Solutions for Integrating Photovoltaic Panels into Low-voltage Distribution Networks

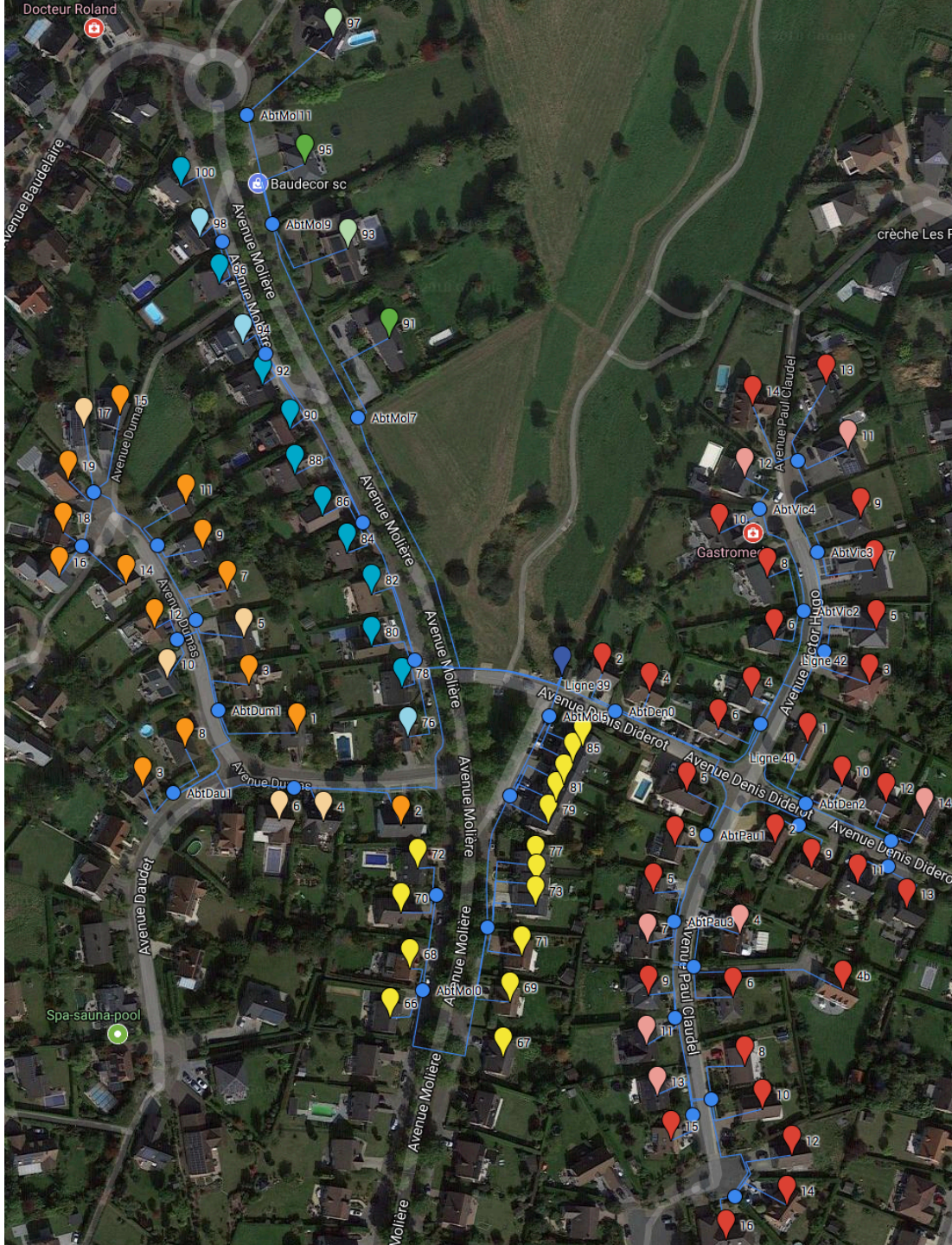
2018

Frédéric Olivier

Advisor: Prof. Damien Ernst

LV distribution network

- Distribution transformer
- Electrical lines
- Nodes (buses)
- Houses
- Smart meters



PV panels and LV distribution networks

Voltage too high

Disconnection of PV

Loss of renewable energy production

Loss of earnings

Slowing down the energy transition

How to increase the hosting capacity?

- Reinforcing the network
- Balancing the phases of the network
  - Identifying the phases of the smart meters
  - Balancing the production and consumption on the three phases
- Actively managing the network
  - Controlling the active and reactive power flows inside the network

Part 1
Phase Identification of Smart Meters

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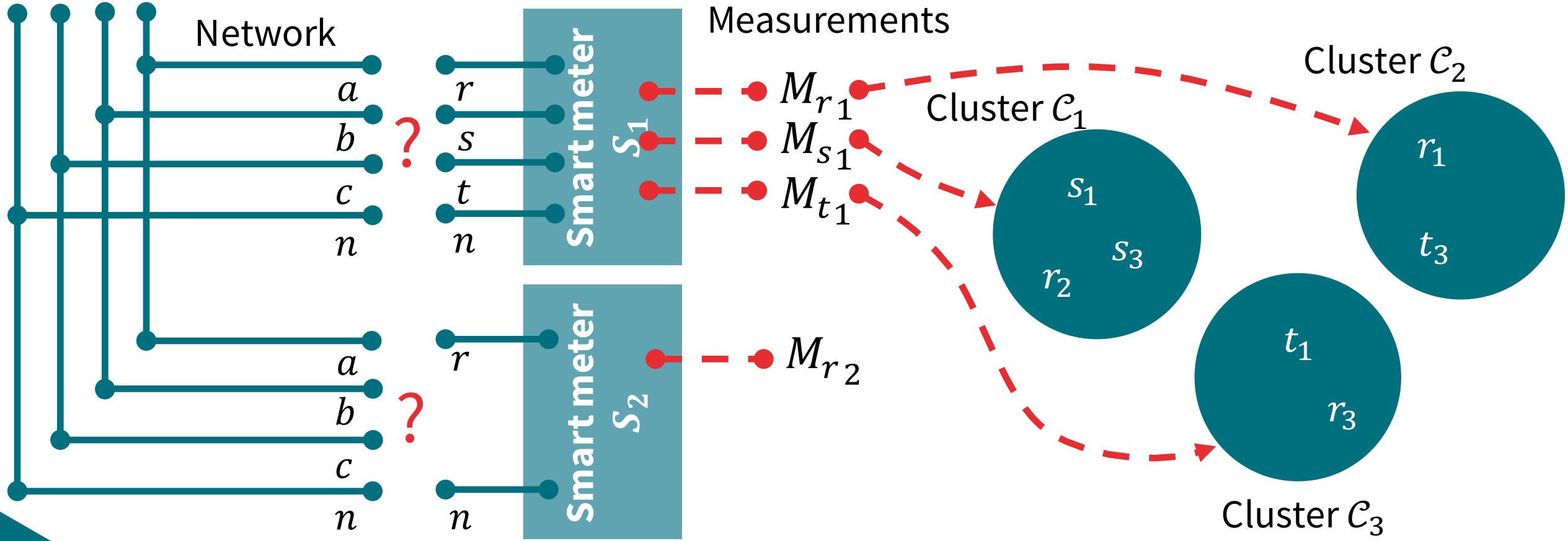
The phase identification problem



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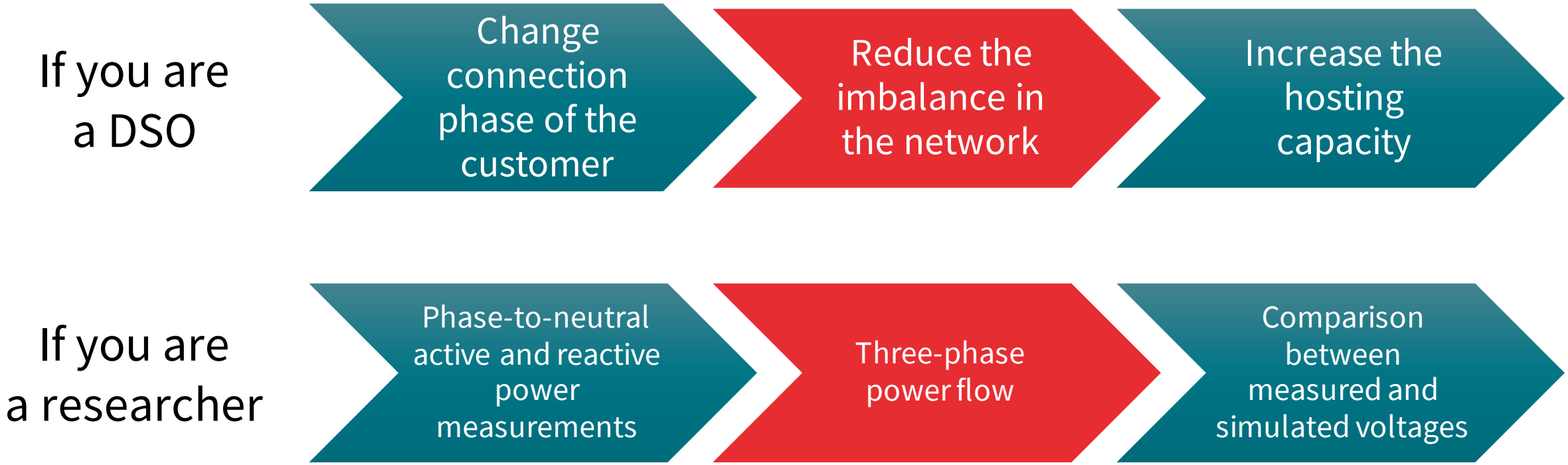
- Why is the phase information important?
- What are the existing solutions?
- What is the algorithm we propose?
- What is its performance ?

On the importance of phase identification



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Existing solutions

Manual

Phase identifiers

Automatic

Smart meters with PLC

k-means clustering

Graph theory

Contributions

1. Novel algorithm
    1. Using the underlying structure of the network
    2. Using the advantages of both graph theory and correlation
    3. Identifying the measurements that should be linked together and cluster them.
2. Performance compared to those of a constrained k-means clustering
3. Tested on real measurements from a distribution network in Belgium, in a variety of settings.

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Distances

- Distance between two voltage measurements:
  - Pearson's correlation

$$d(M_l, M_i) = 1 - PC(M_l, M_i), \qquad \forall l, i \in \mathcal{I}$$

- Distance between a voltage measurement and a cluster

$$\Delta(\mathcal{C}_k, M_i) = \min_{l \in \mathcal{C}_k} d(M_l, M_i)$$

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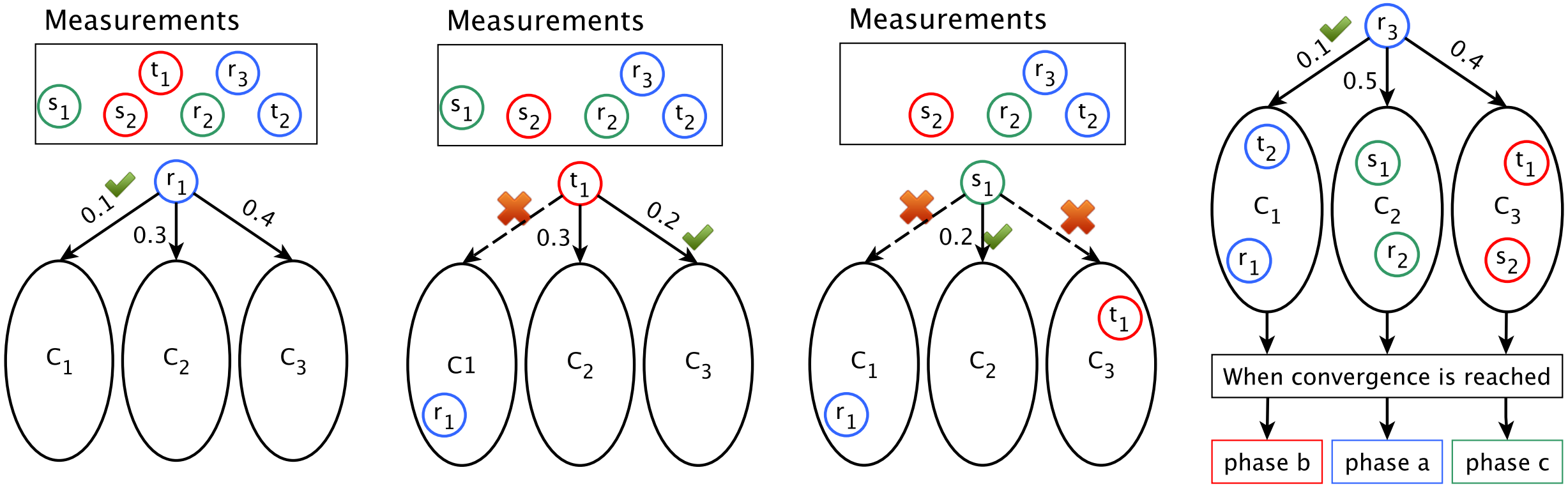
Reference algorithm
Constrained k-means Clustering



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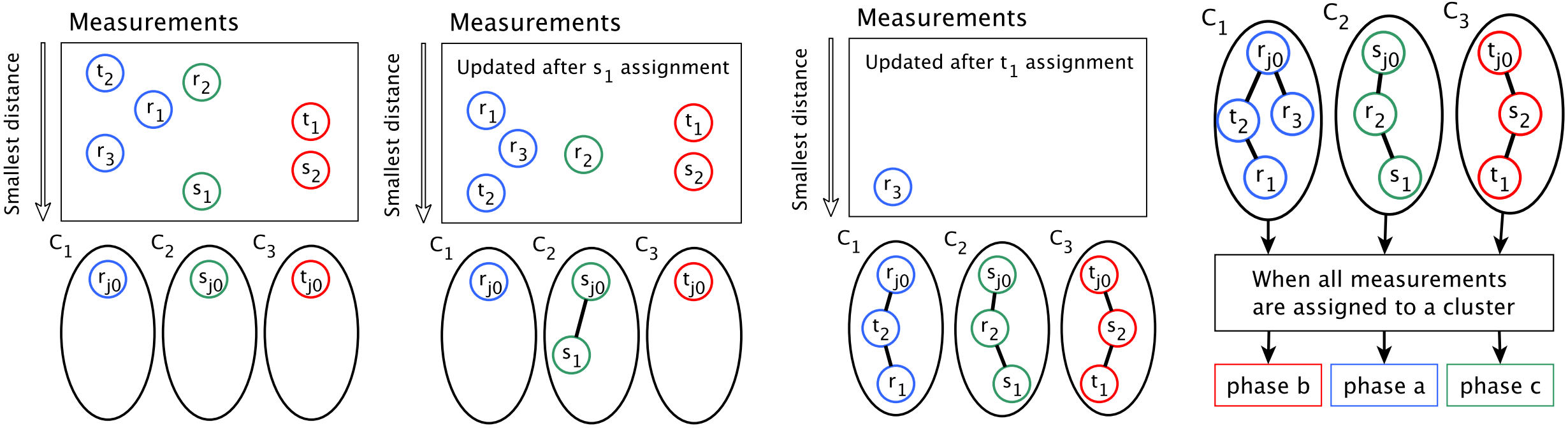
Proposed algorithm
Constrained Multi-tree Clustering



Olivier, F., Sutera, A., Geurts, P., Fonteneau, R., & Ernst, D. (2018). Phase identification of smart meters by clustering voltage measurements. In *Proceedings of the XX Power Systems Computation Conference (PSCC 2018)*.

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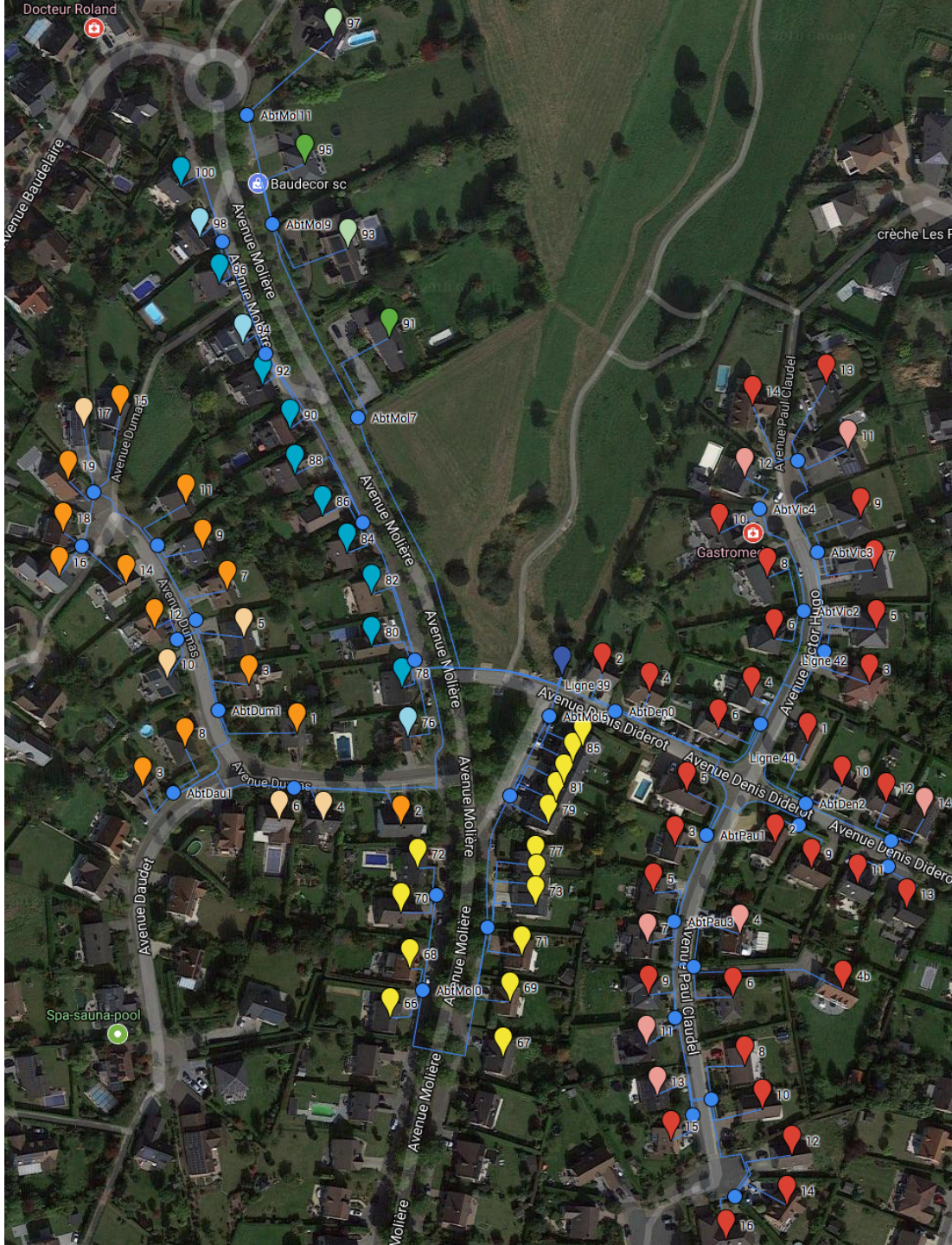
Test system

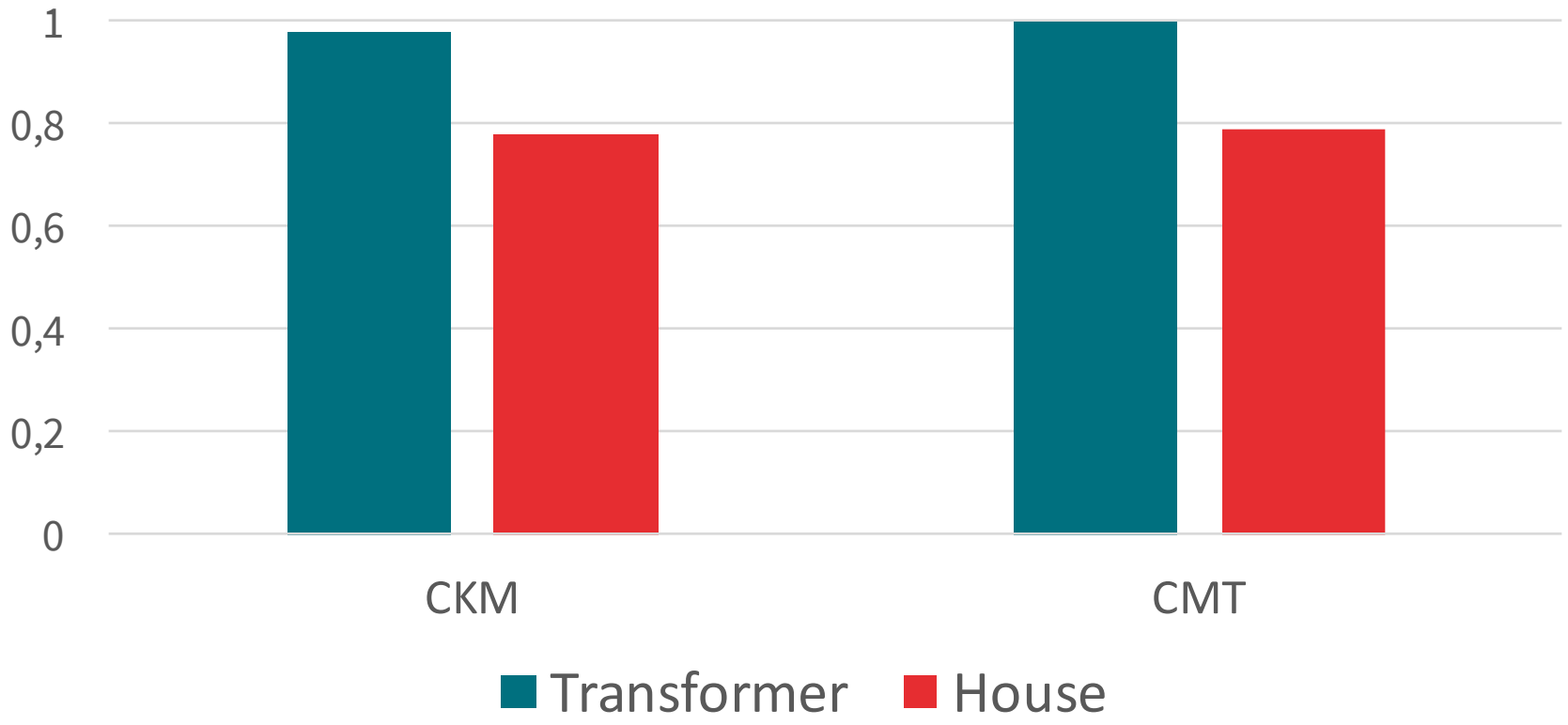
- Belgium LV distribution network
- 5 feeders, star configuration 400 V
- 79 three-phase smart meters
- 2 single phase smart meters
- Average phase-to-neutral voltage measurements every minute

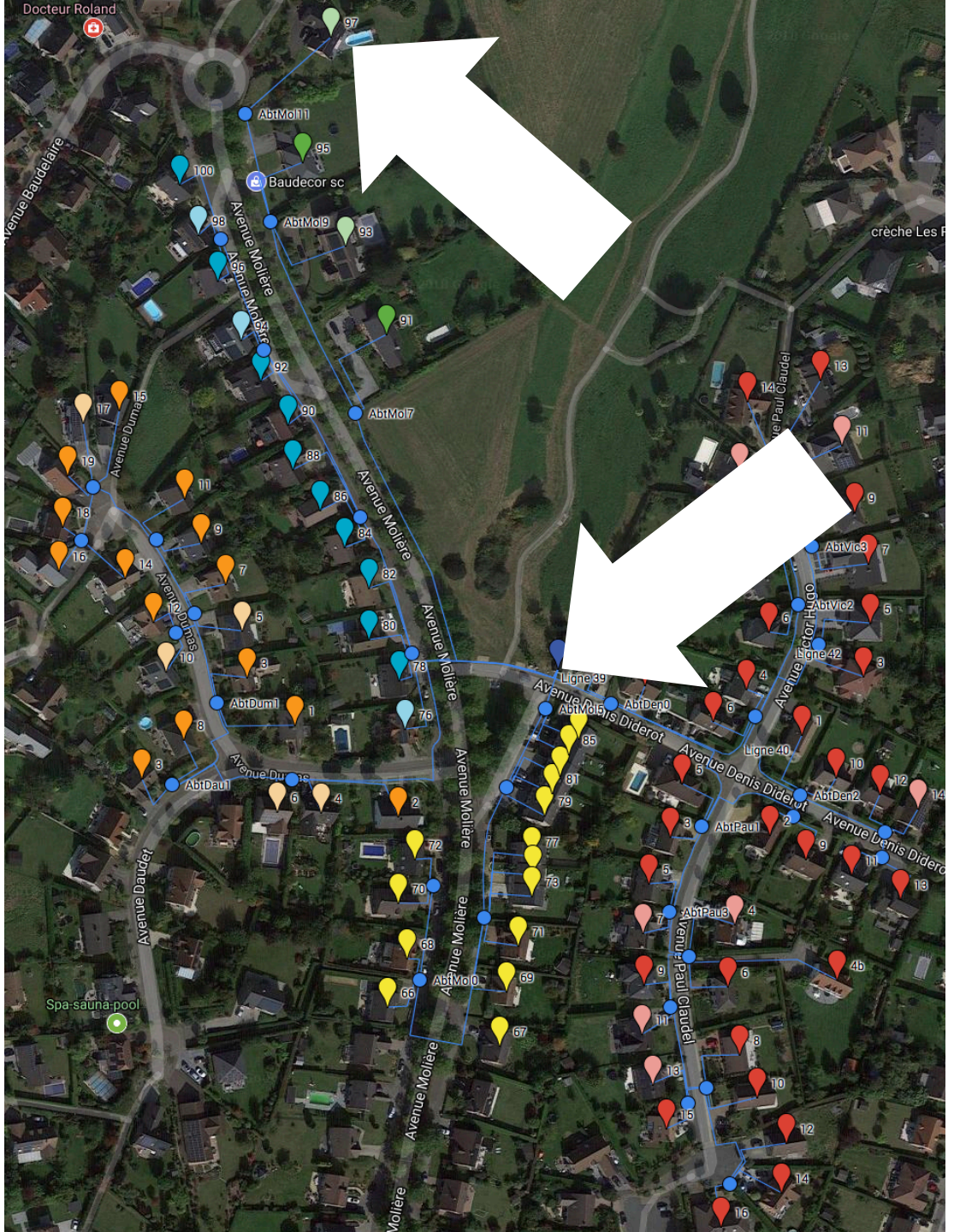


Results for the test sets
Discussions on the selection of the root

Performance measure

The ratio between the measurements correctly identified and the total number of measurements




Docteur Roland
Avenue Baudelaire
Avenue Molière
Avenue Dumas
Avenue Daudet
Avenue Denis Diderot
Avenue Victor Hugo
Avenue Paul Claudel
Baudecor sc
crèche Les P
Spa-sauna-pool
AbtMol11
AbtMol9
AbtMol7
AbtMol5
AbtMol0
AbtDum1
AbtDau1
AbtDen0
AbtDen2
AbtPau1
AbtPau3
AbtVic3
AbtVic2
Ligne 39
Ligne 40
Ligne 42

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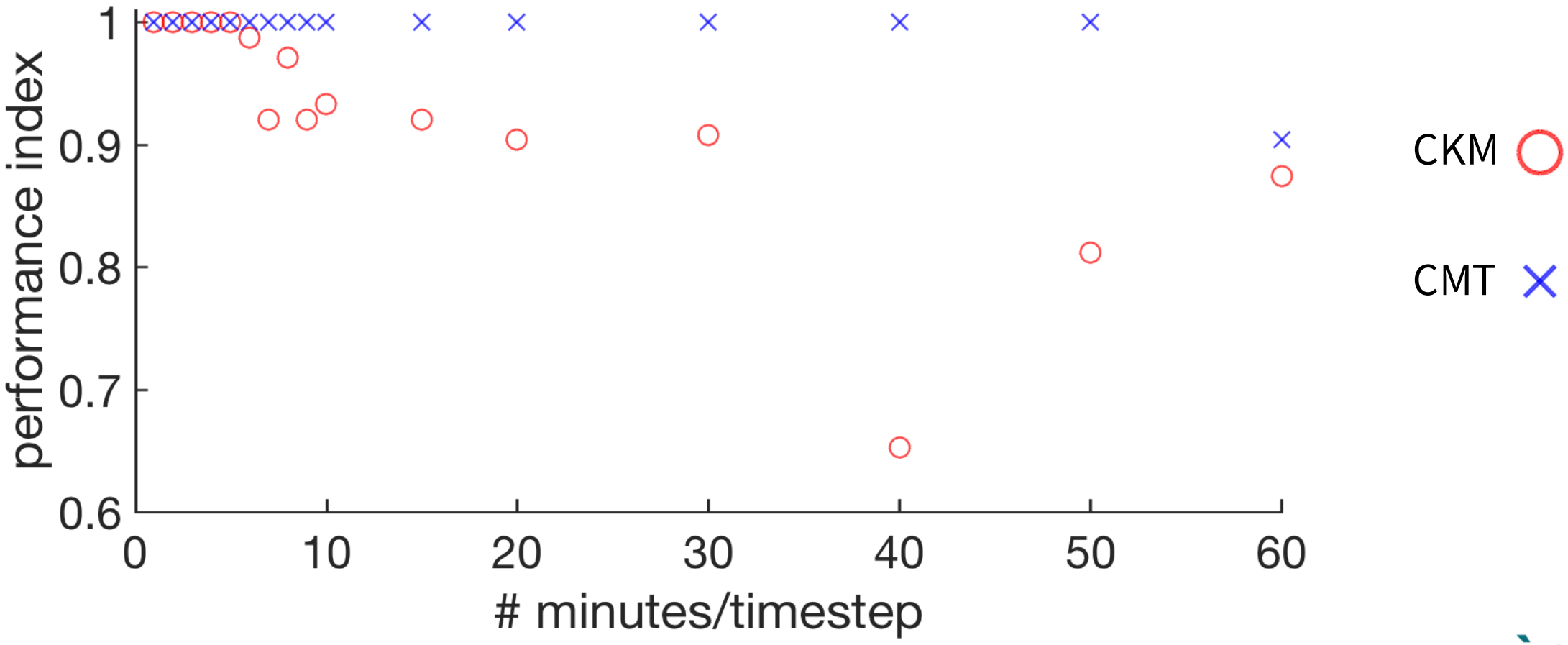
Influence of the voltage-averaging period



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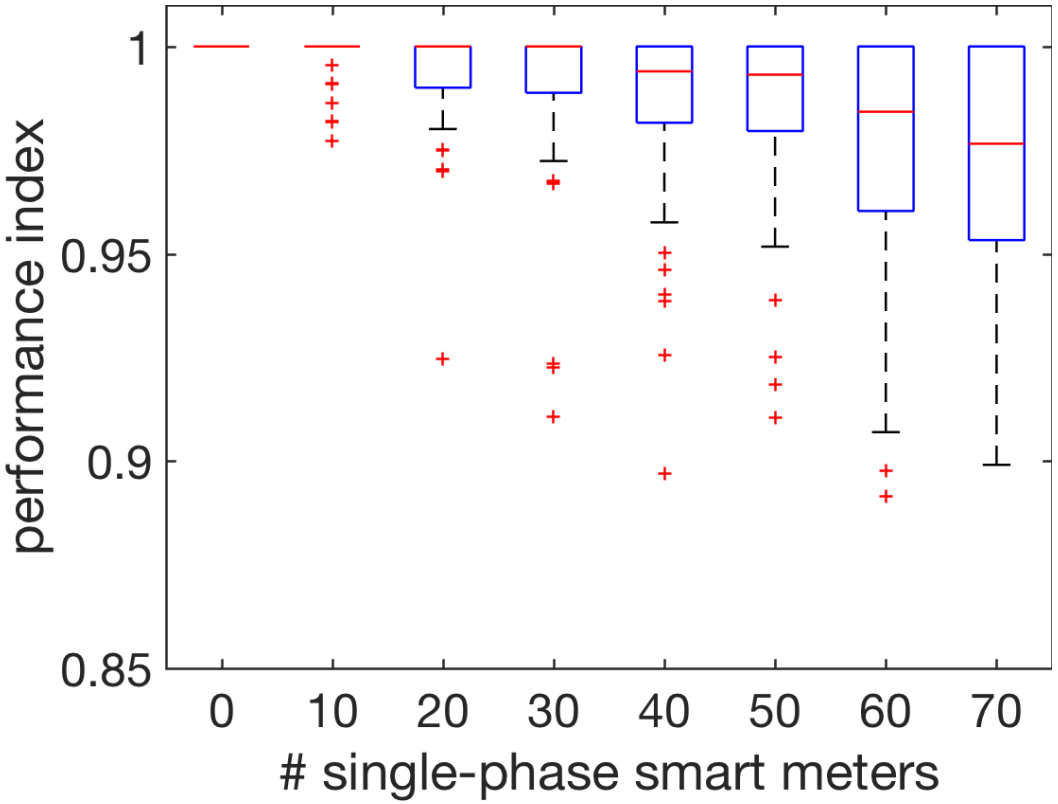
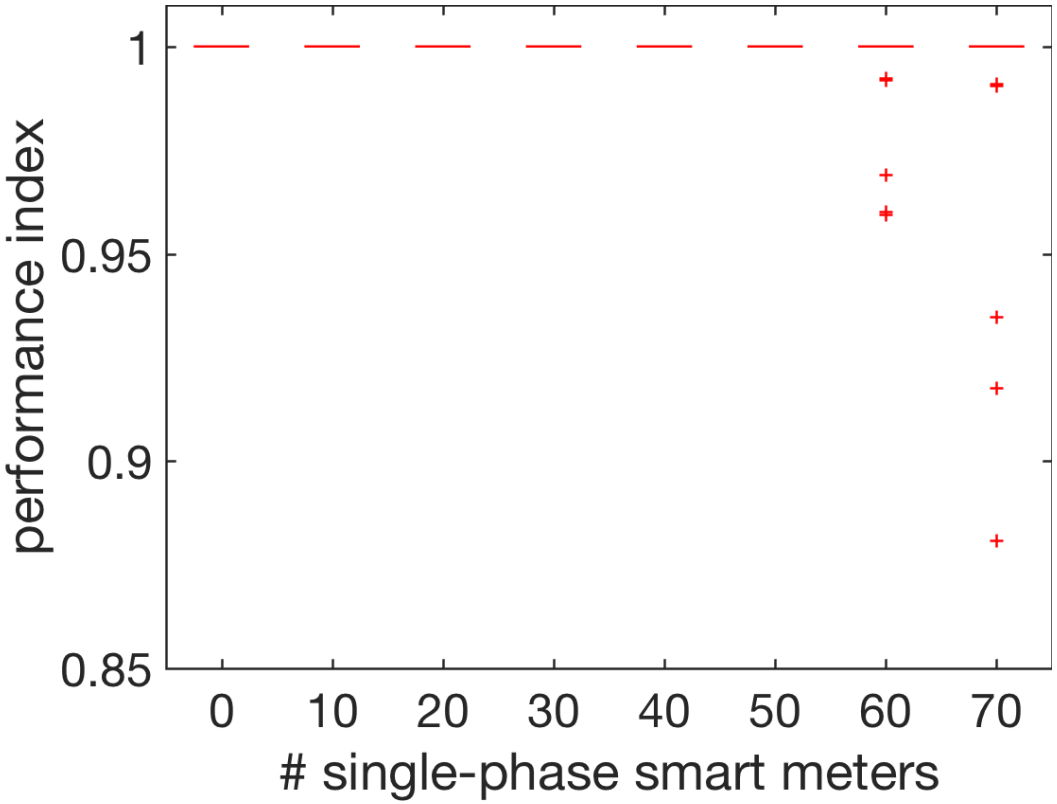
Influence of ratio single-phase – three-phase smart meters



CKM



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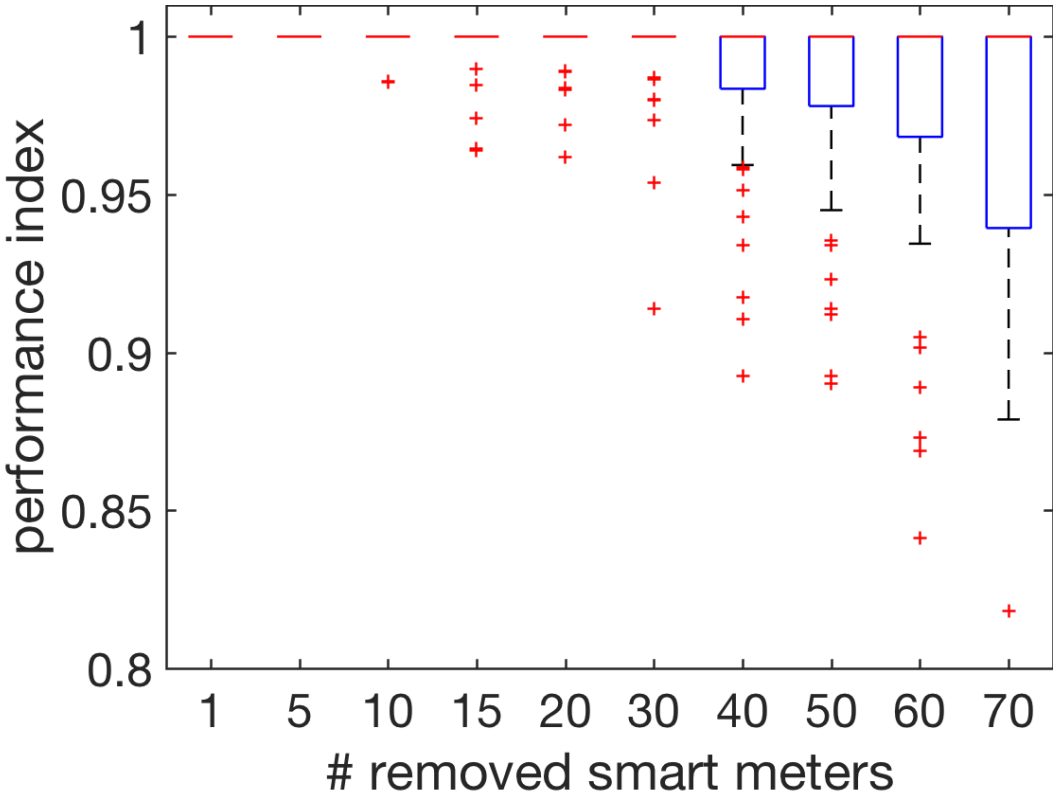
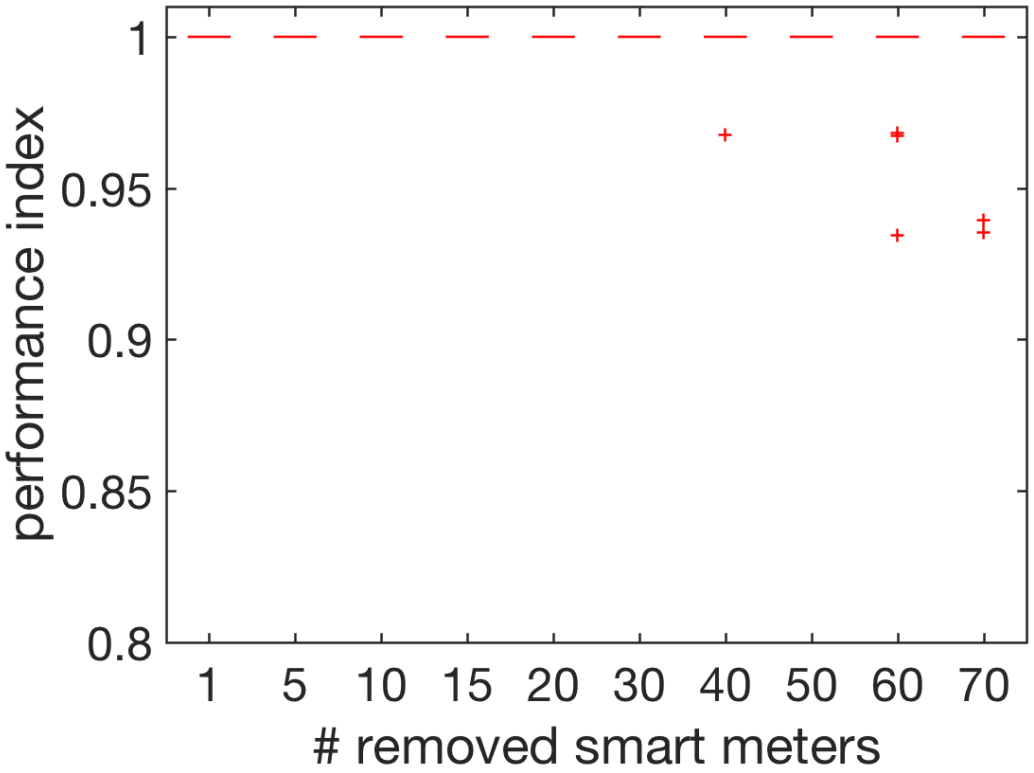
Influence of the number of smart meters



CKM



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Part 2
Active network management

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Active network management

Objective

Design strategies to control the active and reactive power injected by the PV panels into the distribution grid so as to ensure that the voltages stay within their limits

Active network management

Centralized controller

- Model required
- Communication infrastructure

Distributed controllers

- Model-free
- Little communication
- Simpler logic

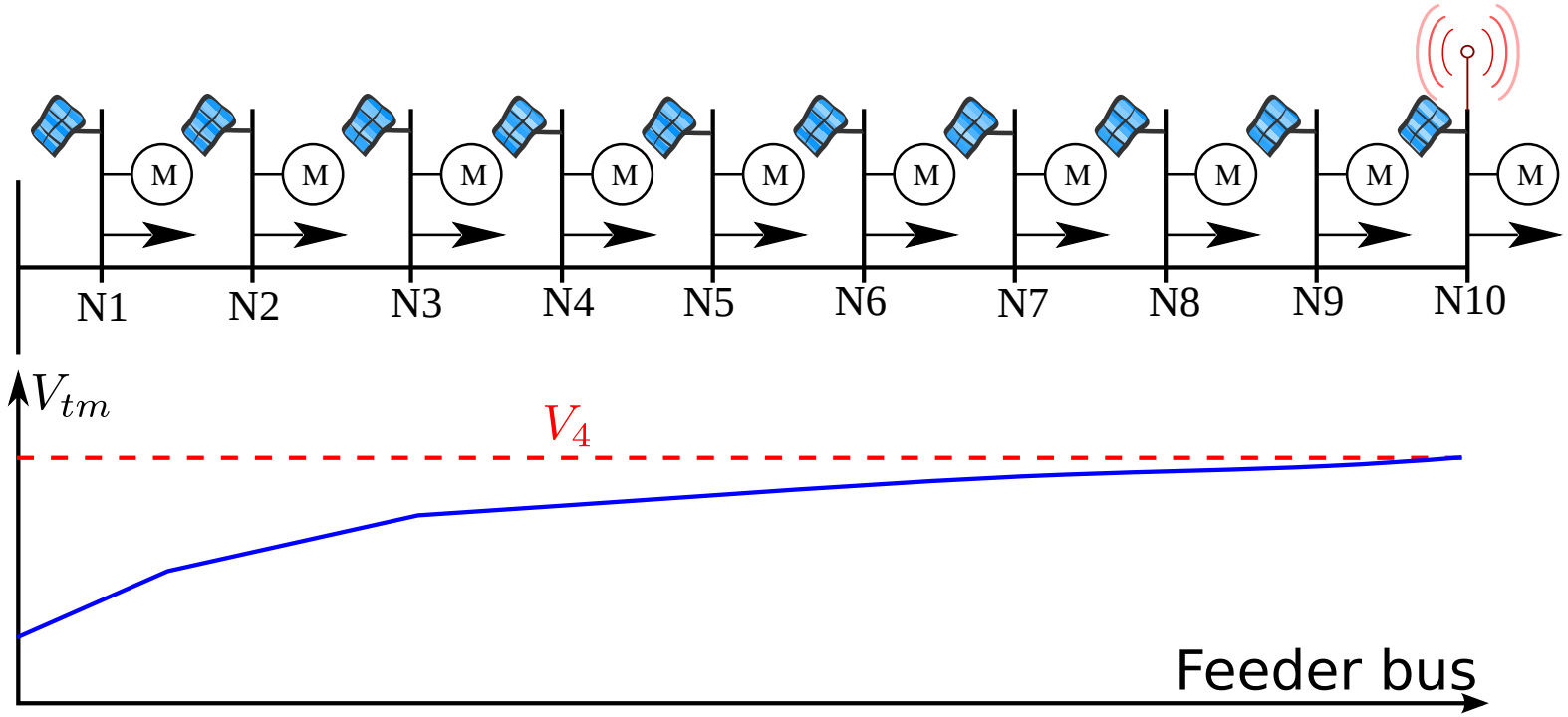
- What are the key principles of the control scheme?
- What is the structure of the algorithm?
- How can we adapt the control scheme to three phases?
- What is its performance compared to other algorithms?

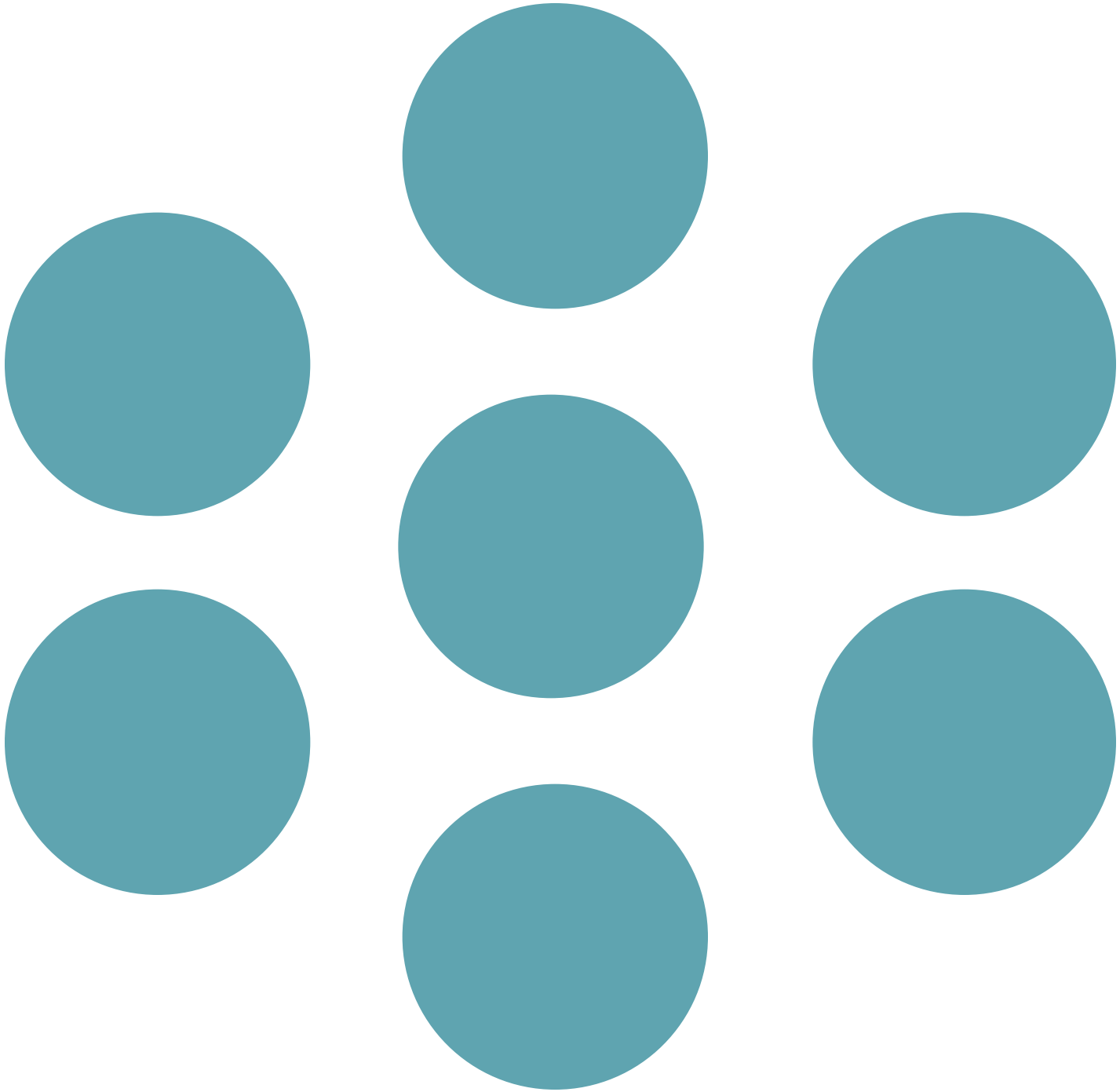
Key principles

- Distributed algorithm
- No central entity
- Each inverter applies locally the algorithm
- No model required
- First use reactive power
- Curtail active power as a last resort
- Limited communication in the form of a distress signal to pool the resources

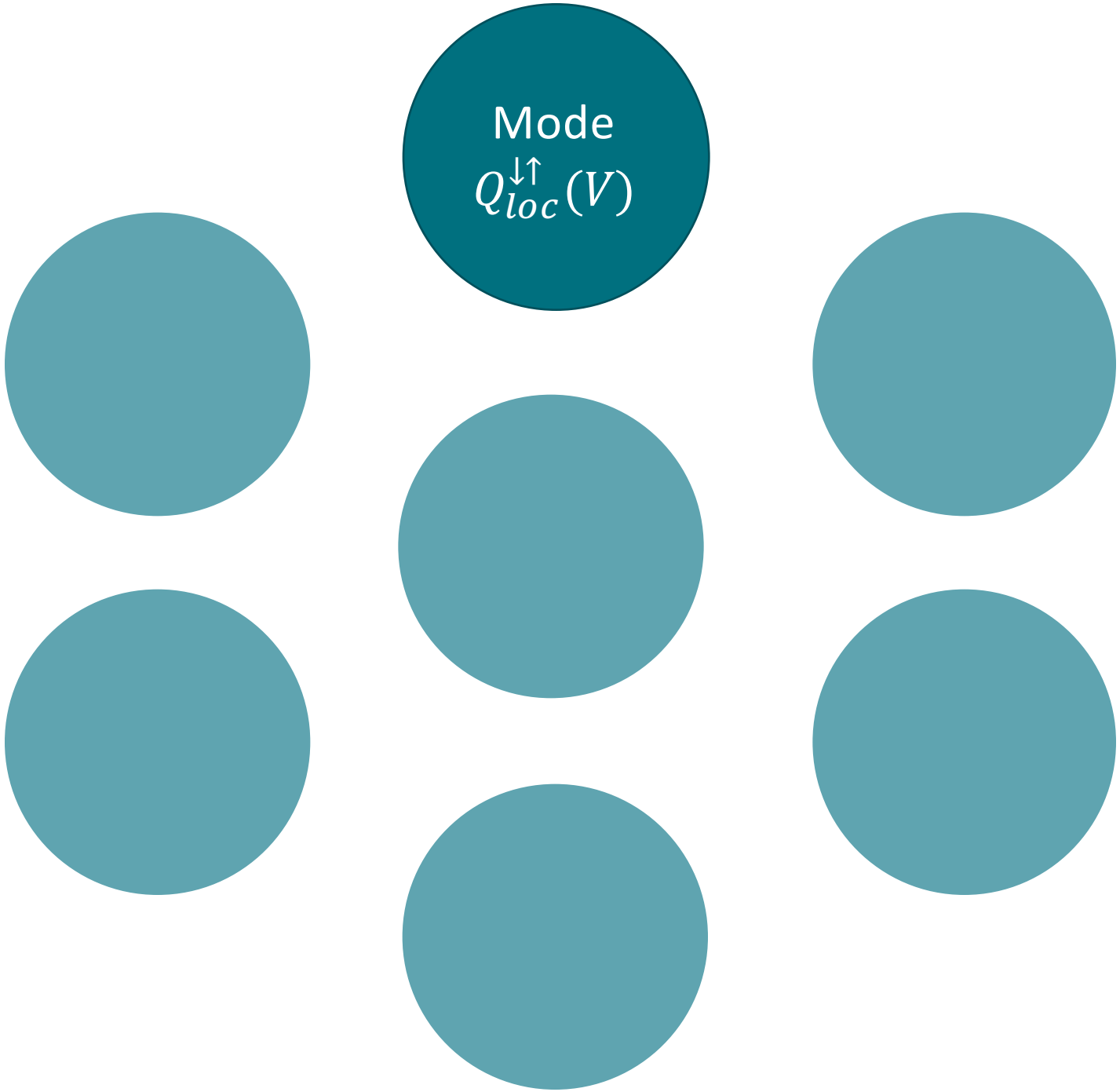
Olivier, F., Aristidou, P., Ernst, D., & Van Cutsem, T. (2016). Active management of low-voltage networks for mitigating overvoltages due to photovoltaic units. *IEEE Transactions on Smart Grid*, *7*(2), 926-936.

Assuming that the three phases are balanced

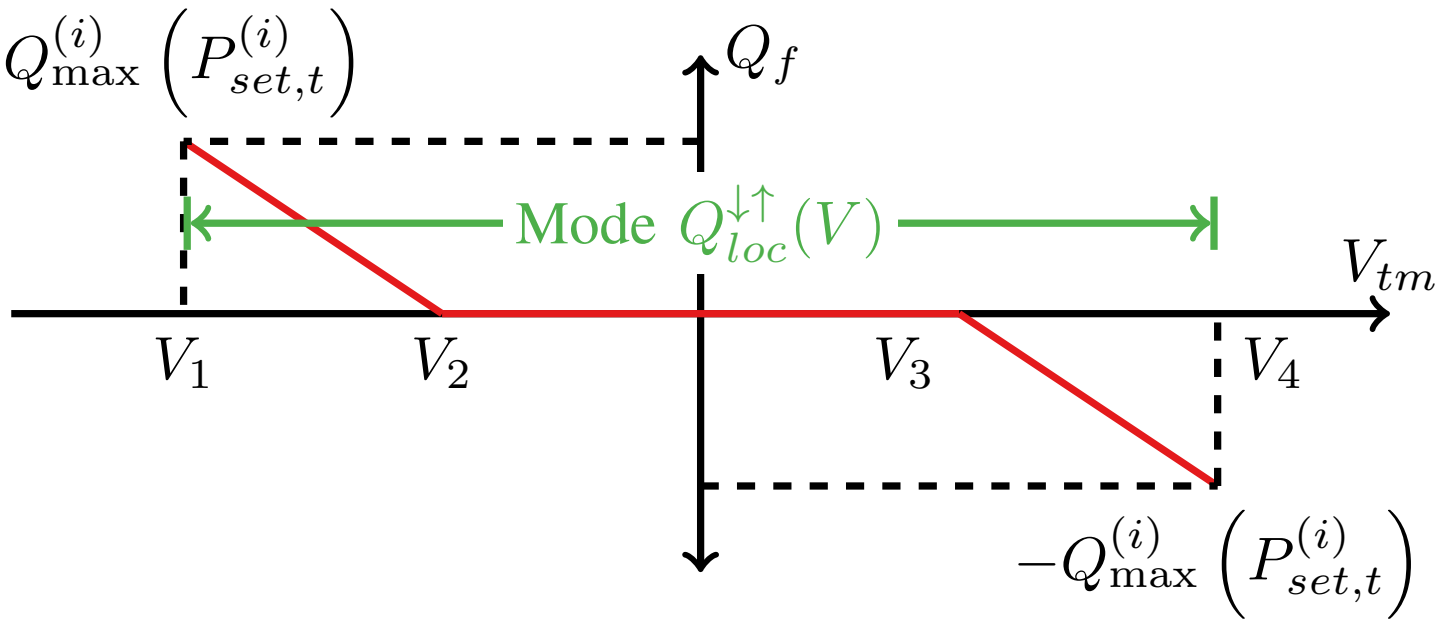




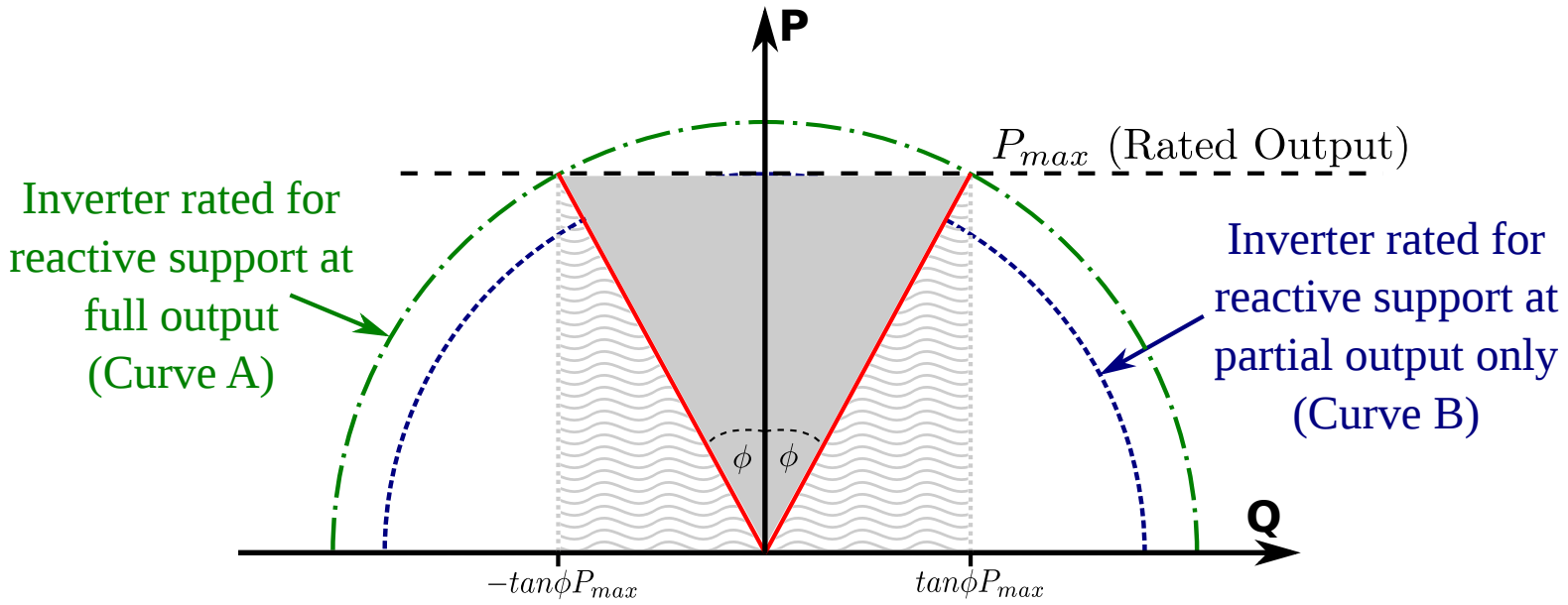
Modes of the algorithm

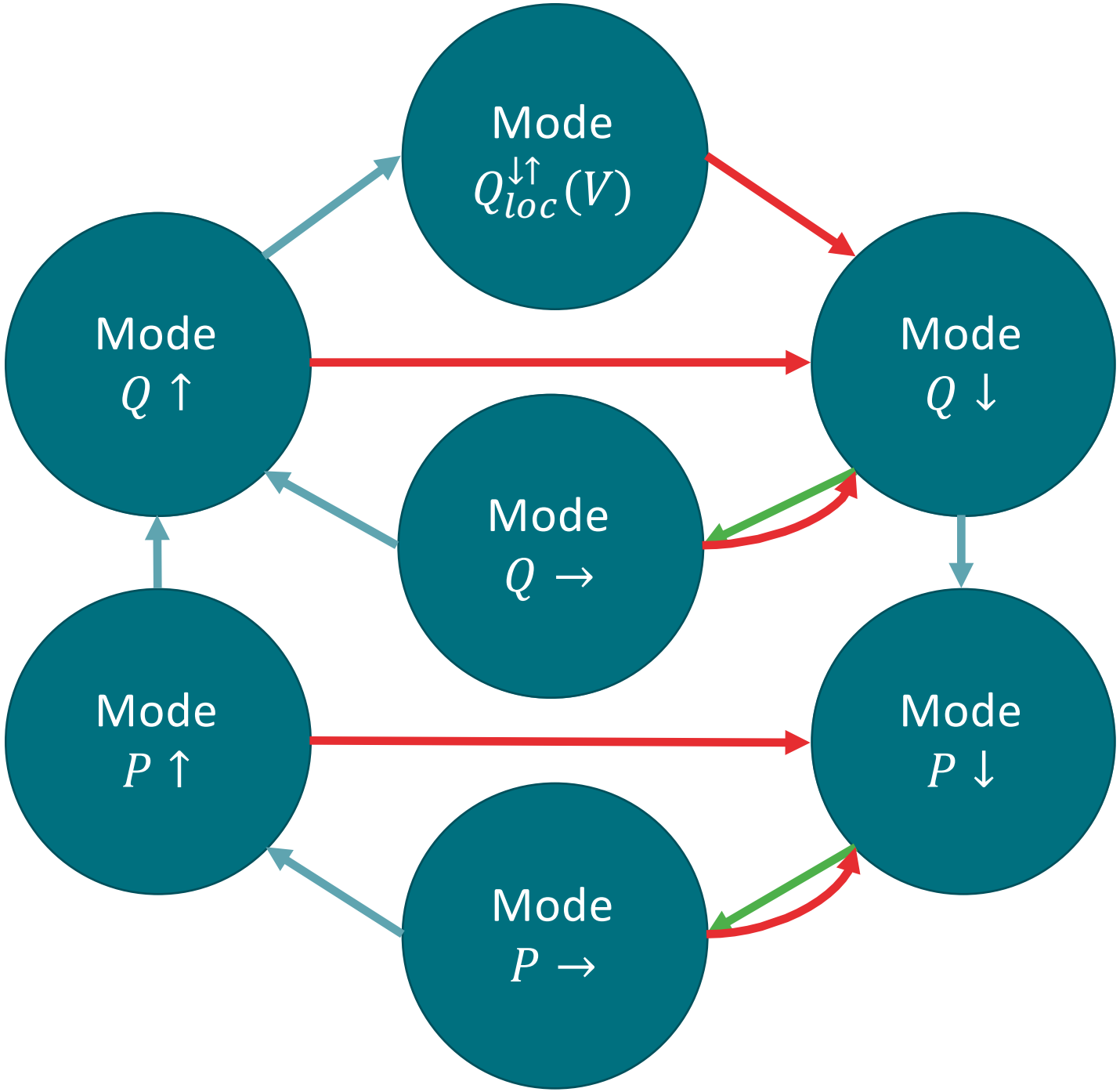


Mode $Q_{loc}^{\downarrow\uparrow}(V)$



Capability curve of PV inverters





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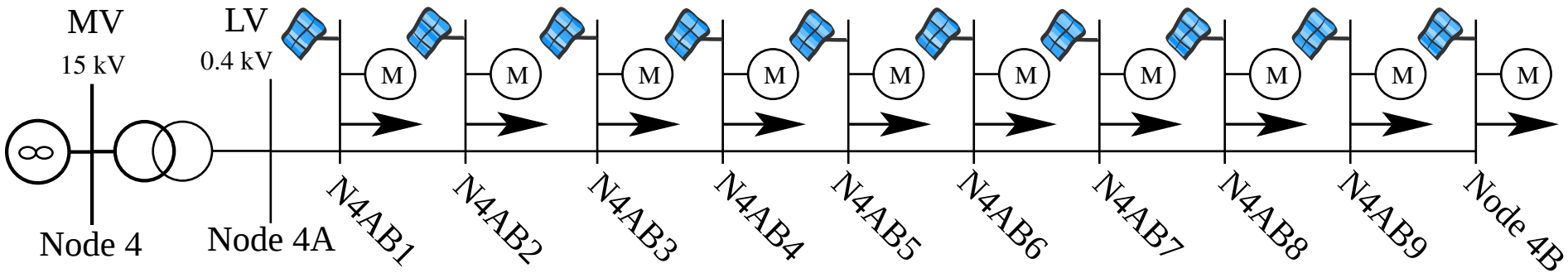
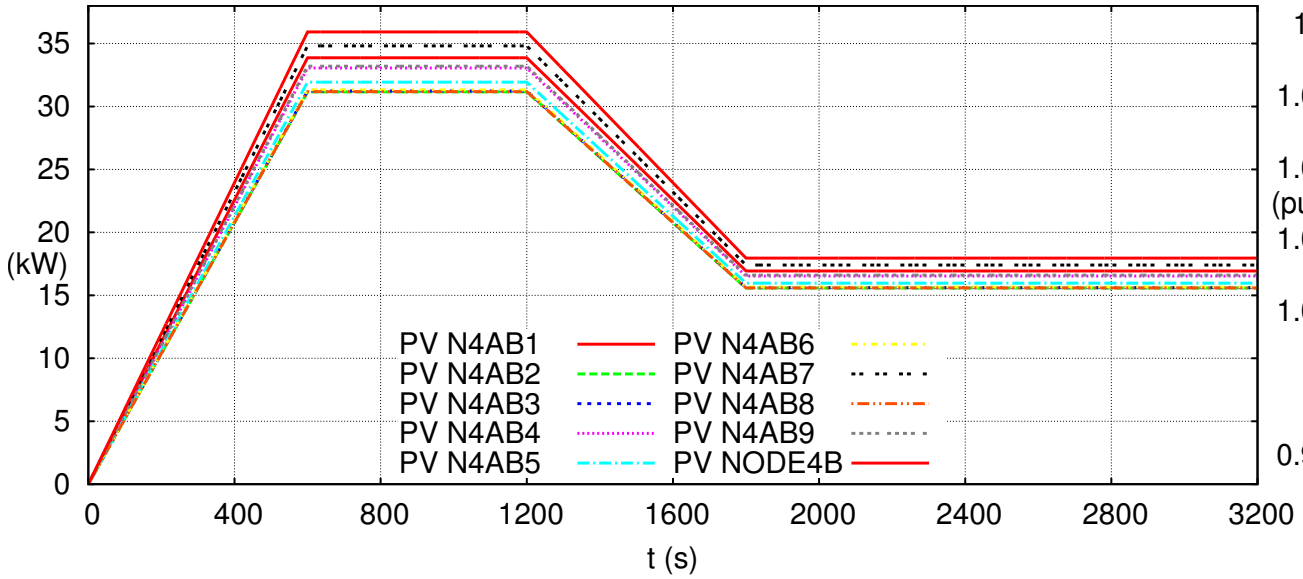
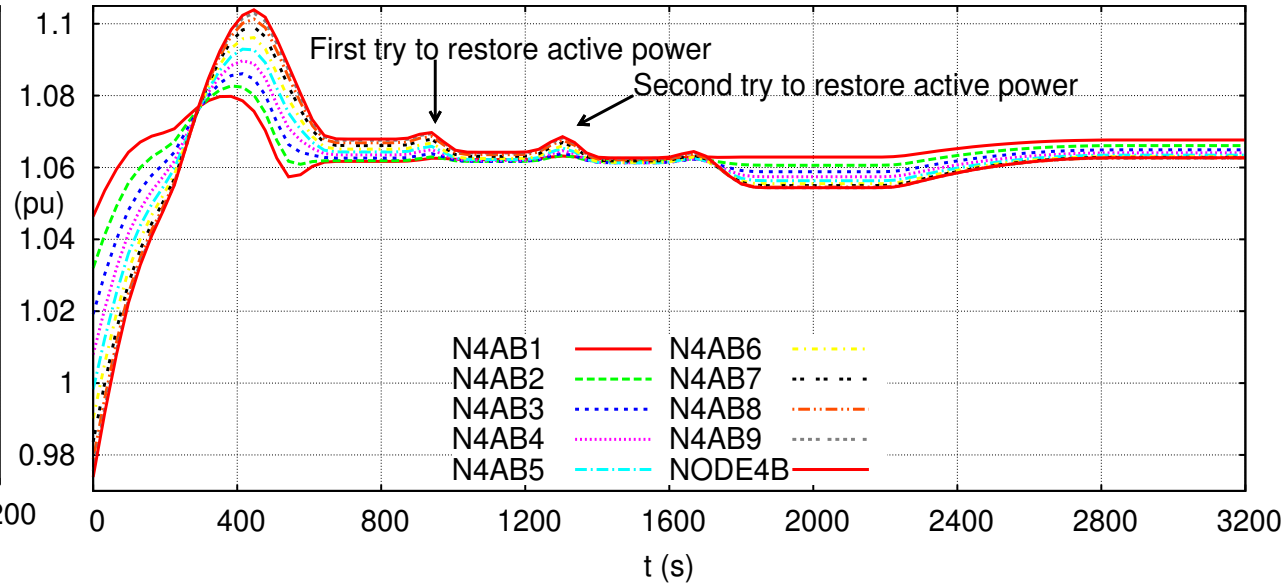
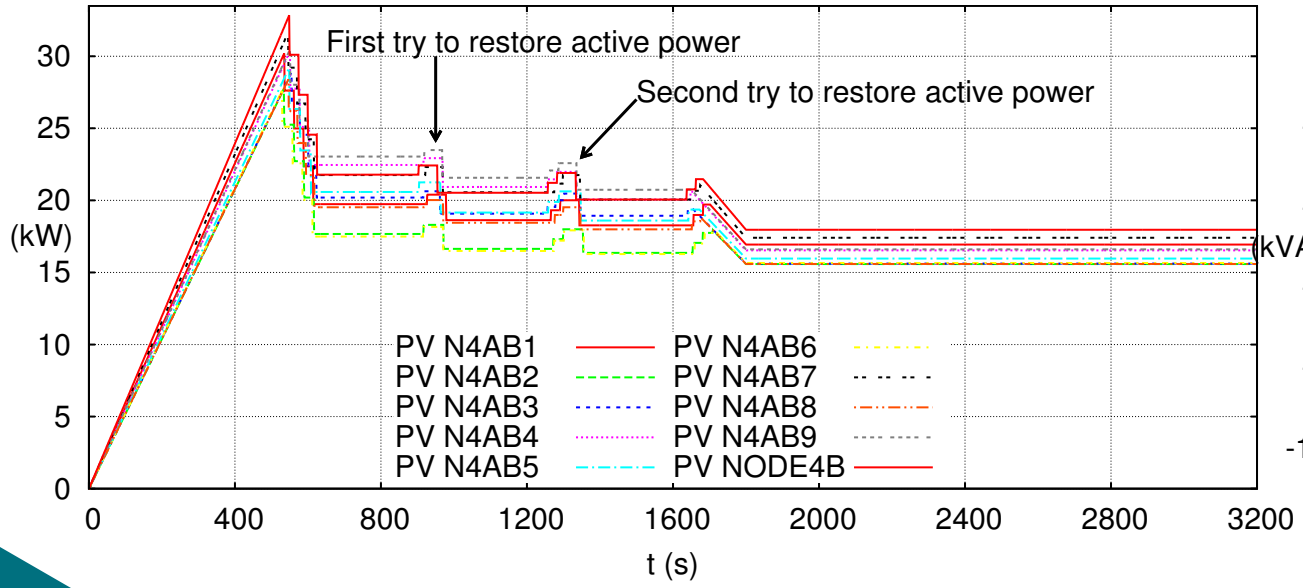
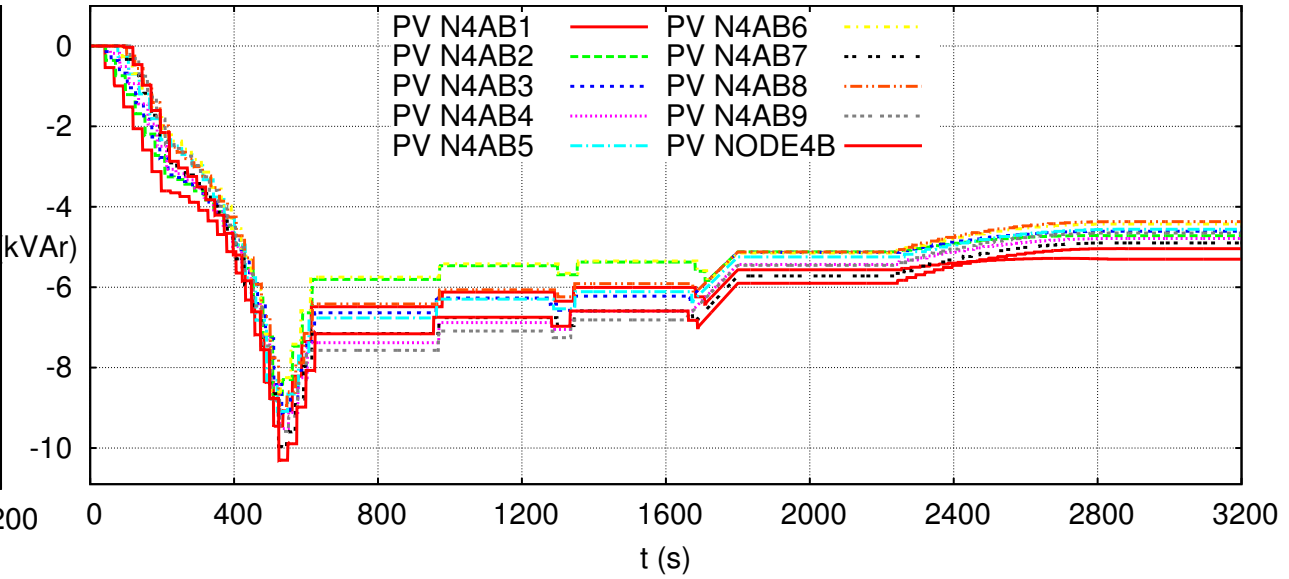
Single feeder test system











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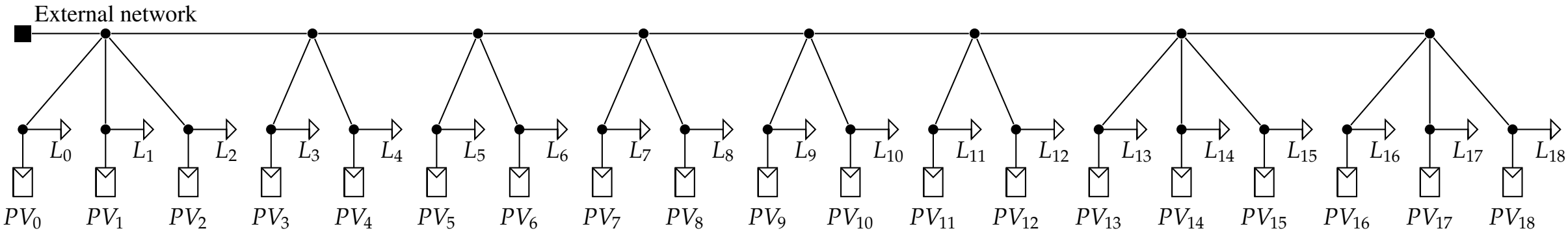
When the three phases are unbalanced

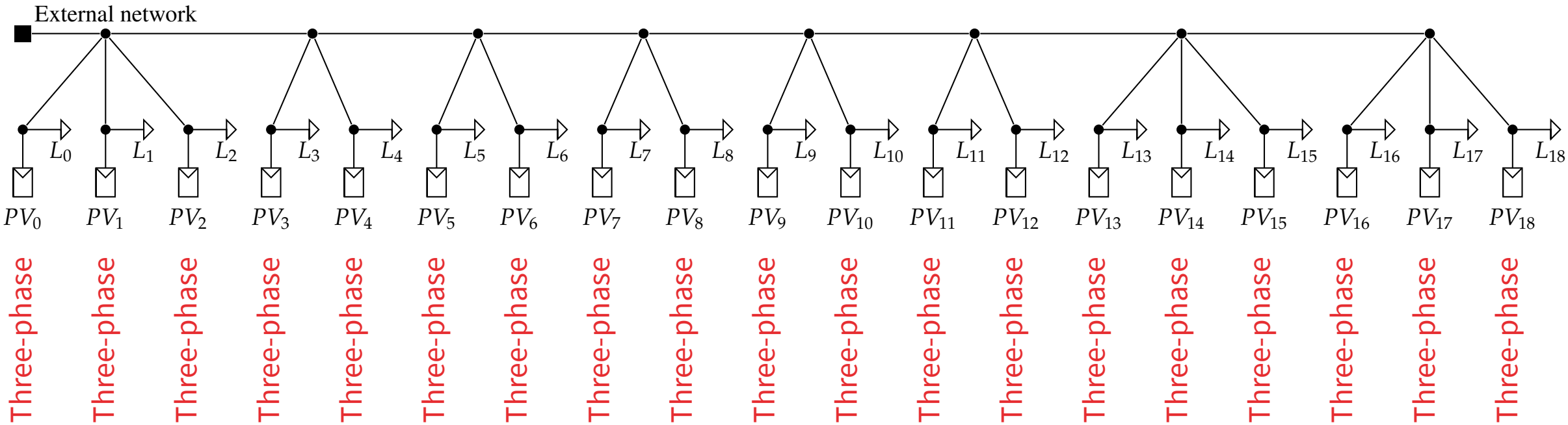
- Four groups of inverters
  - One for each phase and one for three-phase inverters
- Three distress signals
  - One per phase
- Each group applies the control scheme independently

Unbalanced test system



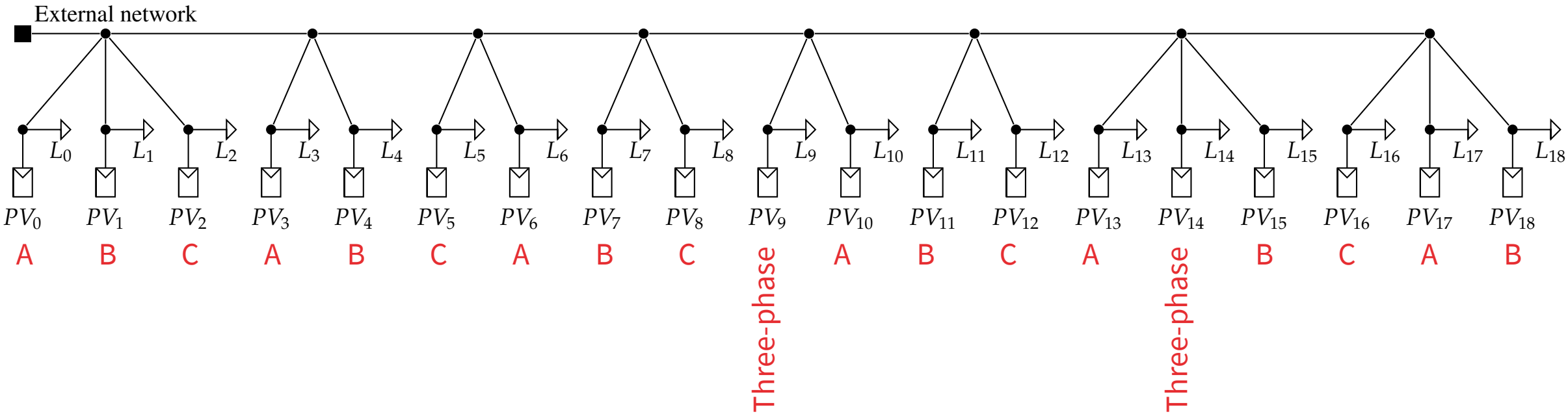
PV connection scenarios

Scenarios 3P



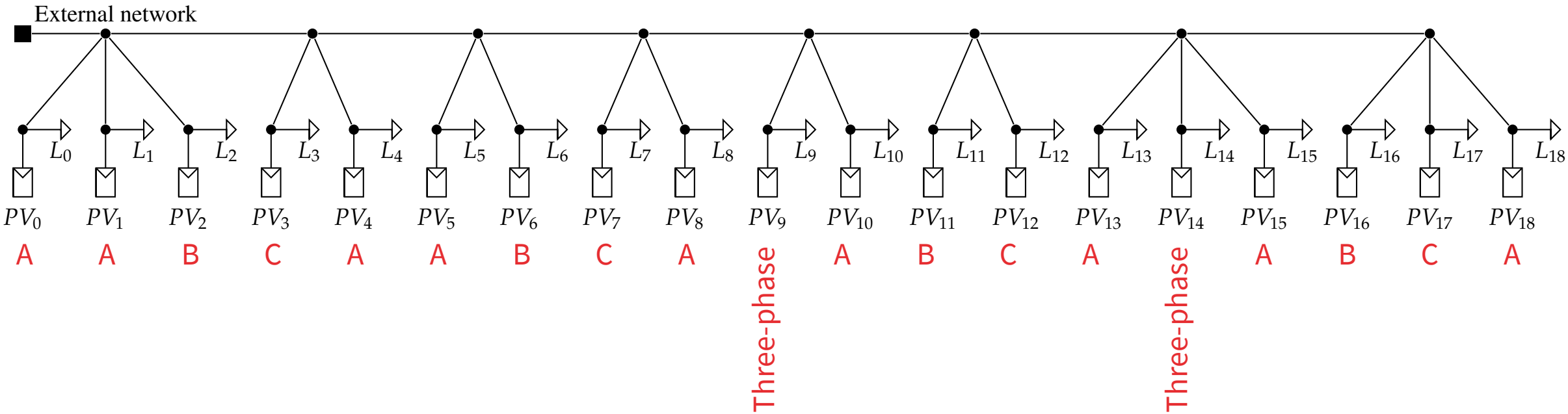
PV connection scenarios

Scenarios ABC



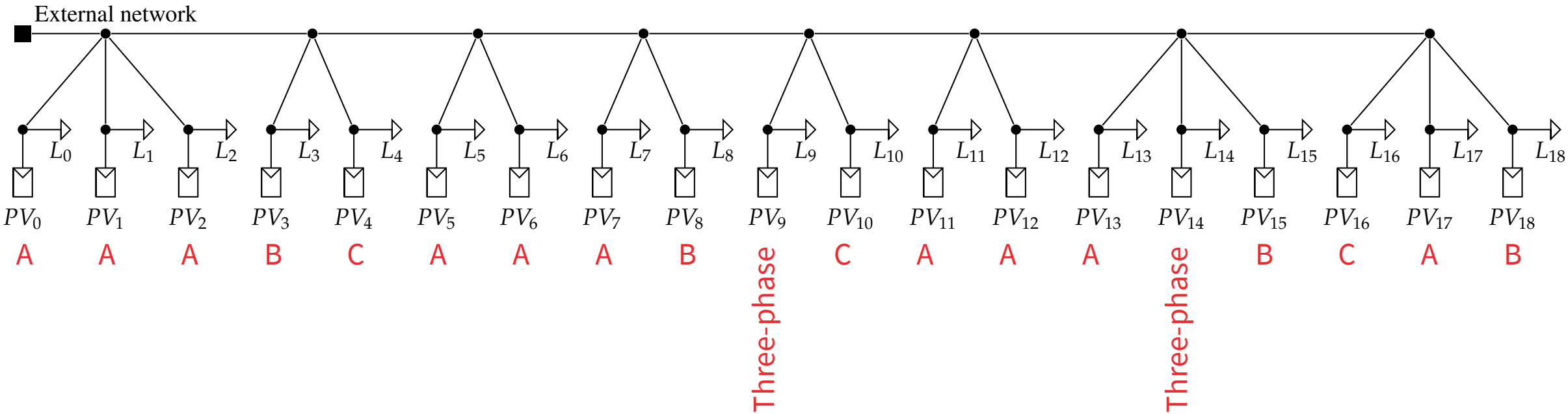
PV connection scenarios

Scenarios AABC



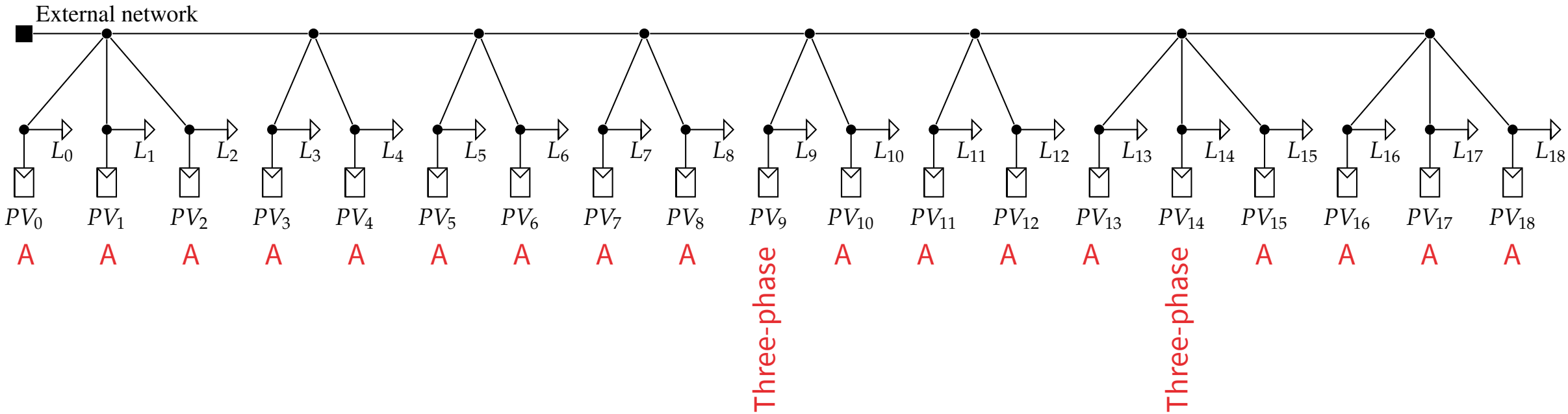
PV connection scenarios

Scenarios AAABC

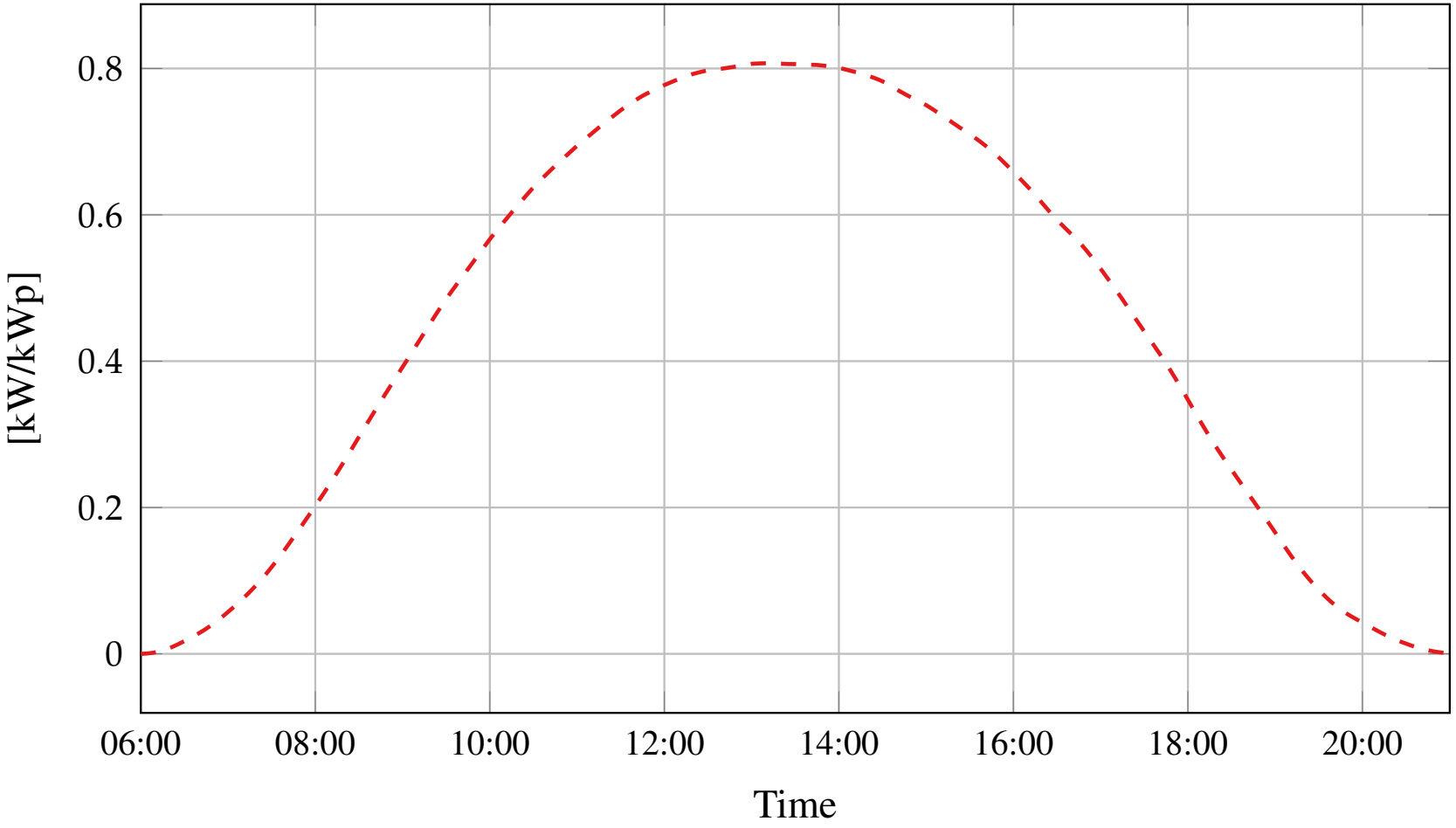


PV connection scenarios

Scenarios AAA



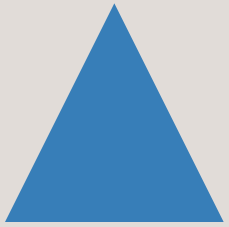
Simulations for a sunny day



Comparison between algorithms

On-off

- The one already implemented in commercial inverters



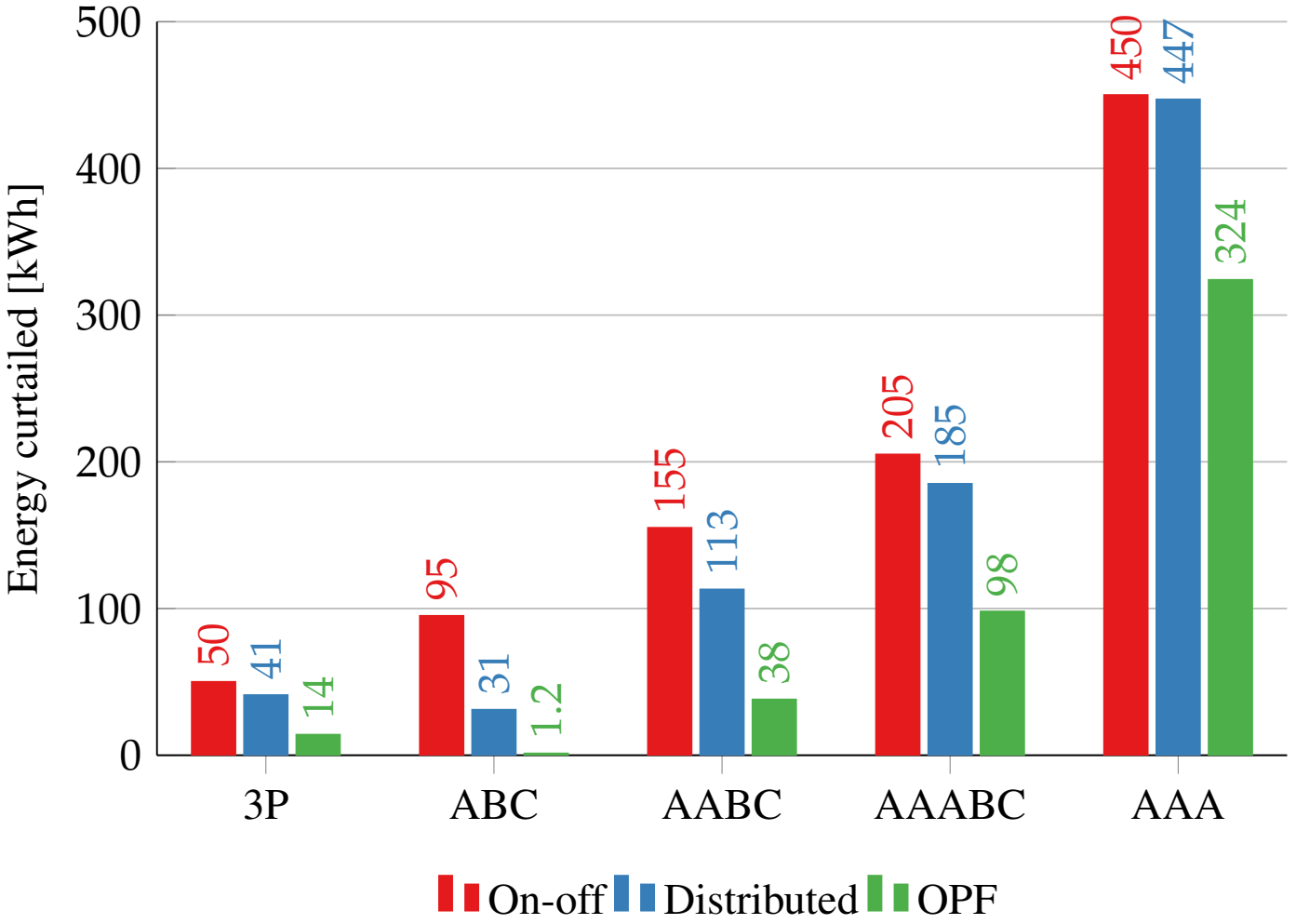
Distributed

- The one we propose

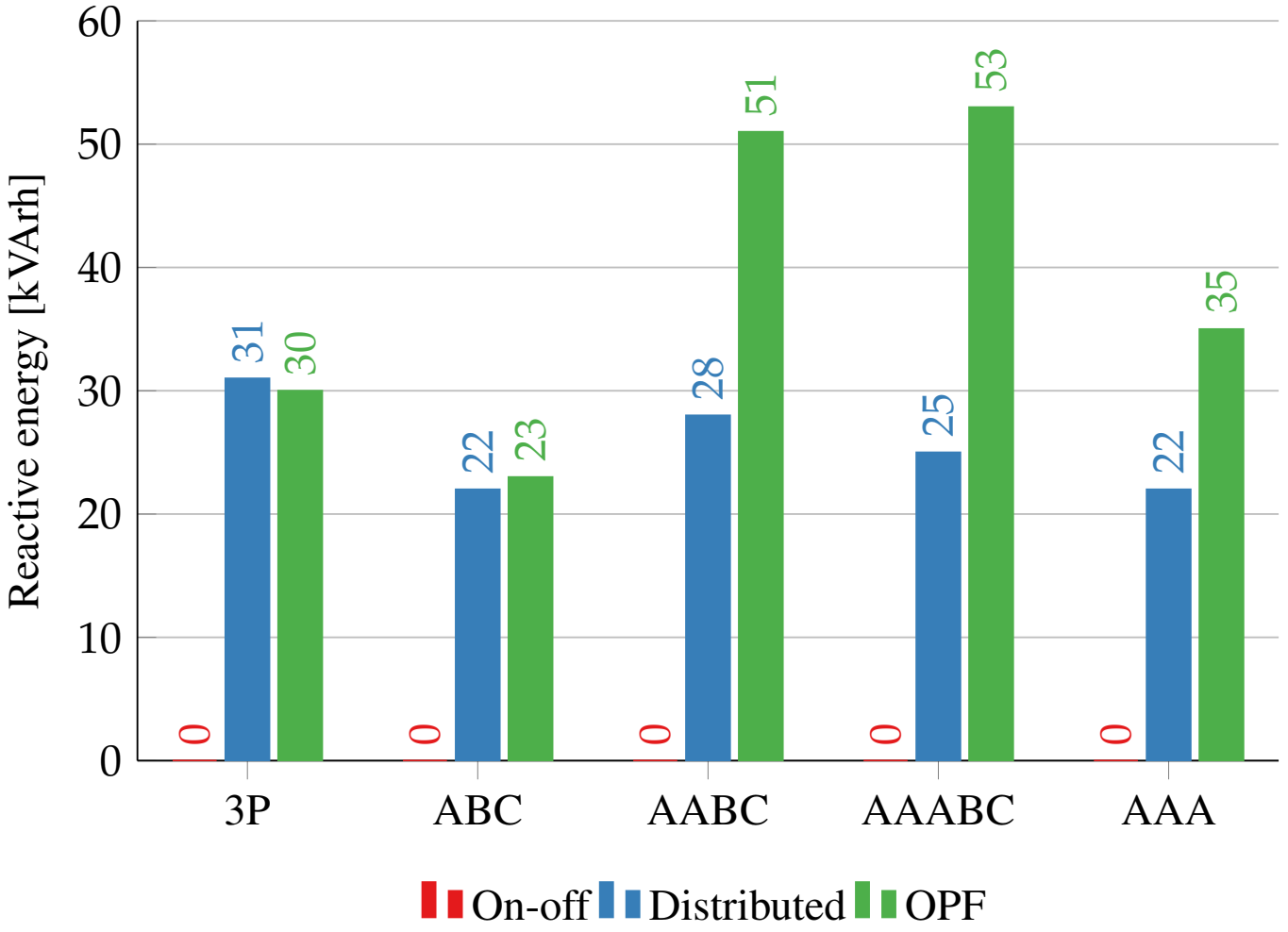
Optimal power flow

- The one centrally optimizing the power produced by the PV

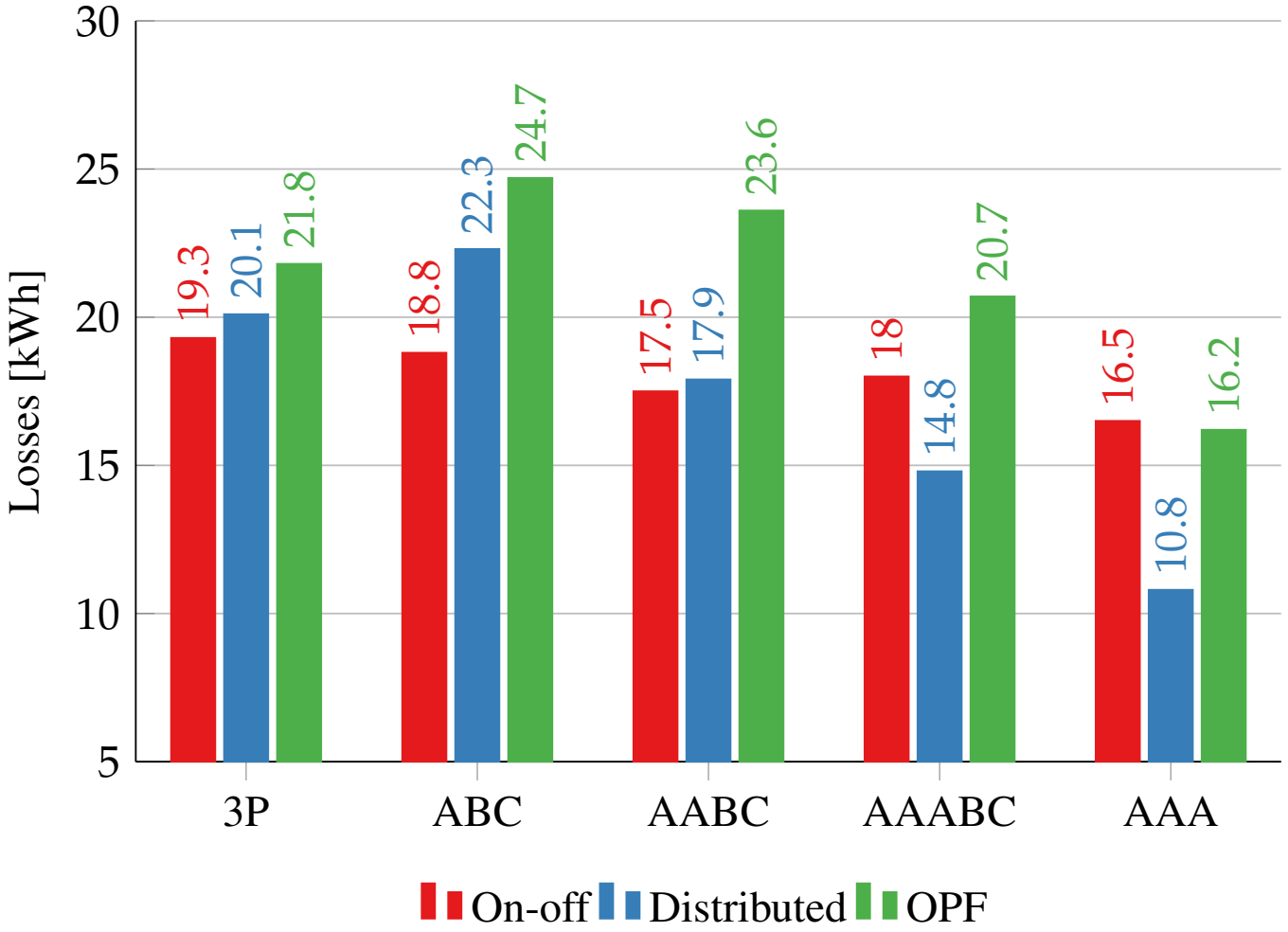
Energy curtailed



Reactive energy usage



Losses


30
25
20
15
10
5
Losses [kWh]
19.3
20.1
21.8
18.8
22.3
24.7
17.5
17.9
23.6
18
14.8
20.7
16.5
10.8
16.2
3P
ABC
AABC
AAABC
AAA
On-off
Distributed
OPF

Batteries

Local energy communities

- Definition

> Electricity distribution system containing loads and distributed energy resources (such as distributed generators, storage devices, or controllable loads), that can be operated in a controlled, coordinated way

Local energy communities

- Drivers
  - With a shared infrastructure between the members
  - Without a shared infrastructure
    - Network operation
    - Energy market

Communities extend the perimeter of self-consumption from one prosumer to several to pool production and flexibility means

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Electric vehicles

Conclusion – From research to industry

Question 1
Identifying the network topology and the phases of the smart meters

Question 2
Computing the hosting capacity networks

Question 3
Preventive actions

Question 4
Corrective actions

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