I. COMPONENTS & SYSTEMS

I.A. 1000193.00 PHEV Advanced Series Gen-set Development/Demonstration Activity

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I.A.1. Abstract

Objectives

- The objective of this project is to integrate ORNL advancements in vehicle technologies to properly design, and size a gen-set for various vehicle applications and then simulate multiple advanced series hybrid (HEV/PHEV) vehicles with the genset models.

Major Accomplishments

- Built on first year simulation study to partner with industry and obtain additional data about previously selected technologies
- Industry-supplied experimental data was used to refine component models
- Finalized technology selection based on expanded simulation study

Future Achievements

- Expand simulation study to include larger vehicle platforms

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I.A.2. Technical Discussion

Background

The cost and weight of a battery limit the range of an electric vehicle. The use of a range extending gen-set (engine-generator set) to convert an EV in a series PHEV (or EREV) can alleviate range anxiety and reduce battery size and cost.

Series HEV and PHEVs present a unique configuration when a gen-set is used to recharge the Energy Storage System (ESS). In a true series architecture, the gen-set is not mechanically coupled to the drivetrain and therefore may be operated at its optimum efficiency point, regardless of driving conditions. As such, gen-sets provide unique opportunities for component sizing optimization, internal combustion engine operating regimes, exhaust after-treatment, cost effective technology components, electric machine and power electronics selection.

Introduction

This project will draw from the extensive experience in power electronics and electric machinery from the Power Electronics and Electrical Power Systems Research Center as well as the broad knowledge in advanced combustion and emissions after-treatment through the Fuels, Engines, and Emissions Research Center. Both centers are parts of the transportation section of ORNL. The emphasis will be placed on technologies currently under development in each respective center. It will attempt to focus on a modular gen-set that could have multiple applications outside of a vehicle, which would reduce cost based on high volume production.

This project will investigate several advanced technologies for each key component considering several aspects in its selection process such as efficiency, cost, strategic benefits (rare earth / non rare earth) and complementarity of the engine and motor technology.

Approach

Based on the simulation study performed during FY12, the project team had selected a technology combination to be further investigated. Partnerships with engine and electric machine manufacturers will help procuring experimental data for such technologies. That data will be converted into new refined models that will be exercised to finalize our technology selection.

Results

The simulation study performed during FY12 had identified alternative fuels such as ethanol and advanced combustion as the most promising engine technologies for increased combustion efficiency, and non-rare earth induction machine as best cost and efficiency balance for electric machine technology.

The focus for FY13 is to find industry partners to collaborate with, in order to further investigate those technologies in the context of a gen-set application.

An NDA was signed with Mahle Powertrain to evaluate their existing gen-set unit as the base for further efficiency improvements. Mahle had designed a 2-cylinder 900cc 4-stroke PFI gasoline engine called REx (for Range Extender) with the intent to be a “low cost unit with a small package volume and good NVH attributes”. Mahle is also conducting a separate research study in collaboration with the Department of Energy to “develop a next-generation combined ignition/turbo-charging concept known as 'Turbulent Jet Ignition' “. The effect of that technology on a gen-set application will be quantified.

Figure 1: Mahle REx gen-set

ORNL Power Electronics and Electric Machinery group has a DOE APEEM-funded project involving the development of an inverter for a Remy induction machine machine as well as the optimization of its controls in order to get maximum efficiency over its complete speed and load range. Remy has authorized ORNL to retain that motor after testing and use some of their modeling results to include in our simulation study. Since the prototype machine is more powerful (180kW) than the genset application requires, it will be scaled down for the purpose of the simulation study.

Figure 2: Remy Aluminum rotor induction machine

An Autonomie model of the base (Port Fuel Injected) Mahle REx engine as well as its Turbulent Jet Ignition (TJI) variant were generated based on experimental data provided by Mahle. Also the Remy machine was modeled with Autonomie. Those models were added to the list of technologies tested during FY12.

The PFI REx engine did not perform as well as the original PFI engine used in the preliminary study because that engine used a scaled down version of an Atkinson cycle engine. The TJI variant significantly improves engine efficiency at low load (up to 20%), but its effect is more modest at high load (4%). Because the genset operates the engine at high load and high efficiency points that are independent of road load conditions, TJI does not benefit the genset application as much as expected: it performs better than its PFI variant and is on par with an Atkinson cycle engine (see Figure 3)

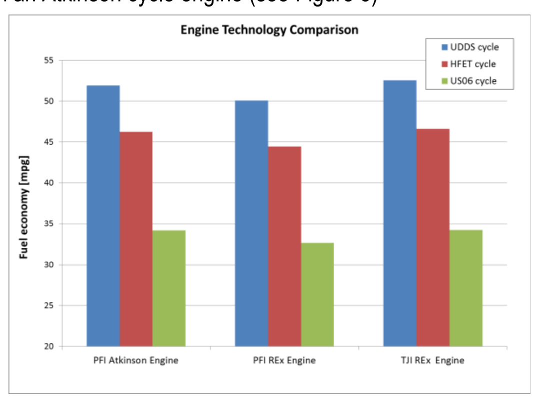

Figure 3: Engine technology comparison when combined with an induction machine

Since the gen-set operates the engine at high loads, as identified previously in this study, ethanol fuel would be beneficial for the REx engine too thanks to its increased knock tolerance at high loads. Therefore an ethanol variant of the REx engine is expected to deliver similar fuel economy at a lower cost than TJI, while not relying on petroleum. Unfortunately, no experimental data is available for that ethanol configuration.

The gasoline PFI REx engine model was then coupled to three different electric machine models: a Remy induction machine, a generic induction machine and a Remy permanent machine. The simulation study showed that the Remy induction machine was on par with the permanent machine thanks to its operation being limited to its most efficient region in a gen-set application.

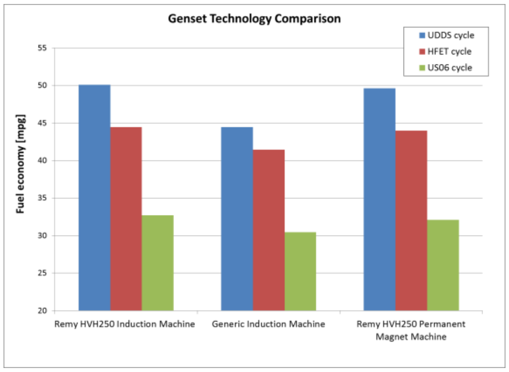

Figure 4: Electric machine technology comparison when combined with a PFI engine

Conclusions

The collaboration with industry partners enabled the upgrade of some of the generic models used so far to some experimental data-based models.The use of such refined models confirmed the findings of the preliminary study conducted during FY12: a 30kW gen-set combining preferably an ethanol PFI engine and induction electric machine offers the best efficiency trade-off for a PHEV passenger car application.