Energy assessment in Shift2Rail European Rail Research Program

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Abstract

Shift2Rail (S2R) is a major European initiative with research and innovation focused on strengthening the role of rail in the European mobility system. One high-level objective of the S2R research projects FINE1 (Future Improvements on Noise and Energy) and OPEUS (Modelling and Strategies for the Assessment and OPtimisation of Energy USage Aspects of Rail Innovation) is to systematically assess and benchmark the impact of innovative technologies regarding both energy demand as well as costs in European railway system. This includes the development and the implementation of an appropriate methodology, the definition of representative scenarios (energy baseline) and the evaluation of improvements with respect to the energy key performance indicators (KPI) due to the technical solutions developed in S2R technical projects. The results presented are a single train simulation tool implemented by the affiliated open-call project OPEUS as well as the results of the tool verification process. The energy baseline reference scenarios consisting of representative vehicle datasets and service profiles for the main S2R service categories high speed, regional, urban and freight are presented as well as exemplary results of the energy KPI evaluations in these service categories. The service profiles are derived from previous EU projects (e.g. Roll2Rail [1]) and from the preliminary standard prEN 50591 – “Specification and verification of energy consumption for railway rolling stock”; FINE1 closely cooperates with the standardization group developing this standard.

Keywords: Shift2Rail, Rolling Stock, Energy KPI, Single Train Simulation

1. Introduction

The Shift2Rail FINE1 project addresses the topic “S2R-CFM-CCA-02-2015 – Energy and sustainability, including noise and vibrations baselines assessment” of the first call for proposals for Shift2Rail (S2R) Joint Undertaking members, aimed at driving innovation in railways. The FINE1 energy sub-project aims to assess and reduce the operational costs of railways through a reduction of energy consumption in Europe. This shall lead to a reduction of environmental impact, enable an increase of traffic and enhance the attractiveness and competitiveness of railway transport. The main objectives of the energy sub-project are to provide support to all S2R Innovation Programs (IPs), Technology Demonstrators (TDs), Integrated Technology Demonstrators (ITDs) and System Platform Demonstrators (SPDs) and gather their potential contribution in terms of energy saving. The actions undertaken within the energy sub-project are related to the following specific objectives:

- To achieve and assess the overall energy reduction on S2R TDs and SPDs;
- To help and support all actions related to energy saving across the IPs and TDs;
- To cooperate on energy standards with respect to existing state-of-the-art and future developments, energy strategic views and needs with S2R internal and external stakeholders;
- To link energy and sustainability actions with existing initiatives outside S2R

Within the energy sub-project, the methodology for estimating the energy usage is developed and was considered as a basis for the revision of the existing energy standard TS 50591 - “Specification and Verification of Energy Consumption for Railway Rolling Stock” to derive the preliminary standard prEN 50591. With regards to the main challenge of the energy sub-group, the scope of the energy sub-project includes three points related to this paper:

- Definition of operational scenarios for the four traffic segments (high speed, regional, urban and freight traffic) with regards to estimating the energy saving of S2R innovations.
- Development and evaluation of an energy baseline as a reference for the analysis of energy savings based on new S2R technologies.
- Development and implementation of an energy calculation methodology to allow the monitoring of all TDs with respect to energy saving in different traffic segments.

To quantify the improvements of energy demand due to technological innovations of the S2R projects and to communicate them to in an easily understandable way Key Performance Indicators (KPIs) for energy demand have been defined:

1. Energy usage per train-kilometer [Wh/km] (for freight and passenger trains)
2. Energy usage per passenger-kilometer [Wh/p.km] (for passenger trains)
3. Energy usage per seat-kilometer [Wh/s.km] (for passenger trains)
4. Energy usage per tonne-kilometer [Wh/t.km] (for freight trains)

2. Shift2Rail Energy Saving Innovations

FINE1 quantifies respectively collects and analyses energy savings achieved by technologies which are developed by other Shift2Rail Innovation Programs and projects. For this purpose, the energy simulation tool which is described in section 4 is applied. Among the Shift2Rail future technologies with positive impact on energy efficiency there are for example: Medium frequency transformer with electronic converter (project PINTA), composite car body shell with fiber reinforced plastic (project PIVOT) and double fed power supply for 50 Hz overhead lines with increased substation distance and no switches for separation of overhead line sections [2]. FINE1 also serves as the central point of contact and advise for energy-related topics within all Shift2Rail Innovation Programs. In this function, FINE1 provides the reference method for energy savings quantification for maximized comparability between technologies.

3. FINE1 Energy Baseline

The FINE1 energy baseline [3] defines the reference for assessing the improvements of Shift2Rail innovations with respect to energy. It is aligned with the overall Shift2Rail reference scenarios and system platform demonstrators (SPD), developed within the Shift2Rail project IMPACT-1 [3], [5] and with the OPEUS deliverable D3.1 “Scenarios Set Up and Description” [6]. The energy baseline consists of the following main parts:

- SPD service categories and service profiles for the traffic segments high speed, regional, urban and freight including line parameters such as timetables, gradients, speed limits, etc.
- State-of-the-art technology with respect to energy of all railway subsystems (vehicles, traction components, infrastructure, command & control system, energy supply)
- Definition of reference simulation data for the SPDs consisting of vehicle parameters, line parameters and traction component data

Table 1 gives an overview of the service profiles used for the different service categories. In accordance to prEN 50591 a gradient is only defined for freight mainline in order to consider the capability of the locomotive to manage the gradient. For all other profiles no gradients are considered.

Table 1: Overview of reference service profiles for the service categories [3]

Main Service Category	Sub Service Category	Max. profile speed [km/h]	Average Station Distance [km]	Station standstill time [min]	Route length [km]	Operational travel time [hh:mm:ss]	Source of profile
High Speed	High Speed 300	300	150	3	300	01:47:00	prEN 50591
	High Speed 250	250	100	3	300	02:03:00	High speed from prEN 50591, but limited to 250km/h, 2 additional stops
	Intercity	200	28	2 – 3	250	02:39:00	prEN 50591
Regional	Regional 160	160	15	1 – 2	250	02:57:00	Intercity from prEN 50591, but limited to 160km/h 7 additional stops
	Regional 140	140	5	1 – 2	70	01:09:00	prEN 50591
Urban	Suburban	120	3,6	1	40	00:43:00	prEN 50591
	Metro	80	1,0	0,5	21,5	00:41:00	based on EU-project OSIRIS [7]
	Tram	50	0,5	0,5	10,7	00:29:40	based on EU-project OSIRIS [7] incl. UITP suggestions
Freight	Freight Mainline	100	50	1 – 5	300	04:17:15	prEN 50591
	Freight Shunting	42	-	-	37	04:32:00	CleanER-D [8] Pmax 870 kW

4. Energy Simulation Tool

One of the tasks of the FINE1 and OPEUS projects is the development and implementation of a simulation tool which allows the user to calculate the energy consumption of various railway vehicles as well as their components. Within Shift2Rail this tool is used to investigate energy losses in the traction chain and to assess the energy saving potential of innovative technologies developed in S2R projects.

The requirements for the development of the simulation tool have been defined in FINE1 [9] while the implementation process took place within OPEUS. The OPEUS tool is based on a simulation tool developed by University of Rostock, Chair of Mechatronics in the EU project CleanER-D [8]. It is implemented with the MATLAB/Simulink environment. The general approach is based on behavioral modelling of a single running train and its powertrain components over a defined duty cycle. The power requirements and the prediction of component performance are evaluated in the time domain. The focus is on the evaluation of power flows, while specific characteristics such as harmonics are excluded. The MATLAB/Simulink environment is utilized as it provides the user with some good degree of flexibility allowing to simply apply desired changes and to integrate and simulate other architectures. To avoid a profound interaction of non-experienced users with the internal MATLAB implementation, the basic version of the tool used for the pre-defined use cases of the energy baseline and their modifications also offers the possibility to operate it via Microsoft Excel. The Excel user interface allows to define the input data as well as to evaluate the simulation results for the energy simulation runs.

The determination of speed profiles for the given track and vehicle input data is handled by the trajectory planning part of the OPEUS tool. The trajectory planner allows choosing between three driving modes:
The so called All-out-mode results in the speed profile representing the fastest journey under the given restrictions such as speed limits, train mass, tractive effort and acceleration / deceleration limits. The other two modes generate speed profiles according to the timetable defined with the line data. One mode integrates coasting sections to increase the run time between stations while the other mode decreases the maximum speed to fulfill the timetable.
The speed profiles are passed to the Simulink-based powertrain model, in order to calculate the energy usage of the running train in a backward-facing manner for a defined architecture. In the backward-facing approach (Fig. 1), the wheel forces are calculated directly from the speed profiles or during the development of speed profiles. The forces are then translated into torque/power values and passed to the powertrain components inversely, that is against the flow of traction power. The energy demand is then determined at the calculation point of the energy sources. This approach allows utilization of efficiency maps gathered from the TDs. The separation of trajectory planning and powertrain simulation also allows determining the energy demand for measured speed profiles of real train runs.

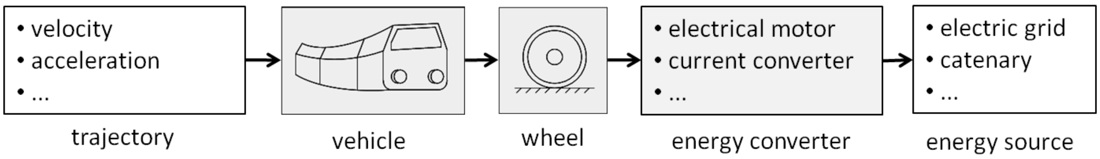

Fig 1: Backward simulation approach for a railway vehicle [10]

Various traction system topologies have been identified for implementation and consideration within the energy simulation tool. They are built up with modular components to ensure reusability of a once implemented component model and the parameters used within the model. Dotted lines in the topology diagram stand for alternative component or interface variants providing the user with the option to choose the variant to be simulated. The first topology T01 (Fig. 2) describes trains supplied by 15 kV_{AC} or 25 kV_{AC} voltage via an overhead catenary system and a conventional main transformer.

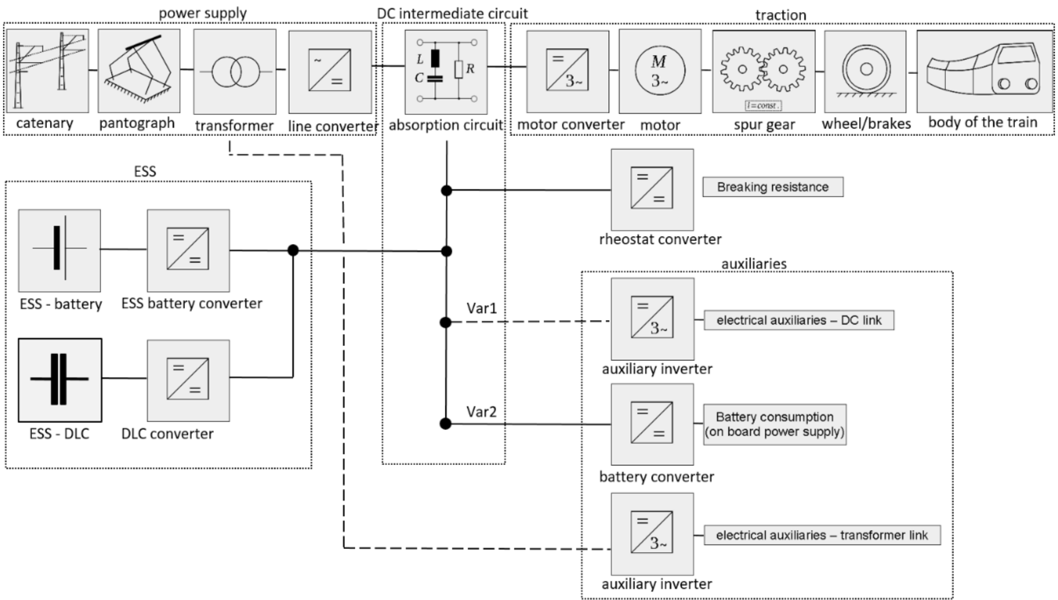

Fig 2: AC traction system topology with conventional transformer (T01) [10]

The second topology T02 describes trains supplied by 15 kV_{AC} or 25 kV_{AC} voltage via an overhead catenary and a power electronic traction transformer. The third topology T03 describes trains supplied by 750 V_{DC}, 1.5 kV_{DC} or 3 kV_{DC}. The powertrain from the DC-link to the wheels has the same structure with the topologies T01 and T02. Diesel topologies are not part of the required topologies, because the OPEUS tool is based on the existing tool from CleanER-D project which already contains validated models of diesel-hydraulic and diesel-electric traction systems.
The data management of the tool provides a clear and conversant user interface with a predefined folder structure. Amongst others it includes a train data library, where train and component parameters are stored as well as a track data library with data describing for example number of sections, distances between stations, speed limits, gradients, curve radii, tunnel parameters and the desired timetable of the route. For each simulation run performed with the tool the simulation results are stored together with the selected simulation inputs in a simulation output library. This leads to a clear relation between the simulation inputs and the resulting simulation outputs. In addition the simulation outputs are documented in an Excel output file including various energy values for the total travel as well as for station-by-station (e.g. traction energy at the wheel, recuperated energy at the catenary, etc.). Additionally, the total travel effort is summarized by previously mentioned key performance indicators.

5. Validation and Approval of OPEUS Simulation Tool

In order to validate and approve the energy simulation tool implemented by University of Rostock, Chair of Mechatronics within the OPEUS project a closed-loop review and validation process had been performed. Firstly, the tool was checked against the design requirements specified by FINE1 in [9]. With regards to the design requirements, a requirements checklist was produced and checked for each requirement in a closed-loop process between DLR and the University of Rostock, Chair of Mechatronics. Concerning the design requirements the tool fulfills all requirements.
Secondly, the tool's functionality and calculation methodology have been checked. This was accomplished via simulation of predefined train configurations with the OPEUS tool and comparison of results against data from either real measurements or from simulation runs with proprietary tools of the volunteering FINE1/OPEUS partners who performed the validation. Each volunteering FINE1/OPEUS partner provided approval reports stating deviations and necessary improvements of the tool, which have been implemented by University of Rostock. After final approval of all partners the individual reports, which describe the simulation and result comparison methodologies, have been documented as contributions to FINE1 Deliverable 4.1 [11].
The conclusion of the aforementioned processes is that the developed FINE1/OPEUS energy simulation tool fulfils all requirements and is approved for energy assessment activities and the evaluation of energy Key Performance Indicators (KPI) within the S2R FINE1 project.

6. Exemplary KPI Evaluation for Energy Baseline

In this section, exemplary simulation results and energy KPIs from [12] for the sub-service categories ''HS300'', ''HS250'', ''Intercity'', ''Regional 160'', ''Regional 140'', ''Suburban'', ''Metro'', ''Tram'' and ''Freight Mainline'' are presented for the energy baseline defined in FINE1 D3.1 [3]. The ''Timetable with coasting'' was considered as the main driving style for two season setups (winter/summer and spring/autumn). The ''All-out trajectory'' driving style was used for comparison purposes only for the spring/autumn season setup. An analysis on the summarized simulation outputs was performed and the main findings were highlighted in [12].
The KPI results outlined in Fig. 3 are going to be used for the evaluation of energy savings achieved by S2R developments. These KPI values have been cross-checked by the FINE1 partners versus available energy demand from real life operation. In all cases driving according to the timetable needs less energy than the All-out driving style. The specific difference of each sub-service category reflects the influence of the underlying use case, mainly in terms of time reserve, share of HVAC energy, time at stations and number of stops. Furthermore for the sub-service categories high speed, regional and

suburban reflects the underlying seasonal variation of auxiliary energy demand. In an upcoming FINE1 deliverable, the comparison of updated energy vs. the presented energy baseline will be documented.

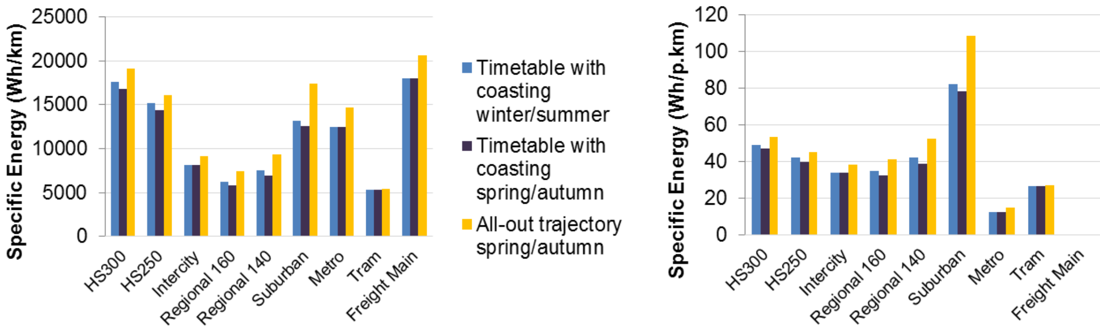

Fig. 3: Energy KPI Wh/km (left) and Wh/p.km (right) for energy baseline [12]

7. Conclusions

FINE1 accomplished a very important task in terms of harmonizing energy quantification methodology throughout S2R. Via the link to energy standardization group, FINE1 contributes to fostering a single European energy quantification approach. The Energy Simulation Tool developed and implemented in close cooperation between OPEUS and FINE1 is a powerful instrument for energy savings quantification. Together with a projection of energy cost and initial cost for the respective technology, return on investment analyses are possible.

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