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ANALYSIS OF CURRENT STATE OF ALTERNATIVE PROPULSION IN A SECTOR OF PASSENGER RAILWAY TRANSPORT

Abstract. Green railway transport (RT) is not always a completely green transport solution, as there are still many non-electrified or partially electrified lines in operation with polluting engine traction. Although electric rail is the most environmentally friendly, electrification of lines is a time-consuming and costly project, especially on less busy lines where electrification would be inefficient and unprofitable. Even though electric railway is the most environmentally friendly solution, electrification of lines is a time-consuming and expensive project, especially on less frequented lines where electrification would be inefficient and unprofitable. Alternative propulsion (AP) in RT is not only a way to reduce the operational emissions of passenger trains, but also to save energy and fuel, save time due to vehicle changes, and reduce the overall carbon footprint from transporting goods and people.
The aim of this paper is to examine in detail the current state of development and availability within the AP railway industry, specifically for passenger transport needs, and to transparently present the results in a simple and clear way. In addition, the paper explores the possibility of applying the alternatively powered system to the conditions of the H0 model railway and research with this model.
Keywords: alternative propulsions, railway passenger transport, multiple units, rolling stock

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Introduction

With the growing awareness of environmental challenges and the need to switch to sustainable modes of transport, it is becoming increasingly important to examine the current state of the alternative propulsion sector within rail transport (Sládek). As a key player in the global transport system, rail has the potential to play a key role in reducing the overall carbon footprint and minimising the negative environmental impact of transport (EK). Particular emphasis in this research is given to passenger railway transport, where alternative propulsions present a solution to its sustainability on partially or non-electrified lines (Kluth).

Existing initiatives and technological innovations in the automotive industry provide a model for the development and implementation of alternative propulsion in railway transport (Kapetanovič). This paper therefore aims at a systematic review of the current state of the art in the alternative propulsion sector, with an emphasis on its application in the context of passenger transport (Mwambeleko).

The aim of this article is to provide in a transparent and clear way basic information of the alternative propulsion industry in (passenger) RT, such as (dis-) advantages assessment, field of application, specific characteristics, current trends, market availability, etc. In addition, the article outlines a proposed solution to the challenge of investigating a specific alternative propulsion in the conditions of a model railway H0.

1. Theoretical background

AP represent innovative technological solutions in the field of propulsions that differ from traditional systems. They are characterised by the diversity of energy sources, including electric motors instead of fossil fuel engines, fuel cells, solar energy, hybrid technologies, etc. The main goal of applying these technologies is to reduce the industry's negative impact on the environment and ensure sustainability for the future (Dyr).

AP in its various forms is gradually being applied to the transport sector, where road transport is highlighter, mainly in field of private cars and public buses (Voznáková).

These technologies are gradually being applied to the railway sector as an alternative to combustion engine railway vehicles or expensive line electrification. The main reasons for the use of AP in RT are:

- cheaper alternative compared to electrification,
- reduction of transport emissions,
- reduction of dependence on fossil fuels,
- promoting the sustainability of the RT operation,
- achievement of European Green Deal goals,
- noise reduction,
- reduction of operating costs,
- pressure of technological progress and so on (Pohl).

On the second hand, conventional propulsions in RT are utilised more commonly. This sphere includes dependent electric (catenary or third rail supply) traction

and independent diesel traction consuming fossil, possibly other fuels (Gašparík).

The most common AP in RT can be divided into 3 groups regarding to the specific source of energy used, presented in Table 1, where they are also briefly characterised.

Table 1. Short characterization of alternative propulsions, respectively vehicles in RT

Battery vehicles	Hydrogen vehicles	Diesel-hybrid vehicles
- energy source on nonelectric-fied track sector is an energy stored in the batteries	- energy source is a chemical reaction of hydrogen and oxygen in fuel cell (FC) reactor	- a combination of the fossil fuel energy and electric in several versions
- energy is re-charged by catenary or static charging system	- hydrogen is refuelled from static or dyna-mic hydrogen stations	- a combination of engine energy with energy from catenary, batteries, or both of them.
- many types of these vehicles are installed with a panto-graph for bi-mode operation	- energy stora-ges installed in vehicles saves the FC energy fluctuation	- bi mode electro-diesel or hybrid (battery)-diesel and three-mode hybrid electro-diesel

Source: authors according to (Fedele, Jafri and Kapetanovič)

Railway AP vehicles for passenger RT are the most manufactured and utilised in the form of multiple units (MU) (Homolka), therefore, the following analyses will focus primarily on them. In this paper the following MU have been analysed, (with regard to the division in table 1):

- battery vehicles:
  - battery multiple units (BMU),
  - battery-electric multiple units (BEMU),
- hydrogen vehicles:
  - fuel-cell multiple units (FCMU),
  - BEMU-fuel cell (BEMU-FC),
- diesel-hybrid vehicles:
  - electro-diesel multiple units (EDMU),
  - hybrid-diesel multiple units (HDMU),
  - hybrid electro-diesel multiple units (HEDMU).

Presented propulsion systems are among the most developed, researched or implemented in real conditions across the whole world (Sládek).

2. Results of the analyses

The analysis of current state of AP in RT are performed by using of 5 partial analyses focused on the different fields, such as manufactories, properties, trends, etc, and one on AP application in model H0 railway.

The analysis is made by using of basic analytical methods such as analysis, synthesis, concretization and so on, while the available information on the current state and development of AP in the (mainly) passenger RT field is presented by the concise and comprehensible way. The source of data is a synthesis of information from existing literature and scientific articles, information from carriers, rolling stock manufactories and their catalogues.

The goal of these analyses is to provide clear and easy-to-understand information on the current state of AP in the sector of RT, especially in the sector of passenger RT. Beside this, in the article analysis of a selected AP application and testing options in a model railway H0 conditions have been created as a start-up information of the Grant Project.

2.1. Advantages and disadvantages of alternative propulsions in passenger railway transport

Table 2 outlines the general advantages and disadvantages of MU with AP operation within passenger RT conditions.

Table 2. Advantages and disadvantages of the AP MU operation

Advantages	Disadvantages
Flexibility of operation	Limited reduction of emissions
Low-emission operation	Limited availability of energy sources
Higher traveling comfort	Special operating requirements
Cost savings associated with railway electrification	Insufficiently tested technology
Progressive development	Fixation to a particular railway line
Alternative to electrification	High purchasing costs
Onboard recuperation	Higher vehicle weight
Better dynamics compared to DMU	Limited mileage
	Weather sensitivity

Source: authors according to (Homolka)

Some of the advantages or disadvantages indicated in Table 2 are valid for all AP MU solutions (e.g. low-emission operation or alternative to electrification) and some only for selected propulsions, (e.g. onboard recuperation or limited mileage).

2.2. Application of alternative propulsions in railway transport industry

In the Fig. 1 the analysis results of the application of alternative propulsion in the RT sector are shown with examples of non-existing (solid line) or prototype (dashed line) vehicles. In the boxes are particular models of the vehicle and name of the producing rolling stock manufactories. The colour differentiation of the boxes informs about the energy (or combination of them) used by a given vehicle.

Alternative propulsions have been applied as:

- locomotives – mainline locomotives for passenger or freight RT purposes,

- multiple units – MU for regional or long-distance passenger transport,
- light rails – low-weight railway or public transport vehicles, respectively tram-train systems,
- shunting vehicles –vehicles for shunting operation,
- other purposes – mining railways, track repair or maintenance vehicles and so on (Ruf).

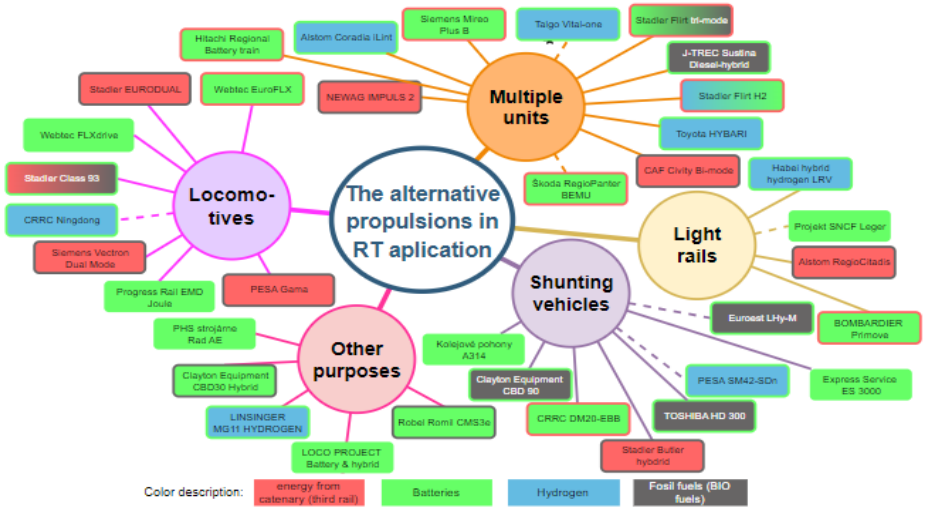


Fig 1. Application of AP in RT industry (Source: authors)

The biggest group of AP railway vehicles is represented by MU, where ALSTOM and STADLER are major competitors (Homolka). Very large group is presented by shunting and mining locomotives with AP, where smaller manufacturers are developing or producing these vehicles too. Very interesting is the AP application in sphere of maintenance vehicles such as hydrogen milling machine LINSINGER MG 11 or Robel Romil CMS3e. The market for mainline locomotives and light-rail vehicles with AP is also gradually increasing.

2.3. Comparative analysis of specific characteristics of alternatively powered multiple units

Comparative analysis of alternatively powered multiple units (AP MU) specific characteristics has to elucidate the specific characteristics and requirements of AP MU in comparison with each other and with conventional propulsions based on the determination of 10 indicators.

Table 3 presents the given MU specifications, which verbal or numerical rated with respect to the propulsion. Some of the assessments are shortly explained. The table is divided into 2 parts due to dimensional reasons.

Table 3. Comparative analysis of AP MU specific characteristics

Characteristics / vehicle	EMU	BMU	BEMU	FCMU	BEMU+FC
Batteries	No	Yes	Yes	Yes	Yes
Number of modes	1 (CAT)	1 (BAT)	2 (BAT + CAT)	2 (BAT + FC)	3 (BAT + CAT + FC)
Recuperation	Yes (CAT)	Yes (ONB)	Yes (ONB + CAT)	Yes (ONB)	Yes (ONB + CAT)
Mileage	Unlimited (within CAT)	± 40 – 120 km	± 40 – 120 km	± 600 – 1200 km	± 600 – 1200 km
BAT recharging	No	Necessary (STAT)	Necessary (STAT + DYN)	Possible (STAT)	Possible (STAT + DYN)
Necessary static TB	CAT	Recharging stations	CAT / CAT in turnover stations	Hydrogen stations	CAT + Hydrogen stations
Restoration of mileage	Fast	Slow (20-60 min)	Slow (20 – 60 min)	Fast	Fast
Energy source	EL	BAT	EL + BAT	Hydrogen + BAT	Hydrogen + EL+ BAT
Weather sensitivity	Low	Higher – BAT	Higher – BAT	Higher – FC + BAT	Higher – FC + BAT
Type of transport	REG + LD	REG	REG + LD	REG	REG + LD
Characteristics / vehicle	**DMU**	**EDMU**	**HEDMU**	**HDMU**	**Explanatory note**
Batteries	No	No	Yes	Yes	CAT – catenary / second rail supply BAT – battery energy storage FC – hydrogen fuel cell reactor ONB – onboard recuperation STAT – static DYN – dynamic EL – electric power REG – regional transportation LD – long distance transportation ENG – combustion engine TB – technical base
Number of modes	1 (ENG)	2 (CAT + ENG)	3 (BAT+ ENG + CAT)	2 (BAT + ENG)	
Recuperation	No	Yes (CAT)	Yes (ONB + CAT)	Yes (ONB)	
Mileage	± 1200 km	± 1200 km	± 1200 km	± 1200 km	
Restoration of mileage	Fast	Fast	Fast	Fast	
BAT recharging	No	No	Possible (STAT + DYN)	Possible (STAT)	
Necessary static TB	Gas stations	Gas stations + CAT	Gas stations + CAT	Gas stations	
Energy source	Fossil / BIO fuels	EL + fossil / BIO fuels	EL + fossil / BIO fuels	Fossil / BIO fuel	
Weather sensitivity	Low	Low	Higher – BAT	Higher – BAT	
Type of transport	REG + LD	REG + LD	REG + LD	REG	

Source: authors

B(E)MU are also the most limited in terms of mileage and its recovery (Ruf). Other alternative systems have a similar mileage to diesel multiple units (DMU). Systems equipped with a sensitive equipment also have the disadvantage of higher sensitivity to the weather conditions. Restrictions also limit the use of AP MU regarding the passenger train category.

2.4. Preferred operation of alternatively powered multiple units

Analysis of the preferred operation presents the most suitable mode of operation of AP MU in consideration of electrification of the railway lines is presented in Table 4.

Table 4. Preferable operation of alternative MU

Vehicle	Non-electrified	Semi-electrified	Both options
BMU	X		
BEMU			X
FCMU	X		
BEMU + FC		X	
EDMU		X	
HDMU	X		
HEDMU		X	

Source: authors on the basis (Sládek)

On the non-electrified lines, it is most advantageous or efficient to operate vehicles that are not equipped with a pantograph. On semi-electrified lines it is most advantageous to operate vehicles fitted with a pantograph as this maximises the utilisation of the existing electrification. However, the electrified section should be long enough to ensure efficiency. BEMUs should be preferably operated on semi-electrified lines, but in the case of a non-electrified line, electrification of the turntable(s) is a requirement and the pantograph would be used as a charging connector, instead of building special charging stations (Sládek).

2.5. Trends in sector of alternative propulsions in railway transport

Based on a survey of the alternative propulsion market in the railway industry, the most significant current trends and their impacts, respectively descriptions are transparently shown in the figure 2.

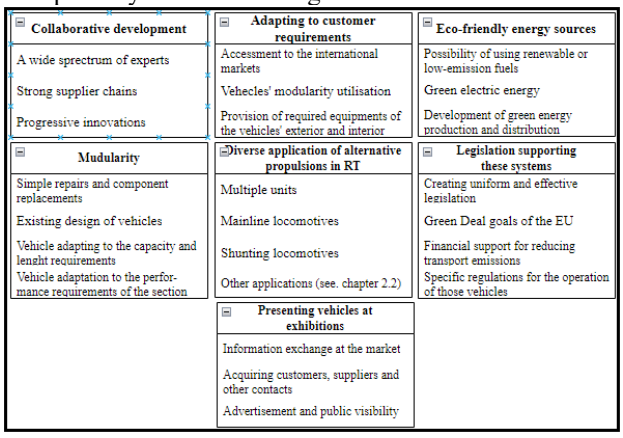


Fig 2. Current trends of AP in RT industry; (Source: authors)

In addition to the trends presented in Figure 2, there are many others, such as inspiration in other modes of transport, recuperation supporting, multi-mode vehicles and so on.

2.6. Availability alternatively powered multiple units at the rolling-stock market

The vast majority of the announced 23 MU vehicles are, or will soon be, available on the global market, and operators of passenger rail transport can purchase them. The graph in Fig. 3 shows the cumulative number of available RT vehicles for passenger transport on the market in the 21st century in relation to used traction.

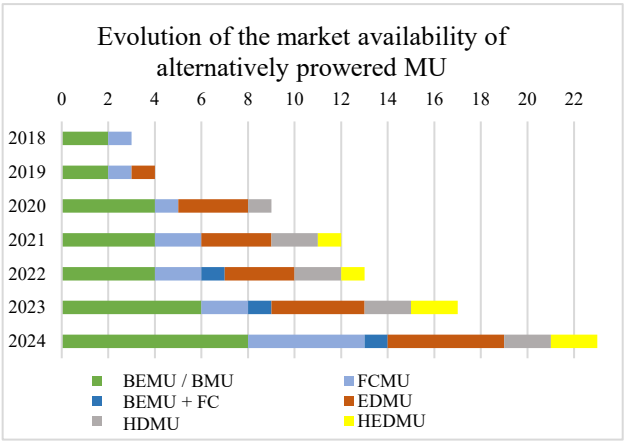


Fig 3. MU' availability on the rolling stock market; (Source: authors)

The currently most available MU with AP for a specific market segment are those with battery, hydrogen, and electro-diesel traction. These vehicles have been available for purchase since 2018 or 2019. Among the latest available vehicles with AP are diesel hybrids and BEMU-FC. It is planned that a total of 24 different vehicles with AP will be available on the market by 2024, although some of these vehicles may be delayed in their release.

2.7. Possibility of the research of alternatively powered multiple units in H0 conditions

The subchapter shortly introduces the application and research possibilities of the selected AP within the conditions of the model railway line H0 (1:87) in RT laboratory of Railway transport department at University of Zilina. As the most rational solution of AP for H0 the battery propulsion has been selected, which will be applied to the 5-car MU model of Alstom Coradia Donau-Isar, which would create a model vehicle BMU.

BMU in H0 scale experiment will be carried out on a model railway H0 to collect information and data from MU operation in the different passenger transport conditions, such as:

- regional (short distance) or long distance train,
- main rail operation or furthest platforms and rails,
- different idle times,

- different number of rounds on one recharging,
- different combination of an available relief and so on.

The main measured variables will be distance, battery status (before and after the experiment), recharging time, altitude reached, energy consumption, total ride and idle time, speed and many more, according to the need of the specific experiments.

Conclusion and discussion

The main goal of this article was to provide information briefly and clearly about the current state of the AP in the operation of RT, while the article was mainly oriented to the railway passenger transport. The paper also briefly introduced the intentions and possibilities within the Grant Project aimed at testing AP in the conditions of H0 model railways.

The first chapter briefly characterized the possibilities of alternative propulsion systems currently developed for the purposes of railway, especially passenger transport. The propulsions determined in this chapter were part of the performed analyses.

Six specific analyses were carried out within the framework of the article, most of them (four) were focused on the passenger railway sector and two were focused on RT in general and the possibilities of alternative propulsion in this industry.

The analyses in the article can provide the reader with interesting information about AP in the RT industry, which can be used in his/her research without the necessity of laborious research from the "scratch". The information contained in the article is brief, but sufficiently processed and presented in a lucid form. In addition, the reader can inform him/herself about the intentions of testing AP in H0 conditions, where he/she can provide some ideas and possibilities for the future implementation into the project.

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