Power Electronics R&D

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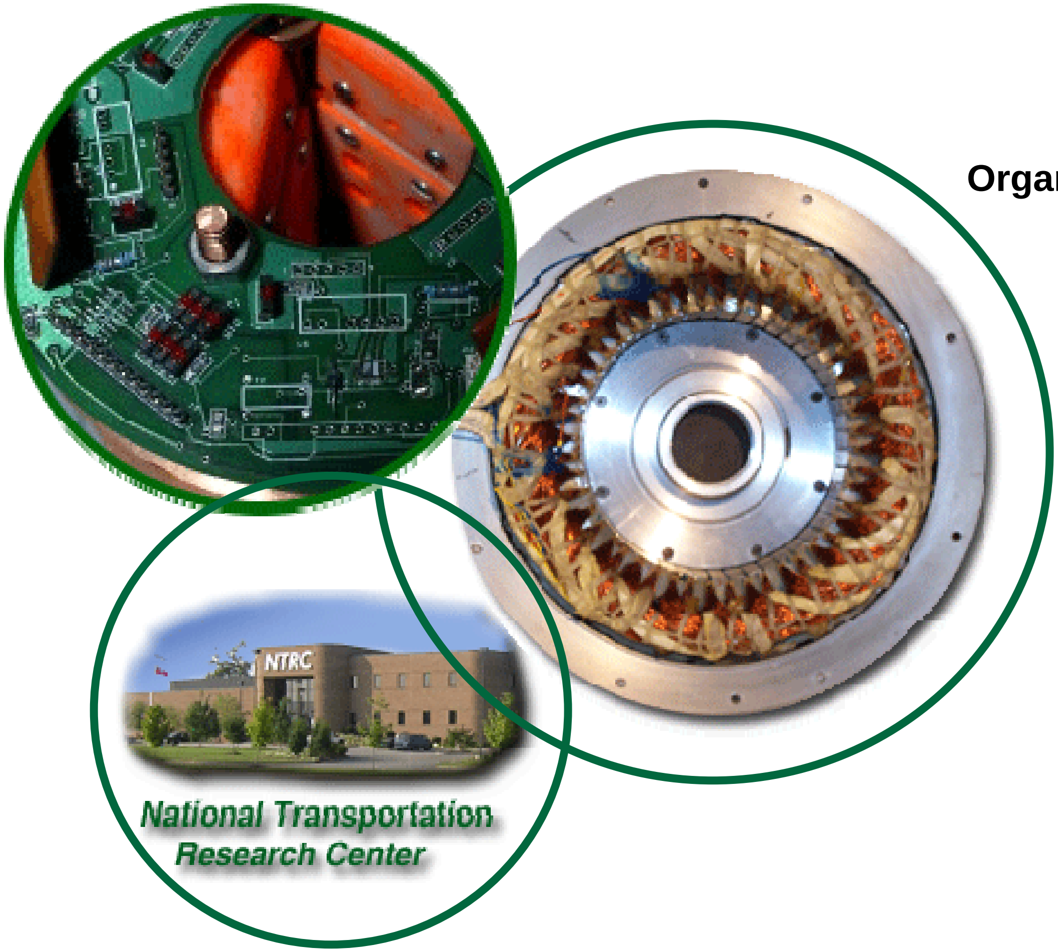

DOE Vehicle Technologies Program
Overview of DOE VTP APEEM R&D

North Marriott Hotel and Conference Center
Bethesda, Maryland

February 28, 2008

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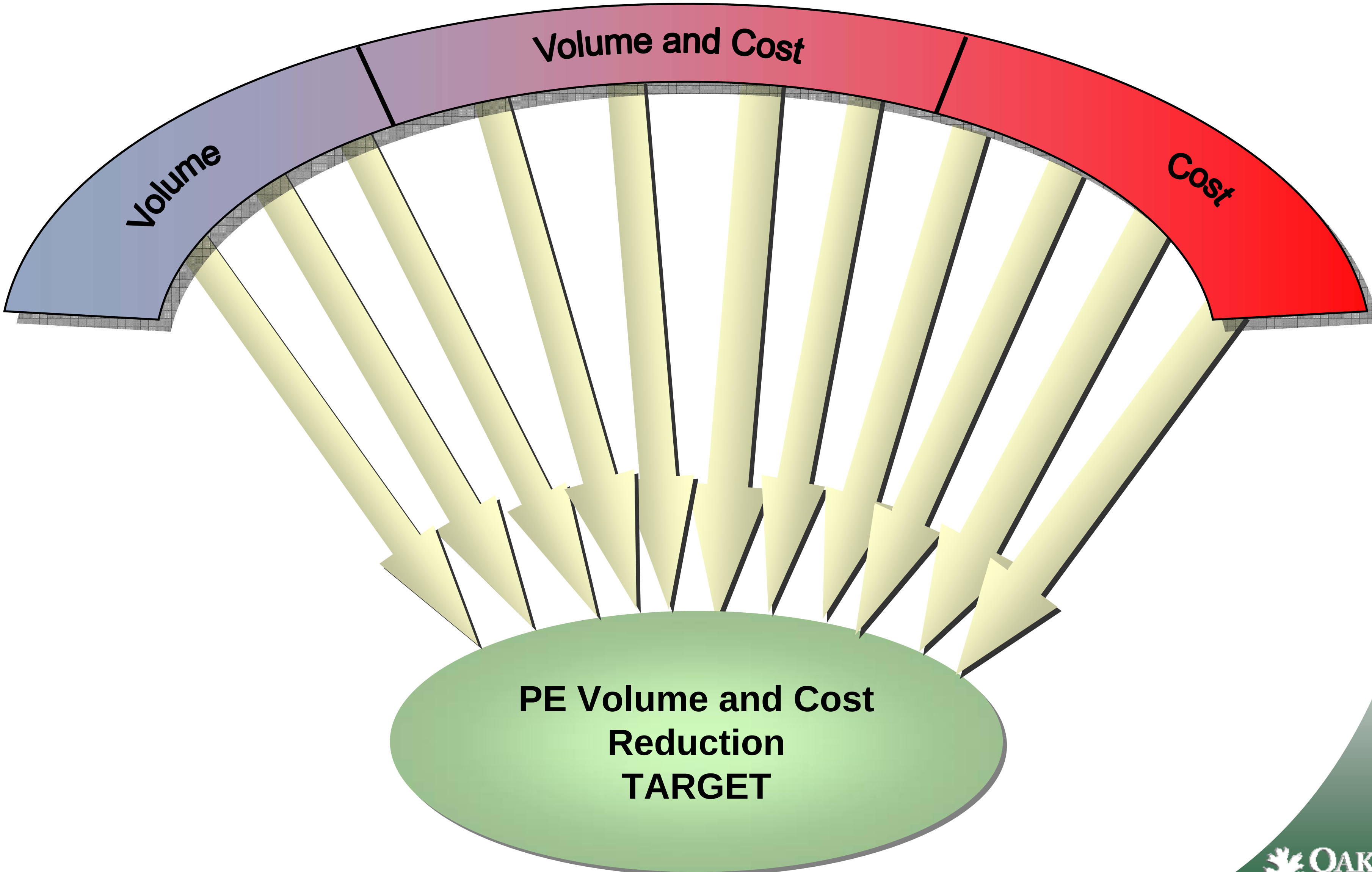
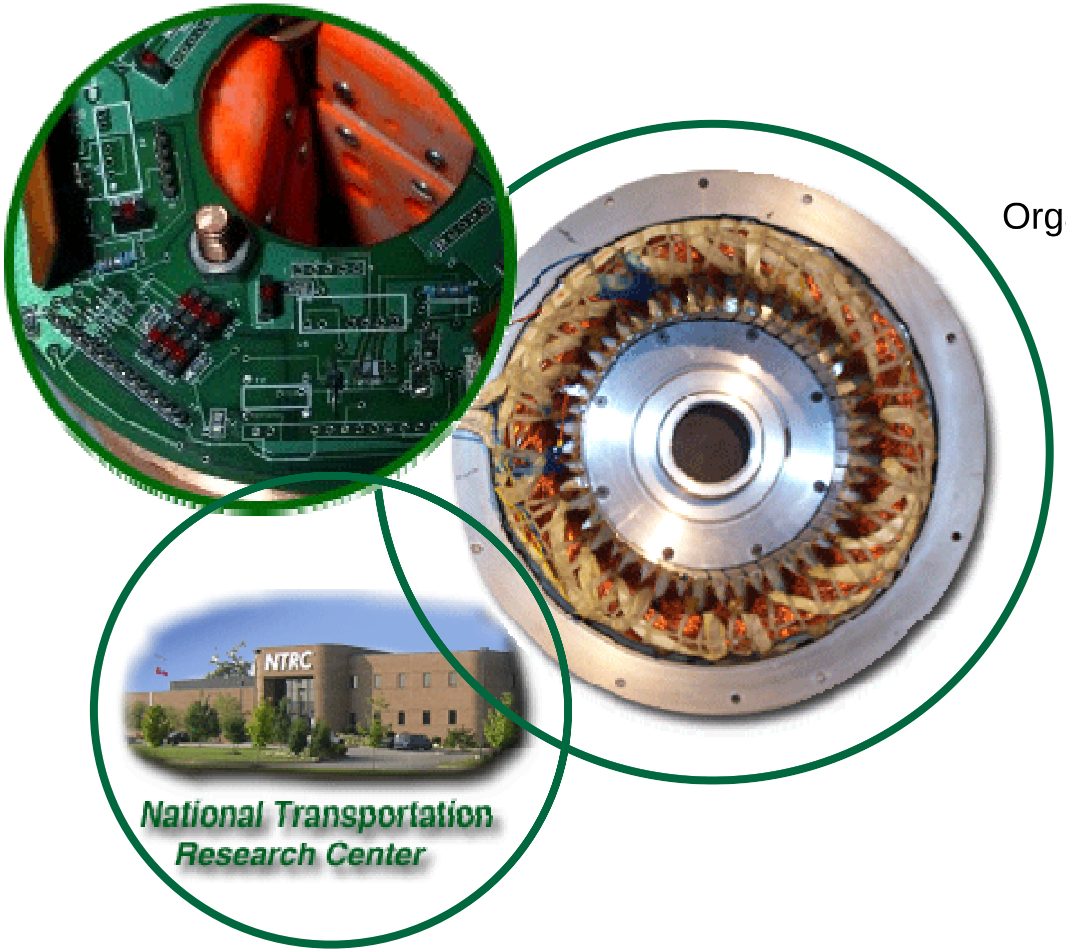
Multiple Pathways Pursued: Increase Potential for Success and Provide Portfolio of Options



Projects vs. Pathways

	Decrease Reject Heat	Increase Heat Xfer	Increase Temp Capability	Eliminate Separate Cooling Loop	Increase Cap Performance	Reduce Cap Requirements	Eliminate Boost Converter	Reduce Manufacturing Costs	Reduce Part Count	Reduce Component Costs	Sub Less Costly Components
Current Source Inverter		X				X	X		X		X
Utilizing the Traction Drive Power Electronics System to Provide Plug-in Capability for PHEVs	X	X				X		X	X		
Advanced Converter Systems for High Temp HEV Environments	X	X	X	X							
An Active Filter Approach to the Reduction of the DC Link Capacitor			X			X					X
Wide Bandgap Materials	X	X	X	X		X					
High Dielectric Constant Cap for PE Systems			X		X					X	
Glass Ceramic Dielectrics for DC Bus Capacitors			X		X					X	
High Temperature Film Capacitors			X		X					X	

Current Source Inverters for HEVs and FCVs



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Principal Investigator: Gui-Jia Su
Agreement: 13268

Project Duration: FY07 to FY10
FY08 Funding: $772K

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Purpose of Work

Demonstrate that the current source inverter (CSI) is capable of

- **Integrating voltage boost function into the inverter thereby eliminating the need for a separate boost converter**
- **Reducing the cost and volume by 25% compared to a comparable voltage source inverter**
- **Reducing capacitance requirements by more than 50%**
- **Reducing levels of electromagnetic interference (EMI)**

Responses to Reviewers' Comments

This is a new start in FY08; no previous review has been conducted

Barriers

VTP Related Challenges

- **Because the commercial availability of reverse blocking IGBT modules is unknown, industry may be reluctant to embrace the approach.**

Technology Related Challenges

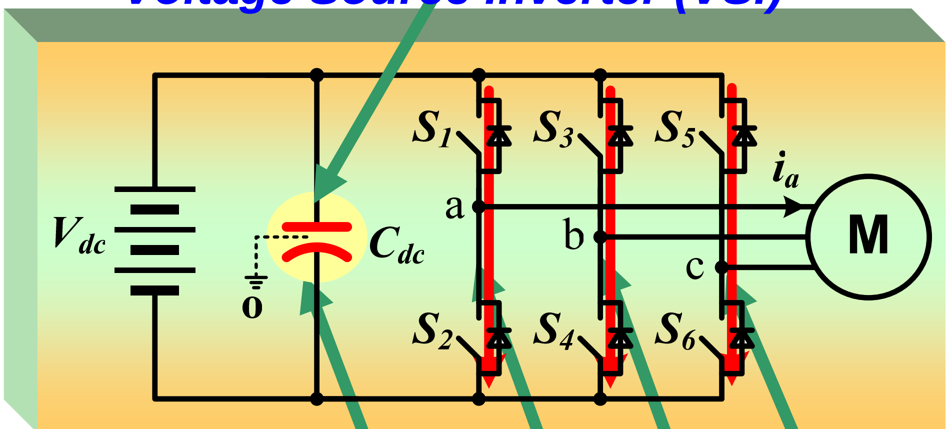
- **Reverse blocking IGBT modules are still under development. Engineering samples are available from Fuji Electric but difficult to obtain.**
- **Incorporating regeneration function into CSI.**

Technical Approach Background

- **The voltage source inverter with many drawbacks presents tough hurdles for meeting the DOE targets, especially at high coolant temperatures.**

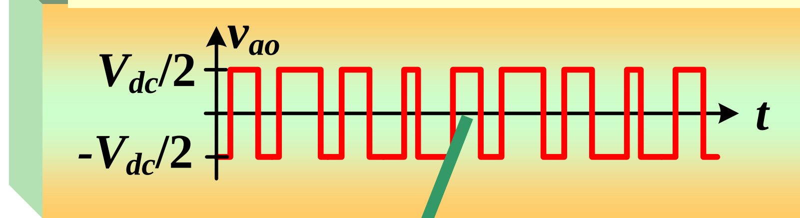
  - **Costly and bulky, about ⅓ of inverter volume and cost**
  - **A major hurdle for high-temperature operations**

Voltage Source Inverter (VSI)



- **Possible shoot-through limits long-term reliability**

Undesired voltage waveform

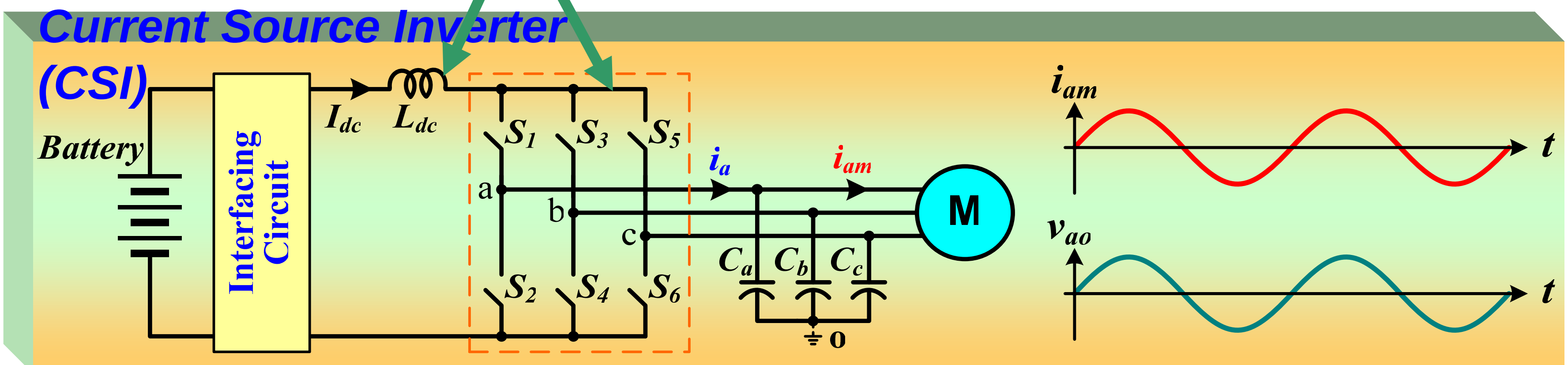


- **High EMI noises**
- **High stress on motor insulation**
- **High-frequency losses**
- **Bearing-leakage currents**

Technical Approach (cont'd)

- **The CSI with a novel interfacing circuit**

-
  bulky DC bus capacitor
- **Eliminate the antiparallel diodes**
- **Not only tolerate phase-leg shoot-through, but used to boost output voltage**



- ***ble the CSI to control the motor at low speeds and charge the battery***

-
  currents to the motor

Technical Approach (cont'd)

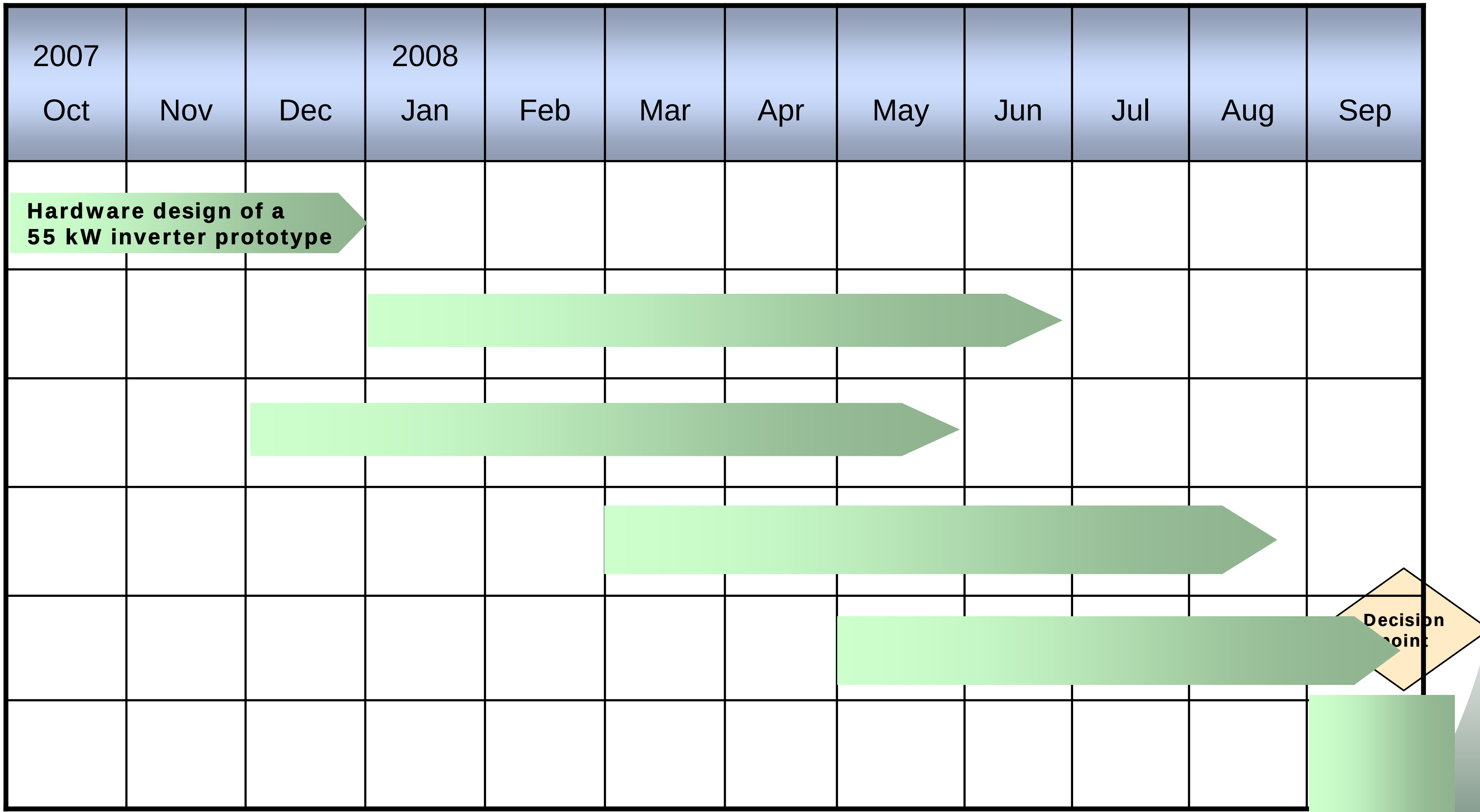
1. **Design – Incorporating the simulation study, a 55 kW inverter prototype will be designed**
   - **IGBT modules**
     IGBT and diode chips connected in series
   - **Inductor**
   - **Power circuit layout**
   - **Heat sink**
   - **DSP control PCB based on TI TMS320F2812**
   - **Gate driver PCBs**
2. **Fabricate – A prototype of a 55 kW inverter will be fabricated based on design specifications**
3. **Develop DSP control code – The maximum torque per amp control algorithm for interior permanent magnet (IPM) motors will be implemented**
4. **Test and evaluate – The 55 kW prototype will be tested at first with a R-L load and then with a permanent magnet (PM) motor**

Technical Approach - Uniqueness

- **Use of a novel interface circuit to enable the CSI to**
  - **Operate from a voltage source (battery) and control a motor from 0 to higher motor speed**
  - **Charge the battery during dynamic breaking**

- **Impacts**
  - **Reduce cost and volume**
  - **Improve inverter and motor lifetime**
  - **Increase motor efficiency**
  - **Increase constant-power speed range**
    - **Eliminate need for boost converter**
  - **Reduce the cost and size of batteries in plug-in HEVs**
  - **Enable SiC based inverters operate at elevated temperature environments**

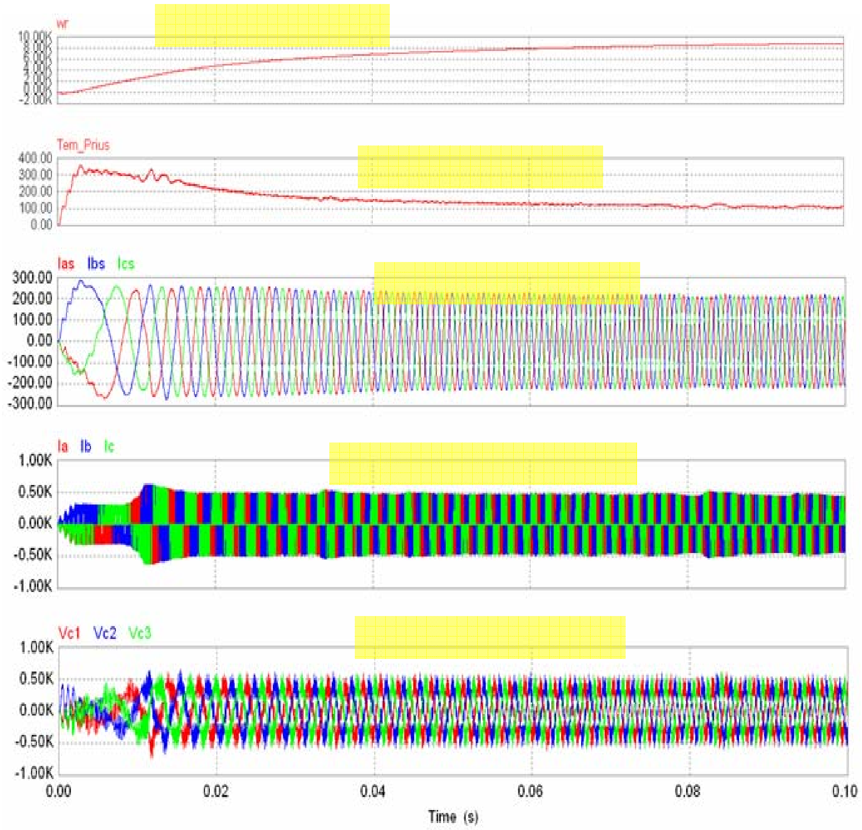
Timeline for FY08



Decision point discussion: Prototype and test results will be evaluated on the potential of the current source inverter to operate with a 105º C coolant.

Technical Accomplishments FY08

- **Completed simulation study and proved the concept**
- **Investigated both carrier based and space vector PWM schemes and developed an optimum PWM method for prototype development**
- **Developed a strategy for maximum torque per amp control of IPM motors**
- **Completed a hardware design of a 55 kW prototype**



Technology Transfer

- **Held discussions with industry for possible technology transfer and have received positive feedbacks.**

- **This work would eliminate the hurdles of capacitors for an inverter to operate at elevated temperature environments and thus support the introduction of 105°C engine coolant cooled inverters.**

Future Work

- **FY09**
  - **Redesign a prototype that can operate with a 105°C coolant**

- **FY10**
  - **Test the prototype with a 105°C coolant**

Summary

- **The proposed CSI can**
  - **Operate a motor from a battery from 0 to higher speed with a voltage boost ratio of 3**
  - **Charge the battery during dynamic breaking**
  - **Reduce the capacitance by 90%**
  - **Improve inverter and motor lifetime**
  - **Reduce the cost and size of batteries in plug-in HEVs**
  - **Eliminate the hurdles of capacitors for an inverter to operate at elevated temperature environments**
- **Work is progressing on schedule**
  - **A hardware design of a 55 kW prototype has been completed and prototype fabrication is ongoing**
  - **Design of DSP control and gate driver PCBs is continuing**
- **Discussions with Industry have been held for possible technology transfer**
- **In FY09, a new prototype will be designed for operating with a 105°C coolant**

Publications, Presentation, Patents

- **A patent application is being filed.**

Questions

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Utilizing the Traction Drive Power Electronics System to Provide Plug-in Capability for HEVs

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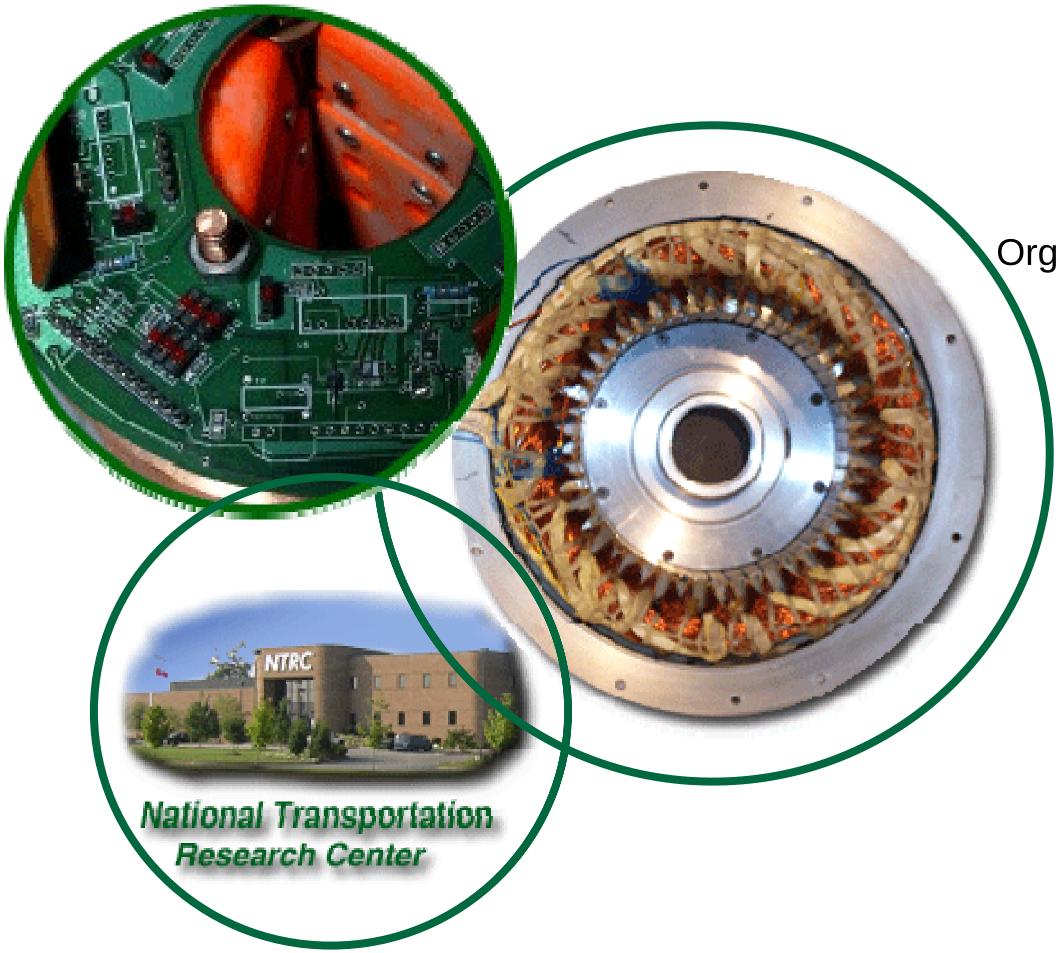

Principal Investigator: Gui-Jia Su
Agreement: 13270

Project Duration: FY07 to FY10
FY08 Funding: $662K

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Purpose of Work

- **Demonstrate the proposed charging design is capable of**
    - **Rapid charging at greater than 20 kW**
    - **A 95% reduction in cost and volume compared to standalone battery chargers**

Responses to Reviewers' Comments

This is a new start in FY08; no previous review has been conducted

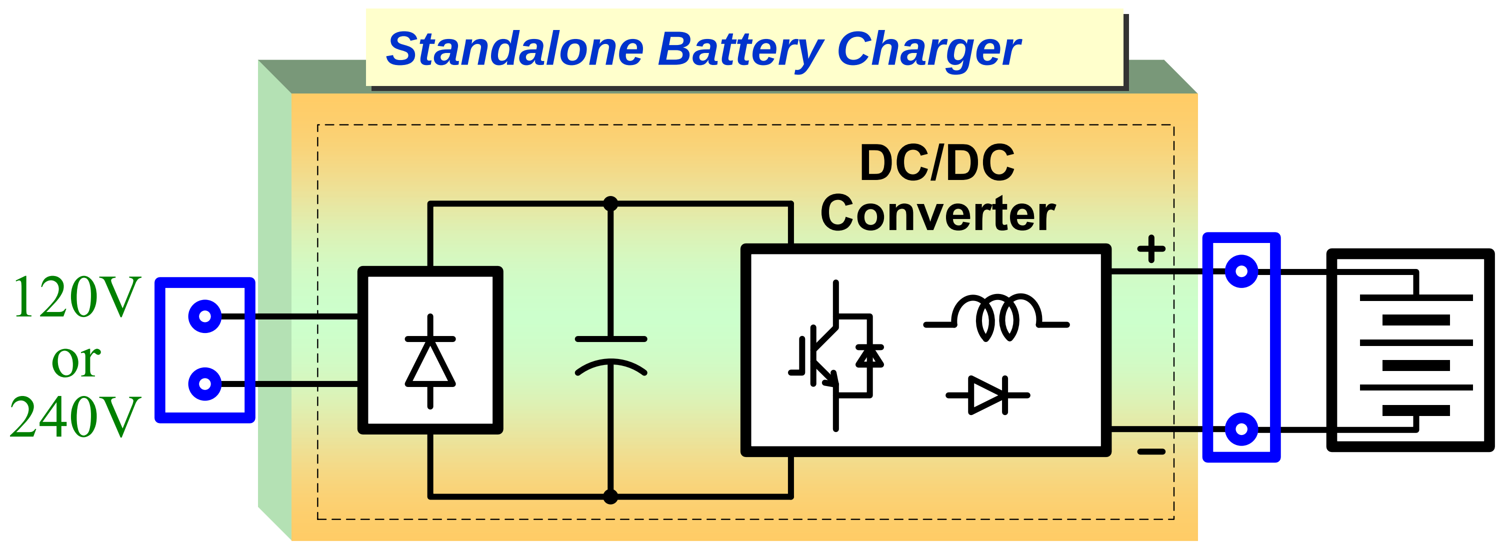
Barriers

VTP Related Challenges

- High power charging stations are not widely available for using a rapid charging capability.
- Grid interface codes and regulations for smart charging and V2G have not been established.

Technical Approach Background

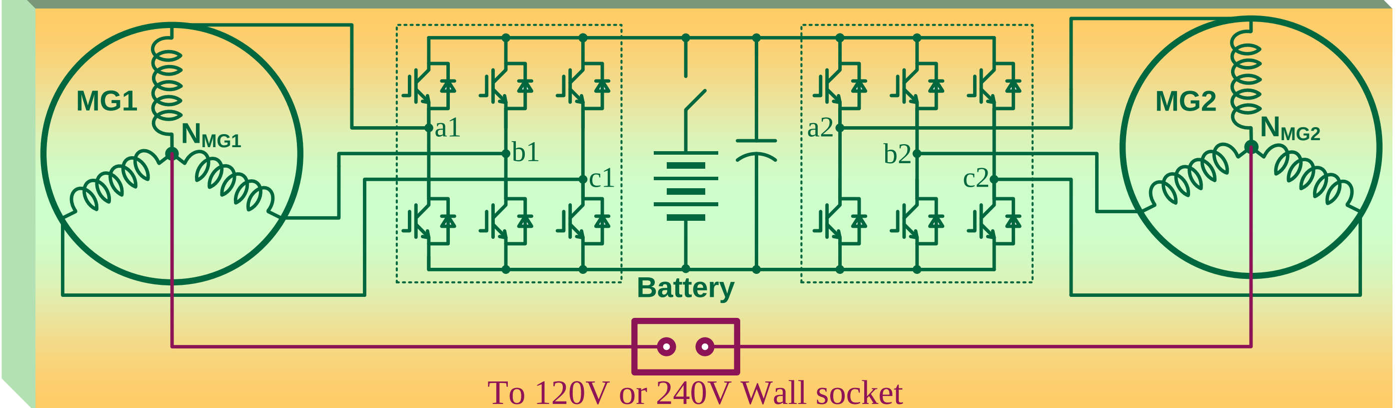
- **Drawbacks of standalone battery chargers**
  - **Need additional components**
    - **switches, diodes, inductors, capacitors**
  - **Adds a significant cost**
  - **Have limited charging capability, long charging times**
  - **Unidirectional (can only charge the battery)**



Technical Approach (cont’d)

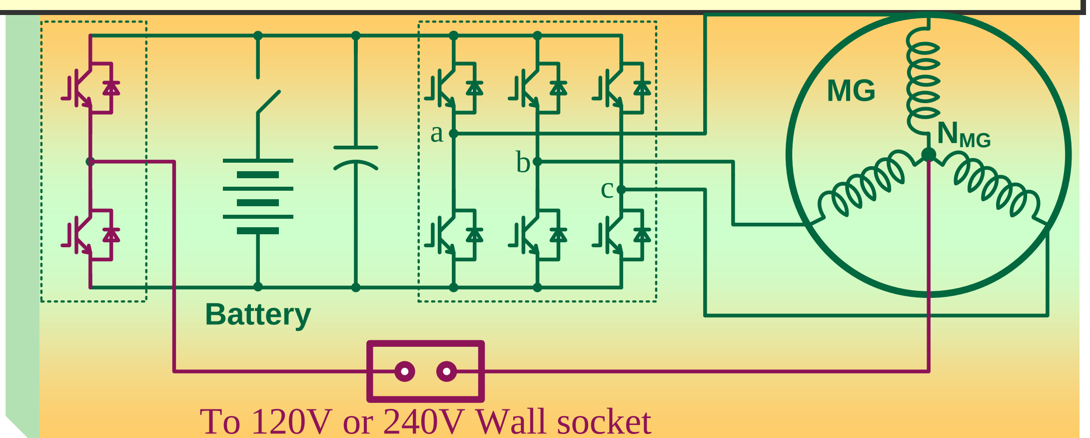
- **Utilize onboard inverter(s) and motor(s)**

For HEVs using multiple inverters and motors



No additional components

For HEVs using single inverter and motor



Two additional switches

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Technical Approach (cont'd)

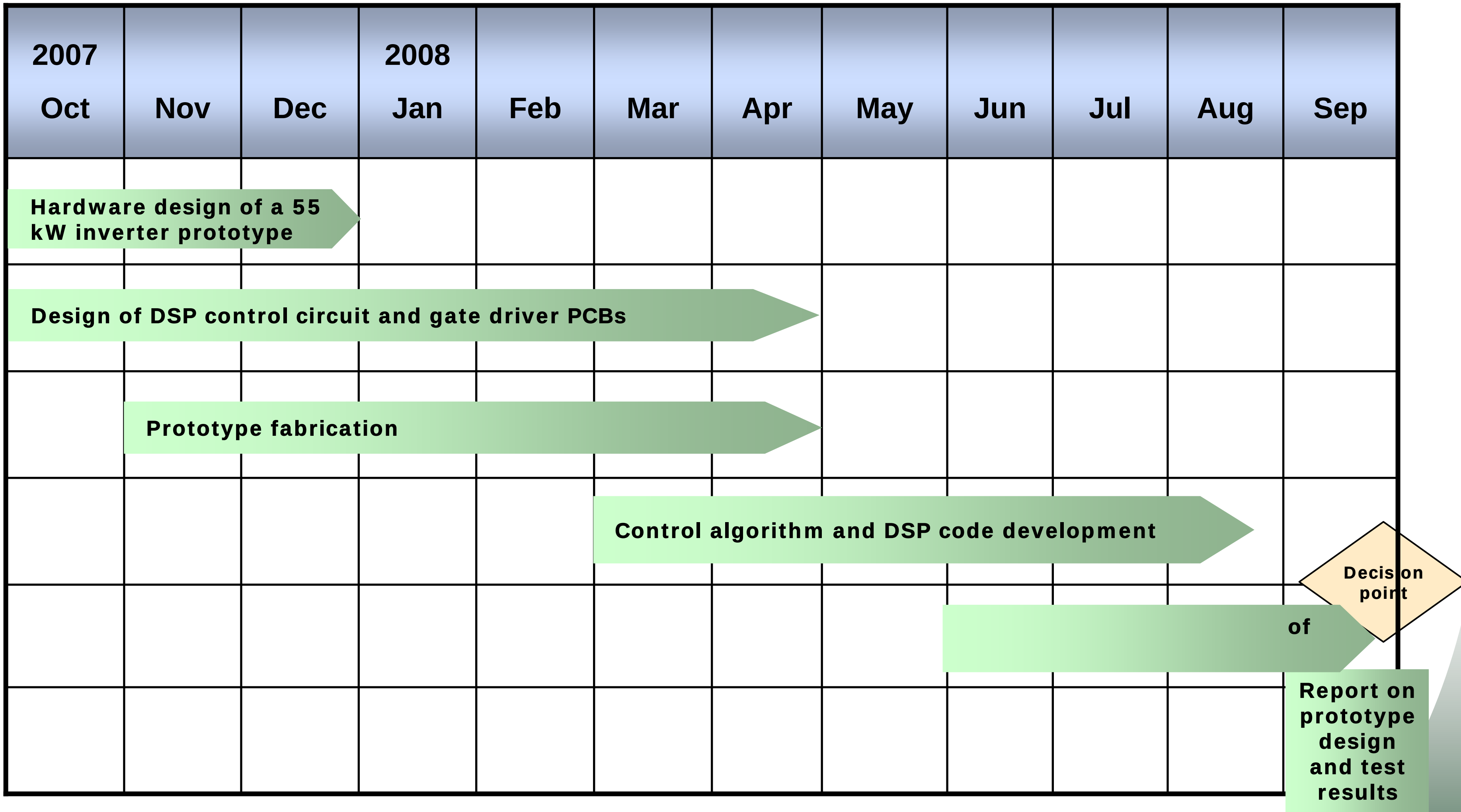
1. **Design – Incorporating the simulation study, a 55 kW inverter prototype will be designed**
   - **Power circuit layout**
   - **Heat sink**
   - **DSP control PCB based on TI TMS320F2812**
   - **Gate driver PCBs**
2. **Fabricate – A prototype of a 55 kW inverter will be fabricated based on design specifications**
3. **Develop DSP control code – The battery charging control algorithms for both slow and rapid charging will be implemented**
4. **Test and evaluate battery charging capability – The 55 kW prototype will be tested at first for charging capacitor banks and then for batteries**

Technical Approach - Uniqueness

- **Virtually no additional components are needed to provide plug-in charging capability and enable**
  - **Rapid charging capability for use at high power charging stations**
  - **Mobile power generation or V2G capability**

- **Impacts**
  - **A significant reduction (90%) in the battery charging related cost and volume**
  - **Enhanced vehicle value and acceptance due to the added capabilities**

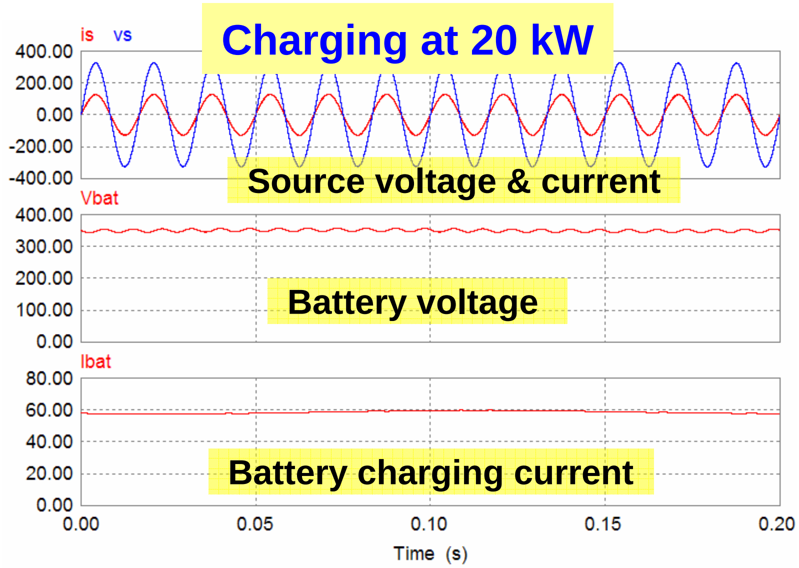
Timeline for FY08

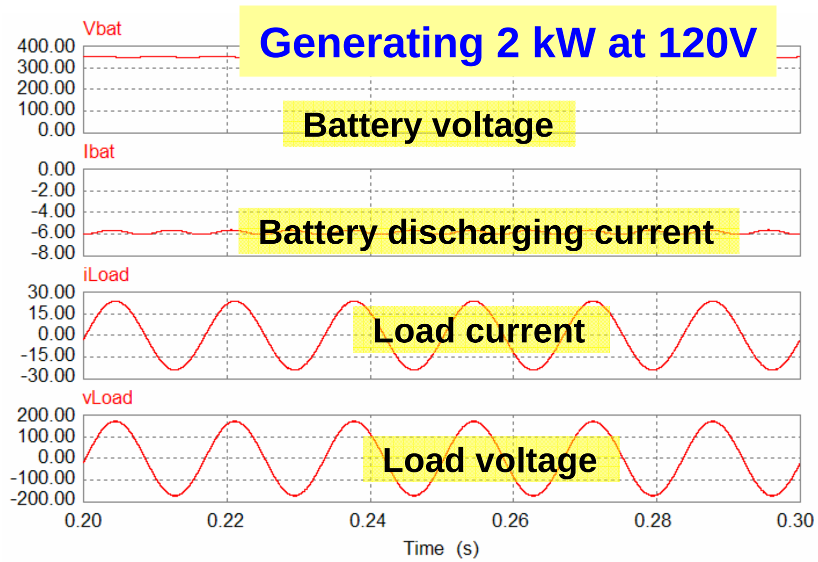


Decision point discussion: Assess whether implementing additional capabilities will provide sufficient merits for further work in the following years.

Technical Accomplishments FY08

- **Completed simulation study and proved the concept**
- **Developed battery charging and mobile power generation control strategies**
- **Completed a hardware design of a 55 kW prototype with the plug-in charging capability**





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Technology Transfer

- **Held discussions with industry for possible technology transfer and have received positive feedbacks.**

Future Work

- **FY09**
  - **Implement and demonstrate mobile generator capability**
  - **Assess thermal control requirements for mobile generation and rapid charging operations**

- **FY10**
  - **Assess the interface protocols for smart charging to determine the requirements of hardware and software for implementing the protocols**
  - **Implement and demonstrate smart charging capability**

Summary

- The proposed technology requires virtually no additional components to provide plug-in charging capability and enables;
  - A significant reduction (90%) in the battery charging related cost and volume
  - Rapid charging capability for use at high power charging stations
  - Mobile power generation or V2G capability
- All tasks are on schedule
  - A hardware design of a 55 kW prototype has been completed and prototype fabrication is ongoing
  - Design of DSP control and gate driver PCBs is continuing
- Discussions with Industry have been held for possible technology transfer
- In FY09, mobile generator capability will be implemented and demonstrated

Publications, Presentation, Patents

- **A patent application has been filed.**

Questions

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