EVS30 Symposium

Stuttgart, Germany, October 9 – 11, 2017

Analysis of a fictive active e-trailer

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Executive Summary

Trucks consume an enormous amount of diesel annually and contribute greatly to the total CO_2 emission around the world. Electrification of these freight vehicles will lead to reduction of fuel consumption and CO_2 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, adding propulsive force.

The analysis of the fictive active e-trailer is focused on the reduction of 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 truck-trailer combination with the e-trailer applied. Differences between the two simulated vehicle combinations are analyzed and documented.

The whole system is self-sustaining by using the regenerating energy from breaking. However, better results can be achieved by charging the power pack periodically. By doing so, the fuel cost and emission reduction can be increased significantly.

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

1 Introduction

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. Many tend to believe that freight vehicles are cargo ships, however a lot of cargo is also being driven into the city by trucks. These trucks move cargo from other countries to Rotterdam and back, and also distribute their load from one region within the port area to another. The trucks are responsible for consuming an enormous amount of diesel and are responsible for a third of the total road transport related CO_2 emission of Rotterdam, which is expected to rise above 45% in 2025 [2]. The city has been searching for possible solutions to prevent this from happening. On a small scale, the electrification of trucks has started for city distribution to reduce CO_2 emission. The port area is a great place to start electrification, since the trucks within the area drive short distances before unloading and heading to the next location. Electric vehicles prove to be much more efficient here.

However, there are still a large number of international fleet diesel consuming vehicles on the road for heavy transport. This fleet is far too big to completely convert into electric vehicles, thus other options have to be explored to reduce the massive CO_2 emission. Moreover, modern day diesel trucks are highly developed, making it even more difficult to reduce emissions. The engine of these trucks are created in such a way that, regarding the reduction of emissions, it leaves barely any room for improvement.

Currently, one might find the best results within e-technology. Electrical components have many applications and they can prove their worth during the inevitable changes within the automotive sector. Preparing for change right now is the best thing to do in order to prevent major problems from happening in the future. Completely converting to electric trucks is not feasible, but working towards it is.

2 Call for alternative technology: active e-trailer

Most heavy freight trucks are trucks with a trailer attached to it on which the load is transported. The truck usually provides propulsive force for the complete vehicle combination. When comparing combustion engines to electrical motors one can derive positive and negative aspects from both techniques. Combustion engines are currently dominating the world of cargo transport over land and merely a small percentage of cargo transport is done by electric vehicles. However, before the combustion engines can effectively be replaced by electrical motors, a great number of problems must be dealt with during the transition phase. A way to avoid this is by wondering, why not combine the best of both? This question was the main drive behind the creation of the e-trailer concept. The e-trailer is a combination of a truck and a modified trailer. The trailer is equipped with two direct drive engines and a power pack of limited size. With these adjustments, the modified trailer will be covering a whole new set of added functions:

1. The e-trailer provides extra propulsive force when needed
2. Direct drive motors lead to high efficiency and minimal energy loss
3. The power pack can be charged by regenerative breaking and a plug-in cable (option)
4. The e-trailer can function as a hybrid or full electric, cutting its emissions greatly
5. Using energy for the electrical motors increases the active radius of the truck
6. Regenerative breaking is enabled, resulting in lower fuel consumption and energy recycling
7. Installment of a communication unit allows for the system to work with any regular truck

2.1 Functions and components explained

(1) Adding the e-trailer to a regular truck requires an additional communication unit between the truck and the trailer. Sensors will be able to detect moments in which the freight vehicle could use assistance the most. The trailer acts upon the readings of the sensors and adds propulsive force in order to assist the truck when instructed to do so. There are many variables to be taken into account in order for this to be possible, such as: jackknifing, the speed of the vehicle combination, the efficiency of the combustion engine and the electrical motor under variable circumstances, the power output of both power sources, the state of charge of the power pack and many more. Remarkably, they all come together in an engineered strategy which allows the system to determine when it is safe, efficient and required to add power through the e-trailer.

(2) There are many electrical motors that can be used to electrify a trailer. When it comes to energy efficiency, direct drive motors are ahead of similar technologies within the automotive sector. With efficiency up to 92%, this technology reduces energy loss tremendously and improves the performance of the e-trailer. Direct drive motors exist of very few parts and do not need any gearbox, differential or other form of transmission to transmit power. Additional parts usually waste some of the energy in order to work, so it is of high importance to use as few parts and transmissions as possible. This is where the strength of the direct drive motors lies and it also explains why its efficiency can reach up to 92%. Preservation of energy will become very important in the next generations to come. Waste is not going to be tolerable anymore if we want to push technology further. The direct drive technology is taking a big leap in the right direction.

(3) Power packs are present day's best solution for an energy carrier within the automotive sector and can be used for this concept. The direct drive motors will be installed on a single axle of the trailer and will be able to perform regenerative breaking. Regenerative breaking occurs when the vehicle is driving faster than the electrical motors. When the motors are engaged, they will serve as a generator and produce energy rather than consume it. However, this will slow down the vehicle, so it has to be done rather strategically in order to optimize the function and prevent it from wasting precious propulsive energy. When energy is produced by the generator function of the electrical motors, it can be channeled to the power pack and stored away for future use.

(4) The e-trailer can fulfill various functions. Firstly, it becomes part of a hybrid powertrain, which will consume both diesel and electricity. The electricity will mainly come from regenerative breaking, but the power pack can be charged prior to shipping cargo in order for there to be an energy supply available for use. A hybrid combination between a combustion engine and an e-trailer will need a preset distribution of power and can be further improved by implementing the principle of peak shaving. Peak shaving focusses on the heavy duty moments of the combustion engine and removes the peaks by requesting power from the electrical motors. This way, the combustion engine will have less inefficient heavy duty moments and perform better overall. In addition, the electrical motors are highly capable of delivering the requested power while maintaining a high efficiency level. The overall efficiency increases and therefore a lot of energy and diesel will be spared compared to the energy efficiency of regular trucks.

Secondly, the e-trailer can fully power the vehicle combination with electricity for a certain duration, resulting in zero emission output. Within the city of Rotterdam, this function will be extremely handy since the city has a zero-emission policy. Regular trucks are not allowed within the city due to their high emission output. A fully electric vehicle would be granted access to the city.

Lastly, the e-trailer can be set in such a way that it solely generates energy by regenerative breaking, without using energy for the electrical motors. This enables the power pack to regulate its state of charge, which will in turn enhance its lifetime.

Clients will be asked to share information about their load case of the truck and daily routines. With this information the e-trailer can be altered to perform its best within that particular case. This allows for the maximization of its use.

(5) Active radius will be increased. The reason for this is that the peak shaving principle will be applied to the vehicle combination, even when no hybrid configuration is selected. The trailer will automatically select moments when the truck is having a rough time, providing enough propulsion and assistance for the vehicle combination. In turn, this will lower the power demand of the combustion engine. Since the combustion engine consumes diesel and has a separate tank for this, active radius can be calculated based on the amount of fuel the tank is able to hold. When adding the e-trailer, the capacity of the power pack will be added to the total energy supply, thus increasing the active radius of the vehicle combination.

(6) Regenerative breaking has many advantages. Since it automatically slows down the vehicle due to the inertia of the generators, the vehicle has to brake less with its mechanical braking system. This will save the braking system of the truck a great deal of wear, thus increasing its overall lifetime.

Furthermore, regenerative breaking generates energy which will be channeled back to the power pack. This energy can then be used to power the electrical motors. When the electrical motors provide power, the power will be deducted from the overall demand of power by the vehicle combination, resulting in a lower amount of power provided by the combustion engine. A lower amount of power means a lower amount of fuel consumption, so regenerative breaking indirectly causes the fuel consumption to drop a great deal. Also, the electrical motors are more efficient compared to the combustion engines, so the overall efficiency of energy usage increases greatly.

(7) Building e-trailers will prove to be quite simple. First, the electrical motors will have to be equipped on an axle of a standard trailer. Then, the size of the power pack has to be determined. It will be based on the application where the trailer is going to provide its services. Next, the power pack will be installed in the trailer; this will not affect the cargo hold of the trailer. Finally, a communication unit has to be installed to connect the trailer with the truck. This last component is very important, because it guarantees safety and affects the efficiency of the e-trailer tremendously.

3 Research: analyzing possible configurations

The research has been conducted mainly within a virtual simulation environment (MATLAB Simulink). By thoroughly analyzing the concept and exploring the possibilities and limitations within the physical world, a set of simulations is created from which fuel consumption and emission reduction can be derived. The focus of this research was the system behind the implementation of the trailer. How is it going to work? What affects the fuel consumption and how will this concept increase energy efficiency? What variations of the e-trailer are there?

While analyzing the e-trailer, the power ratio between the truck and the e-trailer has been altered. Since the e-trailer still lies in the concept phase, a stable power ratio between truck and e-trailer has yet to be discovered before further optimization of the concept. For the simulation of this concept it was important to include the specifications of the truck engine (MAN LOH31, 353 kW) and electrical motors (TheWheel SM500/3) used. Different trucks will not affect the results as much. However, using different electrical motors will, since the direct drive motors have higher efficiency than common electrical motors.

3.1 Driving cycle

The driving cycle, shown in figure 1, greatly affects the outcome of the simulation. On one hand, there are trucks that need to drive long distance due to certain jobs. They will have to perform its best while driving at various high speeds. On the other hand, there are trucks that need to drive within urban areas. These trucks will have to brake a lot, accelerate swiftly, perform well while driving at speeds ranging from 0-35 km/h and output less emissions in comparison to trucks on the highway. All these variables are taken into account and as a result, several profiles have been created for each application region of a truck. Aside from the written profiles, a driving cycle has been plotted and simulated. The simulation can use this as input to simulate vehicle speed over time. There are three main application categories in which any truck can be placed: urban, suburban and highway. Urban traffic usually ranges between 0-30 km/h, while performing many acceleration and deceleration actions. Suburban traffic will range between 0-50 km/h with fewer changes in speed compared to the urban category.

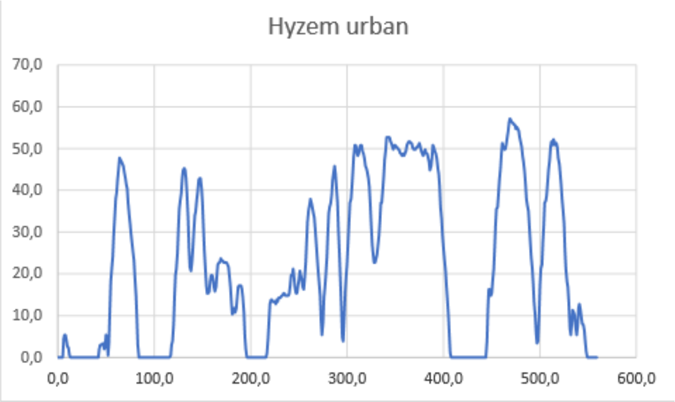

Figure 1: The Hyzem Urban driving cycle

Highway traffic ranges between 0-80 km/h with slight changes in speed. The highway category vehicles drive at a high speed continuously for long periods of time. Since the case study involved the port city Rotterdam, a range between 0 and 60 km/h is converted into a driving cycle. This allows for a realistic view of the main two categories (urban and suburban) and an idea of higher speed performance. For this, the Hyzem urban driving cycle is used. For longer simulations, this cycle is repeated until the total distance travelled is sufficient.

3.2 Power ratio's

For every application, an ideal power ratio between the combustion engine and the electric motors can be found. The electric motors perform greatly under low rpm (revolutions per minute of the wheel), but start losing efficiency when the rpm gets too high, while the combustion engine of the truck has a gearbox and is engineered to perform well during high speed. By combining the strengths and weaknesses of both engine and motors, a strategy of power ratio's between the combustion engine and electrical motors is developed. The e-trailer will provide more power when it is most efficient and less power under high speeds, with the exception of the truck requesting additional power through the peak shaving assist. The exact power ratio's used within the research cannot be disclosed.

3.3 Fuel economy

By using the driving cycle and determining a strategy for different power ratio's, which are guided by power demand and vehicle speed, accurate assumptions can be made regarding the fuel economy. The energy efficiency increased as a result of the power ratio strategy. This will result in a reduction of both fuel consumption and emissions. The power demand of the combustion engine is directly linked to the amount of emissions and fuel consumption. Where a higher demand will result in more fuel consumption and more emissions, a lower demand will result in less fuel consumption and less emissions. Additionally, a higher efficiency of the combustion engine will cut both fuel consumption and emission output as well. This is exactly what the power ratio strategy aims for: finding a balance between ideal efficiency regions of both the combustion engine and the electrical motors and reducing the demand of power for the combustion engine as much as possible. However, sufficient energy has to be available in order to execute this strategy.

4. Results

Table 1 shows the results of the e-trailer in comparison to a regular trailer based on the Hyzem urban cycle (the cycle has been repeated 15 times). Unfortunately, it is not yet clear how much it will cost to convert a regular trailer into an e-trailer. Consequently, a complete analysis of the financial aspect of the e-trailer is not possible. However, the total diesel savings can be derived, thus giving one an idea of the effectiveness of the e-trailer.

Table 1: Comparison e-trailer and 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 COMPARED TO REGULAR TRAILER (%)	***59***

The fuel savings are remarkable. A reduction of 59% would have a great impact on present day's demand for diesel. It will also allow for CO2 emissions per kilometer to drop substantially. The high number is the result of applying the power ratio strategy. As mentioned in chapter 3.2, finding a balance between ideal efficiency regions and peak shaving increases overall efficiency and reduces the fuel consumption. Developing the power ratio strategy more might lead to an increase in the reduction. Even so, this would require further research and since there is no physical e-trailer yet it is very hard to verify if further improvements actually have the same results in reality.

5. Discussion

The current technologies regarding combustion engines are reaching their limit, thus new ideas and improvements are sought after. A lot of research regarding this subject has been done and further research would instantly mean improving the current strategy. However, building a prototype and validating the current research would be a great first step forward.

It is not strange to seek a temporary solution within a hybrid system. The combustion engine has its strengths but also its weaknesses. The the same can be said for electrical motors. Combining the best of both is likely to be the appropriate response to our increasing demand for emission reduction.

Acknowledgments

I would like to thank all my co-authors and Roelof de Haan of Carrosserie.nl for their guidance and contribution to this project. They have been a solid rock throughout this research. Every meeting was of great use and resulted in a lot of progress during the following moments.

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Authors

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