OpenPowerNet

The new Co-simulation Tool for Traction Power Supply

AC Railway

DC Railway / Trolleybus

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Simulation of Traction Power Supply – what for?

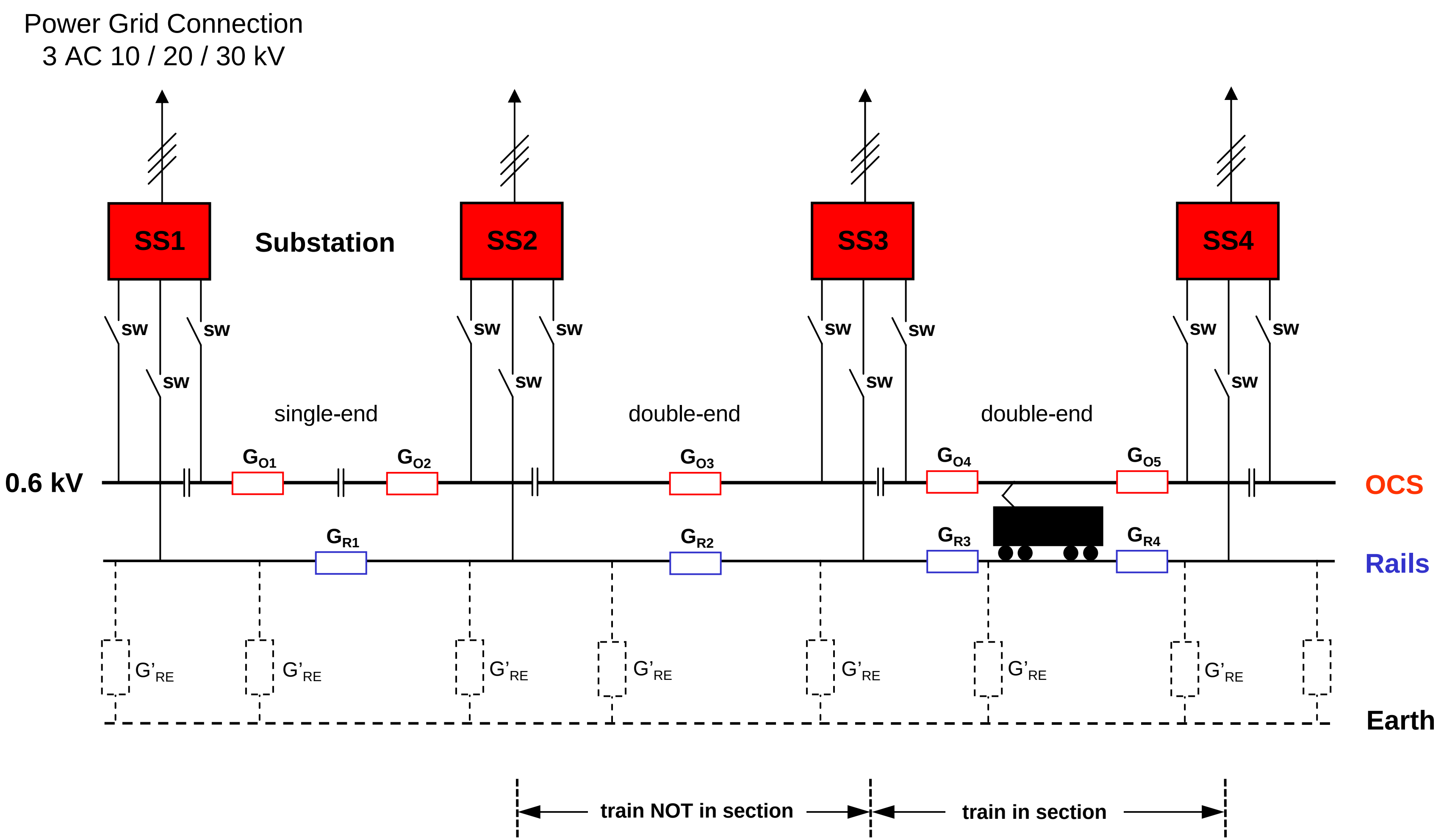
- The voltage situation as well as the network structure influence the electrical load distribution (… current levels and current directions).
- There are energy consumers with time-dependent and position-dependent power demands (… picking up and recovering energy).

$\Rightarrow$ Thus the power supply system influences the energy consumption.

Simulation of these dynamic processes enables:

- Energy consumption analysis and prognosis
- Design and rating verification of the electrical installations
- EMC studies

Power Supply Network Structure (DC 0.6 … 3.0 kV)



Special Requirements

The **network voltage situation** affects the electrical load flows and may have retroaction to the propulsion characteristics of the trains:

- 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,
- 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 …

- each train's driving state and its required traction power,
- the train's positions within the network,
- the layout and the capability of the power supply system.

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

OPENTRACK

Plug-in

Load Flow and Energy

- Train propulsion data
- Power grid parameter
- Substation arrangement
- Feeder lines and cables
- Catenary system
- Earthing system
- Switch status

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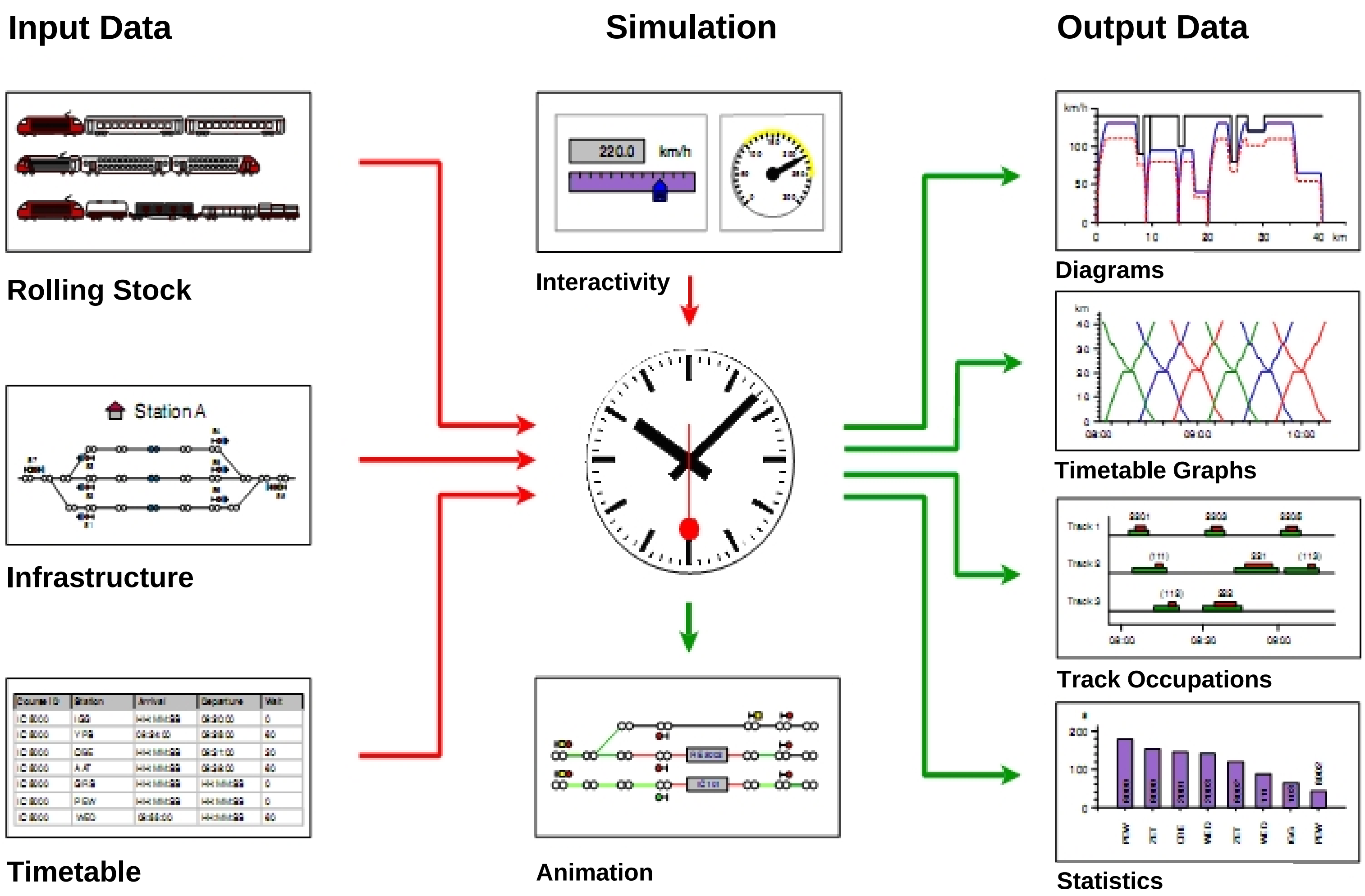
OPEN TRACK



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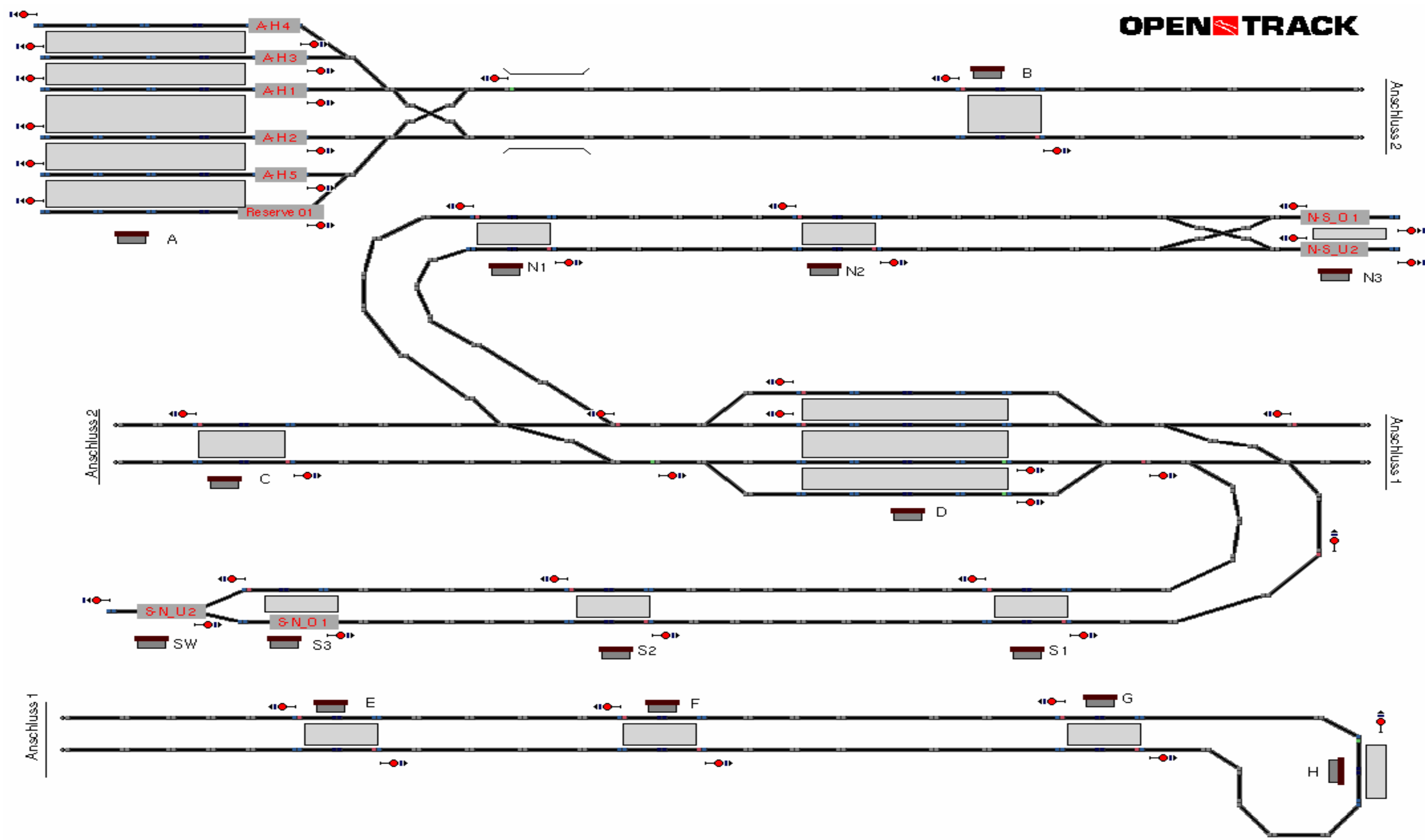
Geometrical Track Model



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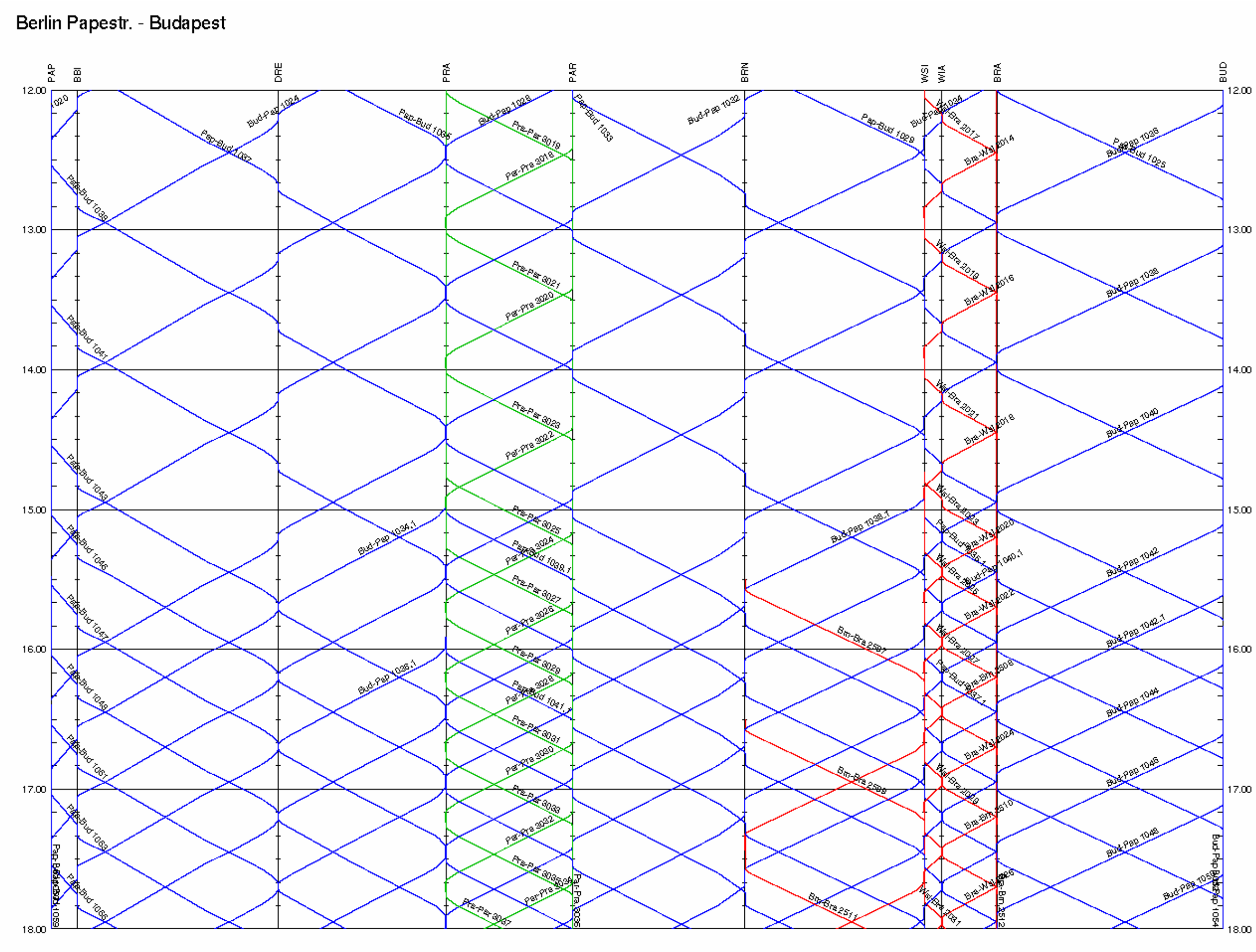
OPEN TRACK



Source: IFB

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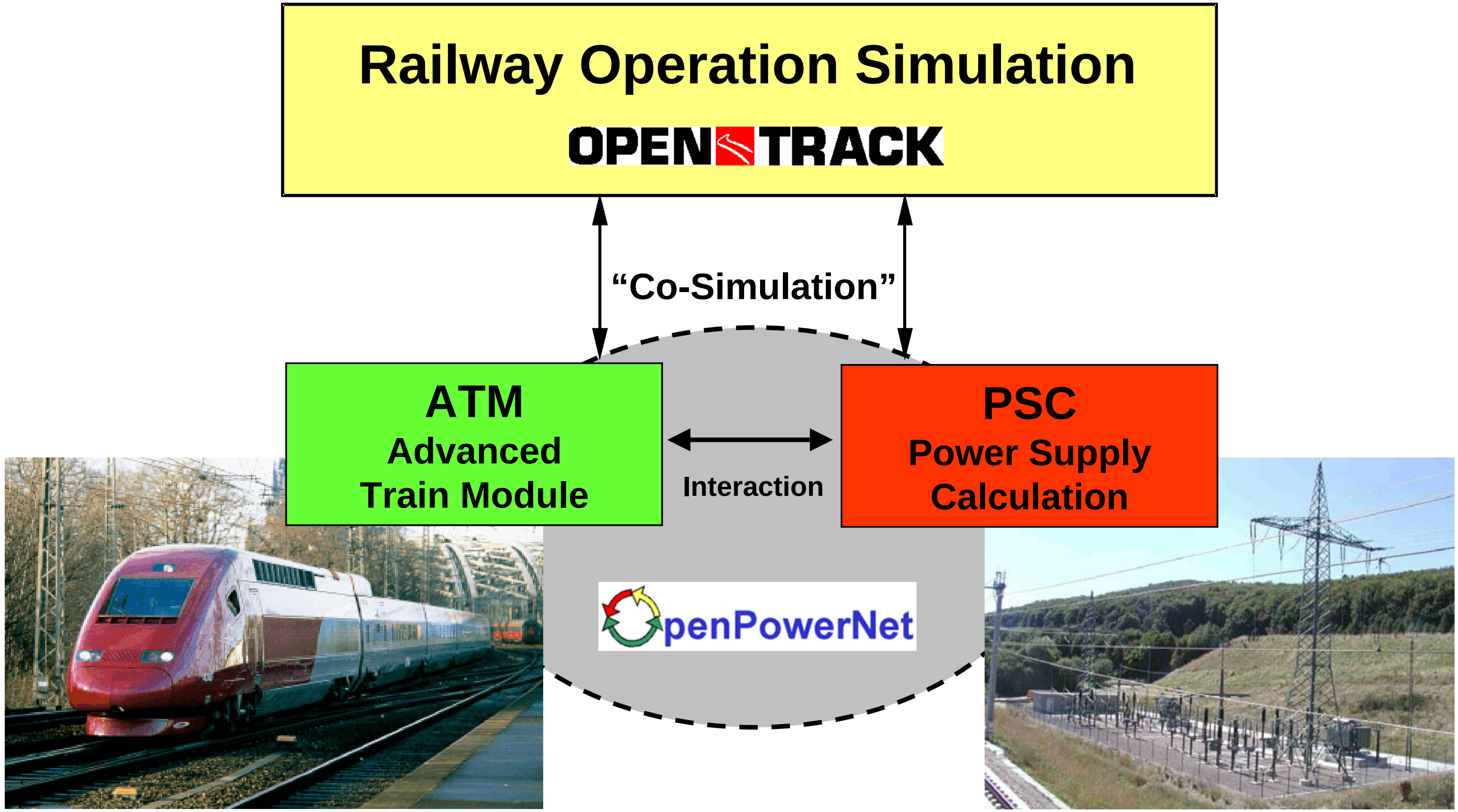
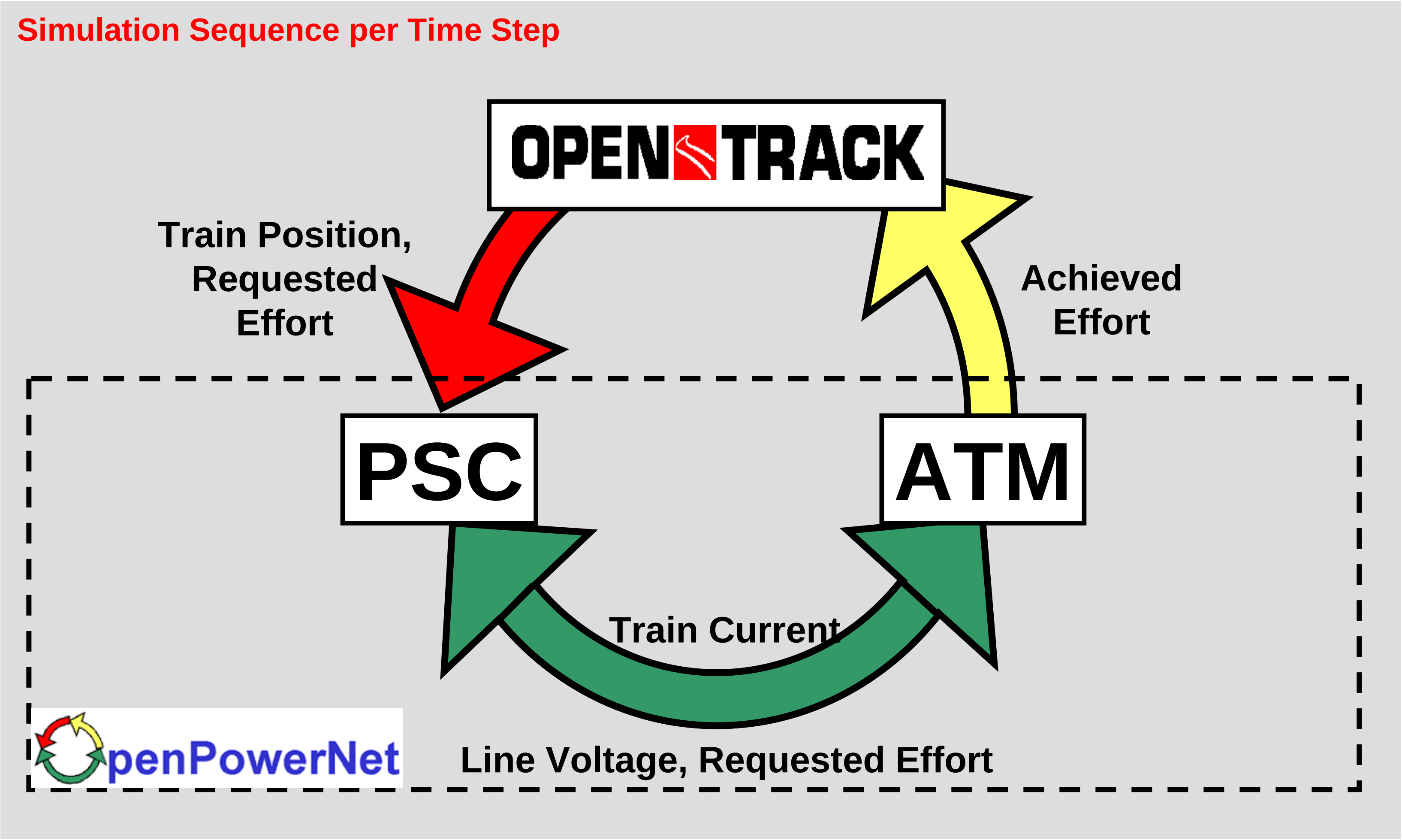
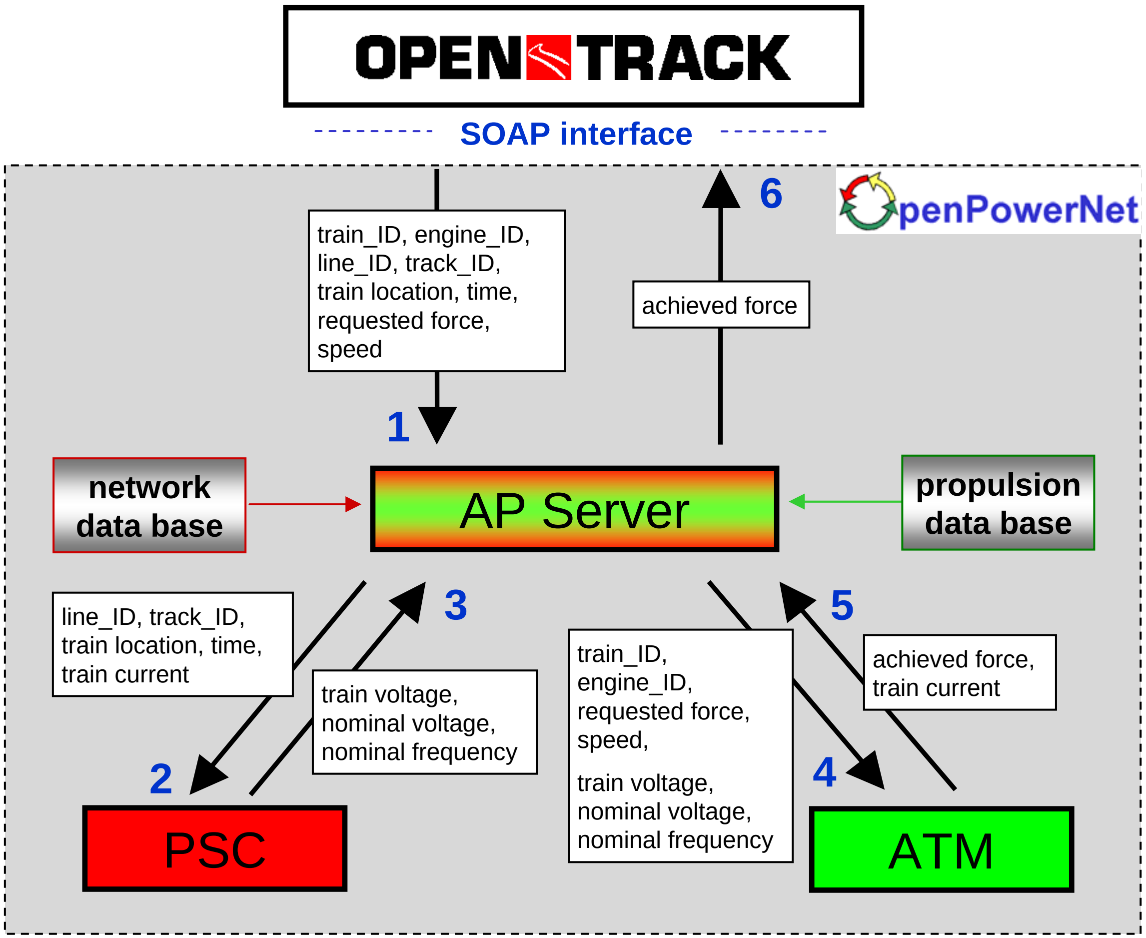


Propulsion Technology

Power Supply System


Simulation Sequence per Time Step
OPEN TRACK
Train Position, Requested Effort
Achieved Effort
PSC
ATM
Train Current
Line Voltage, Requested Effort
OpenPowerNet


OPEN TRACK
SOAP interface
OpenPowerNet
train_ID, engine_ID, line_ID, track_ID, train location, time, requested force, speed
1
6
achieved force
network data base
AP Server
propulsion data base
line_ID, track_ID, train location, time, train current
2
3
train voltage, nominal voltage, nominal frequency
train_ID, engine_ID, requested force, speed,
train voltage, nominal voltage, nominal frequency
4
5
achieved force, train current
PSC
ATM

Modelling levels available for propulsion simulation

a) constant efficiency factors for propulsion equipment

b) driving state related efficiency factors

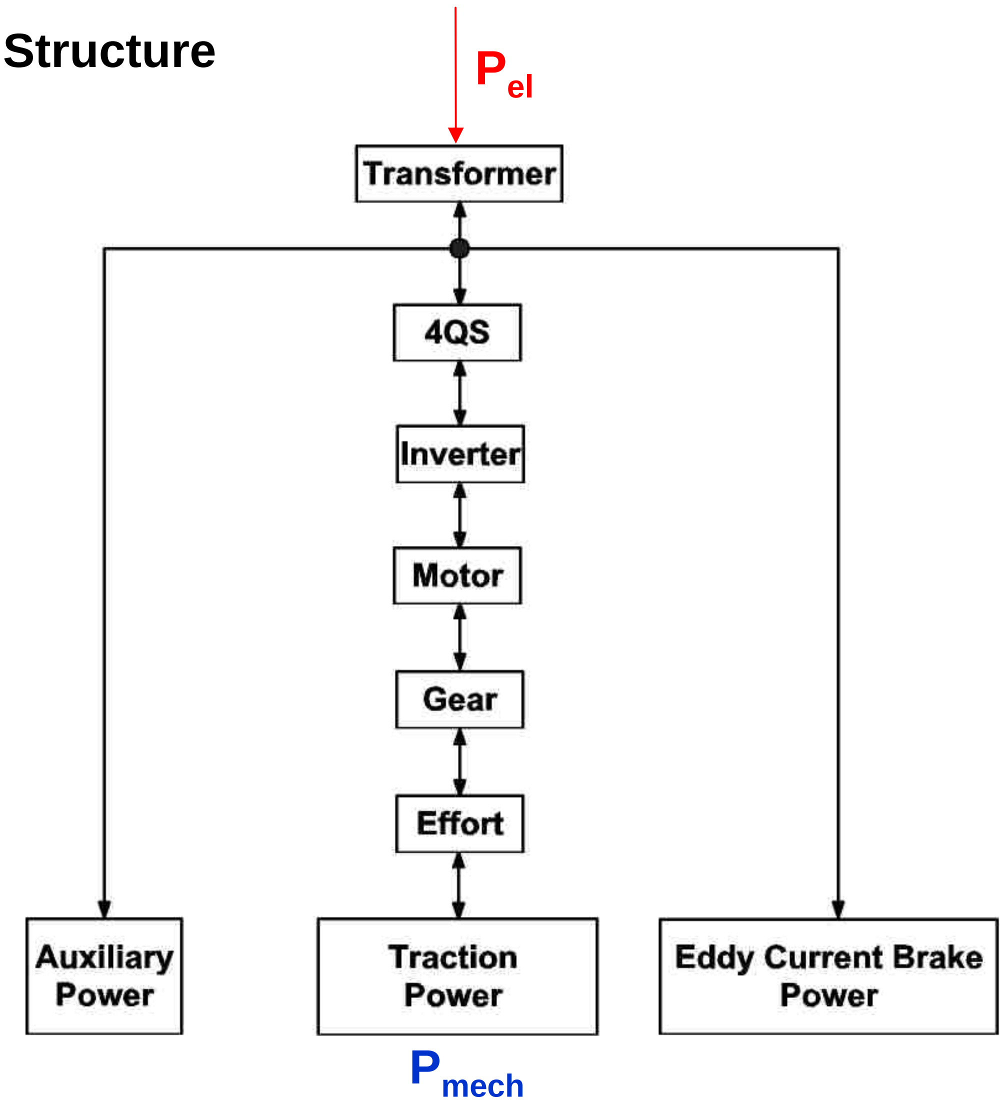
c) load depending efficiency factors of components

d) detailed engine models of components

\+ auxiliaries and eddy current break power

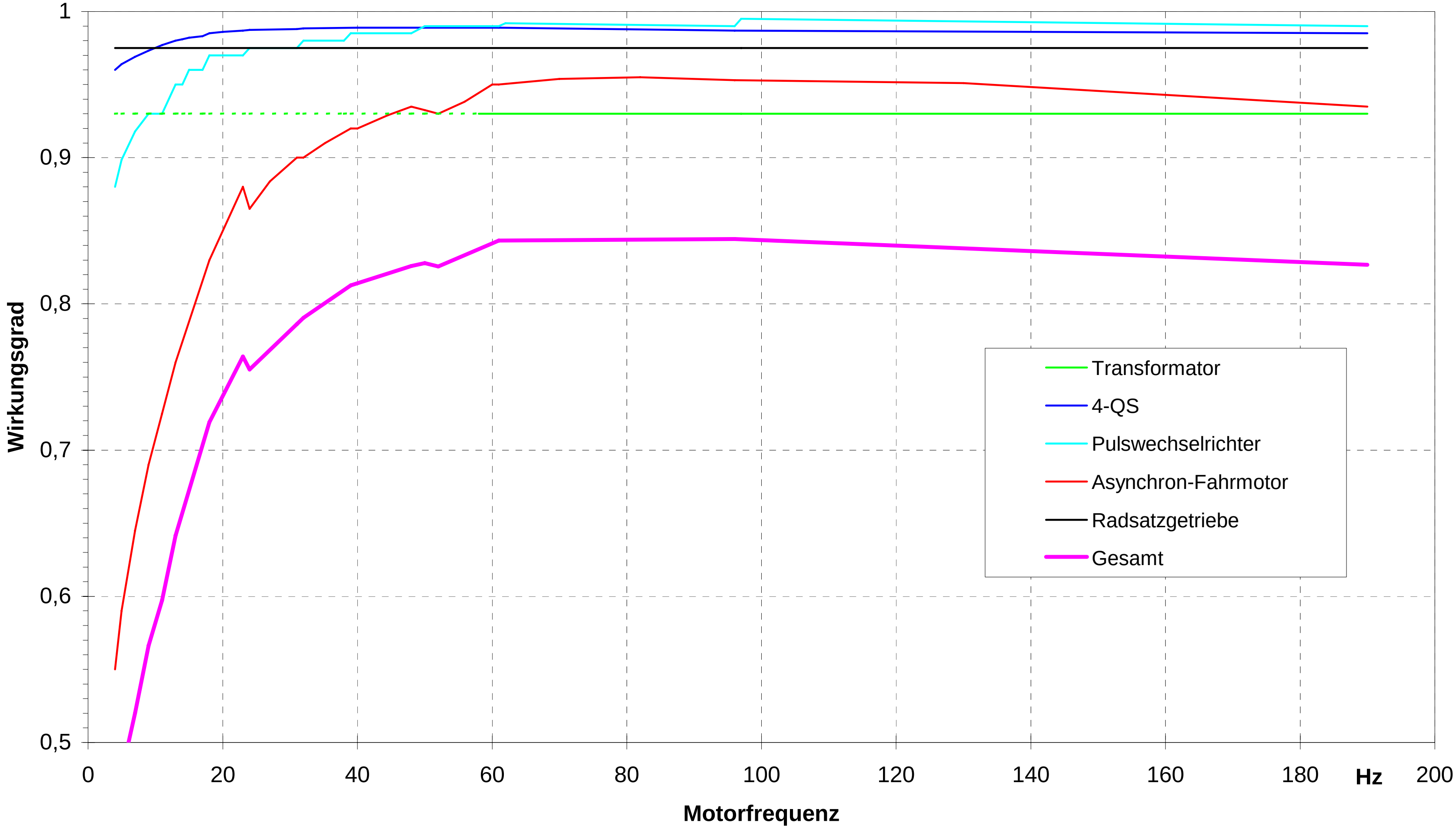
\+ additionally: limiting values of propulsion control (e.g. voltage related current limitation)

Propulsion Structure



Efficiency Characteristics of ICE3 train

1 AC 15 kV 16,7 Hz



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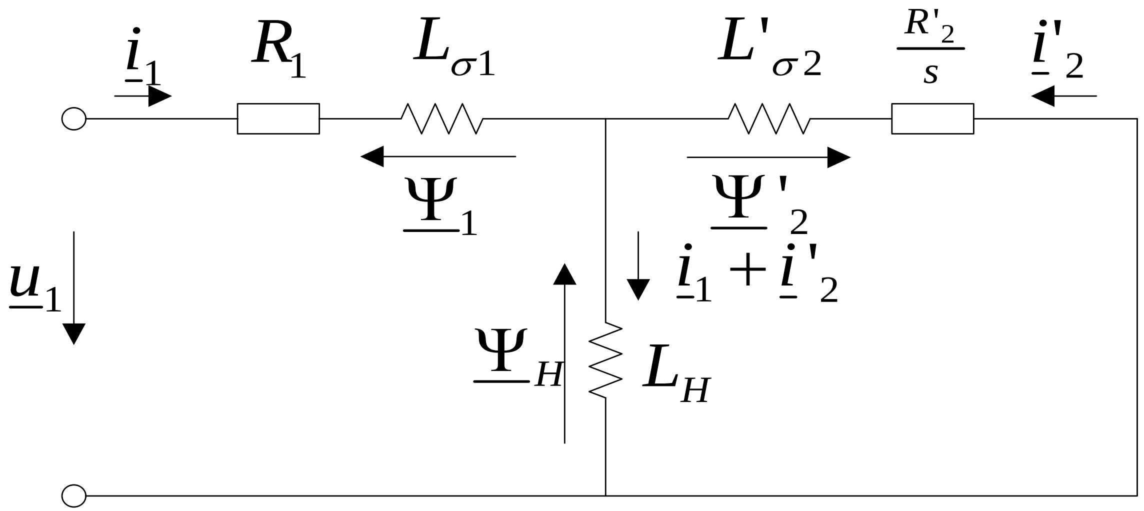
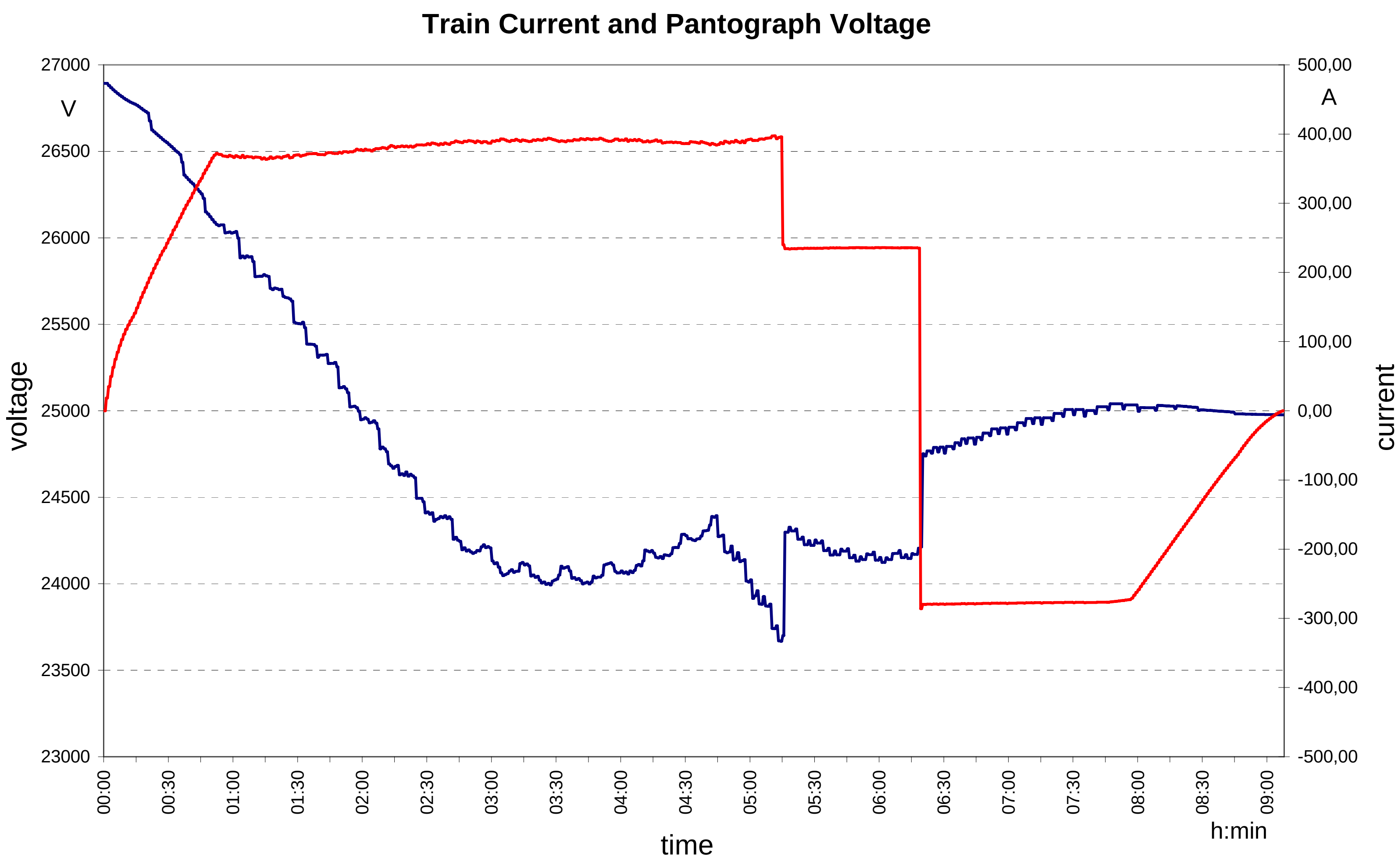
Propulsion Component Modelling (example for traction motor)



$$M_{elekt} = M_{mech} + M_{Läuferverluste}$$

$$M_{Läuferverluste} = \frac{P_{Rotorverluste}}{2\pi n} = \frac{\frac{3}{2}\underline{i}'^{2}_{2} \cdot R'_2}{2\pi n}$$

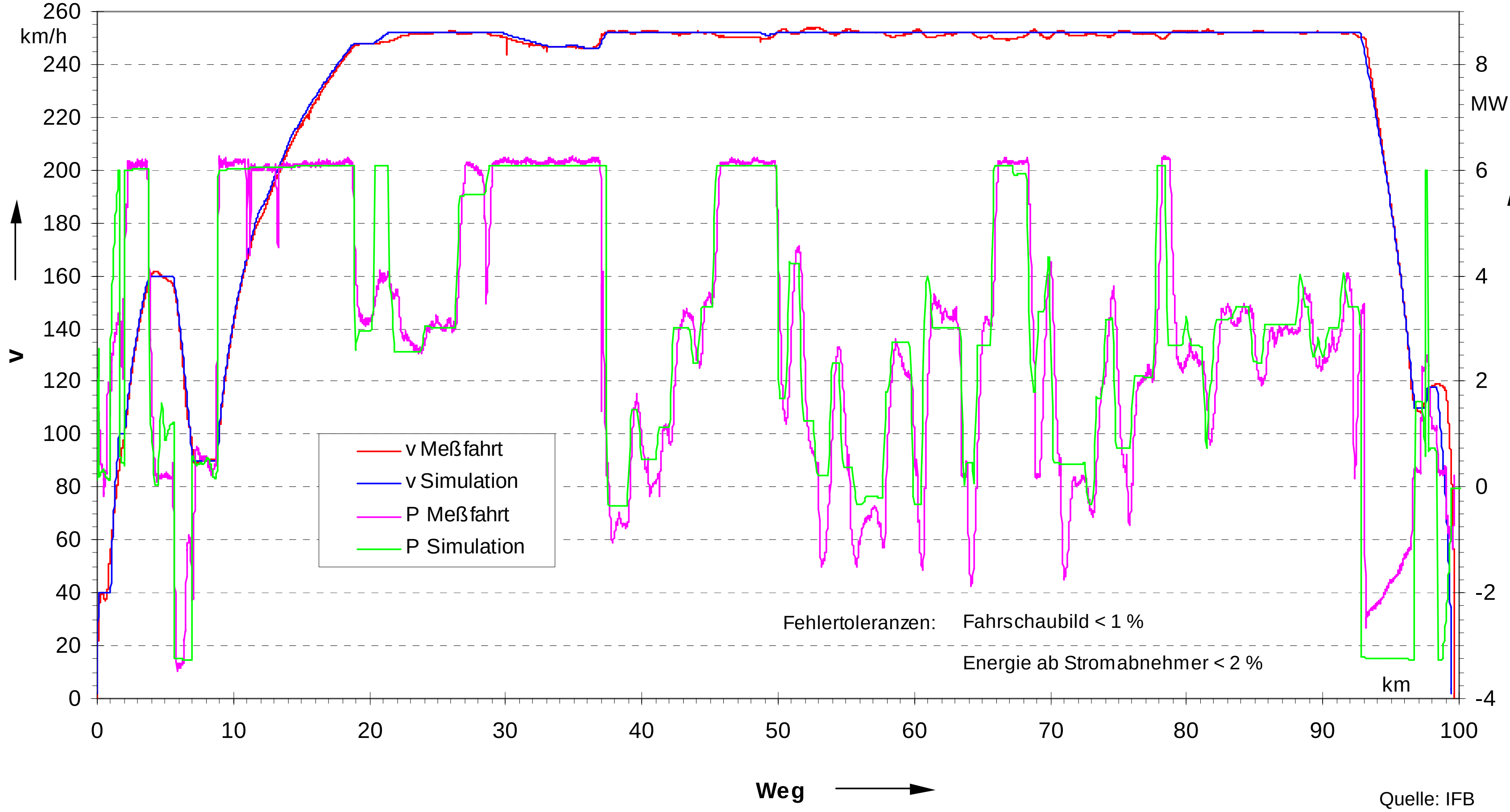
Propulsion Model Verification



Train Speed and Power Characteristics

Measurement and Simulation Results

ICE1 Hannover – Göttingen



Quelle: IFB

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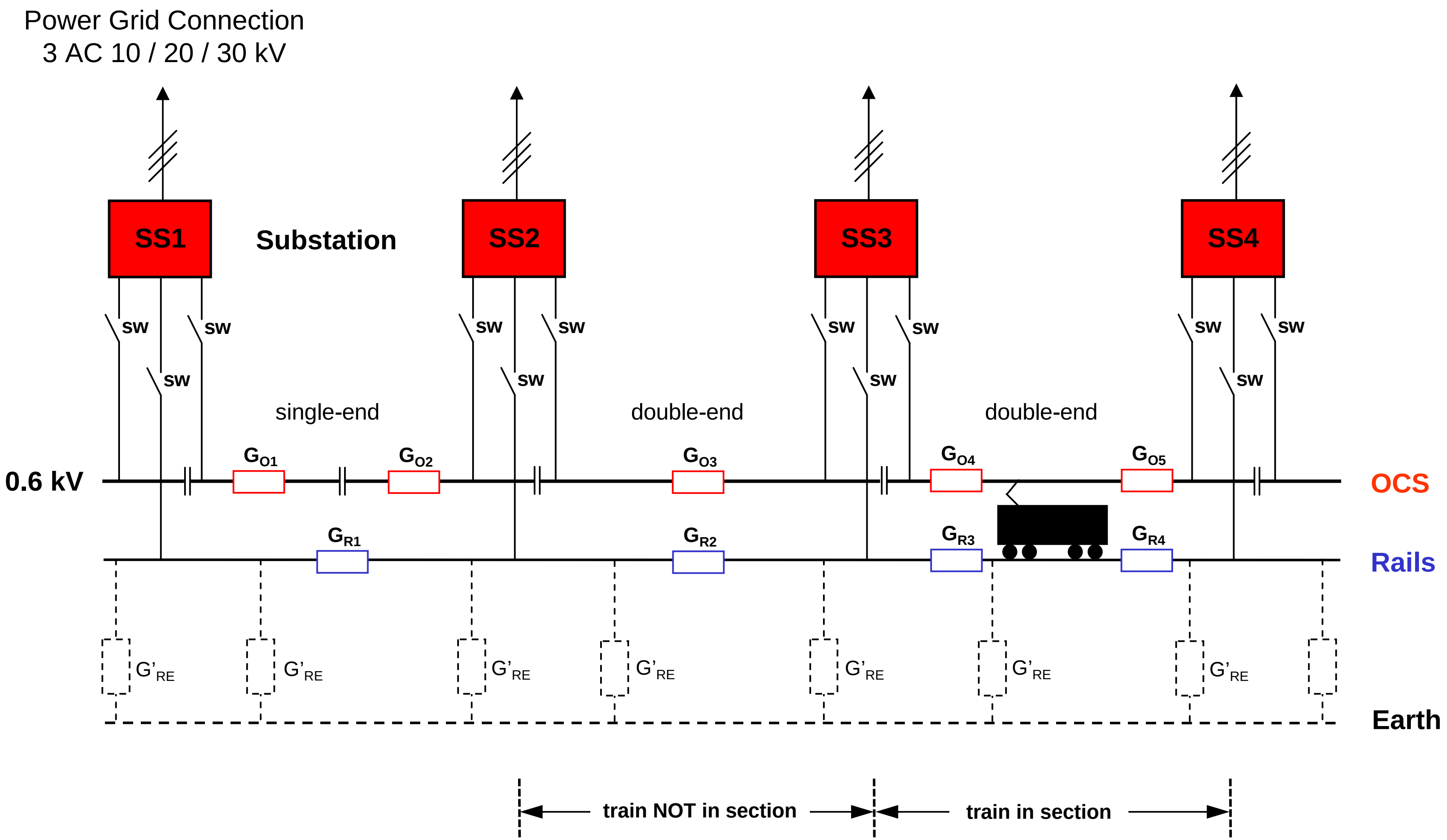
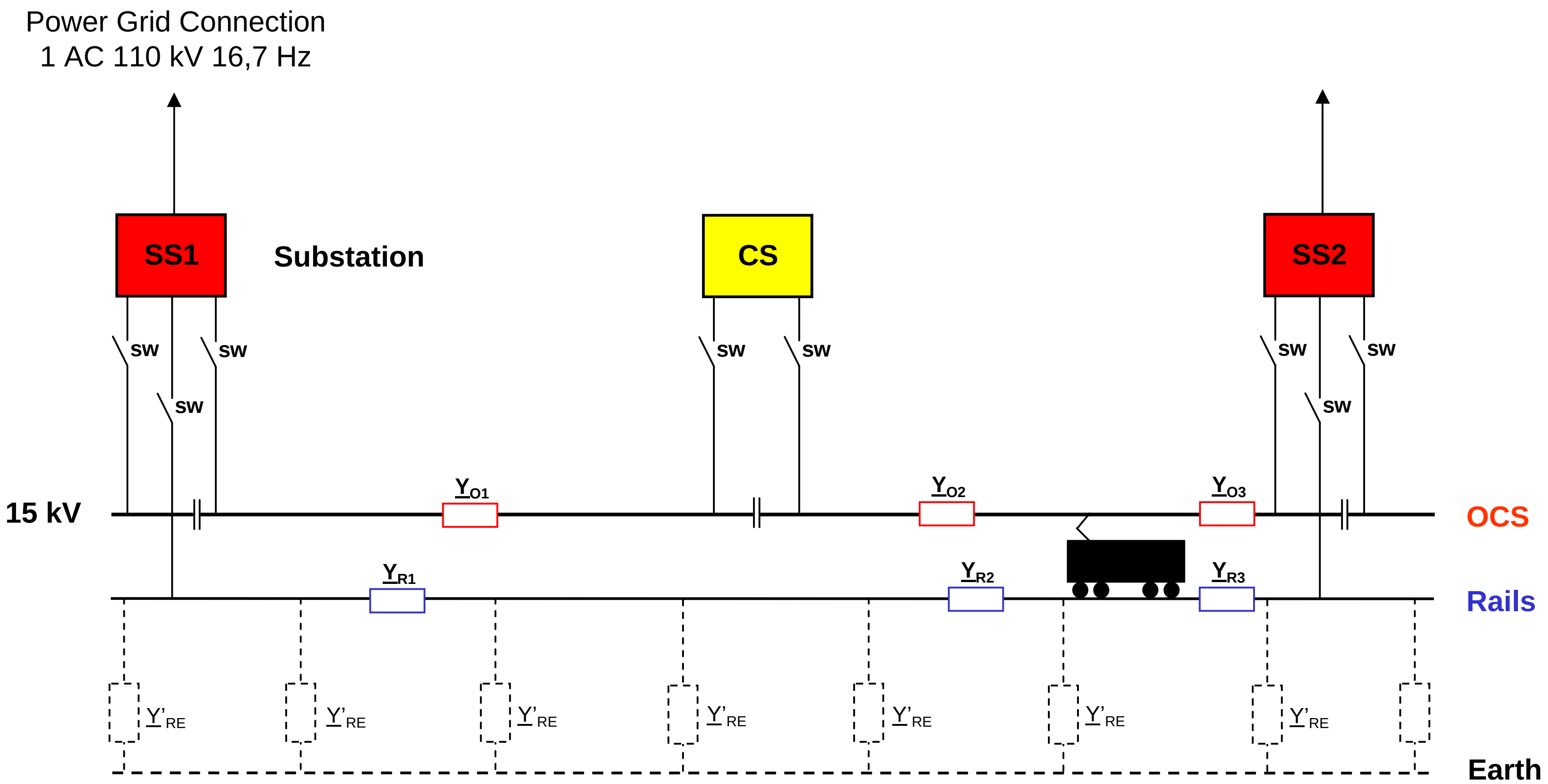
Requirements to the Electrical Network Model

- Simulation of all common AC- and DC-railway power supply systems
- Representation of the entire electrical network structure
- Unrestricted choice of conductor configuration along the line
- 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 Supply Network Structure (1 AC 15 kV 16,7 Hz)



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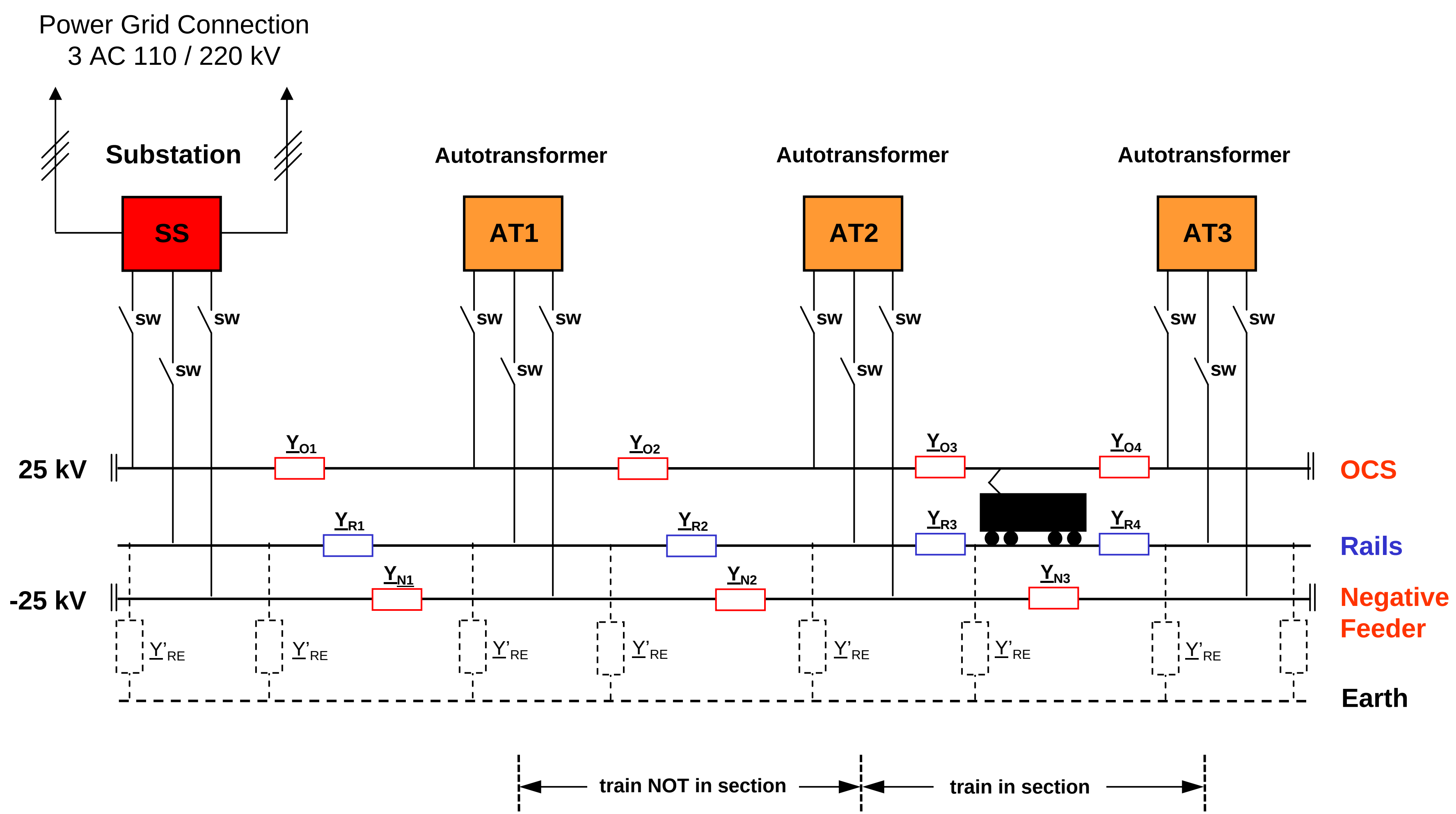
Power Supply Network Structure (2 AC 25 kV ~ 50 / 60 Hz)



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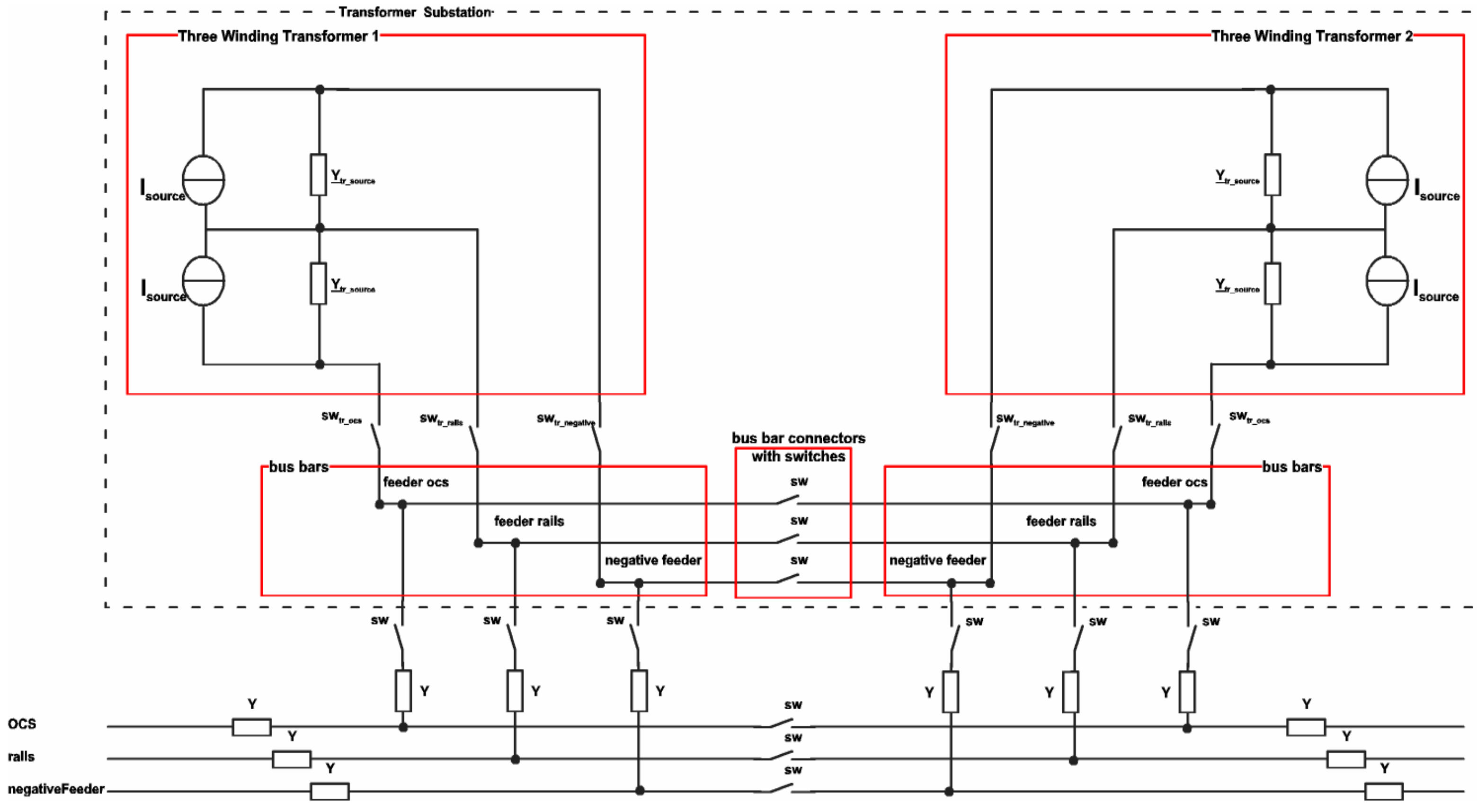
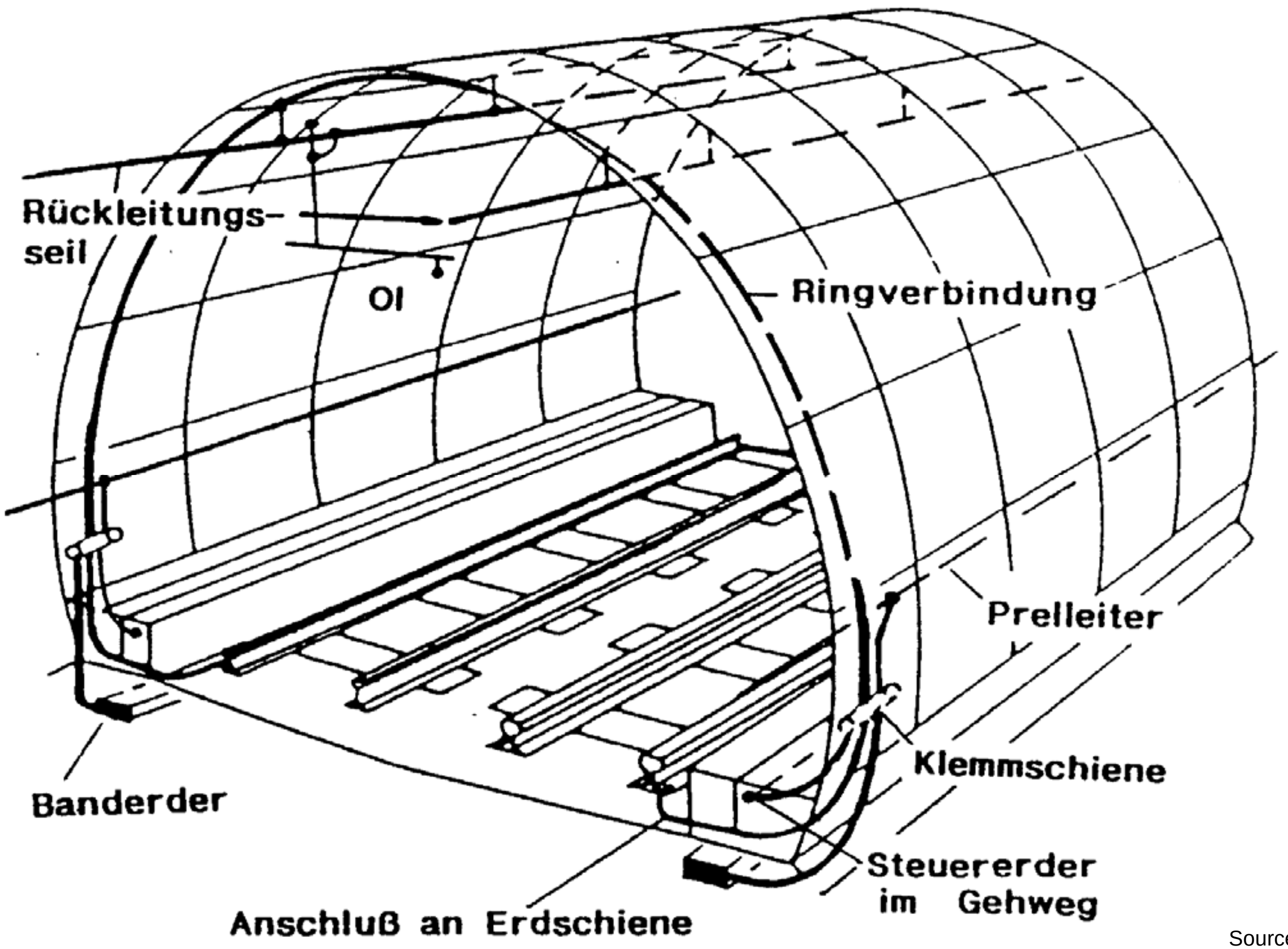
Modelling of the Railway Power Supply System

- Electrical network structure (feeding sections, feeding points, switch state) in congruence to the track topology
- Electrical characteristics of the feeding power grid
- Electrical characteristics of the substations
- Electrical characteristics of the conductors (cables, Catenary wires, tracks, rails)
- Electrical characteristics rail-to-earth
- Modelling of additional power consumers (e.g. switch heatings)
- Loading capacity (conductors, converters, transformers)
- Protection settings

Substation / AT Structure (2 AC 25 kV ~ 50/60 Hz)

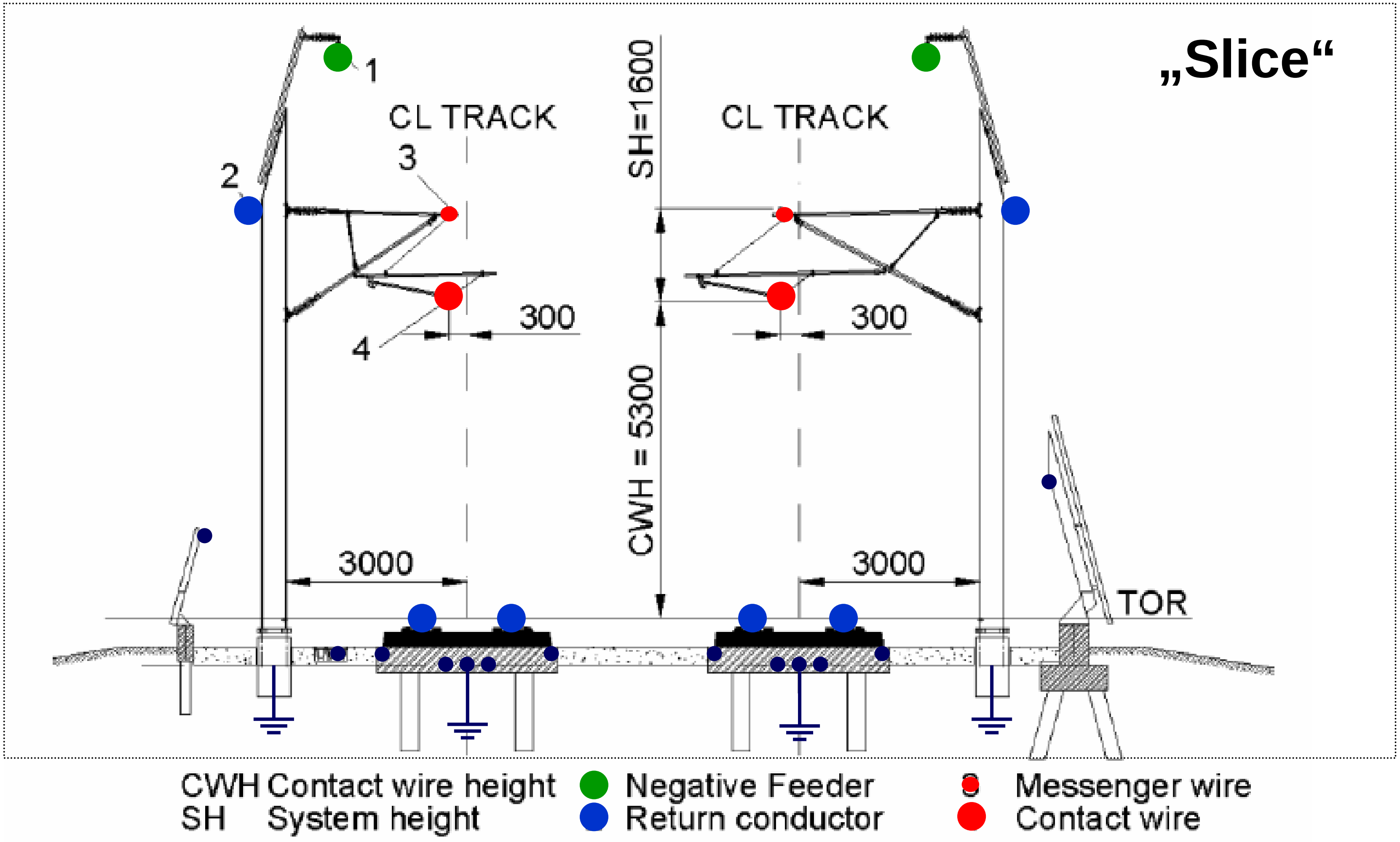


Trackside Arrangement of Conductors



Source: DB KoRiL 997

Catenary Arrangement and Conductor Model



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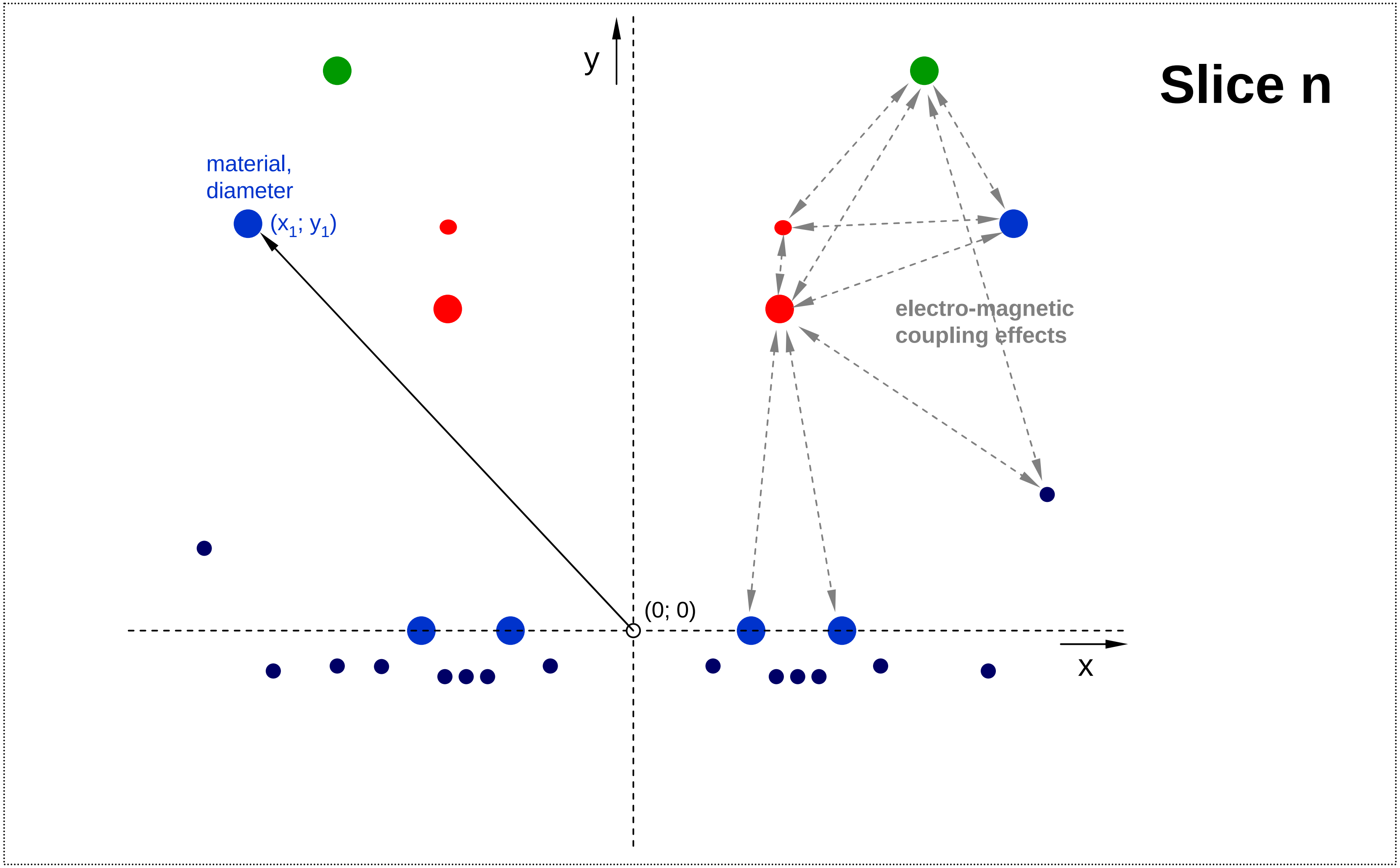
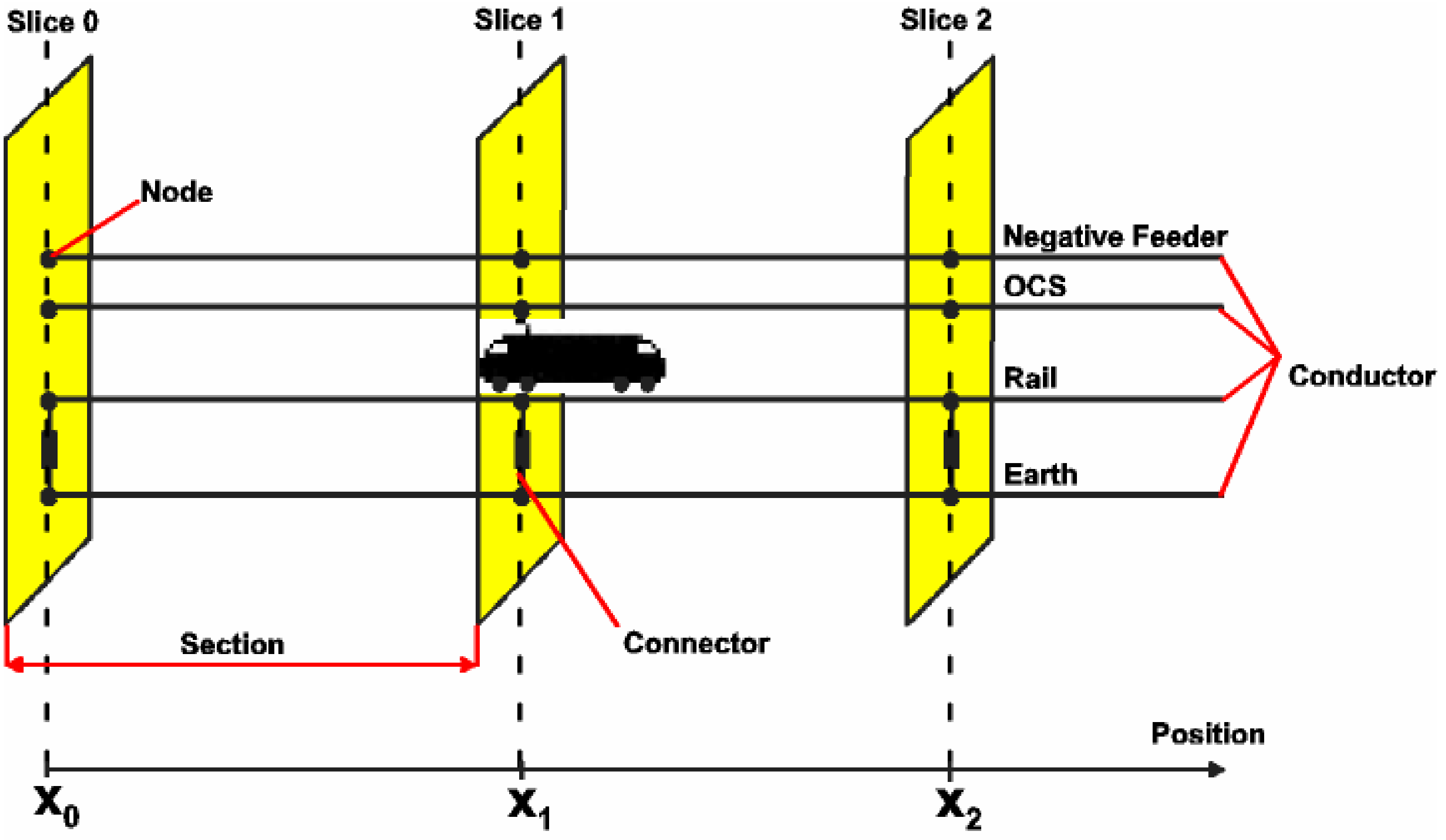
Catenary Arrangement and Conductor Model



Sequence of Slices



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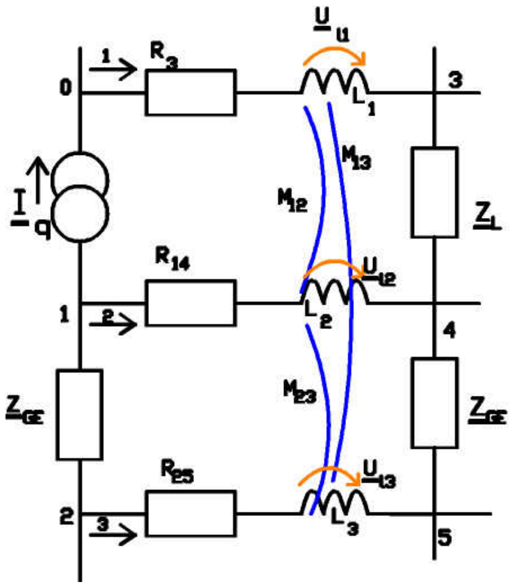

Electrical network calculation using the advanced method of nodes

$$[\underline{Y}]_{(v,v)}(\underline{U}_{v0})_{(v,1)} - [\underline{Y}_2]_{(v,LL)}(\underline{U}_L)_{(LL,1)} = (\underline{I}_q)_{(v,1)}$$

Voltage drops caused by self- and mutual induction

	node voltages					inductive voltages			currents
nodes	$\underline{U}_{10}$	$\underline{U}_{20}$	$\underline{U}_{30}$	$\underline{U}_{40}$	$\underline{U}_{50}$	$\underline{U}_{l1}$	$\underline{U}_{l2}$	$\underline{U}_{l3}$	$\underline{I}_q$
1	$G_{14}+\underline{Y}_{GE}$	$-\underline{Y}_{GE}$		$-G_{14}$			$-G_{14}$		$-\underline{I}_q$
2	$-\underline{Y}_{GE}$	$G_{25}+\underline{Y}_{GE}$			$-G_{25}$			$-G_{25}$	0
3			$G_3+\underline{Y}_L$	$-\underline{Y}_L$		G_3			0
4	$-G_{14}$		$-\underline{Y}_L$	$G_{14}+\underline{Y}_L+\underline{Y}_{GE}$	$-\underline{Y}_{GE}$		G_{14}		0
5		$-G_{25}$		$-\underline{Y}_{GE}$	$G_{25}+\underline{Y}_{GE}$			G_{25}	0

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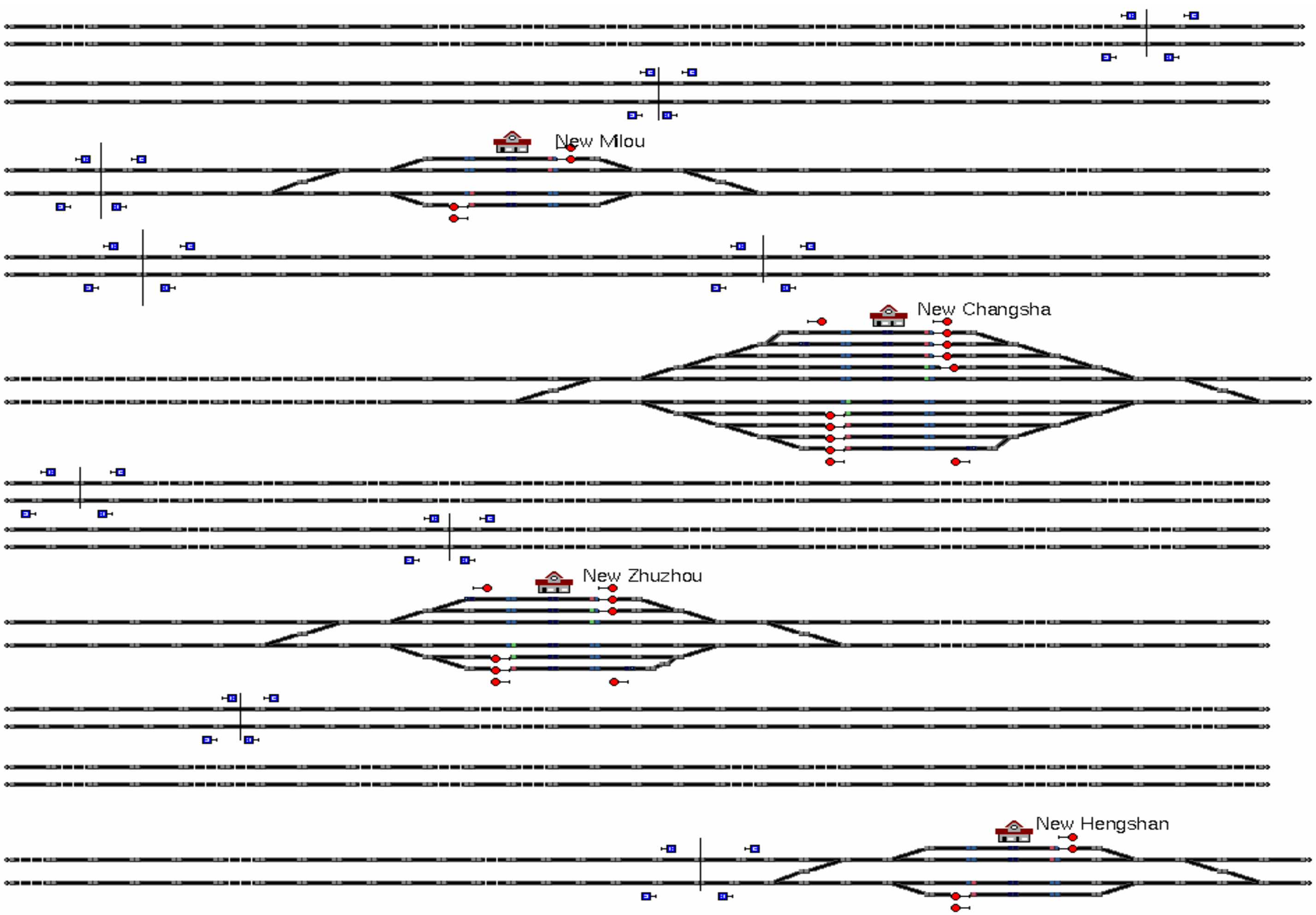
Simulation Example: High Speed Railway 966 km, Track Alignment (Detail)



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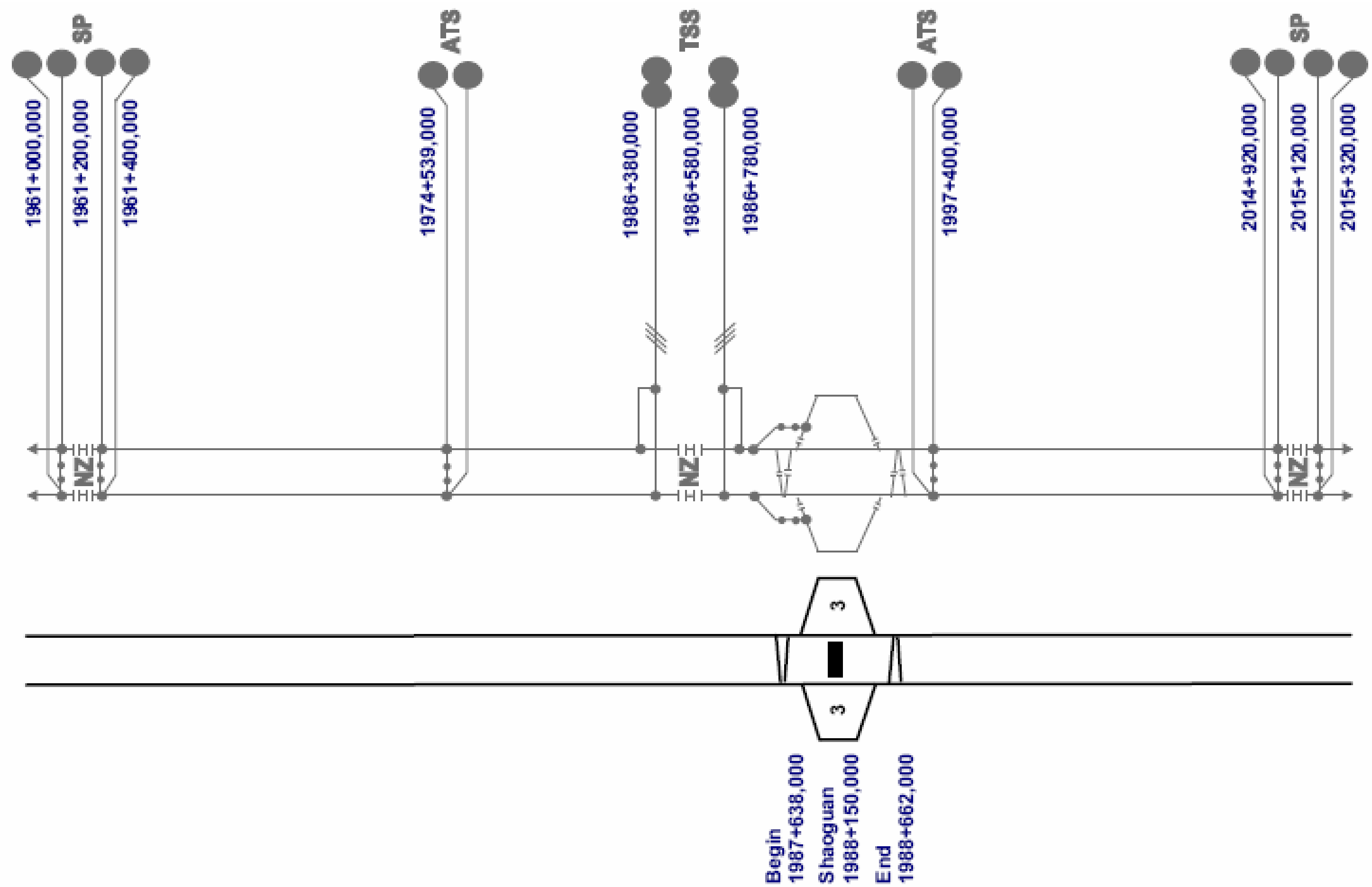
Simulation Example: High Speed Railway 966 km, OCS Infeed (Detail)



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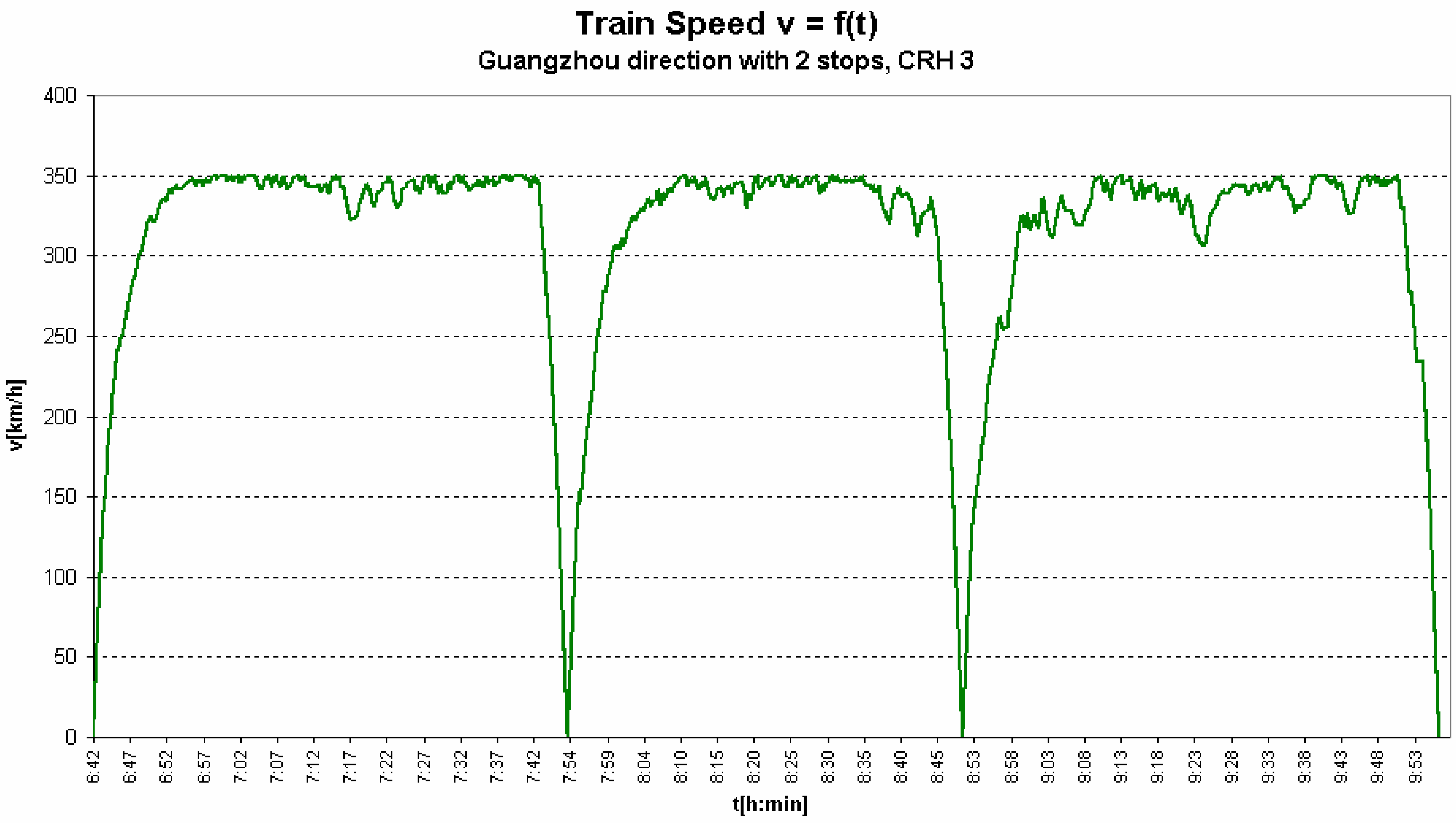
Simulation Results: High Speed Railway 2AC 25 kV



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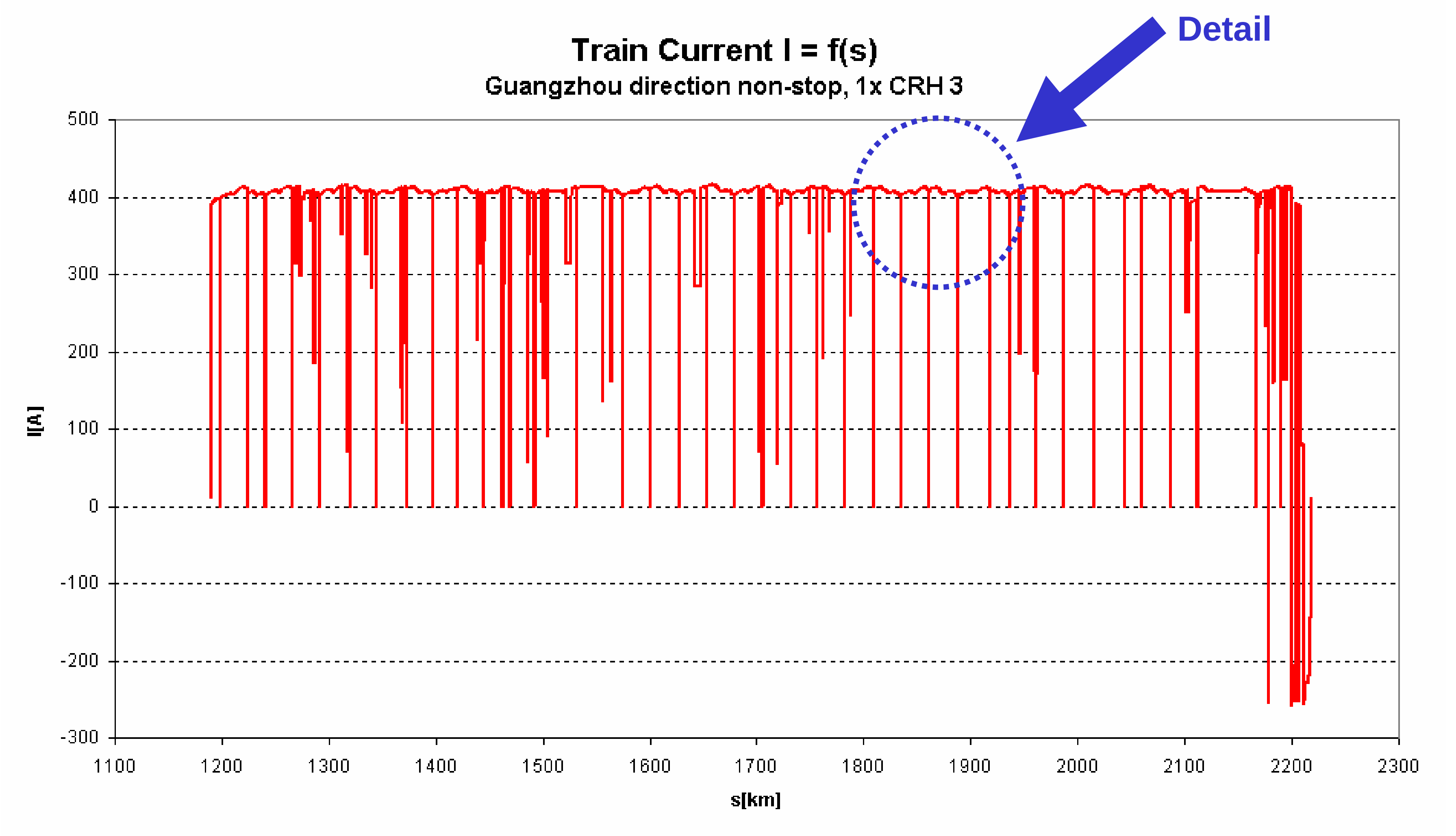

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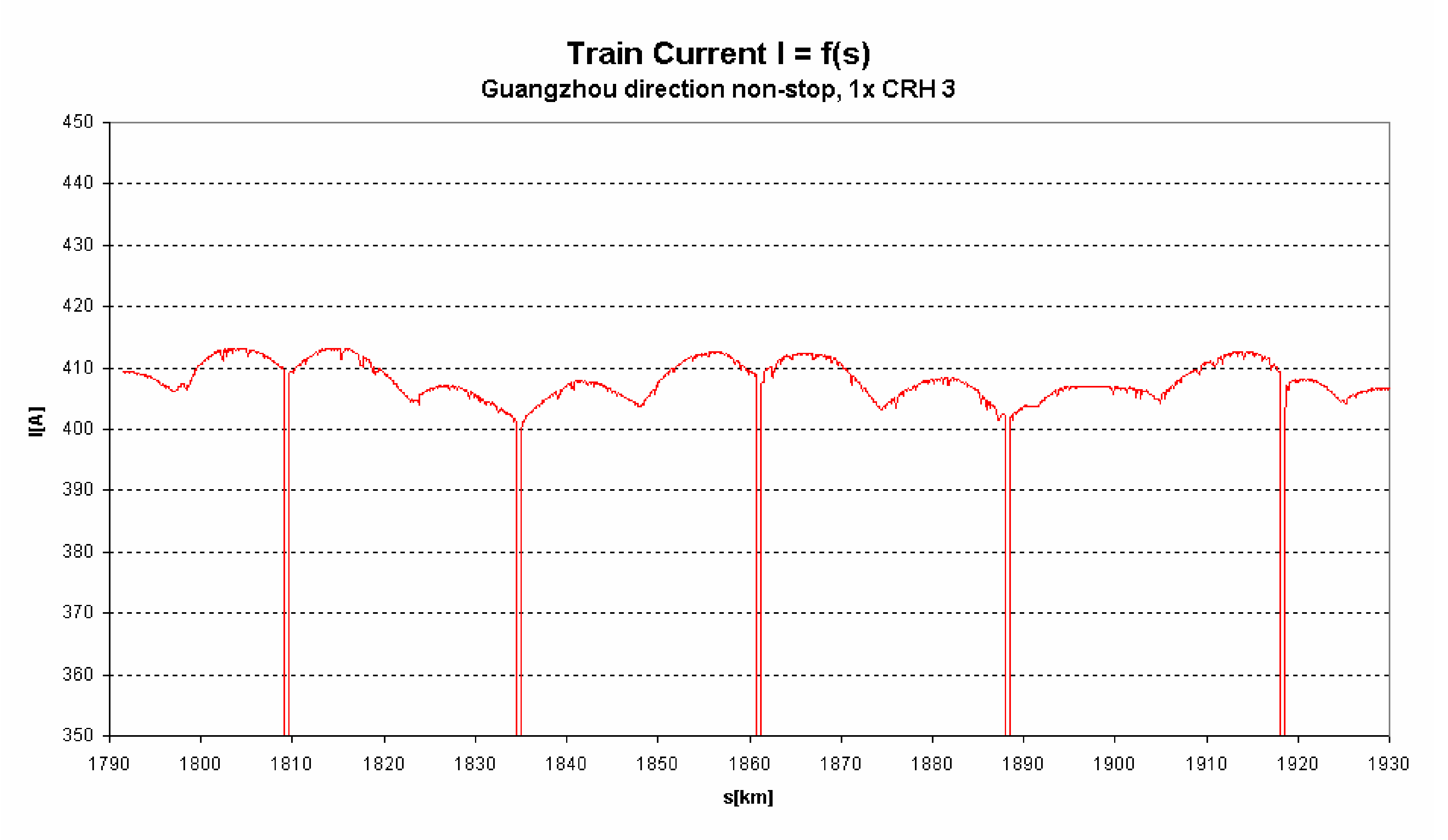

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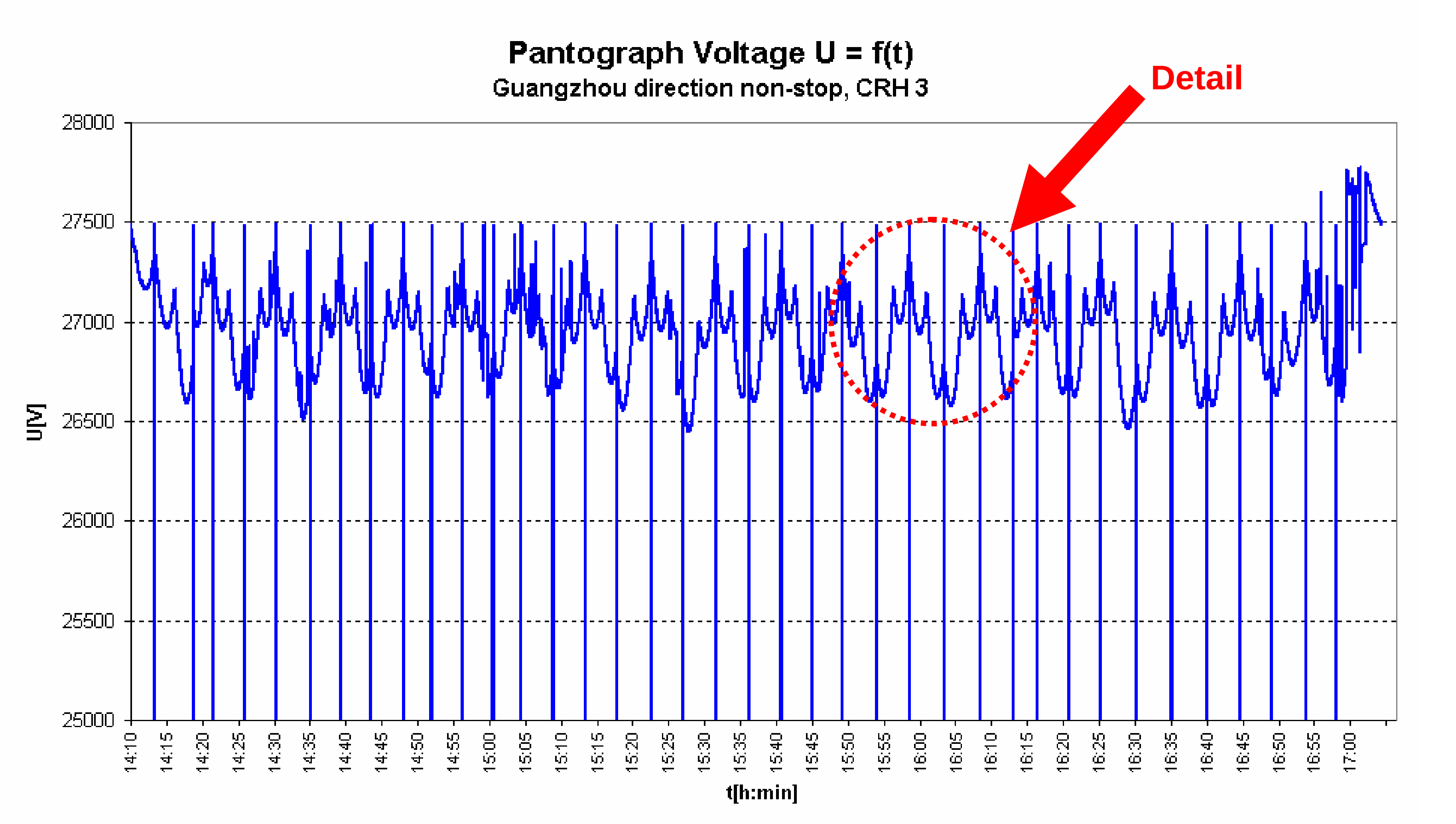

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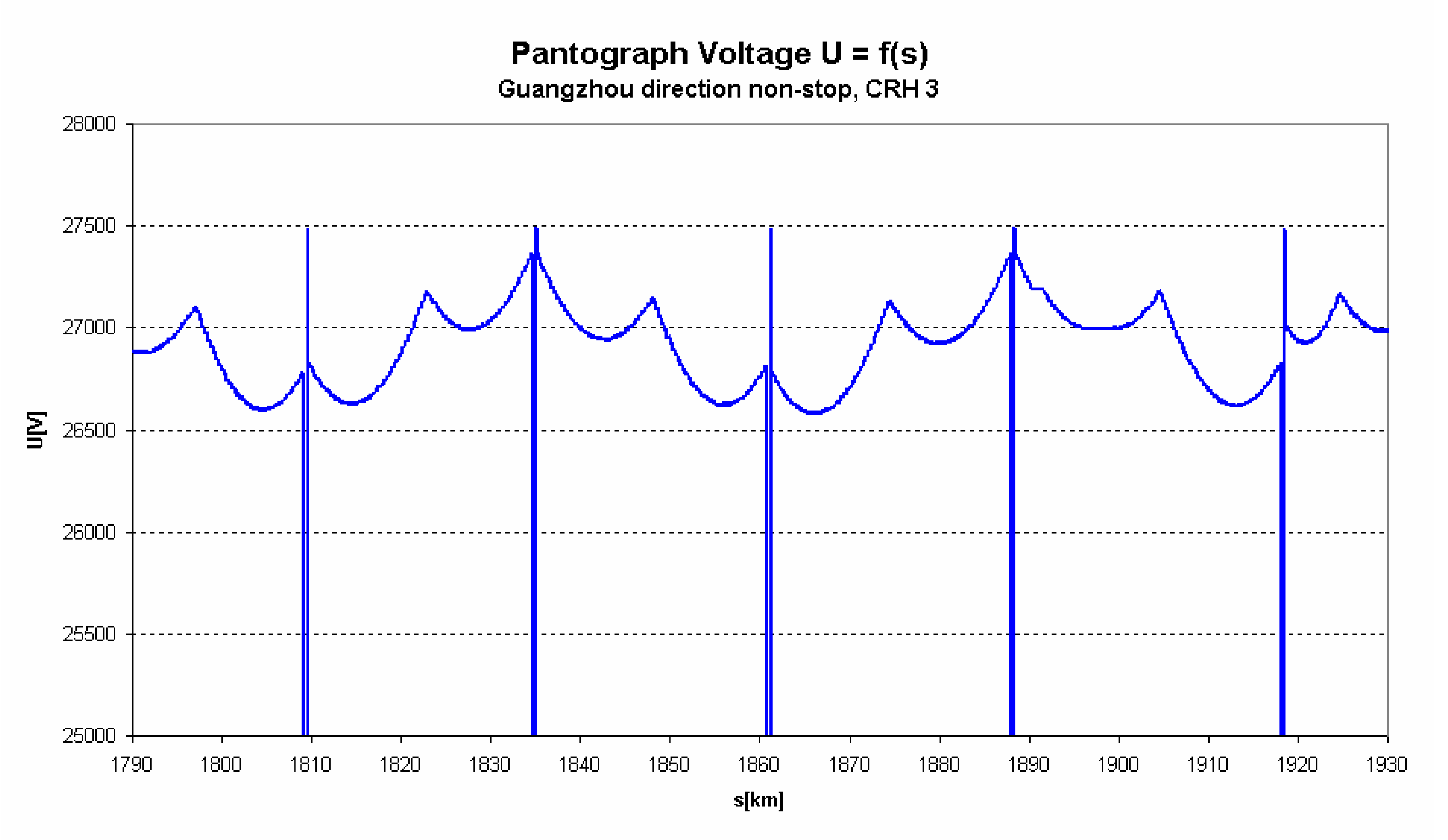
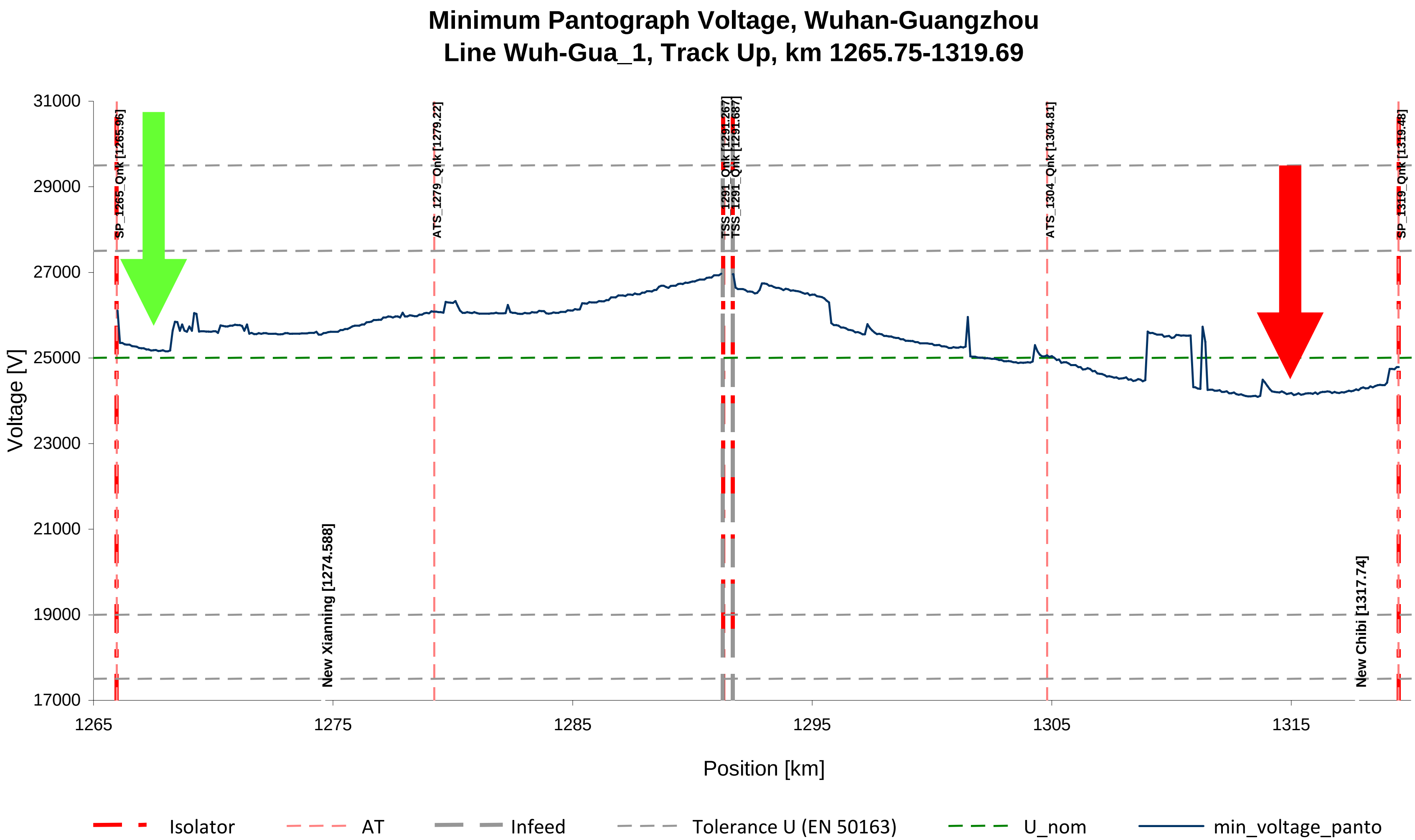


Simulation Results: High Speed Railway 2AC 25 kV



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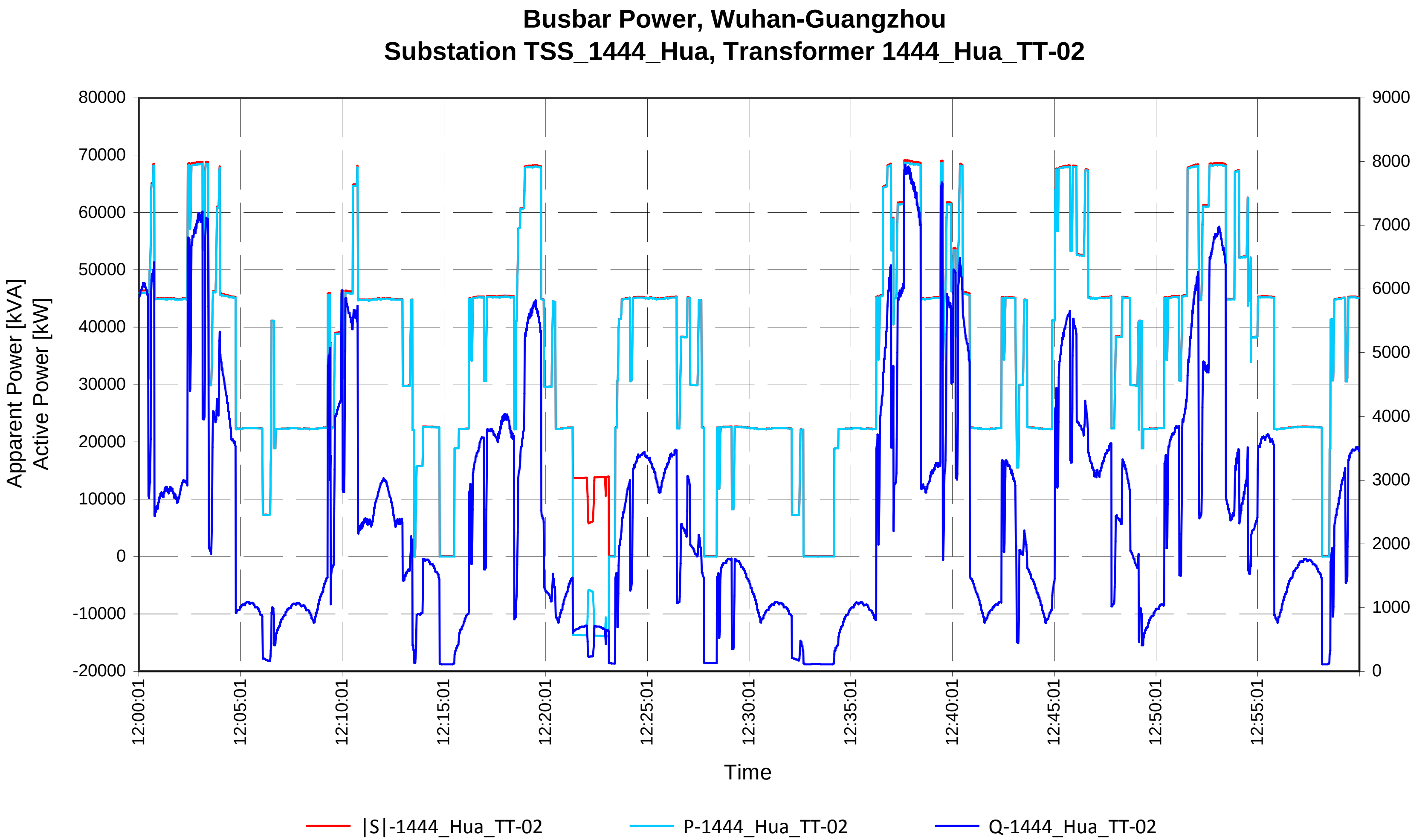
Simulation Results: High Speed Railway 2AC 25 kV



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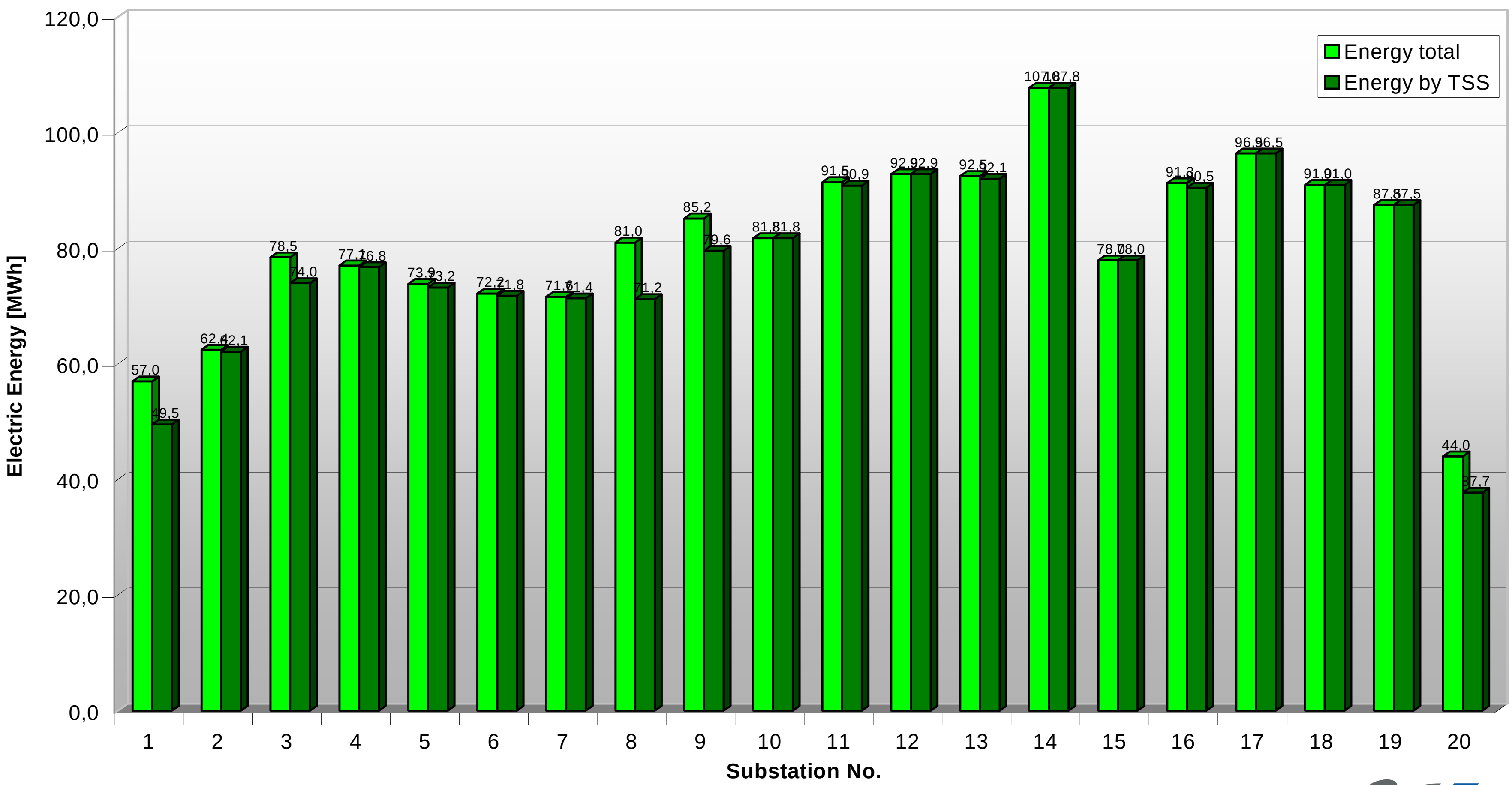
Simulation Results: High Speed Railway 2AC 25 kV

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



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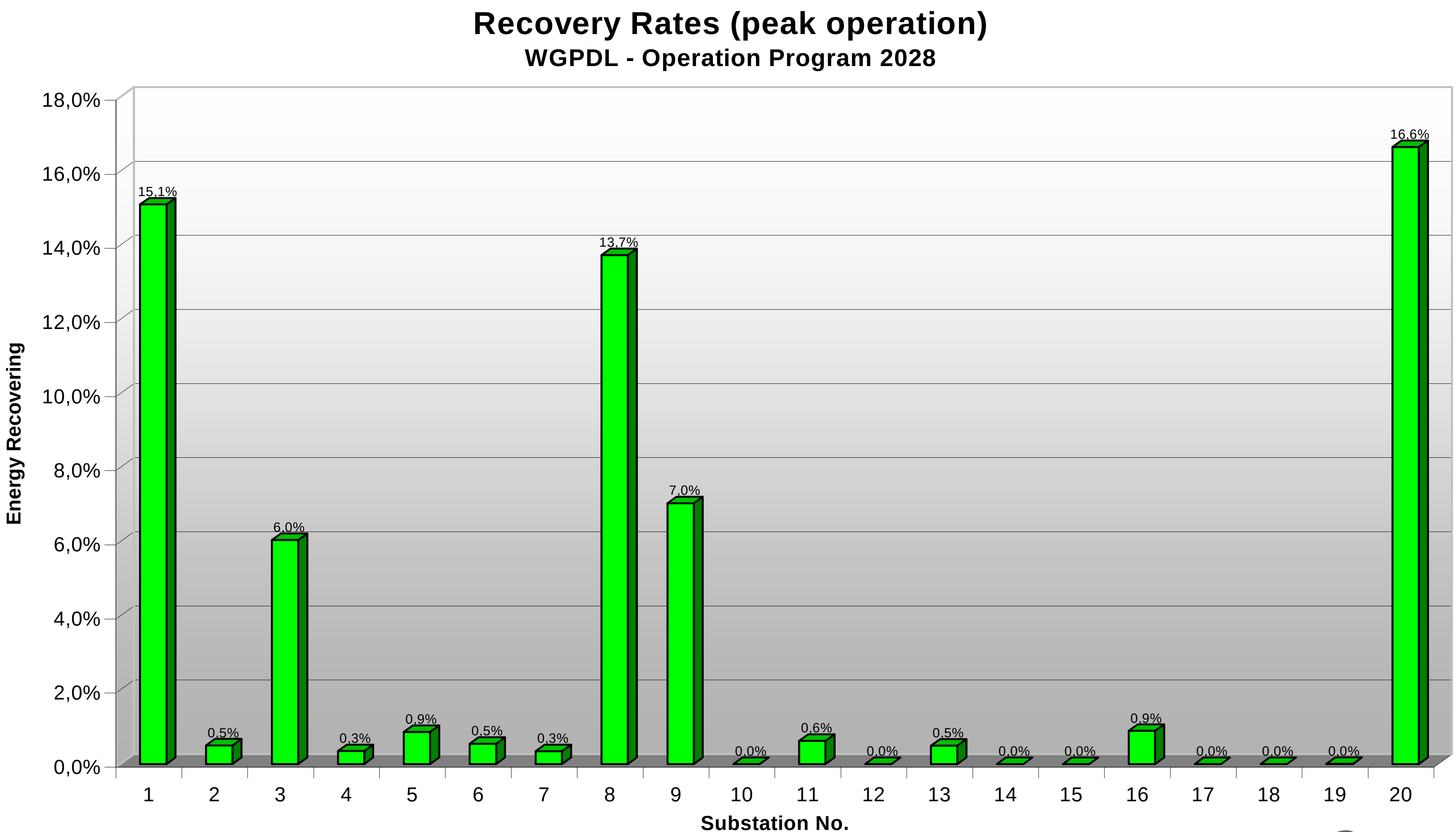
Simulation Results: High Speed Railway 2AC 25 kV



Simulation Results: High Speed Railway 2AC 25 kV

Vehicle Energy Consumption And Recovery Overview, Wuhan - Guangzhou

Ygm 1862-1918

Vehicle Type	EngineID	Transport Work [tkm]	Total Energy [kWh]	Specific Energy [Wh/tkm]	Consumed Energy [kWh]	Recovered Energy [kWh]	Degree Of Regeneration [%]	Available Braking Energy [kWh]	Used Braking Energy [kWh]
CRH3	G469-0	26001,806	1754,227	67,466	1755,741	1,513	0,1	1,942	1,596
CRH3	G469-1	26001,806	1754,227	67,466	1755,741	1,513	0,1	1,942	1,596
CRH3	G371-0	25973,739	1759,052	67,724	1759,052	0,000	0,0	0,000	0,000
CRH3	G371-1	25973,739	1759,052	67,724	1759,052	0,000	0,0	0,000	0,000
CRH3	G299-0	26002,845	1754,247	67,464	1755,755	1,508	0,1	1,936	1,591
CRH3	G299-1	26002,845	1754,247	67,464	1755,755	1,508	0,1	1,936	1,591
CRH3	G355-0	25996,262	1756,881	67,582	1758,806	1,926	0,1	3,791	2,009
CRH3	G355-1	25996,262	1756,881	67,582	1758,806	1,926	0,1	3,791	2,009
CRH3	G509-0	8741,502	588,711	67,347	588,711	0,000	0,0	0,000	0,000
CRH3	G509-1	8741,502	588,711	67,347	588,711	0,000	0,0	0,000	0,000
CRH3	G600-0	7635,276	533,004	69,808	533,004	0,000	0,0	0,000	0,000
CRH3	G600-1	7635,276	533,004	69,808	533,004	0,000	0,0	0,000	0,000
CRH3	G520-0	15460,187	1068,943	69,142	1068,943	0,000	0,0	0,000	0,000
CRH3	G520-1	15460,187	1068,943	69,142	1068,943	0,000	0,0	0,000	0,000

Simulation Results: High Speed Railway 2AC 25 kV

Energy Consumption And Losses Overview, Wuhan - Guangzhou

Cha 1532-1600

Energy output to catenary at substation [kWh]	72300,187
Energy input from catenary at substation [kWh]	1154,082
Total energy at substation [kWh]	**71146,105**

Vehicles energy consumption [kWh]	78540,848
Vehicles braking energy used for auxiliaries [kWh]	639,139
Vehicles braking energy recovered by catenary [kWh]	9230,867
Total used vehicles braking energy [kWh]	9870,007
Total vehicles energy [kWh]	**69309,980**

Total energy consumption [kWh]	**81016,112**
Energy consumption from national power grid [kWh]	71233,480

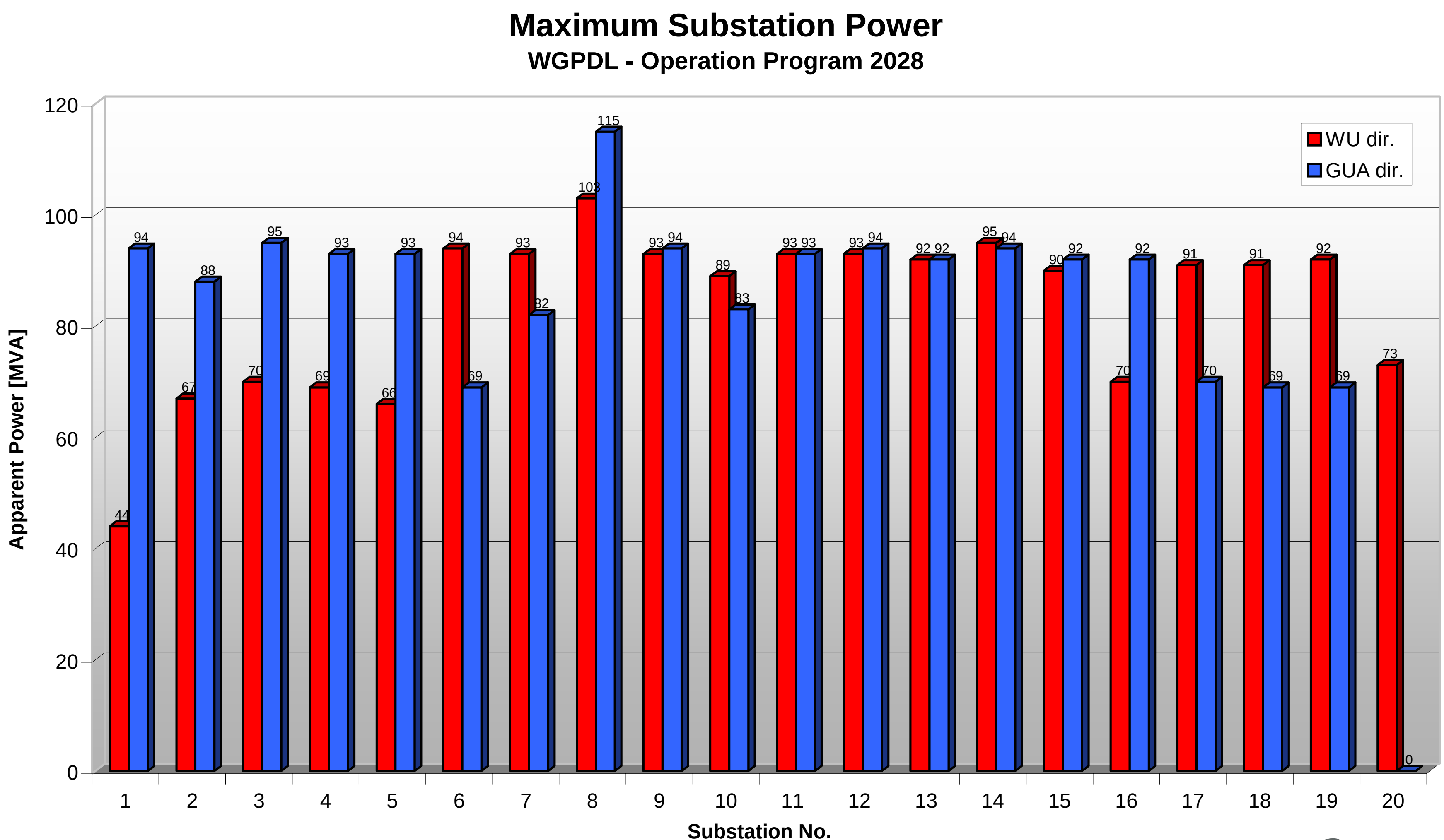
Average efficiency of traction power supply	**97,6%**

Losses in contact wire [kWh]	525,588
Losses in messenger wire [kWh]	565,248
Losses in negative feeder [kWh]	481,426
Losses in return conductor [kWh]	138,879
Losses in left rail [kWh]	13,174
Losses in right rail [kWh]	13,196
Losses in LEBC [kWh]	31,117
Total losses in conductors [kWh]	1768,629
Losses in connectors [kWh]	1,495
Losses in autotransformers [kWh]	21,896
Total losses in catenary system [kWh]	**1792,020**

Losses in feeders [kWh]	44,072

Losses in traction transformers [kWh]	87,375

Simulation Results: High Speed Railway 2AC 25 kV



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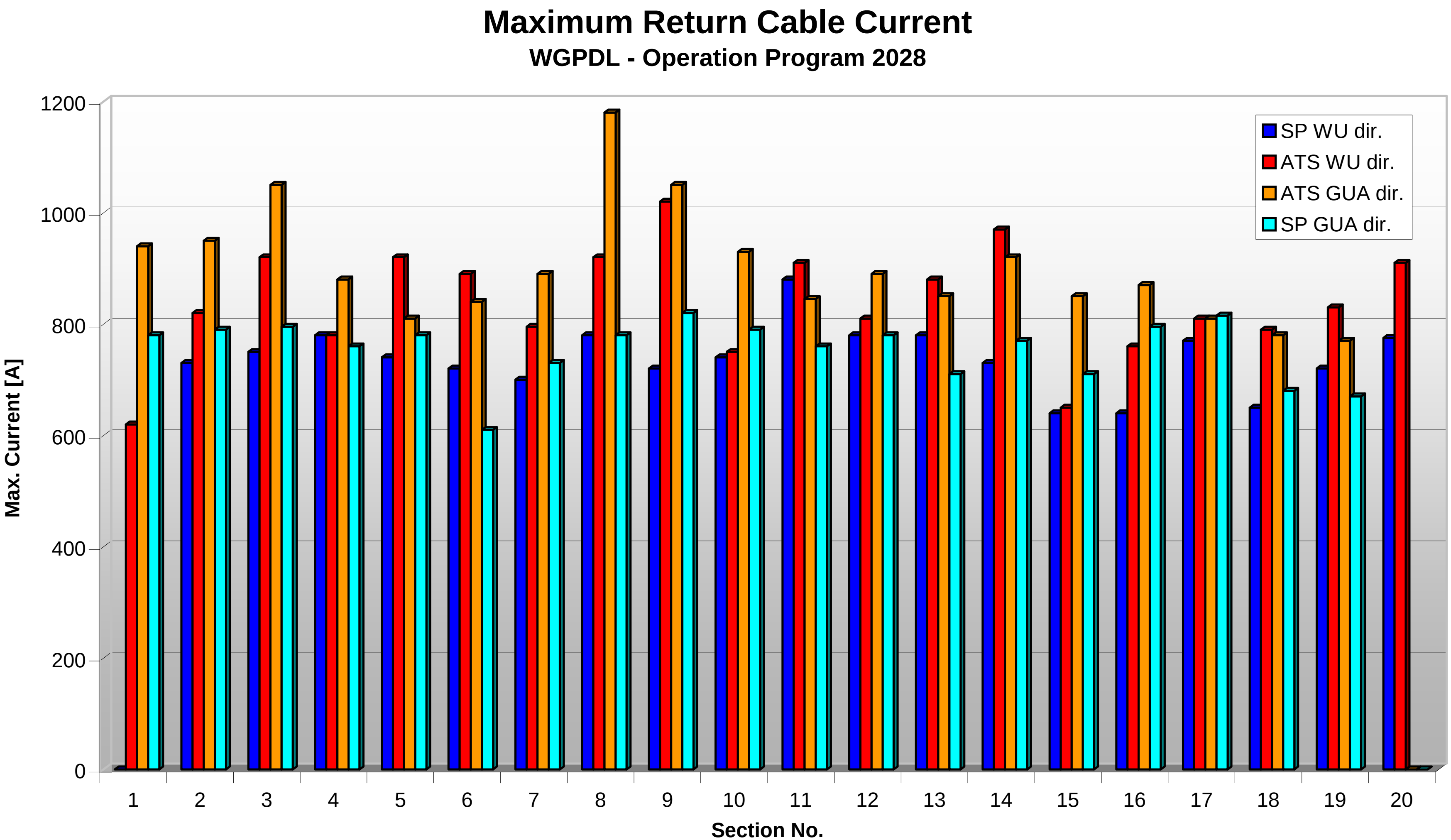
Simulation Results: High Speed Railway 2AC 25 kV



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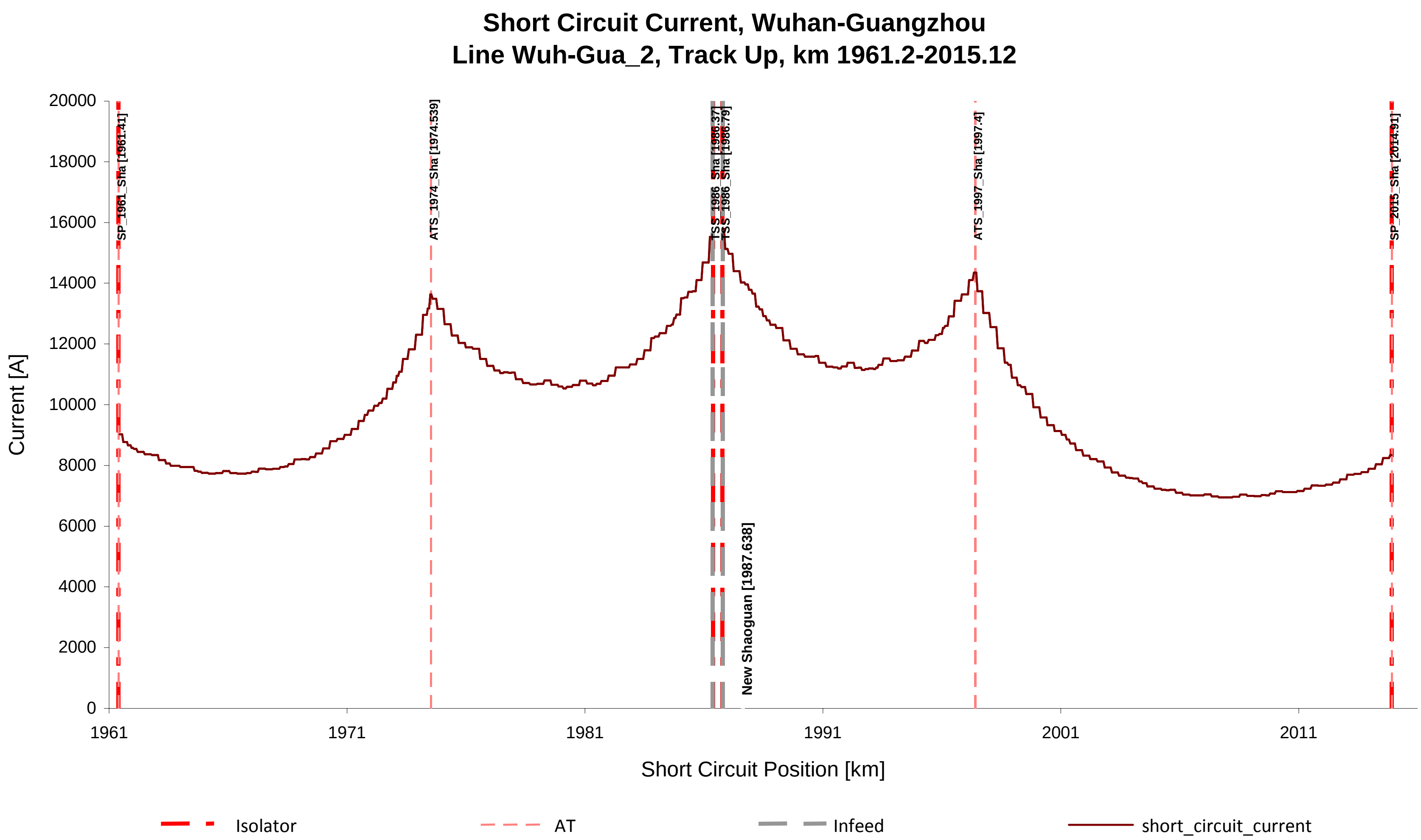
Simulation Results: High Speed Railway 2AC 25 kV



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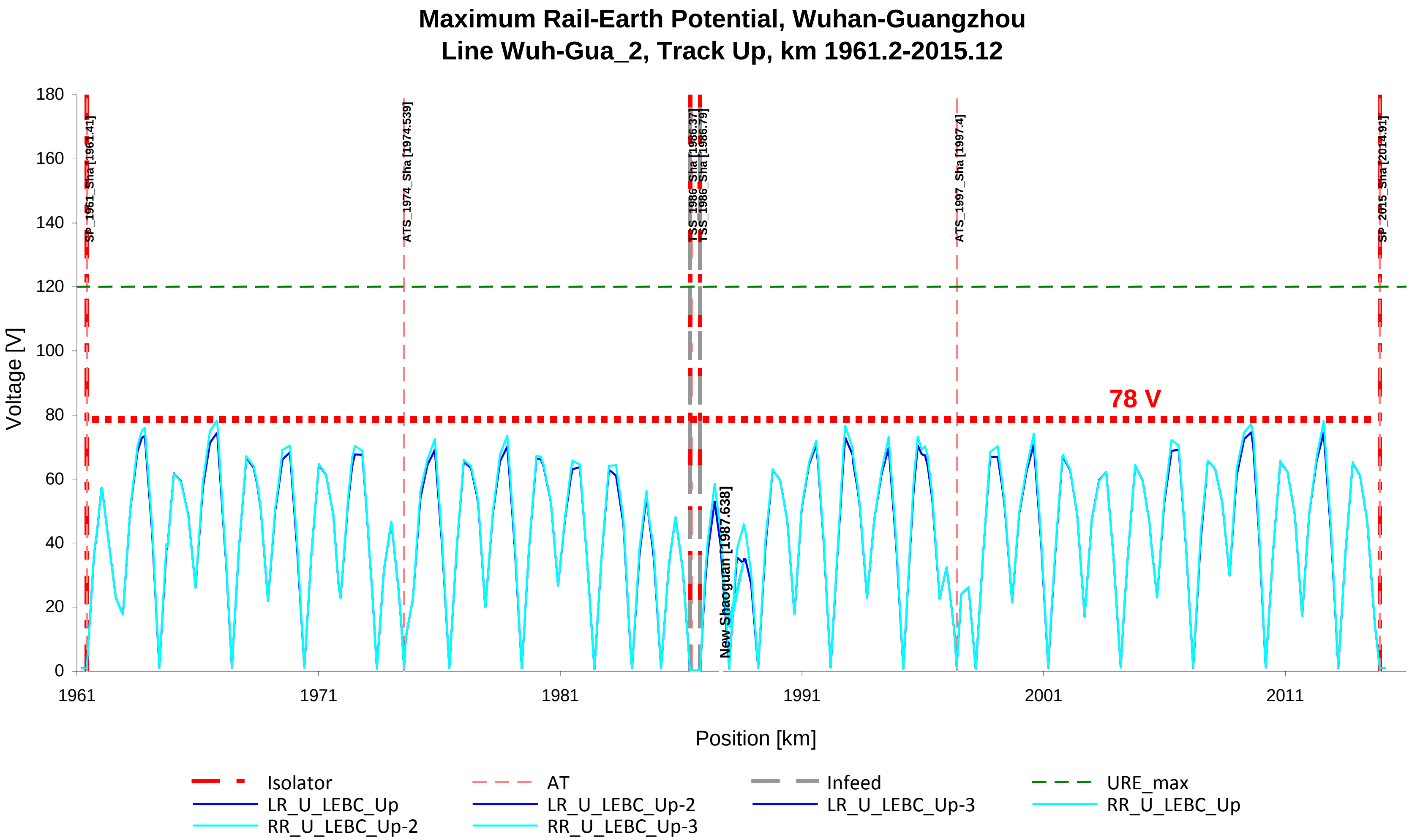
Simulation Results: High Speed Railway 2AC 25 kV



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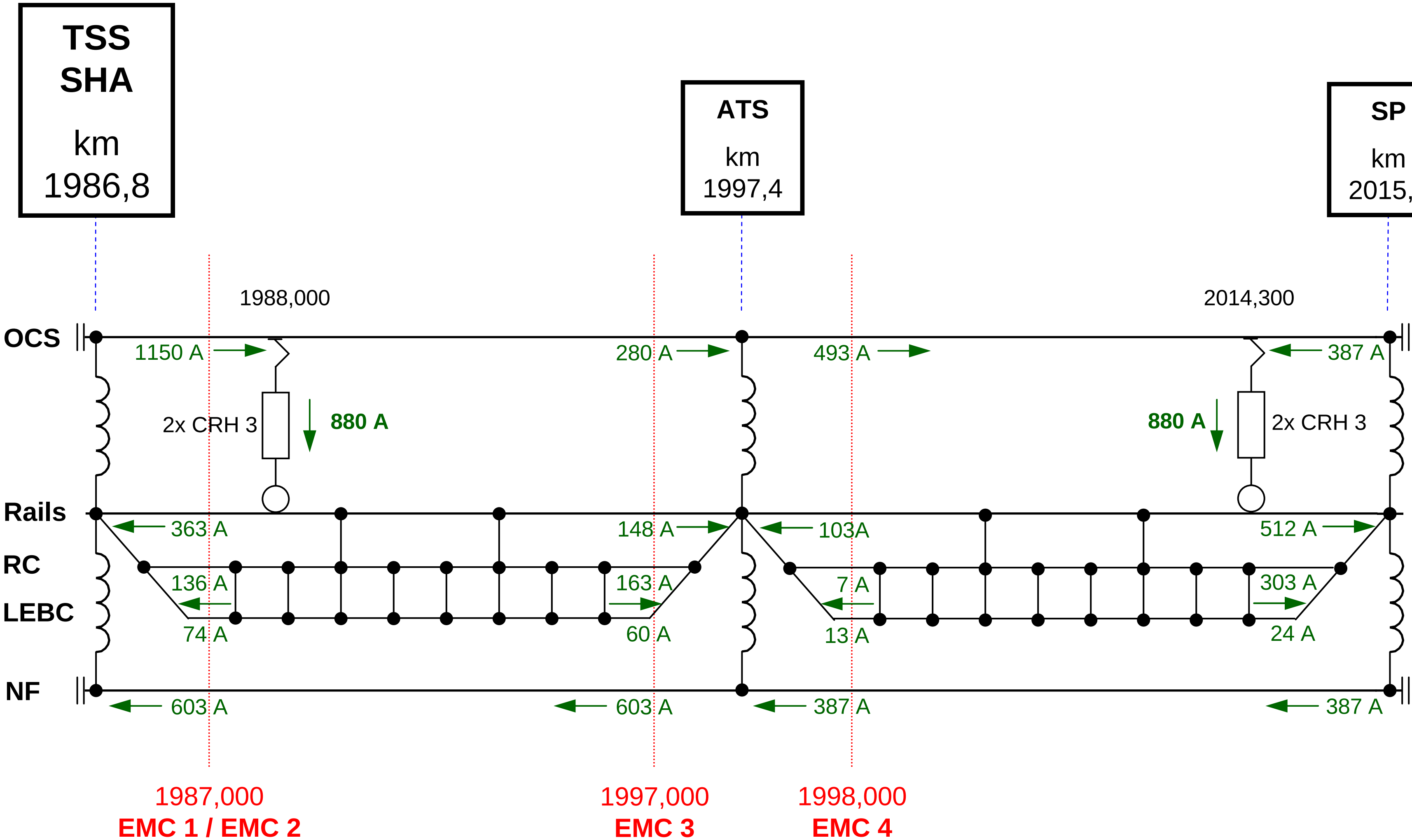
Simulation Results: High Speed Railway 2AC 25 kV



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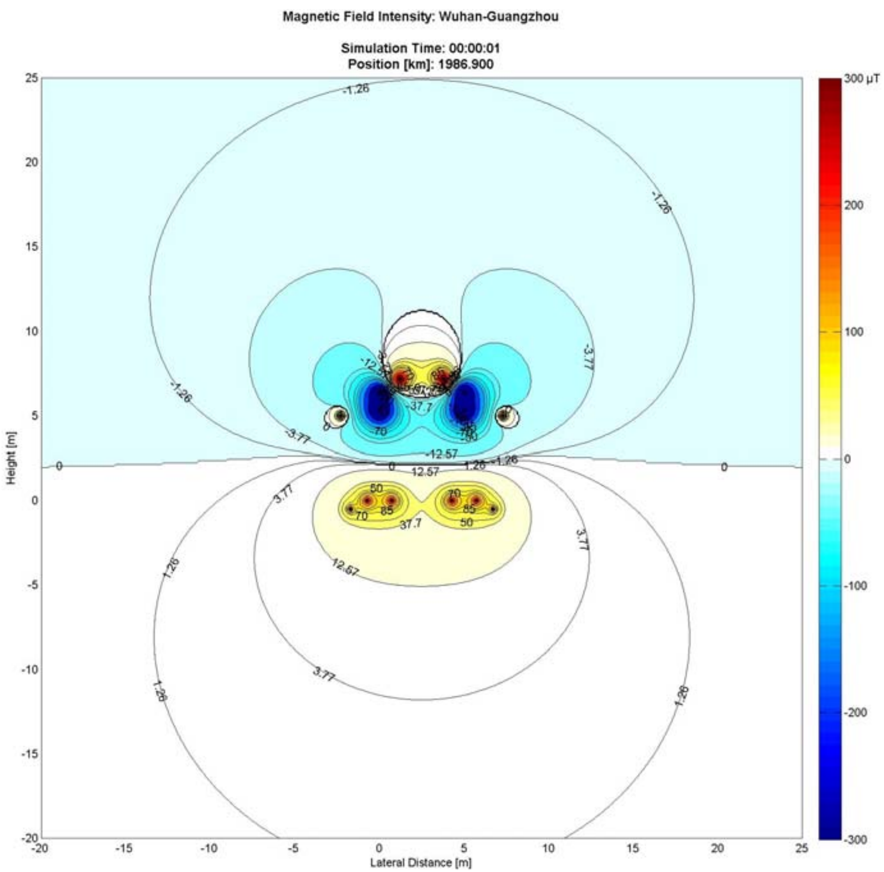
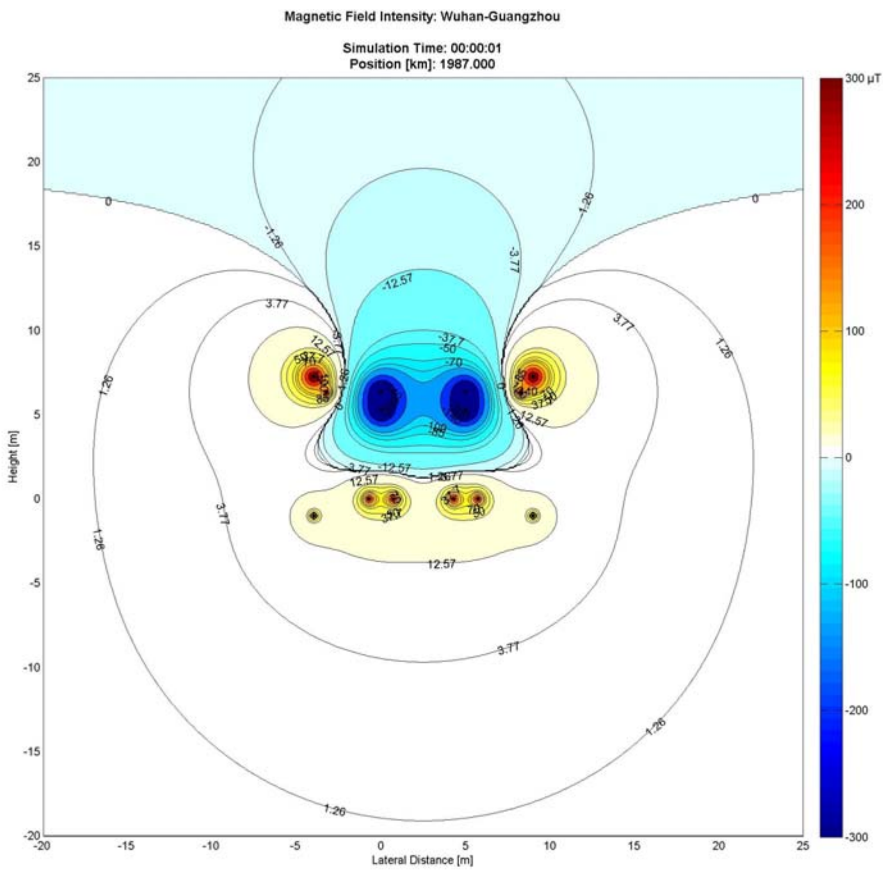
Simulation Results: High Speed Railway 2AC 25 kV



tunnel



subgrade

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City Light Rail Network

300 km TRAM

220 km Trolleybus

DC 600 V

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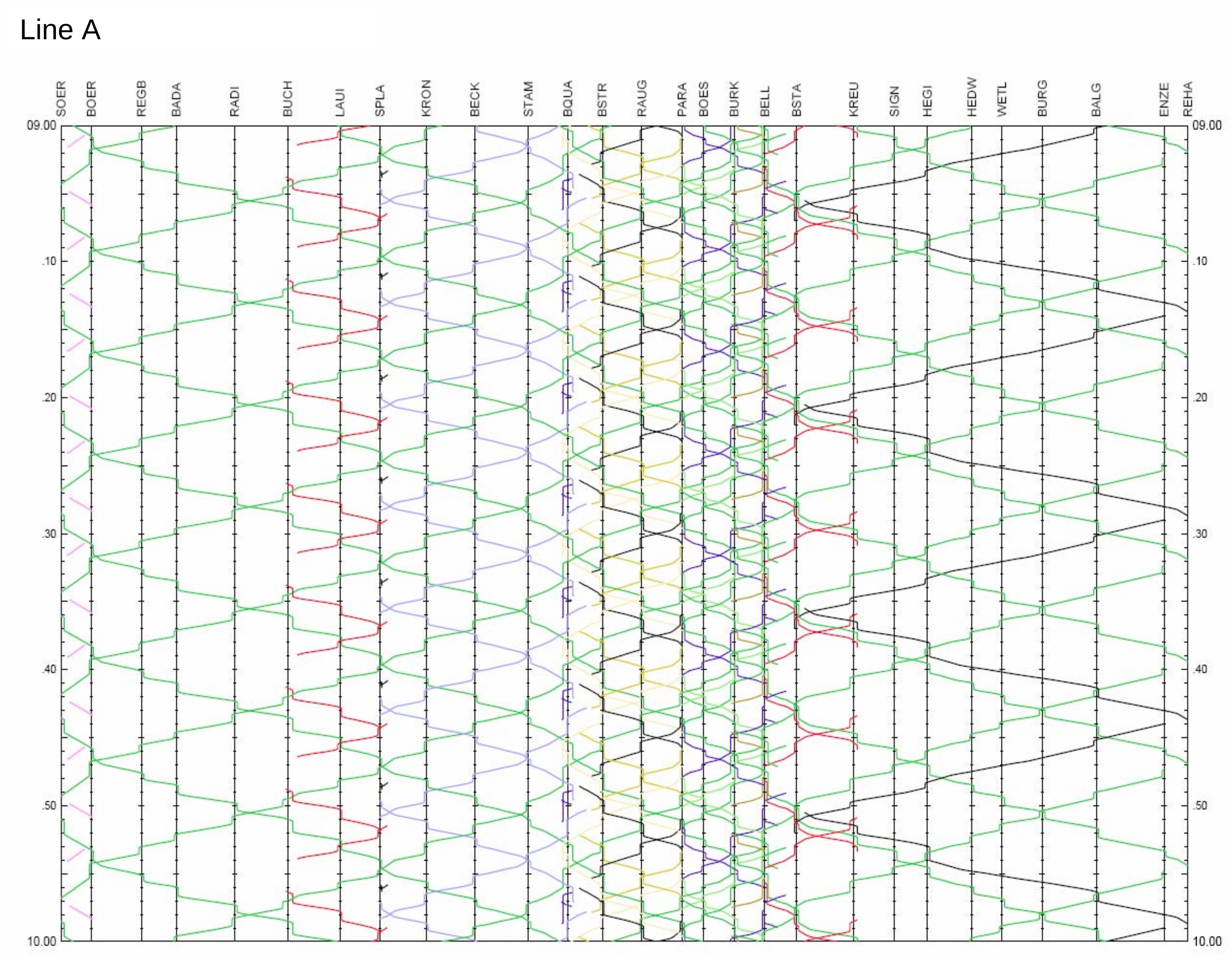
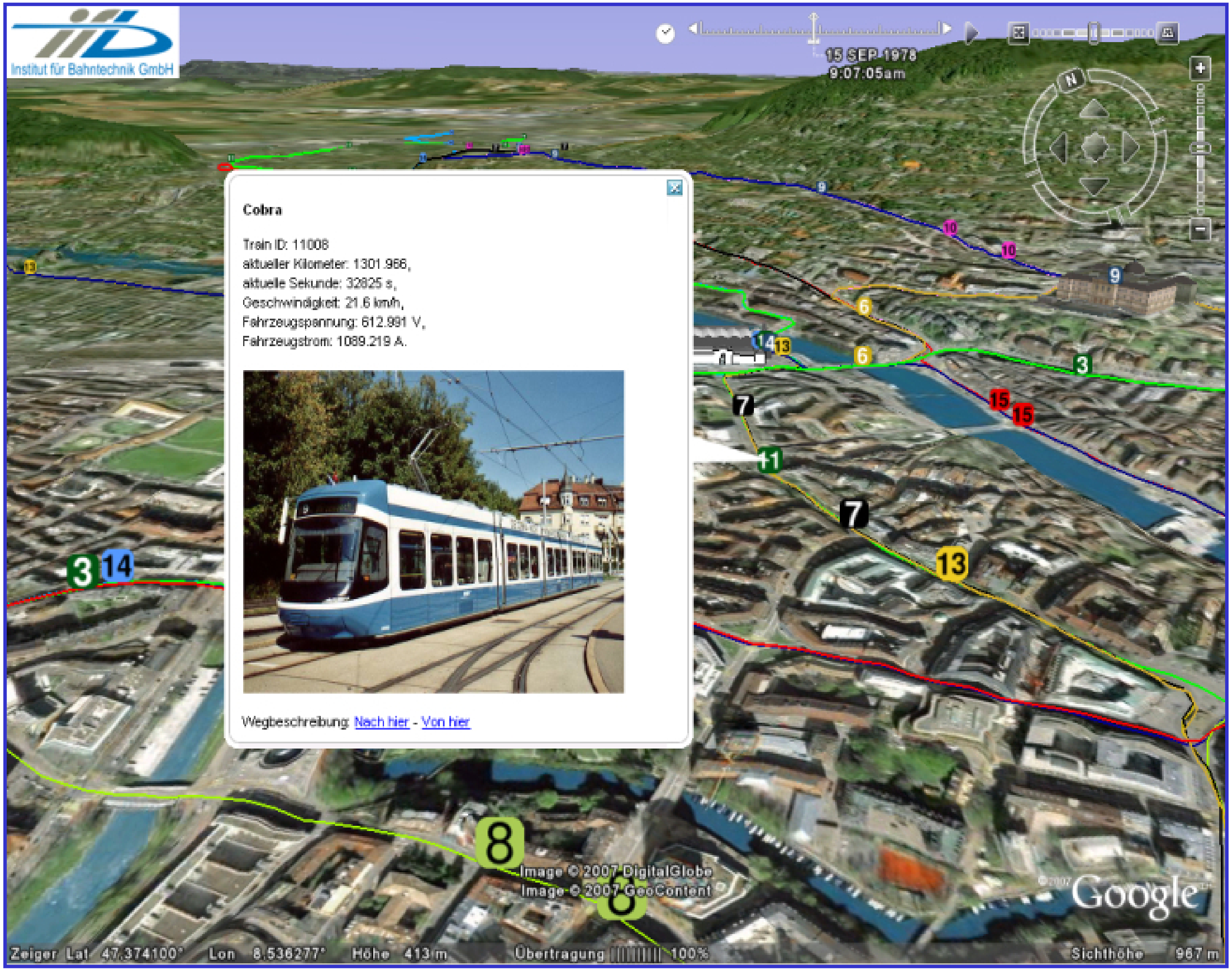
Graphical time table





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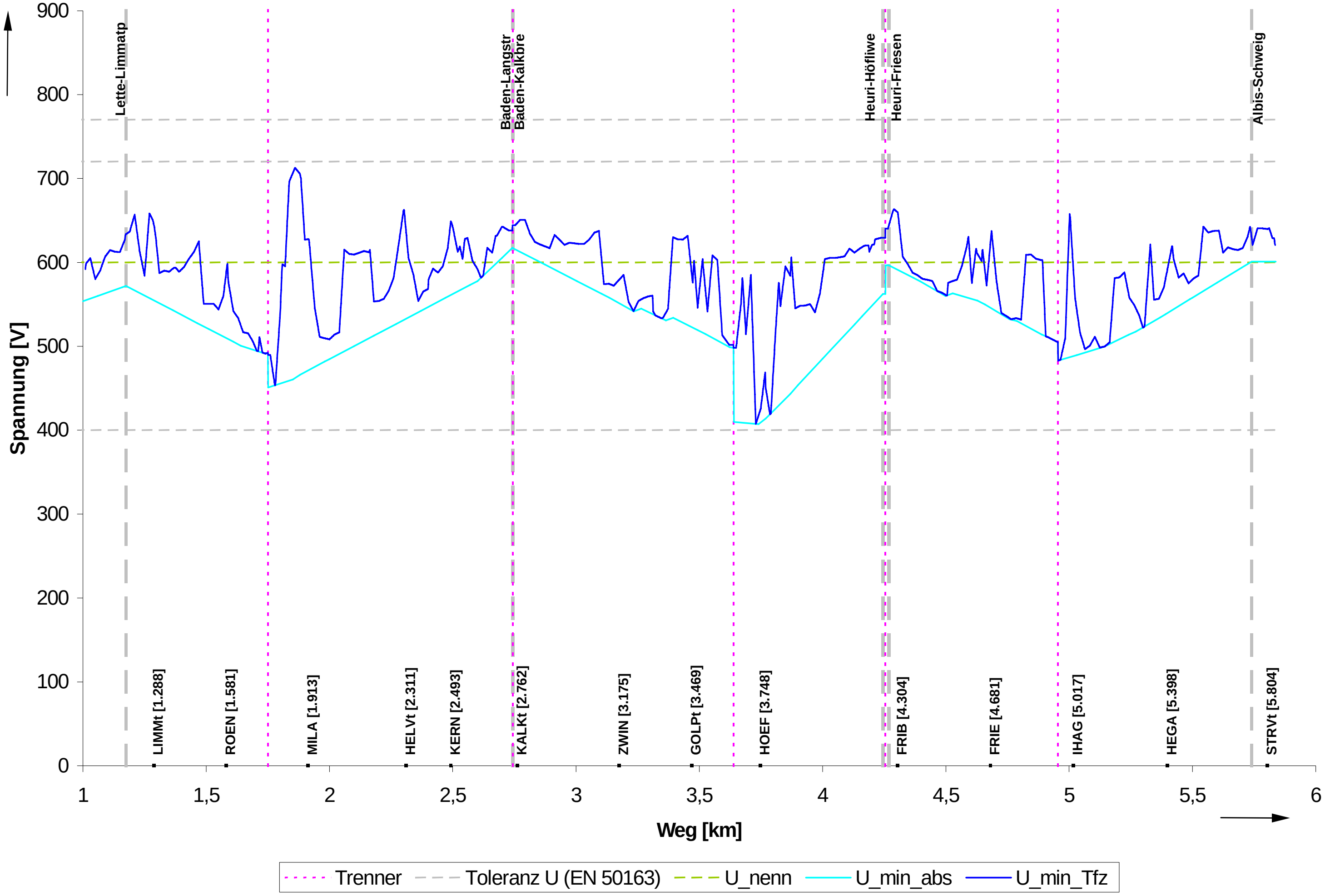
Minimum voltage: catenary and pantograph

Normal operation



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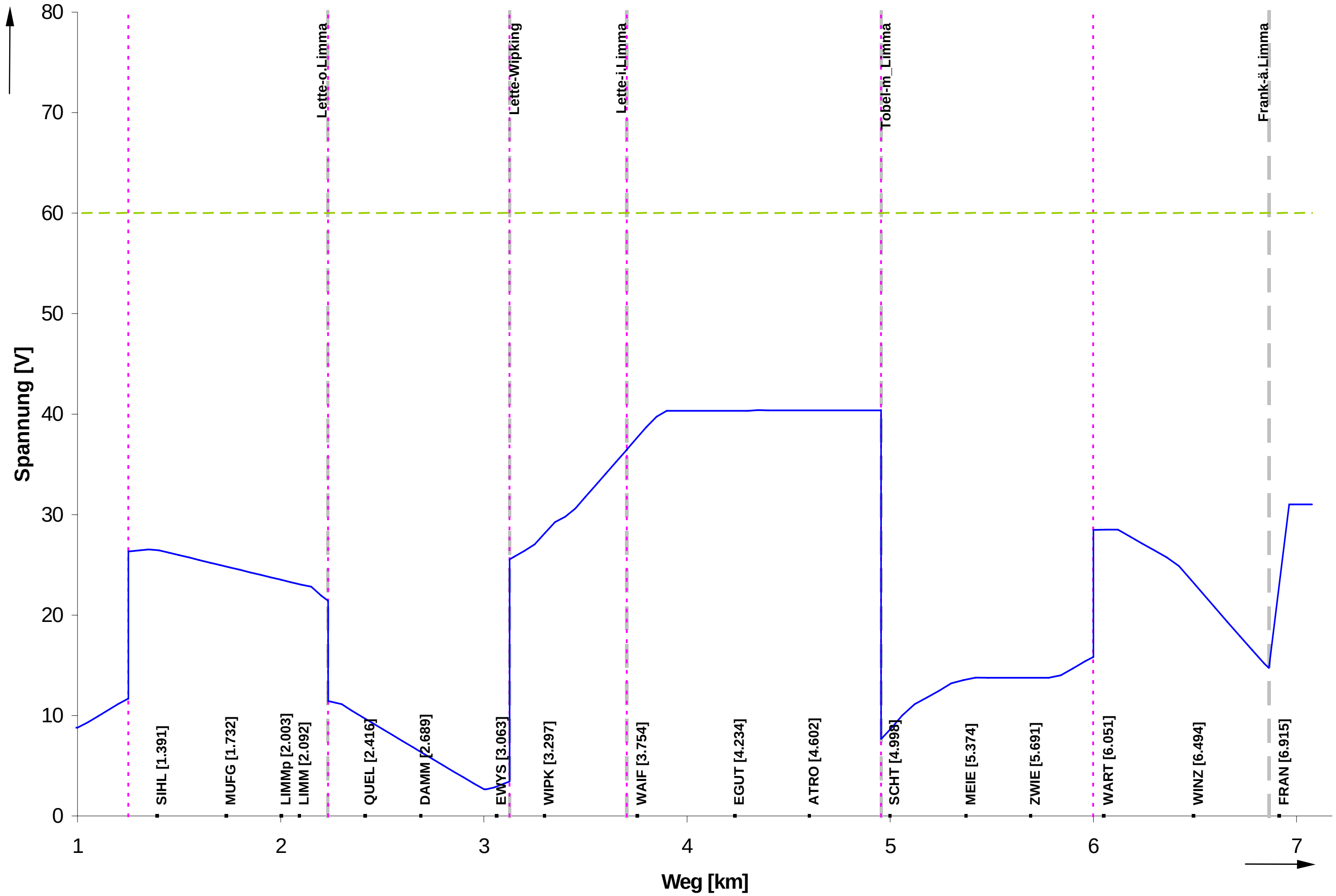
Rail-to-earth potential Normal operation



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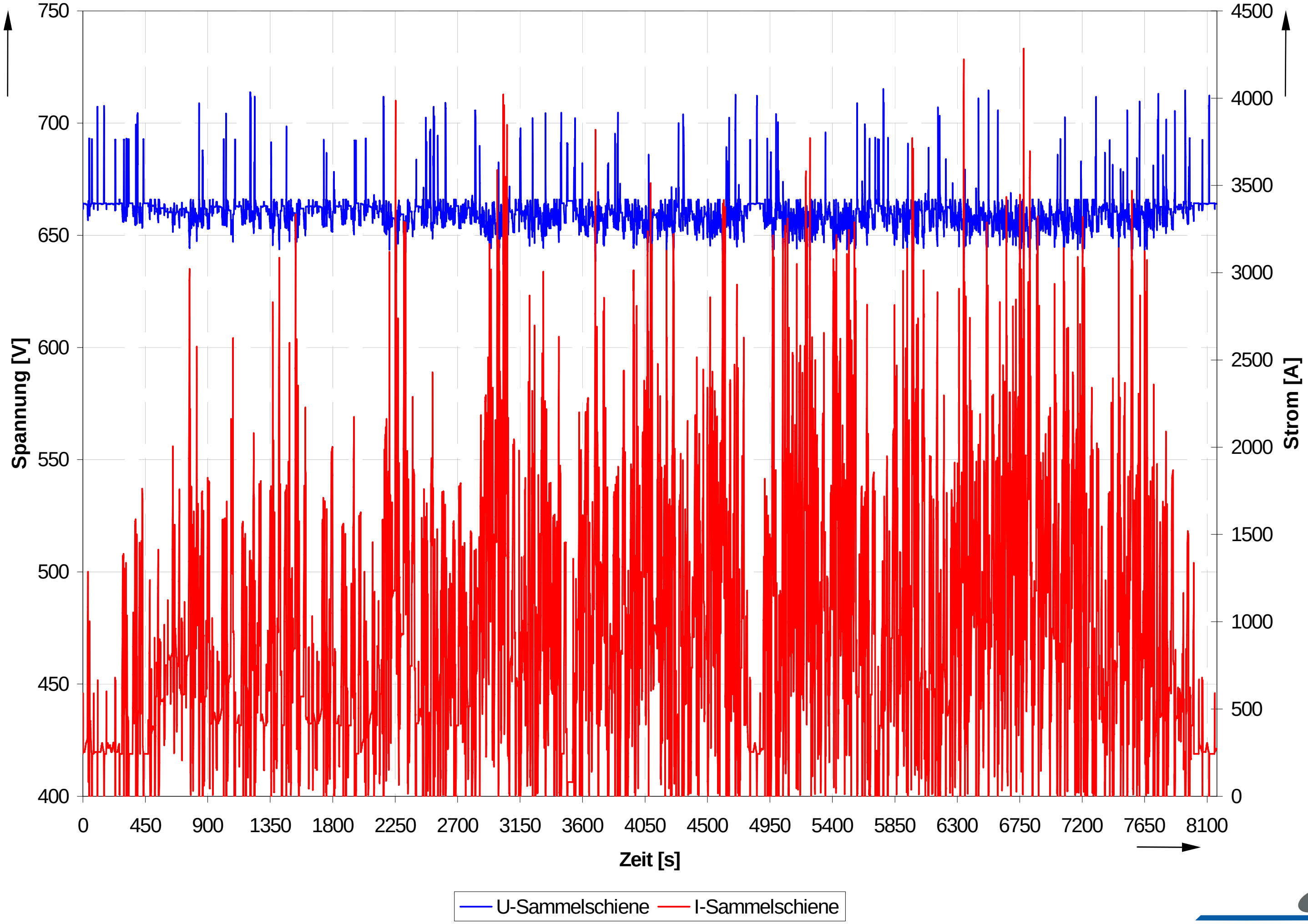
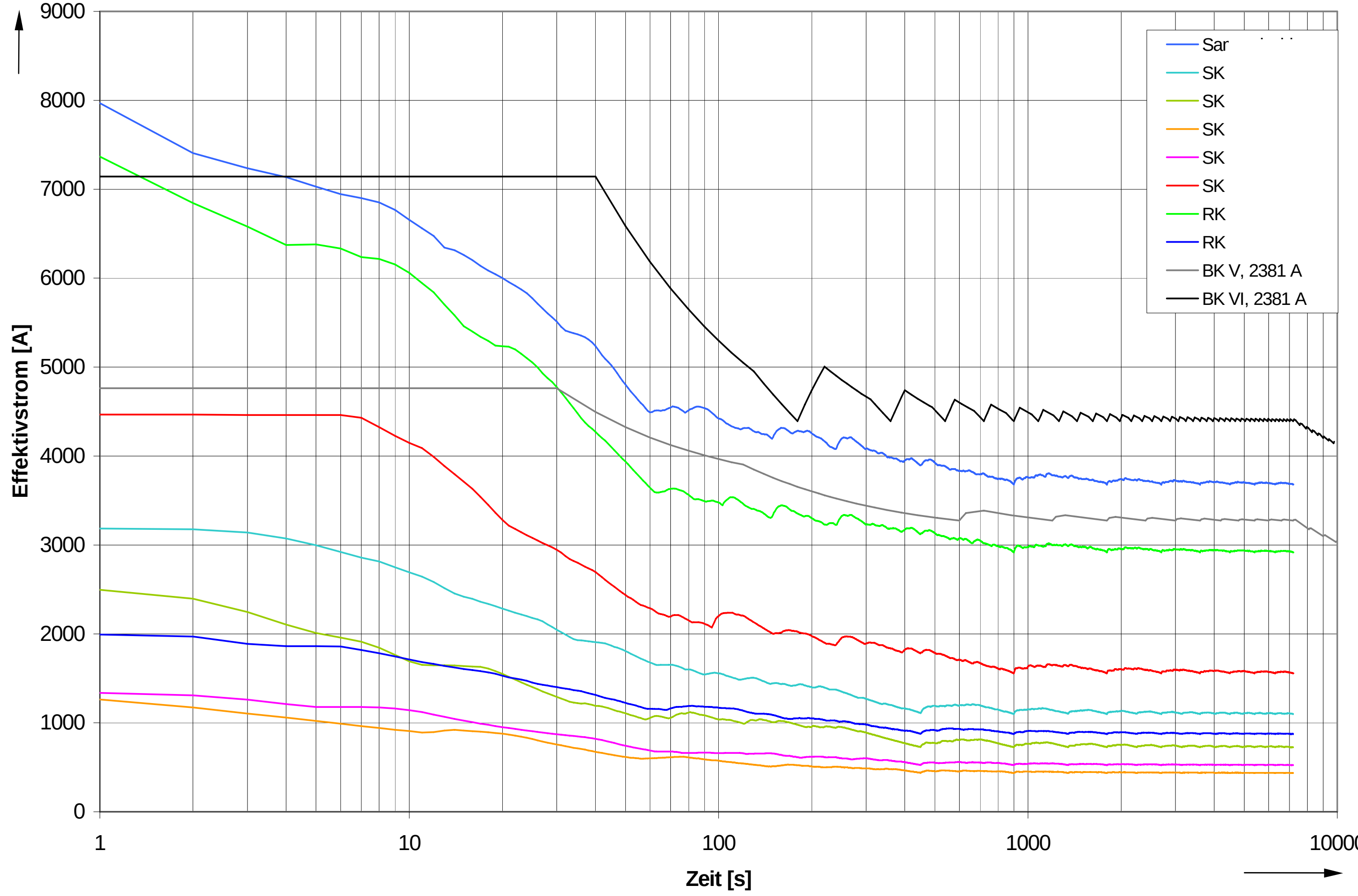
Converter current and bus-bar-voltage   Depot gateway 4:50 - 7:05 h



Load and loading capacity

Substation DC Converter

Normal operation, blackout in neighbouring subst.



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Load values Substation Feeders, Normal operation without blackouts

Station	Sektor	I_{max} [A] 1 s	I_{eff} [A] 7200 s 2 h	P_{max} [kW]	E_{ab} [kWh]	E_{auf} [kWh]	E_{verl} [kWh]	I_{Einst} [kA]	I_{Kmin} [kA]	I_{Kmin}/I_{Einst} soll > 110%	I_{max}/I_{Einst} 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	**3710**	1018	2312	1000	-33	36	**4,2**	12,7	302%	**88,3%**
	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	**2,5**	**2,7**	**108%**	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				
	gesamt	**8773**	**3527**	**5289**	**4305**	**0**	**97**				

SK: Feeder cable
RK: Return current cable

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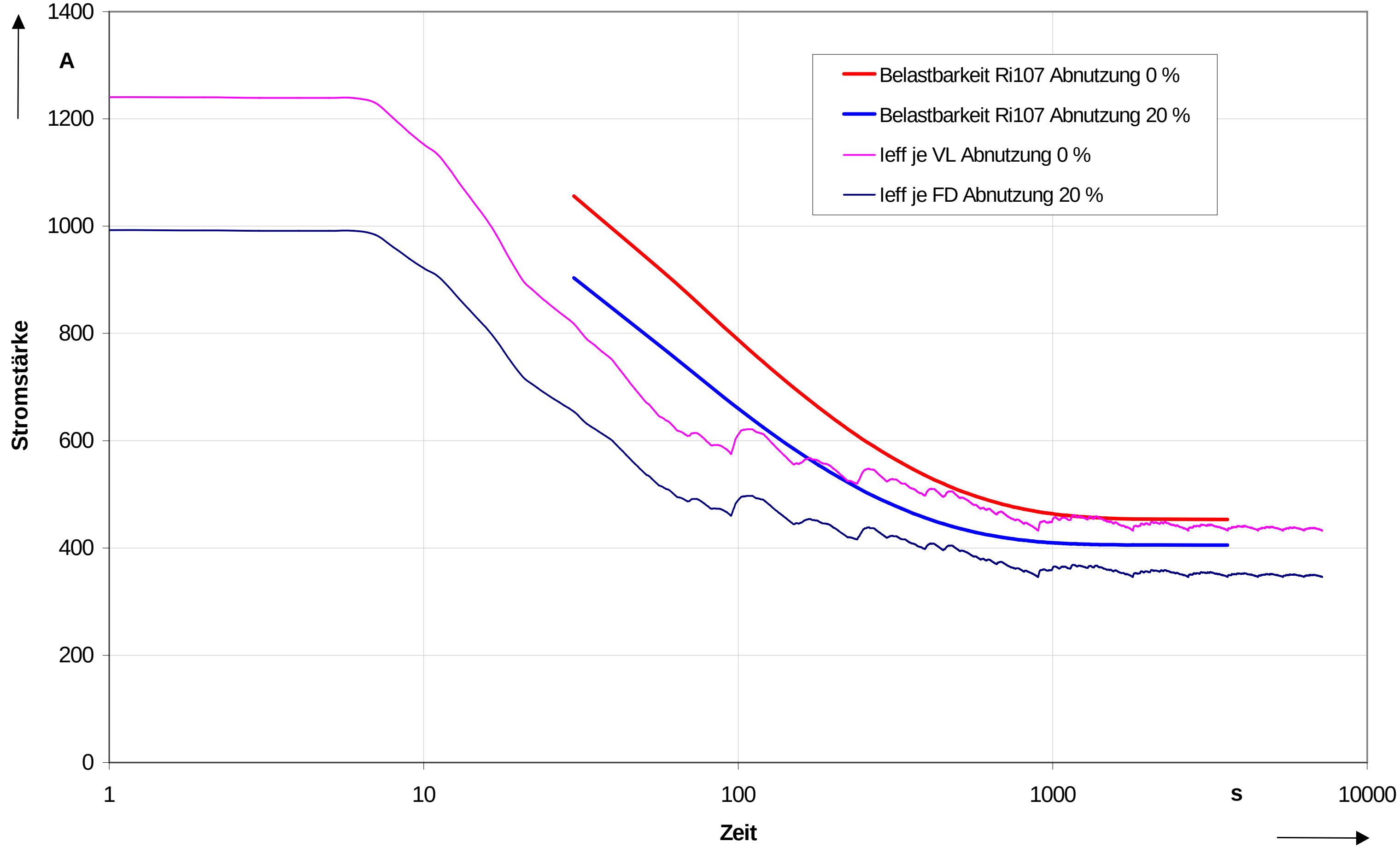
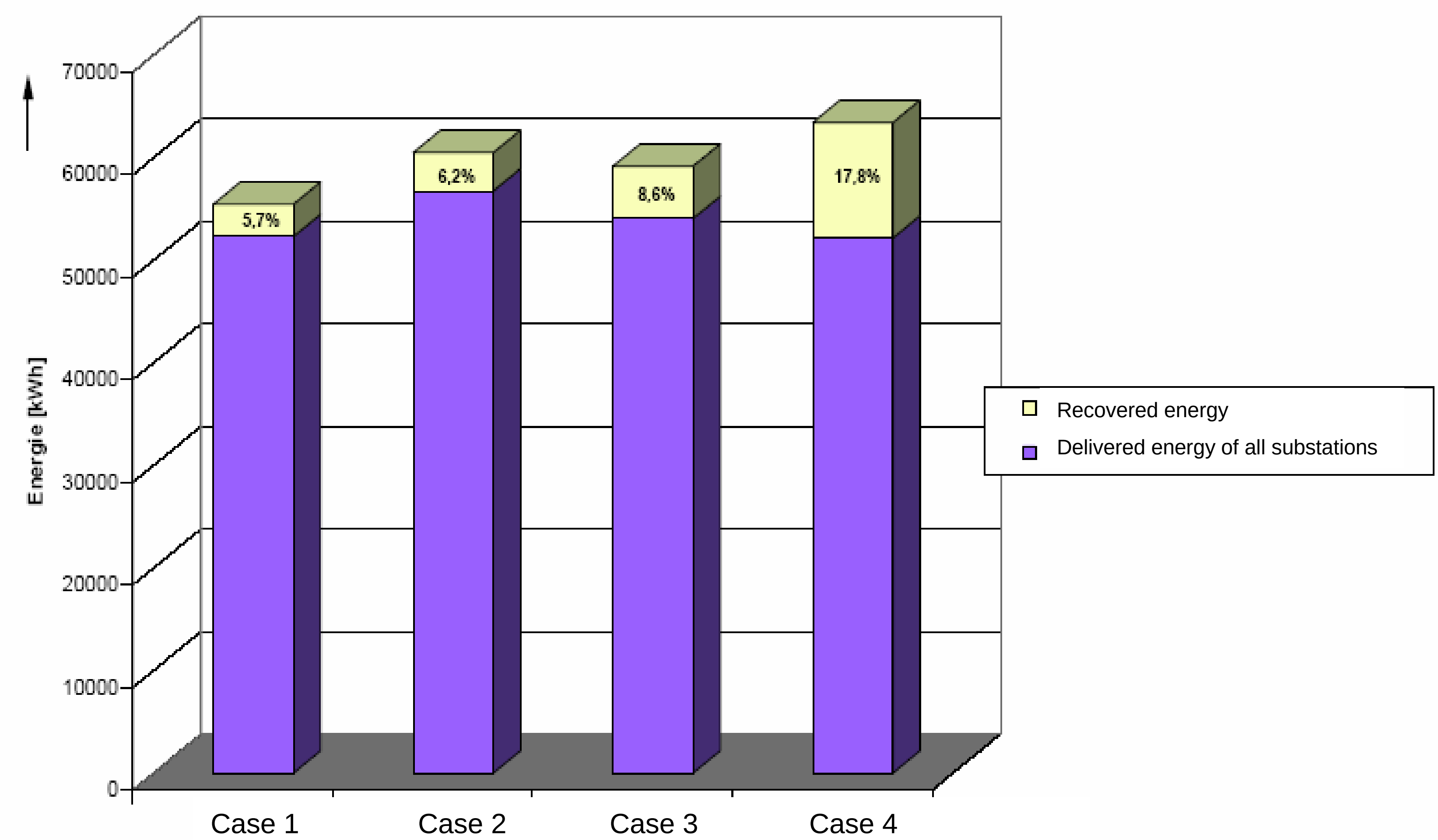
Load and loading capacity

Catenary wire at feeding point

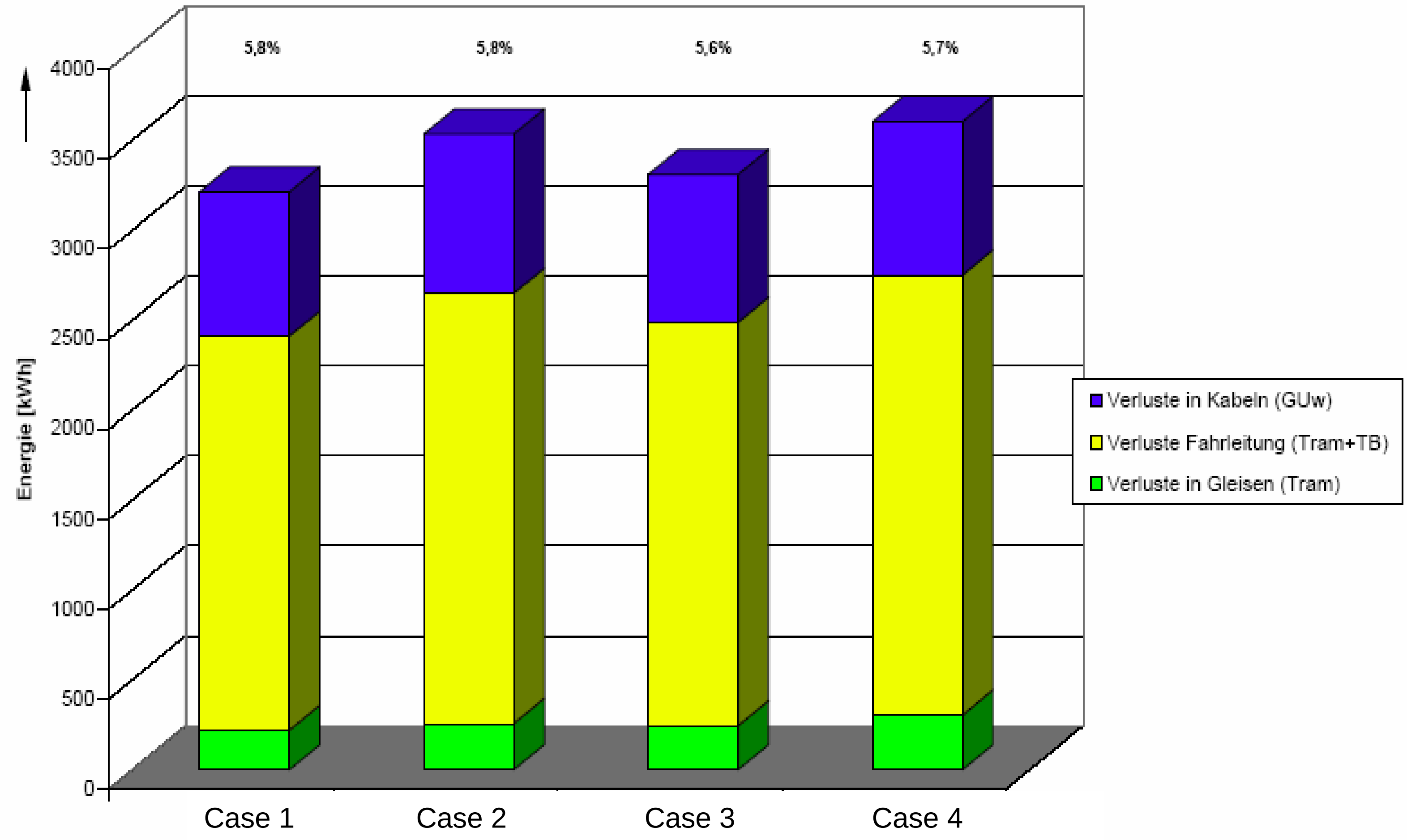
Normal operation, blackout in neighbouring subst.



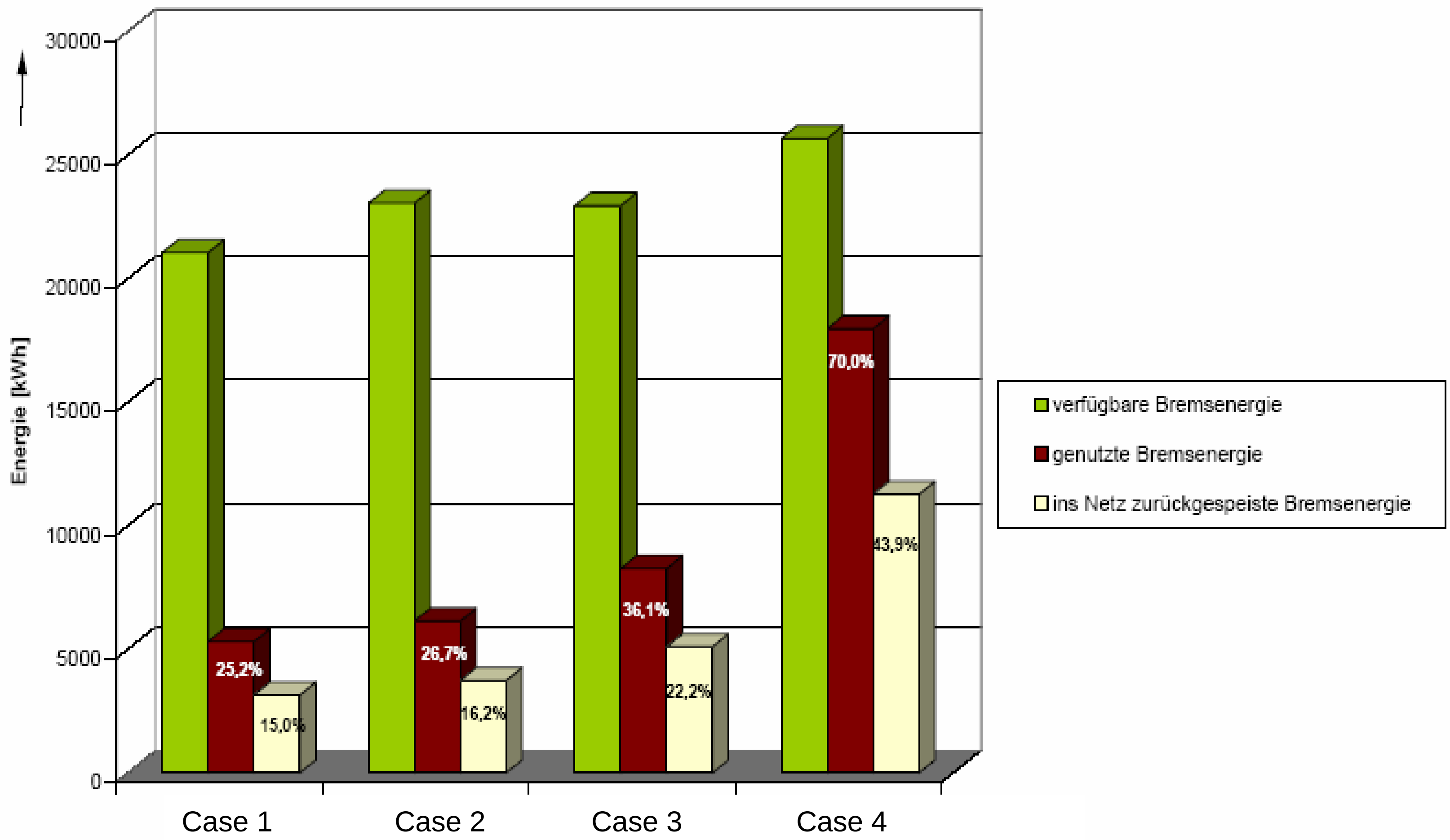
Energy balance



Power losses balance



Recovering balance



Conclusions

- **OpenPowerNet is able to simulate all common a.c. and d.c. railway power supply systems.**
- **OpenPowerNet works as a co-simulation with the commercial OpenTrack railway operation simulator.**
- **The Co-simulation principle is profitably for modelling, data handling and independent software further development.**
- **The accuracy of the electrical network simulation was verified by field measurements.**
- **Simulation service can be provided including or excluding the operation modelling (… already existing models can be used easily).**
- **OpenPowerNet was officially put into the market in 2009.**

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