Optimising the electrical infrastructure of MTSs to increase energy efficiency: when and where to install reversible substations

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13 June 2018
Energy flows in a DC-electrified MTS

- **SUBSTATION LOSSES**
- **RECTIFIED**
  - Flowing Through Catenary
  - Absorbed From Catenary
  - Consumed by Trains
  - Traction
  - Auxiliary Services
  - Regenerated Back to Catenary
  - Regenerated to Auxiliary
  - Useful Regenerated
  - Rheostat Losses
- **CONDUCTION LOSSES**
- **Power Chain Electrical Losses “Go”**
- **Mechanical Losses**
- **REGENERATED**
- **Power Chain Electrical Losses “Return”**
The problem of limited receptivity

- How could this be fixed?
  - Improving or optimally operating the electrical infrastructure
Let’s put some numbers to the problem...

- **19 km double-track line**
- **23 stations ➔ 860 m average inter-station**
Let’s put some numbers to the problem...

- ATO speed profiles (flat-out)
- Speed limitations (max. line speed = 70 km/h)
Preliminary analysis results

Regenerative braking ⇒ large efficiency increase (40 %)

Infrastructure improvements welcome!
Preliminary analysis. Improvement techniques

**IMPROVEMENT TECHNIQUES**

**LOW INVESTMENT**
- No-load voltage
- SS shutdown

**HIGH INVESTMENT**
- Nominal voltage level
- Improve conductors
- Rev. Substations (RSs)
- Energy Storage (ESSs)
- Others

Large rheostat losses $\Rightarrow$ investment required $\Rightarrow$ RISK

**Important**: tools and models to take right decisions
Our tool to assist decision taking

- **ECONOMIC INFORMATION**
- **TECHNICAL RESTRICTIONS**
- **LAYOUT RESTRICTIONS**
- **INFRASTRUCTURE OPTIMISER**
- **OPTIMUM INFRASTRUCTURE SEARCH METHOD (PSO)**
- **ELECTRIC SIMULATOR**
- **TRAFFIC SCENARIO SET**
- **TRAFFIC GENERATOR**

Decision variables → Simulation results

Simulation results → Decision variables
High sensitivity to the traffic model

Necessary to include more scenarios
Traffic model concept and concerns

**Single traffic scenario**
- Perfect schedule

**Traffic space**
- Enough samples of stochastic traffic scenarios

**Compressed traffic scenarios**
- The representative subset, compressed

**Representative traffic scenarios**
- A representative subset

- **Inaccurate**
  - Comp. burden

- **Accurate**
  - Comp. burden
Some figures in a typical optimisation process

<table>
<thead>
<tr>
<th>Nº scenarios</th>
<th>Accuracy</th>
<th>Optimisation time (rough estimation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-scenario</td>
<td>POOR!</td>
<td>13 hours</td>
</tr>
<tr>
<td>Traffic space</td>
<td>The highest</td>
<td>9.3 MONTHS</td>
</tr>
<tr>
<td>Representative scenarios</td>
<td>Good!</td>
<td>93 hours</td>
</tr>
<tr>
<td>Compressed Repr. Scen.</td>
<td>Still good!</td>
<td>18.6 hours</td>
</tr>
</tbody>
</table>
Optimiser details
# Headway weekly composition

## Headway distributions

### Working day

- **Sparse headway (hours):** 2
- **Off-peak headway (hours):** 13
- **Peak headway (hours):** 4

### Ferial day

- **Sparse headway (hours):** 6
- **Off-peak headway (hours):** 13
- **Peak headway (hours):** 0

## Weekly total

<table>
<thead>
<tr>
<th>Sparse headway (hours)</th>
<th>2</th>
<th>6</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-peak headway (hours)</td>
<td>13</td>
<td>13</td>
<td>91</td>
</tr>
<tr>
<td>Peak headway (hours)</td>
<td>4</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>
Economic concerns

**RS cost**

\[ C_{RS} = C_{Fixed} + \alpha_{PWR} \cdot P_{RS} \]

E.g.: 2-MW RS \( \Rightarrow \) 0.55 M€

**Investment feasibility: Net Present Value**

\[ NPV = \sum_{t=1}^{T} \frac{ES_t}{(1 + r)^t} - C_0 \]

NPV \( \geq 0 \) \( \Rightarrow \) Feasible investment
Search space analysis. Some savings curves

NPV vs. savings. Several RS sizes and number

Global optima
The optimiser in action!
Useful outcomes for operators

- Insights on the **effect of traffic in receptivity**
  - and thus in **achievable savings**

- **Methods and models** to represent the traffic in any system

- **Modular** concept design
  - Optimiser, simulator & traffic model can be plugged into other concepts

- **Uncertainty** on investment return (and so **risks**) reduced
Thank you for your attention!
Questions?