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Analysis of a fictive active e-trailer

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Abstract

Trucks, consume an enormous amount of diesel annually and contribute greatly to the total CO2 emission around the world. Electrification of these freight vehicles will lead to reduction of fuel consumption and CO2 emission. Trailers as part of heavy freight vehicles are a great opportunity for innovative change. Electrifying the trailer allows the combustion engine of the truck to cooperate with the electric motors in the trailer. The trailer will be able to regenerate energy using the electric motors, which are built into the rear axis of the trailer. The regenerated energy will be stored in a battery power pack for later use.

Using the principle of peak shaving, the combustion engine will be assisted by the active e-trailer. Peak shaving occurs when the calculated load [1] on the combustion engine is highly above average, for example during accelerating, climbing a hill or during high speed. Energy from the power pack will be routed to the electric motors, assisting the propulsion force.

The analysis of the fictive active e-trailer is focused on the reduction in fuel consumption and emissions. The energy consumption of the trailer and the energy regeneration has been studied. For this analysis, two vehicle configurations have been simulated within MATLAB Simulink. One truck-trailer combination without the e-trailer application and one vehicle combination with the e-trailer applied. Differences between the two simulated vehicle combinations are analyzed and documented..

The whole system is able to be self-sustaining by using the regenerating energy from breaking. However, better results can be achieved by charging the power pack once in a while. If doing that, the fuel cost and emissions saving can be significant.

Keywords: Freight transport and heavy-duty vehicles, Special vehicle technologies, (plug-in) Hybrid powertrain, Environmental impact assessments.

Problem and case

Rotterdam is an international port city where many freight vehicles come and go into the ports. They deliver their load and return to their (international) home base. Also, many freight vehicles move within the region from one port to another. Trucks, consume an enormous amount of diesel annually and contribute to about 1/3 of the total CO2 road transport related emission of Rotterdam, and is expected to rise above 45% in 2025 [3]. Electrification of the trucks has been started on small scale for city distribution, but there is still a large fleet of diesel consuming vehicles on the road for heavy transport. Moreover, in the port area many the container trucks drive only short distances. Moreover, modern diesel engines are highly developed, which makes it more and more difficult to reduce emissions further. How are we going to reduce emissions if the engines have no room for more reduction?

Call for e-trailer

Most heavy freight trucks are tractors having a trailer behind it on which the load is transported. The trailer usually just gets dragged behind the truck. When the trailer is equipped with two electrical direct-drive motors [2] on one of the rear axles, along with a power pack to provide energy for these engines, the possibility to push the truck forward will become reality. The trailer will be able to provide propulsion for the whole combination. With this adjustment to the freight vehicle, new possibilities are born. The active e-trailer is born.

The freight vehicle will be able to use two separate sources of propulsion to accelerate. Given the energy level of the power pack, the active e-trailer will be able to determine the amount of power output that the trailer can assist the truck with. The load of the diesel engine will be reduced, because the trailer will provide additional traction power. Given that the trailer is outfitted with electrical motors, it is also able to regenerate energy while breaking. This electric energy will be redirected towards the power pack and stored for later use.

Research

The research is directed towards the moments where the freight vehicle will need to be assisted most by its trailer, focusing on the moments where vehicle resistances are highest while the desired speed is high as well. Peak shaving is one of the core principles within this project. The trailer will literally shave the peaks of the amount of load that the diesel engine has to provide and delivers the excessive load itself. This will reduce fuel consumption and emission of CO2 where the load is highest.

The application can also be used for a hybrid system or as a full electric vehicle. As a hybrid, the trailer will shave peaks off of the load that the diesel engine has to provide and provides the excessive load itself, aside of delivering a continuous amount of power, which is pre-determined and load- and energy level dependent. As a full electric vehicle, the diesel engine will be shut down and the trailer will cover the complete demand for load. The active e-trailer will become the complete powertrain and the truck will be pushed forward for e/g last mile zero emission driving.

The hybrid system will result in the extension of driving range, a reduction in fuel consumption and CO2 emissions, whereas the full electric system will allow zero emissions and fuel consumption. However, the hybrid and the full electric system will consume energy, which is provided by the power pack. This has to be monitored when a system is selected. The vehicle combination will not be able to use its hybrid or full electric capabilities when the energy levels are depleted.

Input and results

The research is based on a simulation with the given parameters and calculates the results (based on total vehicle mass, drive cycle, truck model and the peak shaving system). Results are given in percentage reduction of fuel consumption, emission reduction and energy consumption.

The simulation has been created by using standard Automotive formula's, along with some physical data. From there, the complete powertrain for the fictive vehicle combination is simulated. Using the driving cycles, which were provided for this research, the simulation calculated the differences between a regular truck-trailer combination and implementation of the e-trailer. The e-trailer showed significant reduction in both emission and fuel consumption, while also saving money.

The results from the simulation have been analyzed and summarized. Table 1 originates from this research and calculates the total savings using the e-trailer on a daily basis, while charging 24.2 kWh a day and saving up to 8 liters a cycle. The cycle used for this research is the Hyzem urban cycle (figure 1), repeated fifteen times to cover about 50 km driving. Other aspects of the simulation have been analyzed as well. For example: the state of charge (SOC) of the battery pack, the CO2 emission reduction, a regular truck-trailer combination, multiple variations on the 'peak shaver' and many more.

Table 1: Calculation of savings as a result of using the e-trailer instead of a regular trailer.

E-TRAILER TABLE [DAILY CHARGING]	RESULTS
CONVERTING TO E-TRAILER COST (€)	N/A
USED ENERGY PER CYCLE	41.48 kWh
REGENERATED ENERGY PER CYCLE	17.26 kWh
TOTAL ENERGY USAGE	24.2 kWh
TOTAL USED DIESEL PER CYCLE [REGULAR TRAILER] (L)	13.70
TOTAL USED DIESEL PER CYCLE [E-TRAILER] (L)	5.61
COST KWH GREEN ENERGY (€)	0.19
COST KWH FAST CHARGE ENERGY (€) (OPTION)	0.36
FUEL REDUCTION EACH CYCLE (%)	59.03
COST LITER DIESEL (€)	1.35
EMISSION RIGHTS PER YEAR (6 €/1000 KG CO2)	47.04 €
ANNUAL FUEL REDUCTION (€)	3.986
COST GREEN ENERGY (€)	1.678
COST FAST CHARGE ENERGY (€) (OTION)	3.180
TOTAL DIESEL SAVINGS COMPARING TO REGULAR TRAILER (%)	***59***
TOTAL ANNUAL SAVINGS GREEN ENERGY (€)	***2.355***
TOTAL ANNUAL SAVINGS FAST CHARGE ENERGY (€) (OPTION)	***863***

Figurer 1: The hyzem urban cycle. The cycle used for this research contains 15 consecutive hyzem urban loops. Note: Horizontal axe are seconds vertical axe is speed in km/hours

Future state

The research has been currently documented with the numbers above. However, there is a lot of room for improvement. The limited timeframe for the research to did not allow for further research in the possibilities of fuel and emission reduction. The project will continue to grow from this point onwards. We showed the potential of the active e-trailer as 'peak shaver'. Some extra theoretical and practical research is needed to further optimize its efficiency and the study other dive cycles.

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Authors

Steven Boonstra is a student Automotive Engineering at Hogeschool Rotterdam, Rotterdam. During his education years, he started to focus on future mobility and environmental issues. Knowing that the Automotive industry cannot maintain its current form as it is today, research is required into new fields. Electric powertrains and battery power packs are to be researched in the future and Steven wants to play his part in this upcoming battle. His past projects were the Shell Ecomarathon, where he worked on the drivetrain of a Hydrogen vehicle, and the active e-trailer.

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