Traction Drive System Modeling

Burak Ozpineci

Oak Ridge National Laboratory

2013 U.S. DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting

May 14, 2013

Project ID: APE048

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

- Start – FY13
- Finish – FY15
- 22% complete

Budget

- Total project funding
  - DOE share – 100%
- Funding for FY12: $ 0K
- Funding for FY13: $750 K

Barriers

- Optimum operation of the traction drive system (TDS) not the component.
- More detailed simulation of TDS in a vehicle simulation.
- Improved cost and efficiency.

Targets Addressed

- Traction Drive System
  - Cost: $8/kW (2020 target)
  - Efficiency > 94% (2020 target)

Partners

- Madhu Chinthavali, Tim Burress, Curt Ayers, Omer Onar, David Smith (ORNL), Sreekant Narumanchi (NREL), Argonne National Laboratory

Project Objective

- **Overall Objective**
  - To reduce the TDS cost and increase its efficiency in the overall traction drive system torque-speed working space.
  - To develop complementary detailed TDS model that can be incorporated in Autonomie Simulation Software.
- **FY13 Objective**
  - To develop a baseline circuit simulation model – 2012 Nissan LEAF Traction Drive
  - To find the high energy throughput points of a 2012 Nissan LEAF traction drive over the Combined Driving Schedule (CDS) which is formed by adding five driving schedules in series (UDDS+US06+HWFET+LA92+UDDS).

Milestones

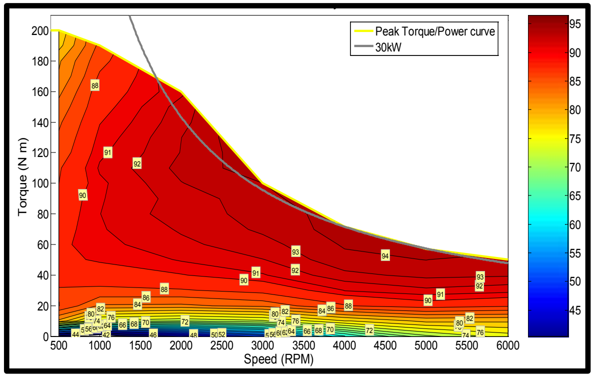
Date	Milestones and Go/No-Go Decisions	Status
Sept-2013	Milestone: Completed 2012 Nissan LEAF full traction drive system model.	On track.
Sept-2013	Go/No-Go decision: The successful completion of the traction drive system models.	

Approach/Strategy

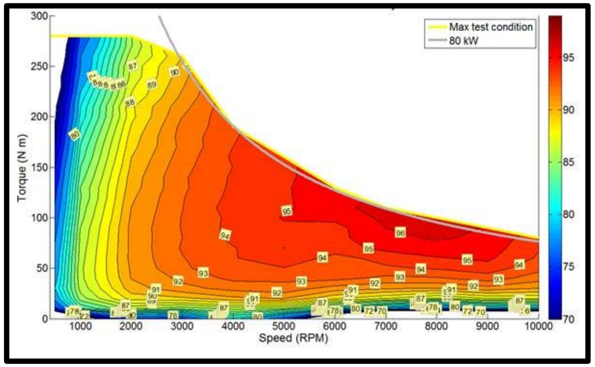
1- Top-down approach…

A. Use vehicle system simulation runs to determine the most optimum traction drive parameters and refine the component performance requirements.

- Form a combined driving schedule (CDS) using UDDS, US06, HWFET, LA92, and UDDS in a row.
- Run the Nissan LEAF simulation on Autonomie over CDS and record the results as the baseline for this project.
- Analyze the operating points of the inverter and the motor and identify the most frequent operating points.
- Inform the APEEM PIs to modify their power electronics and motor designs considering these frequent operating points for more efficient results.



2011 Hyundai Sonata motor efficiency map



2012 Nissan LEAF motor efficiency map

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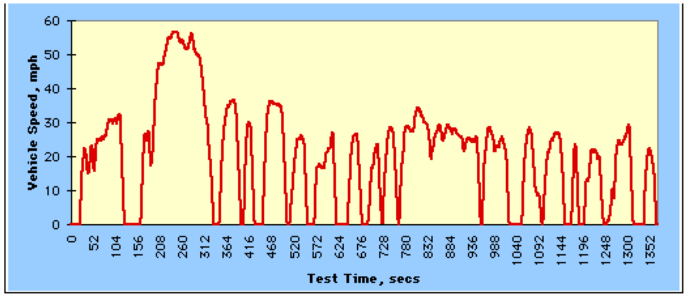
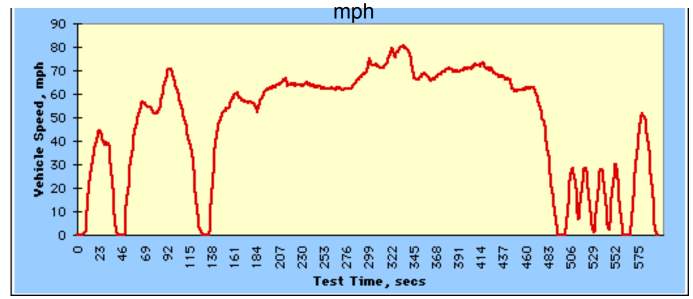
Approach/Strategy

Five cycles to form the Combined Driving Schedule (CDS)

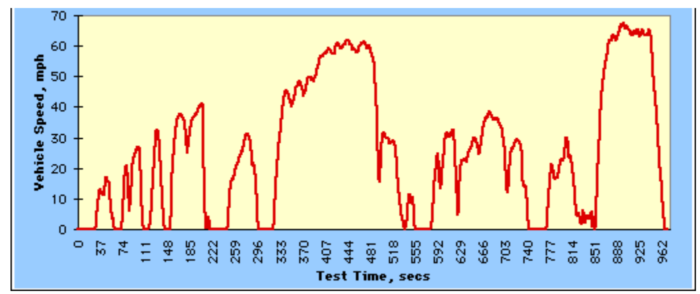
EPA Urban Dynamometer Driving Schedule
Length=1369 sec; Distance=7.45 mi; Average speed=19.59 mph



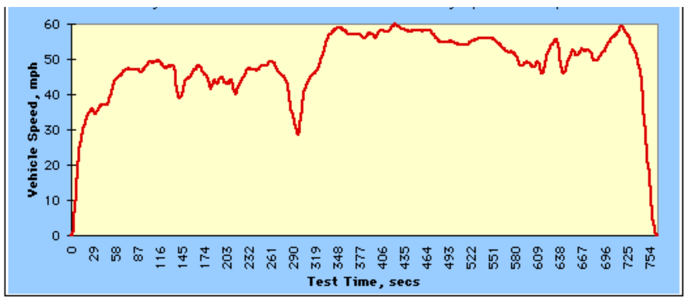
US06 or Supplemental FTP Driving Schedule
Sample Period=596 sec; Distance=8.01 mi; Average speed= 48.37 mph



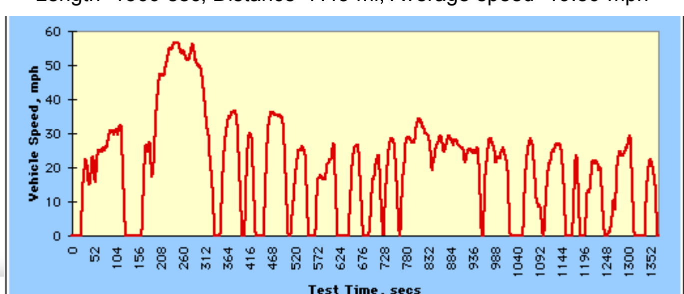
LA92Short "Unified" Dynamometer Driving Schedule
Sample Period=969 sec; Distance=6.99 mi; Average speed=25.97 mph



EPA Highway Fuel Economy Test Driving Schedule
Length=765 sec; Distance=10.26 mi; Average speed=48.3 mph



EPA Urban Dynamometer Driving Schedule
Length=1369 sec; Distance=7.45 mi; Average speed=19.59 mph

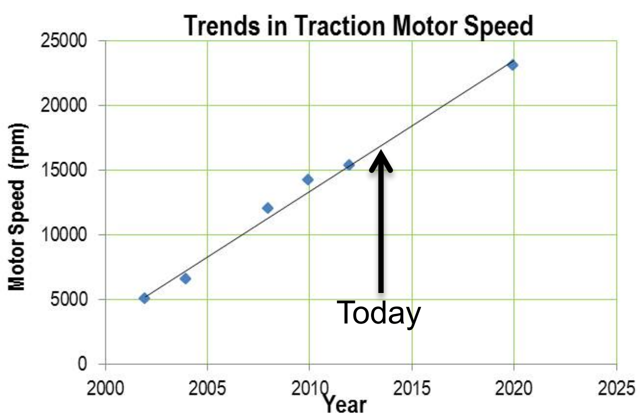


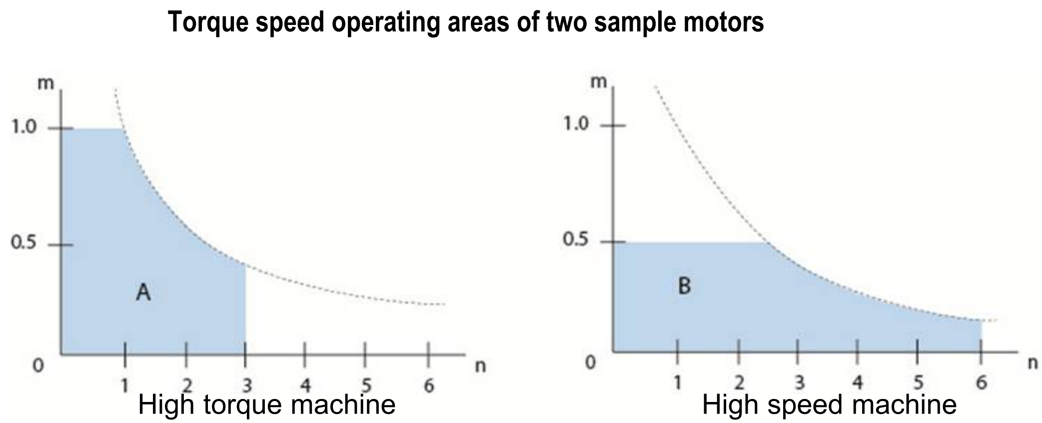
Plots from EPA.gov

Approach/Strategy

B. Two main traction drive parameters that will impact the efficiency and the cost of a traction drive system are the dc link voltages and motor speeds.

- Run the Autonomie simulation for dc link voltages in the range of 650 V and 1300 V and for motor speeds greater than 20,000 rpm.
- Compare the efficiency and bill of materials (BOM) cost results and identify the most optimum dc link voltage and motor speed combinations.
- Inform the APEEM PIs to modify their power electronics and motor designs considering these new parameters.





Approach/Strategy

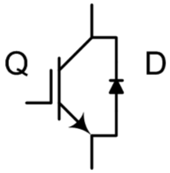
2 - Circuit level simulation approach…

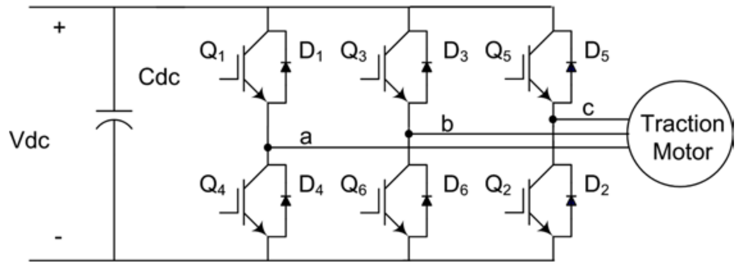
Use circuit level simulation software to model the traction drive system independent of the vehicle system to verify the optimum operation of the traction drive components and their dynamic responses.

- Develop a circuit level simulation model of the traction drive with the inverter and motor, basic models for the battery and the mechanical system for the motor, and a boost converter if needed.
- Run the model and evaluate the dynamic interaction between the components.
- Update the model to include the models of any new traction drive components designed by APEEM PIs and evaluate their performances and efficiencies.
- Using this data, develop models that will be uploaded to Autonomie to validate the performance of the new components on the vehicle system level.

Approach/Strategy

Summary of the Modeling and Simulation Strategy





PSpice
Device Modeling
Sampling time ~1ns
Combined Driving Schedule: 5543s
5.543×10^{12} sampling points

PLECS
Circuit Simulation
(Simulation Sampling Time=1μs)
Combined Driving Schedule: 5543s
5.543×10^{9} sampling points

Autonomie
Vehicle Simulation
(Simulation Sampling Time=0.1s)
Combined Driving Schedule: 5543s
55430 sampling points

Focusing on

- Traction Drive System (TDS) modeling with PLECS
- TDS performance analysis using Autonomie

Technical Accomplishments and Progress

- All the pieces have to fit and are complementary
- *Focus on the interfaces and what adjacent sub-systems require*

System Controls
Coordinated I-M-C for efficiency optimization

ESS

Buck/boost Converter

WBG Traction Inverter

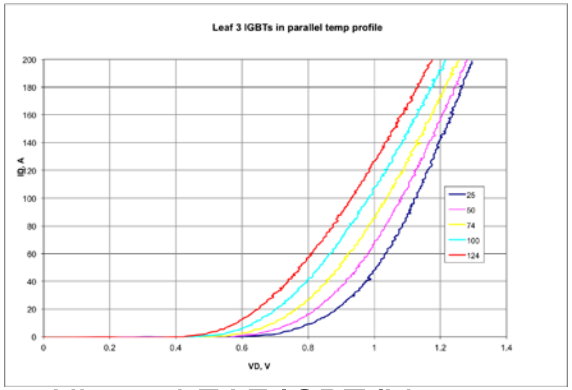
No-RE Trac Motor

Motor Gear Match to drive

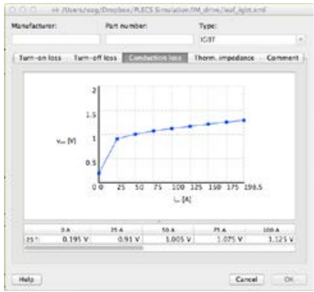
Thermal Management
Single Coolant Loop Goal

Technical Accomplishments and Progress

- Baseline 2012 Nissan LEAF TDS modeling - Inverter

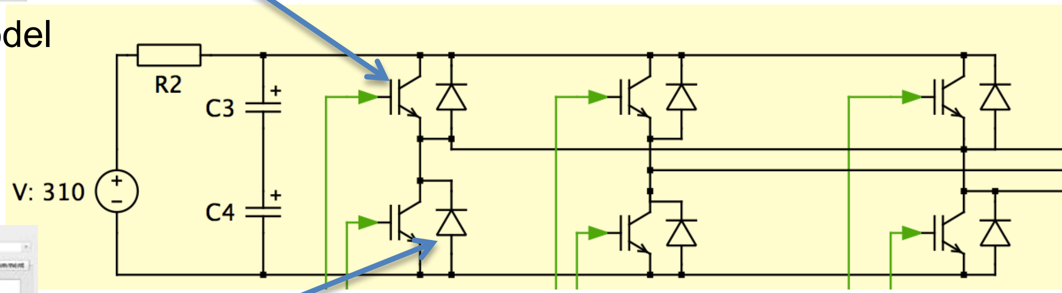


Nissan LEAF IGBT IV curve

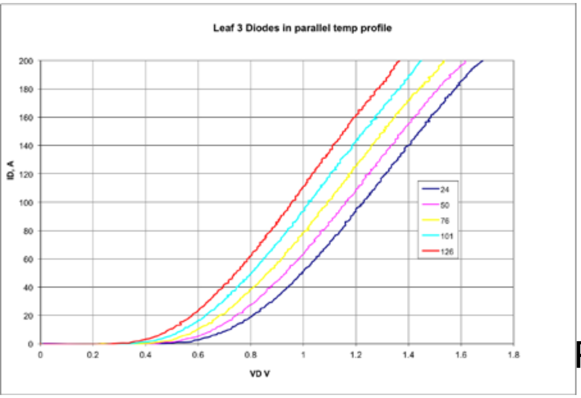


PLECS IGBT model

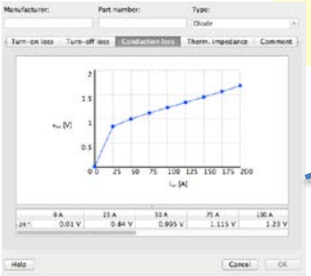
- Tested and characterized the 2012 Nissan LEAF IGBTs and diodes for conduction and switching losses.
- Inserted the loss data into the PLECS device models.



Three-phase inverter model in PLECS



Nissan LEAF diode IV curve

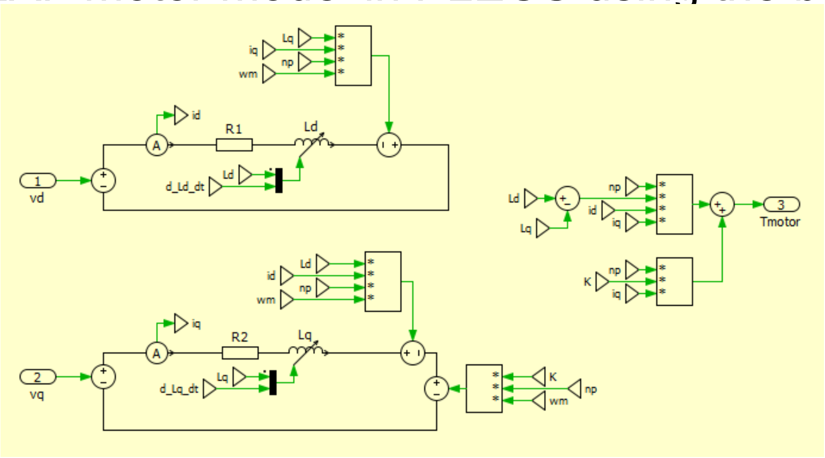


PLECS diode model

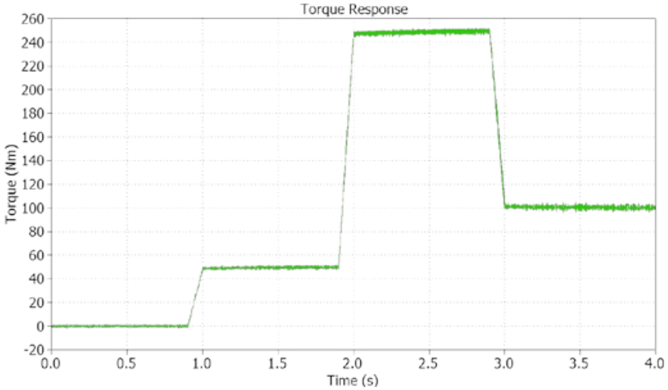
Technical Accomplishments and Progress

- Baseline Nissan LEAF TDS modeling - Motor

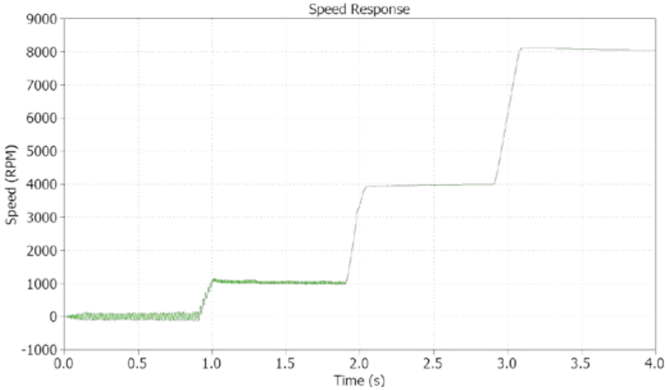
Developed a Nissan LEAF motor model in PLECS using the benchmarking test results.



Nissan LEAF motor model in PLECS



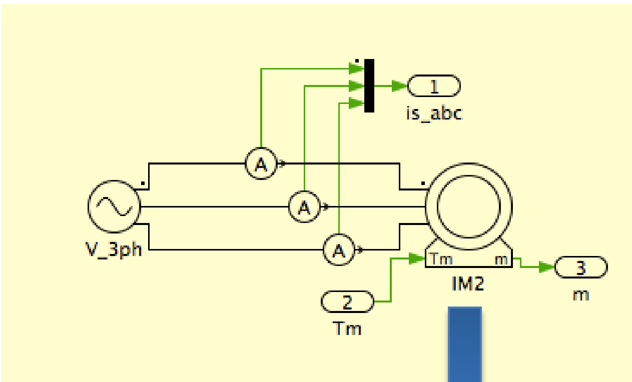
Nissan LEAF motor torque response



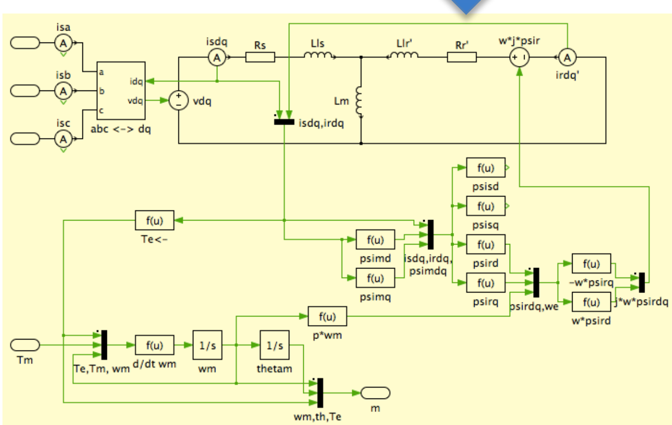
Nissan LEAF motor speed response

Technical Accomplishments and Progress

- Simulated a high speed induction machine



PLECS Induction Machine Model



Induction machine parameters

Induction Machine (Squirrel-Cage) (mask) (link)

Three phase squirrel-cage induction machine. The input signal Tm represents the mechanical torque, in Nm. The vectorized output signal of width 3 contains
- the rotational speed wm, in rad/s
- the mechanical rotor position th, in rad
- the electrical torque Te, in Nm.

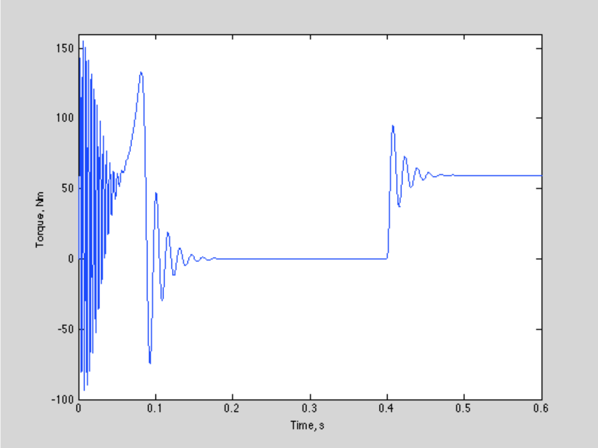
All parameters and electrical quantities are referred to the stator side.

Parameters

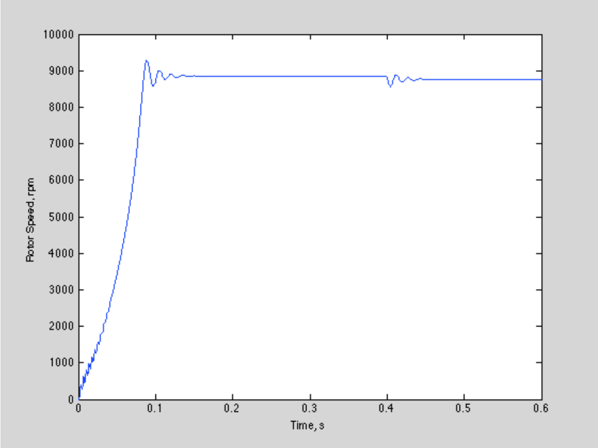
Stator resistance Rs: 87.6e-3	Friction coefficient F: 0
Stator leakage inductance Lls: 150.6e-6	Number of pole pairs p: 2
Rotor resistance Rr': 36.14e-3	Initial rotor speed wm0: 0
Rotor leakage inductance Llr': 114.86e-6	Initial rotor position thm0: 0
Magnetizing inductance Lm: 2.367e-3	Initial stator currents [isa0 isb0]: [0 0]
Inertia J: 0.005956	Initial stator flux [psisd0 psisq0]: [0 0]

Technical Accomplishments and Progress

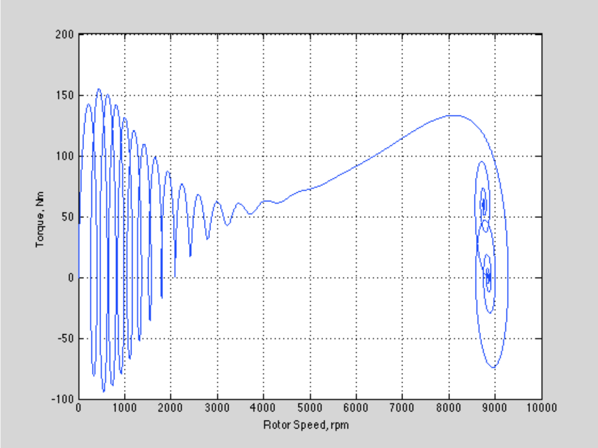
- High Speed Induction Machine Modeling - Direct start results



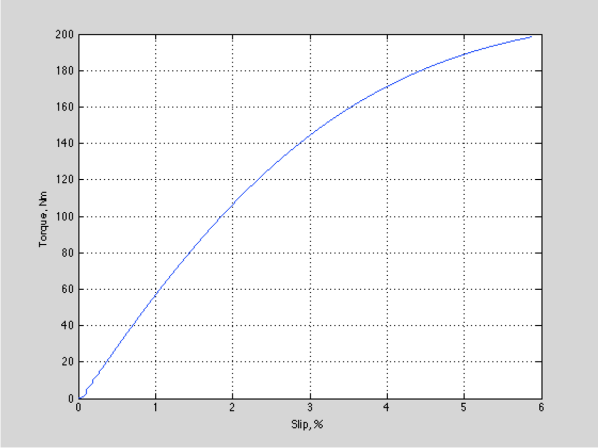
Torque response



Speed response



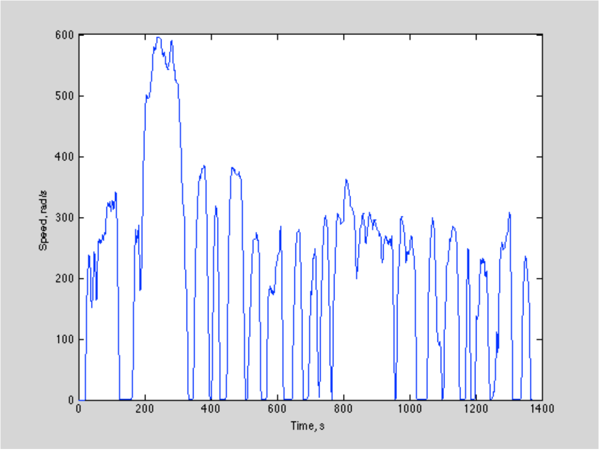
Torque speed curve



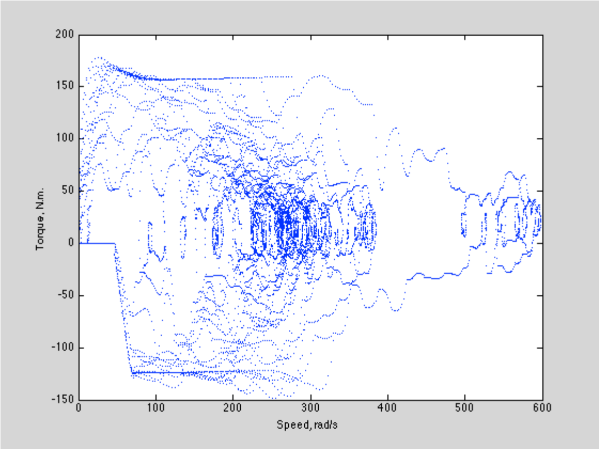
Torque slip curve

Technical Accomplishments and Progress - UDDS

- 2012 Nissan LEAF model was simulated in Autonomie over all of the four driving schedules and the combined driving schedule (CDS).
- The urban dynamometer driving schedule (UDDS) appears at the beginning and at the end of CDS.
- The torque vs. speed plot shows three different regions.



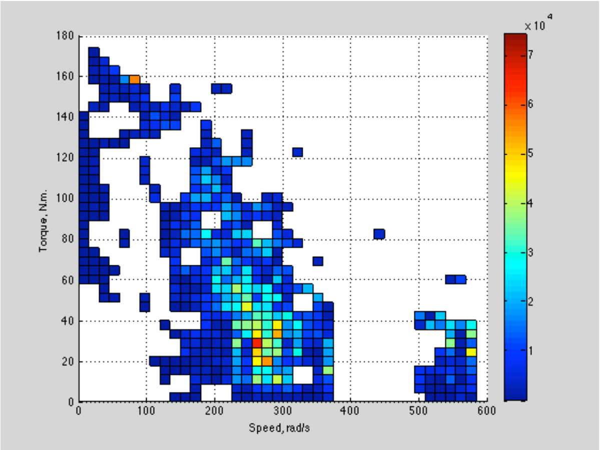
Motor Speed Plot



Traction Motor Torque vs Speed Plot

Technical Accomplishments and Progress - UDDS

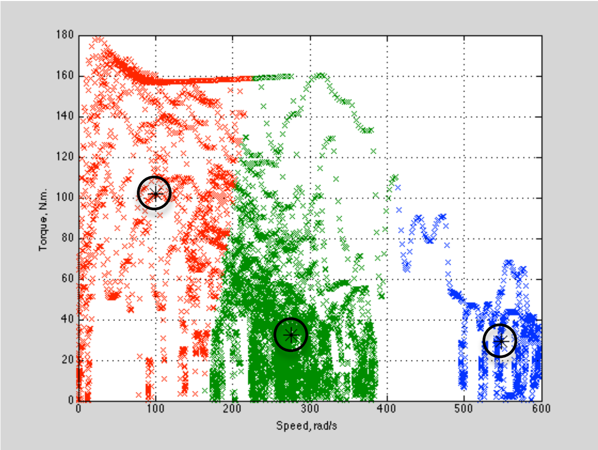
- Energy Histogram: Dividing the torque and speed values in motoring only region into 40 different bins results in 1600 energy bins. Energy was calculated by averaging the power in these bins.
- Clustering: Using k-means theory, the operating points were classified into three clusters.



Traction Motor Torque Speed Plot
High Energy Throughput with 1600 bins
-Energy Histogram-

Speed (rad/s)	Torque (N.m.)
548	29.3
275.4	32.4
100.3	102

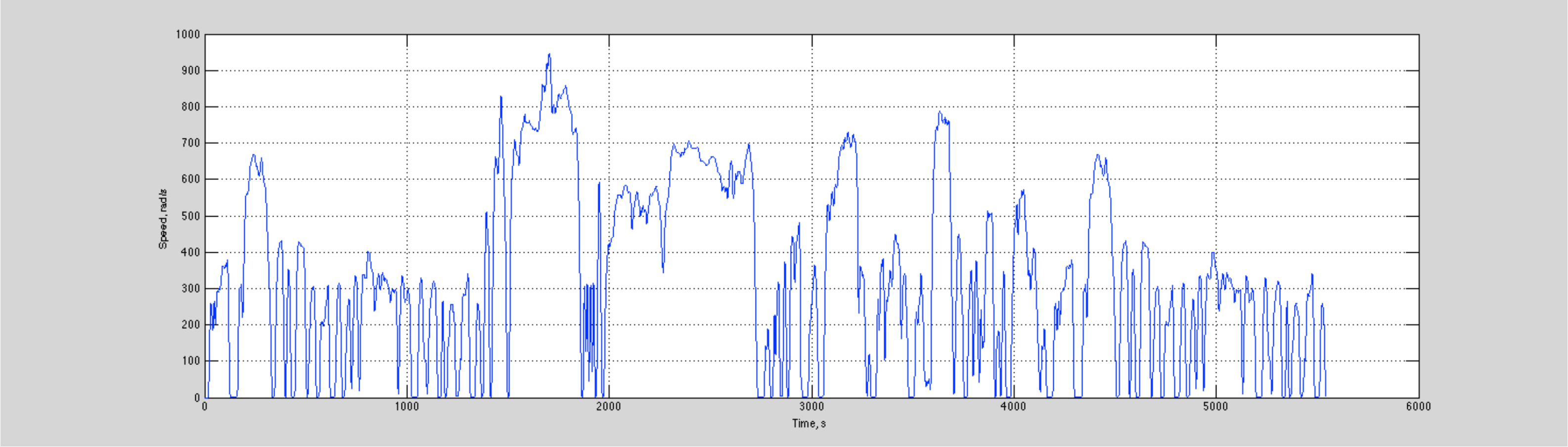
Cluster Centers



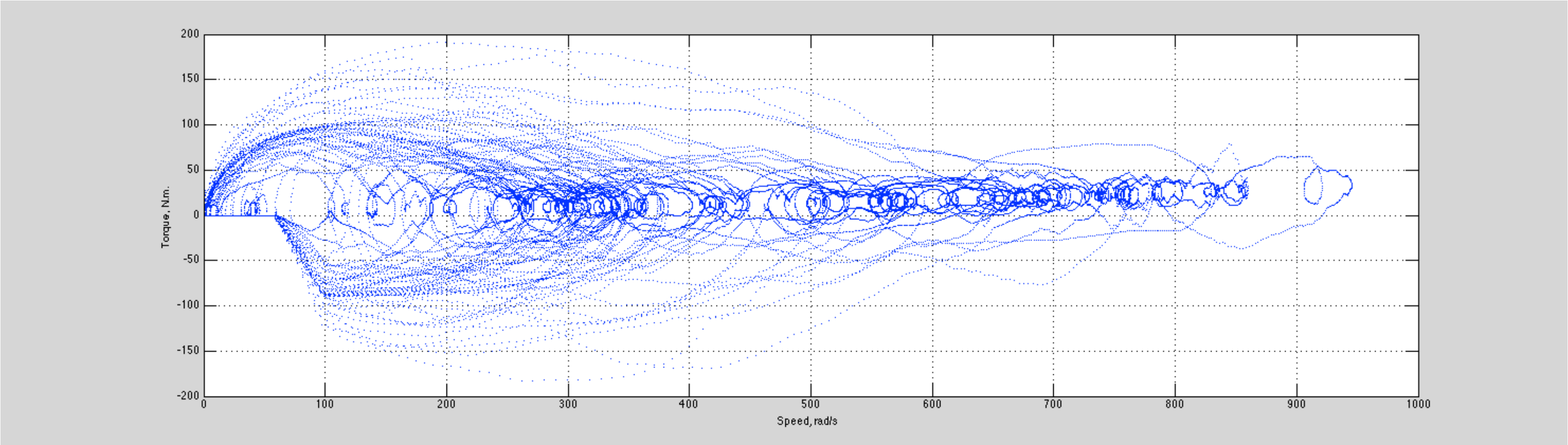
Traction Motor Torque Speed Plot
with three clusters
-Clustering-

Technical Accomplishments and Progress - CDS

- The torque vs. speed plot shows three different regions in the motoring mode with most of the activity.



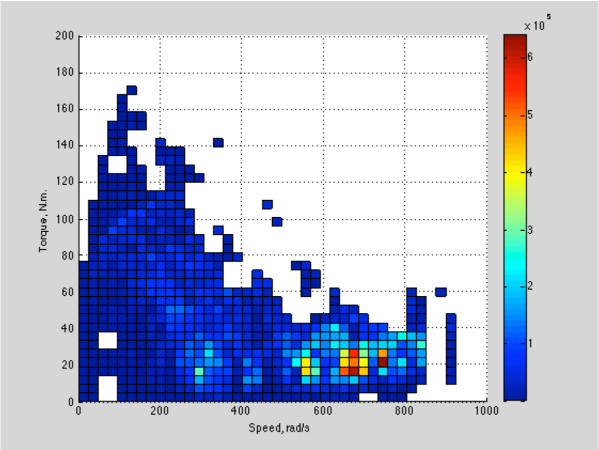
Motor Speed Plot



Traction Motor Torque vs Speed Plot

Technical Accomplishments and Progress - CDS

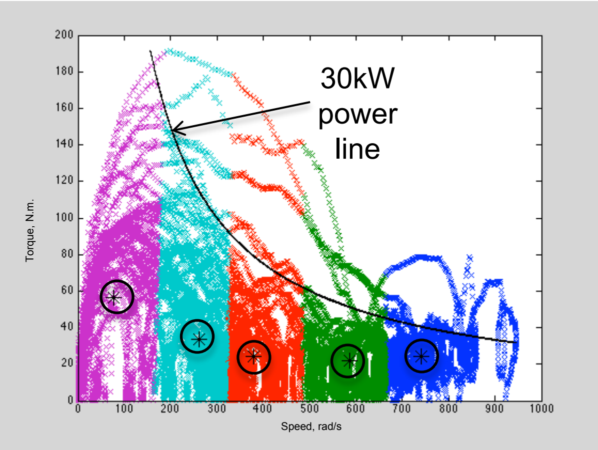
- Energy Histogram: Dividing the torque and speed values in motoring only region into 40 different bins results in 1600 energy bins. Energy was calculated by averaging the power in these bins.
- Clustering: Using k-means theory, the operating points were classified into five clusters.



Traction Motor Torque Speed Plot High Energy Throughput with 1600 bins -Energy Histogram-

Speed (rad/s)	Torque (N.m.)
741.7	24.2
586.5	21.8
380.1	24
262.2	33.7
76.1	56.3

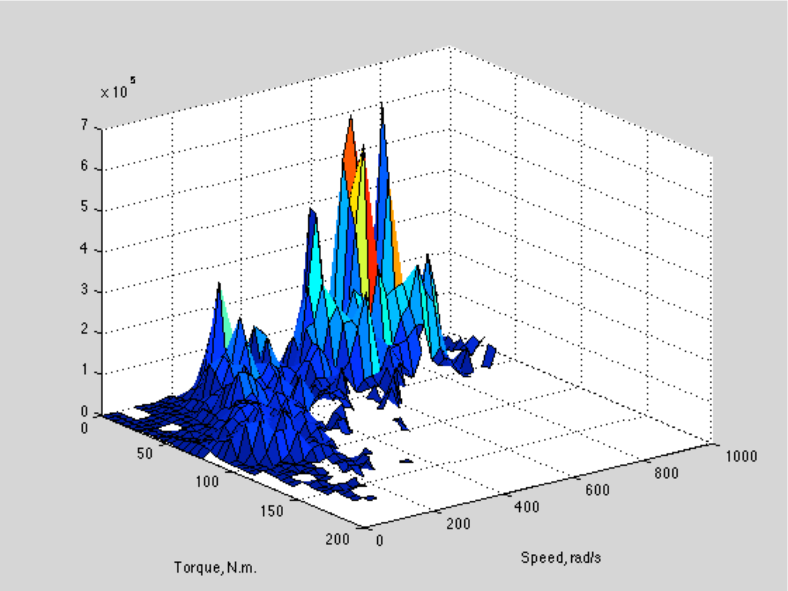
Cluster Centers



Traction Motor Torque Speed Plot with three clusters -Clustering-

Technical Accomplishments and Progress - CDS

- The 3D energy histogram plot shows a concentration of high energy throughput peaks around
  - low torque high speed areas and
  - low speed medium torque areas.



  - The traction drive has to be efficient in these operation areas.

Collaboration and Coordination

Organization	Type of Collaboration/Coordination
National Renewable Energy Laboratory	Thermal management system modeling and simulation.
Argonne National Laboratory	Autonomie software information exchange and coordination.
ORNL Vehicle Systems Program	Autonomie consulting

NREL NATIONAL RENEWABLE ENERGY LABORATORY

AUTONOMIE LMS A Siemens Business Argonne NATIONAL LABORATORY

Proposed Future Work

- **Remainder of FY13**
  - Perform full TDS simulation and show opportunities for cost optimization benefit.
  - Provide TDS operating targets to the power electronics and electric motors areas in the APEEM program.
  - Complete the TDS model in a circuit simulator and simulate the new APEEM developed concepts.
- **FY14**
  - Update the TDS model with new power electronics and electric motor designs.

Summary

- **Relevance**
  - More detailed traction drive system simulation models are required in AEV system level simulations.
  - The focus is on the optimum operation of the TDS not the components.
  - High energy throughput areas have to be identified to design the TDS for better performance.
- **Approach:** Develop and run circuit and vehicle level models of the TDS to optimize the TDS performance.
- **Collaborations:** NREL will be developing the thermal models for the TDS and ANL will be involved in Autonomie integration.
- **Technical Accomplishments**
  - Developed component (IGBT, diode, traction motor) models for the baseline TDS system (2012 Nissan LEAF).
  - Simulated the 2012 Nissan LEAF on Autonomie and determined the first set of high energy throughput areas for traction motors.