New Medium Voltage DC railway electrification system

P. Ladoux : University of Toulouse; H. Caron and C. Courtois : SNCF Réseau
and A. Verdicchio PhD student : University of Toulouse / SNCF Réseau

Reference : “New Medium Voltage DC railway electrification system”, A. VERDICCHIO, P. LADOUX, H. CARON, C. COURTOIS
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MVAC electrification systems

	☹	☺
15 kV 16,7 Hz *(1905 ->)*	- Specific generation and distribution grid - Bulky substation transformers - Locomotive on-board AC/DC conversion and 2.f filters	- No phase break - AC circuit breakers
25 kV 50 Hz *(1950 - >)*	- Single Phase Substations - Neutral Sections - Locomotive on-board AC/DC conversion and 2.f filters	- Supply from public grid - Overhead line cross-section - AC circuit breakers

DC electrification systems

	☹	☺
1.5 kV or 3 kV *(1915 ->)*	- AC/DC conversion in substation - Overhead line cross-section - DC circuit breakers	- Substations in parallel - Three-phase power Supply from public grid - Simple locomotive on-board Power converter *(Input Filter + Voltage Source Inverter)*.

To mix advantages of the existing electrification systems
- Power sharing between Substations
- Three-phase power Supply from public grid
- Simple locomotive on-board Power converter (Input Filter + Voltage Source Inverter)
- Light overhead line and no inductive voltage drop

Power electronics is mature enough
- HVDC power converters (up to +/- 800 kV , 3 GW) are operated everywhere in the world.
- Solid State DC Circuit Breakers for HVDC grids are tuned.
- MV drives for industrial motors (6 KV to 10 kV) are commercially available.
- SiC power semi-conductors enable the realization of compact MV traction converters.

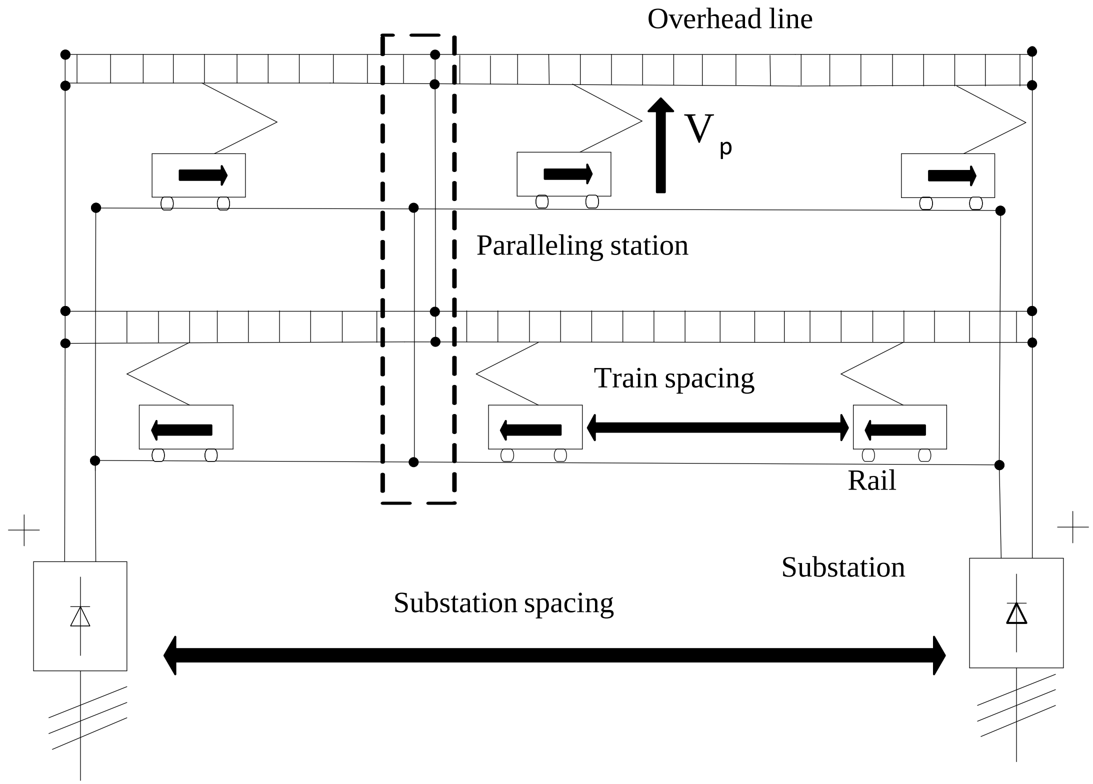
A real breakthrough for the future of rail transportation
- A solution for countries which do not yet have electrified railway lines
- A solution for DC lines renewal (copper savings, energy efficiency increase).
- Easier integration of renewable energy sources and storage elements (MVDC smart grid).

Considered voltage ranges

The same proportionality rule as the European Standard EN 50163 for 1.5 kV DC and 3 kV DC

V_n (kV)	V_{min} (kV)	V_{max} (kV)	$E_{sub\text{-}station}$ (kV)	$E_{sub\text{-}station}/V_n$
1.5	**1.0**	**1.8**	**1.75**	**0.85**
3	**2.0**	**3.6**	**3.5**	**0.85**
4.5	**3.0**	**5.4**	**5.25**	**0.85**
6	**4.0**	**7.2**	**7.0**	**0.85**
7.5	**5.0**	**9.0**	**8.75**	**0.85**
9	**6.0**	**10.8**	**10.5**	**0.85**
10.5	**7.0**	**12.6**	**12.25**	**0.85**

Considered traction circuit



Double track line with a paralleling station at sector mid-point

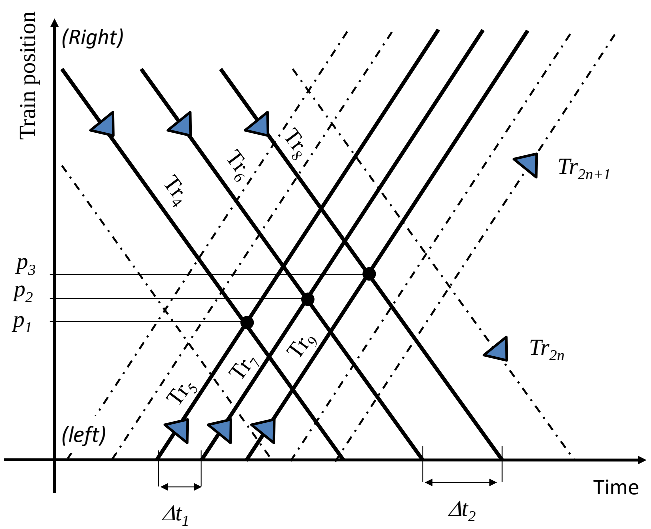
Approach to the problem

Determining substations distance and overhead-line cross-section

Train Characteristics

Transport service	Train Speed	Train Power
Suburban	80 km/h	3 MW
High-speed	280 km/h	12 MW

Railroad traffic



Δt is 5 minutes from left to right and 5 minutes and 30 seconds in the other direction.

Determining substations distance and overhead-line cross-section

- Overhead line resistivity (1,88e-8 Ω.m)
- Rail size (60 kg/km)
- Rail-to-ground conductance (0,075 S/km)

- Ambient air temperature (40°c)
- Wind speed (0.5 m/s)

Input Data

- **Railroad traffic**
- **Train power**
- **Voltage range**

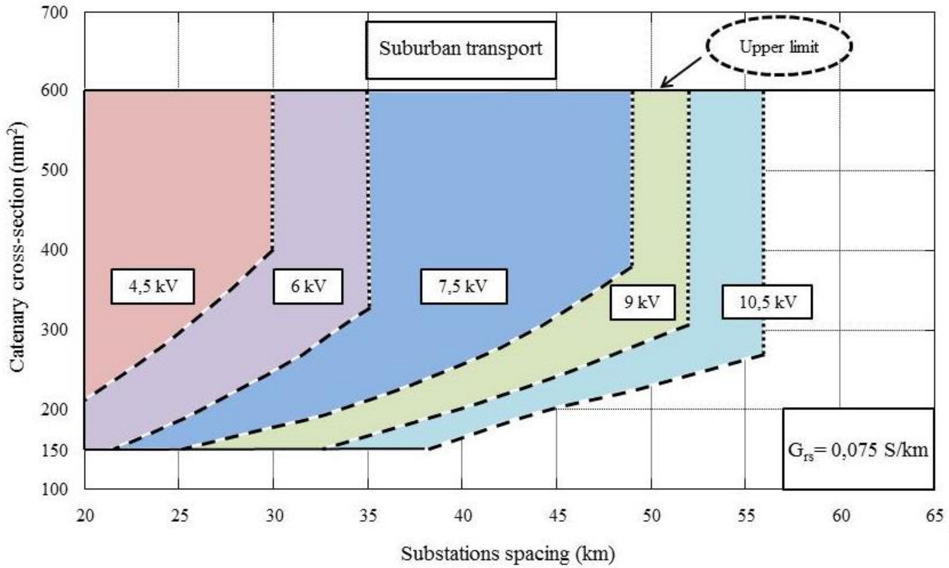
Computational Algorithm

Overhead-line cross-sectional area versus substation spacing

Stress

- Overhead line temperature : T_{max} = 65°c
- Rail to ground voltage : V_{rgmax} = 150 V (IEC 62128-1 Standard)
- Pantograph voltage : Vmin according to table of slide 4

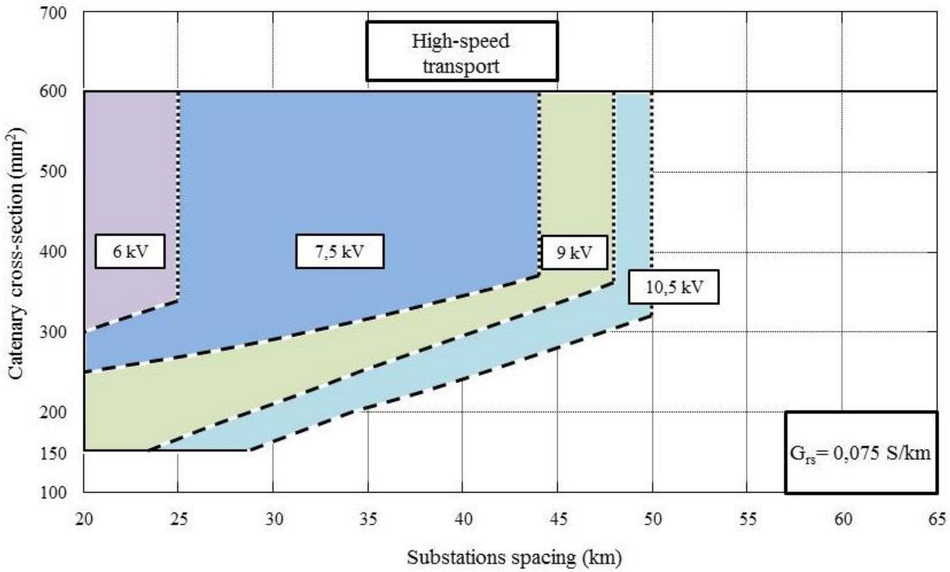
Determining substations distance and overhead-line cross-section



- - - **thermal operating limit**

⋮ **maximal permitted rail-to-ground voltage**

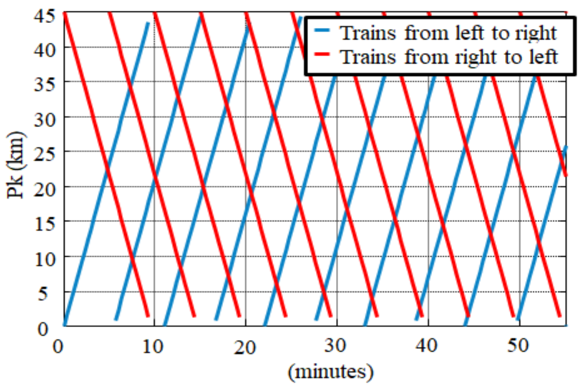
Computation Results



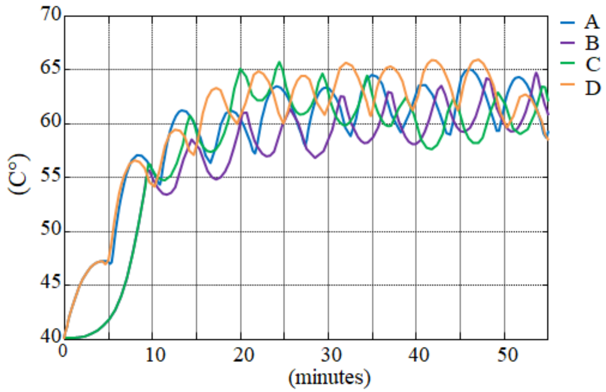
Simulation results

9 kV DC high-speed line – Substation spacing 45 km; Overhead-line cross-section 340 mm². Train power 12 MW; Train speed 280 km/h

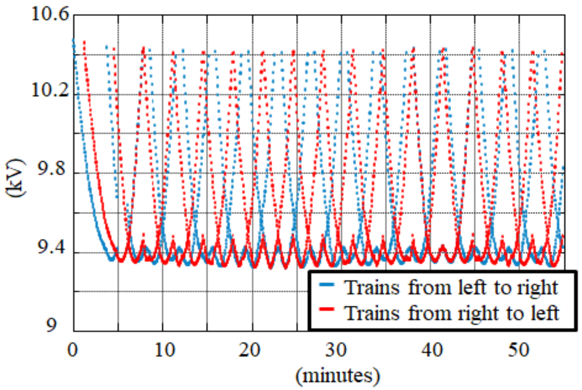
Railroad traffic



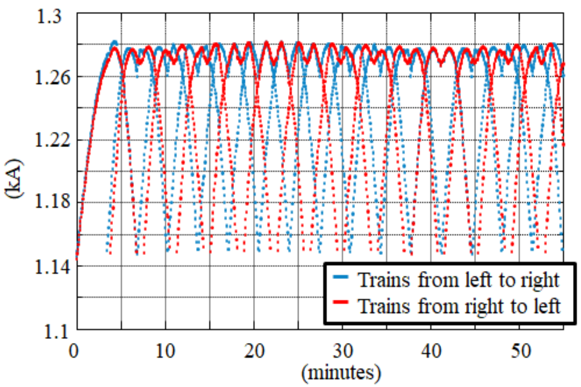
Overhead-line temperatures calculated close to the substations



Pantograph voltages

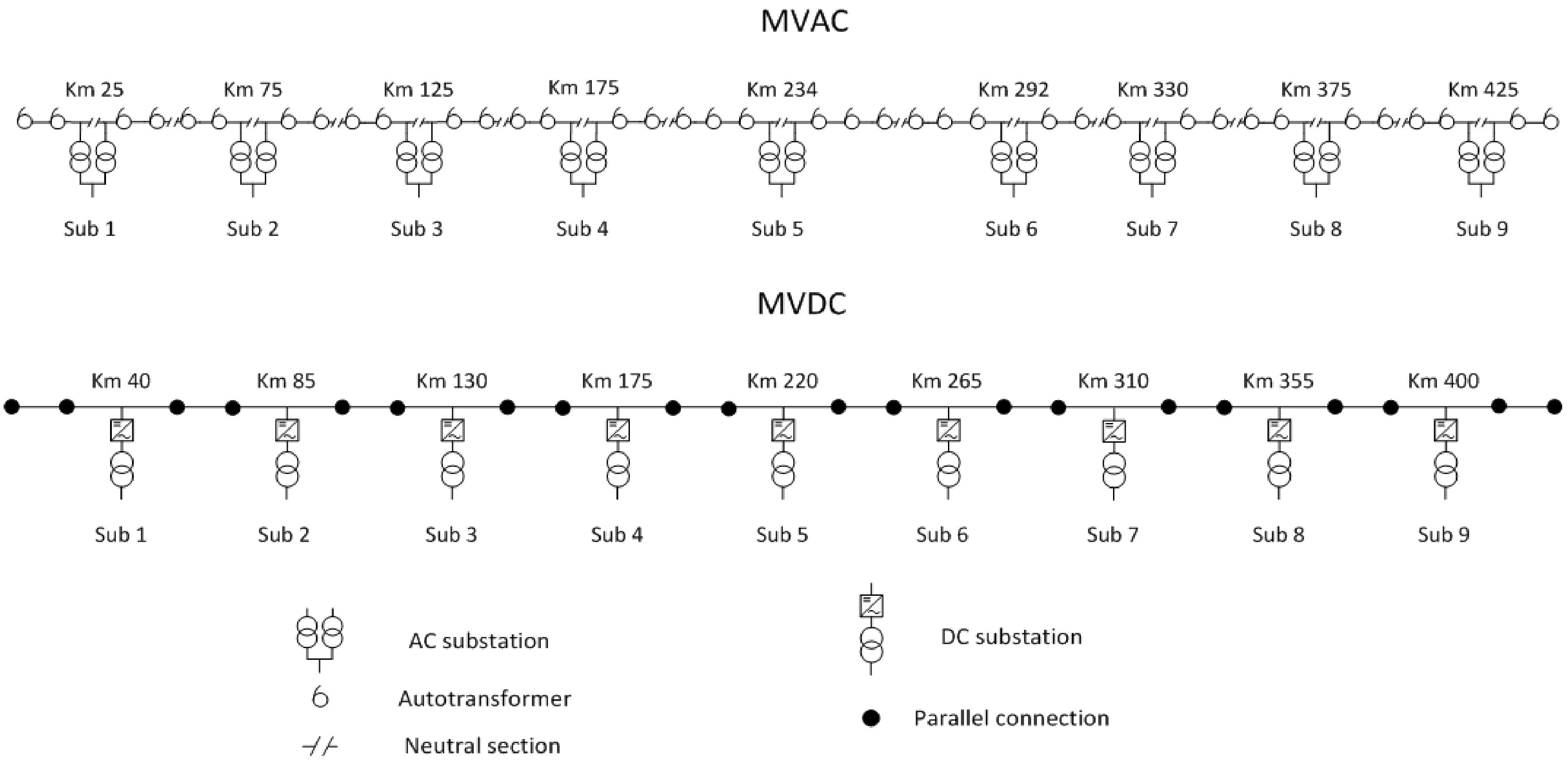


Currents absorbed by trains



Comparison with the existing electrification systems

Paris-Strasbourg high-speed line 2 x 25 kV AC and 9 kV DC

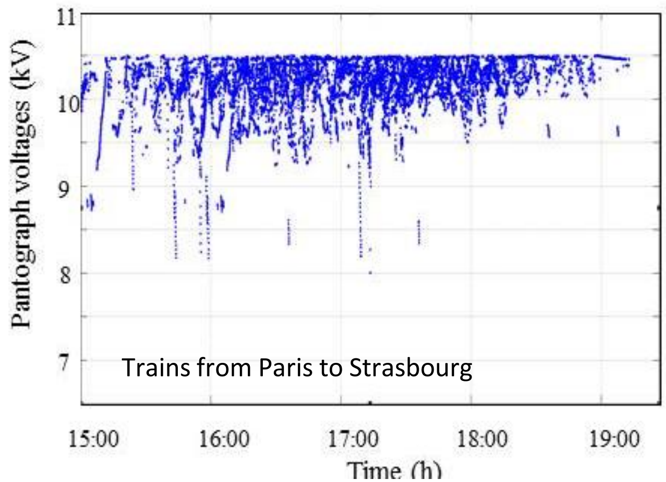


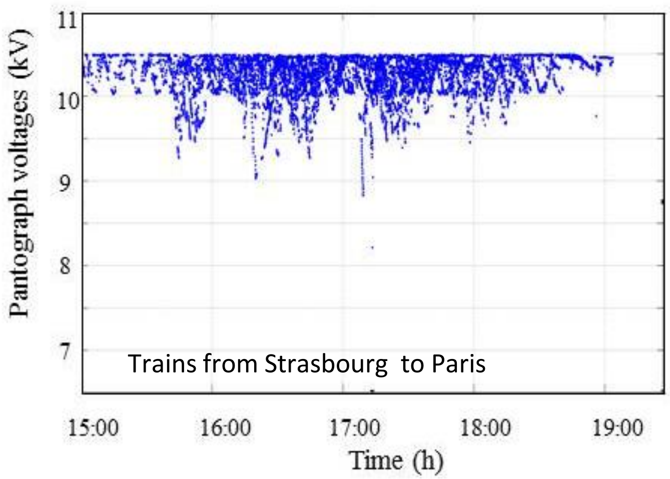
Overhead line equivalent cross-section (100% Cu) for one track : 377 mm^2

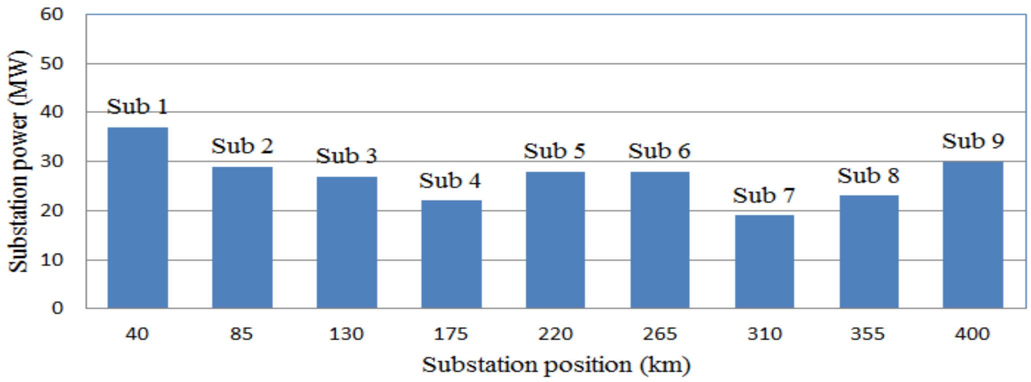
Comparison with the existing electrification systems

Paris-Strasbourg high-speed line with 9 kV DC Electrification system

Simulation results : real railroad traffic between 15:00 and 19:30





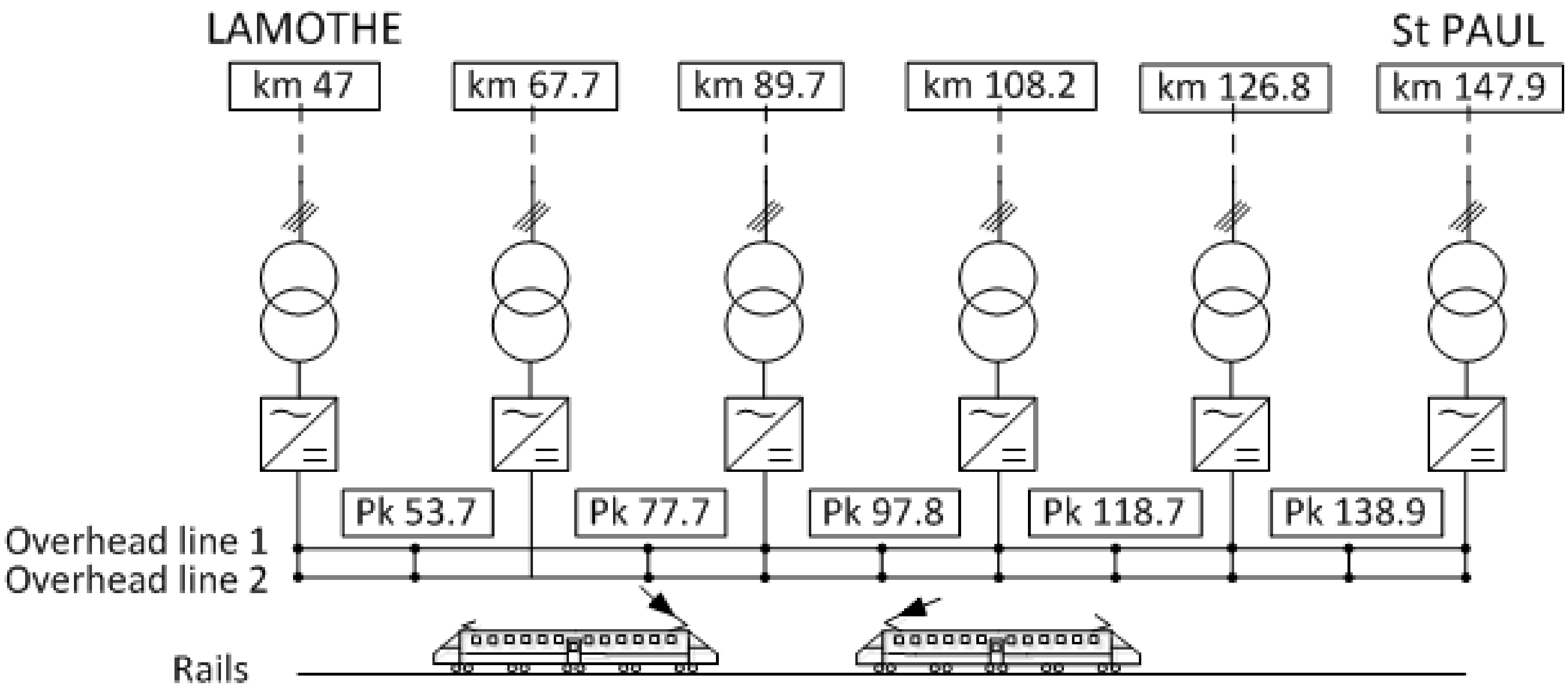


Energy Efficiency of Traction Circuit (Computation from 16:00 to 18:00)

0,94 for 9 kV DC and 2 x 25 kV AC

Comparison with the existing electrification systems

Bordeaux-Hendaye intercity line 1.5 kV DC Electrification system
(Lamothe – Saint Paul Sector)

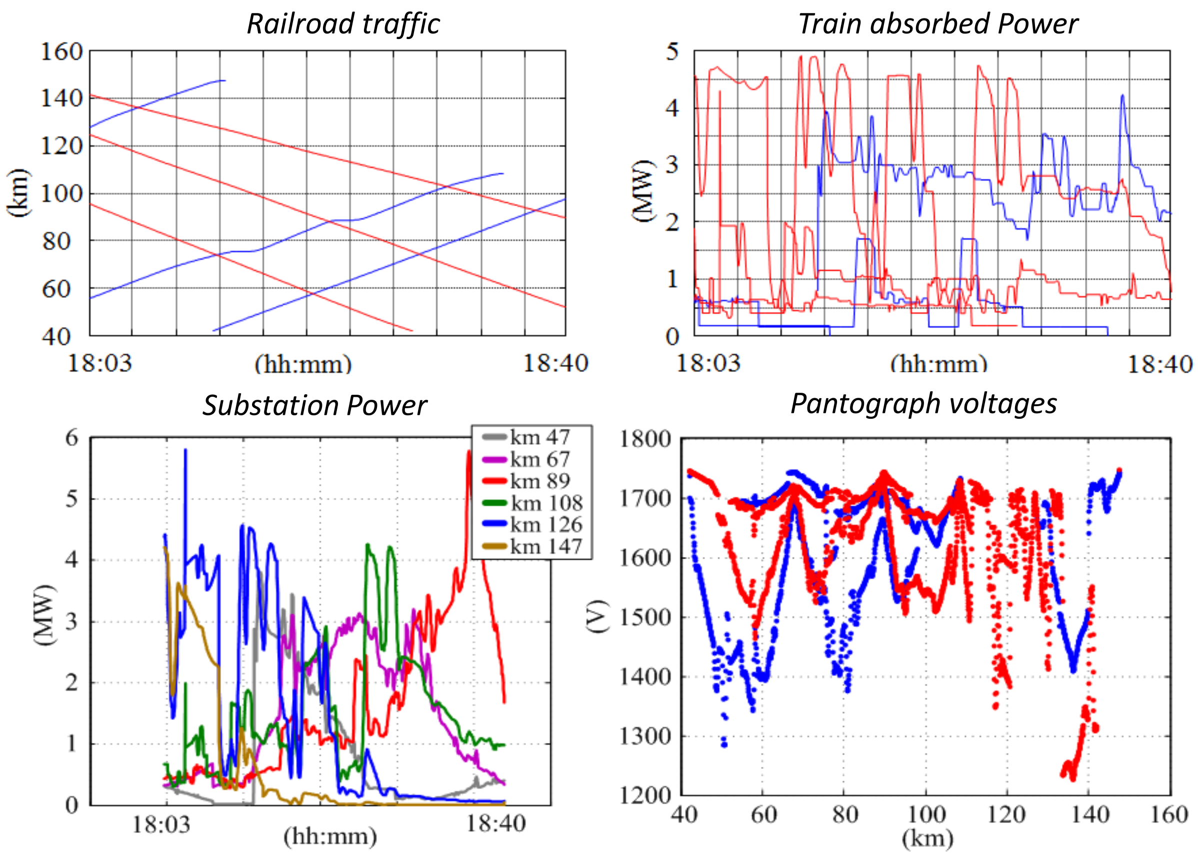


Overhead line equivalent cross-section (100% Cu) for one track : 850 mm²

Comparison with the existing electrification systems

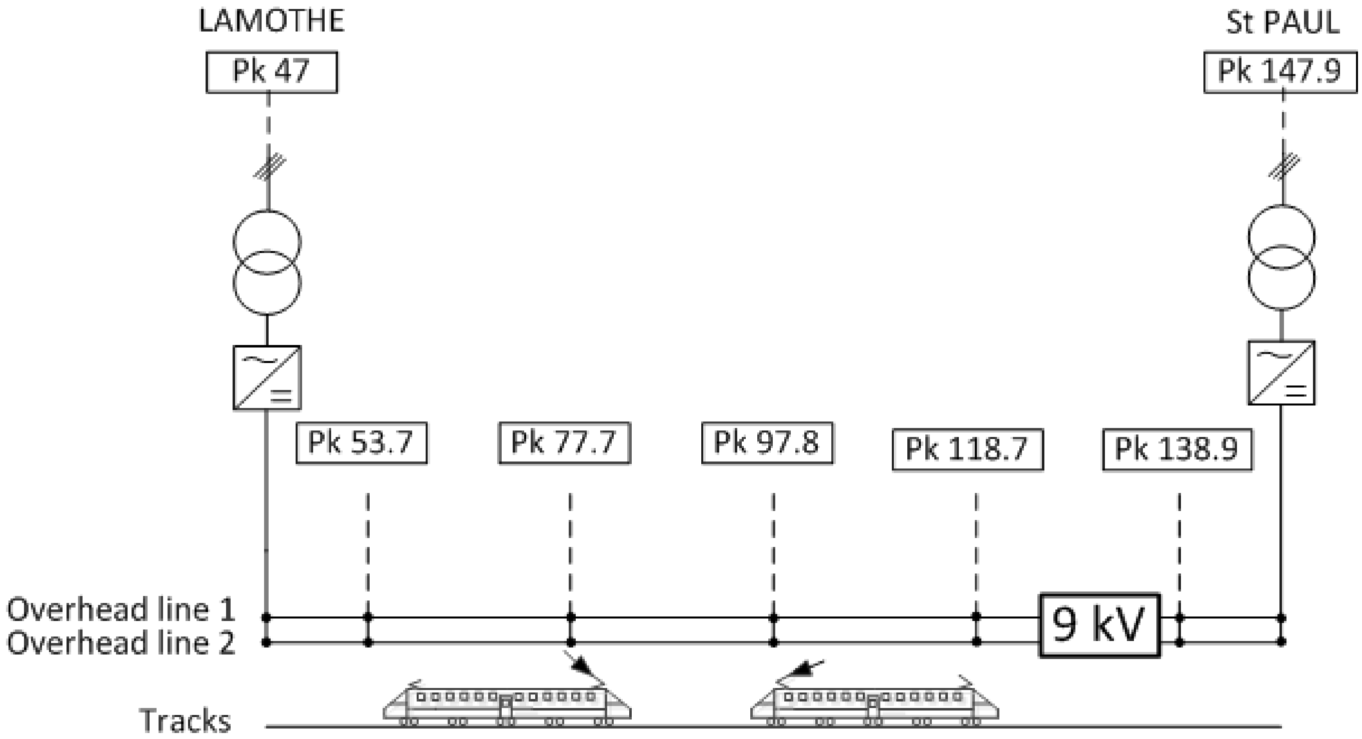
Bordeaux-Hendaye intercity line 1.5 kV DC Electrification system (Lamothe – Saint Paul Sector)

Simulation results considering real railroad traffic



Comparison with the existing electrification systems

Bordeaux-Hendaye intercity line 9 kV DC Electrification system (Lamothe – Saint Paul Sector)

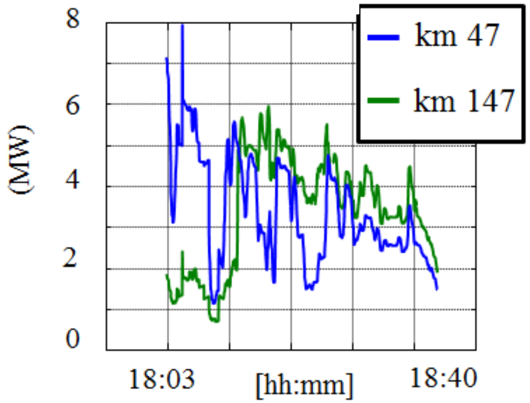


Overhead line equivalent cross-section (100% Cu) for one track : 230 mm²

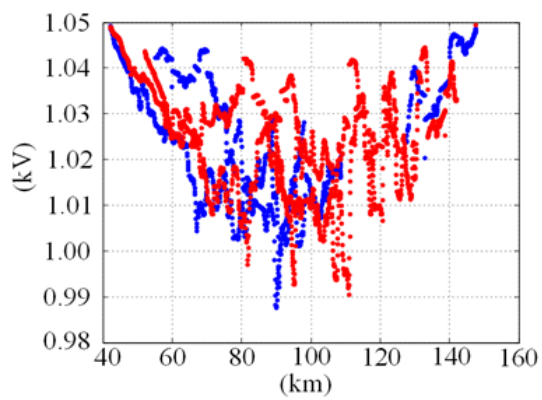
Comparison with the existing electrification systems

Bordeaux-Hendaye intercity line 9 kV DC Electrification system (Lamothe – Saint Paul Sector)

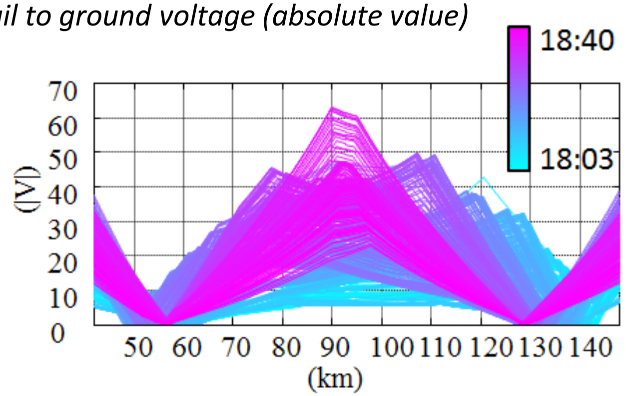
Substation Power



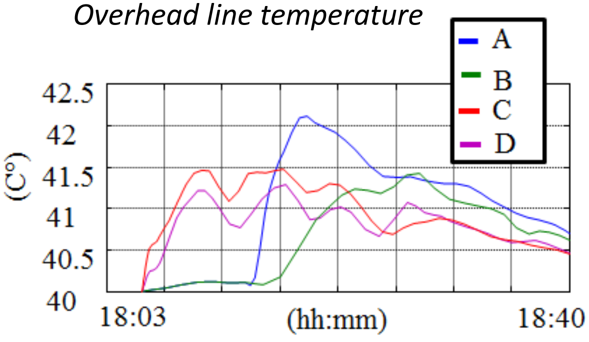
Pantograph voltages



Rail to ground voltage (absolute value)



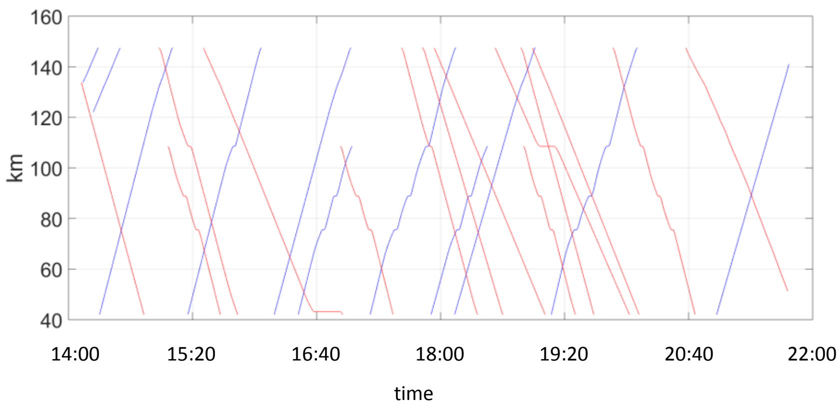
Overhead line temperature



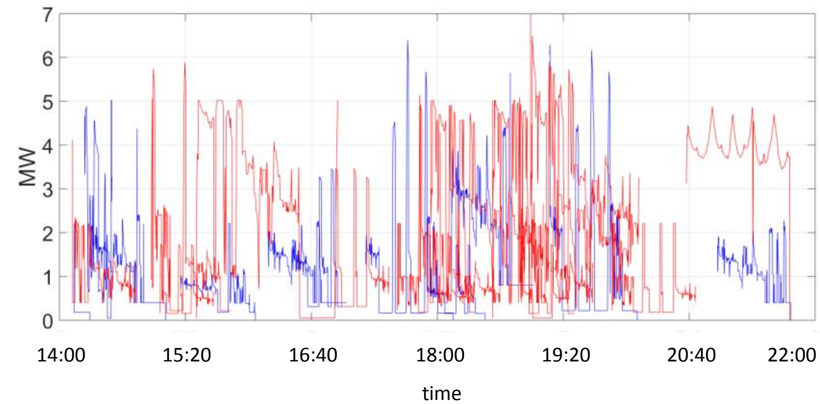
Comparison with the existing electrification systems

Bordeaux-Hendaye intercity line 1.5 kV DC versus 9 kV DC
(Lamothe – Saint Paul Sector)

Railroad Traffic



Power absorbed by trains

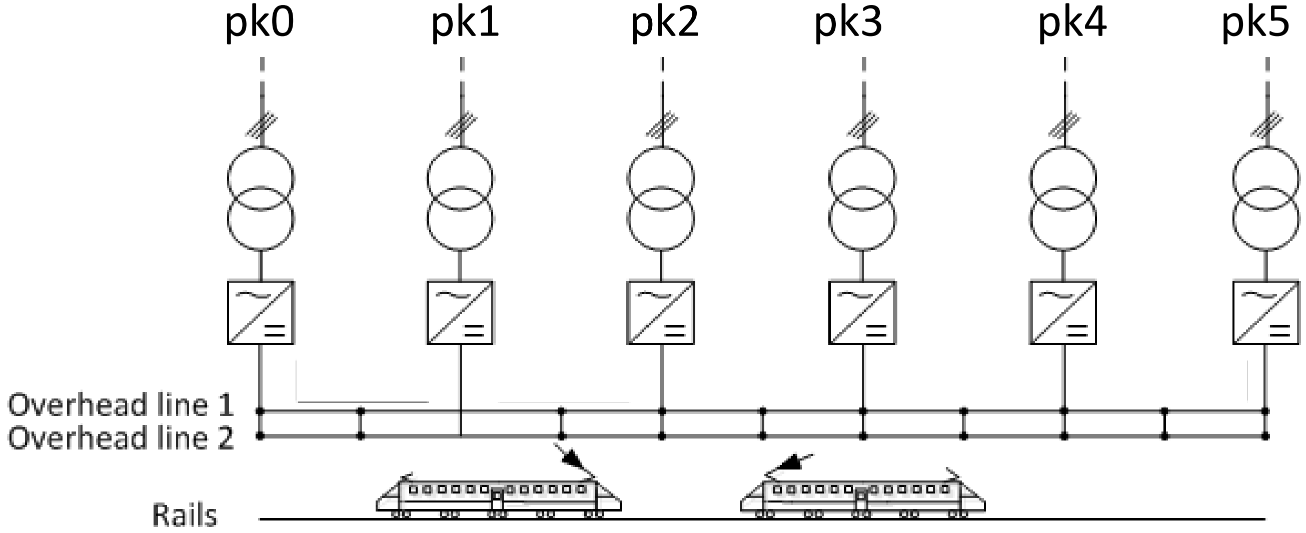


Computation over the time period 14:00-22:00

	1.5 kV ***(with feed-wire)***	**9 kV**	**9 kV** ***(with feed-wire)***
Overhead line equivalent cross-section	850 mm^2	230 mm^2	410 mm^2
Energy efficiency of traction circuit	0,89	0,95	0,97
Total Energy provided by the substations	38 MWh	35,5 MWh	34,9 MWh

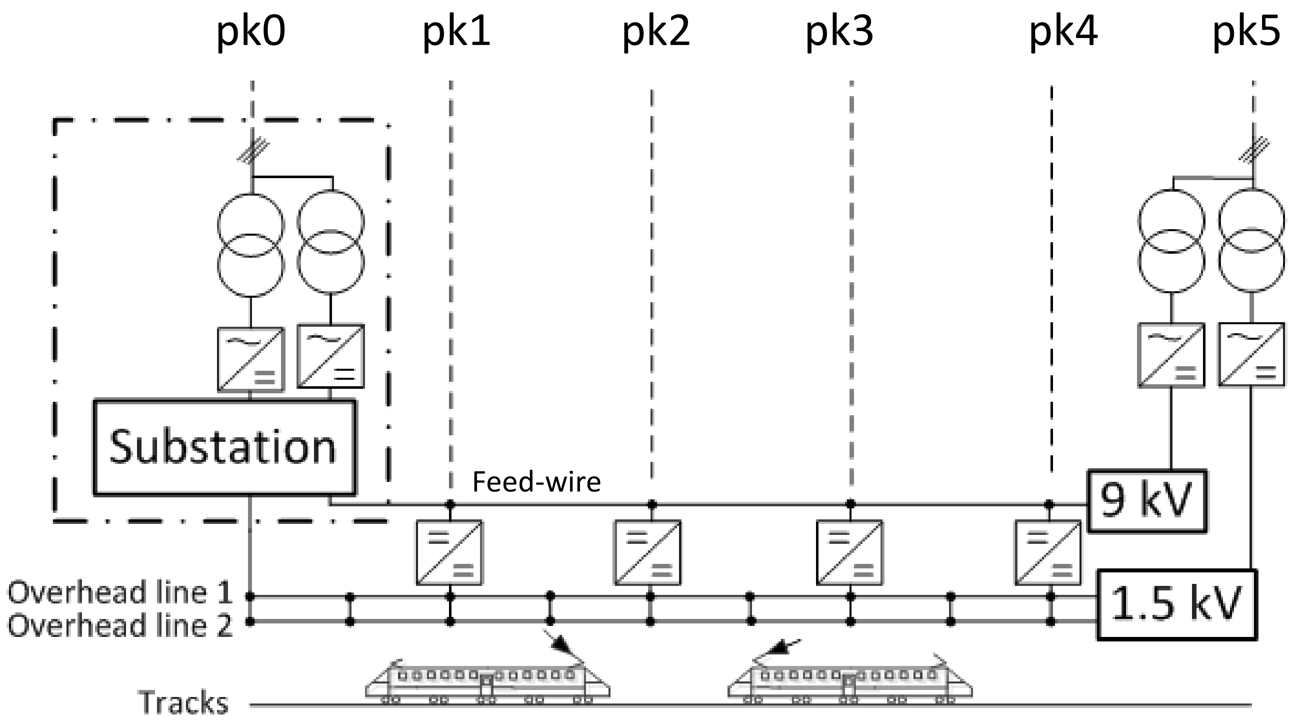
Switching from 1.5 kV to 9 kV DC

Initial Situation



Switching from 1.5 kV to 9 kV DC

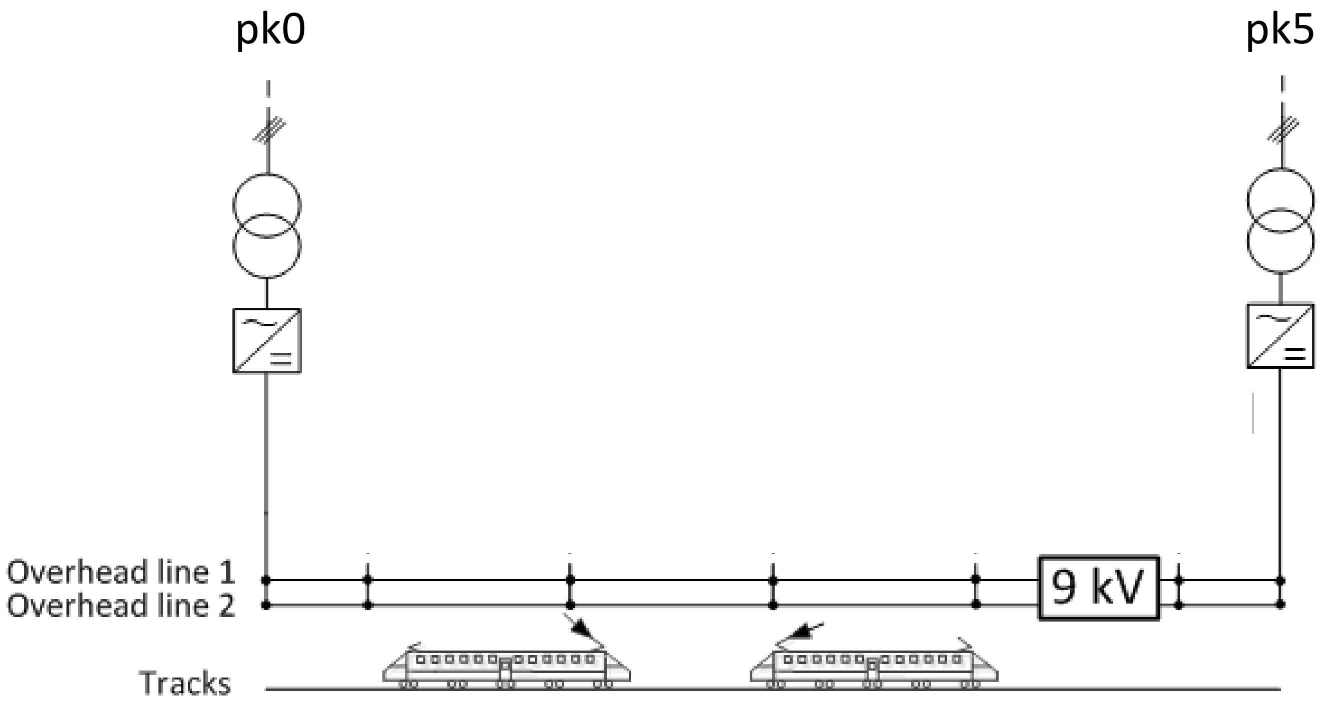
Evolution of infrastructure : intermediate stage



9 kV AC/DC converters to supply a 9 kV feed-wire
DC/DC Power Electronics Transformers (PETs) replace intermediate substations
Unchanged Traction Circuit

Switching from 1.5 kV to 9 kV DC

Evolution of infrastructure : Final stage

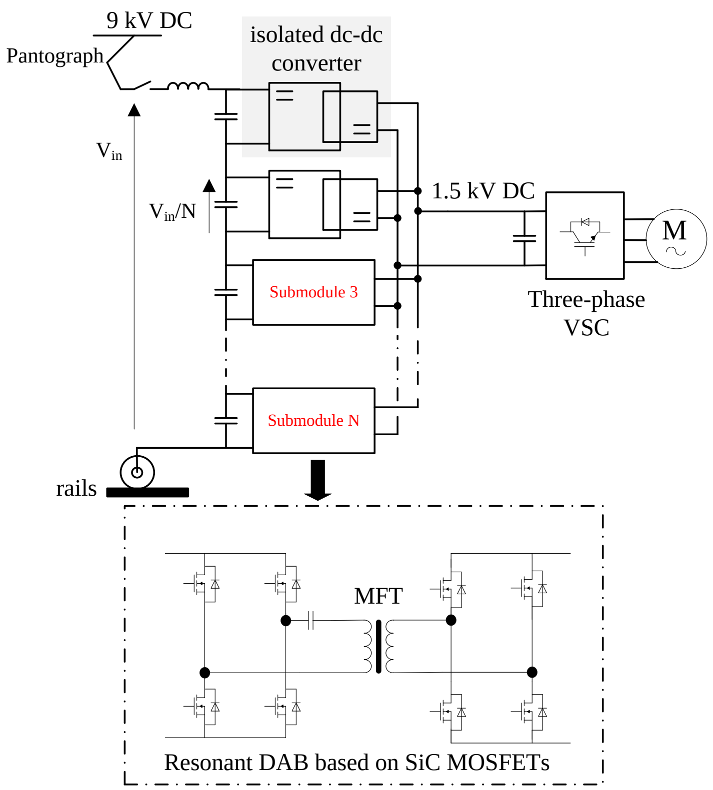


Paralleling station with Hybrid Circuit Breakers are installed along the line

Switching from 1.5 kV to 9 kV DC

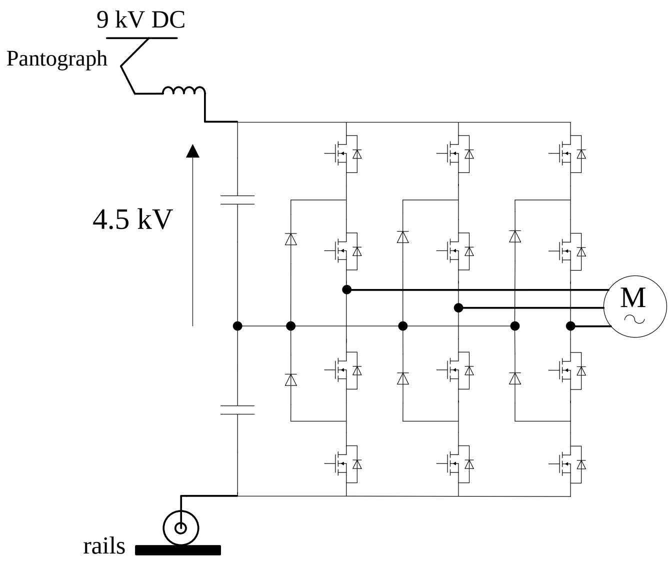
Evolution of traction units

Intermediate Stage : On Board Power Electronics Transformer



3.3 kV SiC MOSFETS are available

Final Stage : MV traction inverter



NPC VSI based on 10 kV SiC MOSFETS