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Improving Heavy-duty Vehicle Energy Efficiency through Connectivity

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Abstract

Improvements to transportation energy use have often focused on the search for a replacement for the internal combustion engine. Currently, several viable alternatives have emerged and research continues to look more deeply at the benefits to the different energy production options. In addition, each of these options can be more efficiently used when paired with connected vehicle structures. In this commentary, the potential impacts of connectivity on the energy efficiency of heavy-duty vehicles are explored.

Keywords: Vehicle energy management ● Connected vehicles ● Hybrid electric vehicles ● Power production

Introduction

Transportation has been highly dependent on petroleum resources throughout recent history, but technological advances, climate change concerns and government mandates are spurning a diversification of the energy sources used in this field. Electrification has emerged as a prominent option for light-duty vehicles and, if coupled with renewable electricity production, can create a significant stride toward sustainable energy use [1,2]. While electrification is promising for light-duty passenger cars, development is still ongoing to fully electrify medium and heavy-duty vehicles. In particular, heavy-duty vehicles have high power demands and also often travel long distances. As such, heavy-duty vehicle energy storage requirements still pose challenges for fully electric options and the search continues for an alternative to the conventional internal combustion engine for heavy-duty vehicles [3]. The primary options being considered are hybridization, the integration of hydrogen fuel cells, the use of internal combustion engines operating with advanced combustion strategies, and the implementation of more carbon neutral fuels [4-7]. Each of these alternatives individually has the potential to improve transportation energy efficiency and/or reduce emissions output, but these options can also be combined. For example, Soloukmofrad examined the use hybridized powertrains leveraging engines operating with advanced combustion strategies and found that superior performance could be achieved [8]. Similar benefits are anticipated with other combinations of these primary power production options.

While new vehicle power production strategies can improve energy use, connectivity can also enhance the effectiveness of all of these options. Specifically, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication can enable more intelligent and optimal energy management. The utility of connectivity has been more extensively explored in the area of Hybrid Electric Vehicle (HEV) energy management. HEVs use a battery and motor system as well as an engine system to produce the required vehicle power and have to constantly manage the energy production between these two systems. Future path and velocity forecasts from V2V and V2I information can provide an estimate of the power demands over the upcoming drive segment and enable the energy management system to achieve lower fuel consumption than a base unconnected hybrid electric vehicle [9-11]. The advantages of connectivity in hybrid vehicles have been extensively explored in light-duty passenger cars, but recent studies have also shown that connectivity can provide advantages in heavy-duty HEVs and enable a 12% improvement in energy use over baseline cases [12].

Connectivity can bring a similar advantage to conventional and hybrid electric vehicles that utilize an engine that is operating with a novel fuel or an advanced combustion strategy. In conventional vehicles, future power demand predictions can be used to optimize gear shifting and enable fuel-cut off during periods of deceleration and idle. Advanced combustion modes typically seek to achieve a more premixed or partially premixed combustion process that can be cleaner and more efficient. However, these modes often have limited operating regions and in order for the engine to operate over the entire needed speed and torque range, they have to switch between conventional combustion strategies and these more advanced approaches. Connectivity can help minimize mode switching thereby improving efficiency and emissions and reducing system wear [12]. It follows that a vehicle operating with a more carbon neutral fuel should also be able to be more optimally used in a connected heavy-duty vehicle, but this topic is still being explored.

Vehicles that rely on electric power either from a battery or in part supplied by a fuel cell system can also take advantage of connectivity, particularly when considered as part of the larger grid system. Electric vehicles could help enable enhanced grid energy management by coordinating their charging and discharging activities with the grid [13,14]. This is particularly valuable in systems that integrate renewable energy sources such as solar and wind given the higher variability of these energy sources. Vehicle battery systems could serve as additional storage source during times of high energy production from wind and solar sources thereby providing greater flexibility for grid energy management strategies and more efficient energy use. Initial studies have shown that coordinated charging and discharging strategies can provide a reduction of 14.3% in terms of the energy cost [15]. Integration of fuel cell vehicles into the grid has not been as extensively explored, but is of significant interest. Excess electrical power from renewables could be used to produce hydrogen which can be more effectively stored for long periods of time than electrical energy in a battery. This concept is part of the "hydrogen economy" idea. While this idea has existed since the 1970s, recent advances in hydrogen production and storage as well as fuel call materials are making this concept more viable [16]. It remains to be seen whether the hydrogen economy comes to fruition, but connectivity would also play a key role in ensuring proper energy management of the various vehicle-grid interactions.

While connectivity brings some clear benefits for energy management, it has broader implications. Connectivity also can be used to produce better advanced driver assistance systems. Increased automation such as lane

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keeping assist or adaptive cruise control on such vehicles could reduce driver stress and improve the quality of life of the drivers of long-haul, heavy-duty vehicles. In addition, connectivity could enable better traffic congestion management [13]. While connectivity will clearly be a part of future vehicles and should provide distinct benefits, it creates a need for more complex control structures suitable and the need for improved cybersecurity. Future work will need to not only examine how connectivity can improve energy use and safety, but also ensure that proper cybersecurity protocols are layered into the system.

Conflict Of Interest

Author has disclosed that he has no conflict of interest.

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