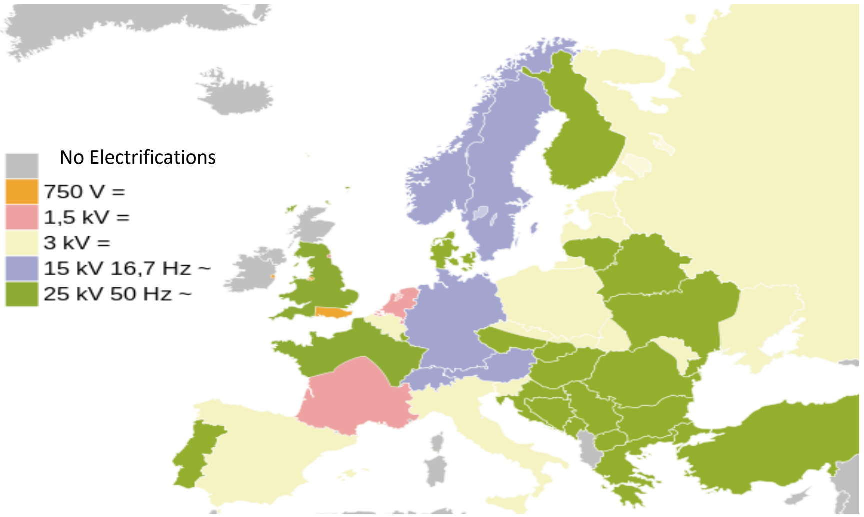
FUTURE DC RAILWAY ELECTRIFICATION SYSTEM

Go for 9kV

UIC Workshop on Energy Efficiency
11/02/2019 Rotterdam

INTRODUCTION

Existing Railway Electrifications in Europe



1905 → 1915 → 1950 → 20xx

15 kV 16,7 Hz - MVAC (1905)
- ❖ Specific generation and distribution grid.
- ❖ Bulky substation transformers.
- ✓ No phase break.
- ✓ AC circuit breakers.

1.5 kV or 3 kV - DC (1915)
- ❖ AC/DC conversion in substation.
- ❖ Overhead line cross-section.
- ❖ DC circuit breakers.
- ✓ Simple traction chain embedded.
- ✓ Substations in parallel.

25 kV 50 Hz - MVAC (1950)
- ❖ Single-phase substations.
- ❖ Neutral sections.
- ❖ Complex traction chain.
- ✓ Supply from public grid.
- ✓ AC circuit breakers.
- ✓ Overhead line cross-section

9 kV-MVDC (20xx)

?

Observation : In France, 6000 km of overhead-line supplied by 1.5 kV DC system need to be renovated:

- ➢ The same electrification system or converted to 25 kV AC.
- ➢ **New MVDC electrification system.**

INTRODUCTION

Why looking to a MVDC Railway Electrification System ?

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.
- Light overhead line and no inductive voltage drop.

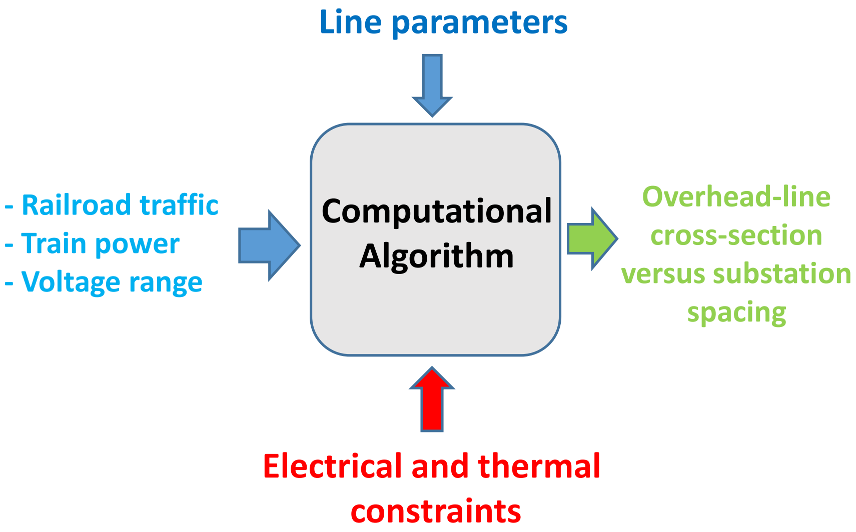
Power electronics is mature enough
- HVDC power converters.
- Solid State DC Circuit Breakers.
- MV drives for industrial motors are commercially available.
- SiC power semi-conductors enable the realization of compact MV traction converters.

A real breakthrough for the future of rail transportation
- A solution for countries not yet electrified.
- A solution for DC lines renewal (copper savings, energy efficiency increase).
- Easier integration of MVDC smart grid concept.

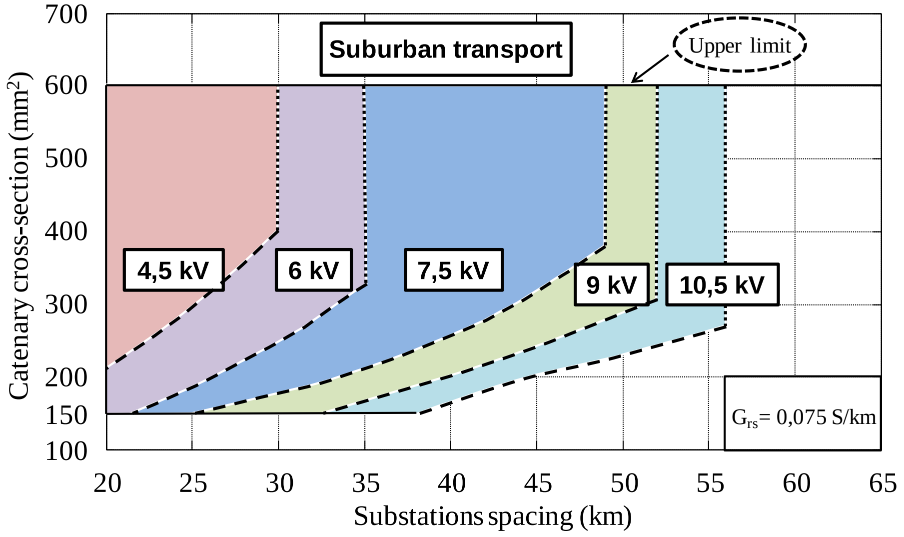
INTRODUCTION

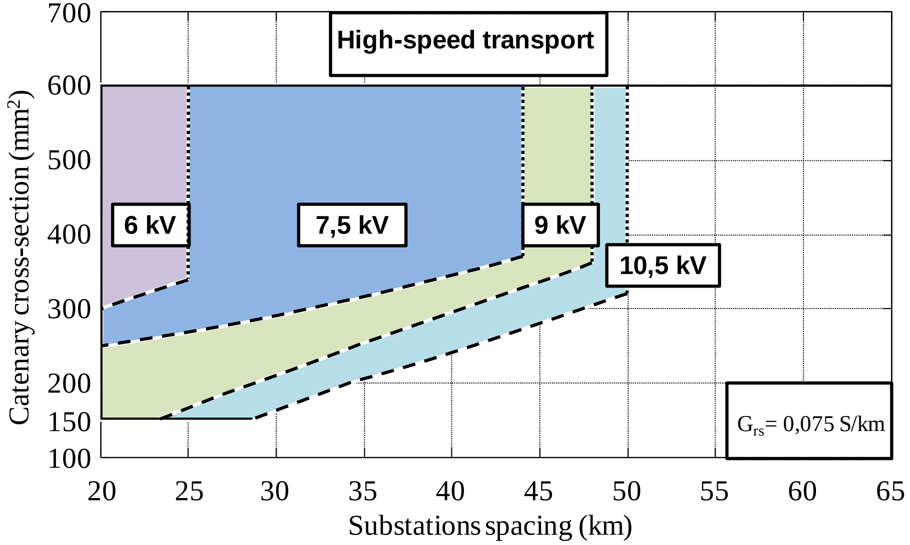
New Medium-Voltage DC Railway Electrification

Determining substations distance and overhead-line cross-section



A. Verdicchio, P. Ladoux, H. Caron and C. Courtois, "New Medium-Voltage DC Railway Electrification System," in *IEEE Transactions on Transportation Electrification*, vol. 4, no. 2, pp. 591-604, June 2018.





Computation Results

$P = 3MW$
v =80km/h
Tim. = 5 min.

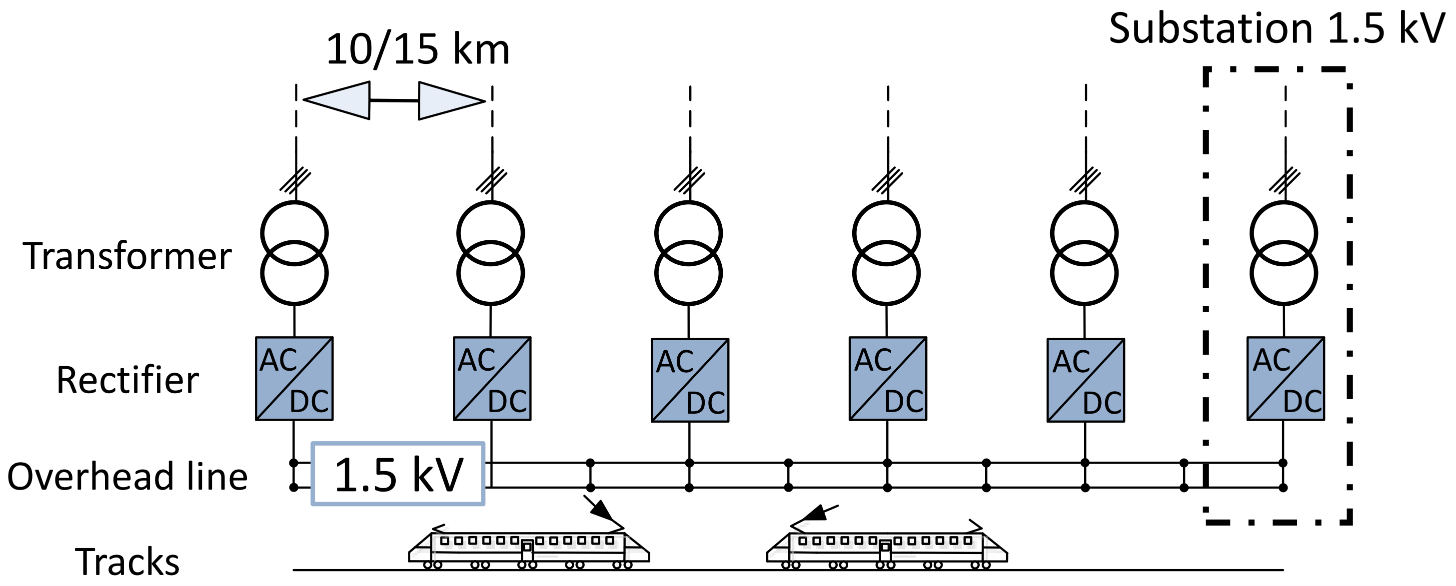
$P = 12MW$
$v = 280km/h$
Tim. = 5 min.

CONTENT

- Electrification Conversion Strategy (from 1.5 kV DC to 9 kV DC)
- Case Study (Bordeaux-Hendaye line)
- Conclusion and future work

ELECTRIFICATION CONVERSION STRATEGY

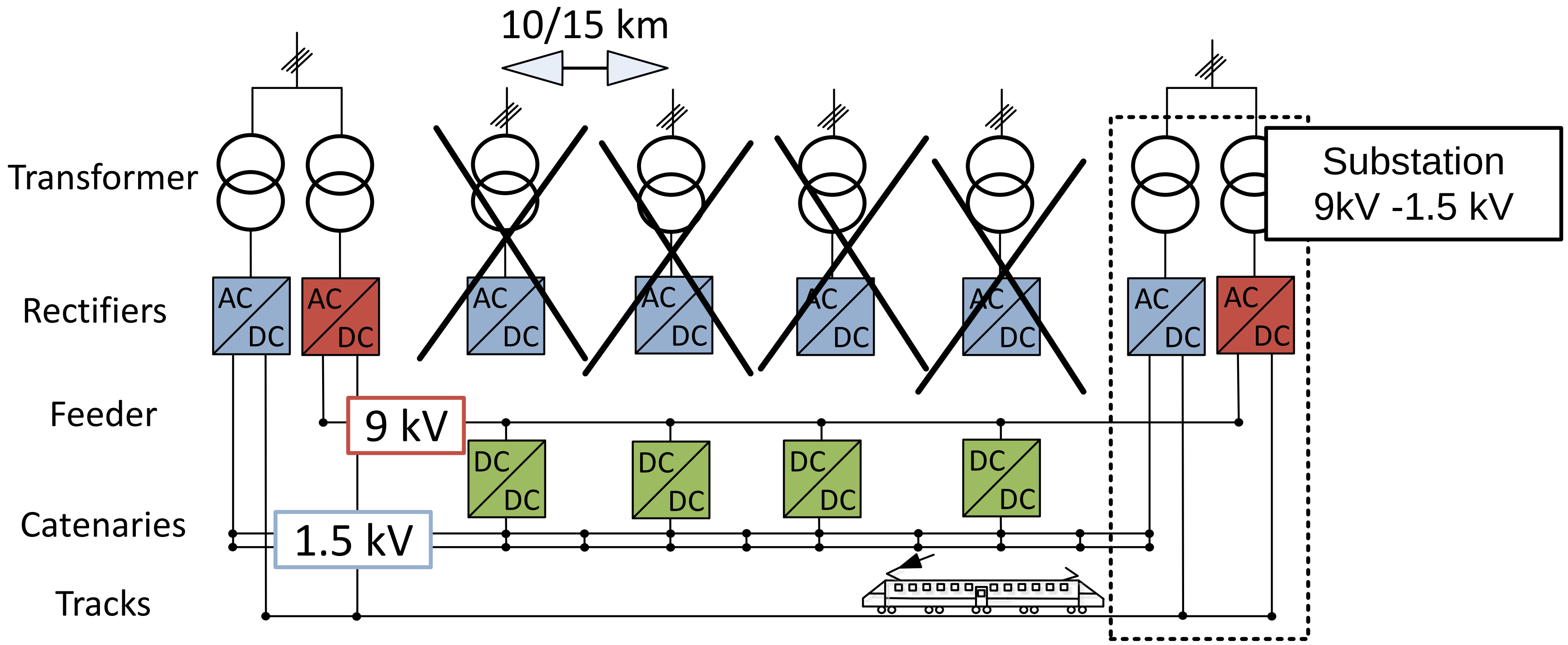
Existing solution: 1.5 kV DC Railway Electrification System



- Low substation distance.
- Heavy overhead line, cross-sections up to 1000mm^2.
- System originally developed for low power rolling stocks.

ELECTRIFICATION CONVERSION STRATEGY

First step: Three-wire supply system 9 kV -1.5 kV

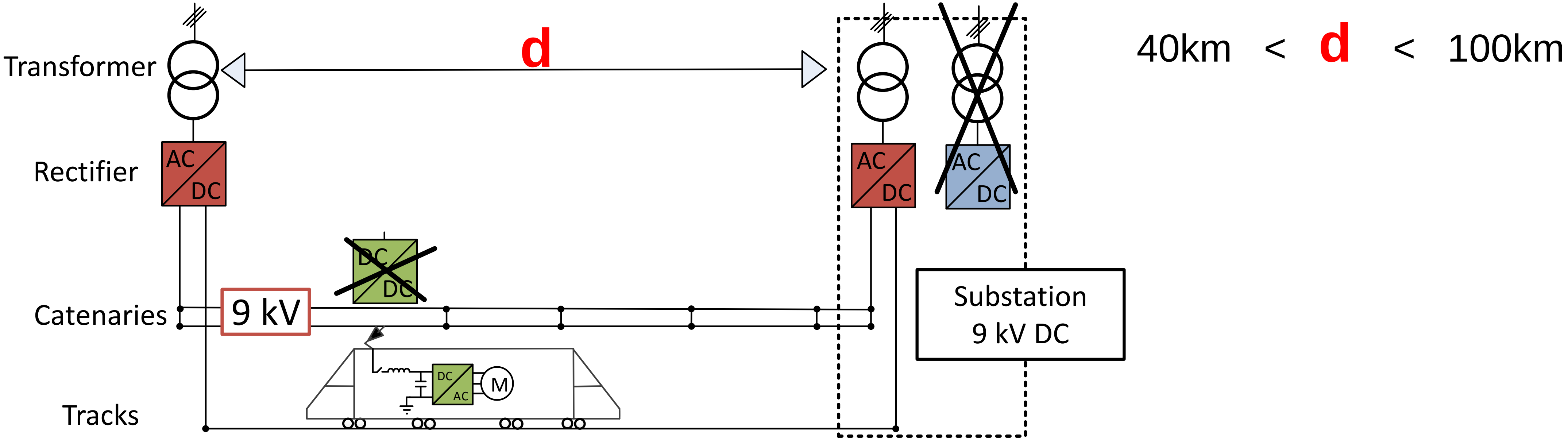


- 9kV transformer-rectifier groups and feed-wires are added.
- Intermediate 1.5kV transformer-rectifier groups are replaced by DC-DC PETs.

PET : Power electronics transformer.

ELECTRIFICATION CONVERSION STRATEGY

Final step: 9 kV DC Railway Electrification System



- Overhead-line supplied by 9kV substations.
- 1.5 kV DC transformer-rectifier groups and PETs completely removed.
- DC-DC PETs or/and MVDC converter embedded in the traction-unit.
- The overhead-line cross-section is reduced.
- The number of substations is reduced.

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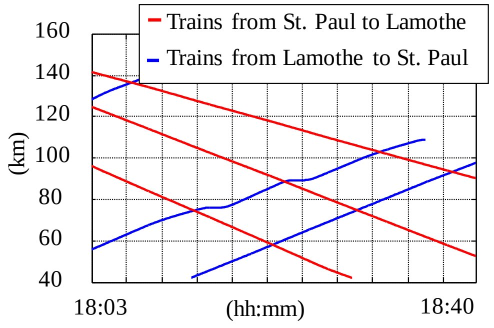
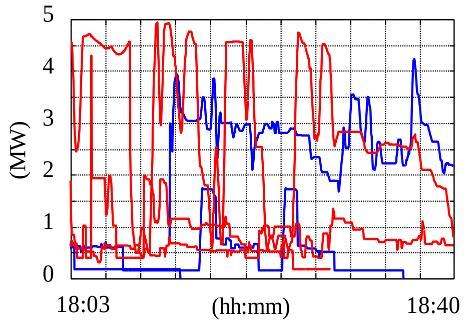
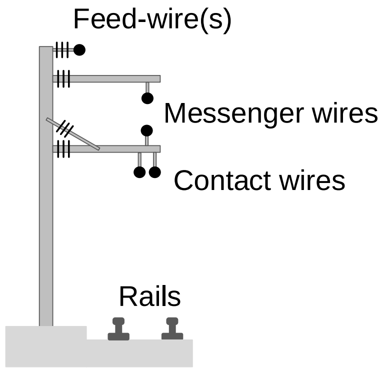
CASE STUDY : Bordeaux-Hendaye line

Railroad traffic

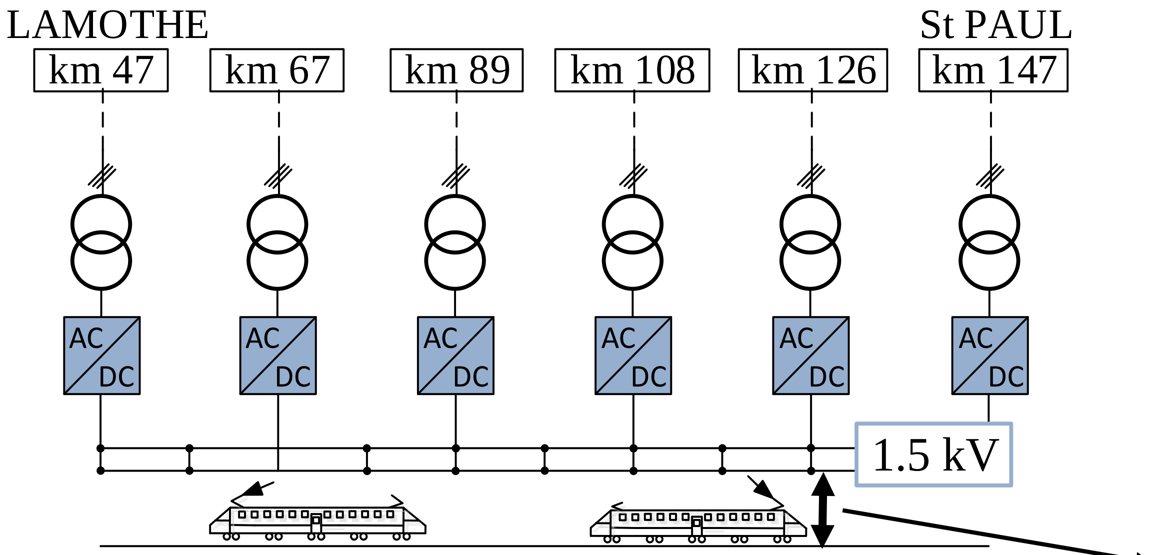


Absorbed Power by trains

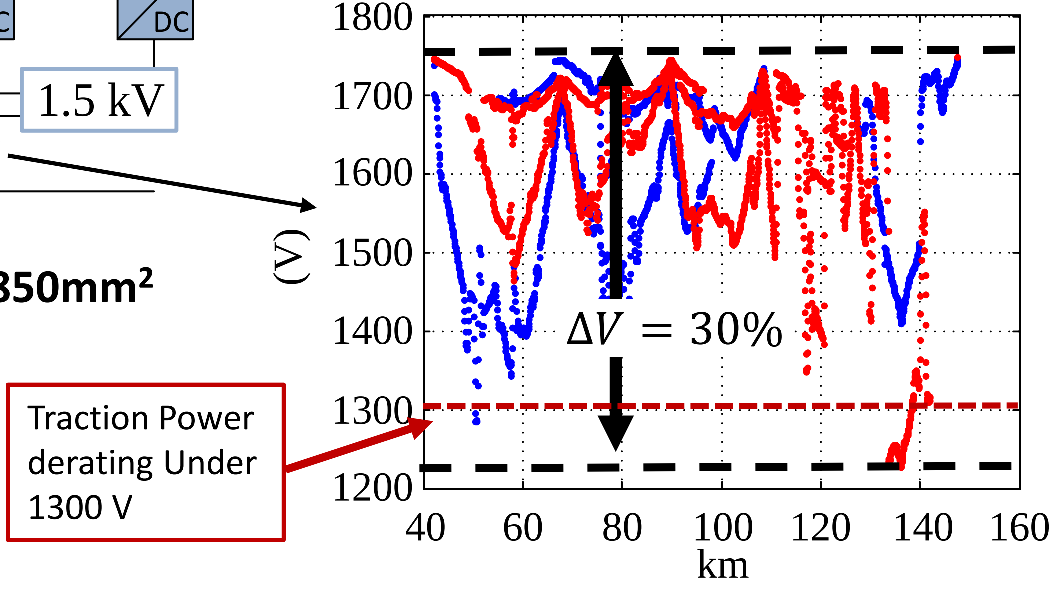




Original power supply 1.5 kV

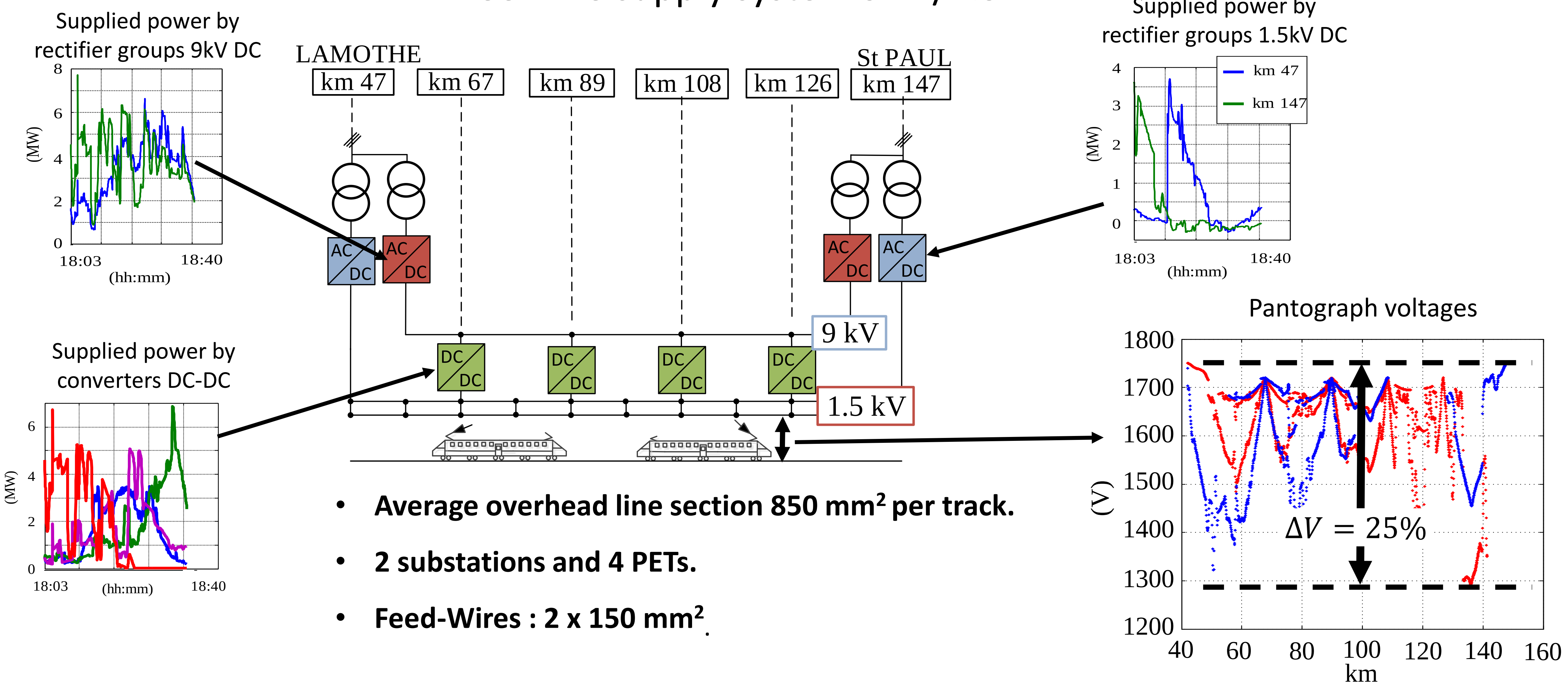


- **Average overhead line cross-section = 850mm²**
- **6 substations**



CASE STUDY : Bordeaux-Hendaye line

Three-wire supply system 9 kV/1.5 kV

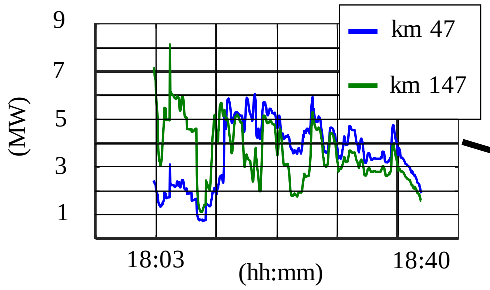


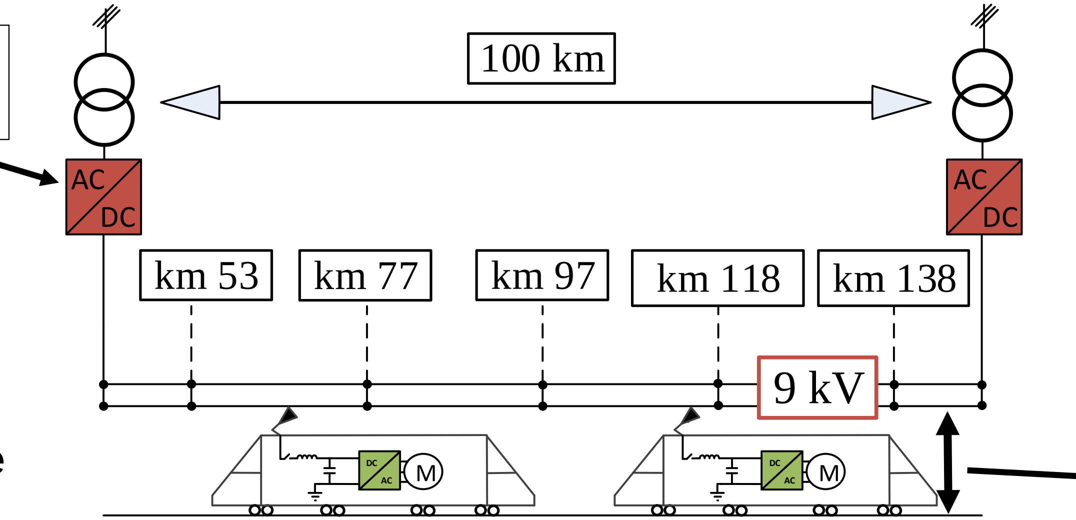
- **Average overhead line section 850 mm² per track.**
- **2 substations and 4 PETs.**
- **Feed-Wires : 2 x 150 mm².**

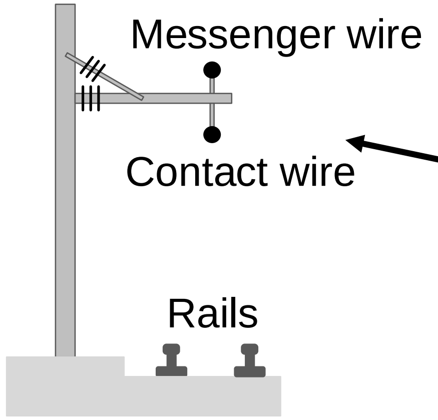
CASE STUDY : Bordeaux-Hendaye line

9 kV DC

Power supplied
by substations 9kV DC

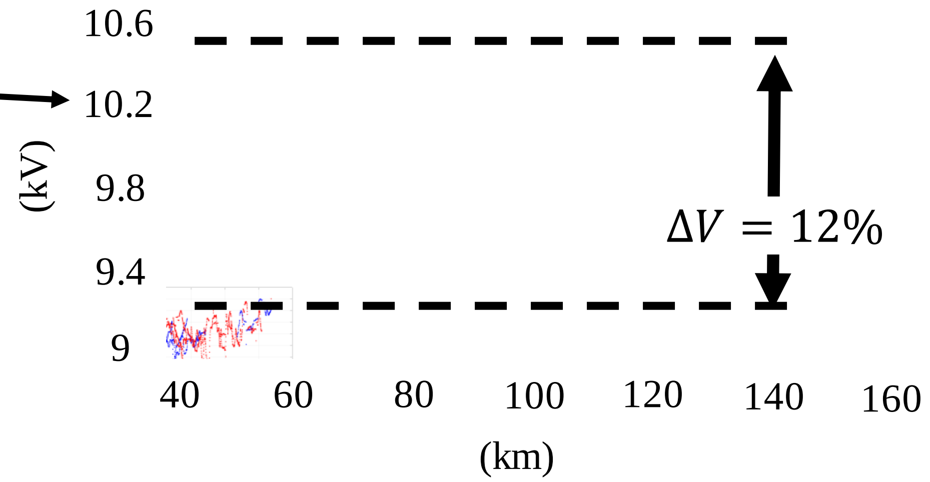






- **Overhead line cross-section per track : 266 mm²**
- **Substations distance : 100 km**

Pantograph voltages

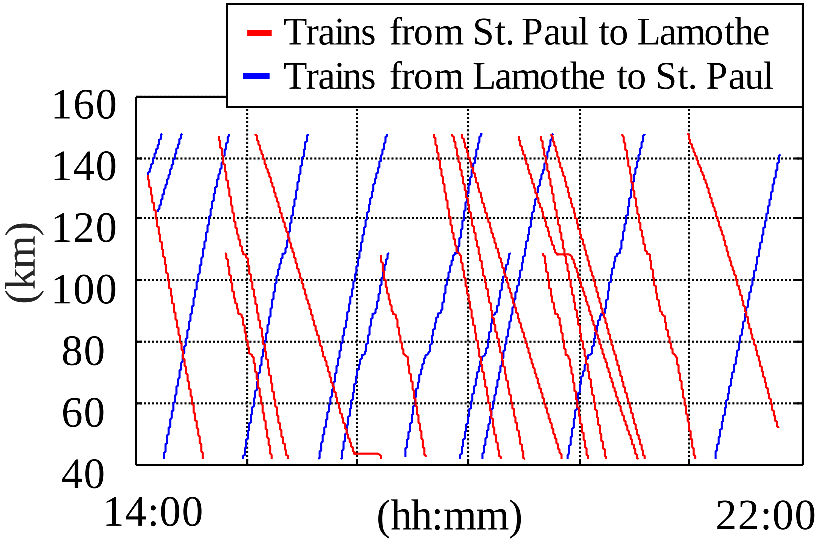


CASE STUDY : Bordeaux-Hendaye line

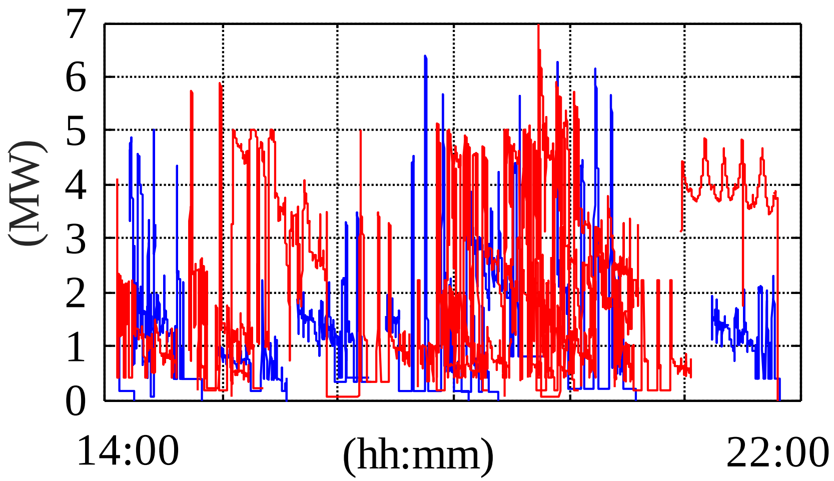
Comparison between 9 kV and 1.5 kV system

Specifications

Railroad traffic for half day



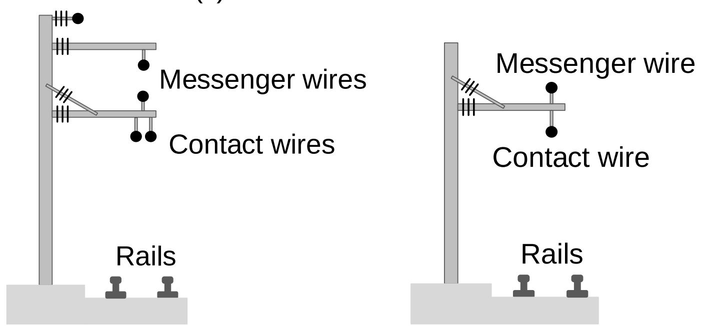
Absorbed Power by trains

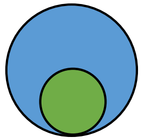


CASE STUDY : Bordeaux-Hendaye line

Comparison between 9 kV and 1.5 kV system

Equivalent overhead-line cross-section



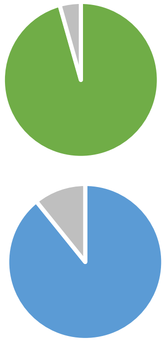


$$\frac{A_{9kV}}{< A_{1.5kV} >} \approx 0.3$$

$< A_{1.5kV} >= 850\ mm^2$

$A_{9kV} = 266\ mm^2$

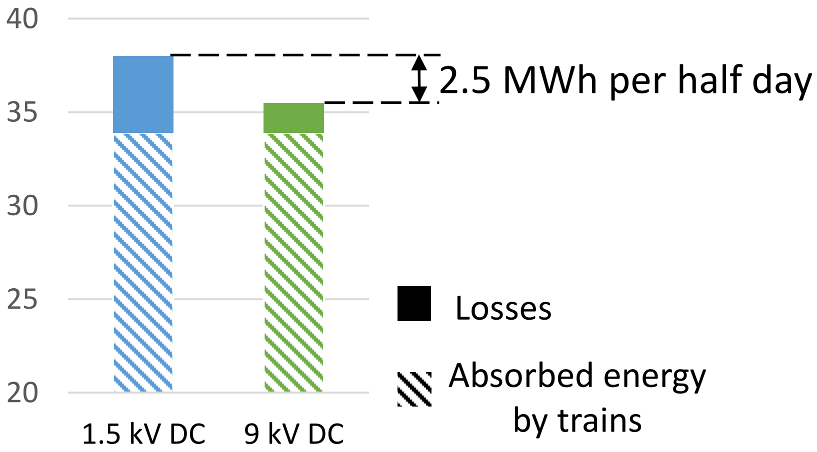
Overhead-line efficiency



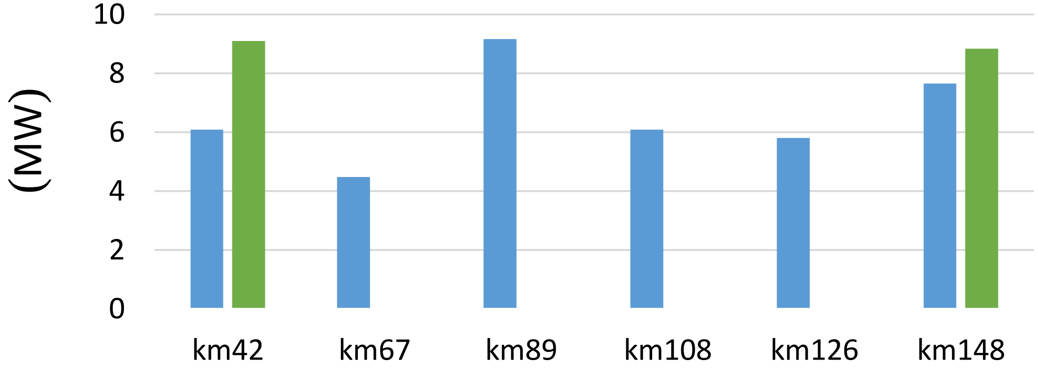
$\eta_{9kV} = 0.95$

$\eta_{1.5kV} = 0.89$

Total Energy supplied by substations



Maximum Power supplied by substations



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CONCLUSIONS and FUTURE WORK

Moving to 9kV allows:

- Reducing the copper of the overhead line (**70% of the cross-section** that is about **20 M€ saved for 100 km**).
- Reducing the number of substations compared to 1.5kV DC (about **60% less installed power**).
- Increasing efficiency (about **6%**).
- Saving **2 GWh per year for 100 km** (about **150 k€ per year**).

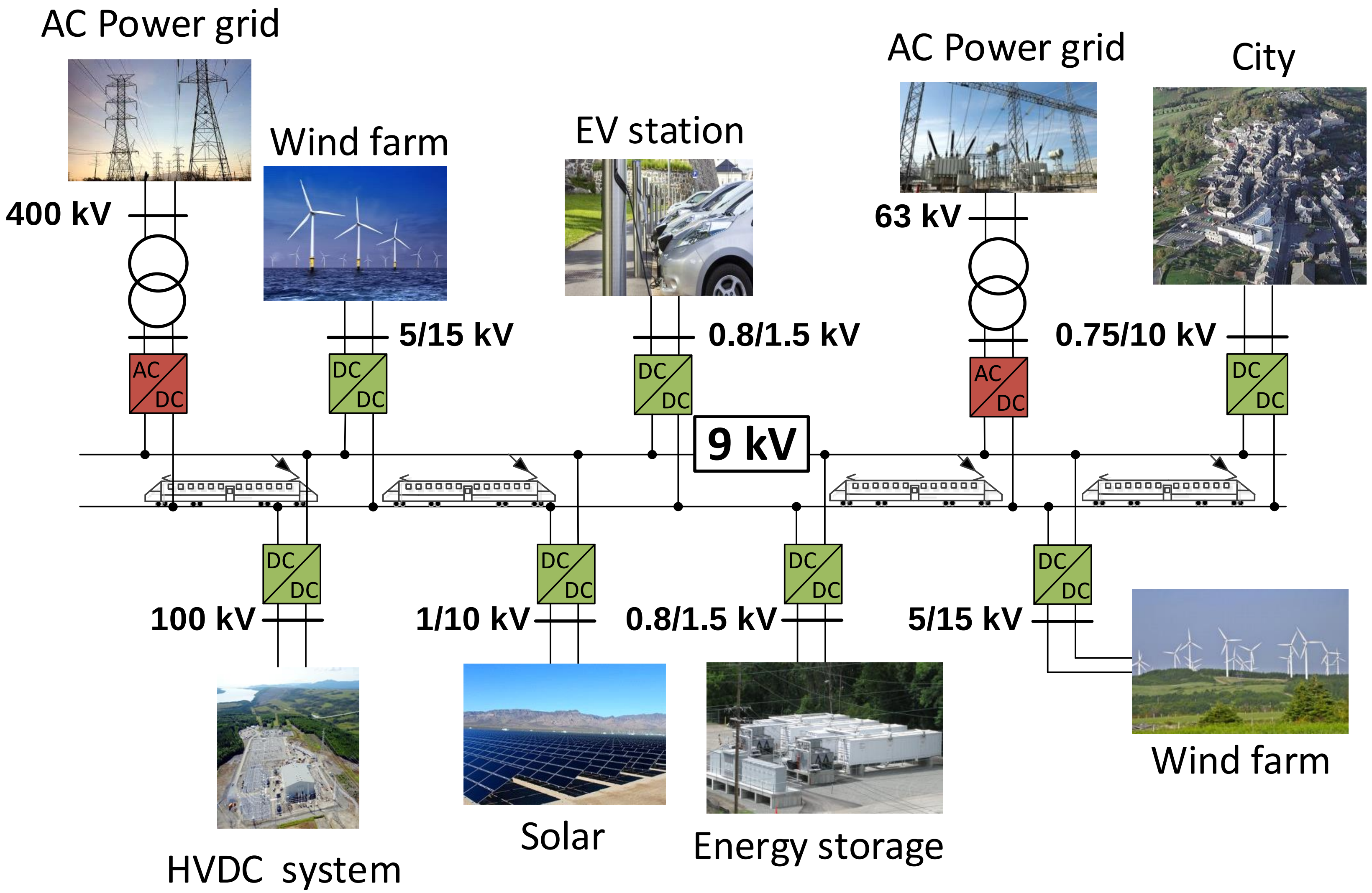
Outlook:

- Very attractive for countries that need to develop an electrified railway network.
- A DC system towards which European railway companies can converge within a long-term.

Work in progress:

- Development of a Power Electronics Transformer based on SiC MOSFETs.

The Dream


AC Power grid
Wind farm
EV station
AC Power grid
City
400 kV
63 kV
5/15 kV
0.8/1.5 kV
0.75/10 kV
AC DC
DC DC
DC DC
AC DC
DC DC
9 kV
DC DC
DC DC
DC DC
DC DC
100 kV
1/10 kV
0.8/1.5 kV
5/15 kV
Wind farm
Solar
Energy storage
HVDC system

Thank you for your attention

The research team

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