2021-01-0727 Published 06 Apr 2021

New Fuel-Cell Hybrid Architecture for Heavy-Duty Trucks Applications

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Citation: El Ganaoui-Mourlan, O., Miliani, E.H., Saber, R., Ditzel Filho, L.A. et al., "New Fuel-Cell Hybrid Architecture for Heavy-Duty Trucks Applications," SAE Technical Paper 2021-01-0727, 2021, doi:10.4271/2021-01-0727.

Abstract

Due to its strong reliance on oil products, the transport sector is one of the major contributors to greenhouse gas emissions in Europe. To achieve long term targets proposed by recent regulations related to climate change measures, several studies are being conducted to reduce GHG emissions in road freight transport. In this context, hybrid vehicle technologies, already well developed for passenger cars and vans, have demonstrated a good potential of reducing fuel consumption also in medium and heavy-duty applications. Alternative fuels such as hydrogen have also demonstrated to be a good option to help reducing petroleum use and still ensure optimal performance. This study presents the feasibility of different hybrid architectures as counter options to a conventional long-haul truck powertrain, not only in terms of fuel economy but, in addition, from an economic point of view.

Introduction

Heavy-duty trucks are commercial vehicles driven for very long distances and have considerably long operational lives. For this reason, while they represent a small percentage of all the road vehicles, long-haul trucks consume a large percentage of fuel and, therefore, represent a large contribution of CO2 emissions [1]. This scenario points toward a spread of low and/or zero emission technologies in heavy commercial vehicles in the near future.

To decarbonize the transport sector, solutions such as improving aerodynamic resistance, reducing rolling resistance, and vehicle weight reduction are fundamental. The use of biofuels can also contribute to achieve lower emissions [2]. However, to achieve deeper GHG emission reduction from HD trucks imposed by new regulations and current strict climate change targets, alternative powertrains appear to be the main option.

Although there is skepticism, not only technically, but mainly in terms of economic feasibility of both battery and hybrid electric trucks (BET and HET), European OEMs have been showing an increasing number in sales and series production of such kind of vehicles, besides growing investments in research and development for the upcoming years [4]. Indeed, numerous studies have demonstrated the potential of HET and BET to significantly reduce fuel consumption for several medium and heavy-duty applications [5].

On the other hand, there are concerns that are mainly related to high costs and weight added to the vehicle by the battery due to the range required for road freight vehicles. Fuel cell-based powertrains allow to reduce the battery size while keeping similar vehicle autonomy.

The proposal of this paper is to determine the best powertrain configuration to achieve fuel consumption reduction when compared to a conventional long-haul truck, while keeping a requirement of full-electric operation in urban conditions. Firstly, an overview of existing technologies is shown. Different hybrid architectures are simulated according to the duty-cycles provided. A different architecture is proposed by combining a diesel engine and a fuel-cell and its benefits are further detailed. A cost analysis is also performed for the simulated architectures.

Hybrid Architectures for Long-Haul Trucks

According to European OEMs, hybridization seems to be the fastest solution for reaching (harsh) emission legislations, while electrification and hydrogen fuel cells are considered to be solutions for the long term [2]. Hybridization allows to improve fuel consumption of HDVs with a conventional combustion engine by adding another 'clean' propulsion unit, that comes along with its own energy storage unit. The advantages of such architectures are a reduced battery size, when compared with full-electric vehicles, extended battery lifetime, and certainly, cost. The cost of the battery is in fact a major part of BET/HET [6].

The main hybrid configurations discussed in this paper are series and parallel architectures. Both configurations are comprised by an ICE, an electric motor, and a battery, but

Where the fixed costs are represented by the annualized capital of the truck and the running costs are the sum of fuel, driver wages and maintenance costs. The obtained result for each architecture is shown below in Figure 16. A yearly mileage of 120,000 km is considered, for a lifetime of 10 years.

Summary/Conclusions

This paper introduces the definition and simulation of a hybrid powertrain architecture for heavy duty long-haul trucks to meet future emissions regulations while passing certain performance criteria. This architecture permits the use of long-haul trucks in cities entirely without any propulsion resulting from combustion, allowing access to low emission zones and places where the use of the ICE is banned. The optimal component sizes for such an architecture propose the downsizing of the benchmarked 13L diesel engine, in addition, the of the other power components (EM, Battery, and Fuel Cell) fall within the range of what is found in today's market. Emphasizing the fact that long-haul trucks travel long distances and are even exposed to several countries, this architecture allows the refueling from any of the alternate energy sources, such as hydrogen, that has been gaining interest over the years, or electricity, that are now emerging and becoming more abundant in today's energy plan for a carbon neutral future. The results from the forward 0-D longitudinal dynamics simulations show significant benefits, not just in emissions, but in overall energy savings.

It is important to note that factors such as durability, packaging, and infrastructure are not included in this analysis. As for this specific architecture containing numerous components and power sources, packaging is surely to be a challenge.

References

1. Çalışkan, K., Yildirim, M., Unlusoy, Y., and Kilic, V., "Development of a Hybrid Electric Heavy Duty Truck," in *Electric Vehicle Symposium and Exhibition*, Barcelona, Spain, 2008.
2. ITF, *Towards Road Freight Decarbonization Trends Measures and Policies* (Paris: ITF Policy Papers, OECD Publishing, 2018).
3. Earl, T. et al., "Analysis of Long-Haul Battery Electric Trucks in EU," in *8th Commercial Vehicle Workshop, Graz*, Austria, 2018.
4. Zhao, H., Burke, A., Zhu, L., "Analysis of Class 8 Hybrid-Electric Truck Technologies Using Diesel, LNG, Electricity, and Hydrogen, as the Fuel for Various Applications", in *Electric Vehicle Symposium and Exhibition*, Barcelona, Spain, 2013.
5. Karbowski, D., Delorme, A., and Rousseau, A., "Modeling the Hybridization of a Class 8 Line-Haul Truck," SAE Technical Paper 2010-01-1931, 2010. https://doi.org/10.4271/2010-01-1931.
6. Mareev, I., Becker, J., and Sauer, D.U., "Battery Dimensioning and Life Cycle Costs Analysis for a Heavy-Duty Truck Considering the Requirements of Long-Haul Transportation," *Energies* 11:55, 2018.
7. Hayes, J.G., and Abas Goodarzi, G., *Electric Powertrain. Energy Systems, Power Electronics and Drives for Hybrid, Electric and Fuel Cell Vehicles* (Wiley, 2018).
8. Kondo, N., Takahashi, H., Yamada, J., Tanabe, K. et al., "Fuel Economy Improvement Potential Study with Energy Management of Heavy Duty Truck HEV for Long Haul Application," SAE Technical Paper 2015-01-1781, 2015. https://doi.org/10.4271/2015-01-1781.
9. Fernandez, R.A. et al., *A New Approach to Battery Powered Electric Vehicles: A Hydrogen Fuel-Cell-Based Range Extender System* (Hydrogen Energy Publications, LLC. Elsevier Ltd, 2016).
10. International Energy Agency: "The Future of Trucks - Implications for Energy and the Environment," 2017.
11. Hunter, C. and Penev, M.: "Market Segmentation Analysis of Medium and Heavy-Duty Trucks with a Fuel Cell Emphasis," DOE Hydrogen and Fuel Cells Program, National Renewable Energy Laboratory, 2019.
12. Niita, N. et al., "Li-Ion Battery Materials: Present and Future," *MaterialsToday* 18(5):252-264, 2015.
13. den Boer, E., Aarnink, S., Kleiner, F., and Pagenkopf, J., "Zero Emissions Trucks: An Overview of State-of-the-Art Technologies and Their Potential," Delft, CE Delft, July 2013.
14. Karlstrom, M. et al, *Can Fuel Cells Become a Mass-Produced Option Globally for Heavy-Duty Trucks 2030+?* (ENERGIFORSK September 2019), ISBN 978-91-7673-604-3.
15. Kleiner, F. and Friedrich, H., "Maintenance & Repair Cost Calculation and Assessment of Resale Value for Different Alternative Commercial Vehicle Powertrain Technologies," in *EVS30 Symposium*, Stuttgart, 2017.
16. Zhu, D., and Pritchard, E., "NCSU Year Three Final Technical Report," SAE Technical Paper 2014-01-2907, 2014. https://doi.org/10.4271/2014-01-2907.
17. Zhu, D., Pritchard, E.G.D., and Silverberg, L.M., "A New System Development Framework Driven by a Model-Based Testing Approach Bridged by Information Flow," *IEEE Systems Journal* 12(3):2917-2924, 2016.

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Definitions/Abbreviations

BET - battery electric truck
DOE - design of experiments
FCET - fuel-cell electric truck
GHG - greenhouse gas
HET - hybrid electric truck
HDV - heavy-duty vehicles
HV - high voltage
ICE - internal combustion engine
SoC - state of charge
TCO - total cost of ownership

ISSN 0148-7191