Numerical Optimization of Speed Profiles of Inverter Trains Considering DC Feeding Circuit

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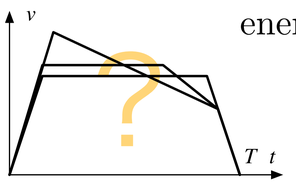
1. Introduction

1.1 Energy-saving operation of inverter trains



energy → min.

$T = \text{const.}$ (running time between stations)

$$\int_0^T v\,dt = \int_0^T \int_0^T a\,dt\,dt = \text{const.}$$

Finding minimum-energy train speed profile

- Considering feeding characteristics and interaction among several trains is essential.
- It has many difficulties in solving.

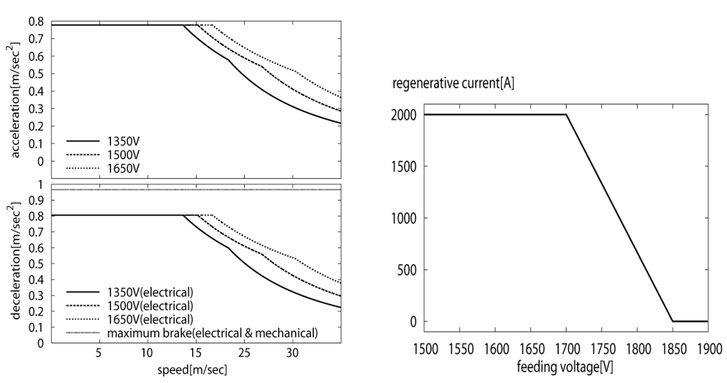
1.2 Objectives

- Proposal of an novel optimization algorithm of train speed profiles for practical use, considering
  - feeding circuit
  - regenerative brake of inverter trains
  - energy exchange among several trains
- Qualitative analysis of the optimized profiles

2. Mathematical Formulation

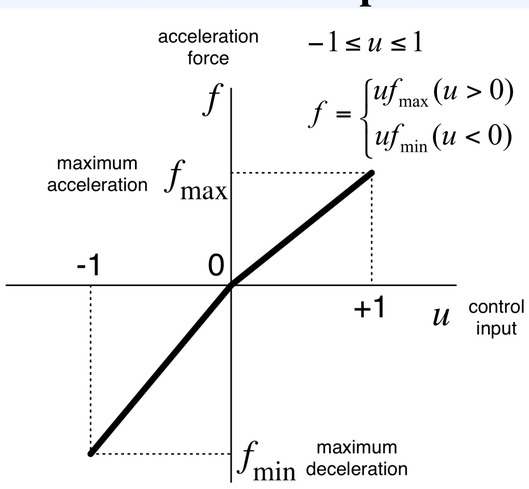
2.1 Optimal control problem

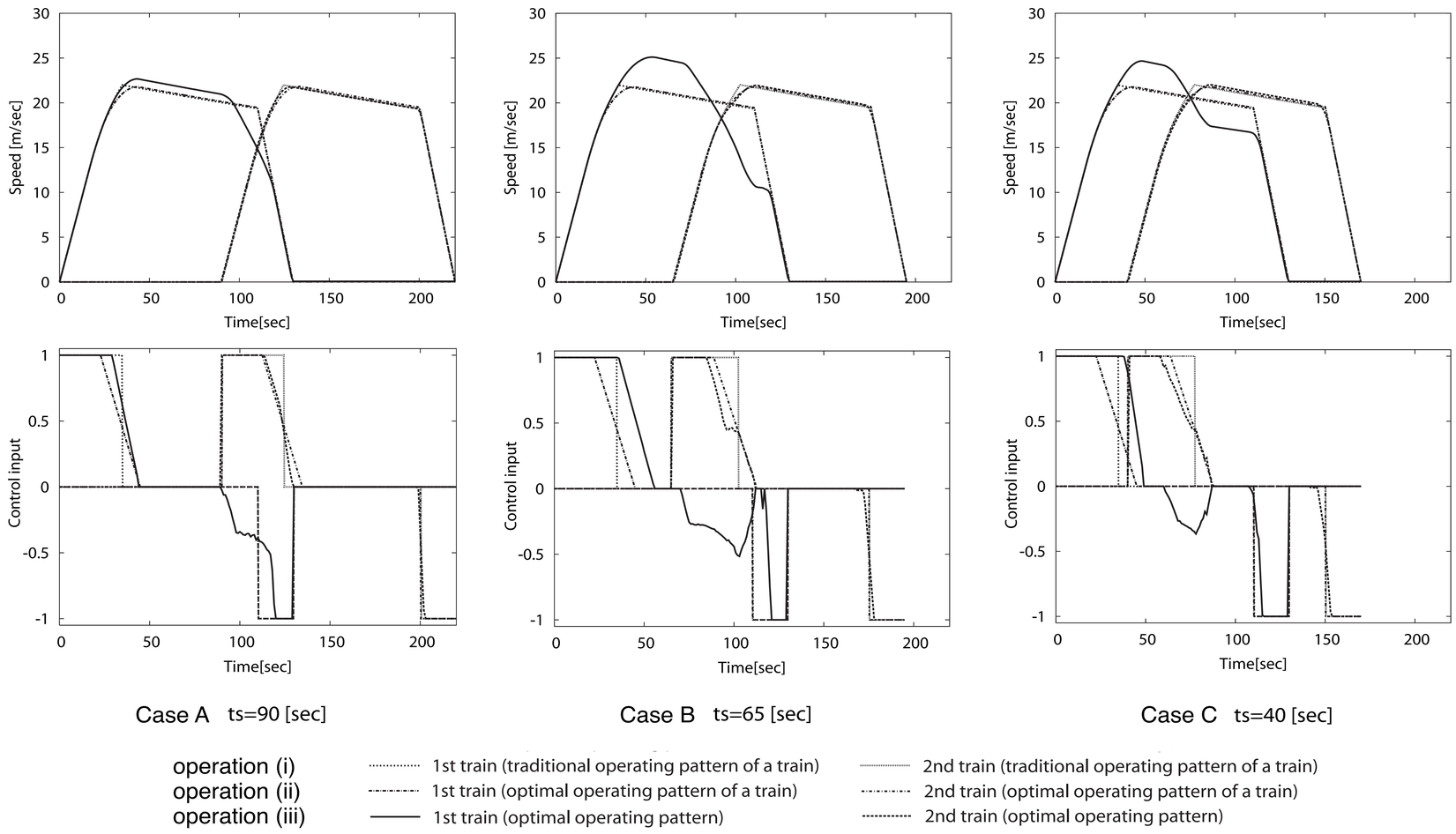
- objective functional
  - total energy consumption at substations
- constraints
  - kinetic equations of trains
  - circuit equations of feeding system
  - torque and speed limitations



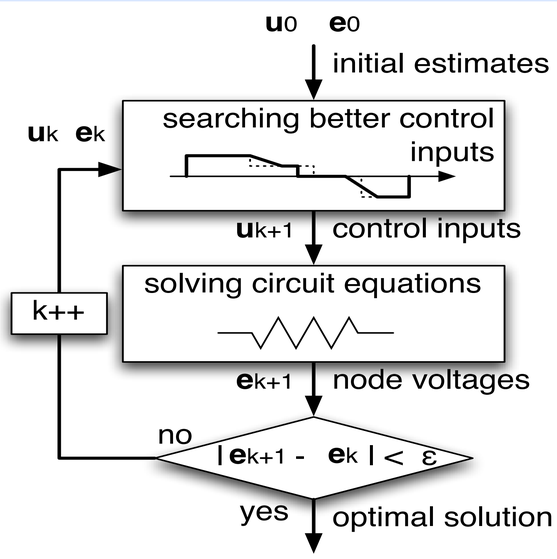
Acceleration/deceleration characteristics & squeezing control

2.2 Definition of control input





3. Numerical Algorithm



4. Simulation Conditions

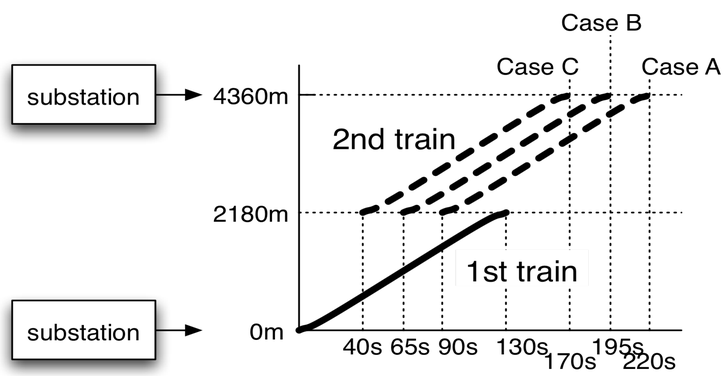
4.1 Operation rules

(i) max. acceleration + coasting + max. deceleration

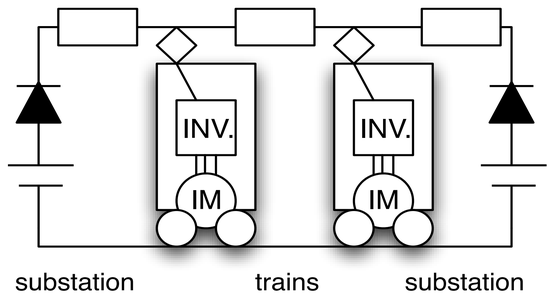
(ii) optimal profile considering only one train

(iii) optimal profiles considering two train (NEW!)

4.2 Other conditions



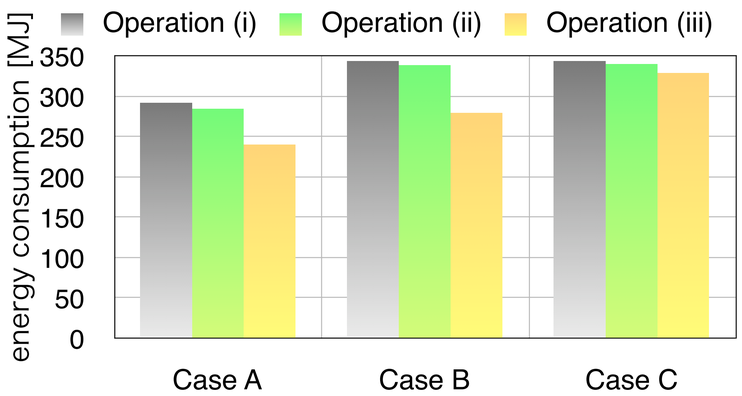
Train schedule and position of substations



Assumed equivalent circuit

5. Simulation Results

- Computation time is less than 1 minute.
- Operation (III) shifts braking timing of the 1st train for supplying the regenerative energy to the 2nd train.
- Operation (III) reduce energy consumption by 4.2~17.9% from operation (i).



6. Conclusions

- Optimizing speed profiles of SEVERAL trains is essential.
- The operation with max. acceleration, coasting and maximum deceleration is NOT always optimal!
- Phase between trains much affects energy consumption.