Train Operation Minimizing Energy Consumption in DC Electric Railway with On-board Energy Storage Device
Kunihiko Matsuda, Hideyoshi Ko, Masafumi Miyatake(Sophia University)

1. Introduction
Energy storage devices
- Enough energy
- High power density

- Equip trains as an auxiliary power supply
- Compensate voltage drop
- Utilize regenerative power

Electric Double Layer Capacitor (EDLC) is used for large power density.

2. Purpose
Many works on the application of the energy storage devices to trains were reported. However, from an energy-saving point of view, their works did not deal enough with the optimal control of the devices.

- Investigation of the optimal control input
- Evaluation of energy saving effect
- Optimizing control inputs together
  - Acceleration/deceleration force of the train (notch)
  - Charge/discharge current of the EDLC

3. Simulation Condition
- Chopper efficiency is constant (95%)  
- Substations can absorb regenerative power

The optimal control problem
Minimizing the objective function
\[
\int_0^T V_S I_S dt
\]
The total consumed energy in substations

Subject to the Constraints
- Motion equation and circuit equation
- Characteristics of the EDLC etc...

- In order to solve this problem, SQP method is applied

4. Simulation Result
Capacity conditions
1. Train operation time is 130[s]
2. Distance between stations \( L = 2000[m] \)
3. Range of the EDLC’s voltage \( V_{cap} \) is 300-560[V]
4. Final voltage of the EDLC is equal to the initial one

Effect is higher

Fig.5 optimization result in case 1 without the EDLC

Fig.6 optimization result with the EDLC
Blue line: \( R_c=0.3 [\Omega] \) (case2)
Red line: \( R_c=0.03 [\Omega] \) (case3)

5. Conclusion
- Compared with and without the EDLC, there are little variation in the train optimal operation
- If the interior resistance of the EDLC is high, the capacitor do not be utilized effectively
- It is clarified that the EDLC does not necessarily fully discharge when the internal resistance is high.

<table>
<thead>
<tr>
<th>Case</th>
<th>Energy consumption [MJ]</th>
<th>Energy-saving effect [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case1</td>
<td>27.55</td>
<td>-</td>
</tr>
<tr>
<td>Case2</td>
<td>27.45</td>
<td>0.35</td>
</tr>
<tr>
<td>Case3</td>
<td>26.74</td>
<td>2.92</td>
</tr>
</tbody>
</table>