Holger Dittus[1], Lukas Proehl[2]

Development of energy assessment methodology and simulation tool in Shift2Rail projects FINE1 and OPEUS

Zoom Authors


Short bios (150 words)

Holger Dittus is a researcher, group leader and project coordinator at Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Germany. He received a degree in Mechanical Engineering (Dipl.-Ing) from RWTH Aachen in 2006. His scientific scope is in energy management for railway vehicles with alternative traction systems, hybrids, BEMUs and fuel cell vehicles. He is Project Coordinator of the EU-Horizon 2020 Project FCH2RAIL since 2021, Project Manager of the DLR Project Propulsion & Coupling (ProCo) since 2022 and he participated in EU S2R-projects Roll2Rail, FINE1, FINE2, X2RAIL-3 and in standardization group for EN 50591:2018 Specification and verification of energy consumption for railway rolling stock.

Lukas Proehl holds a M.Sc. in Mechanical Engineering and is a research scientist at the chair of mechatronics at the University of Rostock. In the scope of research and teaching he is dealing with the modelling and control of mechatronics systems as well as the investigation and application of innovative optimization techniques.
Within OPEUS his focus was on the Matlab implementation of the OPEUS-tool as well as the application of optimization approaches for energy optimized driving & ESS strategies.

Address:
[1]Deutsches Zentrum für Luft- und Raumfahrt (DLR)
Institut für Fahrzeugkonzepte
Pfaffenwaldring 38-40
70569 Stuttgart
Phone: +497116862581
Email: Holger.dittus@dlr.de

[2]University of Rostock
Chair of Mechatronics
Justus-von-Liebig Weg 6
18059 Rostock
Phone: +49 381 / 498 - 9213
Email: Lukas.proehl@uni-rostock.de

Introduction

In times of an increased priority for carbon-free mobility there is also a need for energy efficient and sustainable rail transport. The reduction of the energy demand and environmental impact can also increase the competitiveness of rail in terms of reduced energy costs.

Within the European Shift2Rail (S2R) initiative many projects focussed on technical developments and innovative technologies for rail vehicles such as permanent magnet synchronous motors (PMSM) and silicon carbide (SiC) converters. While these developments have been performed in specific technical projects, often with their own application-specific use cases and objectives, no standardised process to assess the impact of the new developments on energy demand was defined.

Hence, in addition to the technical projects, S2R established additional projects for so called cross-cutting activities. One of these projects was *FINE1 Future Improvement for Energy and Noise* [1]. FINE1 high level objectives related to energy are to assess energy demand and to support the quantification of energy improvements of new technologies with a standardized approach. Within this paper, the process developed and used in the S2R project FINE1 for the evaluation of energy demand is presented. This includes the following:

- A methodology for simulation and prediction of energy demand
- An overview of the energy simulation tool that has been developed
- The reference railway use cases and applications used as energy baseline
- Exemplary results of the energy demand assessment for selected S2R technical developments

Simulation Methodology and Development of Energy Simulation Tool

The objective of this work is to develop the simulation methodology to systematically assess the improvements in terms of energy demand of the innovations, which are developed within the S2R Technical Demonstrators (TDs). The methodology and simulation tool have been developed in close collaboration with the Horizon 2020 project OPEUS [2]. While here only an overview of the requirements can be provided, a detailed description is documented in the FINE1 Deliverable *D3.4 Requirement Specification for Energy Simulation Tool* [3].
The requirements specification for the energy simulation tool and for the prediction of energy demand include amongst others the definition of the modules and parameters that should be considered in the simulation models. The high level requirements for the simulation tool are displayed in Figure 1.

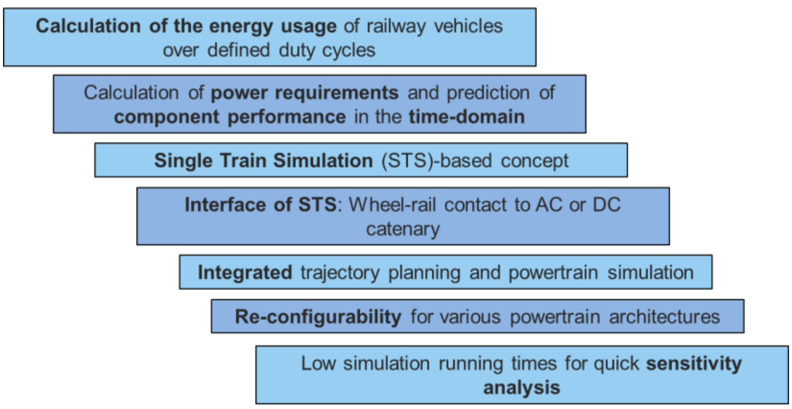

Figure 1: Energy Simulation Tool High Level Requirements

From the energy perspective, driving under standard conditions is the relevant case to be investigated when analysing energy improvements due to technical innovations. Degraded modes are of minor significance in terms of overall energy usage; nevertheless, they are certainly relevant when designing a technical system.

The general approach is based on a backward-facing simulation approach with behavioural modelling of the components. The intention is to avoid going too deep into the physical details of each component and component variant. Thus, the focus is on power flows, while physical modelling of specific characteristics, such as the effect of harmonics in traction drives, are excluded. In the backward-facing approach, the wheel forces are calculated directly from the speed profiles, talking into account resistance forces such as rolling or aerodynamic resistance. The obtained forces are then translated into torque and power values. These are then calculated against the flow of traction power through a powertrain model, which consists of all powertrain components for the specific vehicle configuration. The energy demand is finally determined at the interface to the energy source, for example at the contact point of catenary and pantograph. This approach allows usage of efficiency maps to model the components behaviour.

The *OPEUS energy simulation tool* [4] includes the infrastructural and operational boundary conditions of the line(s) to be simulated such as gradients, line speed limitations, curve radii, station positions and timetables. First a trajectory planning is performed that determines a train speed profile and the corresponding power profile at the wheels. This trajectory planning uses acceleration and deceleration limits in normal operation conditions, hence not being subject to adhesion limitations. These two profiles are used as input for the tractions system models. The traction system are modelled by combination of stand-alone component modules, which allows to reuse already developed models and parameters also for other traction topologies.
Figure 2 exemplary shows the AC traction topology T01 with a conventional transformer. Each component module is labelled with a unique identifier. The model also allows integration of energy storage systems for the simulation of bi-mode or series hybrid traction architectures.

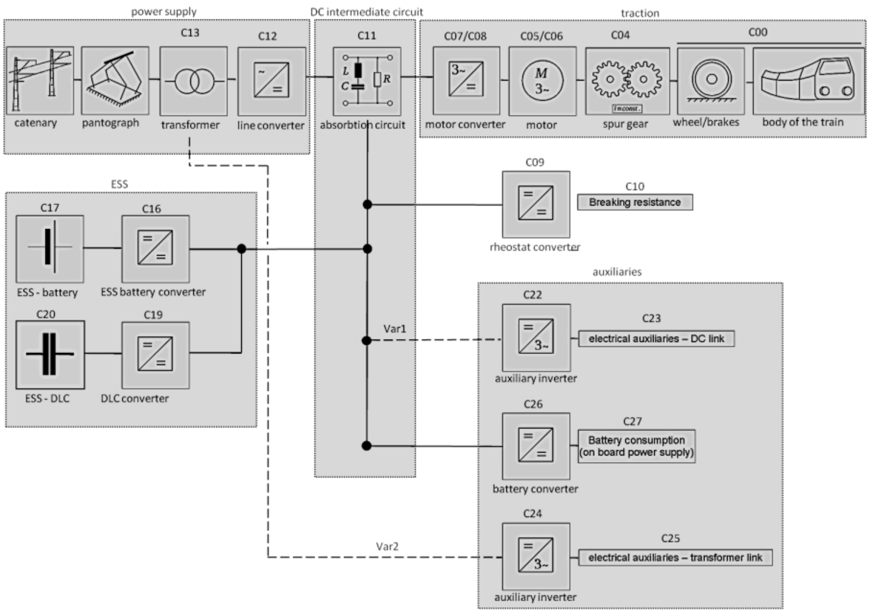

Figure 2: Example of AC traction topology T01 with component modules

Within the FINE1 and OPEUS projects the energy simulation tool has been validated by the project partners in two steps. Firstly, the tool was checked against the functional design requirements defined in FINE1 deliverable *D3.4 Requirement Specification for Energy Simulation Tool* [3]. Secondly, the tool's calculation methodology was checked via simulation of pre-defined train configurations and comparison of the results against established tools or measurements of the individual project partners that performed the validation. The main conclusion of the aforementioned two-step-process is that the developed OPEUS energy simulation tool fulfils the requirements and is approved for energy assessment activities and the evaluation of energy Key Performance Indicators (KPI) within the S2R FINE1.

Energy Baseline

The FINE1 deliverable *D3.1 Energy Baseline* [5] describes the reference parameters and scenarios for assessing the improvements of Shift2Rail innovations with respect to energy. The Deliverable D3.1 includes:

- The analysis of operational scenarios and reference speed profiles for the S2R system platform demonstrators (SPDs) concerning the traffic segments high speed, regional, urban and freight.
- The analysis of State-of-the-art technology characteristics with respect to energy of railway subsystems (vehicles, infrastructure, command & control system, energy supply).
- The definition of simulation data of reference technologies and reference vehicles

The defined simulation data contains the Service Profiles for the simulation of single train runs. Service Profiles are defined as invented in the standard *EN50591 Specification and verification of energy consumption* [6] and describe the boundary conditions of the lines and timetables for a train run. While energy demand or fuel consumption of road vehicles is typically measured in a predefined speed profile with speed as a function of time, the service profile approach defined in EN50591 is based on typical train runs in passenger transport. This service profile approach assumes that a train runs on a defined line consisting of a track description and a timetable. The track is characterised by the stations and their positions, the speed limits in different sections and the track gradients with their positions. The timetable defines arrival, stop and departure times at several or all stations, depending on the type of service profile, i.e. high speed, intercity, regional, etc. The timetable defines a fixed journey time, either for the complete line or section by section. This journey time can be exploited to choose the driving style with respect to the performance characteristics of the vehicle, and if the vehicle performance is sufficient to create a time reserve, energy efficient driving style can be applied, for example by a driver assistance system (DAS).

In addition to the service profiles the Energy Baseline simulation data also defines the complete set of generic parameters for the reference vehicles, for example for high speed, intercity, regional and metro applications. These are more than 150 parameters for each train configuration which can be summarised under the main categories:

- Train parameters such as train design mass and payload, train dimensions, traction topology, passenger capacity, number of seats, etc.
- Train resistance parameters, tractive effort and brake effort characteristics, max. train speed, electro-dynamic braking capabilities, etc.
- Detailed power characteristics and efficiency parameters describing traction components such as traction drives, traction/aux/line converters, transformer, energy storage systems, gear box, etc.

- Heating, ventilation, air conditioning (HVAC) and further parameters from other auxiliary consumers.

For a detailed list of parameters see FINE1 Deliverable *D3.3 Future Railway System* [7].

Exemplary Results

Within FINE1 and OPEUS projects the energy simulation tool has been applied to assess and compare the energy demand of energy baseline with several novel technologies and components that have been developed in the S2R TDs and SPDs, to quantify the potential energy reduction of these subsystems. The process for energy savings assessment is exemplary shown in Figure 3.

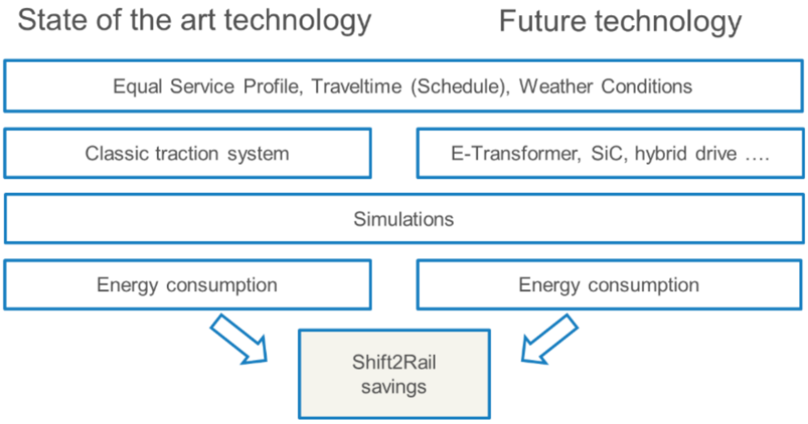

Figure 3: Assessment of S2R future technology energy savings and comparison to energy baseline (state of the art)

The key performance indicator "energy KPI" is used to quantify the relative change in energy demand between baseline and future technologies. The KPI improvements (Figure 4) presented in this paper are focused on combined effects due to mass reductions and improvements of SiC converter efficiency.

The potential mass reductions due to technical improvements on train level range between 2.38% in High Speed SPD, 0.22% in Intercity SPD, 0.54% in Regional SPD, 0.51% in Metro SPD and 1.03% in Tram SPD [8].

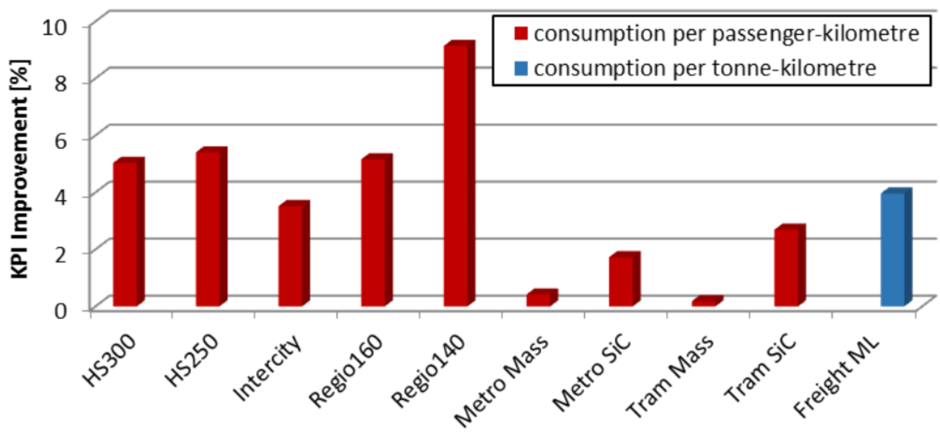

Figure 4: Energy KPI improvement for the combination of mass reductions and SiC converter. For Metro and Tram the improvements are displayed separately. [8]

For those SPDs where calculation of integrated energy KPIs was feasible, the resulting improvements of energy KPI range between 3.5% for SPD Intercity and 9.1% for SPD

Regional140. In Metro and Tram SPD a separate assessment of different technologies was performed, showing the potential of SiC converter application with 1.7% energy KPI improvement for Metro SPD and 2.7% for Tram SPD. In these SPDs the quite small relative mass reductions (-0.51% in both cases) resulted in 0.4% energy savings for Metro SPD and 0.18% for Tram SPD; the improvement of energy KPI due to mass reductions is therefore negligible for SPD Metro and SPD Tram.

Summary and Conclusion

Within the S2R FINE1 and OPEUS projects an energy simulation tool for single train runs has been designed, implemented and benchmarked against existing tools of industrial and research partners. Together with the tool the state of the art with respect to energy demand of railway vehicles in different applications has been defined and documented as so called energy baseline.

The energy simulation tool and the underlying methodology have been applied to assess the improvement of the energy KPI due to different technical solutions that have been developed in the S2R technical projects. Within this paper the potential energy demand reduction due to the application of SiC converter technology and due to weight reduction have been exemplarily presented for different system platforms. The potential energy savings range between 1% and 9%, depending on the type of vehicle, with regional trains showing the best potential in this analysis.

The presented energy simulation tool is currently in use in the FINE1 follow-up project FINE-2 [9], where it is used to assess the energy saving potentials of new or further improved technologies and components that have been developed in the S2R technical projects since FINE1 ended in October 2019.

Acknowledgements

This FINE1 project has received funding from the Shift2Rail Joint Undertaking (JU) under grant agreement No 730818. The JU receives support from the European Union's Horizon 2020 research and innovation programme and the Shift2Rail JU members other than the Union. The OPEUS project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No: 730827. The paper reflects only the authors' view, the JU is not responsible for any use that may be made of the information it contains.

References

[1] Shift2Rail *FINE 1 Future Improvement for Energy and Noise*, Grant Agreement No 730818, https://projects.shift2rail.org/s2r_ipcc_n.aspx?p=FINE%201

[2] Shift2Rail *OPEUS Modelling and strategies for the assessment and OPtimisation of Energy USage aspects of rail innovation*, Grant Agreement No 730827, https://projects.shift2rail.org/s2r_ipcc_n.aspx?p=OPEUS

[3] Shift2Rail FINE1 D3.4 *Requirement Specification for Energy Simulation Tool*, Grant Agreement No 730818, https://projects.shift2rail.org/download.aspx?id=d29b84a6-a45e-4646-bf95-647e78b81197

[4] Shift2Rail OPEUS D2.1 *OPEUS simulation package*, Grant Agreement No 730827, https://projects.shift2rail.org/download.aspx?id=4e263299-f224-41e4-9cc2-6fc991bd56ef

[5] Shift2Rail FINE1 D3.1 *Energy Baseline*, Grant Agreement No 730818, https://projects.shift2rail.org/download.aspx?id=ab79020c-bcd8-48c2-8388-24b3b41092b2

[6] EN50591:2019 Railway Applications - Rolling Stock - Specification and verification of energy consumption

[7] Shift2Rail FINE1 D3.3 *Future Railway System*, Grant Agreement No 730818, https://projects.shift2rail.org/download.aspx?id=d29b84a6-a45e-4646-bf95-647e78b81197

[8] Shift2Rail FINE1 D4.7 *Evaluation of Energy KPI – final*, Grant Agreement No 730818, https://projects.shift2rail.org/download.aspx?id=8e254a94-5e72-4b34-8e89-afa55efae401

[9] Shift2Rail *FINE-2 Furthering Improvements in Integrated Mobility Management (I2M), Noise and Vibration, and Energy in Shift2Rail,* Grant Agreement No 881791, https://projects.shift2rail.org/s2r_ipcc_n.aspx?p=fine-2