Optimised Braking Energy Recovery in Metro and Light Rail Systems

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Overview

• Technologies description
• Methodology
• Ticket to Kyoto experience
  • Reversible substations in the Metro network
• Eliptic Approach
  • Tram Network
• Summary & conclusions
Technologies description
Urban Rail Vehicles: Regenerative Braking & Energy Exchange
Onboard Energy Storage
Reversible Substation
Summary of Technologies

<table>
<thead>
<tr>
<th>Feature</th>
<th>Mobile Storage Systems</th>
<th>Stationary Storage Systems</th>
<th>Reversible Substations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead line or third rail losses are reduced.</td>
<td>✗</td>
<td>✗</td>
<td></td>
</tr>
<tr>
<td>High efficiency due to lower transformation and storage losses.</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Recovered braking energy can supply any equipment (lighting, escalators, etc.).</td>
<td></td>
<td></td>
<td>✗</td>
</tr>
<tr>
<td>Vehicles can be operated without overhead lines/third rail on short sections.</td>
<td>✗</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The systems can be installed without having to modify the vehicles.</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Lower safety constraints as not on-board of the vehicle.</td>
<td></td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Tunnels and stations warming can be avoided by reducing the heat produced by the braking resistors.</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Voltage stabilisation and peak-shaving opportunities.</td>
<td>✗</td>
<td>✗</td>
<td></td>
</tr>
</tbody>
</table>
Evaluation of Potential

• Measurements
  • Vehicles power flows and energy consumption
    • Braking resistors energy = Maximum energy savings potential
    • Auxiliaries
    • Traction
    • Energy sent back to the network
  • Substations
    • Energy consumption and power profile
    • OCV and internal impedance
Evaluation of Potential (II)

• Simulations
  • Modelling the network and vehicles “as it is”
  • Validation of the model with measurements
  • Introduction of energy recovery technologies
    → Find the suitable technology and possible solutions

• Business Case
  Investment
  Maintenance/year
  Energy savings/year
  Other costs/benefits (Installation, CO₂, etc)

Economic Indicator:
  ROI
  Payback Time
  ...

ELIPTIC Webinar: Optimised braking energy recovery in electric public transport systems
Simulations: Validation

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**ELIPTIC Webinar:** Optimised braking energy recovery in electric public transport systems

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**Graphs:**

1. Speed \(v\) vs. Time [s]
2. Current \(I_{chopper}\) vs. Time [s]
3. Power \(P_{chopper}\) vs. Time [s]

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**Legend:**

- **Real**
- **Sim**
Simulations: Validation (II)

Measurements May 2011 [%]  Simulations May 2011 [%]  Substation OCV [V]

Energy restored to the network / Energy consumed for traction [%]

Measurements  Simulation

Peak  Off-Peak  Weekends & Night
Simulation Results

![Graph showing simulation results of inverters energy and substation OCV for different tests.]

- **Inverters Energy [kWh]**
- **Substation OCV [V]**

Tests: Test1, Test2, Test3, Test4

- **Vo**
Simulation Results (II):

Trade-off solution: 6-8 Inverters of 1 to 1.5 MW
Ticket To Kyoto Experience

From evaluation to installation
Tender Process

• Tender answered by 8 companies

  AEG  TranzCom  Ingeteam  SIEMENS

• Each company proposed a solution and estimated the yearly savings
  • Proposals evaluated & challenged by external expert

• After a few corrections, the final proposals from the 3 companies were similar
  → STIB decided to test 3 prototypes in the same conditions
How does a 1.5 MW inverter look?
Trial Phase

- Estimated Payback Time: 5 years (*)
- Differences in Power Factor
- Trial results in line with estimations
Results 2014

• 3 prototypes in the same substation until May

Énergie Récupérée en 2014
Installation and relocation of inverters
Eliptic

Energy Recovery in the Tram Network
Eliptic Approach

• Study of Tram Network
  • Similar approach to the Metro study
  • Higher complexity
    • Interconnected lines
    • Substation feeding different lines
    • Electric feeders and catenary differ in sections
    • Most of the lines are mixed with car traffic

• Use of feedback from real systems installed in the metro lines
Reversible Substations Concept

ELIPTIC Webinar: Optimised braking energy recovery in electric public transport systems
## Quick Comparative: Tram vs. Metro

<table>
<thead>
<tr>
<th></th>
<th>Metro</th>
<th>Tram</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vehicles’ Power</strong></td>
<td>&gt; 2 MW</td>
<td>&lt; 600 kW</td>
</tr>
<tr>
<td><strong>Vehicles’ Speed</strong></td>
<td>Higher (up to 70 km/h)</td>
<td>Lower (dependant on traffic)</td>
</tr>
<tr>
<td><strong>Electric Network</strong></td>
<td>Regular feeders and third rail</td>
<td>Irregular feeders and catenary sections</td>
</tr>
<tr>
<td><strong>Auxiliaries’ consumption</strong></td>
<td>Low</td>
<td>High (expected)</td>
</tr>
<tr>
<td><strong>Stations Nearby</strong></td>
<td>Always</td>
<td>Rarely</td>
</tr>
<tr>
<td><strong>Supply Voltage</strong></td>
<td>900 Vdc</td>
<td>700 Vdc</td>
</tr>
<tr>
<td><strong>Electric consumers near the substation</strong></td>
<td>Always (station): escalators, lighting, shops</td>
<td>Rarely</td>
</tr>
</tbody>
</table>
Tram vs. Metro: Voltage drop par km

This parameter influences “How far the braking energy can be sent”

Despite the differences → similar behaviour
Eliptic Timeline

- Lines Selection
- State of the art review
- Analysis of network
- Comparative Metro vs Tram

- Network Model (ongoing)
- Measurements (ongoing)
- Simulations & Validation
- Energy Recovery Simulations
- Business Case
- Reporting
Summary
Summary & Conclusions

- Overview of methodology and Ticket to Kyoto experience

- Lessons learned:
  - Control expertise is crucial
  - The same hardware can have very different results
  - Importance to challenge the supplier proposal by independent consultant
  - Each network is different → Hard to extrapolate results

- Eliptic:
  - Similar methodology will be used
  - Feedback from Ticket to Kyoto will be used