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Evaluation of 48V and High Voltage Parallel Hybrid Diesel Powertrain Architectures for Class 6-7 Medium Heavy-Duty Vehicles

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Abstract

Electrification of heavy-duty trucks has received significant attention in the past year as a result of future regulations in some states. For example, California will require a certain percentage of tractor trailers, delivery trucks and vans sold to be zero emission by 2035. However, the relatively low energy density of batteries in comparison to diesel fuel, as well as the operating profiles of heavy-duty trucks, make the application of electrified powertrain in these applications more challenging. Heavy-duty vehicles can be broadly classified into two main categories; long-haul tractors and vocational vehicles. Long-haul tractors offer limited benefit from electrification due to the majority of operation occurring at constant cruise speeds, long range requirements and the high efficiency provided by the diesel engine. However, vocational applications can realize a significant benefit from electrified powertrains due to their lower vehicle speeds, frequent start-stop driving and shorter operating range requirements.

As the heavy-duty industry deals with solving challenges around the application of electrified powertrains, there are multiple pathways that can be explored to meet future regulatory requirements. This paper is the first part of a two-paper series that focuses on evaluating electrified solutions for Class 6-7 medium heavy-duty vehicles in the 2027 and beyond time frame. In this paper the focus is on investigation of near-term hybrid solutions that provide reasonable fuel efficiency improvements within a two-year payback period.

To investigate the various hybrid electric architectures, FEV has developed a system level approach for the selection and sizing of heavy-duty diesel hybrid powertrain components using GT-SUITE. The approach has been applied for a Class 6-7 urban vocational truck, which typically experiences low speed driving with frequent start-stops. A dynamic model for the baseline diesel vehicle was developed and calibrated to test data. The baseline diesel vehicle was then updated with hybrid powertrain components to evaluate different parallel hybrid architectures (P1, P2, P3, P4) at two different voltage levels: ≤48V (mild hybrid) and >150V (full hybrids). The evaluation was conducted over multiple drive cycles, including the ARB Transient Cycle and a real-world drive cycle. In the evaluation, key trade-offs were identified between fuel consumption, initial investment cost, payback period and freight efficiency. The trade-off analysis demonstrated that for a two-year payback period, a P3 architecture provided the best fuel consumption value for full hybrid applications. In a P2 or P3 configuration, a 48V system also showed considerable fuel efficiency improvements compared to the baseline diesel vehicle. The final P3 hybrid powertrain configuration for Class 6-7 vocational truck shows a 27% fuel consumption reduction for a 350V system while a 48V system shows a 22% fuel consumption reduction when considering a payback period of two years.

Introduction

As the transportation sector is continuously growing it is expected that the truck freight will continue to rise in the United States (US) by at least 1% every year for the next 25 years [1]. Class 3-8 medium to heavy-duty trucks, primarily used for on-road freight transportation, are responsible for 23% of the total transportation related Greenhouse Gas Emissions (GHG) in the US [1]. In Europe, heavy-duty vehicles are responsible for 5% of the total greenhouse gas emissions [1,2]. Reduction of GHG emissions from the transportation sector will have a major impact and has been undertaken by multiple US government agencies including the Environmental Protection Agency (EPA) and California Air Resource Board (ARB). EPA has already implemented Phase II GHG emission standards requiring 22-25% reduction in CO_2 emissions by 2027 [3]. The European Union [EU] has also mandated that certain categories of heavy-duty trucks reduce their CO_2 emissions by 30% of 2019 emission levels in 2030 [4]. ARB's Advanced Clean Truck regulation released in June 2020 also mandates that the truck Original Equipment Manufacturers (OEM's) begin selling a larger share of Zero/Near-Zero Emission Vehicles (ZEV/NZEV) in

The trade-off analysis demonstrated that when considering a two-year payback period, a 350V P3 architecture provided the greatest fuel consumption benefit at 27%. In a P3 configuration, the 48V mild hybrid system also showed a considerable fuel consumption improvement of 18% when compared to the baseline diesel vehicle. The EPA 2027 GHG emission targets for Class 6-7 urban vocational vehicle can be achieved with a 48V P3 mild hybrid configuration when coupled with mandated engine improvements. The cost of ownership is lower for the 48V P3 mild hybrid architecture when compared to the baseline diesel vehicle. The full hybrid solutions for the P3 architecture had the highest cost of ownership mainly driven by the higher operating and maintenance costs.

Operation over the real-world drive cycle generated using GT-RealDrive demonstrated a lower delta in CO_2 reduction and freight ton efficiency improvements between the P3 48V mild hybrid and full hybrid solutions. It is critical to consider both certification and real-world drive cycles when optimizing the hybrid system specifications. Considering a two-year payback period, the final P3 350V hybrid powertrain solution for the Class 6-7 vocational vehicle provides a 33% freight ton efficiency improvement along with 27% reduction in CO_2 emissions, while a 48V mild hybrid system provides a 24% freight ton efficiency improvement along with 18% reduction in CO_2 emissions.

To further evaluate the potential of a 48V mild hybrid for heavy-duty applications, future studies will focus on evaluating the P3 mild hybrid architecture for Class 4-5 and Class 8 long-haul applications. Studies will also focus on evaluating the use of a 48V belt starter generator with a P3 mild hybrid architecture for Class 4-8 applications.

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Definitions/Abbreviations

US - United States

GHG - Greenhouse Gas

EPA - Environmental Protection Agency

ARB - Air Resources Board

EU - European Union

CO_2 - Carbon Dioxide

OEM - Original Equipment Manufacturer

ZEV - Zero Emission Vehicle

NZEV - Near-Zero Emission Vehicle

NACFE - North American Council for Freight Efficiency

NMC - Nickel Manganese Cobalt Oxide Li Ion Battery

DC - Direct Current

BLDC - Brushless Direct Current

SOC - State of Charge

MPGe - Miles per Gallon Equivalent

BSFC - Brake Specific Fuel Consumption

FC - Fuel Consumption