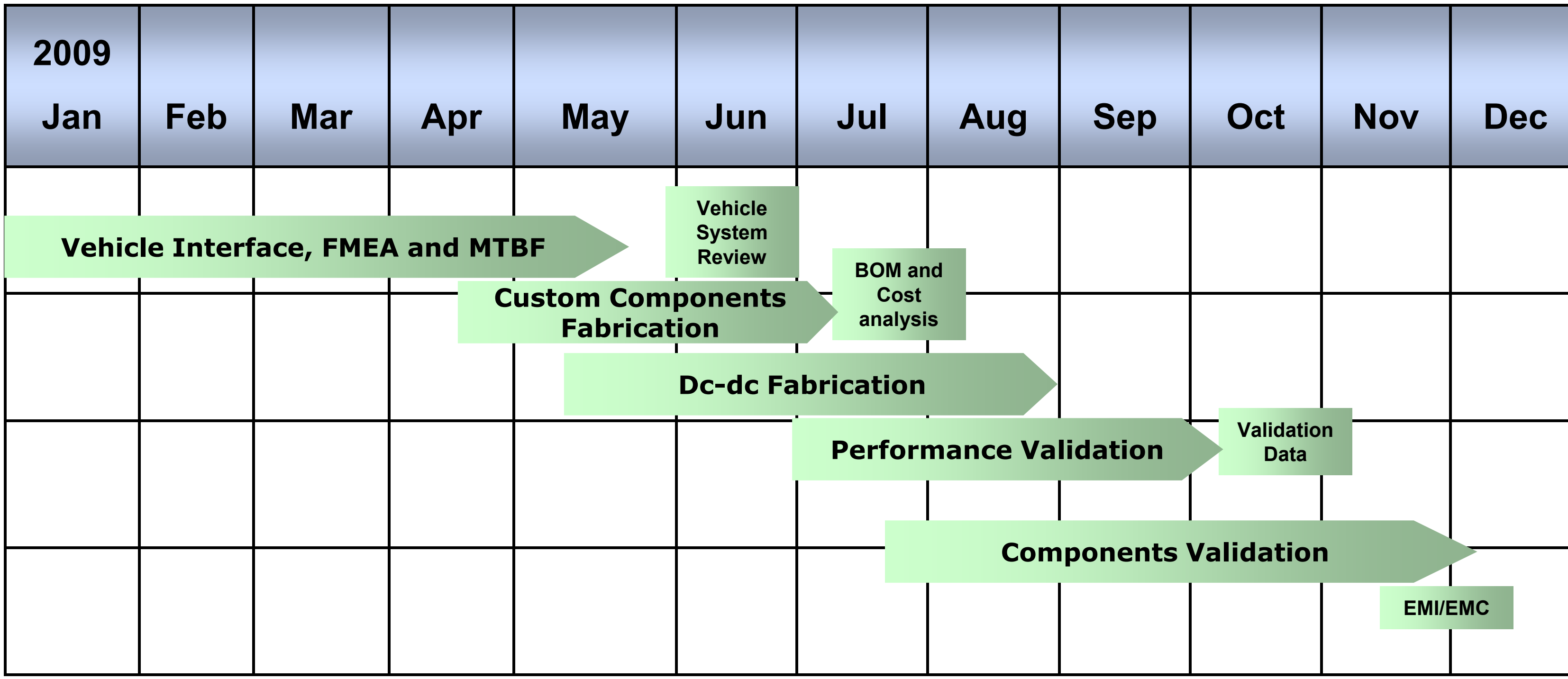
Fabricate a 8kW rated Proof Of Concept "POC" unit and provide design validation testing of the POC unit for performance validation testing, to achieve the following;

- High inlet and ambient temperatures (> 105 ° C)
- High efficiency (> 95 %, Originally 90%)
- High power density (20 – 50 W/in^3, achieved >65W/in^3)
- Low cost (≤ $75 /kW)

Phase II, Timeline



Phase-I Summary and Recommendations

Phase-I summary:

- Vehicle level performance, component Optimization and hybrid control system completed. Dual battery system can increase the efficiency by 13%-18% and reduce battery initial and life cycle cost and provide flexibility in system design.
- SIC and SI based converters and critical components have been modeled and simulated.
- SIC and SI converter components performance has been validated by actual test data.
- Dc-dc converter sizing has been modeled and determined.

Phase I recommendations:

We recommend an 8kW bi-directional dc-dc converter to meet up to the SUV class vehicles driving at UDDS, which is most typical of urban driving for PHEV application.