

The University of Tennessee's GATE Center for Hybrid Systems

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History of GATE at UTK

- One of nine original GATE Centers established in 1998
- Focus on *hybrid drive trains and control systems*
- Housed in the College of Engineering
- Nine faculty members from three departments involved in establishing the GATE Center



- The University of Tennessee (Knoxville, Memphis, Tullahoma)
- The University of Tennessee at Chattanooga
- The University of Tennessee at Martin

History of GATE at UTK

GATE Alumni

- **Two classifications of UTK GATE students**
 - GATE Fellows
 - Sixteen students received fellowships ; twelve have graduated, and one is in progress
 - GATE Research Assistants
 - Ten students received assistantships; seven have graduated, and one is in progress
- **Examples of student research topics**
 - Testing and characterizing the performance of an existing HEV
 - Performance of a microwave regenerated soot filter for diesel engines
 - Silicon carbide power electronic devices in hybrid electric vehicle applications
 - Electronic injection controls for diesel engines
 - State of charge estimation for batteries
 - PHEV engine emissions impacts on control strategy



GATE Goals and Objectives

“The goal of GATE is to overcome technology barriers preventing the development and production of cost-effective, high-efficiency vehicles for the U.S. market by training a future workforce of automotive engineering professionals who are knowledgeable about, and experienced in, developing and commercializing advanced automotive technologies.... GATE Centers of Excellence are an opportunity to equip a new generation of engineers and scientists with knowledge and skills in advanced automotive technologies.”

Funding Opportunity Announcement DE-PS26-05NT42381

UTK GATE Program Objectives and Program Focus

- **Objectives**

- Integrate updated and expanded courses into existing curriculum
- Provide fellowships for students that will be successful in their degree programs and engineering careers

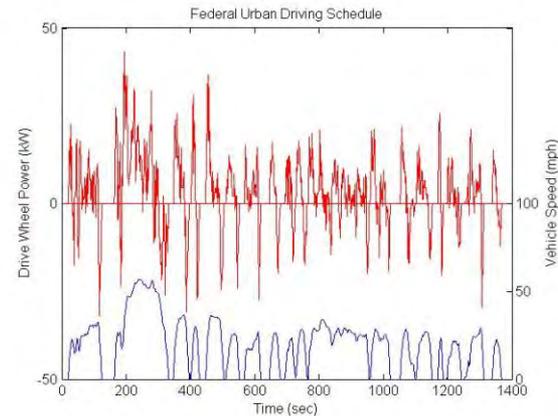
- **Program Focus- Advanced Hybrid Propulsion and Control Systems**

- Enhancing hybrid systems based on IC engines and transitional engine technologies
- Developing optimal strategies for powertrain control and systems integration respective of fuel efficiency, emissions, energy management and dynamic performance
- Developing objective performance measures and mitigation strategies for powertrain performance issues unique to hybrid vehicles that represent barriers to customer acceptance
- Providing metrics for an objective comparison of advanced hybrid vehicles based on detailed performance measures of optimally-controlled systems

Current Courses

- **ME588 Introduction to Hybrid Vehicles**

- Vehicle modeling
- Hybrid vehicle design
- Engine fundamentals
- Emissions
- Vehicle controls and energy management

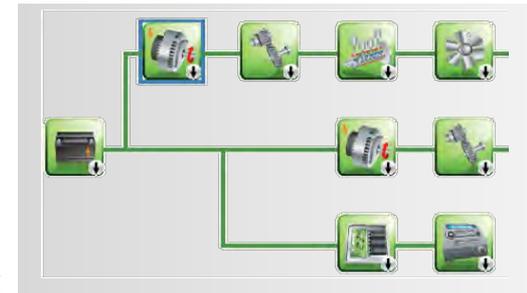


- **ME523 Thermodynamic Modeling of Combustion Engines**

- Matlab based modeling
- Modeling of thermodynamic cycles

- **ME 599 Hybrid Vehicle Simulation and Controls Development**

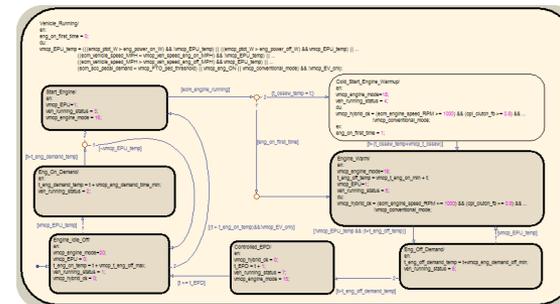
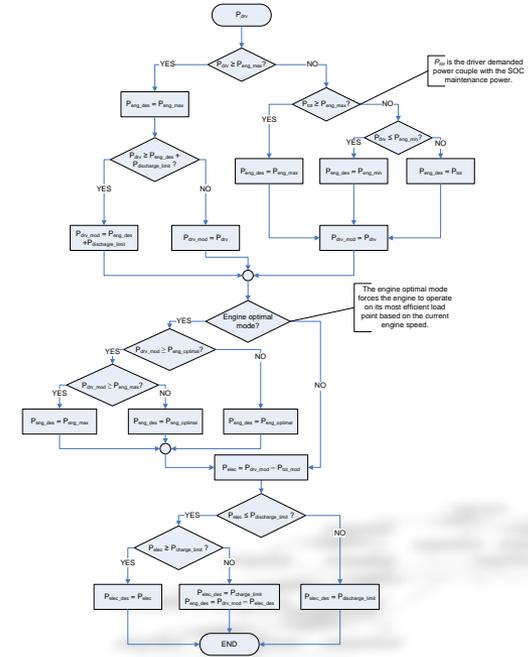
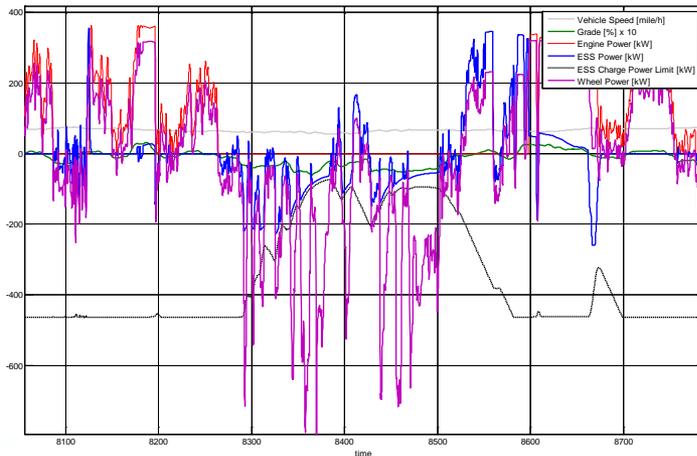
- Advanced vehicle level modeling
 - Fundamental approaches and processes for vehicle modeling
 - Tools for developing complete vehicle models (MATLAB/Simulink, DOE Autonomie)
- Vehicle supervisory control principles for advanced powertrains
- Control system implementation/ rapid control prototyping



Planned Courses

- **ME 6XX Advanced Controls For Hybrid Electric Vehicles**

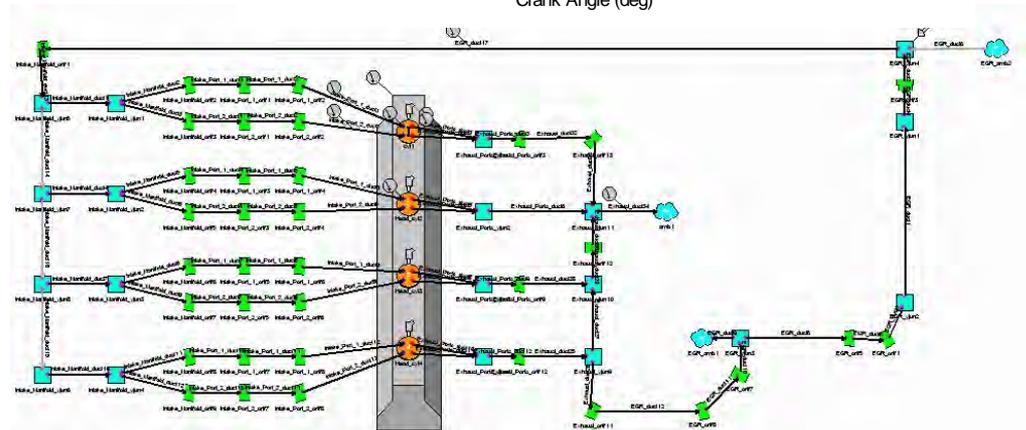
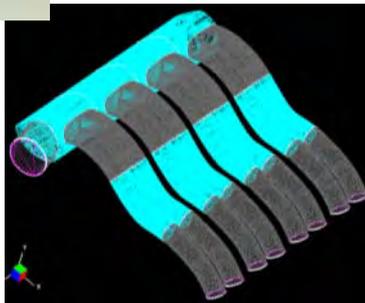
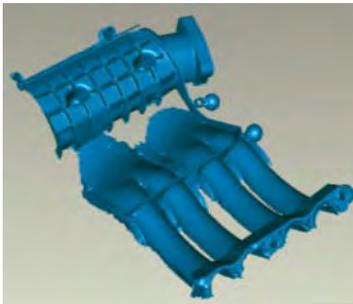
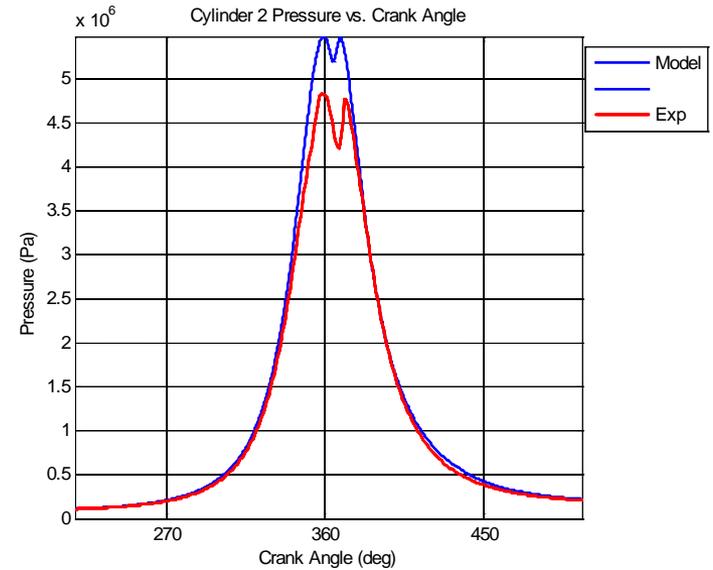
- Nonlinear modeling control issues associated with HEV powertrains
- Fuzzy and neural control techniques
- Adaptive and optimal control schemes for vehicle performance enhancement
- Review of modern automotive control hardware
- Software trends and practices



Planned Courses

- **ME 6XX Advanced Internal Combustion Engines**

- Study of advanced engine designs and non-conventional combustion modes
- Emphasis on improved emissions and fuel economy performance
- Application of commercial engine modeling tools
- Software-in-the-loop model development



Current GATE Students

• GATE Fellows

- Two GATE Fellows are progressing in their degree programs.
 - Benjamin Newcomer is a GATE Fellow who began his graduate studies toward the MS degree in mechanical engineering in August 2009. His research is in the area of PHEV engine control and energy management strategies.
 - Yutian Liu is a GATE Fellow who began her graduate studies toward the PhD degree in electrical engineering in August 2009. Her research is in the area of high temperature power electronics for HEVs

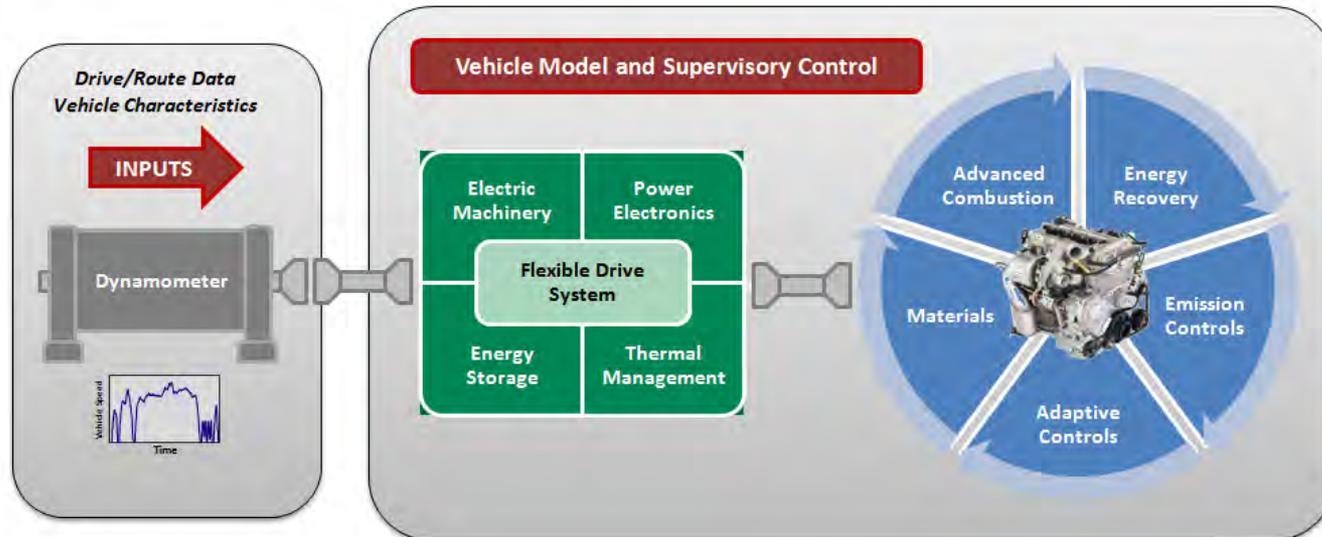
• GATE Research Assistants

- One GATE Research Assistant is progressing in his degree programs.
 - Dean Deter is a GATE Research Assistant who began his graduate studies toward the MS degree in mechanical engineering in August 2010. His research is in the area of PHEV engine control and energy management strategies.

Current Activities & Plans: Current Research

- **PHEV Emissions Impacts on Controls Strategy and Fuel Economy**

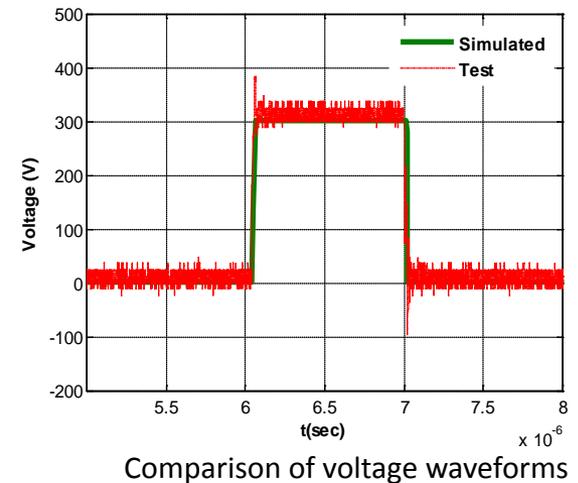
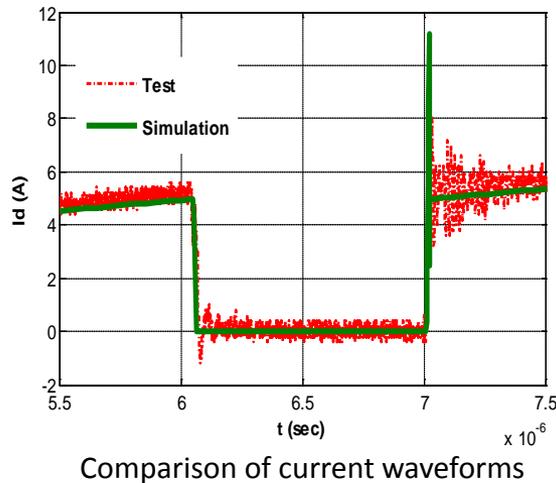
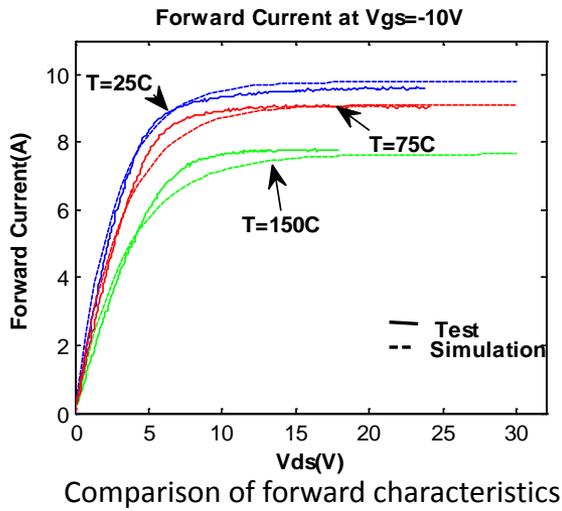
- Investigate novel engine control strategies targeted at rapid engine/catalyst warming
- Implement engine control algorithms into an experimental test stand engine hardware-in-the-loop
- Supervisory control techniques developed during previous research integrated into the vehicle level control system



Current Activities & Plans: Current Research

• SiC Power Devices Used in Hybrid Electric Vehicles

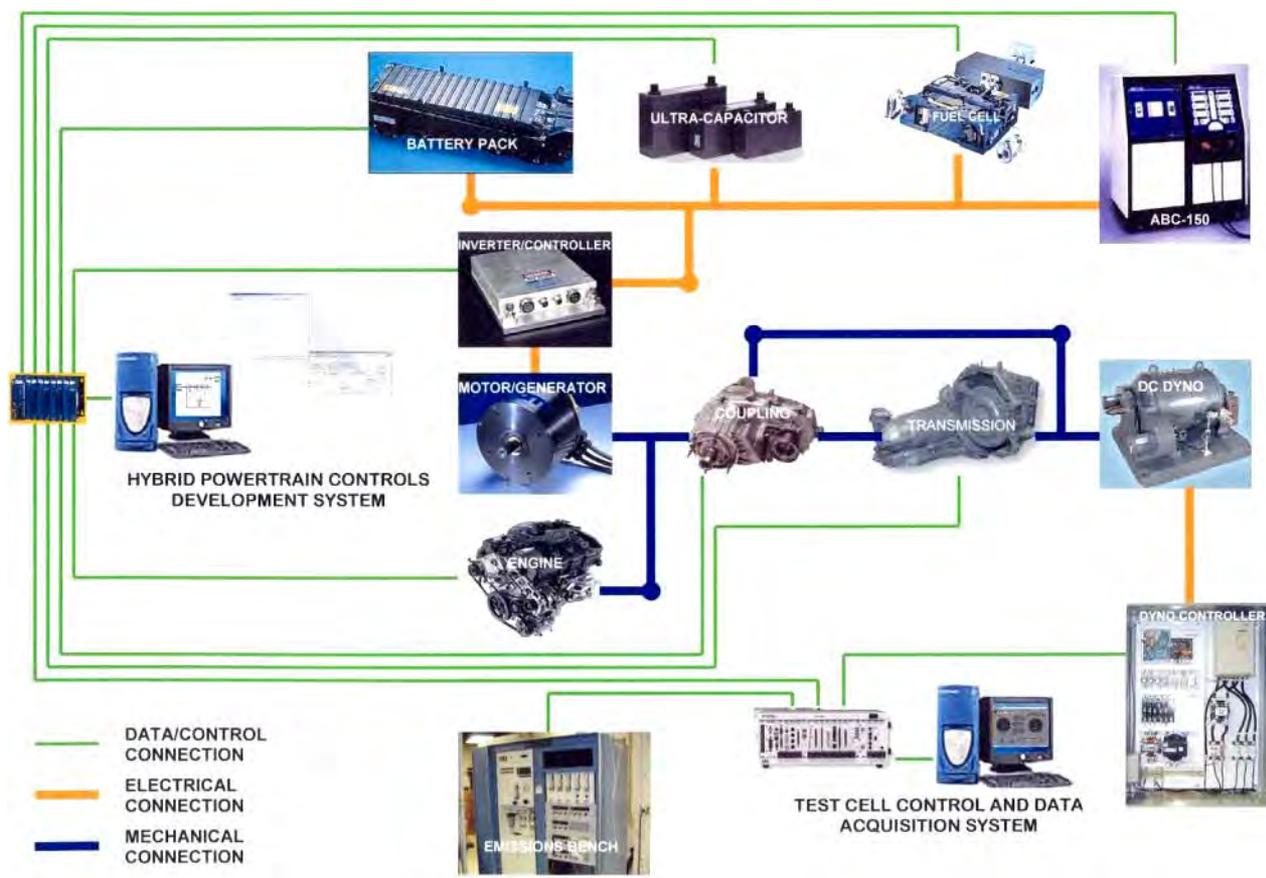
- SiC power devices have higher operational temperature, higher switching frequency, lower power losses than Si devices.
- Electric vehicles using SiC devices are expected to have less cooling requirements, reduced passive components, and higher efficiency.
- To get a more accurate model for the vehicle system, a behavioral model of SiC JFET based on testing data was built in Pspice.



Current Activities & Plans: Facilities

Advanced Powertrains, Controls and Systems Integration (APCSI) Laboratory

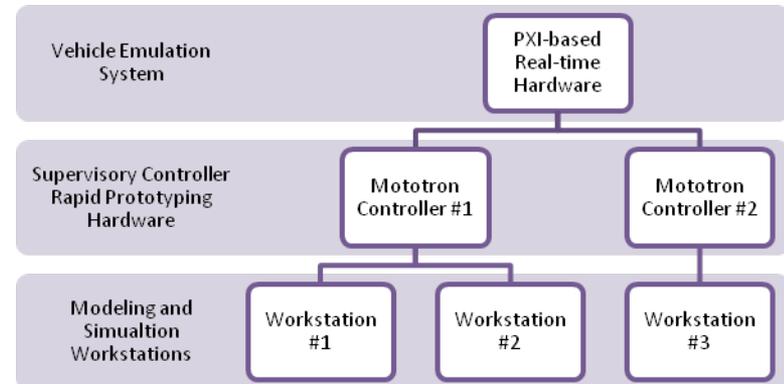
- **Engine Test Cell**
 - 300 hp DC motoring engine dynamometer
 - Controls systems development system
- **Vehicle Test Cell**
 - 300 hp chassis dynamometer
- **Shared Equipment**
 - Data acquisition and control system
 - Emissions measurement capability
 - Fuel consumption measurements



Current Activities & Plans: Facilities

APCSI Modeling and Simulation Laboratories

- **Builds on the existing APCS dynamometer facility at UTK by adding capabilities for:**
 - Detailed vehicle systems modeling and simulation
 - Based on industry standard modeling and simulation tools, such as MATLAB®/SIMULINK®, for general modeling tasks
 - Utilizes DOE custom vehicle level modeling tools, such as Autonomie, to evaluate various advanced powertrain architectures
 - Provides a robust environment for creating advanced vehicle supervisory control strategies for a wide variety of powertrain architectures
 - Rapid controls development and prototyping
 - Embedded, production style control hardware targets available for evaluation and verification of supervisory control algorithms in real-time
 - Hardware-in-the-loop testing (complete real-time vehicle emulation for control hardware debug, fault insertion/mitigation, etc.)
- **Provide additional modeling tools, such as CAD, FEM, etc.**
- **Furnished by NSF ARI grant**



Resources & Industry Interaction

- **Resources resulting from the UTK GATE program**
 - \$2.5 million in grants and contracts from government and industry
 - \$500K from the university in cost sharing and providing facilities
- **Industry Interaction**
 - DOE Advanced Vehicle Technology Competitions
 - DOE Clean Cities Program
 - ExtEngine
 - Delphi
 - 3M
 - State of Tennessee
 - National Transportation Research Center
 - Power Source Technologies
 - Sentech
 - Oak Ridge National Laboratory
 - Argonne National Laboratory
 - Idaho National Engineering Laboratory
 - Denso Foundation

Students Employed in Industry

- Ford Motor Company
- Oak Ridge National Laboratory
- National Renewable Energy Laboratory
- The University of Tennessee
- Southwest Research Institute
- Lynx Motor Technologies
- Volpe Transportation Center
- Detroit Diesel
- Electric Transit Vehicle Institute
- EPRI-PEAC
- Siemens



Summary

- APCSI research facilities relocated in new facility Fall 2010
- New APCSI Modeling and Simulation Laboratories being developed
- Increased course offerings involving adjunct faculty from ORNL staff
- Goal to increase research activity
- Continuity of student recruitment should improve with increased research funding
- Strong proposal prepared for current GATE solicitation