OPEUS
Shift2Rail energy simulation tool for rolling stock

Future Improvements Noise & Energy

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13rd November 2019
Presentation objectives:

- Demonstrate the interest and the positioning of the OPEUS tool to choose the most relevant train technology on one cycle.
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Shift2Rail energy simulation tool for rolling stock
The purpose is to identify all energy-relevant TDs and SPDs, to quantify and follow up energy savings to support increasing cost-effectiveness and sustainability through energy-efficiency.
FINE1 Energy Members & Timeline

Start: 01/09/2016
36 months
Finish: 31/10/2019
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Shift2Rail energy simulation tool for rolling stock
What is the OPEUS-tool for?
- Calculation of the energy consumption of various railway vehicles and their components.

What does the OPEUS-tool need as input data?
- Parameter sets of vehicles and their components, including:
  - Parameter sets of the various components;
  - Track data (time tables, speed limits, altitude,...).

What does the OPEUS-tool allow users to do?
- Create and simulate a variety of traction topologies by rearranging/exchanging the component blocks.
- Investigation and assessment of technical innovations based on the simulated power profiles and simulated energy consumption.
- Easy implementation and comparison of various train parameters.
Simulation structure is implemented in Matlab and Simulink:
- Common software for engineering tasks;

Component models are organized in a Simulink library:
- Avoid ambiguity;
- Easy to implement changes at the component models.

Input data and Output data of the tool are implemented as Microsoft Excel files:
- Easy and familiar interface;
- Even users with less background in Matlab/Simulink are able to execute the simulations;
- Easy processing of the output data.

Track data and train data is organized in Excel libraries:
- Clear handling of data;
- Easy possibility to extend the library with own data.
Different service categories:
- Urban
- Regional
- High Speed
- Freight

Assessment of innovative technologies:
- ESS
- SiC converter
- Synchronous motor
- ...

OPEUS-tool

Simulation inputs
- Track data
  - Track profile
  - Time table
- Train data
  - Topology
  - Components

Simulation model

Simulation outputs
- Consumption of electrical power/energy

Interfaces for technical innovations
Different service categories:
- Urban
- Regional
- High Speed
- Freight

Simulation inputs:
- Track data
  - Track profile
  - Time table
- Train data
  - Topology
  - Components

Simulation model

Simulation outputs:
- Consumption of electrical power/energy

Assessment of innovative technologies:
- ESS
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- ...

Interfaces for technical innovations: OPEUS-tool
Traction System Topologies

Simulation Topology (AC Traction Chain – E-transformer – T02)

catenary → pantograph → E-transformer

electric chain → E-transformer

motor converter → motor → spur gear → wheel/brakes → body of the train

ESS - battery → ESS battery converter

ESS - DLC → DLC converter

rheostat converter → Var1

Var2 → auxiliary inverter

auxiliary inverter → C22

C23: electrical auxiliaries – DC link

C24: auxiliary inverter

C25: electrical auxiliaries – transformer link

C26: battery converter

C27: Battery consumption (on board power supply)
Traction System Topologies
Simulation Topology (DC Traction Chain – T03)
Traction System Topologies

Simulation Topology (Diesel-electric Traction Chain – T05)

Diesel Engine → Gearbox → Main generator → rectifier (3~) → inverter (3~) → motor (M 3~) → Gearbox → Wheel/brakes

Auxiliary generator (3~) → excitation → = → = → = → = → Auxiliary consumption (3~)

Diesel electric traction
Traction System Topologies
Simulation Topology (Diesel mechanic/hydraulic Traction Chain –T05)

Hydraulic/mechanical gearbox

- Diesel Engine
- Gearbox
- Wheel/brakes
Different service categories:
• Urban
• Regional
• High Speed
• Freight

Assessment of innovative technologies:
• ESS
• SiC converter
• Synchronous motor
• ...

Simulation inputs
- Track data
  - Track profile
  - Time table
- Train data
  - Topology
  - Components

Simulation model
  Consumption of electrical power/energy

Interfaces for technical innovations

OPEUS-tool

Inputs and Outputs
13/11/2019

Inputs

**OPEUS-Tool**

**Input data**

Please select train data to be simulated:
- synthetic train, defined for service category - select the corresponding abbreviation from the dropdown list
- own train data - select "own" from the dropdown list

Note: If you pick one of the synthetic vehicles, the tool will copy the data to the "Simulation_Input" folder by itself. If you want to simulate some other data, the tool will request a directory of the data in the further proceeding.

Please select a topology by entering the corresponding abbreviation:
- predefined topologies - select the corresponding abbreviation from the dropdown list
- own topology - enter "own" from the dropdown list

Note: If you pick one of the synthetic vehicles, the tool will copy the data to the "Simulation_Input" folder by itself. If you want to simulate some other data, please copy the train data file into the "Simulation_Input" folder.

Please take into account the assignment between the topology and the pre-defined service categories:

- T01/T02 - AC power supply: HS300, HS250, Intercity, Reg160, Reg140, Suburb, FrMain, FrSh
- T03 - DC power supply: Metro, Tram

Please select track profile to be simulated:
- track profile defined for service category - select the corresponding abbreviation from the dropdown list
- own track profile - enter "own" from the dropdown list

Note: If you pick one of the synthetic vehicles, the tool will copy the data to the "Simulation_Input" folder by itself. If you want to simulate some other data, the tool will request a directory of the data in the further proceeding.

Please select the trajectory mode:
- allout trajectory - enter "allout"
- fulfill timetables (accord. to selected track profile), with coasting - enter "timetable"
- fulfill timetables (accord. to selected track profile), without coasting - enter "timetableNoCoast"
- own trajectory - enter "own"

Please select if a pre-calculated speed profile shall be used for the simulation:
- pre-calculated speed profile - enter "pre-calculated trajectory"
- calculate a new speed profile from the time table - enter "calculate trajectory"

WARNING: The calculation of the speed profile could last up to a few minutes.

Please select the season mode to characterize the auxiliary consumption:
- summer season - enter "sum"
- spring/autumn season - enter "spr"
- winter season - enter "win"

Please select the requested internal combustion engine - 360kW / 560kW / 1000kW

Please select if a partial switch off of traction components is required:
- activate switch off - enter "on"
- deactivate switch - enter "off"

Please select the if partial load distribution between traction components is required:
- activate load distribution - enter "on"
- deactivate load distribution - enter "off"

---

**Legend - vehicle data/track data**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Service Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS300</td>
<td>High Speed 300</td>
</tr>
<tr>
<td>HS250</td>
<td>High Speed 250</td>
</tr>
<tr>
<td>Intercity</td>
<td>Intercity</td>
</tr>
<tr>
<td>Reg160</td>
<td>Regional 160</td>
</tr>
<tr>
<td>Reg140</td>
<td>Regional 140</td>
</tr>
<tr>
<td>Suburb</td>
<td>Suburban</td>
</tr>
<tr>
<td>Metro</td>
<td>Metro</td>
</tr>
<tr>
<td>Tram</td>
<td>Tram</td>
</tr>
<tr>
<td>FrMain</td>
<td>Freight/ Mainline</td>
</tr>
<tr>
<td>FrSh</td>
<td>Freight Shunting</td>
</tr>
</tbody>
</table>

**Legend - traction topology**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Topology</th>
</tr>
</thead>
<tbody>
<tr>
<td>T01</td>
<td>AC power supply</td>
</tr>
<tr>
<td>T02</td>
<td>- E-transformer</td>
</tr>
<tr>
<td>T03</td>
<td>DC power supply</td>
</tr>
<tr>
<td>T05</td>
<td>Diesel-Electric</td>
</tr>
<tr>
<td>T06</td>
<td>Diesel</td>
</tr>
</tbody>
</table>
Summarized results:
Energy values for total trip and station by station.

<table>
<thead>
<tr>
<th>Out table: summary of the simulation results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulated service category</td>
</tr>
<tr>
<td>Reg160</td>
</tr>
<tr>
<td>Integrated Values for journey</td>
</tr>
<tr>
<td>total time</td>
</tr>
<tr>
<td>total distance</td>
</tr>
<tr>
<td>operational speed (total distance per total time)</td>
</tr>
<tr>
<td>traction energy at the wheel</td>
</tr>
<tr>
<td>total braking energy at the wheel</td>
</tr>
<tr>
<td>ED-braking energy at the wheel</td>
</tr>
<tr>
<td>braking energy at the mechanical brakes</td>
</tr>
<tr>
<td>traction energy of motor converters at DC link</td>
</tr>
<tr>
<td>recuperated energy of motor converters at DC link</td>
</tr>
<tr>
<td>auxiliary energy at the DC link</td>
</tr>
<tr>
<td>rheostat braking energy at DC link</td>
</tr>
<tr>
<td>traction energy at the catenary</td>
</tr>
<tr>
<td>recuperated energy at the catenary</td>
</tr>
<tr>
<td>difference of energy stored in onboard energy storage system(s) (if applicable)</td>
</tr>
<tr>
<td>fuel consumption (if applicable)</td>
</tr>
<tr>
<td>energy equivalent for 1l diesel</td>
</tr>
<tr>
<td>energy equivalent for fuel consumption</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specified topology</td>
</tr>
<tr>
<td>component</td>
</tr>
<tr>
<td>ESS-battery</td>
</tr>
<tr>
<td>ESS-DLC</td>
</tr>
<tr>
<td>auxiliary at transformer</td>
</tr>
<tr>
<td>auxiliary at DC intermediate circuit</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Simulation date and time</th>
<th>20-Mar-2018 12:07:15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption per kilometre (Wh/km)</td>
<td>6213.270347</td>
</tr>
<tr>
<td>Consumption per passenger-kilometre (Wh/pkm)</td>
<td>34.51816859</td>
</tr>
<tr>
<td>Consumption per seat-kilometre (Wh/skm)</td>
<td>27.0142189</td>
</tr>
<tr>
<td>Consumption per tonne-kilometre (Wh/tkm)</td>
<td>#DIV/0!</td>
</tr>
</tbody>
</table>
OPEUS Tool

Preliminary study of technology comparison

Next steps and economic valorization

Shift2Rail & FINE-1

Shift2Rail energy simulation tool for rolling stock
Study cases and simulations done: Simulation tool validation

Simulation context:
- All data used in this study come from library delivered with OPEUS tool.
- Train data: Reg160
- Track profile: Measured data (Duration: 96 min / Distance: 105 km)
- Season mode: Winter
- Topology: Diesel electric

1 simulation done

1 Measured data of Diesel-electric train
2 Simulation of diesel-electric train in OPEUS
Study cases and simulations done: Simulation tool validation
Study cases and simulations done:
Simulation tool validation

Error calculating energy consumption by 1%.
Similar bus power behaviors. Up to 30% instantaneous error.
Study cases and simulations done:
Simulation tool validation

The simulation overestimates the consumption by 1%. The OPEUS tool is validated from an energy point of view.
Simulation context:
- all data used in this study come from library delivered with OPEUS tool
- Train data: Reg160
- Track profile: Estimated
- Season mode: Winter
- Topology: Diesel electric

Study cases and simulations done:
Which consumption for one track

1. Diesel-electric train
2. Hybrid train
3. Battery train
4. Fuel cell train

4 simulations done in OPEUS tool
Study cases and simulations done:

Hybrid train simulation with OPEUS

Hybridization with batteries allow to:
- Recover part of braking energy
- Reduce the fuel consumption by 20% on this driving cycle.
Study cases and simulations done:

- Battery train simulation with OPEUS

Use a battery allow to recover a large part of braking energy. Reduce the energy consumption by 70% on this driving cycle.
Study cases and simulations done:
FC train simulation with OPEUS

Use FC – bat. allow to:
- Recover a part of braking energy
- Reduce the energy consumption by 18% on this driving cycle.
Study cases and simulations done:

To sum up:

- Diesel: 0.82
- Fuel Cell: 0.76
- Hybrid: 0.28
- Battery: 0.28

Graph showing consumption over time for different cases.
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Shift2Rail energy simulation tool for rolling stock
Next steps and economic valorization

Just with energy and train price

The diesel electric train seems to be the most relevant one during the first years.
At year 15 the battery train is more relevant.

Assumption:
6 trips a day over the years
Average train price and combustible price
Batteries replacements are not taken into account

What about infrastructure cost?
Next steps and economic valorization

Other parameters: infrastructure

The diesel electric train seems to be the most relevant one during the first years. At year 25 the Hybrid train is more relevant.

Can energy be the lonely criteria to be taken into account?
Next steps and economic valorization

Conclusion

There are plenty of other parameters that have to be taken into account such as:

- Are the maintenance cost is modifying?
- Are there any will from region or national government?
- Is the infrastructure suitable? Investment needs?
- Is the innovative architecture can suit actual exploitation planning? (eg. Charging time)
- Can we add other services with these trains? (Emergency supply, reduction of peak power, smartgrid…)
- …

A systemic approach has to be used in the deployment of a new technology!

Positioning of OPEUS FINE-1 Simulation tool:

- OPEUS tool should not be placed in the first step to choose a new architecture. This tool is suitable to define the energetic benefice and usages of new energetic component (eg. Number of cycle) of architecture but a more in-depth study taking into account government will, exploitation and infrastructure aspect has to be perform.
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Shift2Rail energy simulation tool for rolling stock

More details, deliverables and OPEUS tools available at OPEUS-project.eu and FINE-1 website

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13\textsuperscript{rd} November 2019