The parallel full-approximation-scheme in space and time for electromagnetic transient simulation

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Contents

$v(t)$
x
$\frac{t}{dt}v(t) = f_{DC}(t, v(t))$
$\frac{t}{dt}v(t) = f_{DC}(t, v(t))$
DC/DC
DC/DC
$\frac{t}{dt}v(t) = f_{Piline}(t, v(t))$
t

Part I

Introduction

- Parallel-full-approximation scheme in space and time (PFASST)
- PinTSimE project

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[1] *M. Emmett, M. L. Minion, Toward an efficient parallel in time method for partial differential equations, Commun. Appl. Math. Comp. Sc. 7, no. 1, 105.132, 2012*

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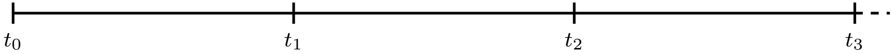

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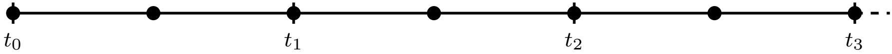

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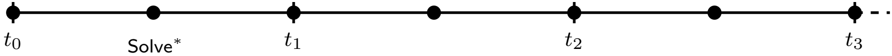

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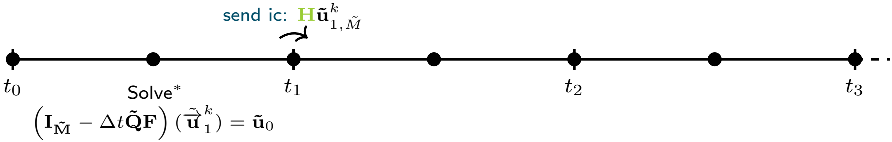

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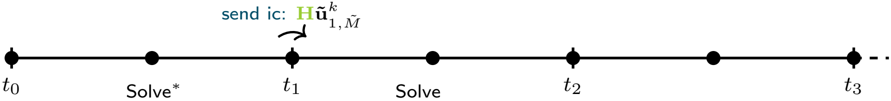

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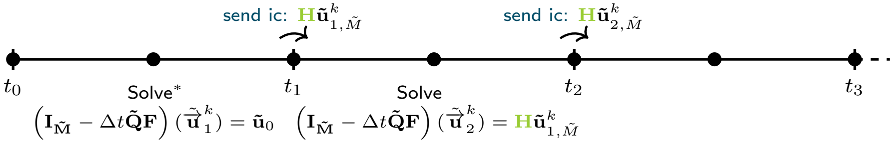

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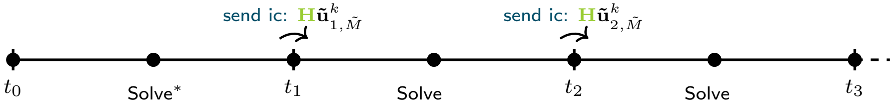

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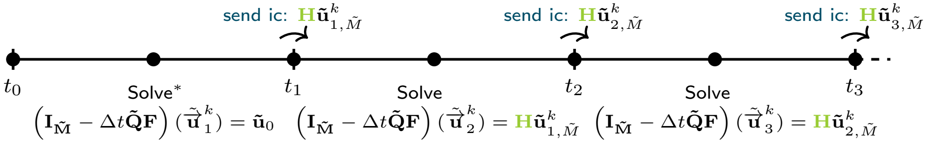

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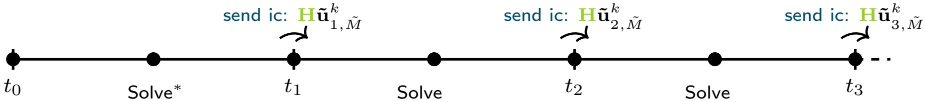

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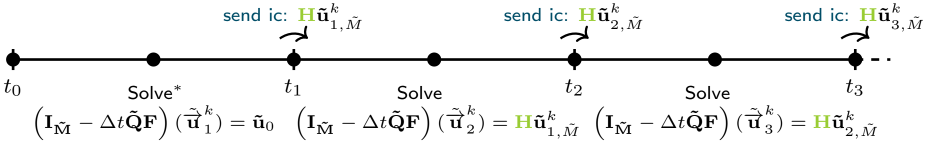

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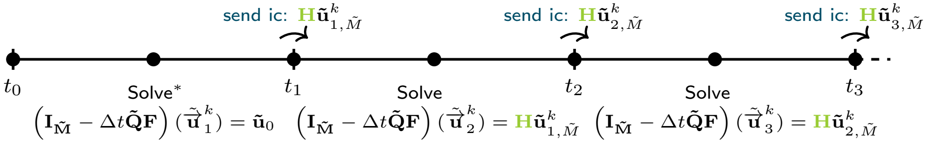

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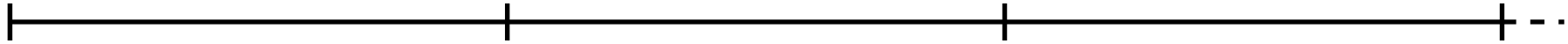

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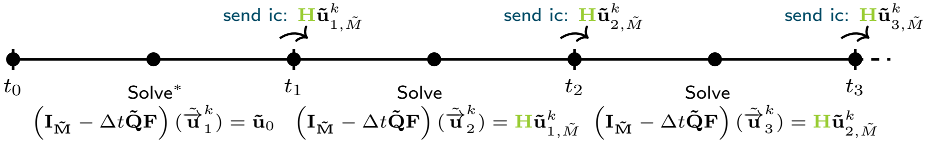

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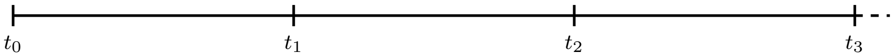

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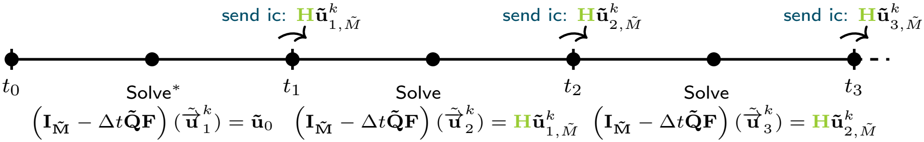
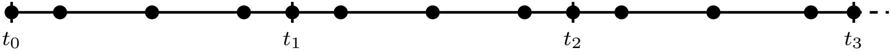


Jacobi on fine level (parallel): $P_J\left(\vec{\mathbf{u}}\right) := \left(\mathbf{I}_{LM} - \mathbf{I}_L \otimes \Delta t \mathbf{Q}_\Delta \mathbf{F}\right)\left(\vec{\mathbf{u}}\right)$



**: a tilde marks values on coarse level*

Collocation problem - The iterative solvers[1,2]

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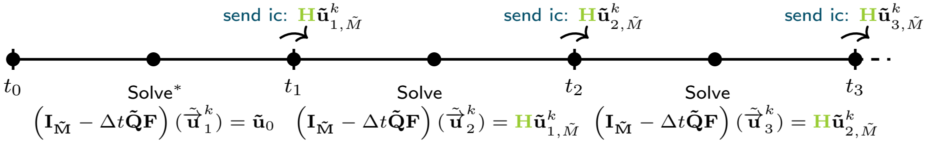

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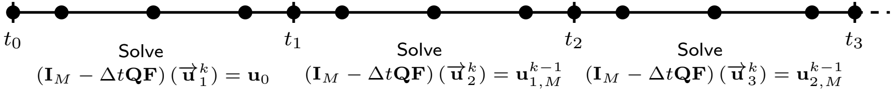

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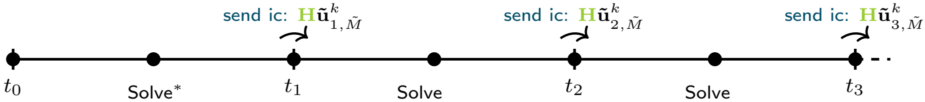

$\left(\mathbf{I}_{\tilde{\mathbf{M}}} - \Delta t \tilde{\mathbf{Q}}\mathbf{F}\right)\left(\vec{\tilde{\mathbf{u}}}^k_1\right) = \tilde{\mathbf{u}}_0$ $\quad \left(\mathbf{I}_{\tilde{\mathbf{M}}} - \Delta t \tilde{\mathbf{Q}}\mathbf{F}\right)\left(\vec{\tilde{\mathbf{u}}}^k_2\right) = \mathbf{H}\tilde{\mathbf{u}}^k_{1,\tilde{M}}$ $\quad \left(\mathbf{I}_{\tilde{\mathbf{M}}} - \Delta t \tilde{\mathbf{Q}}\mathbf{F}\right)\left(\vec{\tilde{\mathbf{u}}}^k_3\right) = \mathbf{H}\tilde{\mathbf{u}}^k_{2,\tilde{M}}$

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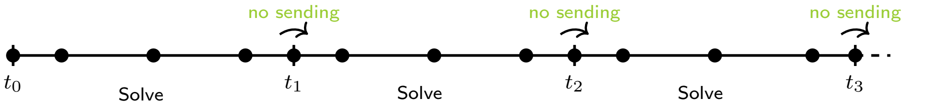

$\left(\mathbf{I}_M - \Delta t \mathbf{Q}\mathbf{F}\right)\left(\vec{\mathbf{u}}^k_1\right) = \mathbf{u}_0$ $\quad \left(\mathbf{I}_M - \Delta t \mathbf{Q}\mathbf{F}\right)\left(\vec{\mathbf{u}}^k_2\right) = \mathbf{u}^{k-1}_{1,M}$ $\quad \left(\mathbf{I}_M - \Delta t \mathbf{Q}\mathbf{F}\right)\left(\vec{\mathbf{u}}^k_3\right) = \mathbf{u}^{k-1}_{2,M}$

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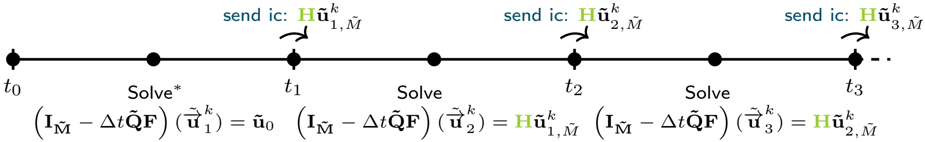

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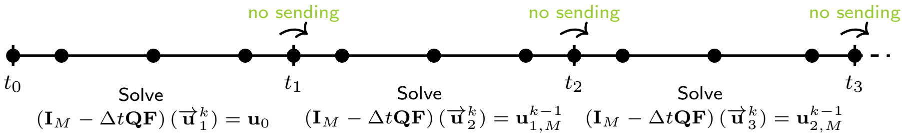

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[2]: *M. Bolten, D. Moser, R. Speck, A multigrid perspective on the parallel full approximation scheme in space and time, Numerical Linear Algebra with Applications 24, 6, 2017*

PFASST Algorithm[1,2]

1. Execute Jacobi solver on fine level in parallel using P_J

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2. Compute τ-correction

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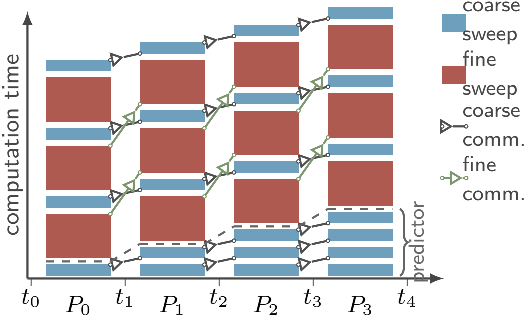

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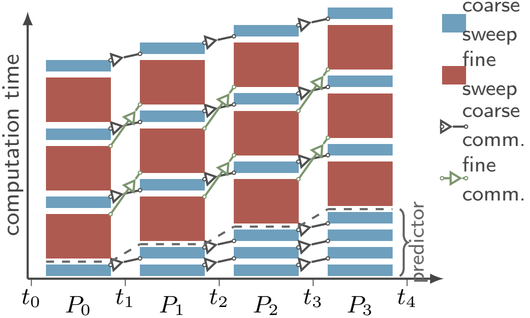

[3]: *Fabian Koehler, PFASST tikz, https://github.com/Parallel-in-Time/pfasst-tikz, 2015*

DFG Project - PinTSimE

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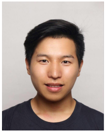

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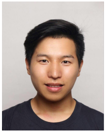

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- PinTSimE - Parallel-in-Time Simulation in multimodal Energy systems

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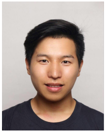

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- Multimodal - Energy system in which different energy grids *are connected* such as power grid, heat grid, gas grid,..

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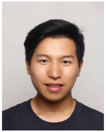
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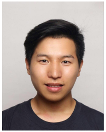

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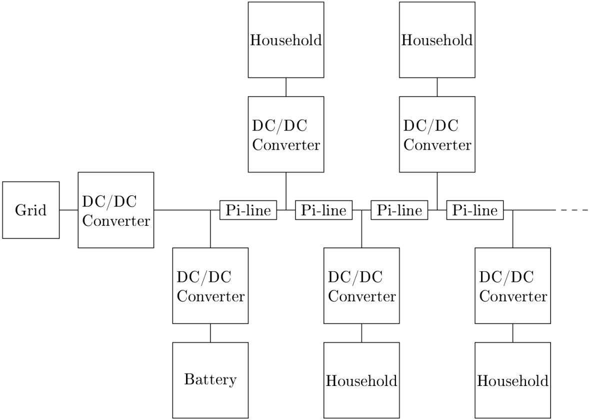
- Goal: Simulation faster than real-time

Part II

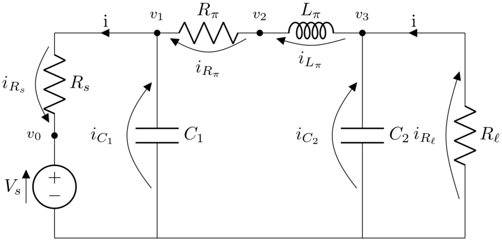
DC microgrid model

- Components
- Switching processes

DC microgrid

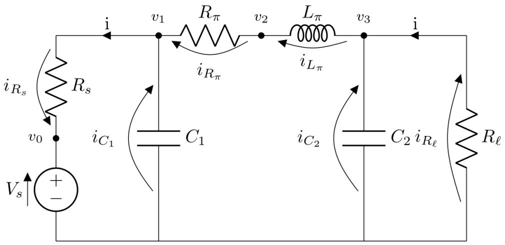


Pi-line model



Pi-line model

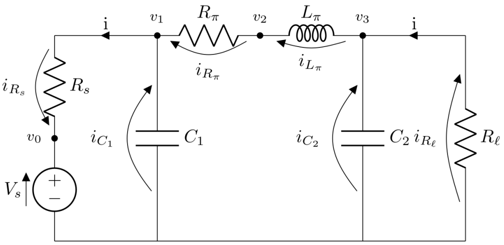
Pi-line model



Pi-line model

Model can be described as
ODE System:

Pi-line model

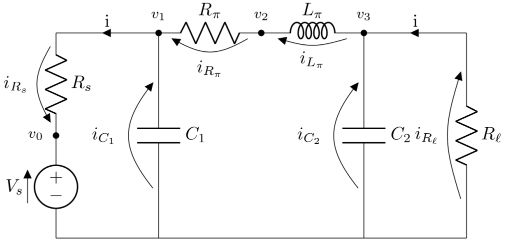


Pi-line model

Model can be described as ODE System:

$$\frac{d}{dt}u(t) = Au(t) + f(t)$$

Pi-line model



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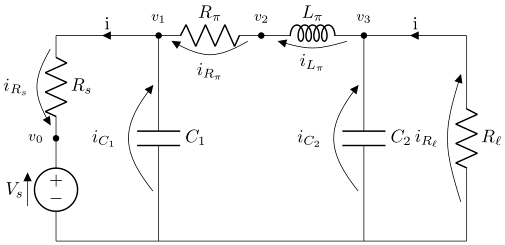
Properties:

Pi-line model



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Properties:

- serves as transmission line in DC microgrid

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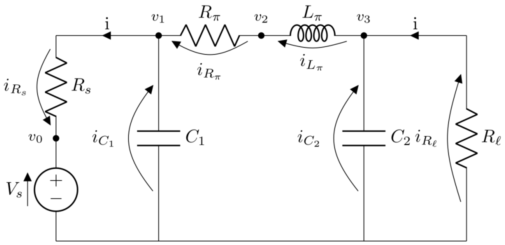


Pi-line model

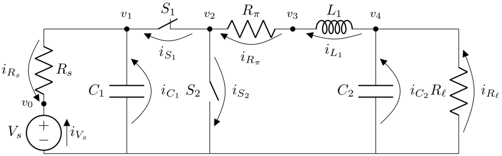
Model can be described as ODE System:

$$\frac{d}{dt}u(t) = Au(t) + f(t)$$

Properties:

- serves as transmission line in DC microgrid
- no special events in the simulation

Buck converter model



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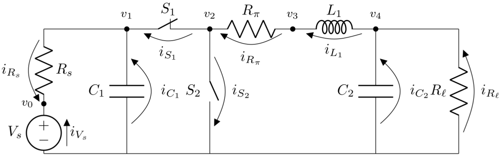
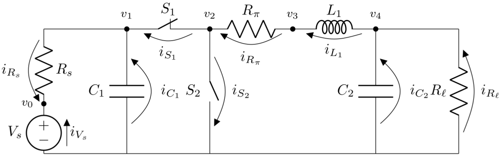


Buck converter model with the states

Buck converter model

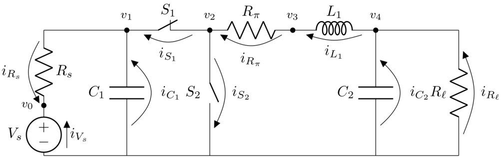


Buck converter model with the states

$$FS = \{S_1 = 1, S_2 = 0\}$$

and

Buck converter model



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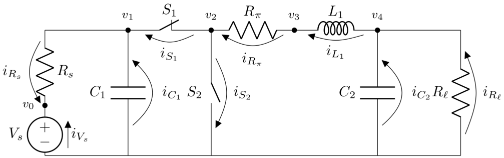
Buck converter model



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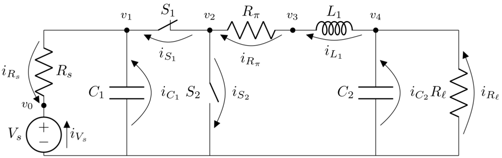

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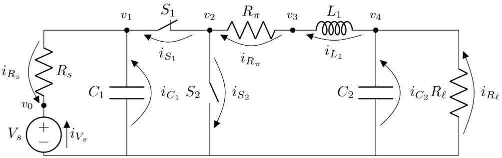

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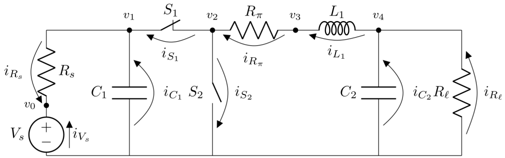
Buck converter model



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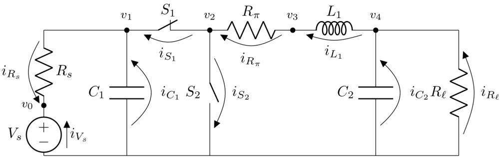
Properties:

- converts large input voltage in a smaller output voltage

Buck converter model



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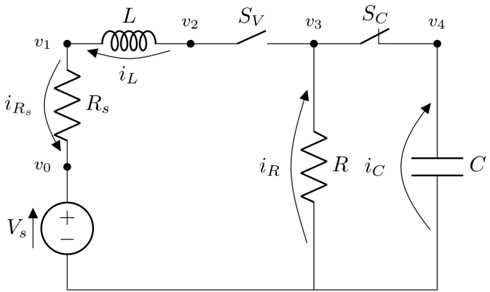
Properties:

- converts large input voltage in a smaller output voltage
- switching produces many discrete events

Battery drain model



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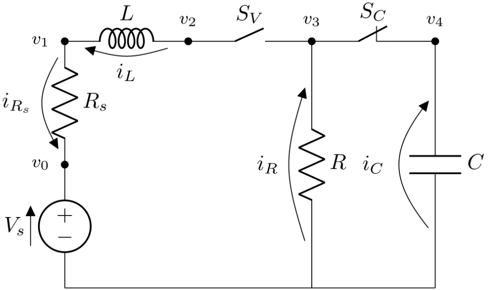

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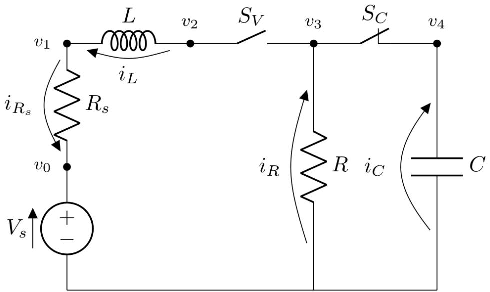
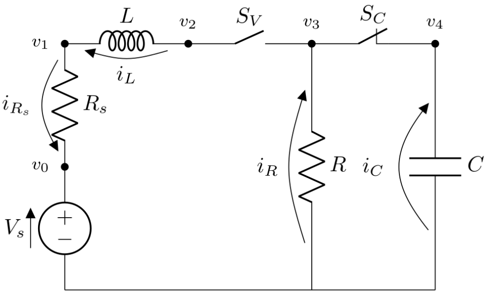


Battery model with the states

$$FS = \{S_C = 1, S_V = 0\}$$

and

Battery drain model



Battery model with the states

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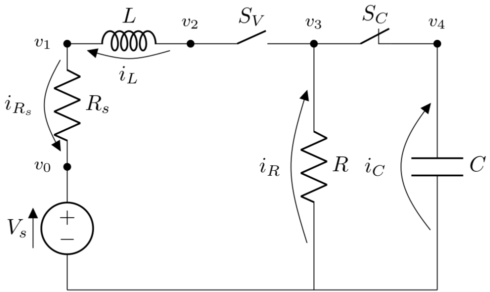
Battery drain model



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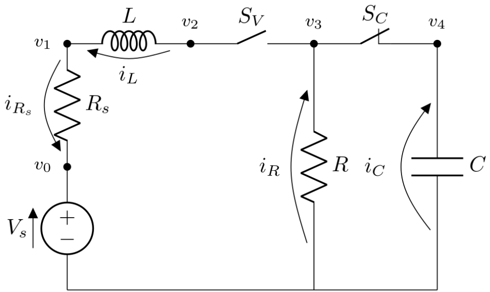

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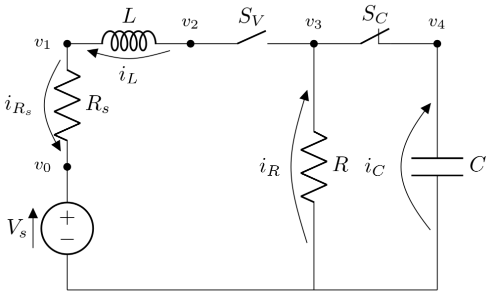

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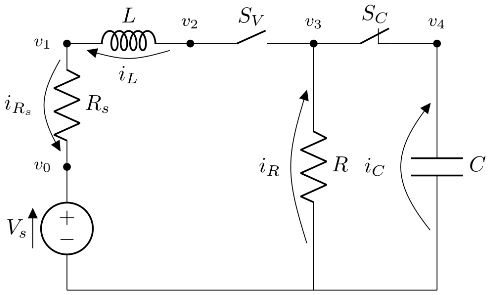

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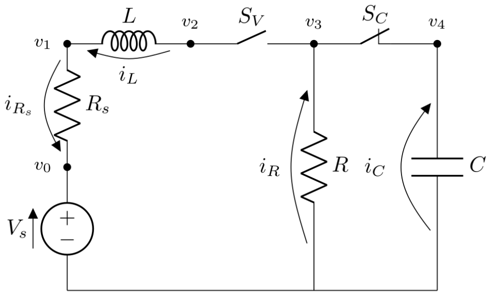
Properties:

- capacitor supplies energy

Battery drain model



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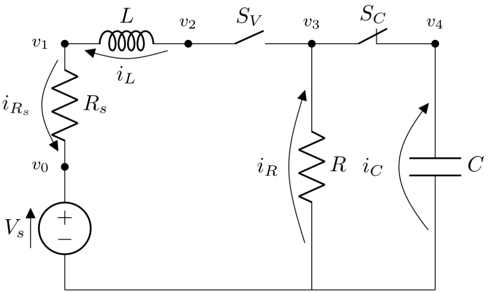
Properties:

- capacitor supplies energy
- when energy drops below a reference voltage, switch to voltage source

Battery drain model



Battery model with the states

$$FS = \{S_C = 1, S_V = 0\}$$

and

$$SS = \{S_C = 0, S_V = 1\}$$

Each state can be described as ODE System:

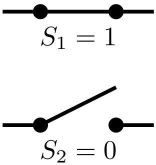
FS: $\frac{d}{dt}u(t) = A_1 u(t) + f_1(t)$

SS: $\frac{d}{dt}u(t) = A_2 u(t) + f_2(t)$

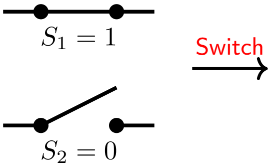
Properties:

- capacitor supplies energy
- when energy drops below a reference voltage, switch to voltage source
- only one single discrete event

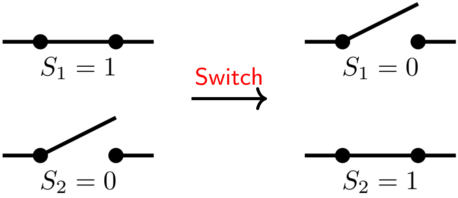
Switching processes



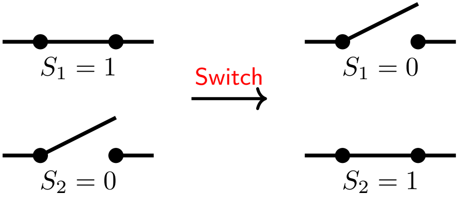
Switching processes



Switching processes

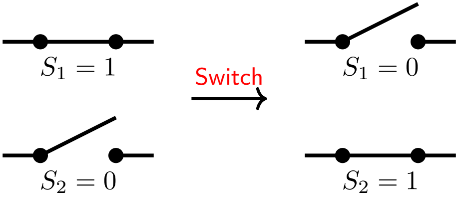


Switching processes



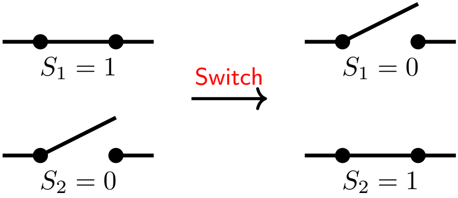
- discrete events

Switching processes



- discrete events
- for models: switching from one ODE system to another

Switching processes



- discrete events
- for models: switching from one ODE system to another
- needs to investigate their behavior in SDC (and PFASST)

Occurence of a switch

Two possibilities, where a switch can occur:

Occurence of a switch

Two possibilities, where a switch can occur:

- on a time step

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Two possibilities, where a switch can occur:

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- between collocation nodes

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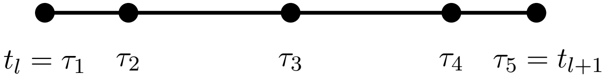

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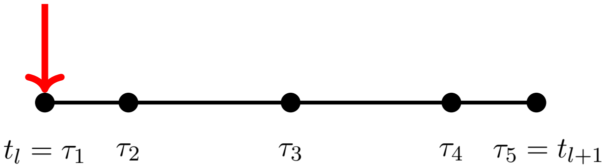

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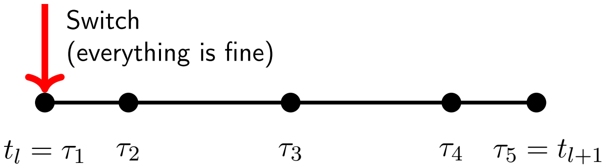

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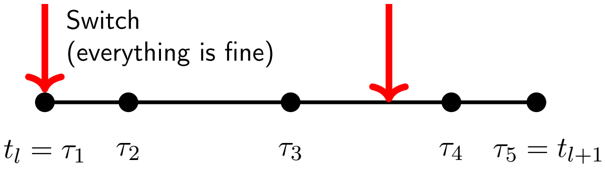

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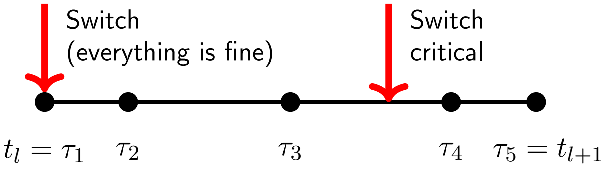

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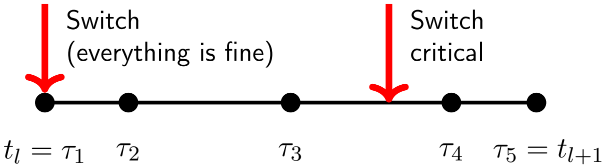

Challenges:

Occurence of a switch

Two possibilities, where a switch can occur:

- on a time step
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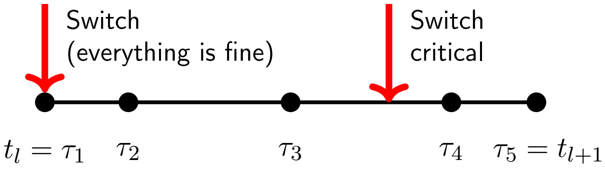

Challenges:

- Occuring of switch between collocation nodes leads to later resolution of behavior

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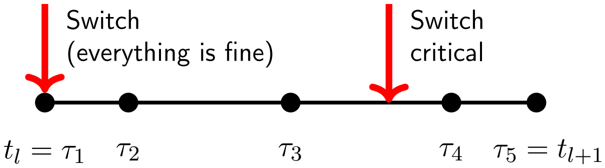

Challenges:

- Occuring of switch between collocation nodes leads to later resolution of behavior
- Accuracy is worse: energy monitoring is delayed

Part III

Results

Pi-line modelling - SDC

Settings:

Pi-line modelling - SDC

Settings:

- $t_0 = 0$, $\Delta t = 10^{-2}$, $T = 15$

Pi-line modelling - SDC

Settings:

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- IMEX SDC with 5 *Gauss-Lobatto (GL)* nodes used for simulation

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- local (per subinterval) $restol = 10^{-13}$

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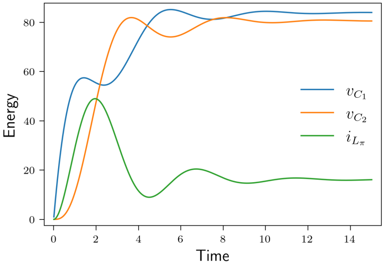

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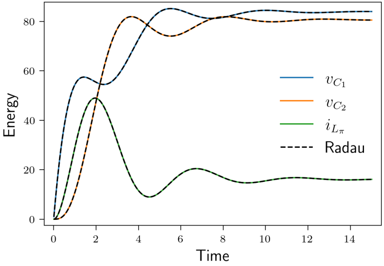

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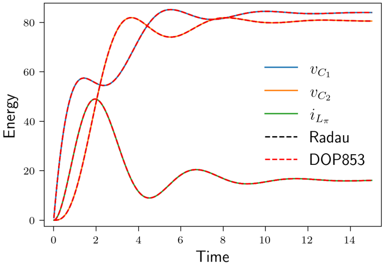

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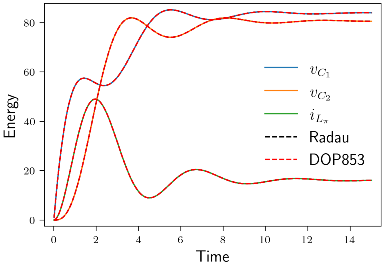

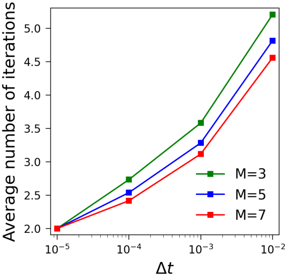

Pi-line modelling - PFASST

Settings:

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Settings:

- Same as for SDC, num_procs $= 8$

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Settings:

- Same as for SDC,
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- Coarse level: 3 GL nodes
  Fine level: 5 GL nodes

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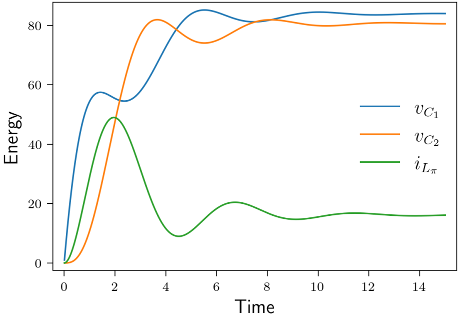

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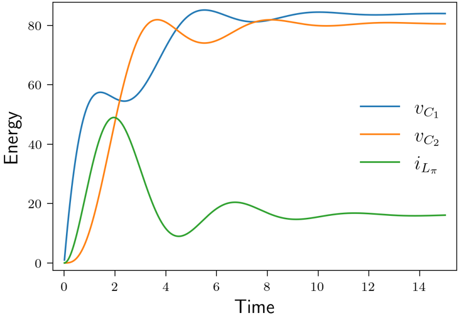

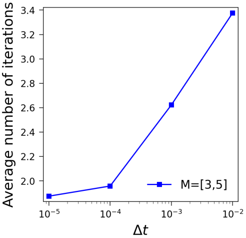

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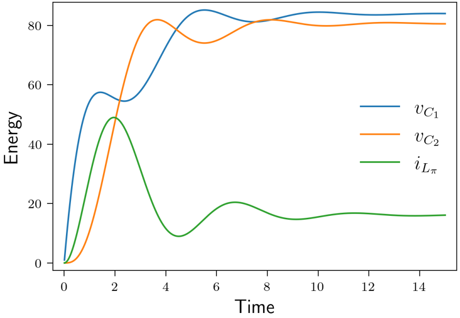

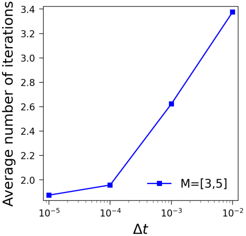

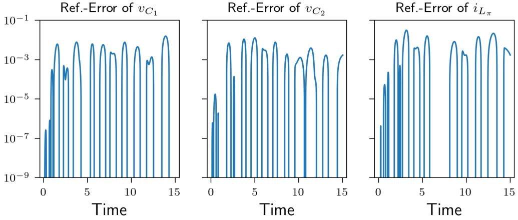

Buck converter modelling - SDC

Buck converter manipulation: Implementation of *only one switch*!

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Reference solution via (IMEX) SDC: $t_0 = 0$, $\Delta t = 10^{-8}$, $T = 0.02$

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Switch falls on time $t_{switch} = 0.01$

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IMEX SDC with 5 *GL* nodes used

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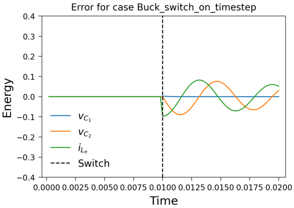

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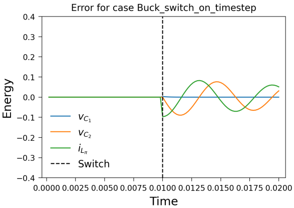

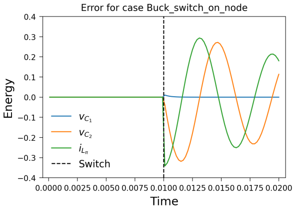

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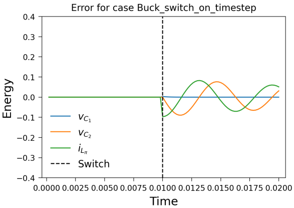

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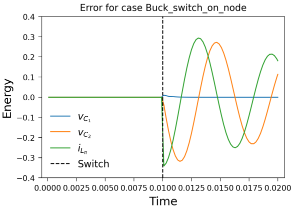

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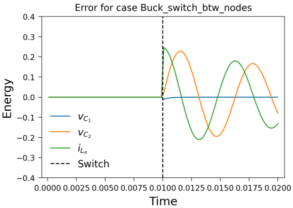

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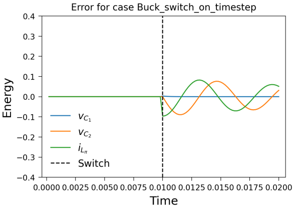

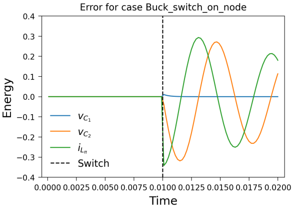

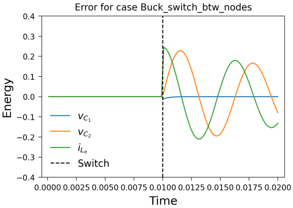

- Error for case *Switch on timestep* relatively small

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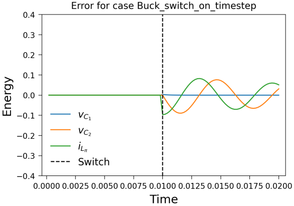

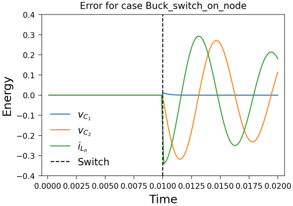

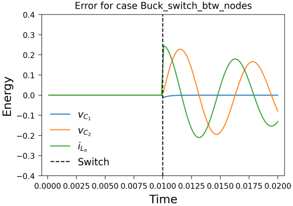

- Error for case *Switch on timestep* relatively small
- Error for *other cases* show larger error

Battery drain modelling - SDC

Battery drain model has *internal switching*: Switching depends on system dynamics

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Battery drain model has *internal switching*: Switching depends on system dynamics

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Battery drain modelling - SDC

Battery drain model has *internal switching*: Switching depends on system dynamics

Settings:

- $t_0 = 0$, $\Delta t = 10^{-3}$, $T = 4$
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Battery drain modelling - SDC

Battery drain model has *internal switching*: Switching depends on system dynamics

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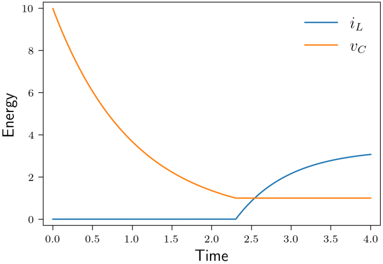

Part IV

Future work

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- Development of switch estimator (first, for SDC - then, for PFASST)

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- Further investigation of each microgrid component
- Parallel simulation of whole DC microgrid
  - Runtime tests for PFASST for each component

The end - pySDC & contact

- PintSimE project is already implemented in pySDC

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Any questions or comments to the talk?