The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 28.1
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.28.1

Comparison of two load profile derivation methodologies for powertrain layout of fuel cell electric shunting locomotives

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Abstract

Currently most shunting locomotives in Europe are equipped with diesel-powered internal combustion engines offering the advantage of being universally applicable and able to operate independently of overhead lines. Concerning international decarbonization goals, the hydrogen-based fuel cell hybrid powertrain can omit local CO_2 emissions completely.

For such novel technologies economic viability is a key factor to allow for rapid adoption by the market. At the moment, no standardized or unified energy and performance-related requirement profiles for shunting locomotives are available as a widely usable database in order to be used as simulative input for an in-depth performance demand analysis. Furthermore, shunting related specifications are more difficult to map than requirements for mainline rail services or other line haul services, since a wide range of operational demands have to be considered.

Therefore, this study compares to methods for determining powertrain requirements for shunting locomotives. Method one is the evaluation of generically created and simulated shunting profiles and method two intents at using operational driving data. Then, the determined energy and performance-related requirements are used to for the exemplary dimensioning of a fuel cell hybrid powertrain for each case. The aim is to investigate to which extent generic requirement profiles for shunting locomotives can be transferred to other applications.

The evaluation of the two described methods for the derivation of dimensioning properties in shunting operations showed that similar results could be generated for the subsequent powertrain layouts. In this analysis the simulated shunting profile indicates to be more demanding. However, a direct comparison of the two methods shows that the fuel cell hybrid system sizes differ only marginally. Nevertheless, it must be emphasized that this study only takes one set of real operational shunting data into consideration.

Therefore, further research is needed to ensure applicability to other operators, by collecting, analysing and clustering of shunting requirements in order to validate or adapt the existing generic shunting profiles. Through unifying and modularizing components and dimensioning sizes for fuel cell hybrid powertrains by using standardized shunting profiles, development costs and authorization efforts can be reduced generating economies of scale and enhancing the economic viability of implementation projects.

In conclusion, standardized driving profiles that reflect the widest possible spectrum of operational requirements for shunting locomotives are necessary in order to offer locally emission free fuel cell powertrain designs that are economically viable, thereby increasing the leverage effect for CO_2 reduction.

Keywords: shunting locomotives, freight transport, fuel cell hybrid powertrain, requirement analysis

1 Introduction

In 2018, 29,7% of the CO_2-emissions throughout the EU were caused by the transport sector, which equates to 946.1 mio. t CO_2. Within this sector, 3353 tkm of freight transport occurred this year, of which 12.6% was covered by rail [1]. Rail transport is particularly efficient for overland freight transport, which is why efforts to shift freight transport increasingly to rail are already being made in order to reduce greenhouse gas emissions, thus increasing the demand for climate-friendly rail vehicles [2].

Currently most shunting locomotives in Europe are equipped with diesel-powered internal combustion engines offering the advantage of being universally applicable and able to operate both shunting and mainline operations independently of overhead lines. Concerning international decarbonization goals, it is of great importance to gradually implement locally emission free powertrains in the shunting locomotive stock.

The hydrogen-based fuel cell hybrid powertrain, whose main advantages are short refueling times and long catenary-independent operations, can omit local CO_2 emissions completely. For such novel technologies economic viability is a key factor to allow for rapid adoption by the market. Accordingly, such a development involves identifying requirement profiles that are as universally valid as possible in order to be used as simulative input for an in-depth performance demand analysis.

At the moment, no standardized or unified energy and performance-related requirement profiles for shunting locomotives are available as a widely usable database. Furthermore, shunting related specifications are more difficult to map than requirements for mainline rail services or other line haul services, since a wide range of operational demands have to be considered. As a result, various operational and energy specifications are to be expected.

To contribute to this research gap, two methods for determining powertrain requirements for shunting locomotives will be compared in this study. Method one is the evaluation of generically created and simulated shunting profiles and method two intents at using operational driving data at dc link.
The aim is to investigate to which extent generic requirement profiles for shunting locomotives can be derived on the basis of the results of this study and transferred to other applications. Standardized requirements for shunting locomotives can then be used to develop fuel cell hybrid drives for the widest possible application profiles to speed up the uptake of alternative powertrains in rail freight transport and generate the greatest possible CO_2-savings potential.

2 Methods

This study compares two methods to determine requirements for shunting locomotives based on different data. In order to identify demands related to energy and power rating, driving profiles are derived and evaluated for each case, firstly a simulation-based and secondly a data-based analysis:

1) Qualitative operational data of shunting locomotive operators in Germany had been derived in a web-based survey. The answers were used to create driving profiles by combining generic shunting movements [3]. Afterwards, the created shunting scenario was simulated using a longitudinal dynamic simulation tool for trajectory calculation in order to obtain and evaluate speed and power trajectories [4].
2) A 7-month dataset logged on a shunting locomotive of the Duisburg Port railroad company was post-processed and analyzed. This data was used to obtain driving cycles, which were statistically evaluated to extract key properties about power and energy demands, focusing on the maximum requirements of all 145 driving cycles in order to ensure that all shunting profiles were represented [5].

The data evaluation of both methods revealed broad operational requirements. Consequently, the operation patterns were separated into shunting and mainline service. This study focusses on the shunting requirements, since the database in this field in particular is currently barely investigated.

Based on the elaborated requirements, an exemplary powertrain design is developed for each case. Therefore, a Vossloh Locomotives DE 18 equipped with a 1,800 kW diesel engine is used as reference. After deducting the installation space used for powertrain-independent components (brake compressors, locomotive control system), a volume of 30 m³ remains for accommodating the components of the powertrain [5] (see figure 1).

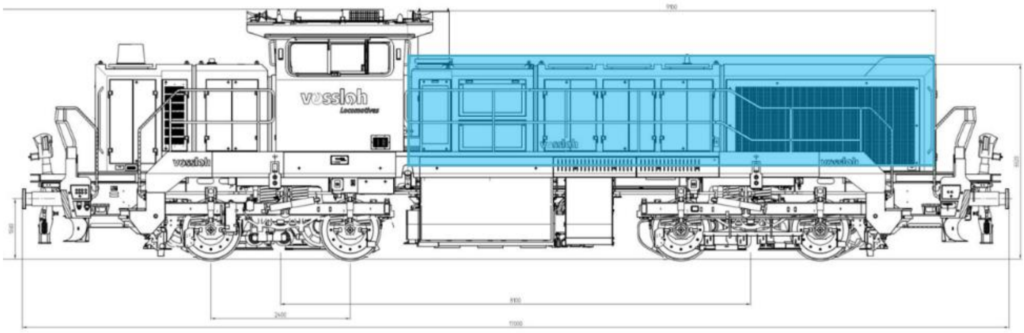

Figure 1: Available installation space (blue) for the components of the fuel cell hybrid powertrain [6]

The schematic fuel cell hybrid powertrain topology is depicted in figure 2.

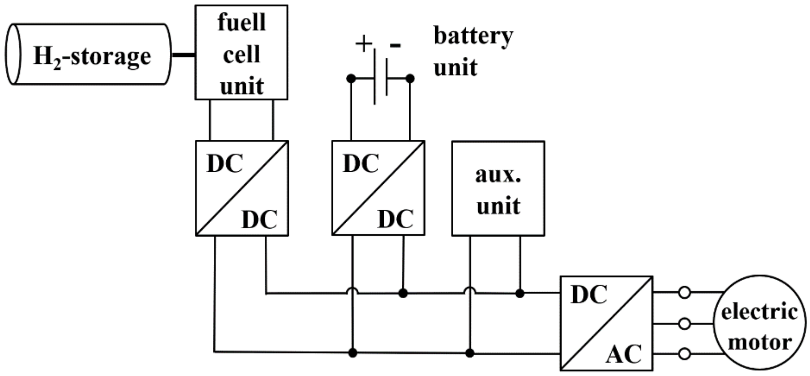

Figure 2: Schematic topology of the fuel cell hybrid powertrain

The operating strategy assumes the fuel cell unit to supply the average power and the battery to cover peak power demands. The battery is charged by the fuel cell during periods of lower power demand (no recuperative braking or external charging). To size the battery, the average peak power ratings at different time windows are calculated and the most demanding power requirement is used. Cooling units for fuel cell and battery are modeled through the respective component efficiencies. The hydrogen storage is dimensioned based on the total cumulative energy sum over one drive cycle, assuming that refueling is possible after each shunting cycle [5].

3 Results

Based on the described approach the energy and performance-related characteristics of shunting cycles for both methods are summarized in table 1.

Table 1: Characteristics at dc link of shunting operation cycles

		Method 1: generic and simulated shunting operation*	**Method 2:** measured and post-processed shunting cycles**
duration	h	11.6	13.9
distance	km	66.3	48.7
total energy demand	kWh	1,652	622
average power	kW	142	108
peak-power over 30 s averaging time	kW	1,360	1,773
peak-power over 20 min averaging time	kW	258	434
peak-power over 60 min averaging time	kW	195	219

*based on web-based survey with 188 operators (response rate: 10-15%, depending on the question)
**maximum values of 145 shunting cycles in total

The dimensioning of the required components for the fuel cell hybrid powertrain was carried out for both methods (see table 2). Therefore, volumetric power and energy densities and the efficiencies of the components based on commercially available components were determined and used for the calculation [5].

Table 2: Component dimensioning of the fuel cell hybrid powertrain for both methods

	Method 1: generic and simulated shunting operation		**Method 2:** measured and post-processed shunting cycles	
fuel cell unit incl. cooling	156 kW	1.56 m³	124.5 kW	1.25 m³
battery unit (usable capacity, LTO, BoL)	120.5 kWh	1.88 m³	165 kWh	2.58 m³
battery cooling (BTMS)	4.7 kW	0.31 m³	9.3 kW	0.62 m³
DC/DC-converter	1,800 kW	0.36 m³	1,800 kW	0.36 m³
H_2 demand per hour	9.7 kg(H_2)/h	0.69 m³	7.4 kg(H_2)/h	0.57 m³
total H_2 storage (350 bar) *	334 kg(H_2)	25.57 m³	325 kg(H_2)	25.17 m³

*after filling the remaining space

LTO battery cell chemistry has proven to be more suitable for both variants. Based on the assumption of a maximum continuous charge rate of 6 C and 10 C for short pulses [5], the battery is able cover the occurring power peaks and resulting c-rates.

The share of fuel cells, batteries and cooling compared to the total installation space in method 1 is 14.8%, while the share in method 2 is 16.1% and thus very similar. The difference is mainly reflected in the split between fuel cells and batteries. For the powertrain design based on method 1, a 25% larger fuel cell unit compared to the design based on real shunting data is required. At the same time the battery is 36% smaller.

The results show, that the simulated shunting profile is more demanding than the maximum requirements of the real data shunting profiles, in particular because of the higher average power that requires a correspondingly larger fuel cell unit. On the other hand, the larger battery for method 2 can be explained by the fact that a higher peak power has to be covered by the battery.

Furthermore, in both methods, almost the same installation space can be used for hydrogen storage, which means that the range can be increased as can the refueling interval, which consequently can generate operational flexibility (see figure 3).

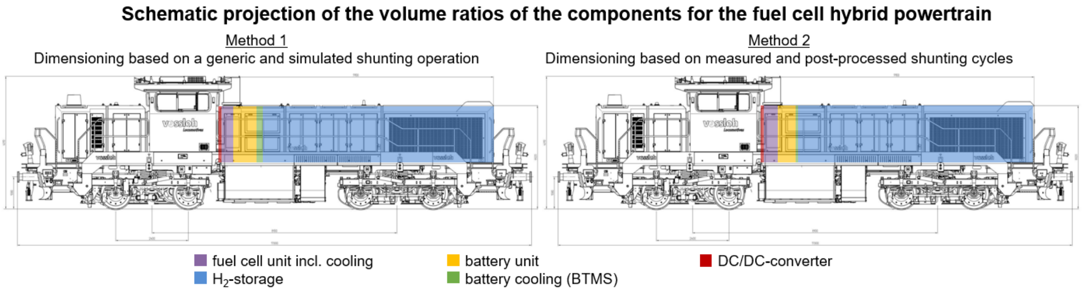

Figure 3: Schematic projection of the volume ratios of the components of the fuel cell hybrid powertrain [6]

In principle, both methods of requirement derivation offer the potential to design a fuel cell hybrid drivetrain that covers the shunting requirements, even in a smaller locomotive with consequently less installation space and capacities for hydrogen storage.

4 Conclusions and Contributions

This study evaluated the derivation of power and energy requirements for shunting operations on the basis of two independent data sources. On the one hand, generic driving profiles were created and simulated, and on the other, measurement data from real shunting operations were evaluated. For each method a fuel cell hybrid powertrain was then designed on the basis of both sets of data.

The evaluation of the two described methods for the derivation of dimensioning properties in shunting operations showed that similar results could be generated for the subsequent powertrain layouts. In this analysis the simulated shunting profile indicates to be more demanding. However, a direct comparison of the two methods shows that the fuel cell hybrid system sizes differ only marginally. Nevertheless, it must be emphasized that this study only takes one set of real operational shunting data into consideration by examining the data given by the Duisburg Port railroad company.

In principle, the evaluation of operation-specific driving data is best suited for special applications, since individual operation properties can thus be ideally considered in powertrain design. As an example, for this study the used dataset was reduced to focus on shunting though the full dataset shows, that in case of the evaluated operator additional mainline rail services need to be provided.

Generically created and simulated shunting profiles, however, offer the advantage and the potential to meet the demands of a larger set of shunting locomotive operators without having to perform data analyses in each individual case.

Therefore, further research is needed to collect and evaluate additional driving data in order to validate or, if necessary, adapt the existing generic shunting profiles. To ensure applicability to other operators, shunting requirements must be further investigated, differentiated and clustered, in addition other requirements such as main line services should be considered. Through unifying and modularizing components and dimensioning sizes for fuel cell hybrid powertrains by using standardized shunting profiles, development costs and authorization efforts can be reduced generating economies of scale and enhancing the economic viability of implementation projects.

In conclusion, standardized driving profiles that reflect the widest possible spectrum of operational requirements for shunting locomotives are necessary in order to offer locally emission free fuel cell powertrain designs that meet as many operational demands as possible and are economically viable, thereby increasing the leverage effect for CO_2 reduction.

References

[1] European Commission (2020). EU transport in figures - Statistical pocketbook. https://data.europa.eu/doi/10.2832/919583

[2] European Commission (2019). Going climate-neutral by 2050 – A Strategic Long-Term Vision For a Prosperous, modern, Competitive and Climate-Neutral EU Economy. https://data.europa.eu/doi/10.2834/508867

[3] Konrad, Marcel und Jäger, Victoria Carolin und Pagenkopf, Johannes und Böhm, Mathias (2021) Concept and Design of a Shunting Locomotive equipped with a hybridized Fuel Cell Hydrogen Powertrain. In: 2021 16th International Conference on Ecological Vehicles and Renewable Energies, EVER 2021. https://ieeexplore.ieee.org/document/9456623

[4] Schenker, M., Schirmer, T. & Dittus, H. (2020) Application and improvement of a direct method optimization approach for battery electric railway vehicle operation. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. SAGE Publications. https://doi.org/10.1177/0954409720970002.

[5] Konrad, Marcel, Pagenkopf, Johannes, Jäger, Victoria Carolin, Dittus, Holger, Dura, Georg, Garbar, Alexander, & Maaß, Jan-Christoph. (2022). Vorstudie Wasserstoffrangierlokomotive Duisport. Zenodo. https://doi.org/10.5281/zenodo.6274512

[6] Hildebrandt, Tim; Schwarz, Alexander (2013): Die neue Lokomotivfamilie aus einem Baukasten von Antriebssystemen von der Konzeption zu den lauftechnischen Nachweisen. Schienenfahrzeugtagung 2013. Graz, 07.04.2013