

Medium-Duty Plug-in Hybrid Electric Vehicle for Utility Fleets

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ABSTRACT

Current concerns about climate change, energy security and record high oil prices have triggered high enthusiasm and push for plug-in vehicles. Widespread adoption of plug-in vehicles would result in significant reductions in CO₂ emissions from transportation. It would also reduce our dependence on fossil fuels by replacing petroleum-sourced energy with renewable, domestically produced electricity.

While a few OEMs have successfully launched hybrid vehicles and even toyed with plug-in hybrid solutions in the passenger car market segment, little attention has been placed on heavier commercial vehicles.

Large utilities operate fleets of several hundred diesel-power trouble trucks to repair and maintain their transmission and distribution infrastructure. Medium-duty segment is over a million vehicles annually. These vehicles are typically driven in densely populated neighborhoods. Idling emissions and noise from Utility service vehicles are disruptive to residential areas and expose operators to diesel exhaust for extended periods.

Plug-in Hybrid technology offers a number of advantages to the traditional utility truck. Using stored battery energy, the vehicles can operate extended hours continuously, running the bucket, power tools, lights and accessories while the engine is turned off.

In 2006, the Electric Power Research Institute (EPRI) and Eaton Corporation partnered in an initiative to develop the first medium duty Diesel plug-in hybrid vehicle, retrofitting a Ford class V F550 trouble truck with Eaton's hybrid power train with a grid-rechargeable 16kWh lithium ion battery.

This paper presents the design, development and testing results of this Plug-in Hybrid Vehicle and details the mechanical and electrical integration of the hybrid drive train, high energy batteries and on-board charging system, to provide quiet and emissions-free standby operations and hybrid operation while driving.

This paper also discuss the benefits and trade-offs of the system architecture, battery sustaining / depleting strategy and estimated impact on the grid.

INTRODUCTION

Large utilities operate fleets of several hundred diesel-powered "trouble" trucks to repair and maintain their transmission and distribution infrastructure. The primary feature of these 'trouble' trucks is a bucket lift that the operator uses to inspect and service overhead lines and equipment. Trouble trucks are typically driven tens of thousands of miles per year, operate in densely populated neighborhoods, and are parked at the operator's home during on-call periods. During their operation, the trucks typically idle at the job-site providing the necessary energy to operate the hydraulics that moves the lift and occasionally an auxiliary power generator to power electrically operated equipment during restoration of outage areas. Idling emissions from utility service vehicles are disruptive to residential areas and expose the operators to diesel exhaust for extended periods, in addition to consuming fuel of the order of one gallon per hour.

Plug-in hybrid electric vehicle technology offers a number of advantages to the traditional utility trouble truck. Using stored battery energy, the vehicles can operate for several hours continuously, running the bucket, power tools, lights, and accessories without the need to run the engine. This type of operation would be less disruptive to utility customers and healthier for the operators. Hybrid powertrain technology will

improve vehicle energy efficiency, lowering operating costs and reducing emissions. Finally, the electric-drive portion of the vehicle can be used for field power generation, allowing the utility to provide power to customers while simultaneously conducting field repairs.

Electric Power Research Institute saw Trouble Trucks as a great application to introduce utility fleets to the plug-in hybrid technology, while being cognizant of the potential for this technology to power wider variety of applications that are in the commercial fleet space and is typically served by medium-duty trucks. The work to-date in electrifying utility fleet vehicles had focused on charge-sustaining hybrid with several players offering products. Plug-in hybrids were not yet pursued. EPRI saw an excellent, proven platform in Eaton's hybrid system already successfully operating with several fleets to build on. Both EPRI and Eaton Corporation realized that without the leadership of the two companies, PHEVs will remain out of reach for fleet customers, and embarked on this project starting 2006.

For the utilities, the value proposition of having such a vehicle in the fleet was to evaluate its impact on fleet fuel savings, air quality improvement, as well as clean and quiet operation at the jobsite. EPRI put together a collaborative of 40+ utilities nationwide and chose Eaton as the development contractors with Ford F550 as the truck platform, coupled with Eaton's tried-and-tested hybrid system coupled with high-energy Lithium-ion battery system and off-board charger.

This paper presents the technical details of the medium duty PHEV requirements, design, functionality and operational details as well as opportunities for commercialization with a discussion on challenges being overcome as this project got a tremendous boost from US Department of Energy's ARRA grant award of \$45M to build and deploy a fleet of 400 such vehicles across various utility fleets.

1. PLUG-IN HYBRID VEHICLE FUNCTIONAL REQUIREMENTS

The primary goal of this project was to develop a plug-in hybrid powertrain system suitable for widespread utility use in service vehicles. This required simultaneous execution of an advanced hybrid powertrain development program alongside a chassis integration effort. The ultimate objective was to produce several hundred vehicles per year with Eaton and Ford Motor Company and deliver them to utility customers. The powertrain design therefore was expected to utilize state-of-the-art production-ready, robust components, focusing on near-term production of vehicles for fleet use. EPRI contracted Eaton Corporation to execute the engineering necessary to start both the diesel and gasoline versions of the PHEV Trouble Truck.

VEHICLE SPECIFICATIONS

The following list is a brief summary of Service Truck attributes:

- Ford F550 regular cab truck, 140.8" wheelbase, 7.5 Ton GVWR
- Engine is a state-of-the-art 6.4L V8 'Power Stroke' diesel version
- The curb weight of a new, unloaded vehicle is 14,000 to 14,500 lbs. Many of the vehicles are right at GVW when fully equipped and loaded.
- The service life of the truck is 4-5 years, and they can exceed 150,000 miles in that time. The truck is replaced typically because the chassis is worn out at that time. Rear axle breakages are common.
- A typical operating profile while doing overhead work is: cabin A/C on full blast, hydraulics operating the bucket, high-powered lights if needed. There may be other accessories like compressors or AC generators.
- Cabinet and storage space is at a premium and the troublemen are not going to want to give up a significant amount of storage. The vehicle should drive and operate with equivalent performance to the stock vehicle. Plugging the vehicle in while off-duty should be convenient and require no more than 4-5 hours of charge time.
- The Ford 6-speed Manual transmission was replaced with Eaton's 6speed automated manual Hybrid Drive Unit (HDU)

HYBRID SYSTEM DEVELOPMENT OBJECTIVES

This brief overview is a summary of the current discussions between EPRI and Alliance members concerning the development and fabrication of Plug-in HEV (PHEV) Service Truck prototypes to be demonstrated in a maintenance fleet.

Alliance members and EPRI established a number of objectives, including:

- Reduce fuel consumption, emissions, and operating costs from stock vehicle
- Minimize vehicle impact on neighborhoods and operators with 6-8 hours of standby work time without engine idle
- Equivalent or superior performance to stock vehicle
- Use of grid electricity for part of the vehicle's daily duty cycle
- Aid compliance with fleet environmental regulations

Product Overview

Primary Hybrid Components

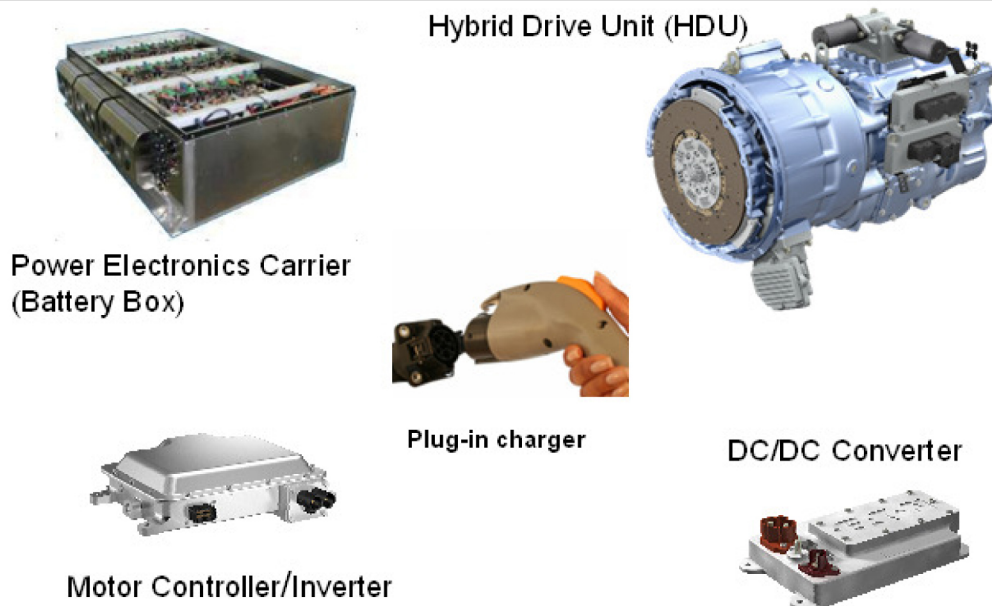


Figure 2.1.

- Vehicle prototypes developed with vehicle manufacturer and with a commercial production path.

UTILITY CLEAN FUEL REQUIREMENTS

Alliance members have listed the following desired attributes for a hybrid service truck:

- 6-8 hours of standby operating time without idling the engine (assuming full battery SOC)
- Eliminate exposure of crew to diesel engine emissions while working
- Diesel mitigation is an issue with fleet vehicles, EPA Act is also an issue
- Reduction in operating costs and fuel consumption
- Use of grid electricity to charge the vehicle batteries, about 80% of 16kWh on-board in a minimum of 3-4 hours
- 5 kW of standby Aux Power Generation capacity.

2. ENGINEERING DESIGN OF PHEV SYSTEM

The primary goal of this project was to lay a foundation for a hybrid powertrain system suitable for widespread utility use in Ford F550 service vehicles, using the proven Eaton Hybrid technology and adding energy storage with plug-in capabilities. This required simultaneous execution of an

advanced hybrid powertrain development program alongside a chassis integration effort

SYSTEM DEFINITION

The base vehicle used on this project was a Ford F550 Chassis with manual transmission, regular cab truck, 140.8" wheelbase, 17,500 lb. GVW, 6.4L V8 Power Stroke diesel engine.

The Plug-in Hybrid Electric System included Eaton's hybrid Transmission (6-speed automated manual), including a liquid cooled 44kW peak (60HP/ 308lbs_{ft}) power/ 420N.m torque, permanent magnet electric motor, 26kW continuous (35HP / 186lbs_{ft}), 252N.m torque and an Electric Clutch Actuator (or ECA). In addition, the PHEV system included the liquid cooled Electric Motor Controller / Inverter, Pushbutton Shifter, DC/DC Converter (1.5kW, 13.5V output) and the high energy Lithium Ion battery pack, 340V nominal, with internal 3.3kW charger. Specific components are shown in [Figure 2.1](#)

The vehicle was fitted with an ALTEC Utility body, including a Model AT37-G standard aerial device and a standard Utility Body with tool cabinets and storage racks.

The energy storage solution used for this system is a high energy, air cooled, and Lithium Ion battery developed in Germany. It includes 100 high powers 45Ah round cells in series, a self power (24V) battery management system (BMS), soft-start power electronics, a ground fault detector,

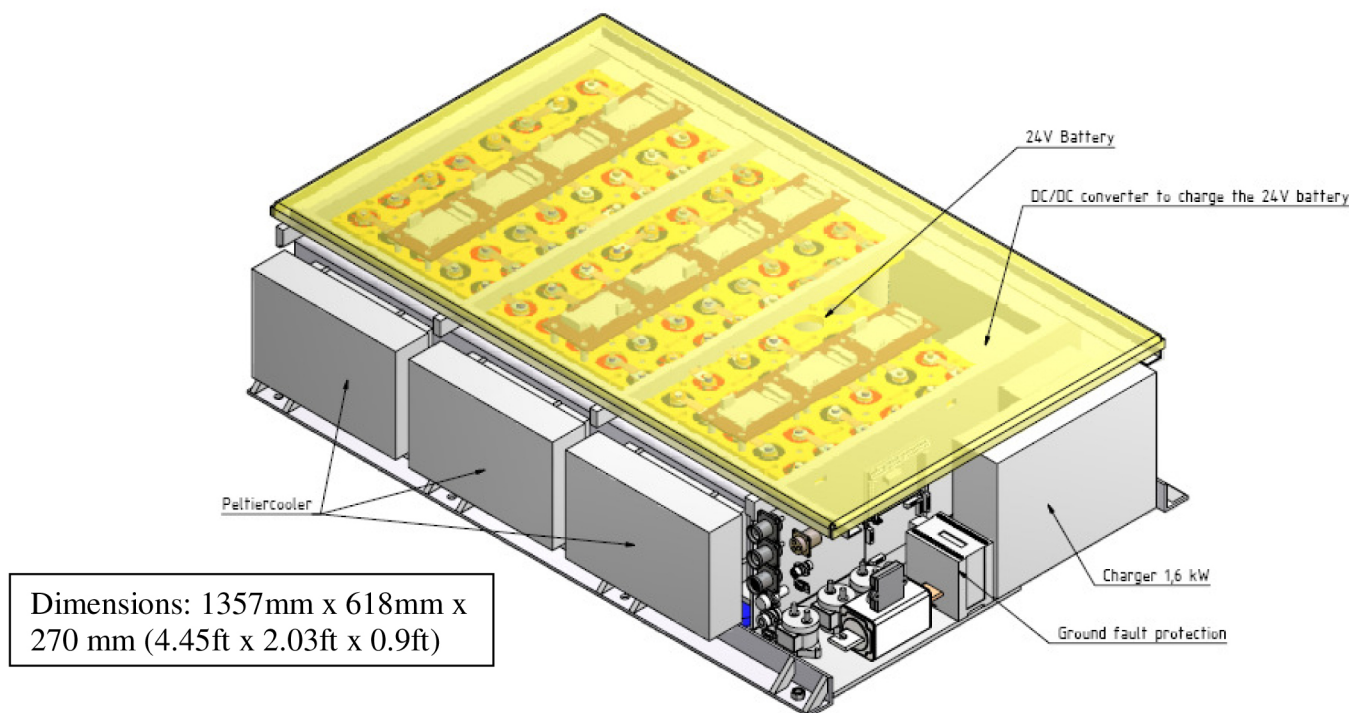


Figure 2.2.

and a 3.3kW charger and weights 262kg (578lbs). The battery pack, seen on [figure 2.2](#), also includes DC converter to keep BMS active when 12 or 24V supply is off.

CONTROL STRATEGY

The control strategy of this system was developed with maximum Fuel Economy in mind. It is estimated that an hour of engine idling at work sites consumes an average of 1.17 gallons of diesel fuel. Similarly, recent analysis of 400+ Hybrid Utility vehicles in the field show that more than two thirds of the fuel saving comes from stationary operation. As a result, the controls were developed to optimize stationary operation at job sites with engine off (depletion mode) and minimal hybrid boosting during driving (sustaining mode).

[Figure 2.3](#) summarizes a typical vehicle drive cycle, starting at full State of Charge (SOC), driving in sustaining mode (1) to the first work site, depleting the battery while operating the aerial device with engine off (2), driving to another work site in sustaining mode (3) and so on and so forth, until the vehicle returns to its station in a charge depletion mode or until the engine restart to recharge the battery (4).

Ideally, the vehicle would return to the station with a completely depleted battery before being plugged to the grid. Such automated control strategy is complex and require inputs from either the fleet (route mapping) or GPS enabled devices.

CHARGING STRATEGY

The plug-in functionality of this design provides the vehicle with three potential sources of energy for battery charging; electricity from the grid, neutral charging from the engine or electricity from the regenerative braking.

Mobile recharge

There are two ways to recharge the batteries while on the go and away from the grid; regenerative braking and neutral charging.

Regenerative braking happens when the truck is slowing down. The motor becomes a generator and uses the momentum of the vehicle to create electricity. The regeneration feels as if the brake is being lightly applied. This charging helps slow down the vehicle. The full power of the service brake is always available to the driver - regardless of the battery's ability to absorb power. The Eaton Hybrid Control Unit automatically shuts off regenerative braking when the batteries are fully charged. The regenerative braking is also automatically shut off during an ABS (anti-lock brake) event, i.e. skidding on ice covered roads while trying to stop the vehicle.

Neutral Regen happens when the vehicle is in stationary mode. The diesel engine automatically starts to recharge the batteries, while providing full PTO drive power. Once the SOC reaches a certain threshold, the engine automatically stops for silent mode operations.