Energy Efficiency in Electric Traction Supply

Increasing the efficiency from Substation to Pantograph... and back

Energy Efficiency, the best fuel to move our trains!
OVERVIEW

Control strategies
Power Electronics

Higher Efficiency

- Energy Storage
  - Flywheels
  - Battery storage
  - Ultracaps

- Better Recuperation of Braking Energy

- Lower Resistance
  - More copper in overhead lines

- System Voltage
  - Brussels - Luxembourg
    - 3 kV → 2x25 kV
  - Norway
    - 1x15 kV → 2x15 kV
  - Netherlands
    - 1.5 kV → 3 kV?

Discussion: other system voltages possible/desirable?

Other?

Feed back to utility grid/own grid
- STIB-MIVB, Brussels

Better interchange between trains: RPC, Japan

Energy Storage
- Flywheels
- Battery storage
- Ultracaps
OVERVIEW

• Speakers:
  • Energy utilisation in a.c. traction power supply system by introducing RPC (Railway Static Power Conditioner)
    Kazumi Nagano, East Japan Railway Company, Japan
  • Braking Energy Recovery – from simulations to tangible results
    Ricardo Barrero, STIB-MIVB, Belgium
  • Energy efficiency by increasing the traction power supply voltage
    Fedor ten Harve & Marcel Walraven, ProRail, The Netherlands
Braking Energy Recovery
From simulations to tangible results

Ricardo Barrero
Environmental Technology Officer
STIB-MIVB

Energy Efficiency, the best fuel to move our trains!
PRESENTATION AS PREZI

http://prezi.com/nsnstlephex/?utm_campaign=share&utm_medium=copy&rc=ex0share

The next slides are some screen shots from this Prezi.
Braking Energy Recovery

Context

Principle

Real World Implementations

UIC Energy Efficiency Days 2014
Need for energy efficiency in public transport

**STIB: between 2007 and 2012**
- +52% energy bill (€)
  - +41% energy cost (€/kWh)
  - +8% in energy consumption (kWh)
- +20% in transport offer
- +10% in efficiency improvement (kWh/pax)

**Past and future CO₂ atmospheric concentrations**

*Mitigation and adaptation required*
Natural energy exchanges between vehicles

Braking

Energy transfer between vehicles

Accelerating
Burnt in braking resistors → Storage → Back to the grid
Network Voltage Evolution

- Braking resistors voltage: 925V
- Substation voltage: 820V

Tram / Catenary voltage:
- Acceleration
- Braking

Braking recovery zone
Stationary applications

Mobile applications
- Supercapacitors
- Batteries
- Flywheels
- Reversible substations
Challenges

**Advanced simulations required**
- Large set of data
- Good expertise
  Follow market evolution
  ⇒ Evaluate potential

**Select technology**
- Compare suppliers
- Optimize
  ⇒ 5V error: Benefits -20%!
  Adapt to network evolution
Implementation

Studies with Brussels university (2 PhD students)
Choice for reversible substations line 2-6
Tender answered by 8 companies (out of 11)
3 selected for trial

AEG  TranzCom  Ingeteam  SIEMENS

3 month comparison in the same substation
Trial

High variability in substation consumption

For a fair comparison we need the same reference

Other challenges: Substation OCV and braking resistors voltage vary
Results

Important note:
Three suppliers still see an important potential of optimization + challenging OCV and braking voltage

Energy consumption reduced by 9% when complete systems deployed
Payback time: Maximum 5 years for 6 systems (before optimization)
Results in line with University simulations
Difference in reactive power generated
Next steps

- Complete installation of 6 systems on line 2-6
- Potential new tender for line 1-5
- Studies for tram which also has high potential

Three publications on this topic from the T2K partners
Energy savings are close from the network calculations made by Elbas.

With the 2 inverters and 1 flywheel, moBiel saves over 900,000 kWh/year.

Payback time: Maximum 10 years for 4 systems (5 year with funding).

- moBiel happy with both flywheel and inverter
- Efficiency is lower (84%) with flywheel than reversible substations (98%)
- Decision to buy third reversible substation
Two inverters made by IMTECH
Simulation results:
- Schiedam substation: 663,000 kWh/year
- Hekelingseweg: 560,000 kWh/year
Conclusion

Braking energy recovery is a complex technology becoming

Several real world implementations in Ticket to Kyoto project
Savings up to 12% depending on network characteristics

Independent electrical and network simulations are key to real benefits
Thank you for your attention
Energy efficiency by increasing the traction power supply voltage

Marcel Walraaven and Fedor ten Harve

Energy Efficiency, the best fuel to move our trains!
INTRODUCTION PRORAIL

- Independent
- Railinfrastructure manager
- Railinfra network operator

Our Mission

ProRail connects people, cities and businesses by a dense, intensively used rail network.

ProRail provides a secure, reliable, punctual and sustainable rail network and comfortable stations, in conjunction with operators and partners.

Our professionals work efficiently and cost-consciously on a rail network focused on pleasant passenger travel and unobstructed freight transport.

ProRail. Certainly on the track.

24/7

1,083,000 passengers per day

Population 16.7 M

4 M local residents

3,300,000 trains per year

115,000 tonnes of freight per day

9 passenger operators

139 M km passenger transport per year

19 freight carriers

10 M km freight transport per year

Source: jaarverslag ProRail 2012
**Facts & Figures**

- 1500 V Power Supply
- 2100 km electrified.
- 243 substations (2.5 – 12 MVA).
- 130 track sectioning stations.
- Distance between substations 3 – 21 km, average 6 km.
- Trains max: 4000 A.
- Energy use yearly: 1400 GWh.
HISTORY OF TRACTION ENERGY
ANALYSIS OF ENERGY EFFECTS

ENERGY USAGE / BALANCE

- Energy from public grid
  - Energy for pantograph
    - auxiliary systems train
  - Energy losses
  - energy use of assets in the railway
  - Power for Traction
    - Power supply Catenary earthing
  - Power efficiency installation
    - energy uses air-resistance
    - energy losses during braking
    - energy uses mass, friction
## Re-evaluation of Traction System 2011/2012

### Table: Re-evaluation Results

<table>
<thead>
<tr>
<th>HERIJKING</th>
<th>25 kVAc</th>
<th>15 kVAc</th>
<th>3 kVac</th>
<th>1,5kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energie</td>
<td>😊</td>
<td>😊</td>
<td>😊</td>
<td>😞</td>
</tr>
<tr>
<td>Toekomstvast</td>
<td>😊</td>
<td>😊</td>
<td>😊</td>
<td>😞</td>
</tr>
<tr>
<td>Betrouwbaar</td>
<td>😊</td>
<td>😊</td>
<td>😊</td>
<td>😞</td>
</tr>
<tr>
<td>Migratierisico</td>
<td>😞</td>
<td>😞</td>
<td>😞</td>
<td>😞</td>
</tr>
<tr>
<td>Kosten</td>
<td>😞</td>
<td>😞</td>
<td>😞</td>
<td>😞</td>
</tr>
</tbody>
</table>

### Diagram:
- **15 kVAc**: Red
- **25 kVAc**: Green
- **3 kV dc**: Blue
- **1,5 kV dc**: Cyan

### Notes:
- **MKBA**: Medium-Kapaciteit Basislicentie Artikel 6
- **25 kVac**: - Energie-efficient
  - Toekomstvast
  - Zeer hoge investeringen
  - EU target systeem

### Additional Notes:
- **3 kVdc**: Energie-efficiënte systeem
  - Toekomstvaster
  - Overeenkomstige investeringen

- **15 kVAc**: - Energie-efficient
  - Toekomstvast
  - Zeer hoge investeringen

- **1,5 kVdc**: - Referentie systeem
  - Energie-efficiente begrensd
  - Toekomstvastheid begrensd
  - Aanzienlijke investeringen

### Brands:
- **INFRABEL**
- **UIC ENER**
ANALYSIS OF ENERGY EFFECTS

- Power consumption substation
- Power consumption train
- Regenerative braking

Savings at substation by regenerative breaking at 3 kV

1500 V
Current situation
50% regenerative breaking

3 kV
100% regenerative breaking

Less energy consumption

More traction power at 3 kV

UIC ENERGY EFFICIENCY DAYS 2014
ANALYSIS OF TRAVEL TIME SAVINGS EFFECT

Power per train ➔ Achievable acceleration

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**Power per train**

- **SLT16 1500V**
- **SLT16 3 kV**
- **SLT16 3000V+20%**

**Achievable acceleration**

- **Traction power limit 1500V system**

**Graphs showing**

- Difference in time until maximum speed of 140 km/h referred to 1500V.
  - 3 kV: 41 sec
  - 3 kV+additional motor: 51 sec

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UIC ENERGY EFFICIENCY DAYS 2014
MONETARY BENEFITS (INDICATIVE)

**Energy**
- Efficiency
- More recuperation
- 20 - 22% saving
- 290 GWh/yr or 133 kton CO2/yr

€.. mio/yr

**Travel time**
- Travel time savings (passenger)
- Excl benefits intercity trains
- Rolling stock reduction
- 7 - 14 sec saving in timetable per stop

€.. mio/yr

• Excluding freight and regional traffic
Migration Plan

Ombouw

2013

1,5 kV dc

2025

3 kV
Costs (Indicative)

.. mio*

.. mio

.. mio

Excluding freight and regional traffic
INDICATION OF CASH FLOWS (INDICATIVE)

Basis variant 3 kV

- Baten energiebesparing
- Baten rijtijden winst
- Baten CO2 reductie
- Investering materieel
- Investering infra

UIC ENERGY EFFICIENCY DAYS 2014
CONCLUSION

• Increasing power supply voltage effects energy and travel time savings.
• A decision has not made yet
Regenerative energy utilization in a.c. traction power supply system by introducing RPC (Railway static Power Conditioner)

Kazumi Nagano
EAST JAPAN RAILWAY COMPANY

Energy Efficiency, the best fuel to move our trains!
OUTLINE

• BACKGROUND

• INTRODUCTION

• BODY

• CONCLUSION AND FUTURE WORK
• BACKGROUND

• INTRODUCTION

• BODY

• CONCLUSION AND FUTURE WORK
D.C. traction power supply system is usually applied in subway and urban area. A.C. traction power supply system is usually applied in high speed railway and local line.
Most vehicle use regenerative braking system in 2012.

We have continually made effort to reduce energy consumption by regenerative energy utilization.
REGENERATIVE ENERGY UTILIZATION

Regenerative energy utilization methods

- Regenerative inverter
- Energy storage system
- RPC (Railway static Power Conditioner)

Energy storage system has already introduced in DC traction power supply system.

First Li-ion battery has introduced at HAIJIMA Substation in February 2013.
ENERGY STORAGE SYSTEM

Speciation

- Li-ion battery
- battery capacity : 170V, 5.5Ah
- rated capacity : 2000kW

Battery system is connected to DC 1.5kV bus and charge and discharge of the batteries are controlled by DC/DC converters.

Consumption power is reduced about 1MWh/day. (5% of total)
OUTLINE OF RPC

Regenerative energy utilization methods

- Regenerative inverter
- Energy storage system
- **RPC (Railway static Power Conditioner)**

RPC has already installed some traction substations for high speed railway in Japan.

**The purpose is not for regenerative energy utilization.**
We introduced RPC as regenerative energy utilization for the first time.
The regenerative power is not consumed unless powering train is in the same feeder section.

Regenerative power is back-flown to the power grid.

AC TRACTION POWER SUPPLY SYSTEM
It becomes possible to increase the utilization opportunity of the regenerative energy in ac traction power supply circuits.
### ENVIRONMENT OF USHIKU SECTIONING POST

<table>
<thead>
<tr>
<th>Substation</th>
<th>Fujishiro St.</th>
<th>Sanuki St.</th>
<th>Ushiku St.</th>
<th>Hitachino ushiku St.</th>
<th>Arakawa oki St.</th>
<th>Tsuchiura St.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>10.51 km</td>
<td></td>
<td></td>
<td>14.07 km</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Train Type</th>
<th>E531</th>
<th>E657</th>
<th>EH500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train Type</td>
<td>local train</td>
<td>limited express</td>
<td>freight car</td>
</tr>
<tr>
<td>Brake Type</td>
<td>regenerative brake</td>
<td>regenerative brake</td>
<td>dynamic braking</td>
</tr>
<tr>
<td>Number / day</td>
<td>136</td>
<td>74</td>
<td>6</td>
</tr>
<tr>
<td>Rated Power</td>
<td>3360 kW</td>
<td>3480 kW</td>
<td>3390 kW</td>
</tr>
</tbody>
</table>

**Fujishiro Substation**

- Fujishiro St.
- Sanuki St.
- Ushiku St.

**Ushiku Sectioning Post**

- Hitachino ushiku St.
- Arakawa oki St.
- Tsuchiura St.

**Tsuchiura Substation**

- Tsuchiura St.
## ENVIRONMENT OF USHIKU SECTIONING POST

<table>
<thead>
<tr>
<th>Fujishiro Substation</th>
<th>Tsuchiura Substation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DC feeding</strong></td>
<td><strong>Teaser</strong></td>
</tr>
<tr>
<td><strong>signal high voltage distribution</strong></td>
<td><strong>66/6.6kV</strong></td>
</tr>
<tr>
<td><strong>AC feeding Ushiku direction</strong></td>
<td><strong>Main phase</strong></td>
</tr>
<tr>
<td>66/1.2kV</td>
<td>66/22kV</td>
</tr>
<tr>
<td>66/6.6kV</td>
<td></td>
</tr>
<tr>
<td>66/22kV</td>
<td></td>
</tr>
</tbody>
</table>

---

**ENVIRONMENT OF USHIKU SECTIONING POST**

**Fujishiro Substation**
- DC feeding
- Signal high voltage distribution
- AC feeding Ushiku direction

**Tsuchiura Substation**
- Teaser
- 66/6.6kV
- Main phase
- AC feeding
- Signal high voltage distribution
Surplus regenerative power is about 500MWh per month
When consumption power of a substation is plus and other substation is minus

RPC interchanges regenerative power
CONTROL SYSTEM OF RPC

Ex1  
regenerative: 3, consumption: 1 (Fujishiro) / consumption: 3 and 1 (Tsuchiura)

Ex2  
regenerative: 5, consumption: 1 (Fujishiro) / consumption: 2 and 1 (Tsuchiura)
CONTROL SYSTEM OF RPC

Specification of RPC

- **rated output**: 1.3 MVA
- **rated voltage**: 22 / 3.25 kV
- **rated frequency**: 50 Hz
- **overload capacity**: 5.3 MW, 1 min.
- **response speed**: within 1 sec.

INV/CONV

Transformer

RPC control panel

### Diagram

- **Tr.1**: 22/3.25 kV
- **INV/CONV**: DC 6 kV
- **Tr.2**: 22/3.25 kV
EFFECT OF INTRODUCING RPC

RPC interchanges regenerative power from the first train to the last train.
EFFECT OF INTRODUCING RPC

Table: Interchange power after introducing RPC

<table>
<thead>
<tr>
<th></th>
<th>Fujishiro</th>
<th>Tsuchiura</th>
<th>Fujishiro → Tsuchiura</th>
<th>Tsuchiura → Fujishiro</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>day 1 (Jan. 31)</td>
<td>57.1 MWh</td>
<td>101.3 MWh</td>
<td>4.8 MWh</td>
<td>2.8 MWh</td>
<td>7.6 MWh</td>
</tr>
<tr>
<td>day 2 (Feb. 1)</td>
<td>54.1 MWh</td>
<td>101.0 MWh</td>
<td>4.9 MWh</td>
<td>2.7 MWh</td>
<td>7.6 MWh</td>
</tr>
<tr>
<td>day 3 (Feb. 2)</td>
<td>44.8 MWh</td>
<td>94.3 MWh</td>
<td>4.0 MWh</td>
<td>2.2 MWh</td>
<td>6.2 MWh</td>
</tr>
<tr>
<td>day 4 (Apr. 24)</td>
<td>47.3 MWh</td>
<td>83.5 MWh</td>
<td>4.7 MWh</td>
<td>3.0 MWh</td>
<td>7.7 MWh</td>
</tr>
<tr>
<td>day 5 (Apr. 25)</td>
<td>48.8 MWh</td>
<td>85.0 MWh</td>
<td>4.6 MWh</td>
<td>3.1 MWh</td>
<td>7.7 MWh</td>
</tr>
</tbody>
</table>

Total interchange power is about 7.6MWh / day.

Surplus regenerative power is reduced about 220MWh / month.

RPC will turn a profit after 14 years, when this energy saving effect continues.
• BACKGROUND

• INTRODUCTION

• BODY

• CONCLUSION AND FUTURE WORK
CONCLUSION

• RPC has started operation since the February 2014 at Ushiku sectioning post of Joban Line.
• Before RPC introduction, surplus regenerative power is about 500MWh per month.
• Surplus regenerative power is reduced about 220MWh per month by introducing RPC.

FUTURE WORK

• Stable operation of RPC is a future work.
• We verify the effect of RPC continuingly.
This is the end of my presentation. Thank you for your kind attention.