New Medium Voltage DC railway electrification system

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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). |
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 (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

<table>
<thead>
<tr>
<th>$V_n$ (kV)</th>
<th>$V_{min}$ (kV)</th>
<th>$V_{max}$ (kV)</th>
<th>$E_{sub-station}$ (kV)</th>
<th>$E_{sub-station}/V_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>1.0</td>
<td>1.8</td>
<td>1.75</td>
<td>0.85</td>
</tr>
<tr>
<td>3</td>
<td>2.0</td>
<td>3.6</td>
<td>3.5</td>
<td>0.85</td>
</tr>
<tr>
<td>4.5</td>
<td>3.0</td>
<td>5.4</td>
<td>5.25</td>
<td>0.85</td>
</tr>
<tr>
<td>6</td>
<td>4.0</td>
<td>7.2</td>
<td>7.0</td>
<td>0.85</td>
</tr>
<tr>
<td>7.5</td>
<td>5.0</td>
<td>9.0</td>
<td>8.75</td>
<td>0.85</td>
</tr>
<tr>
<td>9</td>
<td>6.0</td>
<td>10.8</td>
<td>10.5</td>
<td>0.85</td>
</tr>
<tr>
<td>10.5</td>
<td>7.0</td>
<td>12.6</td>
<td>12.25</td>
<td>0.85</td>
</tr>
</tbody>
</table>
Considered traction circuit

Double track line with a paralleling station at sector mid-point
Determining substations distance and overhead-line cross-section

**Train Characteristics**

<table>
<thead>
<tr>
<th>Transport service</th>
<th>TRAIN SPEED</th>
<th>Train Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suburban</td>
<td>80 km/h</td>
<td>3 MW</td>
</tr>
<tr>
<td>High-speed</td>
<td>280 km/h</td>
<td>12 MW</td>
</tr>
</tbody>
</table>

**Railroad traffic**

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

Determining substations distance and overhead-line cross-section

- Overhead line resistivity \(1.88 \times 10^{-8} \, \Omega \cdot \text{m}\)
- Rail size (60 kg/km)
- Rail-to-ground conductance (0.075 S/km)
- Ambient air temperature (40°C)
- Wind speed (0.5 m/s)
- Overhead line temperature: \(T_{\text{max}} = 65^\circ\text{C}\)
- Rail to ground voltage: \(V_{\text{rgmax}} = 150 \, \text{V (IEC 62128-1 Standard)}\)
- Pantograph voltage: \(V_{\text{min}}\) according to table of slide 4

Input Data

Computational Algorithm

Overhead-line cross-sectional area versus substation spacing

Stress
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*

**MVAC**

**MVDC**

Overhead line equivalent cross-section (100% Cu) for one track: 377 mm²
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 mm$^2$
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

- **Railroad traffic**
- **Train absorbed Power**
- **Substation Power**
- **Pantograph voltages**
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**

<table>
<thead>
<tr>
<th>km 47</th>
<th>km 147</th>
</tr>
</thead>
</table>

**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

![Railroad Traffic Graph]

### Power absorbed by trains

![Power absorbed by trains Graph]

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

<table>
<thead>
<tr>
<th></th>
<th>1.5 kV (with feed-wire)</th>
<th>9 kV</th>
<th>9 kV (with feed-wire)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead line equivalent cross-section</td>
<td>850 mm²</td>
<td>230 mm²</td>
<td>410 mm²</td>
</tr>
<tr>
<td>Energy efficiency of traction circuit</td>
<td>0.89</td>
<td>0.95</td>
<td>0.97</td>
</tr>
<tr>
<td>Total Energy provided by the substations</td>
<td>38 MWh</td>
<td>35.5 MWh</td>
<td>34.9 MWh</td>
</tr>
</tbody>
</table>
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

Final Stage: MV traction inverter

3.3 kV SiC MOSFETS are available