



# OpenPowerNet

## Simulation of Traction Power Supply Systems



in Co-Simulation with  
**OPEN**  **TRACK**

## Simulation of Railway Operation

### Program Description and References



# OpenPowerNet users



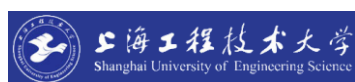
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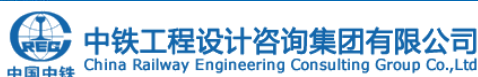
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# OpenPowerNet – Simulation of Railway Power Supply Systems

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## Abstract

The energy consumption of electrical railways is mainly influenced by the driving states and the propulsion efficiency characteristics of the trains as well as by the behaviour of the traction power supply system. For this reason the idea was to create a plug-in simulation module for railway power supply networks using the advantages of an existing commercial railway operation simulator. The new developed energy simulation module called OpenPowerNet works together with the Swiss OpenTrack railway operation simulator as a so called “co-simulation”. OpenPowerNet is able to simulate all common AC- and DC-railway power supply systems taking into account the entire electrical network structure. It can be used as an energy prognosis and analysis tool as well as for the planning and optimisation of power supply installations. The accuracy of the simulation was verified by a lot of realtime measurements.

*Keywords: Simulation Tools, Planning, Operations Quality, Energy Management, Power Supply Systems*

## 1 Introduction

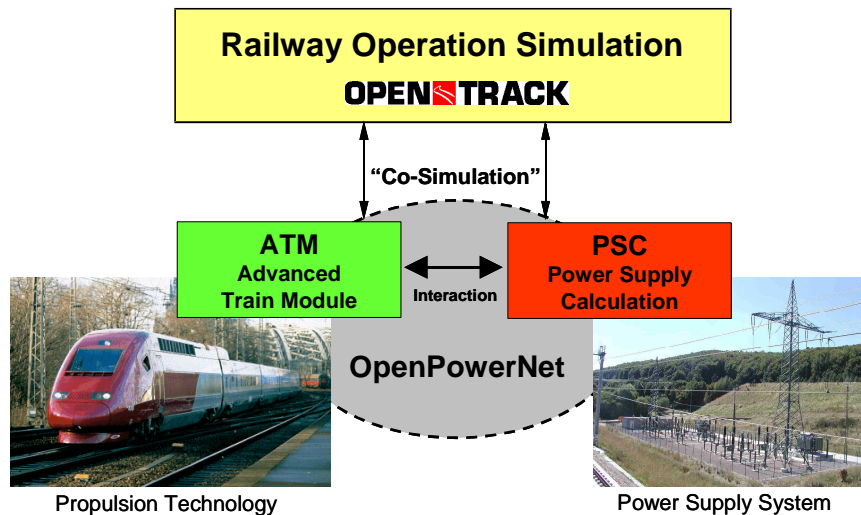
For prognosis and analysis of railway energy consumption the use of simulation tools is state of the art today. For that purpose a considerable number of software tools with different preciseness is available. But the modern software technology offers new possibilities to improve the simulation.

The electrical load flow within railway power supply networks and the train energy consumption depend both on the running trains and the power supply system characteristics. In contrast to public energy distribution systems there are moving energy consumers with a time-dependent power demand picking up and recovering energy at changing locations. The network structure and the voltage situation influence the internal load flows because:

- currents and power losses increase with decreasing voltages,
- under low voltage conditions current or power limitations of the train propulsion control can be activated with impact on the driving dynamics,
- the network voltage determines the braking energy recovering decisively.

Thus the power supply system may influence the traction characteristics of the trains and the railway energy consumption.

The simulation of these dynamic processes allows the analysis and prognosis of load flows and energy consumption as well as the design and rating verification of the electrical installations. However a realistic prognosis by simulation requires detailed information about the present power consumption, the actual position of the trains and the capability of the power supply network available simultaneously. Therefore a series of compromises either concerning the railway operation simulation or the electrical network modelling depth were made in the past. For this reason the idea was to create a plug-in simulation module for railway power supply networks using the advantages of an existing commercial railway operation simulator.



**Figure 1-1** Co-simulation of railway operation and electrical network

## 2 General Requirements

The new electrical network simulation module called **OpenPowerNet** was designed by IFB to enable a so called “co-simulation” with the Swiss **OpenTrack** railway operation simulator (Figure 1-1). Each program should have its clearly delimited task. OpenTrack deals with the timetable-based train operation simulation using the infrastructure and train data. OpenPowerNet shall simulate in sync the entire electrical network taking into account the networks voltage situation depending on the train’s power consumption and position. All retroactive effects to be considered exactly. OpenPowerNet should be able to simulate all common AC- and DC-railway power supply systems taking into account the entire electrical network structure. Furthermore different levels for the train propulsion modelling should be available. Various post-processing tools should enable multiplex data analyses.

## 3 Design and Functionalities

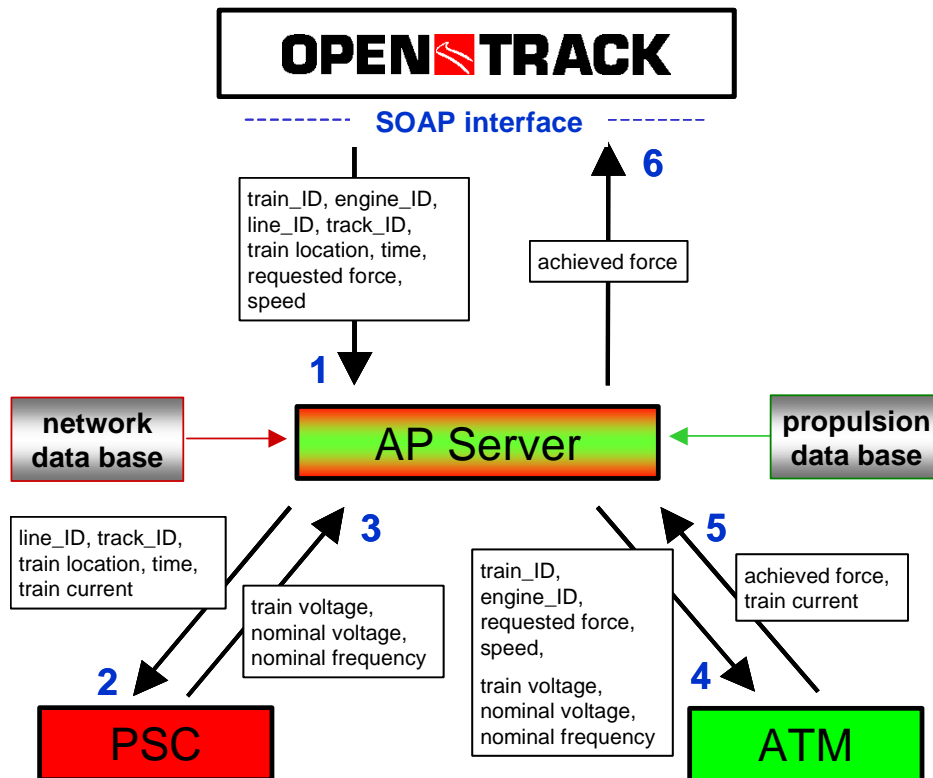
### 3.1 Primary Software Structure

OpenPowerNet itself consists of two modules:

- the “Advanced Train Module” (ATM) modelling the propulsion technology of the trains in detail and
- the “Power Supply Calculation” (PSC) for the electrical network calculation.

During the simulation run time both modules are coordinated with the OpenTrack railway operation simulation using a so called APServer. It is responsible for the data transfer between the single modules and the connected data bases of the network and propulsion data (Figure 3-1).

OpenPowerNet is working on a time step basis synchronised to OpenTrack. In the following the simulation procedure within one time step is explained: To calculate the train driving dynamics OpenTrack normally uses the tractive effort characteristics of its own database. Connected with the OpenPowerNet simulator OpenTrack stops at this point and sends a calculation request to the connected electrical network and propulsion simulation. Therefore all needed information as train\_ID, engine\_ID, line\_ID, track\_ID, present train location, speed and simulation time are transferred to OpenPowerNet. The AP Server ensures that the corresponding electrical loads of the trains are interpolated at the right positions of the electrical network (mileage, track). During the network calculation it controls the iteration processes between the ATM and PSC modules and delivers the results to the data base as well as back to OpenTrack.



**Figure 3-1** Simulation steps and data transfer

Respecting the train positions obtained from OpenTrack the electric power data of the trains are transferred to the PSC. Considering all electrical train loads of the previous time step the PSC at first delivers an initial network voltage distribution. Following the predefined pantograph voltages of the trains are transferred to the ATM. Therewith the propulsion calculation reflecting all properties and limiting values is performed resulting in torques, revs, tractive forces and train currents. Afterwards these current values are transferred back to the PSC network calculation and the calculation cycle is repeated until an iteration limit is fallen short of. Lastly the achieved tractive force reflecting the propulsion capacity under the real voltage conditions is transferred back to the railway operation simulation. OpenTrack now continues its operation simulation using the results of OpenPowerNet. Thus the influence of the electrical processes on the railway operation is modelled exactly. Additionally all power supply network and energy consumption data are available for further evaluation.

The communication between OpenTrack and OpenPowerNet is realised via a SOAP (Simple Object Access Protocol) interface using XML-based data descriptions and TCP/IP protocols. Normally both software systems should run on the same hardware simultaneously due to performance criteria, but it is also possible to run the simulations in parallel on different computers connected via Internet. The data transfer between the modules is organised utilising the RailML standard.

### 3.2 ATM - Advanced Train Module

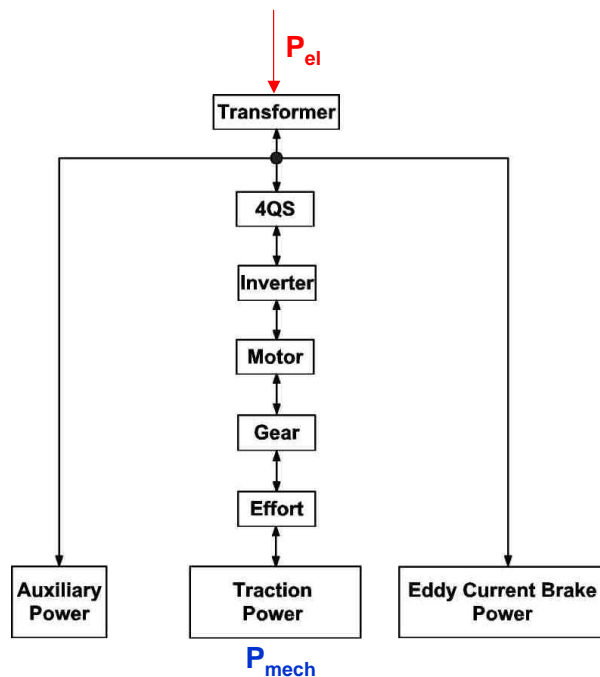
The Advanced Train Module (ATM) was integrated into OpenPowerNet in order to simulate the propulsion system behaviour of the trains depending on the networks voltage situation. It offers a more detailed modelling as it is implemented in the railway operation simulation. Thus the propulsion characteristics resulting from the ATM calculation have top priority. Besides the propulsion characteristic simulation the ATM also controls the energy recovering management during braking processes considering the energy absorption capability of the power supply network.

Within the ATM there are 4 modelling levels available for the propulsion simulation:

- 1) constant efficiency factors for the entire propulsion equipment,
- 2) driving state related efficiency factors,
- 3) load depending efficiency factors of single components,
- 4) detailed mathematical engine models of components.

Additionally the auxiliary and the eddy current break power consumption can be considered as fixed values or time functions respectively. Furthermore any limiting values of the propulsion control (e.g. voltage related current or power limitations) are implemented. The component structure of the ATM is shown in Figure 3-2 for an AC powered train.

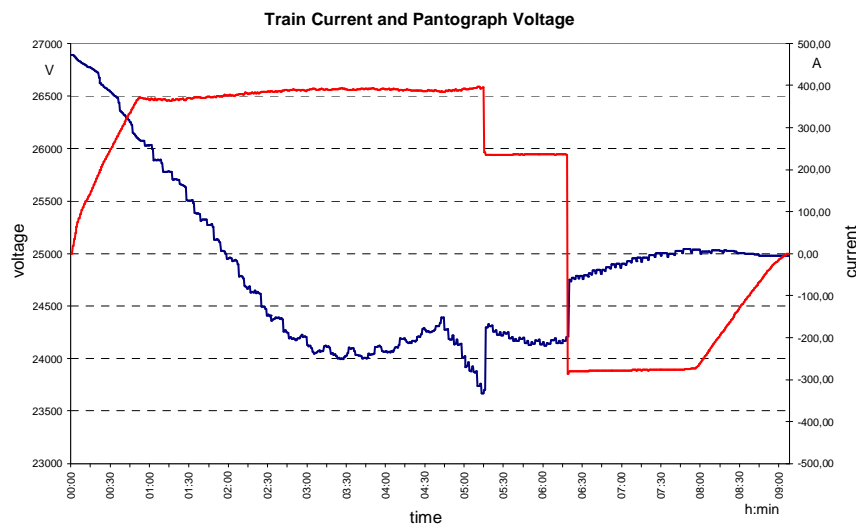




**Figure 3-2** Arrangement of the propulsion system components for the ATM

The propulsion simulation was verified by a lot of comparison measurements. As an example Figure 3-3 shows the pantograph voltage and the current characteristics of a high speed train accelerating up to 300 kph, persisting at the maximum speed and braking to zero again. It is clearly visible how the network voltage is influenced by the train's power depending on its position. On the other hand the decreasing network voltage increases the current level. During the braking phase the voltage is raised due to the energy recovering.

Using the existing data interfaces the ATM could be replaced in the future by an origin train propulsion control unit enabling a so-called "hardware in the loop" simulation. This would offer the possibility to use a common railway operation simulator for equipment test laboratories dealing with realistic railway line simulations.



**Figure 3-3** Propulsion model verification

### 3.3 PSC – Power Supply Calculation

Regarding conventional task formulations for power supply network simulations the following development requirements to the PSC module were set up:

- simulation of all common AC and DC railway power supply systems,
- representation of the entire electrical network structure,
- unrestricted configuration of longitudinal conductors along the line,

- precise consideration of the electromagnetic coupling effects between the longitudinal conductors within single phase AC systems,
- switch status changes of the railway power supply system during the simulation run,
- retroaction to the railway operation simulation (OpenTrack),
- iterative communication with the propulsion simulation (ATM),
- configurable data output,
- interfaces to professional post-processing tools like MATLAB or EXCEL.

Figure 3-4 shows the universal power supply network structure for a DC 0.6 kV system, Figure 3-5 gives an example for an AC 2 x 25 kV 50/60 Hz railway power supply. The modelling of the electrical network structure (i.e. feeding sections, feeding points, connecting points, switch status) must be in congruence to the track topology of the railway operation simulation. Therefore a uniform mileage as well as a coordinated line\_ID and track\_ID declaration is to apply. Respecting this basic approach the following data have to be implemented:

- electrical properties of the feeding power grid,
- electrical characteristics of the substations (transformers, converters, switchgears),
- electrical characteristics of the installed conductors (cables, catenary wires, tracks, rails),
- electrical characteristics rail-to-earth,
- modelling of additional power consumers (e.g. switch heatings, depot loads),
- loading capacities (cables, wires, converters, transformers),
- protection settings.

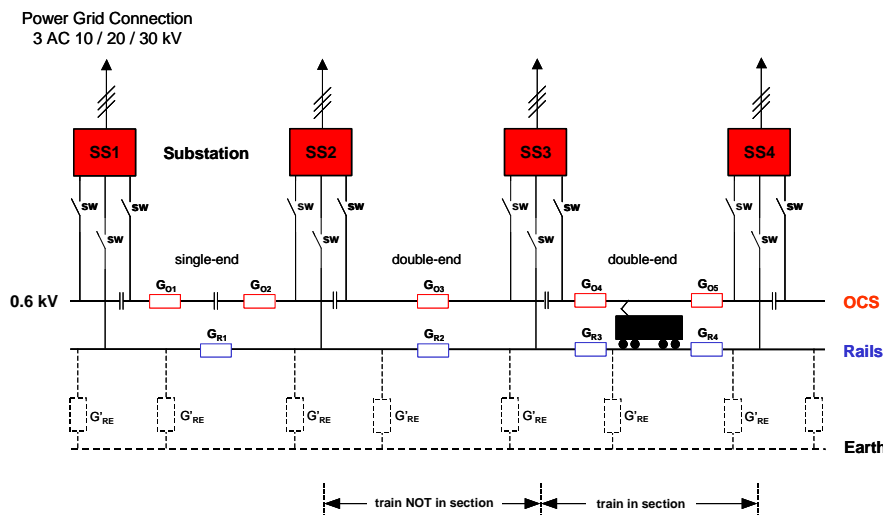


Figure 3-4 Power supply network structure (DC 0,6 kV)

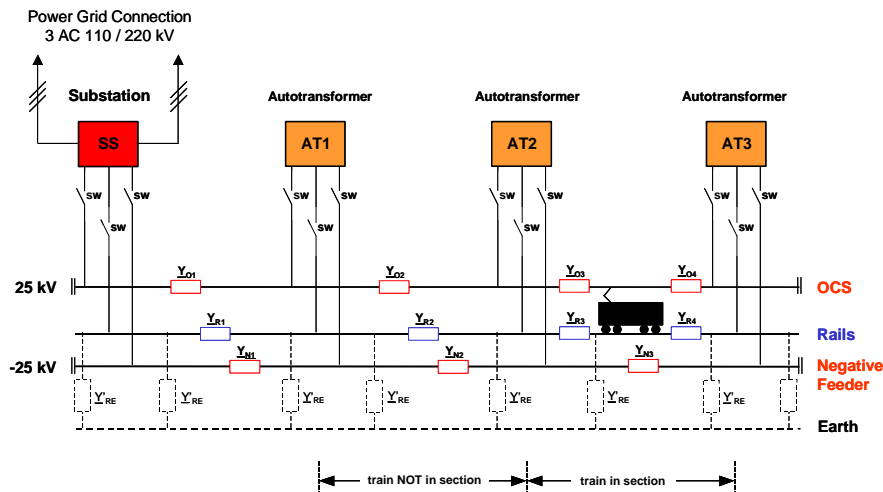
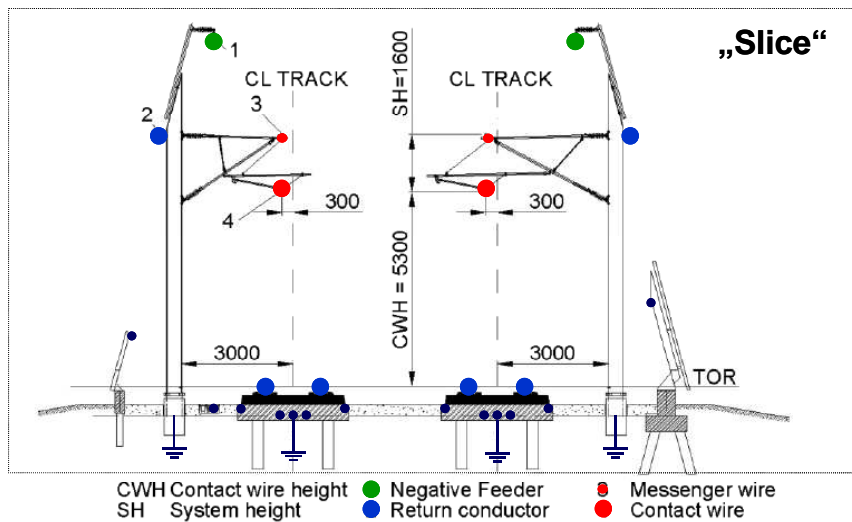
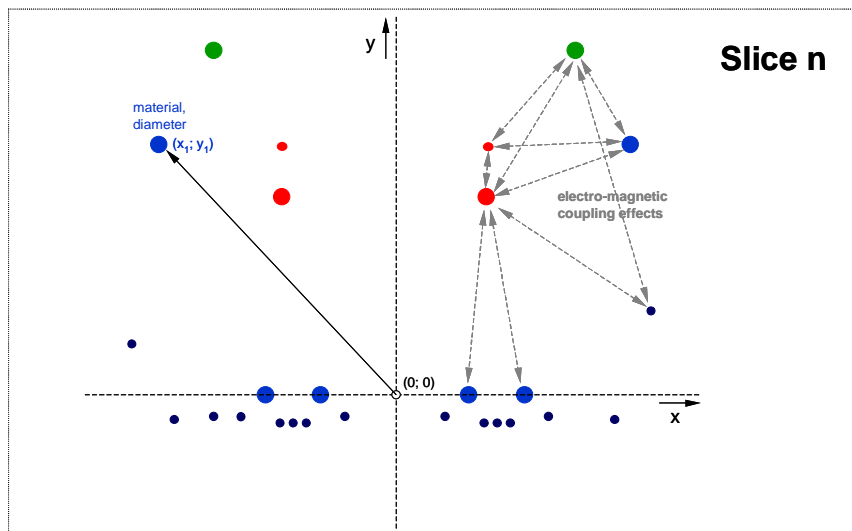


Figure 3-5 Power supply network structure (AC 2 x 25 kV 50/60 Hz)

The modelling of the overhead catenary and return current system (Figure 3-6) is realised by a sequence of slices representing only the geometric conductor arrangement and the material properties (Figure 3-7). Thus an arbitrary number of longitudinal conductors can be modelled. Based on the conductor's positions and the current direction the electromagnetic coupling effects and their impact on the current distribution of the single conductors within AC systems is considered.

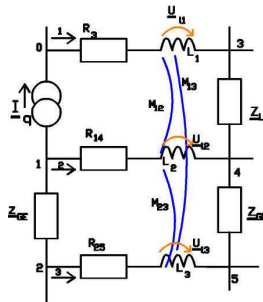


**Figure 3-6** Arrangement of conductors of the overhead catenary system



**Figure 3-7** Geometric conductor model for the overhead catenary system

Due to the excessive geometrical arrangement description there is no need for any impedance determination in advance. For the electrical network calculation the well known method of nodes is applied using an automated matrix and vector description. However there is a special extension of this method considering the voltage drops caused by self- and mutual induction by a new mathematic procedure (for AC systems only). Using transformation matrices for the inductive voltages the electromagnetic coupling is implemented without the need of an iteration. Thus both the computing time and the result inaccuracy could be decreased.



### Electrical network calculation using the advanced method of nodes

$$[Y]_{(v,v)} (U_{v0})_{(v,1)} - [Y_2]_{(v,LL)} (U_L)_{(LL,1)} = (I_g)_{(v,1)}$$

Voltage drops caused by self- and mutual induction

nodes	node voltages					inductive voltages			currents
	$U_{10}$	$U_{20}$	$U_{30}$	$U_{40}$	$U_{50}$	$U_{11}$	$U_{12}$	$U_{13}$	
1	$G_{14} + Y_{GE}$	$-Y_{GE}$		$-G_{14}$			$-G_{14}$		$-I_g$
2	$-Y_{GE}$	$G_{25} + Y_{GE}$			$-G_{25}$			$-G_{25}$	0
3			$G_3 + Y_L$	$-Y_L$		$G_3$			0
4	$-G_{14}$		$-Y_L$	$G_{14} + Y_L + Y_{GE}$	$-Y_{GE}$		$G_{14}$		0
5		$-G_{25}$		$-Y_{GE}$	$G_{25} + Y_{GE}$			$G_{25}$	0

Figure 3-8 Electrical network calculation principles applied in OpenPowerNet

The verification of the PSC was done at first by a large number of punctual theoretical tests as

- current sum zero for single network slices,
- energy picking up and recovering balances,
- correspondence of voltage minima / maxima and jumps respectively with the network structure during constant load test.

Additionally the simulation results were compared with network measurement data of predefined load cases from tramway and trolleybus networks as well as from high speed railway lines. As evaluation criteria the driving dynamics of the trains, the current-, voltage- and power characteristics were utilised. The differences ascertained by comparison of simulation results and measurement data were less than 3 %.

## 4 Commercial Application

### 4.1 Intentions and Advantages

The railway power supply simulator OpenPowerNet superimposing on the railway operation simulation tool OpenTrack can be used as an energy prognosis and analysis tool as well as for design and optimisation tasks of power supply installations. The outstanding advantage of the co-simulation is the separation of the different simulations tasks. From the software provider's view this allows an independent development and maintenance strategy for both software tools respecting only the interface specification. Each side can focus on the improvement of its own very specialised tasks. But also from the user's view the presented solution offers respectable advantages: The railway power supply simulation requires a network modelling with a very high complexity. Therefore the set up of an executable operation simulation at first without the complex electrical network is a solid basis. After that the electrical simulation can be added step by step. Thus the fault probabilities are minimised.

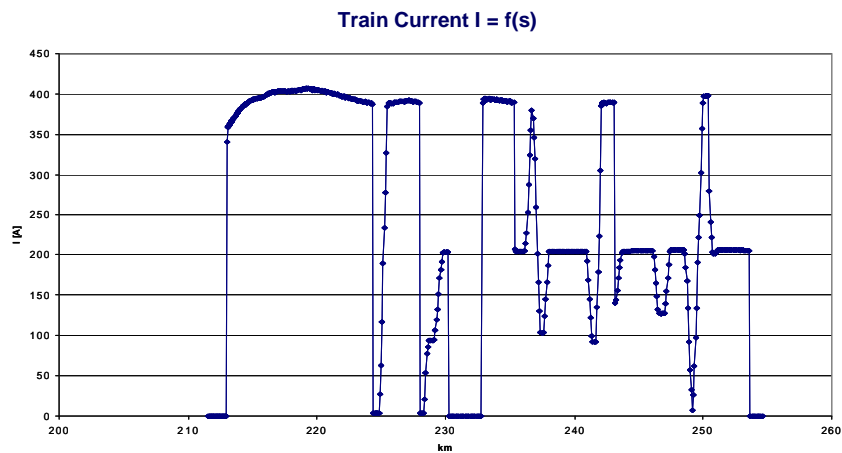
Meanwhile a lot of railway and tram operators use operation simulation tools like OpenTrack for planning and analysis tasks in their daily business. However the electrical network simulation is restricted to very special problem cases because of the extensive modelling effort. Besides mostly a department different from the operation planning team is responsible for the electrical issues. Applying conventional power supply network simulators in each case the railway operation simulation must be set up once again. Using OpenPowerNet the already existing railway operation models of OpenTrack as track alignment, signalling structure, train and engine library or time table can be easily adopted. The modelling process can be concentrated on the electrical issues exclusively. This saves time and costs.

### 4.2 Simulation Examples

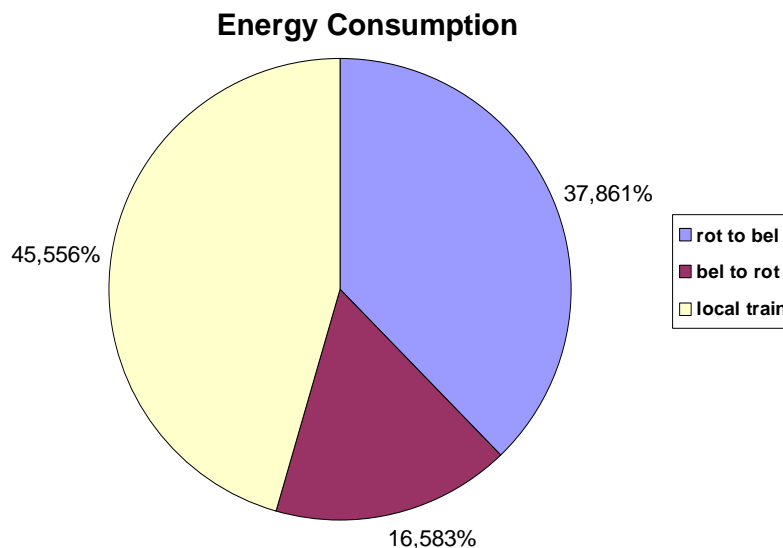
#### 4.2.1 High Speed Railways with AC Power Supply

On the new High Speed Line Zuid in the Netherlands the OpenPowerNet simulator is intended to apply for the commercial train energy billing of different train operators. Based on the present timetables and the used train types (Figure 4-1) the energy consumption of all trains including the electrical network losses is simulated and

partitioned to the train operating companies on substation level (Figure 4-2). The simulation results for the failure-free operation are the basis for the monthly energy cost accounting. Thus extensive measurements onboard the trains of different train operators and a voluminous data transfers is not necessary.



**Figure 4-1** Simulated current diagram of a high speed train on HSL Zuid (NL)



**Figure 4-2** Partition of the total energy consumption to different train groups

Currently for the new Chinese high speed line from Wuhan to Guangzhou with a length of approximately 1,000 km the rating of the entire power supply and return current system is examined with OpenPowerNet. For the regular daily operation with high speed and regional trains a minimum operating headway of 3 min is required. The enormous extent of the line and the densely operation program can be considered as a worst case for the capability of the simulation tools. Nevertheless OpenPowerNet was able to simulate the entire power supply network structure including the overhead catenary system of the line for a representative 2 hours peak operation phase. As results the following values and characteristics were obtained:

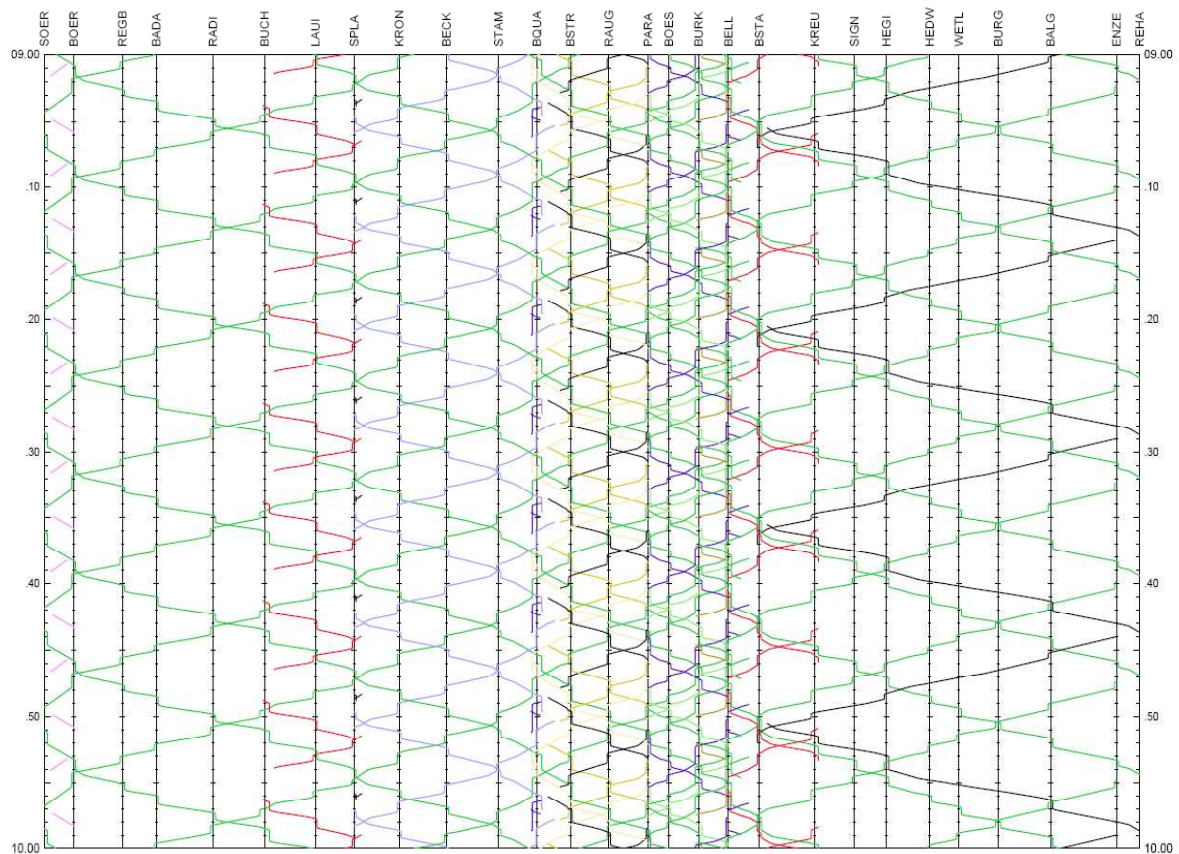
- train diagrams (speed profiles, graphical timetables),
- train current characteristics,
- minimum and maximum pantograph and overhead line voltages,
- contact wire and cable currents,
- transformer loads,
- power and energy consumption on substation and power grid level,
- total energy balance,
- efficiency characteristics including component-related power losses balance,
- rail-to-earth potentials.

#### 4.2.2 Tramway and Trolley Bus Networks with DC Power Supply

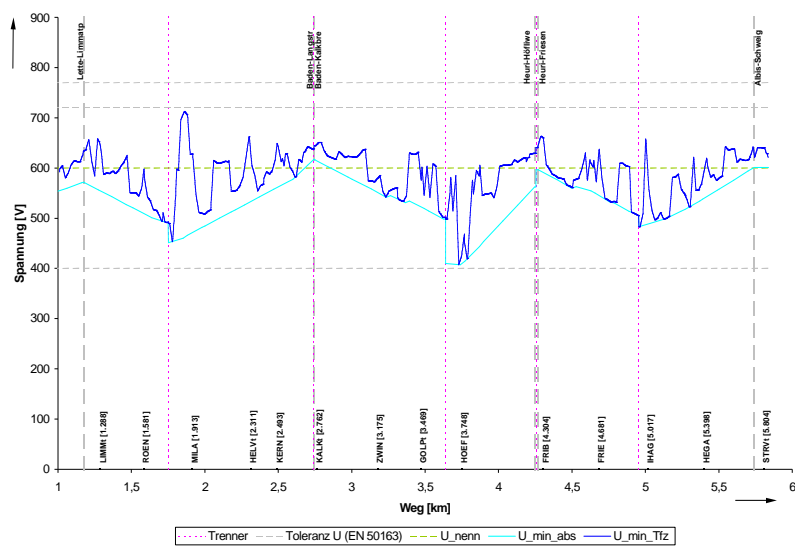
Recently the analysis and optimisation of the entire Zurich Tram and Trolley bus power supply network was successfully performed with OpenPowerNet. The purpose of this investigation was on the one hand a weak point analysis for the power supply system and then again a network optimisation study for future operation and rolling stock scenarios. Considering a Tram network length of approximately 300 km and an electrical connected Trolleybus network of 220 km length with more than 40 DC 0.6 kV substations in total also this application can be indicated as a worst case from the simulation point of view. However OpenTrack as well as OpenPowerNet were able to simulate the afternoon peak operation with 7.5 min headway on each line all at once without separating any parts of the operation or the electrical network. Due to the large network size the electrical simulation needs multiple real time. That's why the simulation duration should be restricted to the peak operation interval with the maximum load .

Considering the enormous amount of result data coming out of the simulation the post-processing (i.e. the creation of diagrams and statistics) had to be automated using the commercial MATLAB software. Respecting the investigation tasks with simulations of 4 future operation scenarios (2007, 2010, 2015, 2020) approximately 2,500 result diagrams were produced automatically only for the weak point analysis. The diagrams and tables from Figure 4-3 to Figure 4-8 show some selected result examples.

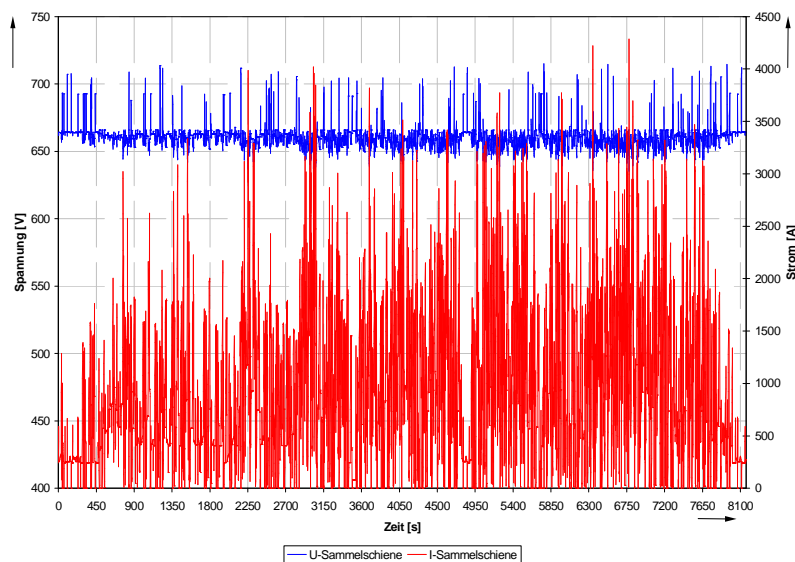
Line A



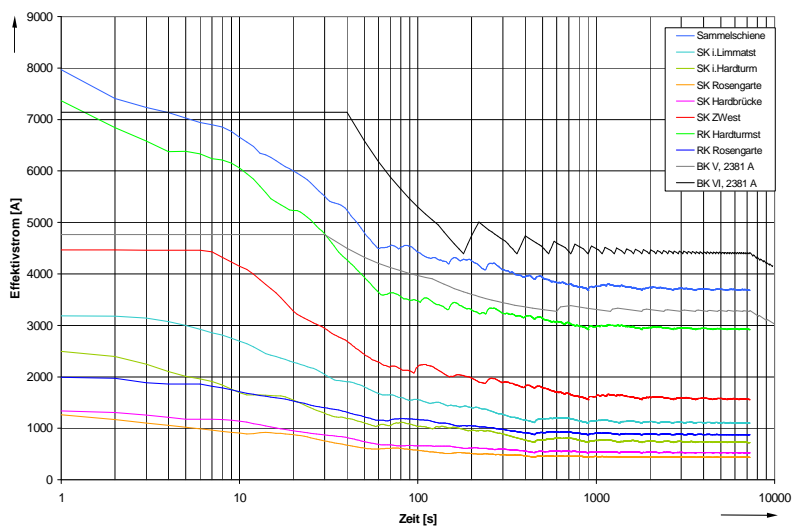
**Figure 4-3** Train graph (graphical timetable) of a Zurich tramway line



**Figure 4-4** Minimum pantograph and overhead line voltage level of all courses



**Figure 4-5** Converter current and substation busbar voltage during operation



**Figure 4-6** Substation load diagram and converter load capacity curves



Station	Sektor	$I_{max}$	$I_{eff}$	$P_{max}$	$E_{ab}$	$E_{auf}$	$E_{vert}$	$I_{Einst}$	$I_{Kmin}$	$I_{Kmin}/I_{Einst}$	$I_{max}/I_{Einst}$
		[A] 1 s	[A] 7200 s 2 h	[kW]	[kWh]	[kWh]	[kWh]	[kA]	[kA]	soll > 110%	soll < 90%
	SK	1915	588	1221	520	-10	4	3,5	14,0	400%	54,7%
	SK	1686	404	1072	264	0	2	3,0	11,7	390%	56,2%
	SK	1961	475	1252	417	0	3	3,0	10,4	347%	65,4%
	SK	1665	332	1048	257	0	4	3,5	10,4	297%	47,6%
	SK	<b>3710</b>	1018	2312	1000	-33	36	<b>4,2</b>	12,7	302%	<b>88,3%</b>
	SK	1128	310	720	290	0	1	3,0	34,0	1133%	37,6%
	SK	172	50	111	36	0	0	3,0	23,0	767%	5,7%
	SK	1145	316	738	220	0	1	3,0			38,2%
	SK	2824	1075	1770	1226	-6	18	3,5	16,6	474%	80,7%
	SK	912	279	582	153	-28	1	<b>2,5</b>	<b>2,7</b>	<b>108%</b>	36,5%
	RK	-1242	513	-749	0	-627	3				
	RK	-2164	678	-1324	2	-789	8				
	RK	-649	238	-393	0	-281	2				
	RK	-3425	1375	-2065	0	-1683	8				
	RK	-1742	657	-1050	0	-804	7				
	RK	-912	279	-582	28	-153	1				
	<b>gesamt</b>	<b>8773</b>	<b>3527</b>	<b>5289</b>	<b>4305</b>	<b>0</b>	<b>97</b>				

SK: Feeder cable  
RK: Return current cable

Figure 4-7 Cable load statistics and protection limits of a substation switchgear

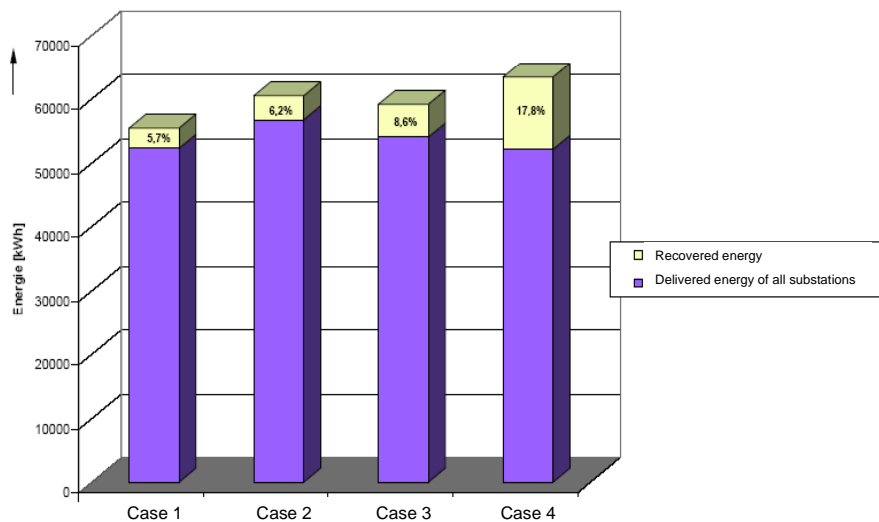


Figure 4-8 Total network energy balance for 2 hours peak operation

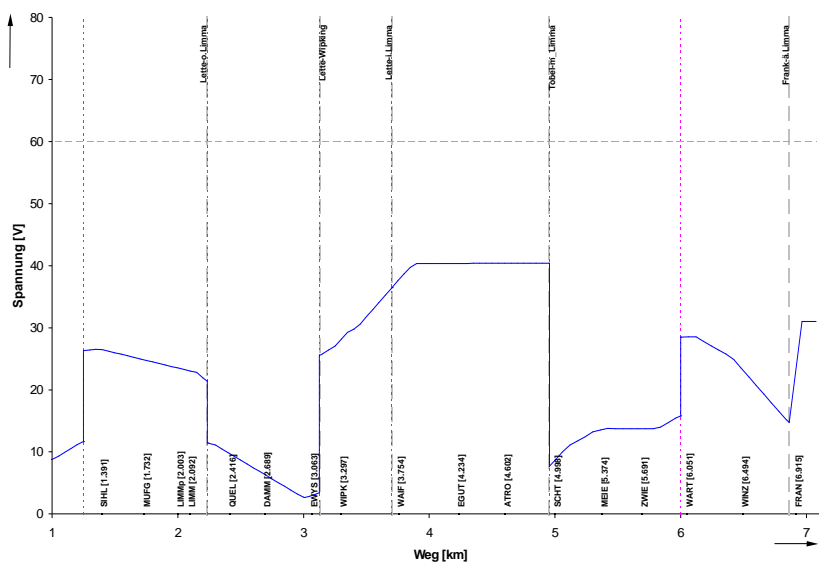


Figure 4-9 Rail-to-earth potential of a city tramway line during peak operation



## 5 Summary

In order to simulate railway power supply networks based on the operation program considering all infrastructural and rolling stock related impacts a new simulation tool called OpenPowerNet was developed by IFB. OpenPowerNet works together with the common Swiss railway operation simulator OpenTrack as a co-simulation. The tasks and properties of the simulation tools can be summarised as follows:

### Operation Simulation (OpenTrack)

- precise railway operation simulation as a commercial simulator,
- co-simulation with the electrical network calculation of OpenPowerNet,
- online-communication between operation and electrical network simulation via SOAP-Interface using the RailML data interchange format,
- retroaction of the electrical network conditions to the train driving dynamics within the railway operation simulation,
- automatic disturbance generating caused by the power supply.

### Load Flow and Energy Calculation (OpenPowerNet)

- complete electrical network calculation reflecting the network structure, the conductor properties and the electromagnetic coupling effects,
- input of the electrical network parameters by use of the geometrical conductor arrangement and the material properties with unrestricted configuration,
- switch status changes of the electrical network during the simulation,
- configurable modelling depth for the train propulsion system,
- comprehensive analysing and interpreting tools (energy, load flows, currents, voltages, temporal / local) as well as data export for post-processing.

The main advantage of this solution is the clear separation of the different simulations tasks. On the one hand this allows an independent development and maintenance strategy for both software tools respecting only the interface specification and on the other hand it decreases the modelling effort and the failure possibilities.

OpenPowerNet can be used for the entire spectrum of railway power supply systems from DC tramway networks up to AC powered high speed railways. By means of selected simulation results the capability of OpenPowerNet as a new OpenTrack family member could be demonstrated.

# OPENTRACK

## Simulation of Railway Networks

OpenTrack began a few years ago as a research project at the Swiss Federal Institute of Technology. The aim of the project, Object-Oriented Modeling in Railways, was to develop a user-friendly tool to answer questions about railway operations by simulation.

Figure 1 shows how the simulation tool works. Predefined trains run on a railway network according to the timetable. During the simulation, OpenTrack calculates train movements under the constraints of the timetable and the signaling system. After a simulation run, OpenTrack can analyze and display the resulting data in the form of diagrams, train graphs, occupation diagrams and statistics.

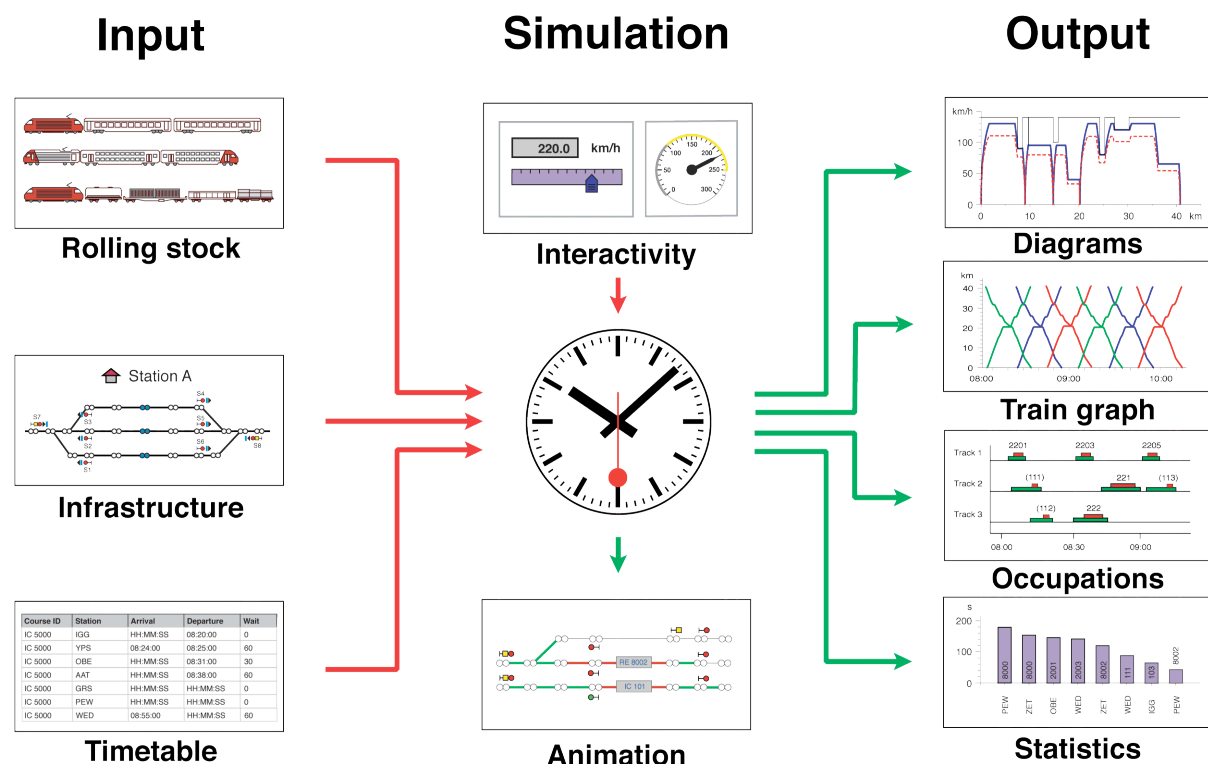


Figure 1: The modules of the simulation

## Rolling stock data

OpenTrack stores each locomotive's technical characteristics, including tractive effort/speed diagrams, load, length, and adhesion factor. A database organizes locomotives into groups called depots. A simulated train consists of one or more locomotives from a depot together with a number of passenger or freight cars (carriages or wagons). Another database can store the simulated train.

## Network data

OpenTrack describes a railway network in special graphs called double vertex graphs. A user can edit the network's topology graphically. Every element of the graph holds various attributes. An edge, for example, holds a track section's length, gradient, maximum speed for different train categories and much more. A user can create and manage objects for edges and vertices, and also signals, switches, stations and routes. Figure 2 shows an example for a station.

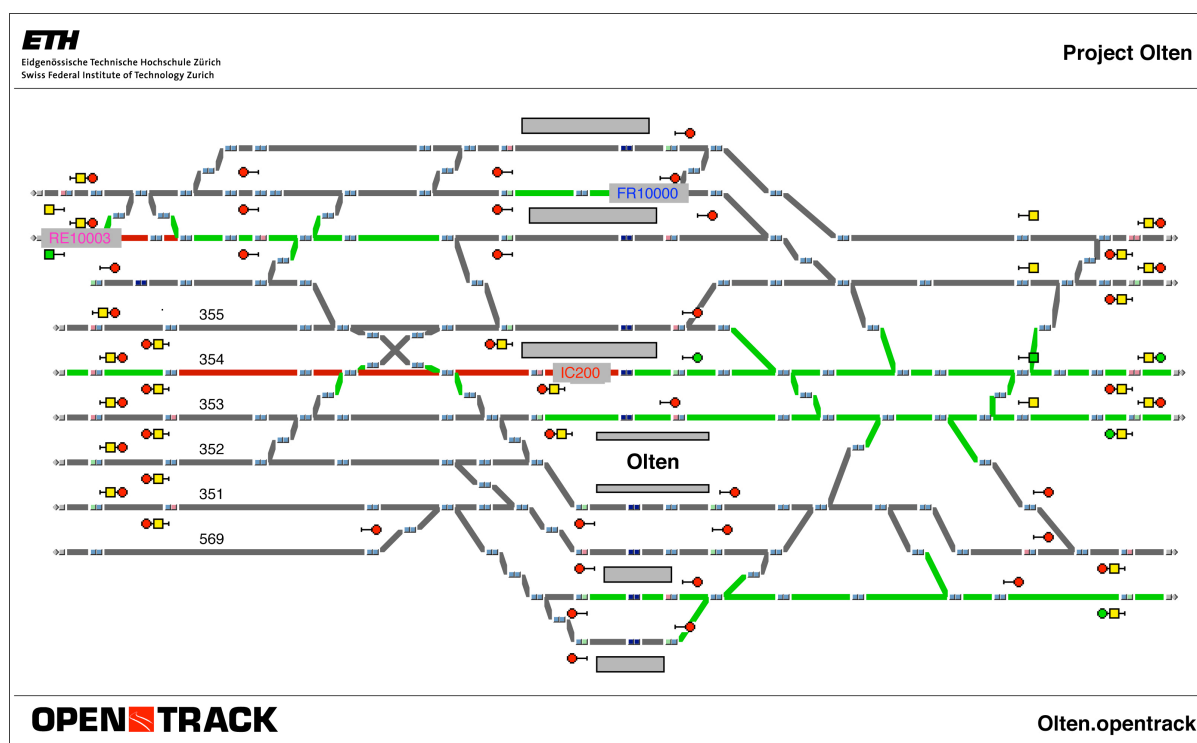


Figure 2: Layout of a station

## Timetable data

The timetable database stores information for each train at each station, including arrival and departure times, minimal stop time, and connections to other trains.

## Simulation

During a simulation, trains try to obey the given timetable. The differential equations for speed and distance are the basis for calculating a train's movement. The signaling system of the railway network poses constraints. Occupied tracks and restrictive signal aspects may impede a train's progress.

During the simulation, every train continuously stores its speed, acceleration, position, power consumption and other data. This data can be evaluated after the simulation as shown in Figures 3 to 7.

The user can watch the simulation in an animation mode, which shows the trains running and lets the user analyze occupied tracks, reserved tracks and signal aspects.

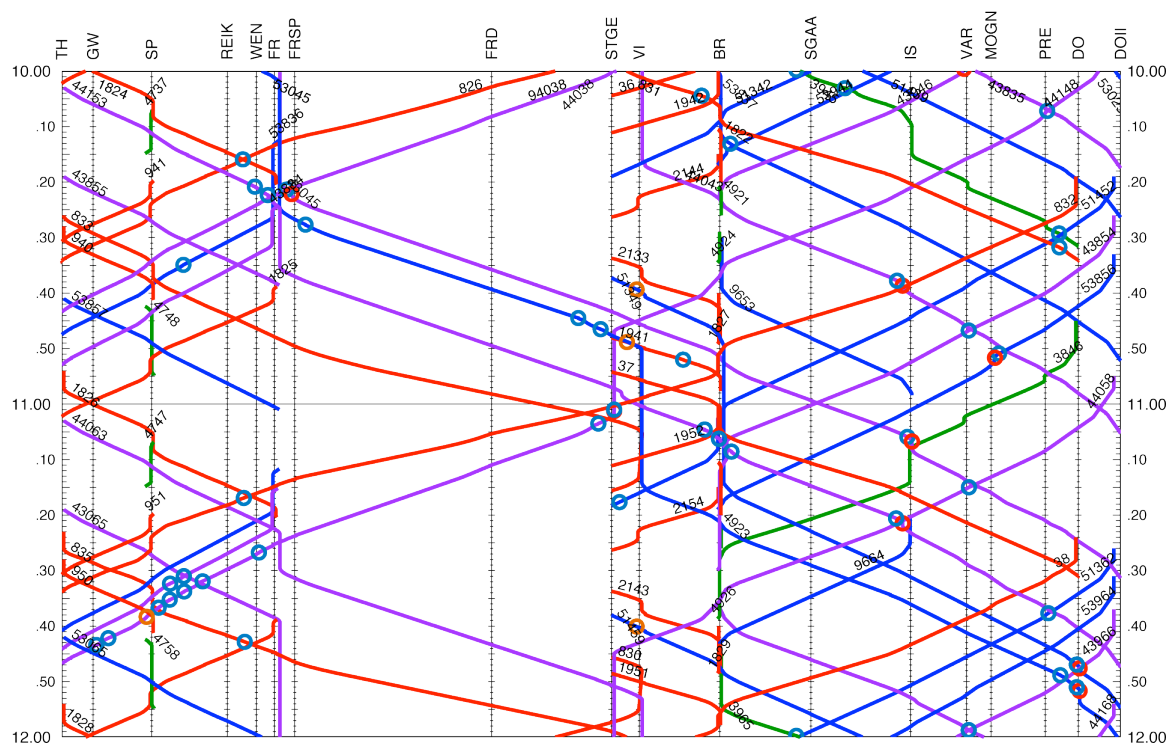


Figure 3: Train graph (train diagram)

## Output data

After a simulation, OpenTrack offers output data in a number of forms. Evaluations of a train, line or station are possible. For a train, OpenTrack offers diagrams such as acceleration vs. distance, speed vs. distance (Figure 4), and obstructions. For a line, there are evaluations in the form of diagrams of train movements (Figure 3), track occupation (Figure 5) and line profiles. Every station produces output about all the trains that used it, including arrival, stopping and departure times.

The user can view output data in either a diagram or an Excel table, or export it as a readable ASCII table.

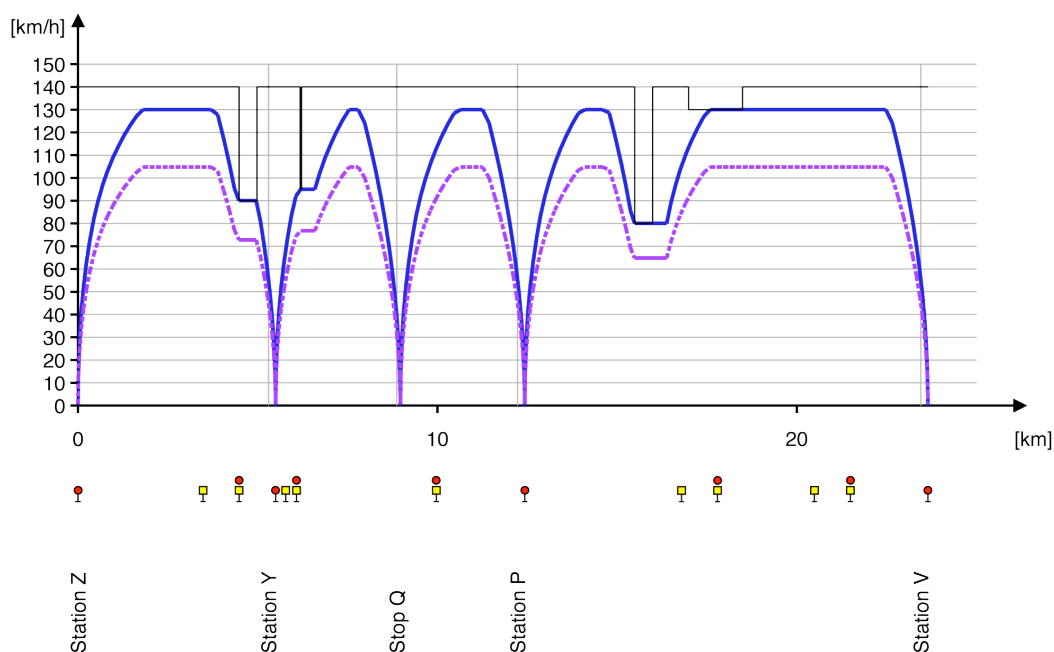


Figure 4: Speed/distance diagram

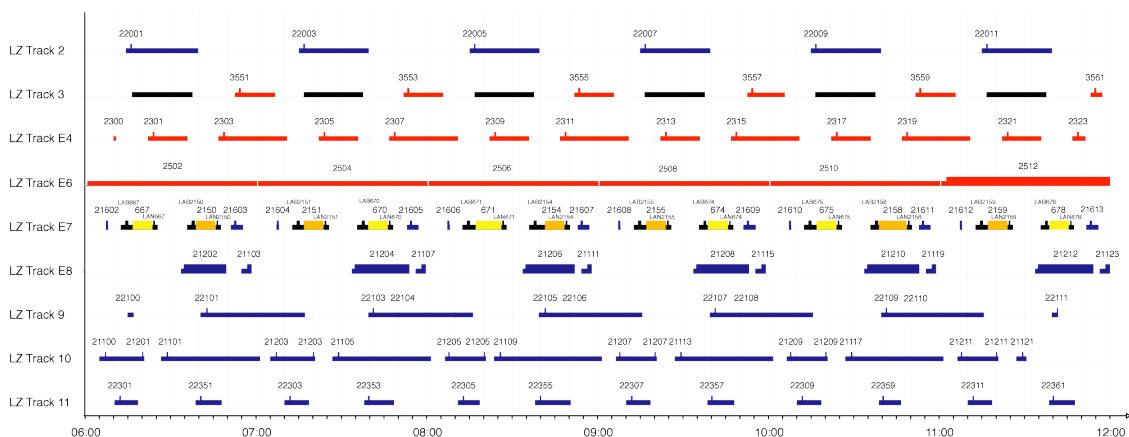


Figure 5: Occupation of selected platform tracks

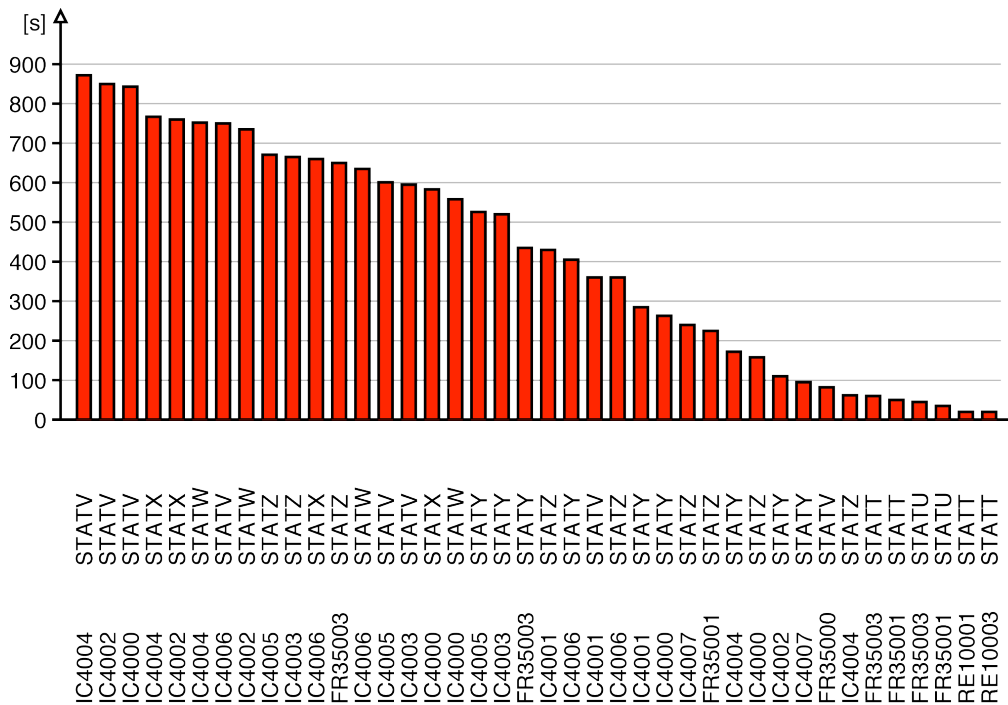


Figure 6: Delay statistics

OT\_TimetableStatistics.bt - Excel

Course	Station	Arr. Planned [HH:MM:SS]	Dep. Planned [HH:MM:SS]	Arr. Actual [HH:MM:SS]	Dep. Actual [HH:MM:SS]	Arr. Del. [s]	Dept. Del. [s]
18021	ZMUS	07:04:00	07:05:20	HH:MM:SS	07:07:00	0	100
18021	ZMUO	HH:MM:SS	HH:MM:SS	HH:MM:SS	07:07:26	0	0
18021	ZSTH	07:09:00	07:10:30	07:09:04	07:10:30	4	0
18021	ZHOT	HH:MM:SS	HH:MM:SS	HH:MM:SS	07:11:40	0	0
18021	STET	07:14:00	07:14:00	HH:MM:SS	07:13:52	0	-8
18021	NGUT	HH:MM:SS	HH:MM:SS	HH:MM:SS	07:14:20	0	0
18021	CHRI	HH:MM:SS	HH:MM:SS	HH:MM:SS	07:14:50	0	0
18021	DUE	HH:MM:SS	HH:MM:SS	HH:MM:SS	07:15:22	0	0
18021	SCWE	HH:MM:SS	HH:MM:SS	HH:MM:SS	07:16:56	0	0
18021	NAEN	HH:MM:SS	HH:MM:SS	HH:MM:SS	07:18:16	0	0
18021	UST	07:21:00	HH:MM:SS	07:20:26	HH:MM:SS	-34	0
18022	UST	HH:MM:SS	07:37:20	HH:MM:SS	07:39:00	0	100
18022	NAEN	HH:MM:SS	HH:MM:SS	HH:MM:SS	07:40:46	0	0
18022	SCWE	HH:MM:SS	HH:MM:SS	HH:MM:SS	07:42:06	0	0

Figure 7: All outputs can be viewed in Excel

## The OpenTrack application

The OpenTrack application is available for the following operating systems: *Windows* (7, 8, 10) and *macOS*.

The application is available in two versions. The full version of OpenTrack offers an unlimited number of running trains per simulation. The limit of the OpenTrack Light version is two trains per simulation.

Figure 8 shows an example of the application during a simulation run. OpenTrack animates the running trains on the screen.

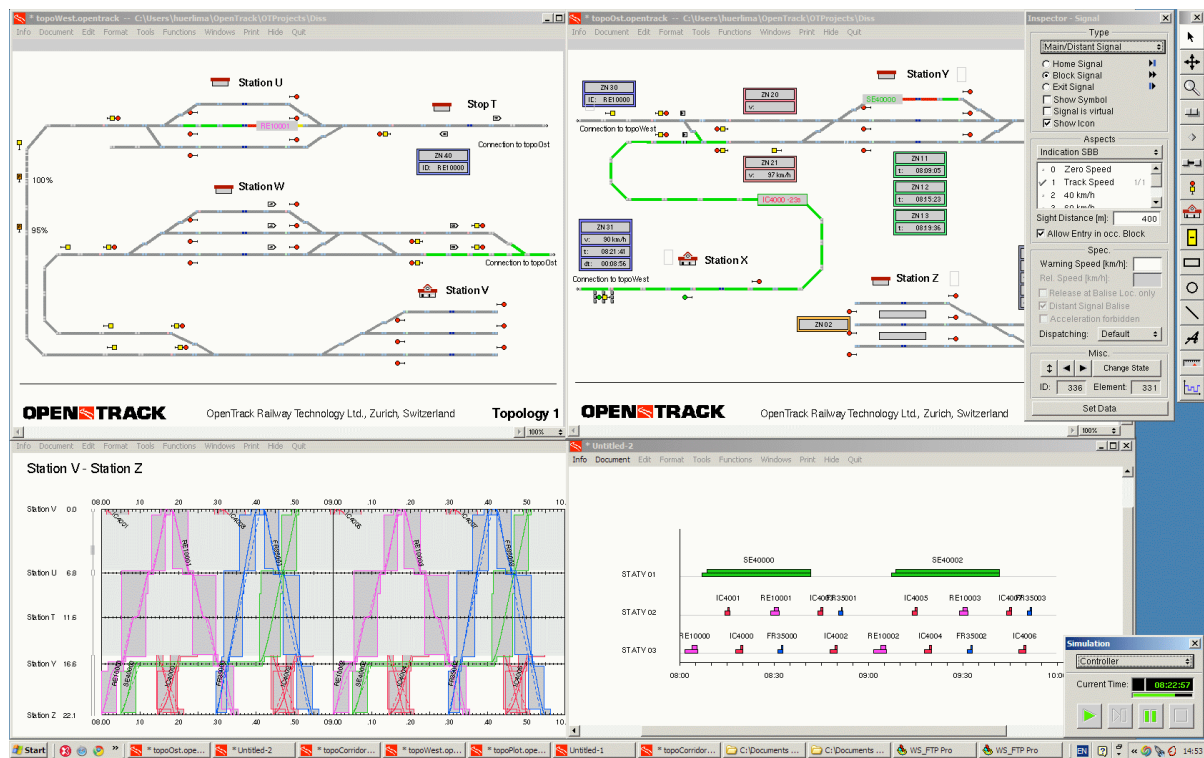


Figure 8: Screenshot (OpenTrack for Windows)

## For more information

For more information, please contact:

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 WWW: <http://www.opentrack.ch>

IFB Institut für Bahntechnik GmbH  
Niederlassung Dresden  
Wiener Str. 114-116  
D-01219 Dresden

Zürich, 27. August 2010/IPE

## **Bestätigung der Ergebnisse zur Vergleichsmessung mit der OpenPowerNet Simulation**

Sehr geehrte Damen und Herren

Im Rahmen der Netzstudie für die Verkehrsbetriebe Zürich (VBZ) wurde die Überprüfung der Simulationssoftware OpenPowerNet vereinbart. Ziel der Überprüfung war es, aufgrund von Vergleichsmessfahrten die von der Simulationssoftware OpenPowerNet erzeugten Ergebnisse auf deren Korrektheit hin zu untersuchen.

Hierzu wurden drei verschiedene Streckenabschnitte und eine Fahrzeugbauart von den VBZ bestimmt. Diese wurden am Institut für Bahntechnik GmbH (IFB) in Simulationssoftware OpenPowerNet modelliert und anhand mehrerer typischen Fahrspiele berechnet. Die vom IfB berechneten Fahrspiele bildeten das Fahrprogramm, welches als Basis für die am 21.11.2007 von den VBZ durchgeführten Messfahrten diente.

Ein Vergleich der Kennlinien aus den Messfahrten mit denen aus den Simulationen hat ergeben, dass die Effektivwerte der Fahrzeugströme um maximal 6 % abweichen. Dabei ist zu bemerken, dass die während der Messfahrten schwankende Hilfsbetriebe- und Heizungsleistung des Fahrzeugs in der Simulation durch einen konstanten Wert abgebildet wird. Zudem liessen sich aufgrund von Kraftschlussproblemen nicht alle Messfahrten exakt nach den Vorgaben der Simulation nachfahren.

Bei der minimalen Spannung am Stromabnehmer ergibt sich in den charakteristischen Fahrspielabschnitten (Fahrzeug mit hohem Leistungsbezug) eine ähnliche Übereinstimmung. Die Mess- und Simulationskurven liegen bei identischer Stromaufnahme nahezu übereinander. Die Abweichungen liegen stets im Bereich < 5 %. Dies deutet auf die kor-



rekte Hinterlegung des elektrischen Netzmodells hin; die vertraglich geforderten Genauigkeitsanforderungen sind somit erfüllt.

Bei Bremsvorgängen sind Abweichungen zu verzeichnen, die sich jedoch mit den angesetzten Randbedingungen der Simulation erklären lassen. Während die Fahrzeugsteuerung die Bremsspannung am Stromabnehmer (aufgrund vorhandener Abnehmer im Netz oder an Bord) immer auf 720 V aufregelt, stellt das Fahrzeugmodell beim Bremsen ohne externe Abnehmer die Spannung auf die Leerlaufspannung des Netzes ein. Energetisch ist dieser Prozess jedoch bedeutungslos, da die dabei im Netz fließenden Ströme entweder nahe oder vollständig Null sind.

Aufgrund der erfolgreichen Überprüfung wurde OpenPowerNet als Simulationssoftware für die durchgeführte Netzstudie von den VBZ zugelassen und somit werden die berechneten Ergebnisse anerkannt.

Freundliche Grüße



David Borschberg  
Leiter Projektierung Bauten

# **VBZ (Zurich Public Transport) reference letter translation**

IFB Institut für Bahntechnik GmbH  
Branch Office Dresden  
Wiener Str. 114-116  
D-01219 Dresden

Zurich, August 27<sup>th</sup> 2010

## **Confirmation of the OpenPowerNet Simulation Results compared to Measurements**

To whom it may concern,

As part of the network study for the Zurich Public Transport (VBZ) a validation of the simulation software OpenPowerNet were agreed. The aim of the validation was to check the OpenPowerNet simulation results against measurements.

Three different line sections and one vehicle type was selected by VBZ. The IFB (Railway Technology Institute) modelled the electrical network as well as the vehicle and simulated typical driving characteristics. The simulated driving characteristics were the basis of the measurements by the VBZ on November 21<sup>st</sup> 2007.

Vehicle pantograph RMS currents of the measurement and simulation were compared and the maximum deviation was approximately 6%. For the comparisons it is to make the point that the auxiliary power during the measurement was not constant due to changing auxiliary and heating power but the simulation vehicle was modelled with a constant power. Furthermore due to friction problems it was not possible to drive exactly according to the driving characteristic of the simulation.

For the typical driving characteristic (vehicle with high power demand) the minimum pantograph voltage has congruence. During periods with identical currents the measurement and simulation charts almost the same. The deviation between both is always < 5%. This means the electrical network model is correct and in accordance with the agreed tolerance.

There are deviations during braking due to simulation constraints. While the vehicle control system always sets the pantograph voltage to 720V (due to other power consumer in the network or onboard) were the line voltage in the simulation set to nominal voltage because of none existing other power consumers. From the energetic point of view this is irrelevant due to network currents almost or completely zero.

Due to the successful validation the simulation software OpenPowerNet was qualified by VBZ for the network study and the simulation results accepted.

Best Regards

David Borschberg  
Head of Project Planning Buildings

# Queensland Rail purchases power supply performance tool

**Australian railway simulation software reseller, Plateway, has entered into an agreement to supply Queensland Rail with a power supply performance tool.**

Have your say | Add Comment



Courtesy Plateway

Queensland Rail controls some 400 route kilometres of electrified track in the Brisbane suburban area and were seeking software that would simulate the traction power supply required to successfully operate their existing and proposed timetables.

According to Plateway managing director Phillip Imrie, the technical task of simulating the traction power supply performance is a difficult challenge as a result of the large number of variables impacting the operation of the railway power supply system.

“These variables include differences in power requirements of individual trains, train driving styles, train position on the network, as well as the switching configuration and physical parameters of the overhead traction system,” Imrie said.

Plateway and Queensland Rail undertook extensive trials in developing a proof of concept for the product. Imrie said the trials were arguably the most extensive calibration and verification exercise undertaken between a power supply simulation and measured system performance of a rail network.

The trial measured the actual power supply performance of single trains and the energy consumption on Queensland Rail’s Cleveland Line during five days of peak hour operation.

“These actual measurements were found to closely align with the accuracy of an equivalent simulation,” he said.

The software tool, known as OpenPowerNet, was developed by the Institute for Railway Technology, Dresden (IFB Dresden) in Germany. It has been brought to Australia as a value-add to the highly successful infrastructure and network performance simulation software package OpenTrack.

“We have been marketing OpenTrack in Australia for some years now and have been impressed by its ability to faithfully represent the operating railway,” Imrie said.

"OpenPowerNet allows us to now test power supplies to the railway as part of a co-simulation exercise and will allow users to accurately assess the potential of their existing and proposed infrastructure."

Germany's IFB Dresden wished to create a plug-in simulation module using the advantages of an existing commercial railway operation simulator. OpenTrack was chosen as the ideal tool due to its excellent capability and relative ease of use.

OpenTrack deals with the rail network simulation under normal and disturbed timetable situations using the infrastructure and train data. In a synchronised simulation, OpenPowerNet can present an energy prognosis of the entire electrified railway taking into account engine and train power consumption and location within the network.

OpenPowerNet is already used in Europe and China for the simulation of both AC and DC railway traction systems and is considered one of the most advanced software tools for this purpose on the market.

On the new Netherlands high speed Line Zuid, it is used for the commercial train energy billing of different train operators. For Chinese high speed lines, it has been used to test the rating of the current return system. The analysis and optimisation of the Zurich Tram and Trolley bus power supply network is also done using OpenPowerNet.

The tool has been purchased by Queensland Rail to allow proof of new design concepts, analysis of their existing system performance, and to improve their investment decision making.

A full technical paper on OpenPowernet has been submitted for inclusion in AusRAIL 2012, to be held in Canberra in November.

18 April 2012

Mr Phillip Imrie  
Plateway Pty Ltd  
Unit 6, 3 Sutherland St  
Clyde NSW 2141

Dear Phillip,

**Power Systems Capacity Planning Project  
CONTRACT NO. AT.2486**

The purpose of this letter is to confirm the successful completion of the Proof of Concept exercise as of 30 March 2012, and advise Queensland Rail Limited's acceptance to enter into contract for the provision of the Power Systems Capacity Planning Project as outlined in Plateway's revised offer dated 21 September 2011.

Plateway Pty Ltd will be provided Contract Documents (in duplicate) for execution where flagged.

Any questions or concerns please do not hesitate to contact the individual listed below.

Kind Regards,



**Owen Moir**  
Buyer  
Queensland Rail Limited

# Queensland Rail's proof of concept for OpenPowerNet

Trevor Bagnall, Brisbane; Ian Imrie, Sydney; Martin Jacob, Dresden

Queensland Rail is the Brisbane City network operator and conducted a prove of concept for the railway power supply simulation tool OpenPowerNet. OpenPowerNet runs in co-simulation with the railway operation simulator OpenTrack. The average total energy consumption deviation was with 6.1% well in the accepted range and made Queensland Rail confident to order multiple licenses of the simulation tools.

## QUEENSLAND RAIL – MACHBARKEITSSTUDIE FÜR OpenPowerNet

Queensland Rail veranlasste eine Machbarkeitsstudie für das Simulationsprogramm OpenPowerNet zur Bahnenergieversorgungsberechnung. OpenPowerNet läuft in einer Co-Simulation mit dem Betriebssimulator OpenTrack. Die Abweichung des durchschnittlichen Energieverbrauchs war mit 6,1% deutlich im akzeptierten Bereich und veranlasste Queensland Rail mehrere Lizenzen der Simulationsprogramme zu bestellen.

## ETUDE DE FAISABILITÉ DE QUEENSLAND RAIL POUR OpenPowerNet

Queensland Rail, l'opérateur du réseau ferré à Brisbane, a mené une étude de faisabilité pour le programme de simulation OpenPowerNet qui calcule l'alimentation électrique du réseau. OpenPowerNet fonctionne en co-simulation avec le simulateur d'exploitation OpenTrack. Avec 6,1%, l'écart avec la consommation d'énergie moyenne était dans la fourchette acceptable. Ce résultat qui a incité Queensland Rail à commander plusieurs licences des programmes de simulation.

## 1 Queensland Rail

In 1976, construction commenced on an ambitious 25kV AC system which would eventually provide electric suburban, interurban and freight services over the most extensive electrified system in Australia.

The first electric trains operated from Mitchelton to Darra in 1979. From this first service the system has been expanded with extensions and new lines to the network that exists today.

Today, Queensland Rail operates 201 3 car Electric Multiple Unit train sets on the City network, see Figure 1. The network covers the Brisbane suburban area with 145 stations. Services transported 55 million passengers in the 2010/2011 fiscal year.

The City network is radial. Through services from the North operate via the city centre to the Western, Southern and South Eastern suburbs and vice versa. The major stabling centre for City network services is on the northern city centre periphery at Mayne with limited outlying stabling areas towards the network extremities.

way Technology Dresden (IFB Dresden) to simulate rail network performance in conjunction with the OpenTrack [2] rail network simulator developed by OpenTrack Technology GmbH of Zurich Switzerland. Plateway Pty. Limited is the Australasian distributor of both products.

The operational simulation is done by OpenTrack in co-simulation with OpenPowerNet. OpenPowerNet has a retroactive effect to OpenTrack, see Figure 2.

OpenPowerNet is designed to calculate:

- electrical load flow of DC, 1 AC and 2 AC railway power supply systems
- electromagnetic coupling due to conductor arrangement and current [3]
- energy balance considering recovery and station as well as vehicle energy storages
- load analysis of equipment
- touch voltage
- electromagnetic field
- short circuit currents

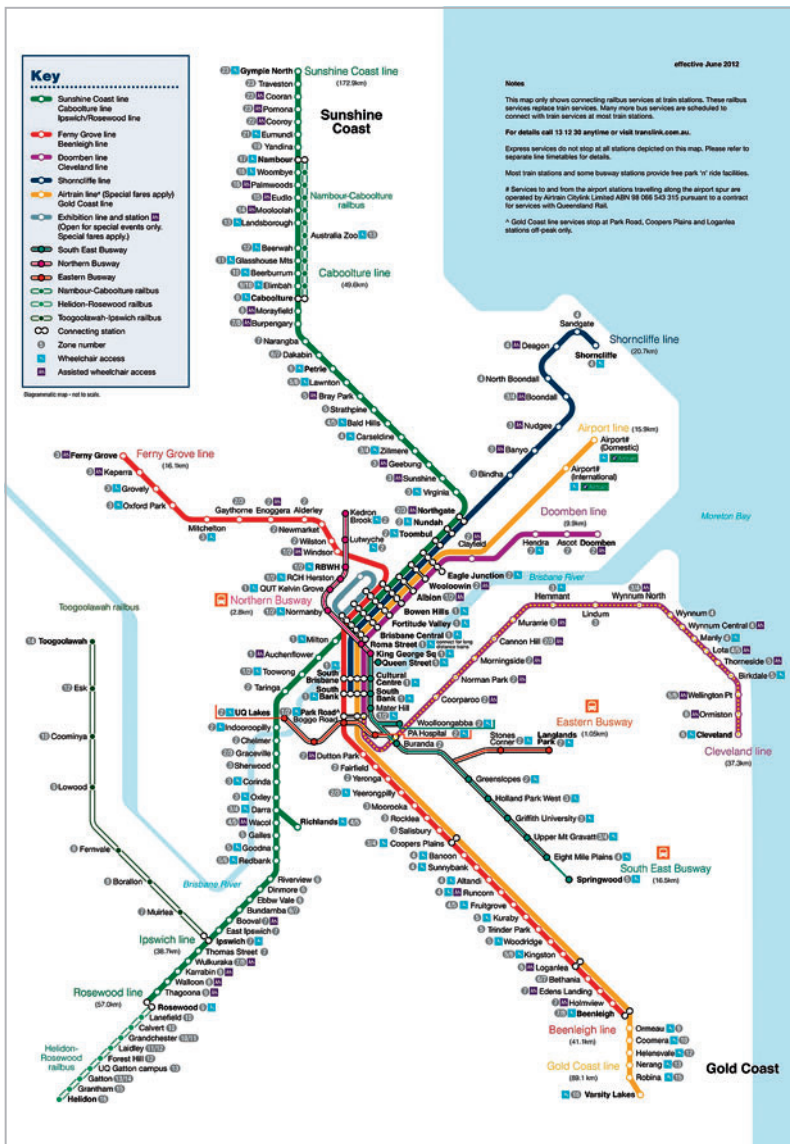
## 2 The simulation tool OpenPowerNet

The power supply performance software tool OpenPowerNet [1] was developed by the Institute for Rail-

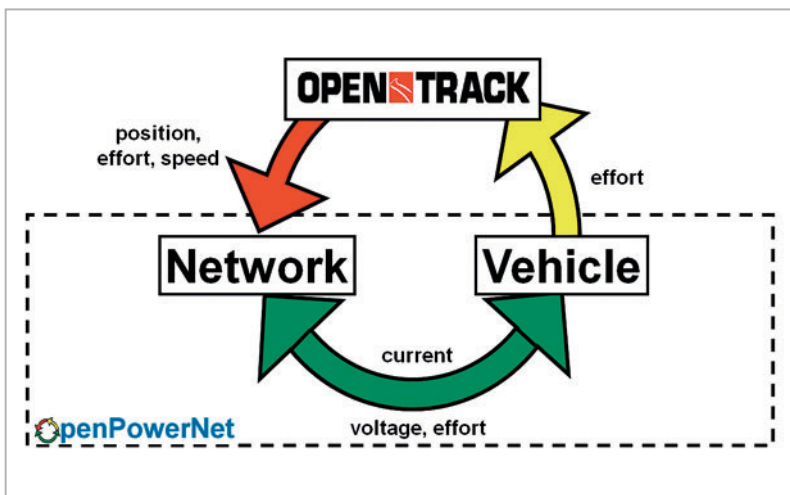
## 3 Proof of Concept Setup

The proof of concept was designed to validate the simulation software OpenPowerNet and to verify the model configuration. The test was conducted in close cooperation between Queensland Rail pro-





**Figure 1:** Queensland Rail City network with Cleveland line, the simulation scope is marked with a yellow dotted line [4].



**Figure 2:** The co-simulation of OpenTrack and OpenPowerNet.

viding input data and measurements, Plateway Ltd. creating the OpenTrack model and IFB Dresden preparing the OpenPowerNet model.

In the first step, the model would be verified by comparing single train runs to the simulation. A single train run has the advantage to have well defined and known measurement conditions.

The second step was to compare the measured energy consumption for 5 consecutive days of a 4 h morning peak period with the simulation. The pass fail criteria were defined by Queensland Rail as a maximum 10% deviation between measurement and simulation. The simulation should be performed not knowing the measurements to have an impartial evaluation.

The Cleveland line was chosen, as this line is typical for Brisbane's commuter network. The test section was from Park Road to Cleveland. The line is feed from Lytton Junction transformer station. The station has two transformers, each feeding in separate directions, see Figure 3.

The traction power supply system is 1AC 25kV 50Hz utilising 18 booster transformers to reduce stray currents. The total line length is 32km with a 19km double track section and an 11 km single track section.

## 4 Modelling

The first step was to assess the existing data and to compare this data as far as possible with the installation on site. For instance the existence and location of all booster transformers, connections from return wire to rails, signal locations and speed indicators.

After assessment the modelling was straight forward using the following main input parameter:

- track gradients, curves, line speed limit
- turnout location
- stations and platform
- traction effort
- maximum deceleration
- vehicle mass, length
- auxiliary power
- vehicle efficiency of the traction power system
- traction power and booster transformers
- resistance and cross section configuration layout of all conductors

The vehicle mass was considered particularly as the passenger load changes from station to station. Evaluation of the ridership proved a steady weight of passenger rise from Cleveland to Park Road, see Figure 4. This was modelled by trains having different payload. As the current OpenTrack version allows to change the payload at each station it would have been easier today.

As the timetable has a time reserve, especially at the single track section, this needed to be considered. An overall performance factor of 90% and a separate performance factor of 80% at the single line section considered the time reserve. The performance factor reduces the utilised traction power and maximum travel speed.

The modelling of the timetable includes 42 courses for each 4 h morning peak. As Queensland Rail has seven different vehicle types and the type allocation to courses varies every day it was necessary to prepare a separate timetable for each day.

## 5 Calibration

The calibration run took place early morning January 30<sup>th</sup> and January 31<sup>st</sup> 2012. The runs included express runs and all stations runs according to the timetable. Acceleration runs at both ends of the test section on both tracks were also carried out. All measurements were compared to simulations. Comparing the voltage drop during acceleration at the end of the lines allowed the verification of the electrical network model.

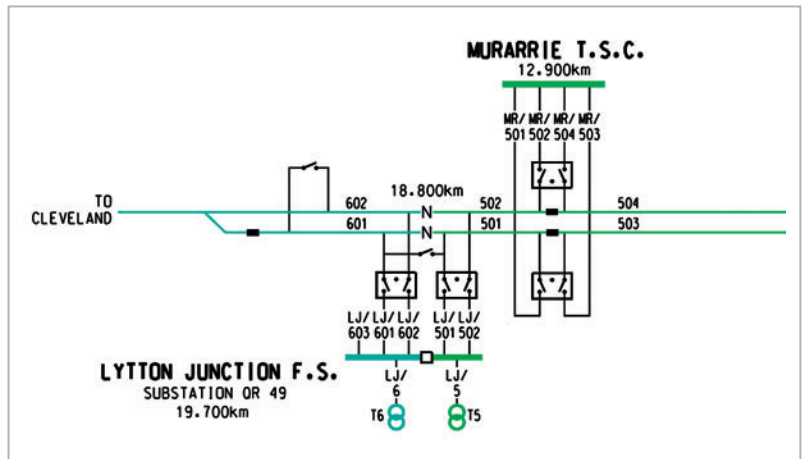
The measurements at the train were the basis to verify the total efficiency, maximum acceleration and auxiliary power consumption of the train. This was an important step as the existing vehicle data has been not very detailed. Figure 5 shows the very good congruence of the measured and simulated values. It also shows the significant influence of the driving behaviour as the congruence is only good where the measured and simulated speed respective acceleration is the same.

## 6 Simulation and results

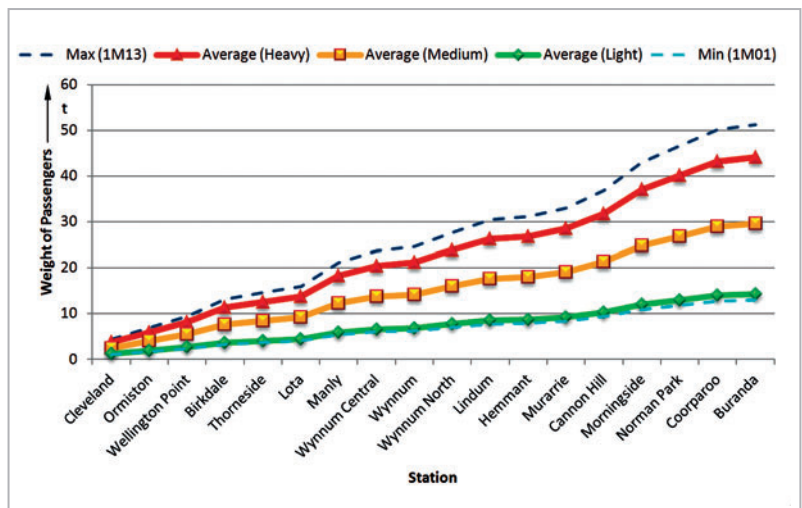
A simulation per day was done in about one hour plus half hour to run the automatic analysis. The consideration of timetable reserve and used performance factor gives a good congruence between planned and simulated timetable, see Figure 6.

Beside the consumed energy a number of other simulation results are available. These are minimum pantograph voltage, traction and booster transformer load, feeder load etc., see Figure 7 to Figure 10.

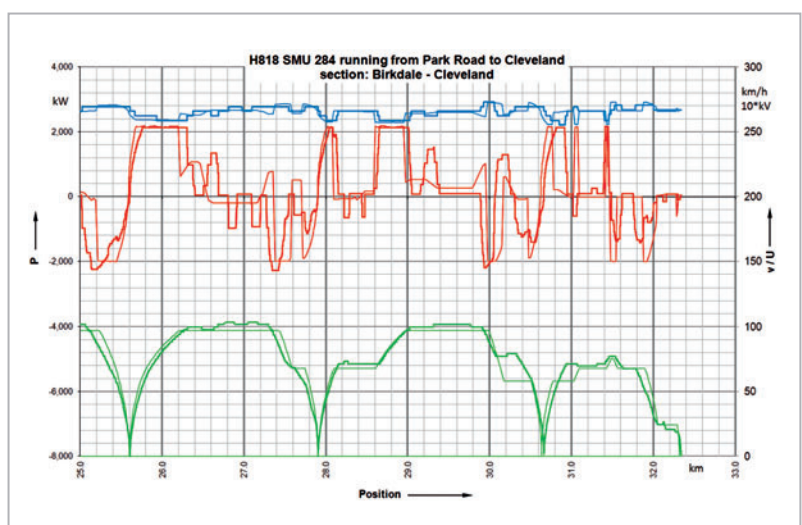
The total energy consumption per day has been presented to Queensland Rail and compared to the measurements. These results showed that OpenPowerNet was able to simulate the actual energy consumption within the required accuracy of 10% for the 5 day average as well as for each individual day, see Figure 11.



**Figure 3:**  
Cleveland Line sectioning diagram.



**Figure 4:**  
Cumulative passenger weight of the Cleveland line.



**Figure 5:**  
Calibration run H818 from Park Road to Cleveland at section from Manly to Cleveland.  
thick curves measurements red electrical power  
thin curves simulation green speed  
blue voltage



**Figure 6:**

The Tuesday morning peak timetable.

dashed planned time

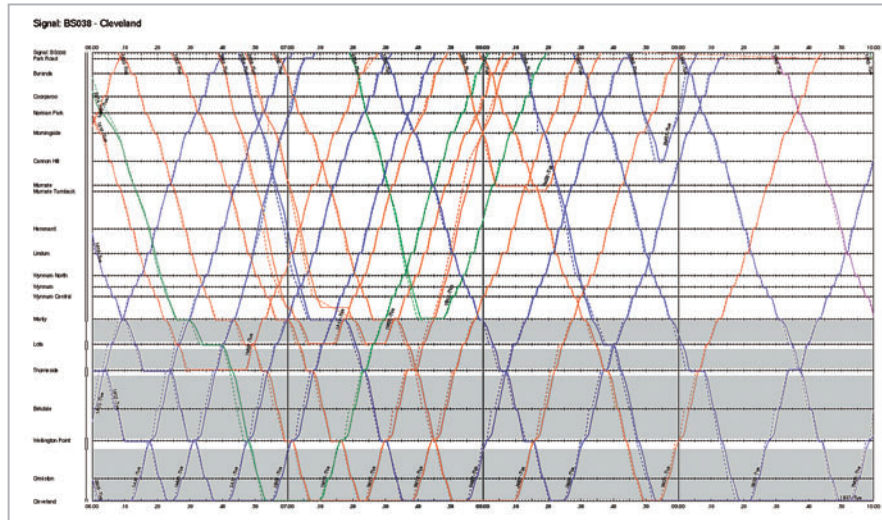
solid simulated time

green 6 Car EMU 6 motor (no recovery)

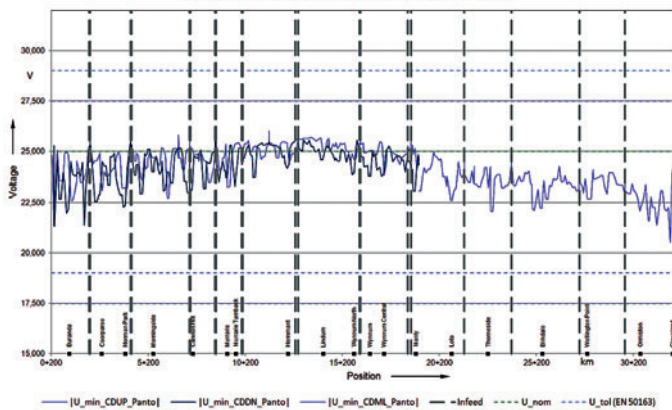
orange 6 Car EMU 8 motor (no recovery)

blue 6 Car SMU/IMU (with recovery)

pink 6 Car Hybrid EMU 6 & 8 motor (no recovery)



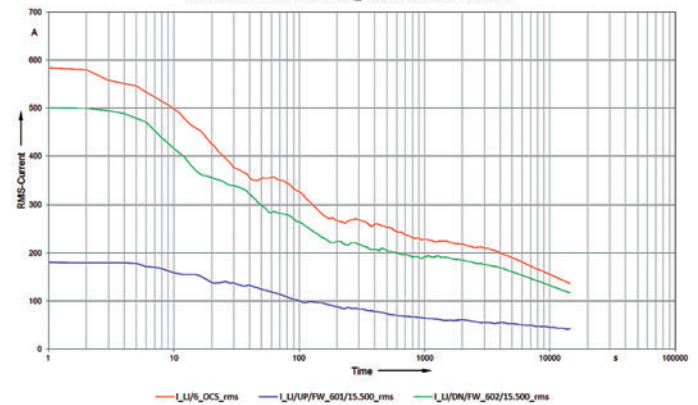
Pantograph Voltage, QR POC, tuesday peak  
Line Cleveland, km 0+200 to 32+400, 06:00:00.0 - 10:00:00.0



**Figure 7:**

Minimum pantograph voltage of the Tuesday morning peak from 6 am to 10 am at the Cleveland line.

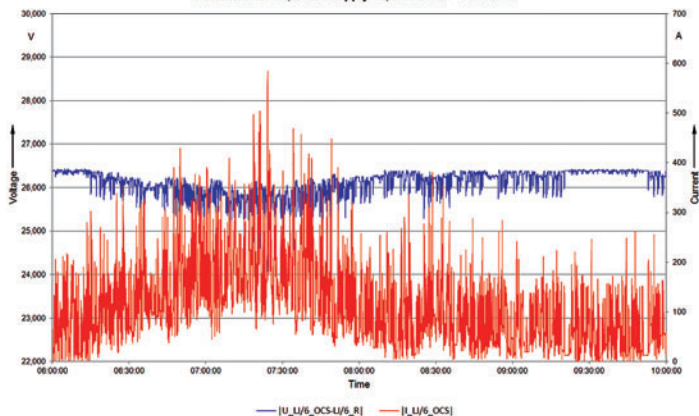
Busbar and Feeder Load, QR POC, tuesday peak  
Substation LJ FS, Busbar LJ6\_OCS, 06:00:00.0 - 10:00:00.0



**Figure 8:**

Busbar and feeder load of the Lytton Junction substation as time rated load periods curve.

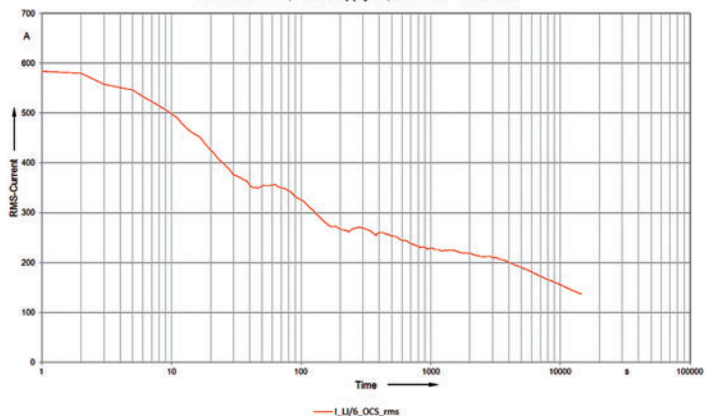
Busbar Voltage and Current, QR POC, tuesday peak  
Substation LJ FS, PowerSupply T6, 06:00:00.0 - 10:00:00.0



**Figure 9:**

The busbar voltage and current versus time of the Lytton Junction substation.

Busbar Load, QR POC, tuesday peak  
Substation LJ FS, PowerSupply T6, 06:00:00.0 - 10:00:00.0



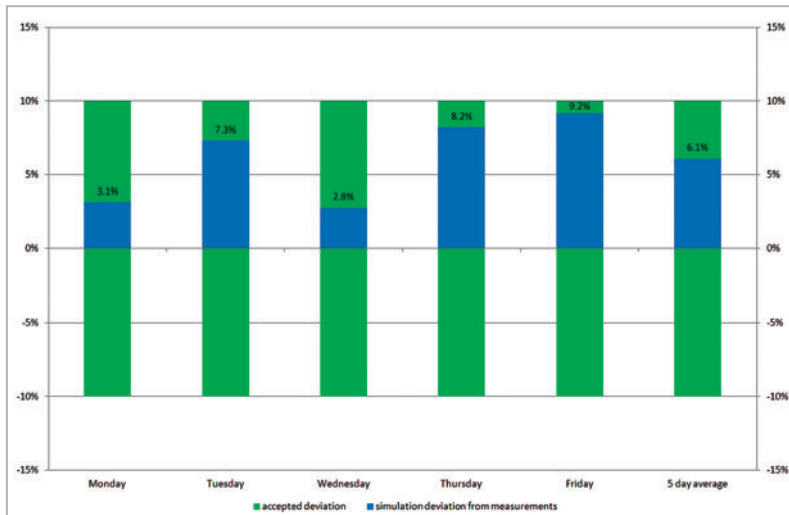
**Figure 10:**

The busbar current of the Lytton Junction feeder as time rated load periods curve.

After cross checking the measurements to the simulation a glitch in the model could be detected. It was then obvious that the auxiliary power consumption of the courses waiting at the terminus in Cleveland has been much lower than expected. According to the timetable there is always one train stabling in Cleveland. Additional simulations considered this effect and result in an even better congruence between the measurements and the simulations, see Figure 12.

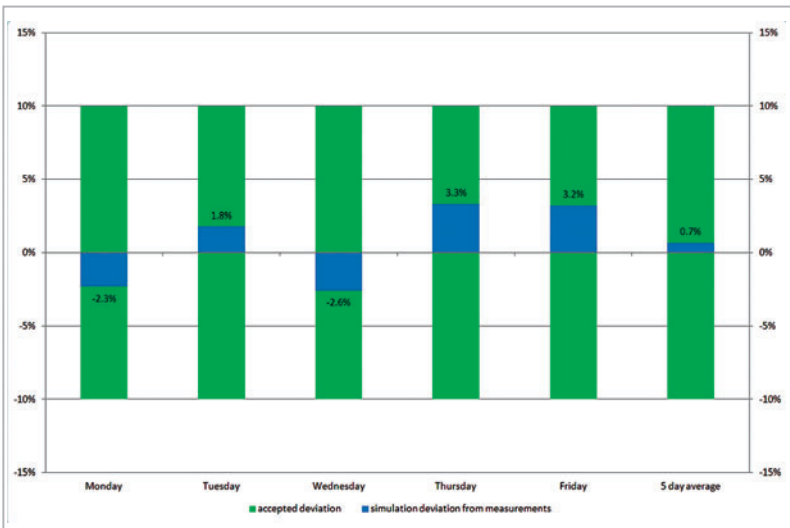
## References + Links

- [1] <http://www.openpowernet.de>
- [2] <http://www.opentrack.ch>
- [3] *Lehmann, M.; Neumann, H.*: Network calculation with method of node potentials and consideration of electromagnetic coupling. *Elektrische Bahnen* 106 (2008), H. 8-9, S. 416–420.
- [4] TRANSLink website: <http://translink.com.au/resources/travel-information/network-information/maps/120618-busway-and-train-network.jpg>



**Figure 11:**

Deviations of simulated energy consumption to measurements at Lytton Junction Feeding Station from 30.01.2012 to 03.02.2012 at morning peak 6 am to 10 am, Cleveland to Park Road for the proof of concept.



**Figure 12:**

Deviations of simulated energy consumption to measurements at Lytton Junction Feeding Station from 30.01.2012 to 03.02.2012 at morning peak 6 am to 10 am, Cleveland to Park Road considering the lower auxiliary power at Cleveland terminus.

### AUTORENDATEN



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Address: Plateway Ltd., 6/3 Sutherland Street, CLYDE NSW 2142, Australia.



**Dipl.-Ing. (FH) Martin Jacob** (38), 1997–2002 study of automation technology at the Hochschule für Technik und Wirtschaft Dresden, since 2002 member at the Institut für Bahntechnik GmbH, Branch Dresden.

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