Design and Analysis of a Regio-Shuttle RS1 Diesel Railcar Converted to Fuel Cell Hybrid Propulsion

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DLR
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1. DLR Overview
2. Next Generation Train (NGT)
3. Motivation
4. Approach
5. Boundary Conditions
6. Simulation
7. Design FC-EMU
8. Operation & H₂ Infrastructure
9. Conclusion & Outlook
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DLR Overview

- Exploration of the Earth and the solar system
- Research aimed at protecting the environment
- Development of environmentally-friendly technologies to promote mobility, communication and security
- Approx. 8,000 employees
- 33 research institutes and facilities
- 20 locations
- Branch offices in Brussels, Paris, Tokyo and Washington
Agenda

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Next Generation Train (NGT)

Project overview

- Ultra-high – speed railcar passenger train (400 km/h)
  NGT HST

- High – speed railcar passenger train (230 km/h)
  NGT LINK

- Autonomous railcar freight train (400 km/h)
  NGT CARGO
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Motivation
EU28: Line electrification and CO₂-emissions from railways

• 46% of railway lines were non electrified in 2012 [1]
• Service on these lines typically provided by diesel traction with significant CO₂-, NOₓ and PM emissions
• Example SBB in 2017 [2][3]:
  o Line electrification > 95%
  o Diesel energy consumption < 5%
  o But 35% of total CO₂-emissions
• Internal CO₂ - reduction target of UIC (baseline 1990) [4]:
  o by 2030: -50%
  o by 2050: -75%

• Alternative propulsion systems with zero emissions at point-of-use → Fuel Cell Hybrid propulsion system

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Approach
Way of proceeding

Boundary conditions
(vehicle, line, gradients, speed, timetable)

Simulation
(longitudinal dynamic simulation, FC-Hybrid system)

Design FC-EMU
(components, packaging)

Infrastructure & Operation
Agenda

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Boundary Conditions
Reference vehicle 1/2

- Regional single-car DMU 650 ("Regio-Shuttle") with a fuel cell hybrid propulsion system as a case for simulation
- Following parameter set was used for the system design:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (empty)</td>
<td>42 t</td>
</tr>
<tr>
<td>Mass (fully loaded)</td>
<td>56 t</td>
</tr>
<tr>
<td>Maximum passenger number</td>
<td>155</td>
</tr>
<tr>
<td>Nominal power</td>
<td>2 x 228 kW</td>
</tr>
<tr>
<td>Maximum speed</td>
<td>120 km/h</td>
</tr>
<tr>
<td>Starting acceleration</td>
<td>1,20 m/s²</td>
</tr>
<tr>
<td>Average acceleration up to 50 km/h</td>
<td>0,98 m/s²</td>
</tr>
<tr>
<td>Driving range</td>
<td>approx. 1.200 km</td>
</tr>
</tbody>
</table>
Boundary Conditions
Reference vehicle 2/2

Diesel traction

Electric traction

Source: Voith – Triebwagen Regio Shuttle RS1 mit DIWA-Getriebe D864, Umkehrgetriebe V863, G 1471 d 8/2004 1000 MSW/WF
Boundary Conditions

Rail Network

- 4 lines are operated
  - WBA1 – 71.5 km
  - WBA2 – 14.5 km
  - WBA3 – 31.5 km
  - WBA4 – 24.8 km

- At least 8 vehicles (V) are needed
  - 5 V for WBA1 and WBA2
  - 1 V for WBA3
  - 2 V for WBA4
    - Double and triple traction is not considered
    - V names in presentation: A, B, C, D, E, F, G, H

- Hydrogen refueling station in Zwiesel as a hub is recommended
Boundary Conditions

Timetable

- Timetable derived from Waldbahn schedule
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Simulation
Design Constraints

• Balanced battery state of charge at start and end position
• Auxiliary power = 52 kW (constant)
• $H_2$ consumption
  • based on Hydrogenics HD30 curve
  • Calculated regarding operation with 50% passenger volume
• Efficiency of Battery charge/discharge (incl. DC/DC-converter) = 0.94

Hydrogenics HD30 Performance

Simulation Example

WBA1: Plattling - Bay. Eisenstein - Plattling

- Power [kW]
- Battery Energy [kWh]

- P_DC-FC [kW]
- P_DC-Batt [kW]
- E_Batt [kWh]
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Design FC-EMU
Fuel Cell system

Fuel Cell

<table>
<thead>
<tr>
<th>Statistics Fuel Cell</th>
<th>Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{\text{required}}$ [kW]</td>
<td>A  B  C  D  E   F  G  H</td>
</tr>
<tr>
<td>178     180     179     179     179     102   98   98</td>
<td></td>
</tr>
<tr>
<td>$H_2$-consumption 50% load [kg/km]</td>
<td>0,16 0,15 0,15 0,14 0,15 0,16 0,15 0,15</td>
</tr>
<tr>
<td>$H_2$-consumption 100% load [kg/km]</td>
<td>0,17 0,16 0,16 0,15 0,16 0,17 0,17 0,17</td>
</tr>
</tbody>
</table>

$\Rightarrow P_{\text{FC}} (7 \times \text{HD30}) = 210 \text{ kW}$

Source: www.hydrogenics.com
Design FC-EMU
Battery system

Battery

<table>
<thead>
<tr>
<th>Statistics Battery</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{\text{chg, max}}$ [kW]</td>
<td>627</td>
<td>627</td>
<td>627</td>
<td>627</td>
<td>627</td>
<td>627</td>
<td>627</td>
<td>627</td>
</tr>
<tr>
<td>$P_{\text{dchg, max}}$ [kW]</td>
<td>607</td>
<td>664</td>
<td>612</td>
<td>594</td>
<td>598</td>
<td>597</td>
<td>599</td>
<td>599</td>
</tr>
<tr>
<td>$P_{\text{RMS}}$ [kW]</td>
<td>199</td>
<td>201</td>
<td>197</td>
<td>197</td>
<td>197</td>
<td>161</td>
<td>147</td>
<td>147</td>
</tr>
<tr>
<td>$E_{\text{Batt, use}}$ [kWh]</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>46</td>
<td>30</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>$E_{\text{Batt, throughput, day}}$ [kWh]</td>
<td>755</td>
<td>1.310</td>
<td>1.626</td>
<td>1.686</td>
<td>1.246</td>
<td>937</td>
<td>812</td>
<td>650</td>
</tr>
</tbody>
</table>

Source: www.Akasol.com

- 4 x Akasol AKM 18M NANO (12s1p)
  - $U = 583 – 907$ V
  - $E = 4 \times 36.8 \text{ kWh} = 147.2 \text{ kWh}$
  - $P_{\text{chg}}(10s) = 4 \times 184 \text{ kW} = 736 \text{ kW}$
  - $P_{\text{dchg}}(10s) = 4 \times 487 = 1.948 \text{ kW}$
  - $P_{\text{RMS}} = 4 \times 92 \text{ kW} = 368 \text{ kW}$

1 100% payload
2 50% payload
Design FC-EMU

Packaging concept

- As many H₂ tanks on available roof area as possible
- H₂ capacity = 165 kg
- Worst case demand at 100% load = 128 kg
- Sufficient energy on board for daily operation
- Approx. 1,100 kg heavier than DMU
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Operation & H₂ Infrastructure
Hydrogen refueling infrastructure

• Full fill of one train max. 150 kg, a 8-train fleet would consume ~1,000 kg hydrogen per day (capacity of existing HRS for cars/buses: 4-40 kg per refueling)

• As a consequence, novel hydrogen refueling concepts for trains are required
• DLR works on identification of suitable refueling concepts and delivery options
  • on-site/off-site delivery
  • LH₂ vs. CGH₂
  • HRS costing
  • Production from renewables
    • Integrated energy
    • Advantage rail car: H₂-demand is plannable (kg, day, location)
Operation & H₂ Infrastructure

**Operation**

### H₂-tank capacity during operation

<table>
<thead>
<tr>
<th>Time [h]</th>
<th>H₂-Tank capacity [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>180</td>
</tr>
<tr>
<td>12</td>
<td>160</td>
</tr>
<tr>
<td>24</td>
<td>140</td>
</tr>
<tr>
<td>36</td>
<td>120</td>
</tr>
<tr>
<td>48</td>
<td>100</td>
</tr>
<tr>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>72</td>
<td>60</td>
</tr>
<tr>
<td>84</td>
<td>40</td>
</tr>
<tr>
<td>96</td>
<td>20</td>
</tr>
<tr>
<td>108</td>
<td>0</td>
</tr>
</tbody>
</table>

**Vehicle:**

- A
- B
- C
- D
- E
- F
- G
- H

Refueling times (during night)

Refueling station with two dispenser is required
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Conclusion

• This study basically proved the feasibility of converting the Regio-Shuttle into a FC-Hybrid railcar in compliance with a given timetable using the Waldbahn rail network as an example.
• Due to high space requirements of H₂-tanks, it is essential to consider a network of routes in a differentiated way.

Outlook

• Develop fuel cell and battery aging model to make a statement about the lifetime of these components.
• Investigate infrastructure and regional conditions regarding H₂ supply/production.
• Calculate costs for components, conversion and operation → compare with DMU.
• Calculate greenhouse gas emission savings for using FC-EMU instead of DMU on Waldbahn railway network.
Thank you for your attendance!

Questions?

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