Simulation of Railway Power Supply Systems

AC Railway

DC Railway / Trolleybus
Simulation of Railway Power Supply Systems

AC Railway

DC Railway / Trolleybus

Prof. Dr.-Ing. Arnd Stephan
Simulation of Railway Power Supply Systems – why?
Simulation of Railway Power Supply Systems – why?

The electrical load flows and the energy consumption within railway power supply networks depend on the running trains and the power supply system characteristics.
Simulation of Railway Power Supply Systems – why?

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- The voltage situation as well as the network structure influence the electrical load flows (… current levels and directions).
Simulation of Railway Power Supply Systems – why?

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• There are energy consumers with time- and location-dependent power demands (… picking up and recovering energy).
Simulation of Railway Power Supply Systems – why?

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**Simulation** of these dynamic processes enables:
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- Energy consumption analysis and prognosis
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**Simulation** of these dynamic processes enables:

- Energy consumption analysis and prognosis
- Design and rating verification of the electrical installations
Special Requirements

The network voltage situation affects the electrical load flows and may have retroaction to the propulsion characteristics of the trains:
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- currents and power losses increase with decreasing voltage,
- under low voltage conditions current or power limitations of the train propulsion control are activated ⇒ … impact on driving dynamics,
Special Requirements

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- currents and power losses increase with decreasing voltage,
- under low voltage conditions current or power limitations of the train propulsion control are activated $\Rightarrow$ … impact on driving dynamics,
- the network voltage influences the braking energy recovering decisively (energy absorption capability).
Initial Situation

Energy consumption simulation for electrical railway systems requires detailed information concerning
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• each train’s driving state and its required traction power,
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• the layout and the capability of the power supply system.
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All these information are needed exactly at the same time.
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In the past a number of **compromises** were made
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• either concerning the complexity of the railway operation simulation,
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All these information are needed exactly at the same time.

In the past a number of compromises were made

• either concerning the complexity of the railway operation simulation,
• or regarding the modelling depth of the propulsion technology and the electrical network.
Separation of Simulation Tasks

Railway Operation

- Line routing and alignment
- Track layout
- Signalling system
- Train data
- Timetable
- Connecting conditions
- Operating rules

Load Flow and Energy

- Train propulsion data
- Power grid parameter
- Substations arrangement
- Switch states
- Feeder lines and cables
- Catenary system
- Earthing system
Separation of Simulation Tasks

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Plug-in
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Plug-in

OPEN TRACK

penPowerNet
OpenPowerNet – Simulation of Railway Power Supply

COMPRAIL 2008

OPENTRACK

Input

Rolling Stock
Infrastructure
Timetable

Simulation

Interactivity Disturbances
Animation

Output

Diagrams
Train Graphs
Occupations
Statistics

Source: ETHZ

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Railway Operation Simulation
Railway Operation Simulation

Propulsion Technology
Railway Operation Simulation

Propulsion Technology

Power Supply System
Railway Operation Simulation

OPENTRACK

Propulsion Technology

Power Supply System

Institut für Bahntechnik GmbH
Railway Operation Simulation
OPENTRACK

ATM
Advanced
Train Module

Propulsion Technology

Power Supply System
Railway Operation Simulation

ATM
Advanced Train Module

PSC
Power Supply Calculation

Propulsion Technology

Power Supply System
Railway Operation Simulation

ATM
Advanced Train Module

PSC
Power Supply Calculation

Interaction

Propulsion Technology

Power Supply System
Railway Operation Simulation

OPENTRACK

ATM
Advanced Train Module

PSC
Power Supply Calculation

Interaction

Propulsion Technology

Power Supply System

openPowerNet
Railway Operation Simulation

ATM
Advanced Train Module

PSC
Power Supply Calculation

“Co-Simulation”

Propulsion Technology

Power Supply System
Simulation Sequence per Time Step

OPEN TRACK

PSC

ATM
Simulation Sequence per Time Step

Train Position, Requested Effort

OpenTrack

PSC

ATM
Simulation Sequence per Time Step

Train Position, Requested Effort

Train Current

Line Voltage, Requested Effort
Simulation Sequence per Time Step

1. **Train Position, Requested Effort**
   - Input to **OpenTrack**

2. **Train Current**
   - Output from **PSC** to **ATM**

3. **Line Voltage, Requested Effort**
   - Input to **PSC**

4. **Achieved Effort**
   - Output from **ATM**

5. **Train Position, Requested Effort**
   - Output from **OpenTrack**

**OpenTrack** acts as the controller, coordinating the cycle of events to simulate railway power supply conditions.
Simulation Sequence per Time Step

- **OpenTrack**
  - Train Position, Requested Effort

- **PSC**
  - Train Current

- **ATM**
  - Achieved Effort

- **Line Voltage, Requested Effort**
OPENTRACK

network database → AP Server → propulsion database

PSC

ATM
Stephan_080915_OpenPowerNet_engl.ppt (Figure 10)
Stephan_080915_OpenPowerNet_engl.ppt – Simulation of Railway Power Supply

COMPRAIL 2008

**OPEN TRACK**

1. **train_ID, engine_ID, line_ID, track_ID, train location, time, requested force, speed**

   **network database**

   **AP Server**

   **propulsion database**

2. **line_ID, track_ID, train location, time, train current**

   **PSC**

   **ATM**
Figure 10 - Simulation of Railway Power Supply

**OPEN TRACK**

1. network database
   - train_ID, engine_ID, line_ID, track_ID, train location, time, requested force, speed

2. PSC
   - line_ID, track_ID, train location, time, train current
   - train voltage, nominal voltage, nominal frequency

3. AP Server

4. propulsion database

5. ATM

**OpenPowerNet**
Stephan_080915_OpenPowerNet_engl.ppt

– Simulation of Railway Power Supply

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AP Server

PSC

ATM

network data base

propulsion data base

1

2

3

4

train_ID, engine_ID, line_ID, track_ID, train location, time, requested force, speed

line_ID, track_ID, train location, time, train current

train_ID, engine_ID, requested force, speed, train voltage, nominal voltage, nominal frequency

train_ID, engine_ID, requested force, speed, train voltage, nominal voltage, nominal frequency

train voltage, nominal voltage, nominal frequency

train_ID, engine_ID, line_ID, track_ID, train location, time, requested force, speed
openPowerNet – Simulation of Railway Power Supply

COMPRAIL 2008

Stephan_080915_OpenPowerNet_engl.ppt   (Figure 10)
Stephan_080915_OpenPowerNet_engl.ppt   (Figure 10)

openPowerNet – Simulation of Railway Power Supply

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OPEN TRACK

network data base

PSC

train_ID, engine_ID, line_ID, track_ID, train location, time, requested force, speed

1

AP Server

train_ID, engine_ID, requested force, speed, train voltage, nominal voltage, nominal frequency

2

propulsion data base

ATM

achieved force

3

line_ID, track_ID, train location, time, train current

train voltage, nominal voltage, nominal frequency

4

achieved force

train_ID, engine_ID, requested force, speed, train voltage, nominal voltage, nominal frequency

5

train current

6
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– Simulation of Railway Power Supply

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network database

line_ID, track_ID, train location, time, train current

train_voltage, nominal voltage, nominal frequency

PSC

train_ID, engine_ID, line_ID, track_ID, train location, time, requested force, speed

AP Server

propulsion database

train_ID, engine_ID, requested force, speed, train voltage, nominal voltage, nominal frequency

ATM

achieved force

achieved force, train current

SOAP interface
Modelling levels available for propulsion simulation
Modelling levels available for propulsion simulation

a) constant efficiency factors for propulsion equipment
Modelling levels available for propulsion simulation

a) constant efficiency factors for propulsion equipment
b) driving state related efficiency factors
Modelling levels available for propulsion simulation

a) constant efficiency factors for propulsion equipment
b) driving state related efficiency factors
c) load depending efficiency factors of components
Modelling levels available for propulsion simulation

a) constant efficiency factors for propulsion equipment
b) driving state related efficiency factors
c) load depending efficiency factors of components
d) detailed engine models of components
Modelling levels available for propulsion simulation

a) constant efficiency factors for propulsion equipment
b) driving state related efficiency factors
c) load depending efficiency factors of components
d) detailed engine models of components

+ auxiliary power and eddy current break
Modelling levels available for propulsion simulation

a) constant efficiency factors for propulsion equipment
b) driving state related efficiency factors
c) load depending efficiency factors of components
d) detailed engine models of components

+ auxiliary power and eddy current break
+ additionally: limiting values of propulsion control (e.g. voltage related current limitation)
Propulsion Structure

\[ P_{el} \]

Transformer

4QS

Inverter

Motor

Gear

Effort

Auxiliary Power

Traction Power

Eddy Current Brake Power

\[ P_{mech} \]
Efficiency Characteristics of ICE3 train

1 AC 15 kV 16,7 Hz
Propulsion Component Modelling  (example for traction motor)

\[ M_{\text{elekt}} = M_{\text{mech}} + M_{\text{Läuferverluste}} \]

\[ M_{\text{Läuferverluste}} = \frac{P_{\text{Rotorverluste}}}{2\pi n} = \frac{3}{2} \frac{i'}{2} \cdot \frac{R'}{2} \]
Propulsion Model Verification

Train Current and Pantograph Voltage

- Voltage in Volt
- Current in Amperes

Time in hours and minutes
Train Speed and Power Characteristics
Measurement and Simulation Results
ICE1 Hannover – Göttingen

Fahrschaubild und Leistungsverlauf ICE1
Betriebsfahrt Hannover - Göttingen, Meßwerte am führenden Triebkopf,
Simulation IFB: Standardparameter und Wirkungsgradmodell ICE1/2

Train Speed and Power Characteristics
Measurement and Simulation Results
ICE1 Hannover – Göttingen

Train speed and power characteristics for ICE1 from Hannover to Göttingen, including measurement and simulation results.

Quelle: IFB
Requirements to the electrical network model
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- Simulation of all common AC- and DC-railway power supply systems
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- Simulation of all common AC- and DC-railway power supply systems
- Representation of the entire electrical network structure
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- Unrestricted choice of conductor configuration along the line
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- Precise consideration of electromagnetic coupling effects of overhead line conductors for a.c.-systems
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- Precise consideration of electromagnetic coupling effects of overhead line conductors for a.c.-systems
- Change of switching status within the power supply network
- Retroaction to the railway operation simulation (OpenTrack)
- Iterative communication with the propulsion simulation (ATM)
- Configurable data output
- Interfaces for post-processing
Power Supply Network Structure (DC 0.6 ... 3.0 kV)

Power Grid Connection
3 AC 10 / 20 / 30 kV
Power Supply Network Structure (1 AC 15 kV 16,7 Hz)

Power Grid Connection
1 AC 110 kV 16,7 Hz
Power Supply Network Structure (2 AC 25 kV ~ 50 / 60 Hz)

Power Grid Connection
3 AC 110 / 220 kV

Substation

Autotransformer

Autotransformer

Autotransformer

SS

AT1

AT2

AT3

OCS

Rails

Negative Feeder

Earth

\(Y_{O1}\)

\(Y_{O2}\)

\(Y_{O3}\)

\(Y_{O4}\)

\(Y_{R1}\)

\(Y_{R2}\)

\(Y_{R3}\)

\(Y_{R4}\)

\(Y_{RE}\)

\(Y_{RE}\)

\(Y_{RE}\)

\(Y_{RE}\)

\(Y_{RE}\)

\(Y_{RE}\)

\(Y_{RE}\)

train NOT in section

train in section
Modelling of infrastructure
Catenary arrangement and switch status
Modelling of the Railway Power Supply System
Modelling of the Railway Power Supply System

- Electrical network structure (feeding sections, feeding points, switching status) in congruence to the track topology
Modelling of the Railway Power Supply System

- Electrical network structure (feeding sections, feeding points, switching status) in congruence to the track topology

- Electrical characteristics of the feeding power grid
Modelling of the Railway Power Supply System

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- Electrical characteristics of the feeding power grid
- Electrical characteristics of the substations
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- Modelling of additional power consumers (e.g. point heatings)
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- Electrical characteristics rail-to-earth
- Modelling of additional power consumers (e.g. point heatings)
- Loading capacity (conductors, converters, transformers)
- Protection settings
Substation / AT Structure (2 AC 25 kV ~ 50/60 Hz)
Trackside Arrangement of Conductors
Trackside Arrangement of Conductors

- hollow coils

- RL
- RR
Trackside Arrangement of Conductors
Trackside Arrangement of Conductors

hollow coils

RL RR

RF
Trackside Arrangement of Conductors

- Hollow coils
- Max. 1500 m
- RL, RR

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Trackside Arrangement of Conductors

- hollow coils
- max. 1500 m

RL  RR

Stephan_080915_OpenPowerNet_engl.ppt  (Figure 25)
Trackside Arrangement of Conductors

- Hollow coils
- Max. 1500 m
Trackside Arrangement of Conductors

- Hollow coils

- Max. 1500 m
Trackside Arrangement of Conductors

hollow coils

max. 1500 m
Catenary Arrangement and Conductor Model

1. CL TRACK
2. SH = 1600
3. CL TRACK
4. SH = 5300

CWH Contact wire height
SH System height
1. Negative Feeder
2. Return conductor
3. Messenger wire
4. Contact wire
Catenary Arrangement and Conductor Model

1. CL TRACK
2. SH = 1600
3. 300
4. CWH = 5300

CWH Contact wire height
SH System height
1 Negative Feeder
2 Return conductor
3 Messenger wire
4 Contact wire

TOR
Catenary Arrangement and Conductor Model

- CWH: Contact wire height
- SH: System height
- CL TRACK: Catenary line track
- TOR: Terminal
- 1: Positive Feeder
- 2: Return conductor
- 3: Contact wire
- 4: Messenger wire
Catenary Arrangement and Conductor Model

2

CWH Contact wire height  
SH System height

300

CL TRACK

3

CWH = 5300

4

CL TRACK

300

SH = 1600

3000

TOR

CWH Contact wire height  
SH System height

Negative Feeder

Return conductor

Messenger wire

Contact wire
Catenary Arrangement and Conductor Model

- CL TRACK
- SH = 1600
- CWH = 5300
- TOR

Legend:
- CWH Contact wire height
- SH System height
- Negative Feeder
- Return conductor
- Messenger wire
- Contact wire
Catenary Arrangement and Conductor Model

„Slice“

CWH Contact wire height
SH System height

Negative Feeder
Return conductor
Messenger wire
Contact wire
Catenary Arrangement and Conductor Model
Catenary Arrangement and Conductor Model
Catenary Arrangement and Conductor Model
Catenary Arrangement and Conductor Model

\[(x_1; y_1)\]

\[(0; 0)\]
Catenary Arrangement and Conductor Model

Material, Diameter

Point: \((x_1; y_1)\)
Catenary Arrangement and Conductor Model

Material, diameter

Electro-magnetic coupling effects

(0; 0)
Catenary Arrangement and Conductor Model

Slice n

material, diameter

\((x_1; y_1)\)

\((0; 0)\)

electro-magnetic coupling effects
Sequence of Slices
Mathematical Network Model
Electrical network calculation using the advanced method of nodes

\[ [Y]_{\nu,\nu} (U_{\nu0})(\nu,1) - [Y]_{\nu,LL} (U_L)_{LL,1} = (I_q)_{\nu,1} \]

<table>
<thead>
<tr>
<th>nodes</th>
<th>$U_{10}$</th>
<th>$U_{20}$</th>
<th>$U_{30}$</th>
<th>$U_{40}$</th>
<th>$U_{50}$</th>
<th>$U_{11}$</th>
<th>$U_{12}$</th>
<th>$U_{11}$</th>
<th>$I_q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$G_{14} + Y_{oE}$</td>
<td>$-Y_{oE}$</td>
<td>$-G_{14}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$-Y_{G2}$</td>
<td>$G_{25} + Y_{GE}$</td>
<td></td>
<td>$-G_{25}$</td>
<td>$-G_{25}$</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>$G_{3} + Y_{L}$</td>
<td>$-Y_{2}$</td>
<td></td>
<td></td>
<td>$G_{3}$</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>$-G_{14}$</td>
<td>$-Y_{2}$</td>
<td>$G_{14} + Y_{2} + Y_{GE}$</td>
<td>$-Y_{GE}$</td>
<td></td>
<td>$G_{14}$</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>$-G_{25}$</td>
<td>$-Y_{6E}$</td>
<td>$G_{35} + Y_{GE}$</td>
<td></td>
<td></td>
<td>$G_{35}$</td>
<td></td>
<td></td>
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Electrical network calculation using the advanced method of nodes

\[
[Y]_{(v,v)} (U_{v0})_{(v,1)} - [Y]_{(v,LL)} (U_{LL})_{(LL,1)} = (I_q)_{(v,1)}
\]

Voltage drops caused by self- and mutual induction

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<td>(-L_q)</td>
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<td>(-G_{14})</td>
<td>(-L_q)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>(-Y_{G2})</td>
<td>(G_{25} + Y_{GE})</td>
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<td>(-G_{25})</td>
<td>0</td>
<td>(-G_{25})</td>
<td>(-G_{25})</td>
<td>0</td>
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<tr>
<td>3</td>
<td>(G_{3} + Y_{L})</td>
<td>(-Y_{2})</td>
<td>(G_{3})</td>
<td>(G_{3})</td>
<td>0</td>
<td>(G_{3})</td>
<td>(G_{3})</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>(-G_{14})</td>
<td>(-Y_{4})</td>
<td>(G_{14} + Y_{L} + Y_{GE})</td>
<td>(-Y_{GE})</td>
<td>(G_{14})</td>
<td>(-Y_{GE})</td>
<td>(G_{14})</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>(-G_{24})</td>
<td>(-Y_{6E})</td>
<td>(G_{35} + Y_{GE})</td>
<td>(G_{35})</td>
<td>0</td>
<td>(G_{35})</td>
<td>(G_{35})</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Verification of the simulation
Verification of the simulation

- Punctual theoretical evaluation
Verification of the simulation

- Punctual theoretical evaluation
  - current sum cero for network slices
Verification of the simulation

- Punctual theoretical evaluation
  - current sum cero for network slices
  - energy picking up and recovering
Verification of the simulation

- Punctual theoretical evaluation
  - current sum cero for network slices
  - energy picking up and recovering
  - correspondence of voltage minimum and maximum / jumps with the network structure during constant load test
Verification of the simulation

- Punctual theoretical evaluation
  - current sum cero for network slices
  - energy picking up and recovering
  - correspondence of voltage minimum and maximum / jumps with the network structure during constant load test

- Comparison of measurement data with the simulation results for predefined load cases
Verification of the simulation

- Punctual theoretical evaluation
  - current sum cero for network slices
  - energy picking up and recovering
  - correspondence of voltage minimum and maximum / jumps with the network structure during constant load test

- Comparison of measurement data with the simulation results for predefined load cases
  - driving dynamics of the trains
Verification of the simulation

- Punctual theoretical evaluation
  - current sum cero for network slices
  - energy picking up and recovering
  - correspondence of voltage minimum and maximum / jumps with the network structure during constant load test

- Comparison of measurement data with the simulation results for predefined load cases
  - driving dynamics of the trains
  - current-, voltage- and power characteristics
Verification: Measurement and Simulation

AB07, Messfahrt F8, mit Halt

![Graph showing comparison between measurement and simulation](Figure 32)
Verification: Measurement and Simulation

AB07, Messfahrt F8, mit Halt

- Spannung [V]
- Strom [A]
- Zeit [s]

Toleranz U (EN 50163)  U_{nenn}  U_{TFZ_2099}  U_{Tfz_Simu}  I_{TFZ_2099}  I_{Tfz_Simu}

Verification: Measurement and Simulation

Stephan_080915_OpenPowerNet_engl.ppt  (Figure 33)
High Speed Railway
350 km/h
966 km Double Track
2AC 25 kV 50 Hz
Simulation Example: High Speed Railway 966 km, Track Alignment (Detail)
Simulation Example: High Speed Railway 966 km, OCS Infeed (Detail)
Simulation Example: High Speed Railway 966 km, Timetable Draft (Detail)
Simulation Results: High Speed Railway 2AC 25 kV

Train Speed $v = f(t)$
Guangzhou direction with 2 stops, CRH3
Simulation Results: High Speed Railway 2AC 25 kV

Train Current $I = f(s)$
Guangzhou direction non-stop, 1x CRH 3
Simulation Results: High Speed Railway 2AC 25 kV

Train Current $I = f(s)$
Guangzhou direction non-stop, 1x CRH 3
Simulation Results: High Speed Railway 2AC 25 kV

Train Current $I = f(s)$
Guangzhou direction non-stop, 1x CRH 3
Simulation Results: High Speed Railway 2AC 25 kV

Pantograph Voltage $U = f(t)$
Guangzhou direction non-stop, CRH 3
Simulation Results: High Speed Railway 2AC 25 kV

Pantograph Voltage $U = f(t)$
Guangzhou direction non-stop, CRH 3

Institut für Bahntechnik GmbH
Simulation Results: High Speed Railway 2AC 25 kV

Pantograph Voltage $U = f(s)$
Guangzhou direction non-stop, CRH 3
Simulation Results: High Speed Railway 2AC 25 kV

TSS Energy Delivery (1 h)
WGPDL - Operation Program 2028

Electric Energy [MWh]

Substation No.
Simulation Results: High Speed Railway 2AC 25 kV

Recovery Rates (peak operation)
WGPDL - Operation Program 2028

<table>
<thead>
<tr>
<th>Substation No.</th>
<th>Energy Recovering</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15.1%</td>
</tr>
<tr>
<td>2</td>
<td>6.0%</td>
</tr>
<tr>
<td>3</td>
<td>6.0%</td>
</tr>
<tr>
<td>4</td>
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</tr>
<tr>
<td>5</td>
<td>6.0%</td>
</tr>
<tr>
<td>6</td>
<td>6.0%</td>
</tr>
<tr>
<td>7</td>
<td>6.0%</td>
</tr>
<tr>
<td>8</td>
<td>7.0%</td>
</tr>
<tr>
<td>9</td>
<td>0.0%</td>
</tr>
<tr>
<td>10</td>
<td>0.0%</td>
</tr>
<tr>
<td>11</td>
<td>0.0%</td>
</tr>
<tr>
<td>12</td>
<td>0.0%</td>
</tr>
<tr>
<td>13</td>
<td>0.0%</td>
</tr>
<tr>
<td>14</td>
<td>0.0%</td>
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<tr>
<td>15</td>
<td>0.0%</td>
</tr>
<tr>
<td>16</td>
<td>0.0%</td>
</tr>
<tr>
<td>17</td>
<td>0.0%</td>
</tr>
<tr>
<td>18</td>
<td>0.0%</td>
</tr>
<tr>
<td>19</td>
<td>0.0%</td>
</tr>
<tr>
<td>20</td>
<td>16.6%</td>
</tr>
</tbody>
</table>
## Simulation Results: High Speed Railway 2AC 25 kV

### Vehicle Energy Consumption And Recovery Overview, Wuhan - Guangzhou

_Ygm 1862-1918_

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CRH3</td>
<td>G469-0</td>
<td>26001,806</td>
<td>1754,227</td>
<td>67,466</td>
<td>1755,741</td>
<td>1,513</td>
<td>0,1</td>
<td>1,942</td>
<td>1,596</td>
</tr>
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<td>G469-1</td>
<td>26001,806</td>
<td>1754,227</td>
<td>67,466</td>
<td>1755,741</td>
<td>1,513</td>
<td>0,1</td>
<td>1,942</td>
<td>1,596</td>
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<td>25973,739</td>
<td>1759,052</td>
<td>67,724</td>
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<td>0,000</td>
<td>0,000</td>
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<tr>
<td>CRH3</td>
<td>G371-1</td>
<td>25973,739</td>
<td>1759,052</td>
<td>67,724</td>
<td>1759,052</td>
<td>0,000</td>
<td>0,0</td>
<td>0,000</td>
<td>0,000</td>
</tr>
<tr>
<td>CRH3</td>
<td>G299-0</td>
<td>26002,845</td>
<td>1754,247</td>
<td>67,464</td>
<td>1755,755</td>
<td>1,508</td>
<td>0,1</td>
<td>1,936</td>
<td>1,591</td>
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<tr>
<td>CRH3</td>
<td>G299-1</td>
<td>26002,845</td>
<td>1754,247</td>
<td>67,464</td>
<td>1755,755</td>
<td>1,508</td>
<td>0,1</td>
<td>1,936</td>
<td>1,591</td>
</tr>
<tr>
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<td>G355-0</td>
<td>25996,262</td>
<td>1756,881</td>
<td>67,582</td>
<td>1758,806</td>
<td>1,926</td>
<td>0,1</td>
<td>3,791</td>
<td>2,009</td>
</tr>
<tr>
<td>CRH3</td>
<td>G355-1</td>
<td>25996,262</td>
<td>1756,881</td>
<td>67,582</td>
<td>1758,806</td>
<td>1,926</td>
<td>0,1</td>
<td>3,791</td>
<td>2,009</td>
</tr>
<tr>
<td>CRH3</td>
<td>G509-0</td>
<td>8741,502</td>
<td>588,711</td>
<td>67,347</td>
<td>588,711</td>
<td>0,000</td>
<td>0,0</td>
<td>0,000</td>
<td>0,000</td>
</tr>
<tr>
<td>CRH3</td>
<td>G509-1</td>
<td>8741,502</td>
<td>588,711</td>
<td>67,347</td>
<td>588,711</td>
<td>0,000</td>
<td>0,0</td>
<td>0,000</td>
<td>0,000</td>
</tr>
<tr>
<td>CRH3</td>
<td>G600-0</td>
<td>7635,276</td>
<td>533,004</td>
<td>69,808</td>
<td>533,004</td>
<td>0,000</td>
<td>0,0</td>
<td>0,000</td>
<td>0,000</td>
</tr>
<tr>
<td>CRH3</td>
<td>G600-1</td>
<td>7635,276</td>
<td>533,004</td>
<td>69,808</td>
<td>533,004</td>
<td>0,000</td>
<td>0,0</td>
<td>0,000</td>
<td>0,000</td>
</tr>
<tr>
<td>CRH3</td>
<td>G520-0</td>
<td>15460,187</td>
<td>1068,943</td>
<td>69,142</td>
<td>1068,943</td>
<td>0,000</td>
<td>0,0</td>
<td>0,000</td>
<td>0,000</td>
</tr>
<tr>
<td>CRH3</td>
<td>G520-1</td>
<td>15460,187</td>
<td>1068,943</td>
<td>69,142</td>
<td>1068,943</td>
<td>0,000</td>
<td>0,0</td>
<td>0,000</td>
<td>0,000</td>
</tr>
</tbody>
</table>
Simulation Results: High Speed Railway 2AC 25 kV

Energy Consumption And Losses Overview, Wuhan - Guangzhou

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy output to catenary at substation [kWh]</td>
<td>72300,187</td>
</tr>
<tr>
<td>Energy input from catenary at substation [kWh]</td>
<td>1154,082</td>
</tr>
<tr>
<td><strong>Total energy at substation [kWh]</strong></td>
<td>71146,105</td>
</tr>
<tr>
<td>Vehicules energy consumption [kWh]</td>
<td>78540,848</td>
</tr>
<tr>
<td>Vehicules braking energy used for auxillaries [kWh]</td>
<td>639,139</td>
</tr>
<tr>
<td>Total used vehicles braking energy [kWh]</td>
<td>9870,007</td>
</tr>
<tr>
<td><strong>Total vehicles energy [kWh]</strong></td>
<td>69309,980</td>
</tr>
<tr>
<td><strong>Total energy consumption [kWh]</strong></td>
<td>81016,112</td>
</tr>
<tr>
<td>Energy consumption from national power grid [kWh]</td>
<td>71233,480</td>
</tr>
<tr>
<td><strong>Average efficiency of traction power supply</strong></td>
<td>97,6%</td>
</tr>
<tr>
<td>Losses in contact wire [kWh]</td>
<td>525,588</td>
</tr>
<tr>
<td>Losses in messenger wire [kWh]</td>
<td>565,248</td>
</tr>
<tr>
<td>Losses in negative feeder [kWh]</td>
<td>481,426</td>
</tr>
<tr>
<td>Losses in return conductor [kWh]</td>
<td>138,879</td>
</tr>
<tr>
<td>Losses in left rail [kWh]</td>
<td>13,174</td>
</tr>
<tr>
<td>Losses in right rail [kWh]</td>
<td>13,196</td>
</tr>
<tr>
<td>Losses in LEBC [kWh]</td>
<td>31,117</td>
</tr>
<tr>
<td><strong>Total losses in conductors [kWh]</strong></td>
<td>1768,629</td>
</tr>
<tr>
<td>Losses in connectors [kWh]</td>
<td>1,495</td>
</tr>
<tr>
<td>Losses in autotransformers [kWh]</td>
<td>21,896</td>
</tr>
<tr>
<td><strong>Total losses in catenary system [kWh]</strong></td>
<td>1792,020</td>
</tr>
<tr>
<td>Losses in feeders [kWh]</td>
<td>44,072</td>
</tr>
<tr>
<td>Losses in traction transformers [kWh]</td>
<td>87,375</td>
</tr>
</tbody>
</table>
Simulation Results: High Speed Railway 2AC 25 kV

Busbar Power, Wuhan-Guangzhou
Substation TSS_1444_Hua, Transformer 1444_Hua_TT-02
Simulation Results: High Speed Railway 2AC 25 kV

Maximum Substation Power
WGPDL - Operation Program 2028

Substation No.

WU dir.
GUA dir.
Simulation Results: High Speed Railway 2AC 25 kV

Maximum Return Cable Current
WGPDL - Operation Program 2028

- SP WU dir.
- ATS WU dir.
- ATS GUA dir.
- SP GUA dir.
Simulation Results: High Speed Railway 2AC 25 kV

Short Circuit Current, Wuhan-Guangzhou
Line Wuh-Gua_2, Track Up, km 1961.2-2015.12

Current [A]

Short Circuit Position [km]

- Isolator
- AT
- Infeed
- short_circuit_current
Simulation Results: High Speed Railway 2AC 25 kV

Maximum Rail-Earth Potential, Wuhan-Guangzhou
Line Wuh-Gua_2, Track Up, km 1961.2-2015.12

Voltage [V]

Position [km]

- isolator
- LR_U_LIBC_Up
- LR_U_LIBC_Up-2
- LR_U_LIBC_Up-3
- RR_U_LIBC_Up
- RR_U_LIBC_Up-2
- RR_U_LIBC_Up-3
- Infeed
- URE_max

78 V
Simulation Results: High Speed Railway 2AC 25 kV

TSS
SHA
km
1986.8

ATS
km
1997.4

SP
km
2015.1

OCS

Rails

NF
Simulation Results: High Speed Railway 2AC 25 kV

- TSS SHA km 1986.8
- ATS km 1997.4
- SP km 2015.1
Simulation Results: High Speed Railway 2AC 25 kV

- TSS SHA
  km 1986,8

- ATS
  km 1997,4

- SP
  km 2015,1

Diagram showing the railway power supply system with key points such as OCS, Rails, RC, LEBC, NF, and the distances and points of interest.
Simulation Results: High Speed Railway 2AC 25 kV

TSS SHA
km 1986,8

ATS
km 1997,4

SP
km 2015,1

1988,000 2014,300

2x CRH 3 880 A 2x CRH 3

880 A

2x CRH 3

2x CRH 3

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Simulation Results: High Speed Railway 2AC 25 kV

TSS
SHA
km
1986,8

ATS
km
1997,4

SP
km
2015,1

Simulation of Railway Power Supply
Simulation Results: High Speed Railway 2AC 25 kV

TSS
SHA
km
1986.8

ATS
km
1997.4

SP
km
2015.1

Simulation Results:

- **TSS SHA**
  - km: 1986.8

- **ATS**
  - km: 1997.4

- **SP**
  - km: 2015.1

**High Speed Railway 2AC 25 kV**

- OCS: 1150 A
- Rails: 880 A
- RC LEBC: 136 A, 163 A, 60 A, 103 A, 7 A, 13 A
- NF: 603 A
- 2x CRH 3: 363 A, 303 A, 280 A, 493 A, 880 A

**Operating Parameters:**

- EMC 1 / EMC 2: 1987,000
- EMC 3: 1997,000
- EMC 4: 1998,000
Simulation Results: High Speed Railway 2AC 25 kV

Magnetic Field Intensity: Wuhan-Guangzhou
Simulation Time: 00:00:00
Position [km]: 1887.250
Magnetic Field Intensity: Wuhan-Guangzhou
Simulation Time: 00:00:00
Position [km]: 1887.250

tunnel

subgrade
City Light Rail Network
300 km TRAM
220 km Trolleybus
DC 600 V
Network modelling: Catenary and cable plan detail
Vehicle modelling
TRAM und Trolleybus

2 x Mirage

Cobra

Tram2000

Tram2000+Pony

Tram2000 Sänfte

Mercedes

GTB Hess

DGTB Hess
Graphical time table

Line A
Stephan_080915_OpenPowerNet_engl.ppt  (Figure 58)
Minimum voltage: catenary and pantograph

Normal operation

![Diagram showing voltage levels along a railway track.](image-url)
Rail-to-earth potential  Normal operation
Converter current and bus-bar voltage  Normal operation
Converter current and bus-bar-voltage  
Depot gateway 4:50 - 7:05 h
Load and loading capacity

Substation

Normal operation, blackout in neighbouring subst.
### Load values

**Substation**, Normal operation without blackouts

<table>
<thead>
<tr>
<th>Station</th>
<th>Sektor</th>
<th>$I_{\text{max}}$</th>
<th>$I_{\text{eff}}$</th>
<th>$P_{\text{max}}$</th>
<th>$E_{\text{ab}}$</th>
<th>$E_{\text{auf}}$</th>
<th>$E_{\text{verl}}$</th>
<th>$I_{\text{Einst}}$</th>
<th>$I_{\text{Kmin}}$</th>
<th>$I_{\text{Kmin}}/I_{\text{Einst}}$</th>
<th>$I_{\text{max}}/I_{\text{Einst}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SK</td>
<td></td>
<td>1915</td>
<td>588</td>
<td>1221</td>
<td>520</td>
<td>-10</td>
<td>4</td>
<td>3.5</td>
<td>14.0</td>
<td>400%</td>
<td>54.7%</td>
</tr>
<tr>
<td>SK</td>
<td></td>
<td>1686</td>
<td>404</td>
<td>1072</td>
<td>264</td>
<td>0</td>
<td>2</td>
<td>3.0</td>
<td>11.7</td>
<td>390%</td>
<td>56.2%</td>
</tr>
<tr>
<td>SK</td>
<td></td>
<td>1961</td>
<td>475</td>
<td>1252</td>
<td>417</td>
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<td>3</td>
<td>3.0</td>
<td>10.4</td>
<td>347%</td>
<td>65.4%</td>
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<tr>
<td>SK</td>
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<td>1665</td>
<td>332</td>
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<td>257</td>
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<td>3.5</td>
<td>10.4</td>
<td>297%</td>
<td>47.6%</td>
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<tr>
<td>SK</td>
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<td>1018</td>
<td>2312</td>
<td>1000</td>
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<td>12.7</td>
<td>302%</td>
<td>88.3%</td>
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<tr>
<td>SK</td>
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<td>37.6%</td>
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<td>111</td>
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<td>3.0</td>
<td>23.0</td>
<td>767%</td>
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<td>316</td>
<td>738</td>
<td>220</td>
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<td>1</td>
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<td>38.2%</td>
<td>38.2%</td>
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<tr>
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<td>-6</td>
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<td>16.6</td>
<td>474%</td>
<td>80.7%</td>
</tr>
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<td>582</td>
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<td>1</td>
<td>2.5</td>
<td>2.7</td>
<td>108%</td>
<td>36.5%</td>
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<tr>
<td>RK</td>
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<td>-749</td>
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<td>-627</td>
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<td>-2164</td>
<td>678</td>
<td>-1324</td>
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<td>-789</td>
<td>8</td>
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<td>238</td>
<td>-393</td>
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<td>-281</td>
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<tr>
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SK: Feeder cable  
RK: Return current cable
Load and loading capacity  Catenary wire at feeding point
Normal operation, blackout in neighbouring subst.

![Graph showing load and loading capacity](image)

- **Belastbarkeit R107 Abnutzung 0 %**
- **Belastbarkeit R107 Abnutzung 20 %**
- **Ieff je VL Abnutzung 0 %**
- **Ieff je FD Abnutzung 20 %**

**A**

**Stromstärke**

**Zeit**

1000 10000
Energy balance

Recovered energy
Delivered energy of all substations
Power losses balance

Case 1  Case 2  Case 3  Case 4

5.8%  5.8%  5.6%  5.7%

Verluste in Kabeln (GüW)
Verluste Fahrleitung (Tram+TB)
Verluste in Gleisen (Tram)
Recovering balance

![Bar chart showing energy consumption in different cases.](Stephan_080915_OpenPowerNet_engl.ppt)
Conclusions
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- Simulation service can be provided including or excluding the operation modelling (... already existing models can be used easily).

- **OpenPowerNet** is intended to bring into the market after a further internal test and documentation phase.
Eine Expertenrunde für das Gesamtsystem Bahn
The Expert Team for the Complete Railway System

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