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CHARGE/DISCHARGE CONTROL OF A TRAIN WITH ON-BOARD ENERGY STORAGE DEVICES FOR ENERGY MINIMIZATION AND CONSIDERATION OF CATENARY FREE OPERATION

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M. Miyatake, K. Matsuda and H. Haga

Sophia University, Japan

INTRODUCTION

Background

* Application of energy storage devices to railway
  * It enables effective use of regenerative energy.
  * Some attempts for energy storage on-board can be seen. Catenary free operation is also demonstrated.
  * Relation between the use of energy storage devices and energy consumption has not been theoretically discussed enough.

Objective

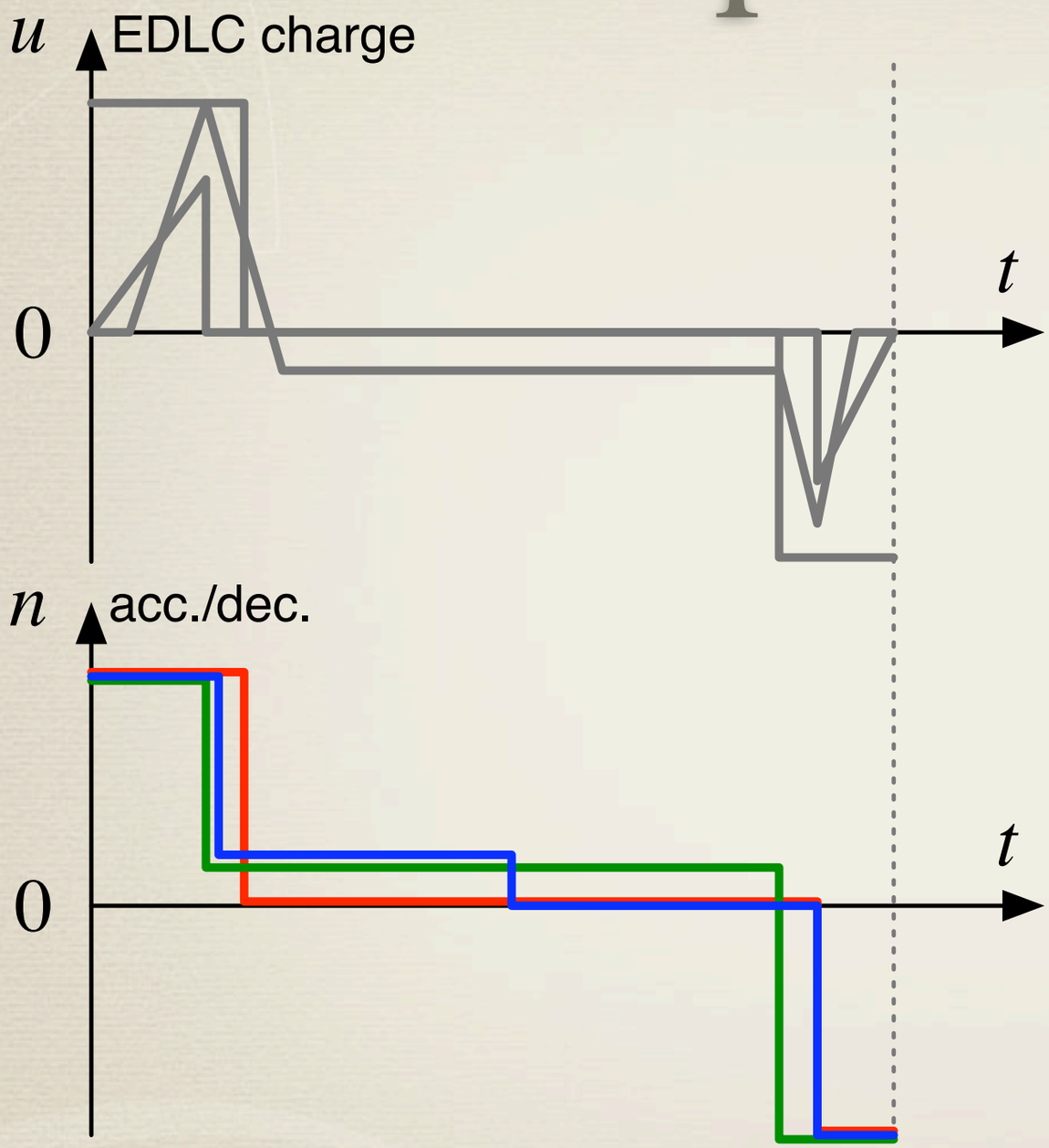
- Proposal of solving energy-saving train operation control problem, considering
  - practical circuit configuration,
    - power feeder from substations
    - energy storage devices
  - practical track profile and train schedule,
  - theoretical optimality.

Contents

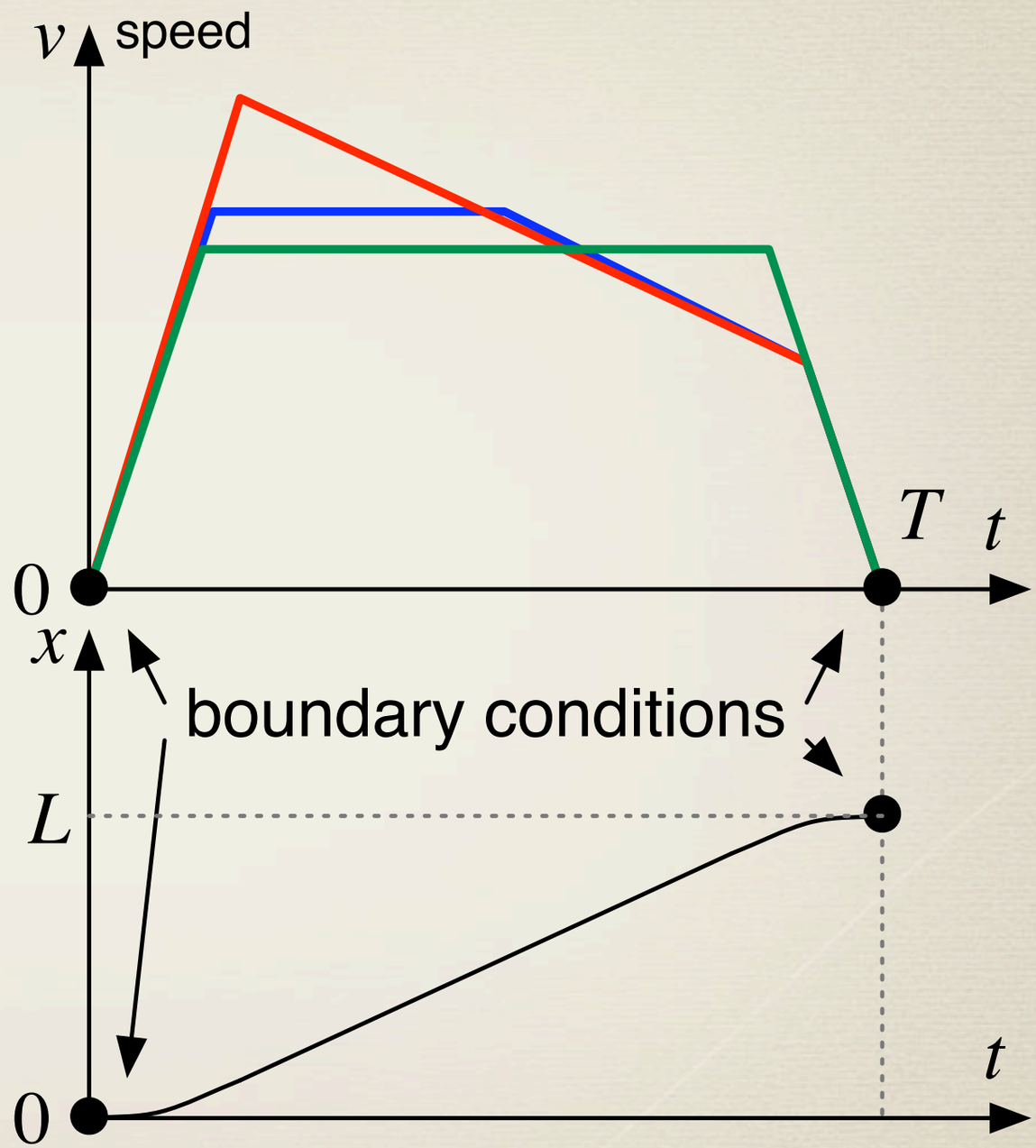
- Introduction
- Modeling
  - circuit modeling
  - numerical optimization
- Results of simulations
  - catenary - EDLC hybrid
  - catenary free mode
- Conclusion

MATHEMATICAL MODELING

Optimization

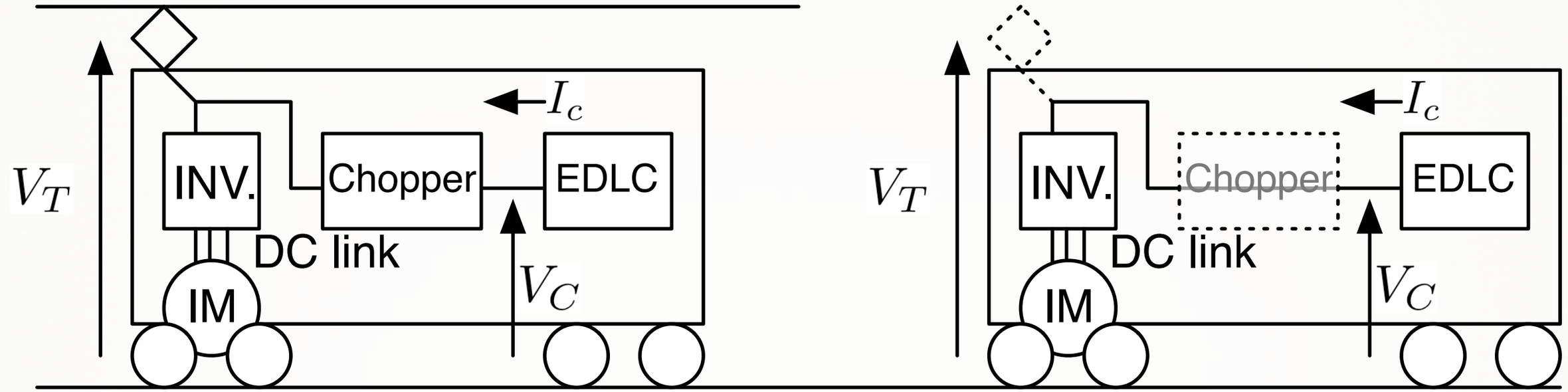


control inputs to optimize



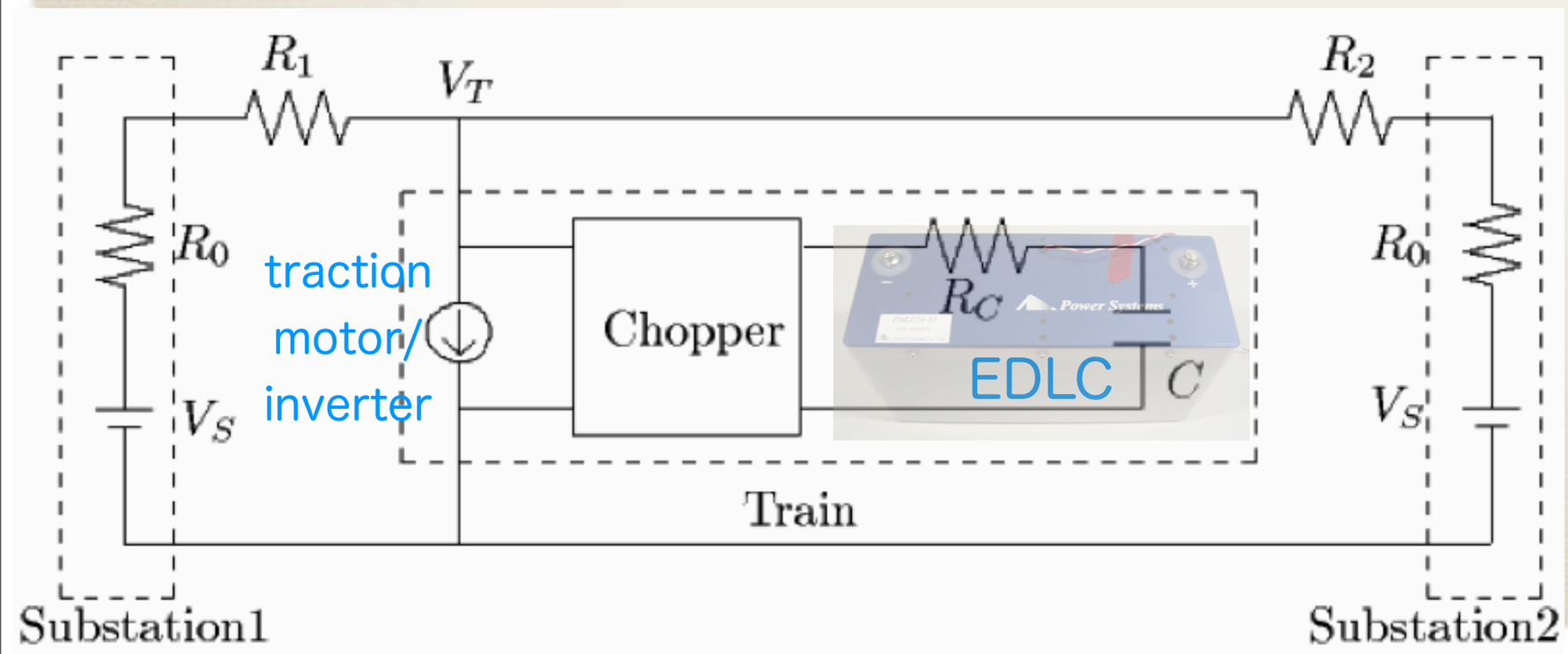
boundary conditions of speed and position

Modeling of a Train



(a) model under catenary

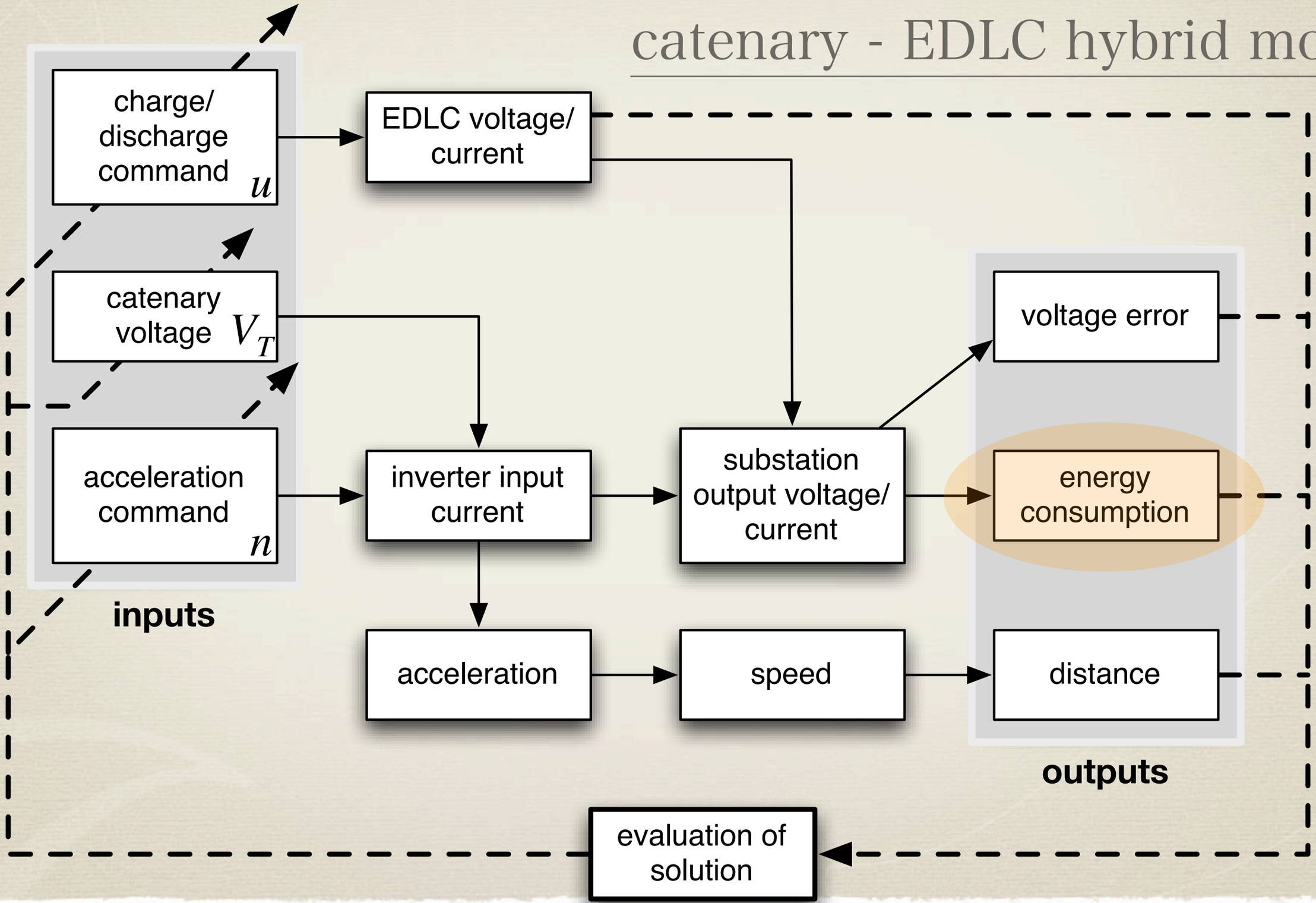
(b) model of catenary free operation



DC power feeder

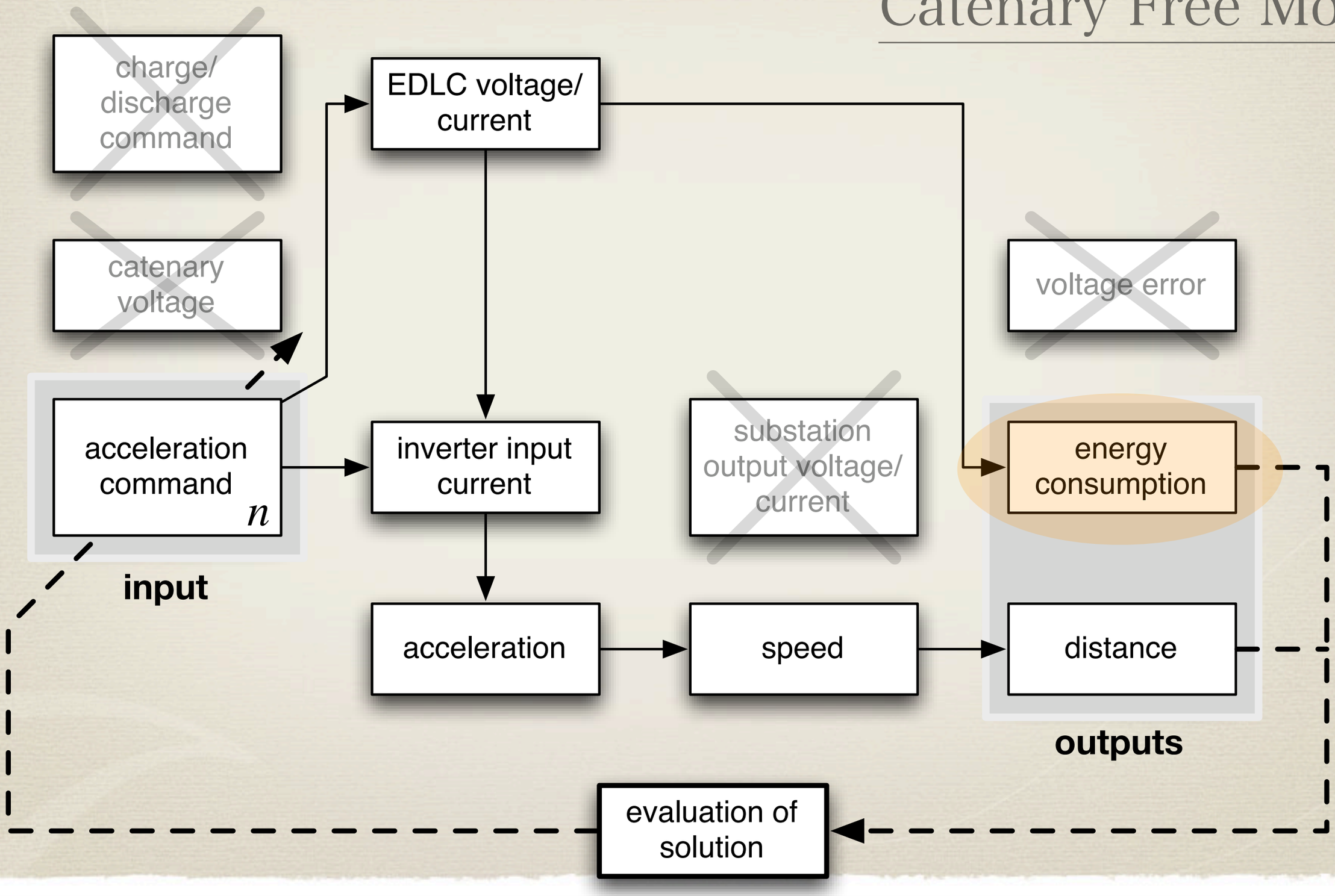
Process of calculation

catenary - EDLC hybrid mode



Process of calculation

Catenary Free Mode



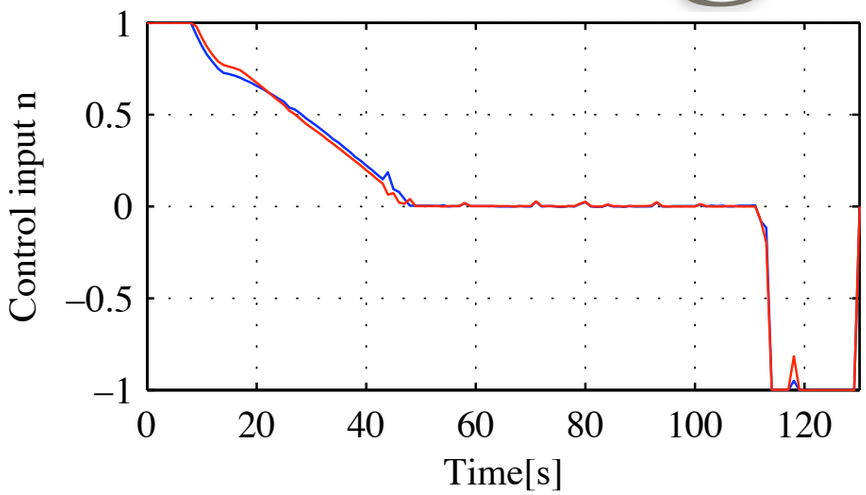
Mathematical programming

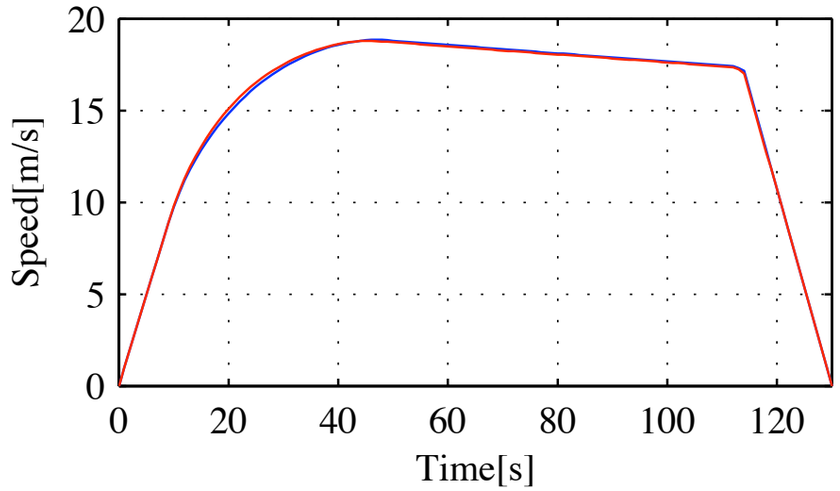
* The problem can be solved by nonlinear programming techniques with discretization.
  * Hybrid mode
    * Sequential Quadratic Programming (SQP).[8]
  * Catenary free mode
    * Dynamic Programming.[11]

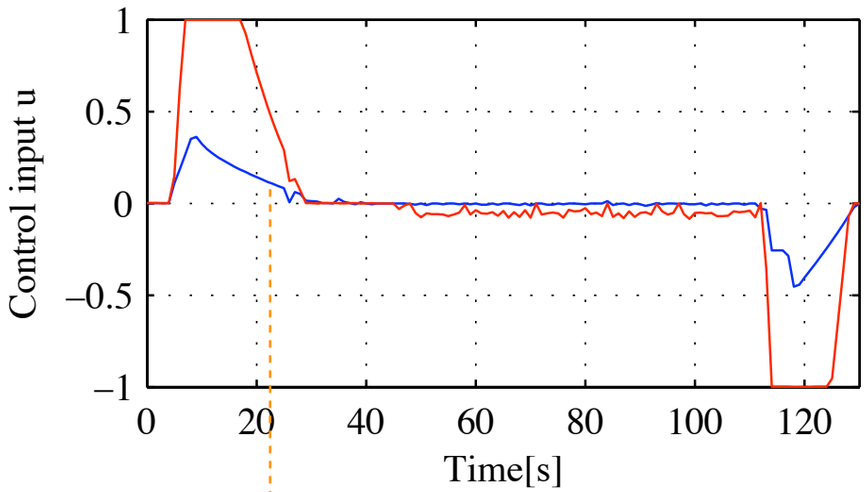
RESULTS OF SIMULATIONS

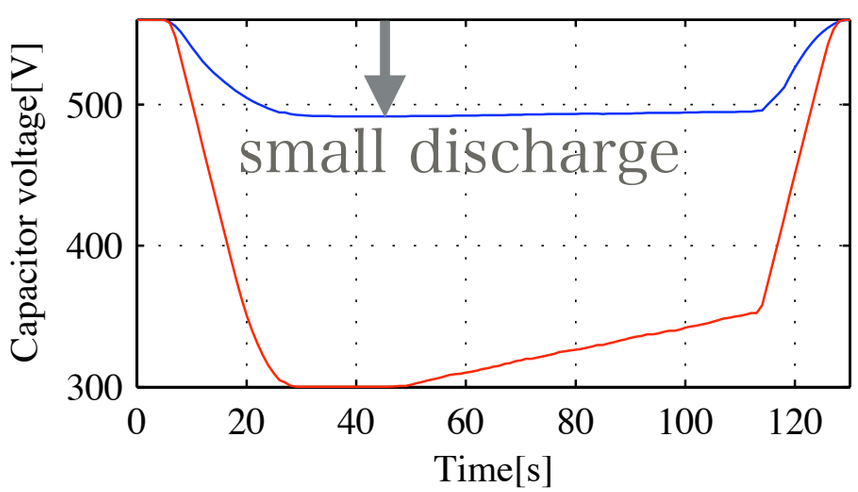
CATENARY - EDLC HYBRID

Running time : 130s

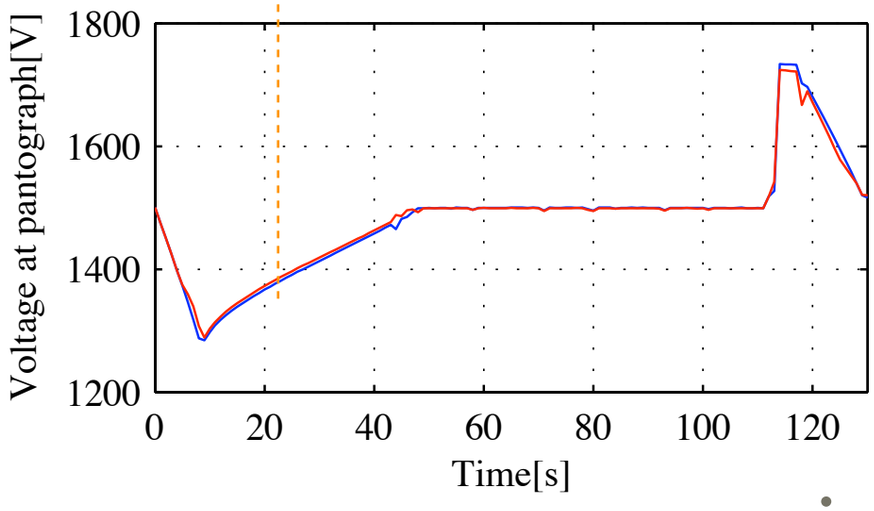


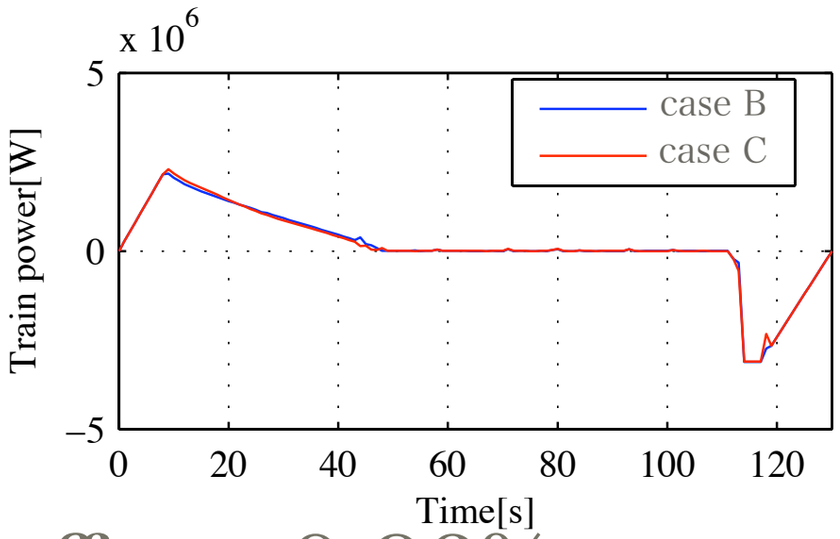






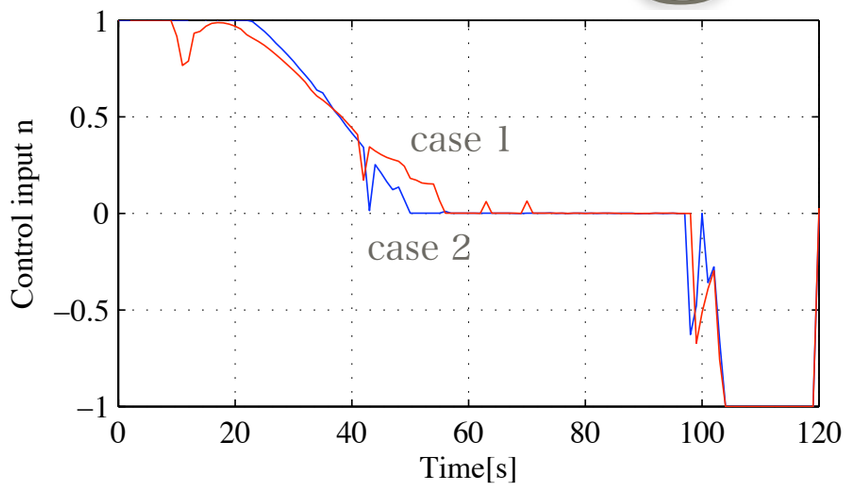
influence of internal resistance

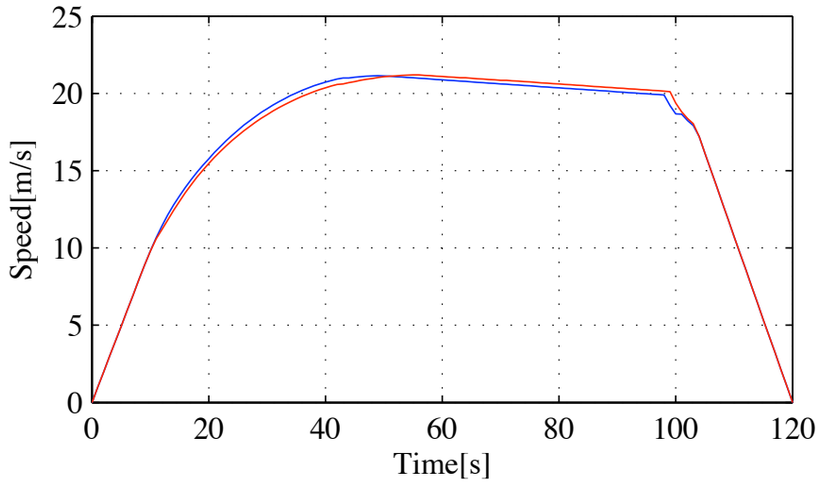


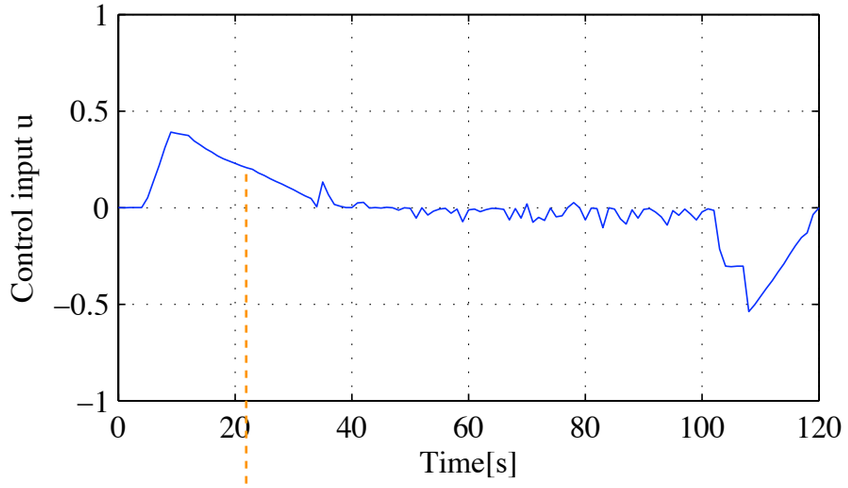


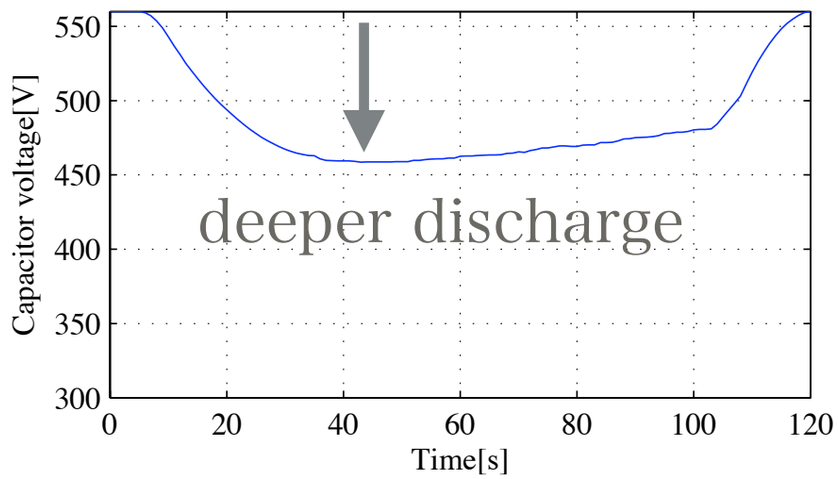
energy saving effect: 0.36%

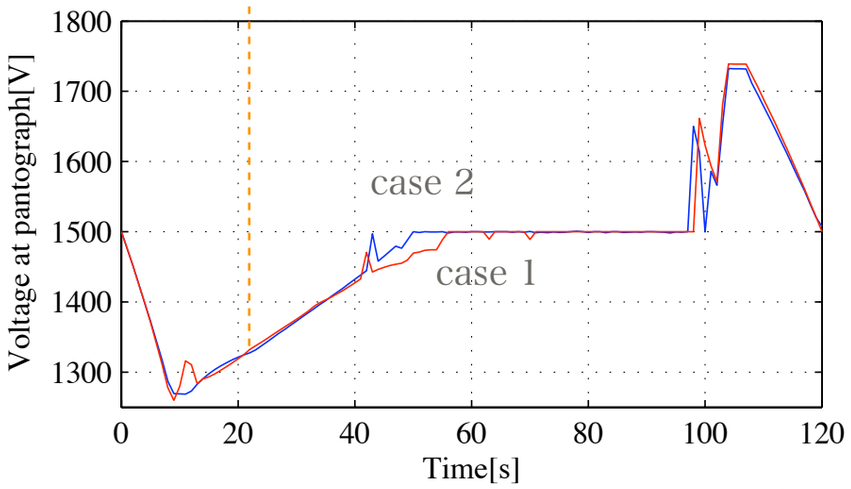
Running time : 120s

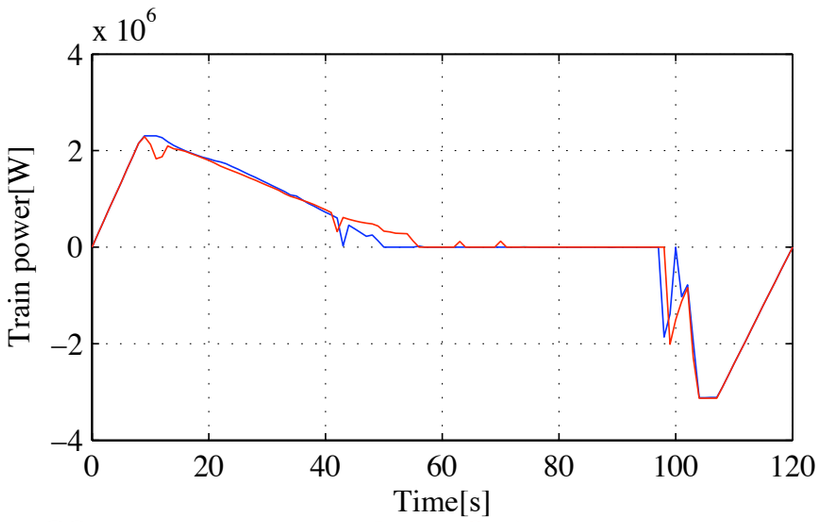










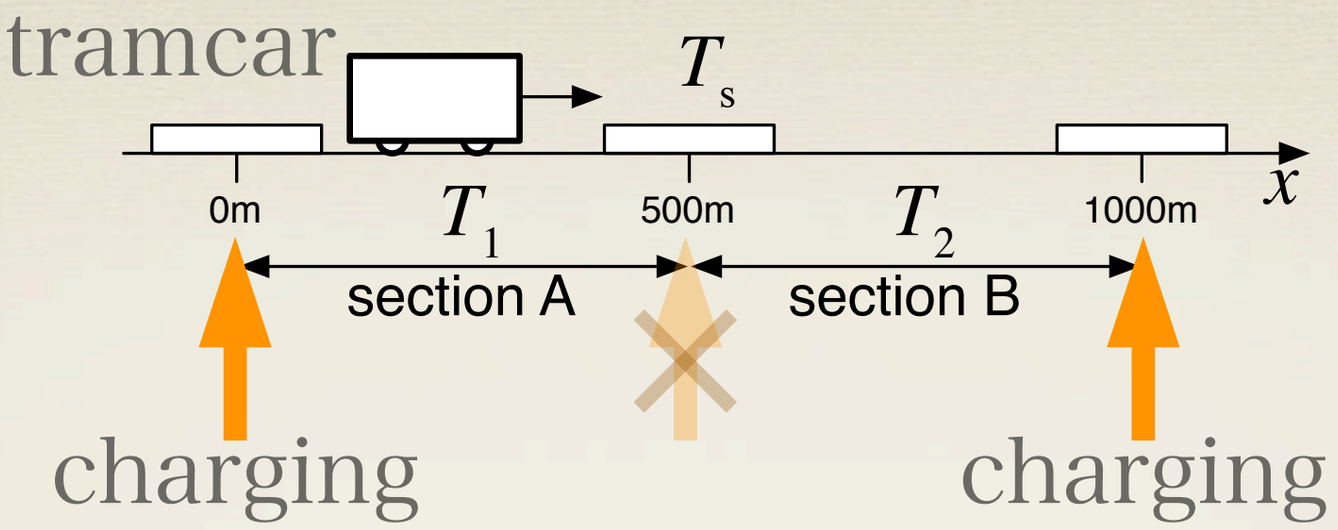


energy saving effect: 5.67%

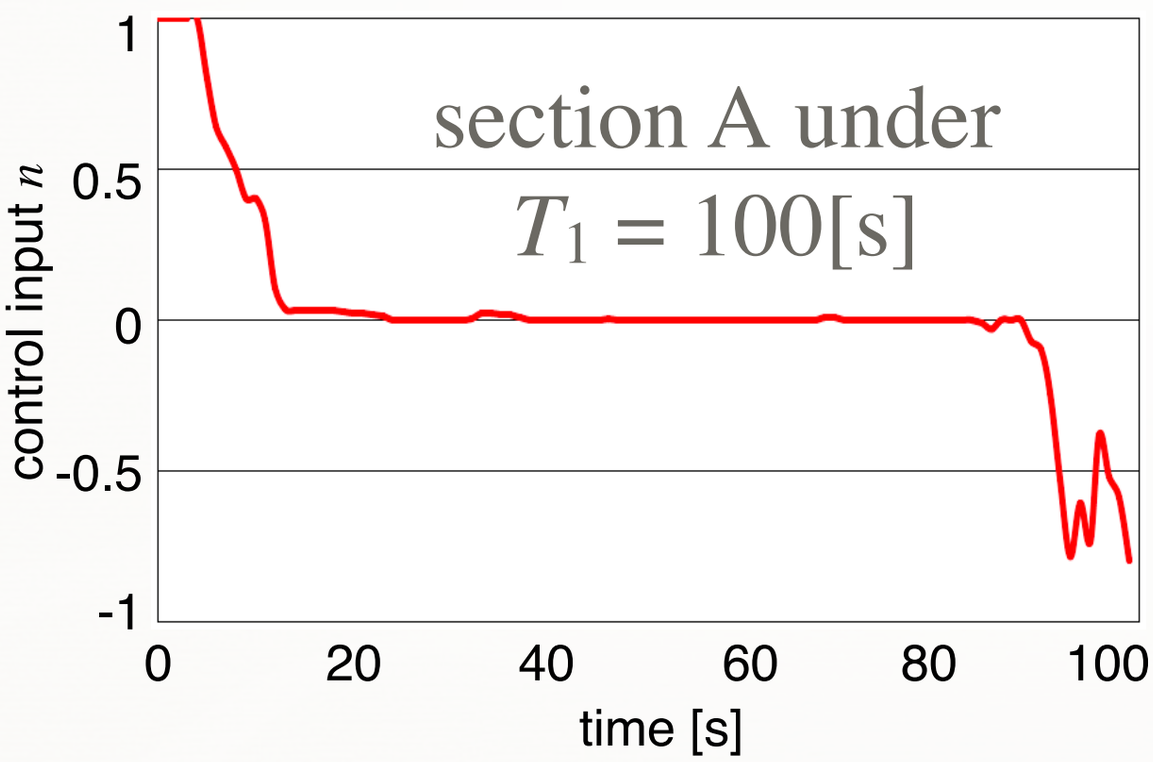
RESULTS OF SIMULATIONS

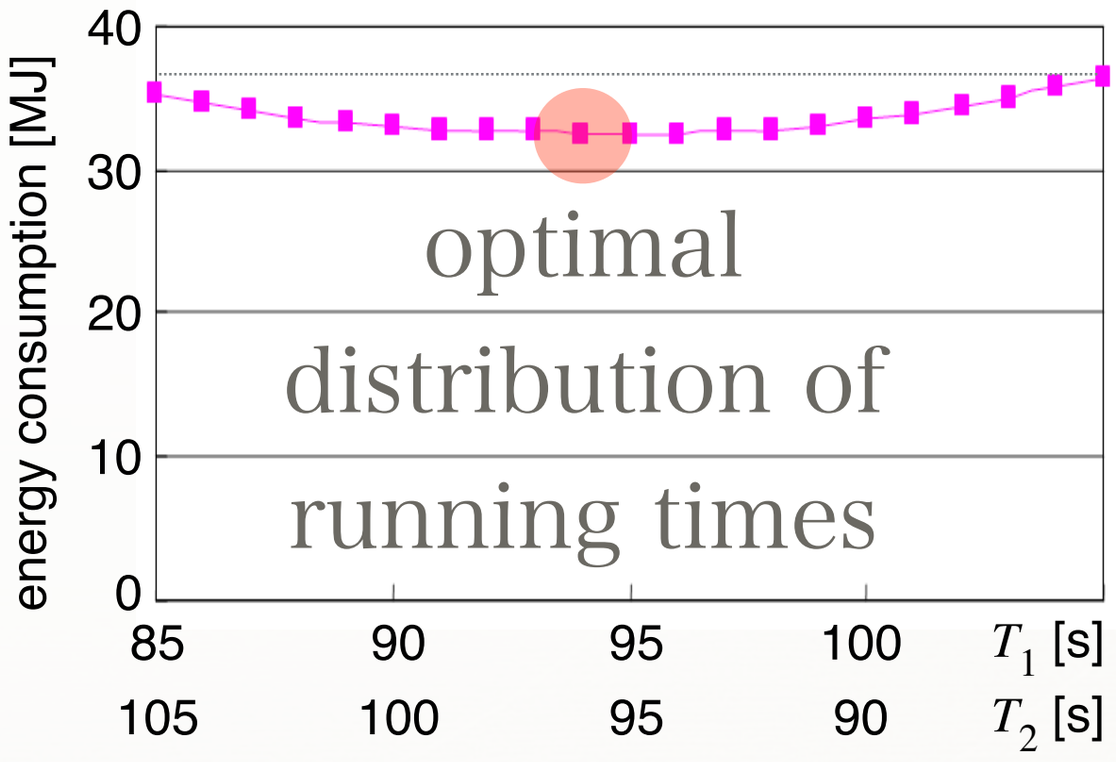
CATENARY FREE MODE

two stops between charge



$T_1+T_2+T_S = 200[s]$ $T_S = 10[s]$





CONCLUSIONS

Summary

* EDLC should increase supply power as the voltage drops when the train speed is low.
* Deep discharge may cause larger energy loss, if the train has much margin time.
* The optimal distribution of times should be discussed, especially in catenary free mode.

Future scope

- Application of the method to
  - other hybrid power sources,
  - quick charging for catenary free operation.
- Realization of on-line control.