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Estimate the energy consumption in order to evaluate new solutions of energy reduction!

Accurate models are required with a fast computation time

Modeling difficulties
- Size of the system (important number of subsystems)
- Non-linear & non-reversible aspects of substations (causality change: voltage/current source)
1. Quasi-static model of Val 208 subway
   • EMR
   • Inversion Based Control
   • Braking Management Strategy

2. Extension to a simplified subway line
   • EMR of a simplified subway line
   • Experimental validation

3. Conclusion & perspectives
“QUASI-STATIC MODEL OF VAL 208 SUBWAY”
EMR'14, Coimbra, June 2014

- EMR of Val 208 automatic subway -

\[ i_{vsi} = \frac{T_{sm} \Omega_{sm}}{\eta_{smeq} u_c} \]

with \( k = \begin{cases} -1 \text{ when } T_{sm} \Omega_{sm} < 0 \\ 1 \text{ when } T_{sm} \Omega_{sm} > 0 \end{cases} \) and \( T_{sm} = T_{sm-ref} \)

\[ i_L = \frac{u_{rail} - u_C}{R_f} \]

\[ \{ \Omega_{sm} \text{ common} \} \]

\[ T_i = T_{sm} + T_{bk} \]

\[ v_{sub} = \frac{1}{M_{eq}} \int (F_{tot} - F_{res}) \, dt \]
1 objective: control $v_{sub}$
1 constrains: limit $u_C$

$T_{bk-ref} = K_{Dbk} T_{t-ref}$
$T_{sm-ref} = (1 - K_{Dbk}) T_{t-ref}$

with $K_{Dbk} \in [0,1]$
- Braking management strategy -

- Respect the maximal braking torque of the PMSM $T_{sm bk max}$

- Limit the maximal value of the DC bus voltage $u_C$

\[
K_{Dbk1} = \frac{\min(\left| T_{i ref} \right|, T_{sm bk max} (\Omega_{sm})), T_{t ref}}{1}
\]

\[
K_{Dbk} = \begin{cases} 1 & \text{during the traction phase} \\ \min(K_{Dbk1}, K_{Dbk2}) & \text{during the braking phase} \end{cases}
\]

\[
T_{sm-ref} = K_{Dbk} T_{i-ref}
\]

\[
T_{bk-ref} = (1 - K_{Dbk}) T_{i-ref}
\]

with $K_{Dbk} \in [0,1]$
« EXTENSION TO A SIMPLIFIED SUBWAY LINE »
- Extension to a simplified subway line -

**Rail modelling**

\[
R_f(x_{sub})i_r + E_{ss} - u_{rail} = 0
\]

\[
i_r = \frac{E_{ss} - u_{rail}}{2R_f(x_{sub})}
\]

**Substation modelling**

\[
i_{ss} = \frac{E_{ss0} - E_{ss}}{R_{ss}}
\]

\[
C_1 : E_{ss0} \geq E_{ss}
\]

\[
C_2 : i_{ss} < 0
\]
« EMR of a simplified subway line »

- Extension to a simplified subway line -

\[
i_{ss} = i_{sub} = 0
\]

\[
E_{ss} = \left( 2R_f(x_{sub}) + \frac{R_f}{4} \right) i_{sub} + u_C = u_C
\]

\[
i_{sub} = i_{ss} = \frac{E_{ss0} - u_C}{R_{ss} + 2R_f(x_{sub}) + \frac{R_f}{4}}
\]

\[
C_1 : E_{ss0} \geq E_{ss}
\]

\[
C_2 : i_{ss} < 0
\]
2 stations, length: 472 m, Maximal velocity: 58 km/h

Measurements:
- DC bus voltage $u_C$
- Traction current $i_{trac}$
- Velocity $v_{sub}$

Inputs variables:
- Velocity $v_{sub}$
- Substation voltage $E_{ss0}$
- Slope
- Auxiliaries $P_{aux}$
« EMR of a simplified subway line »

- Extension to a simplified subway line -

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<table>
<thead>
<tr>
<th>Measurement</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>3,06 kWh</td>
</tr>
<tr>
<td>$\Delta W_{\text{avg}}$</td>
<td>2,98%</td>
</tr>
</tbody>
</table>
« CONCLUSION & PERSPECTIVES »
Conclusion

• Description of a simplified subway line using EMR
• Use of switching element to take into account the non-linearity of the diode rectifier (models commutation)
• Control the DC bus voltage using braking management strategy

Perspectives

• Extend this approach to an entire line with several subways and substations
• Study energy storage systems or reversible substations to improve the global efficiency of a subway line
« BIOGRAPHIES AND REFERENCES »
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EMR of a simplified subway line

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