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Mitigation of cascading failures by real-time controlled islanding and graceful load shedding

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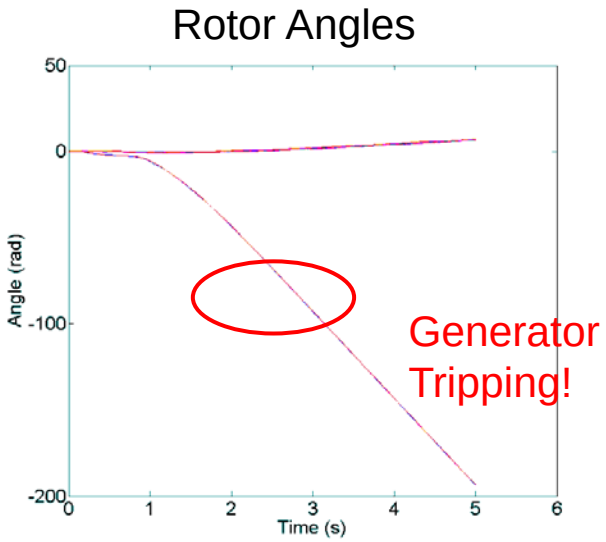
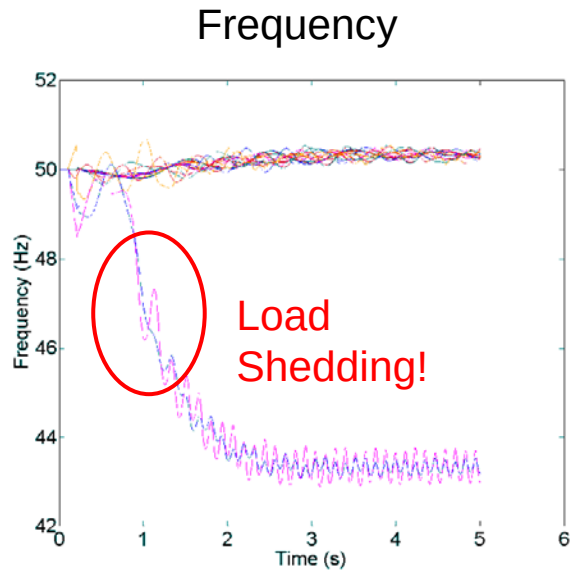




Objective

- Mitigation Measures:
  - Controlled Islanding
  - Load Shedding

} Combine them

Controlled Islanding

- Split the power system into subnetworks with slightly reduced capacity

- Contain cascading events
- Avoid the tripping of the generators due to loss of synchronism
- Faster restoration time

- Objective: Minimum Load-Generation Imbalance

Motivation

Future:

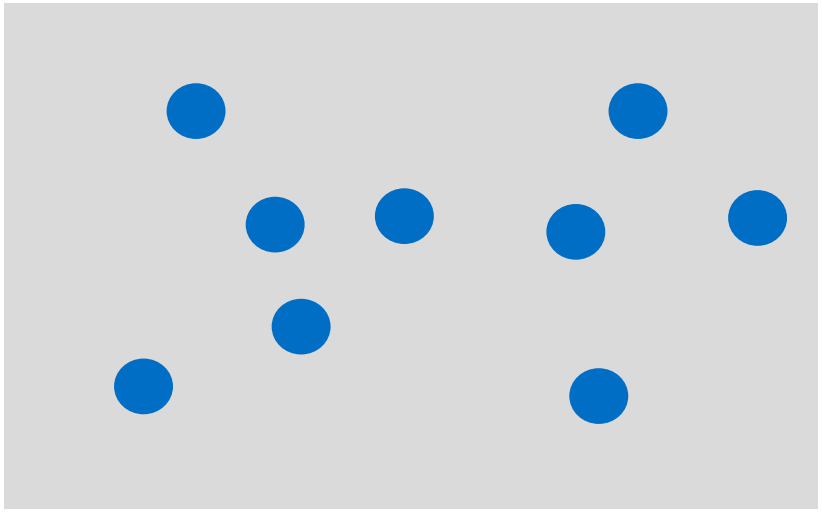
Increased penetration of intermittent generation

- Real-Time controlled islanding
  → K-means controlled islanding
- Do not shed feeders with RES
  → Customer-Level load shedding

OUTLINE

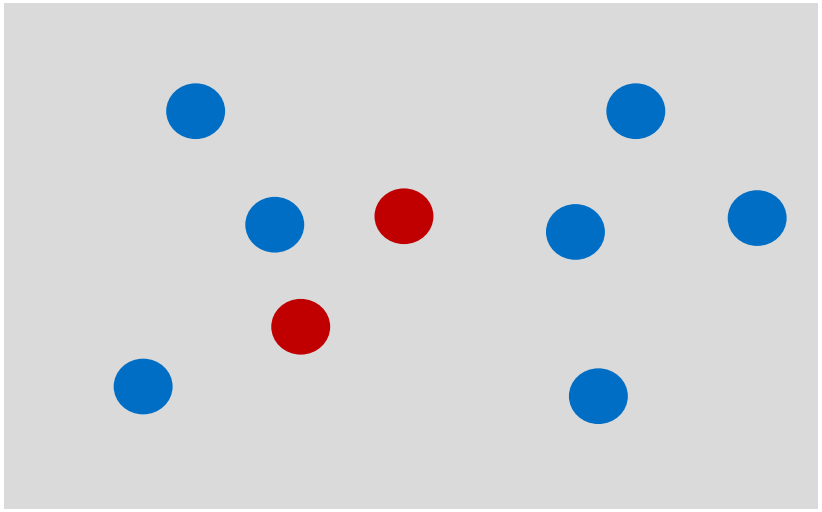
1. k-means controlled islanding
2. Customel level load shedding
3. Dynamic Simulations and Results of Four Case Studies

k-means for Controlled Islanding



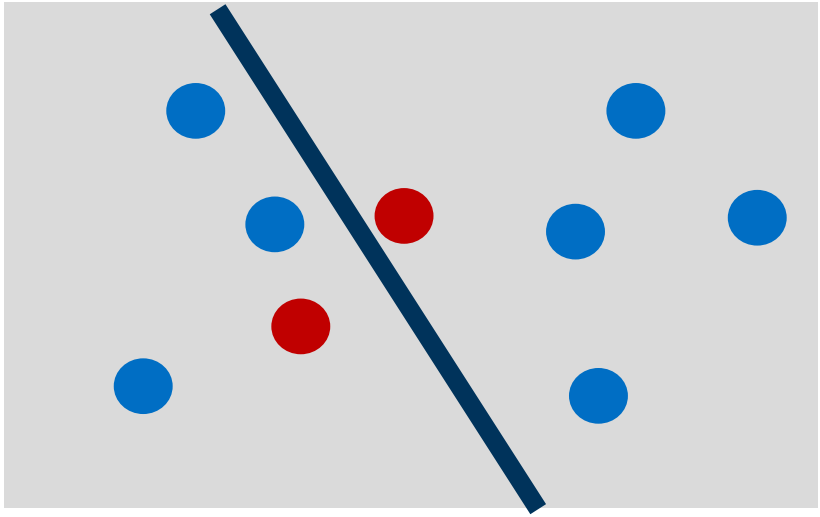
1. Start

k-means for Controlled Islanding

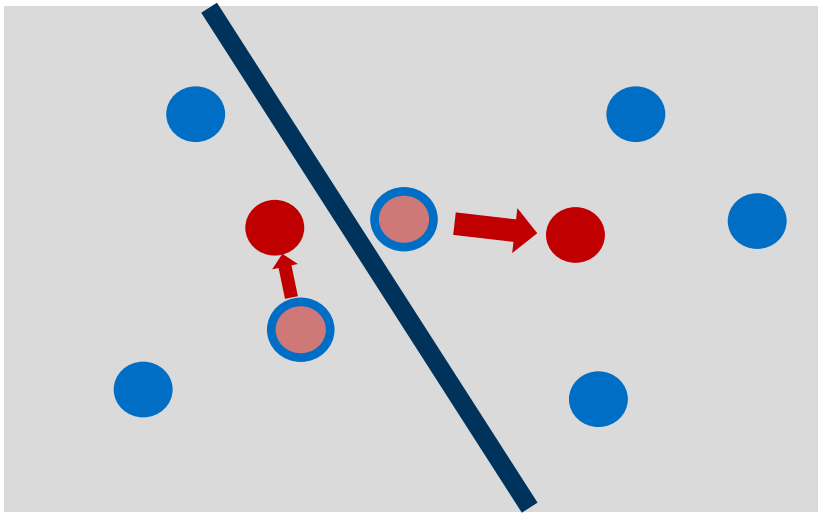


2. Random selection of the initial centroids

3. Assign the points to one of the clusters (minimum distance points – centroid)

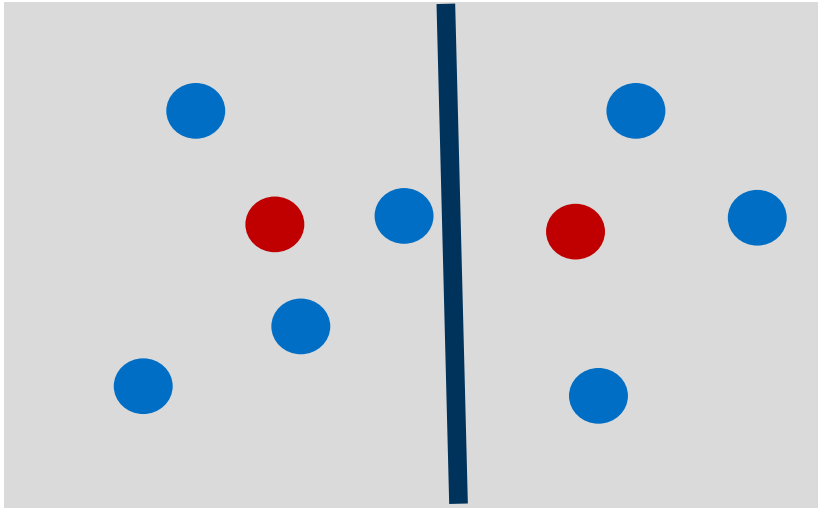


k-means for Controlled Islanding

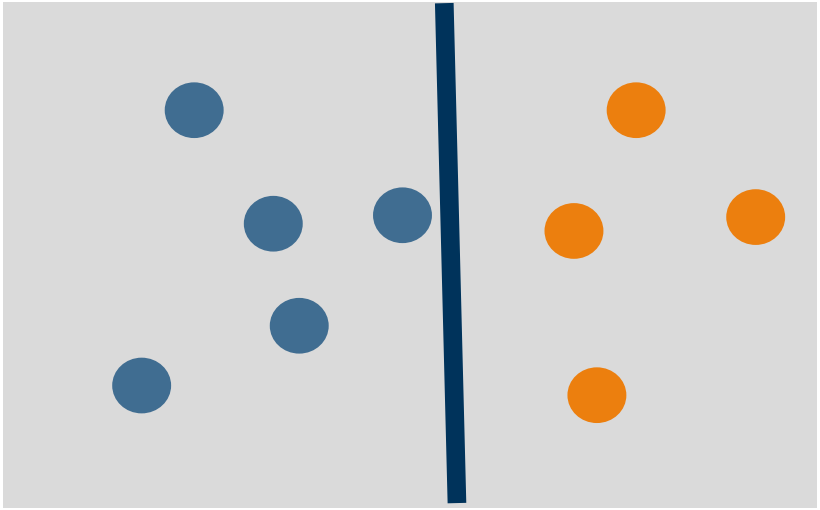


4. Move the centroid to the center of the cluster (min. distance centroid – set of points)

5. Assign the points to the clusters according to the new position of the centroid



k-means for Controlled Islanding



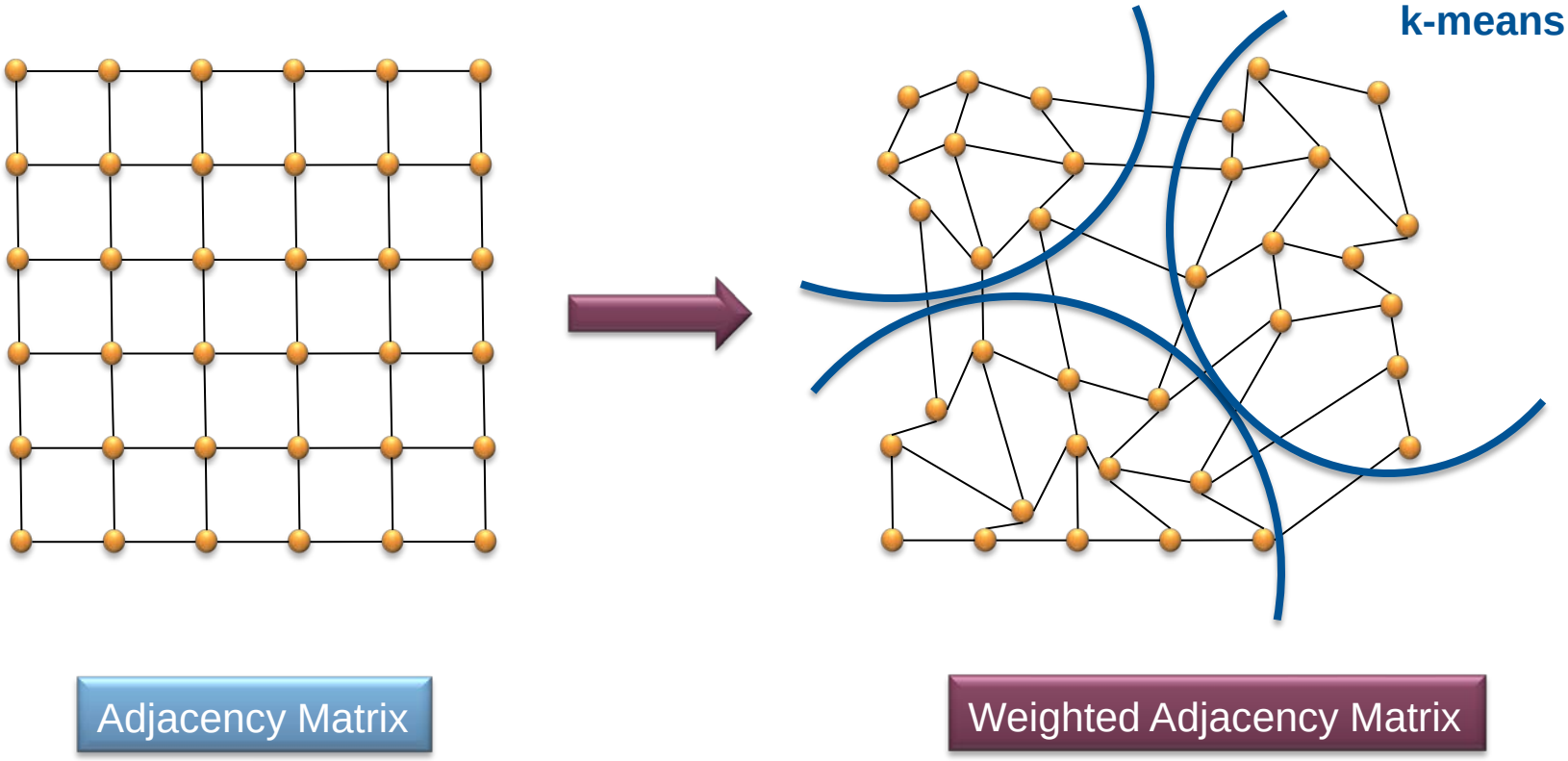
6. Repeat steps 4 and 5 until the clusters do not change

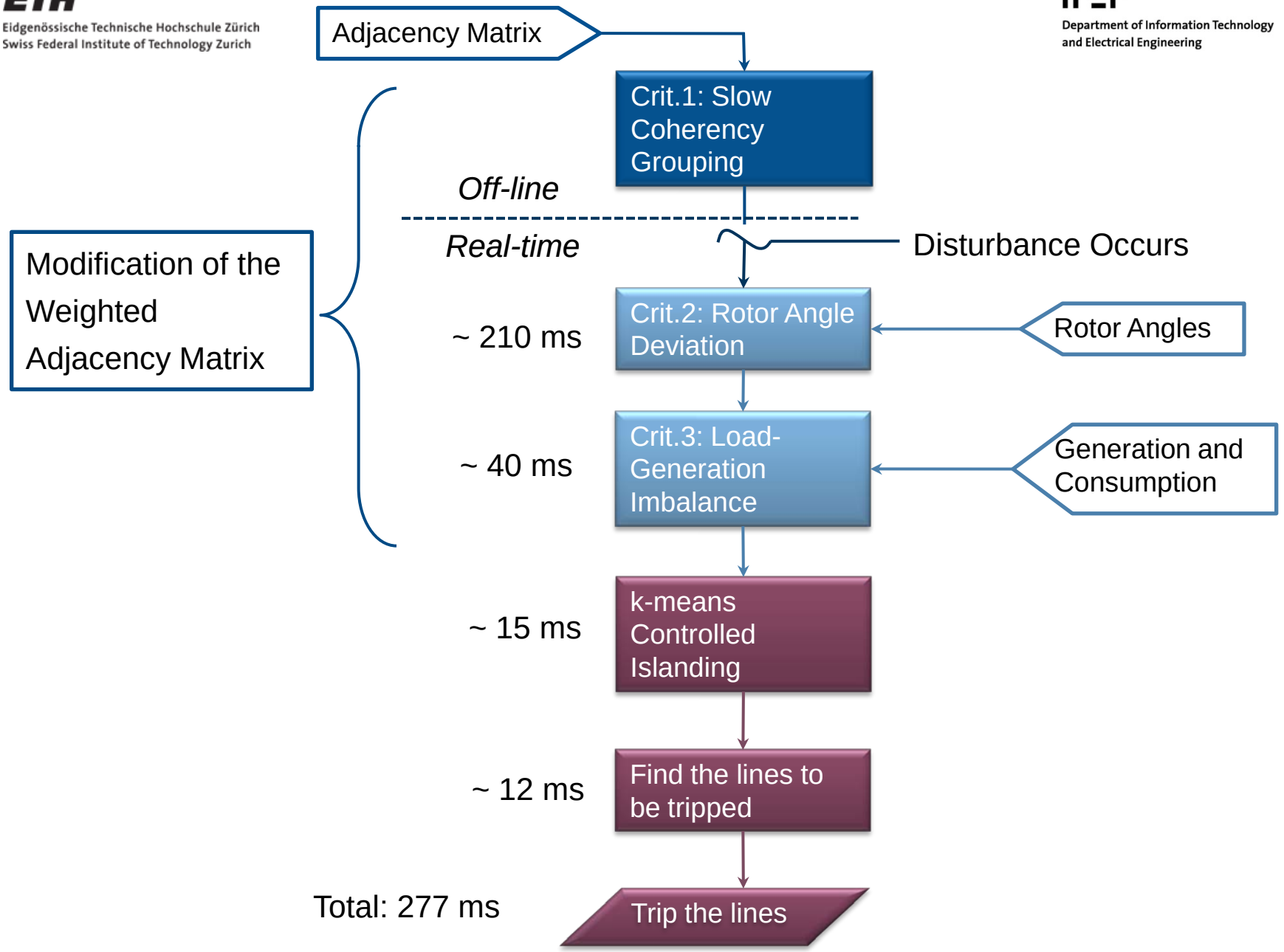
Criteria

- Coherent Generators
- Rotor Angles Deviation
- Load-Generation Imbalance

→ Goal: Transform e.g the rotor angle deviation between the nodes into *distances*

Distances according to Load-Generation Imbalance

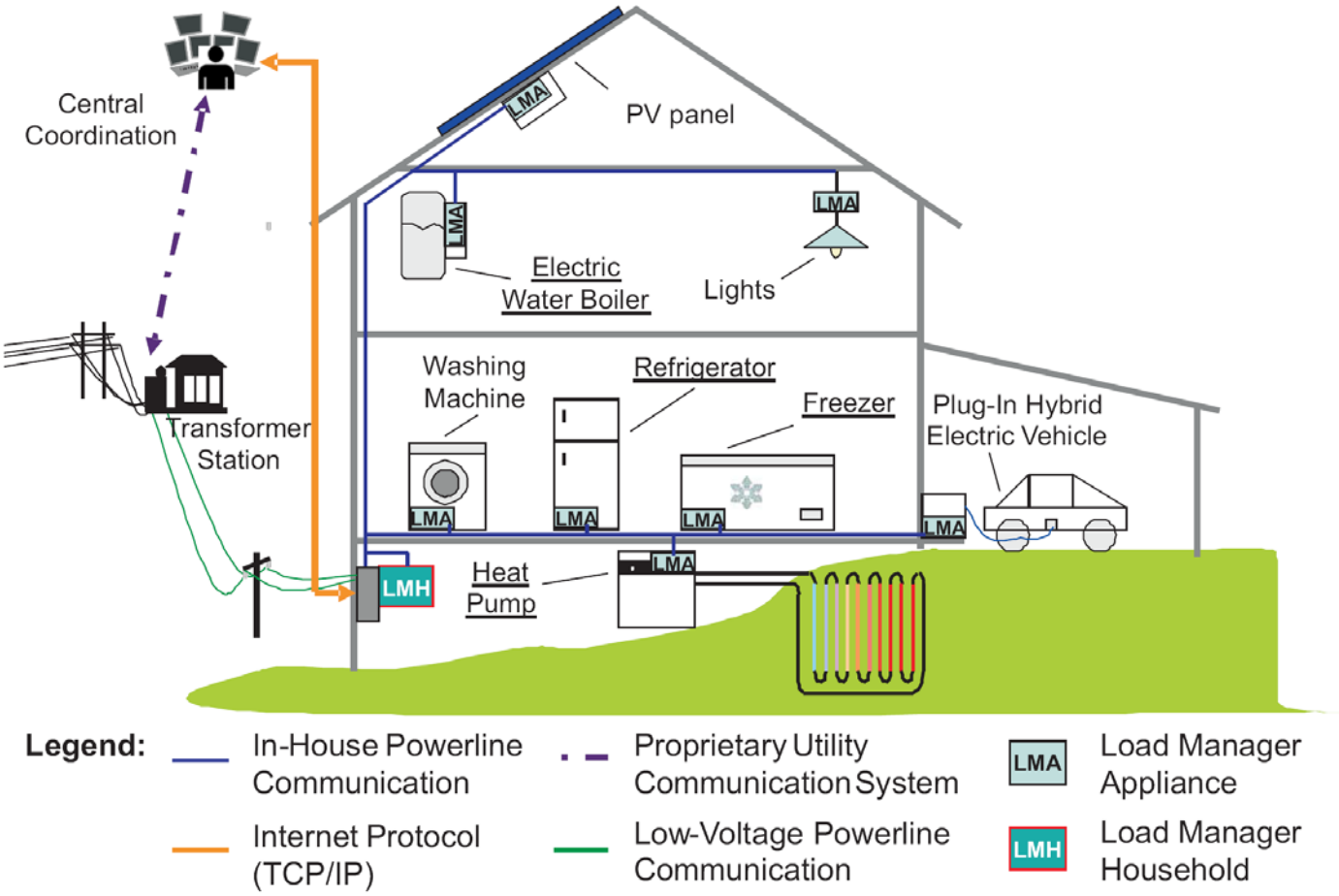



Adjacency Matrix
Crit.1: Slow Coherency Grouping
Off-line
Real-time
Disturbance Occurs
Modification of the Weighted Adjacency Matrix
~ 210 ms
Crit.2: Rotor Angle Deviation
Rotor Angles
~ 40 ms
Crit.3: Load-Generation Imbalance
Generation and Consumption
~ 15 ms
k-means Controlled Islanding
~ 12 ms
Find the lines to be tripped
Total: 277 ms
Trip the lines

- Advantages of the k-means controlled islanding
  - Fast (real-time)
    - less than 300 ms for the IEEE 118-bus system
  - Adaptive
    - can take into account intermittent generation
  - Modular
    - different criteria can be incorporated

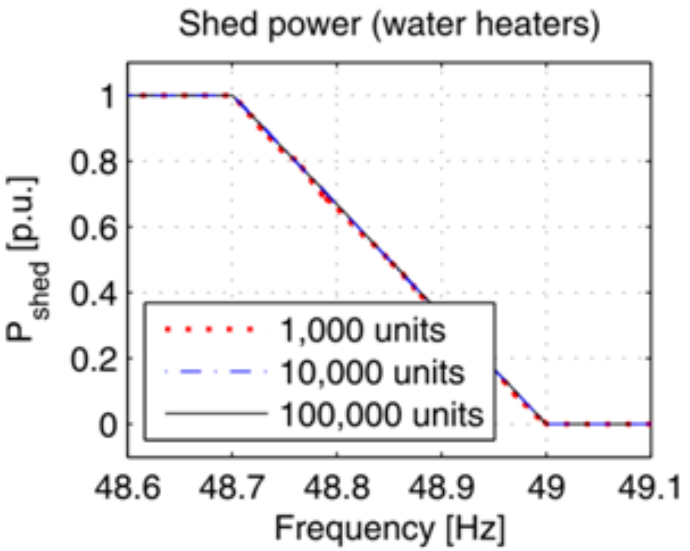
- But, performance depends on:
  - The number of islands
  - The setting of parameters for the weight modification of the adjacency matrix
  - The initial set of centroids

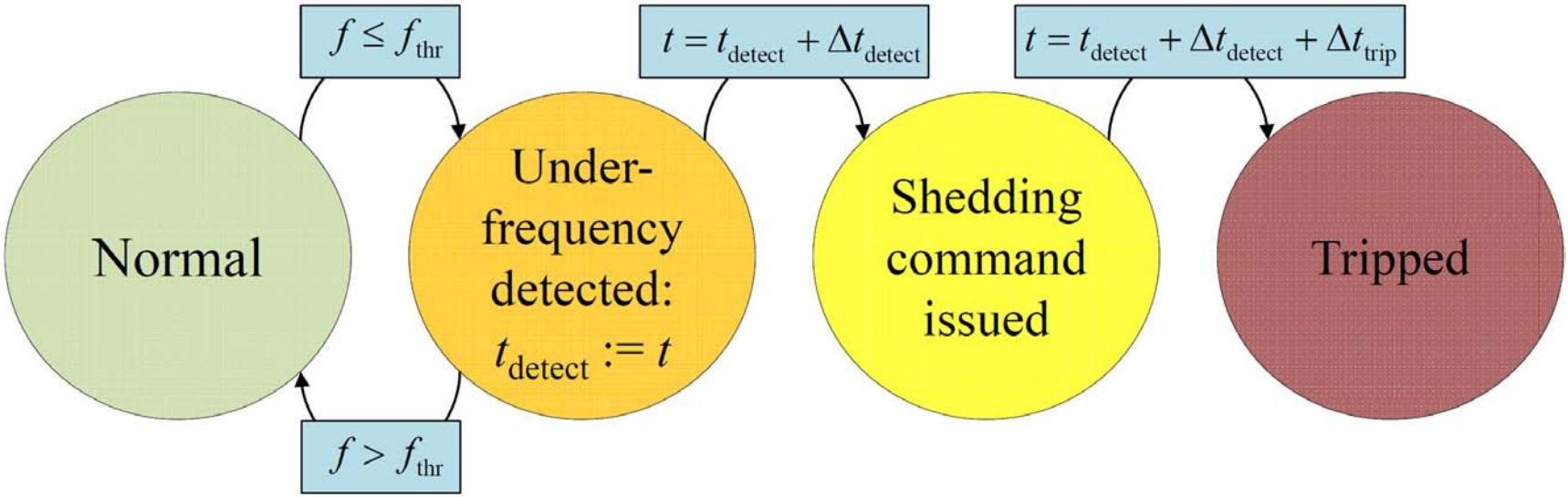
Customer – Level Load Shedding



Main Characteristics

- Clustering according to the function of the appliances
- Centralized off-line computation of the thresholds
- De-centralized on-line reaction, based on frequency only
- Ramp-wise Load Shedding (uniform random values)
- Co-existence with the current load-shedding schemes

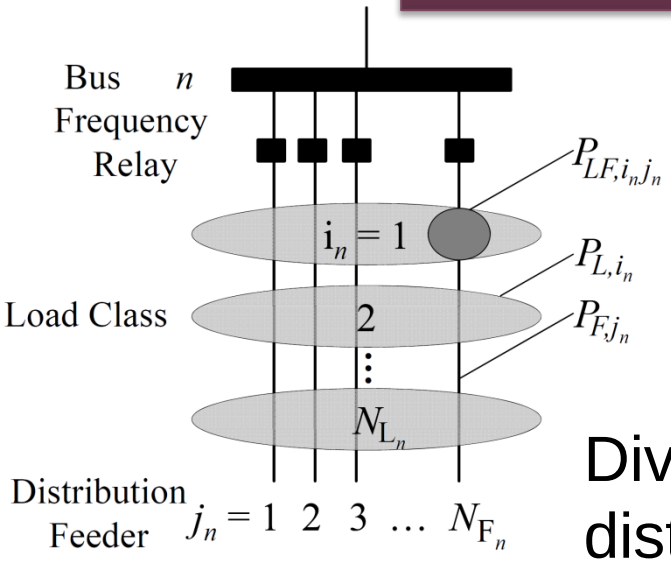




- Frequency thresholds and Detection & Tripping times must be given as input

Conventional Load Shedding	Customer-Level Load Shedding
Feeders → ON or OFF	Load Classes → ramp-wise
Starts at 49 Hz	Starts at 49.8 Hz
Ends at 48.1 Hz	Ends at 49.1 Hz
	Penetration Factor of controllable devices

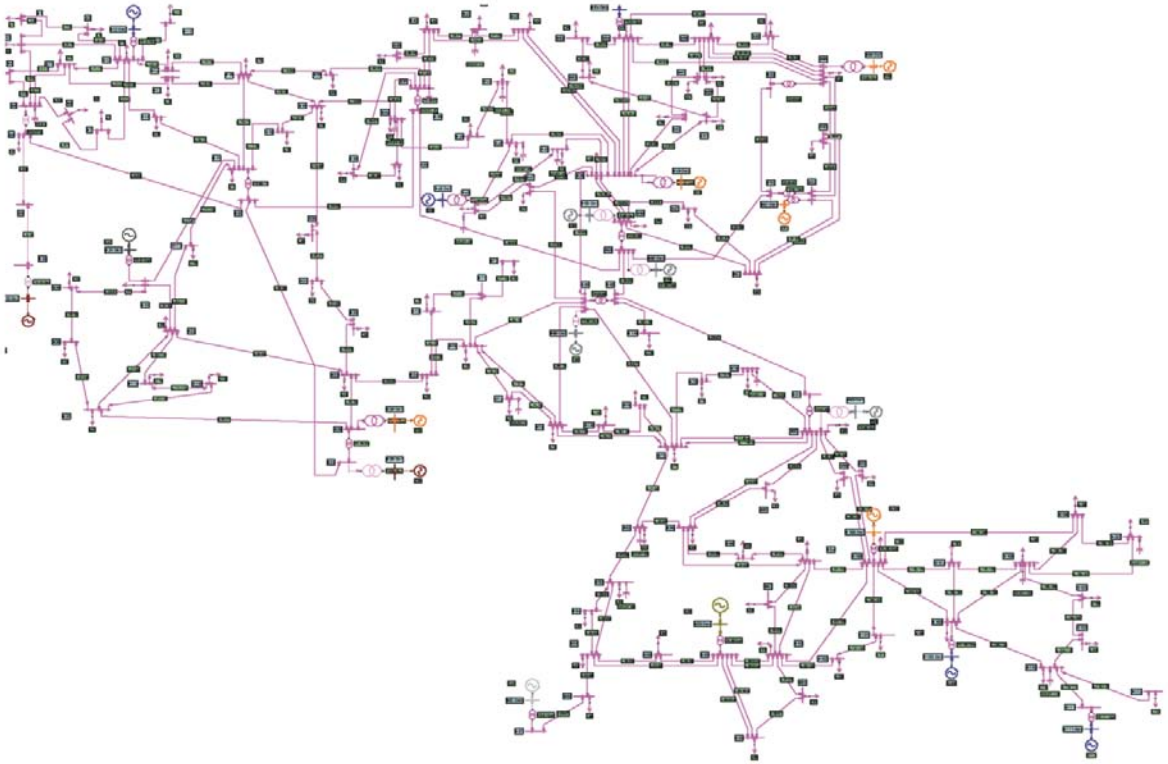
Both approaches are *combined*!



Division of buses into feeders and distribution of load classes

- Advantages of the Customer-Level Load Shedding
  - Acts earlier
    - Frequency deviates less
  - Sheds „interruptible“ loads
    - Smaller loss of comfort
  - Does not shed feeders
    - Intermittent generation can stay connected and help in the stabilization process
  - Is combined with the conventional load shedding strategies until a complete replacement of conventional load shedding can be realized

IEEE 118 bus dynamic model



- Dynamic Modelling of the Generators
- Primary Frequency Controllers
- AVRs
- Voltage dependency of the loads
- Load Shedding Underfrequency Relays

- Model in Neplan® and Matlab®

Four Case Studies

1. Only Conventional Load Shedding

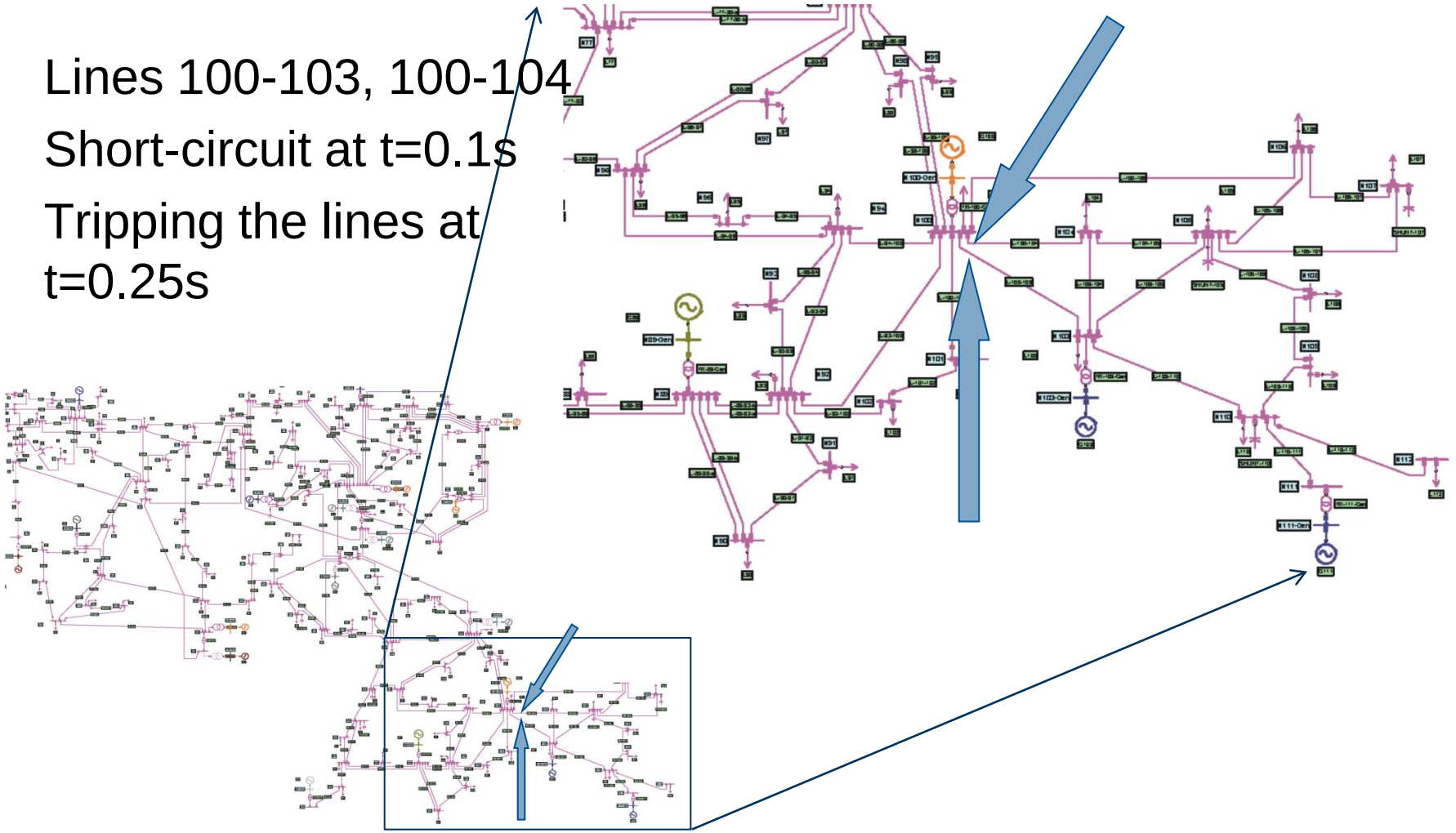
2. k-means Controlled Islanding and Conventional Load Shedding

3. k-means Controlled Islanding, Customer-Level Load Shedding and Conventional Load Shedding

4. k-means Controlled Islanding, Customer-Level Load Shedding and *modified* Conventional Load Shedding

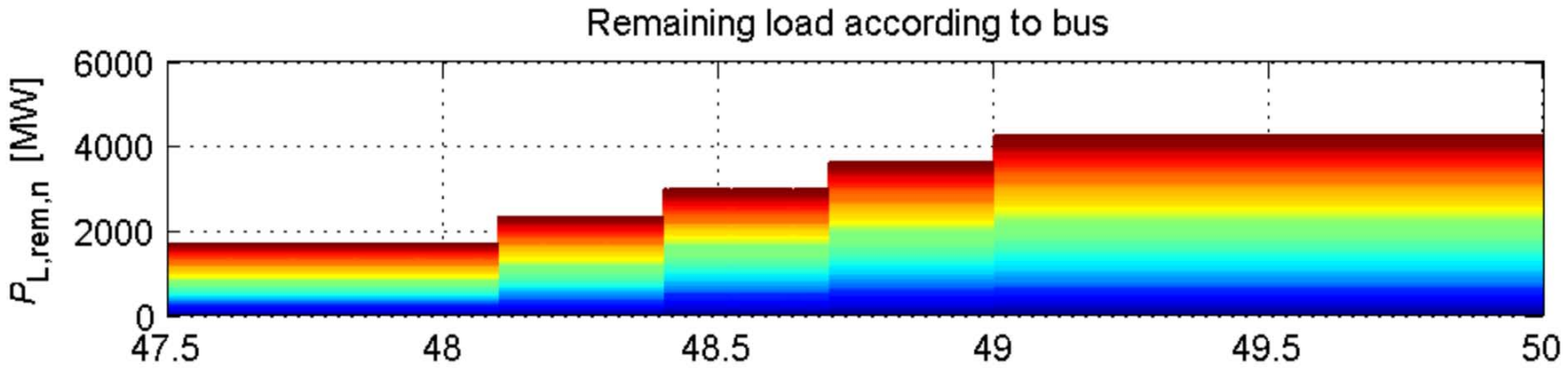
Disturbance

- Lines 100-103, 100-104
- Short-circuit at t=0.1s
- Tripping the lines at t=0.25s

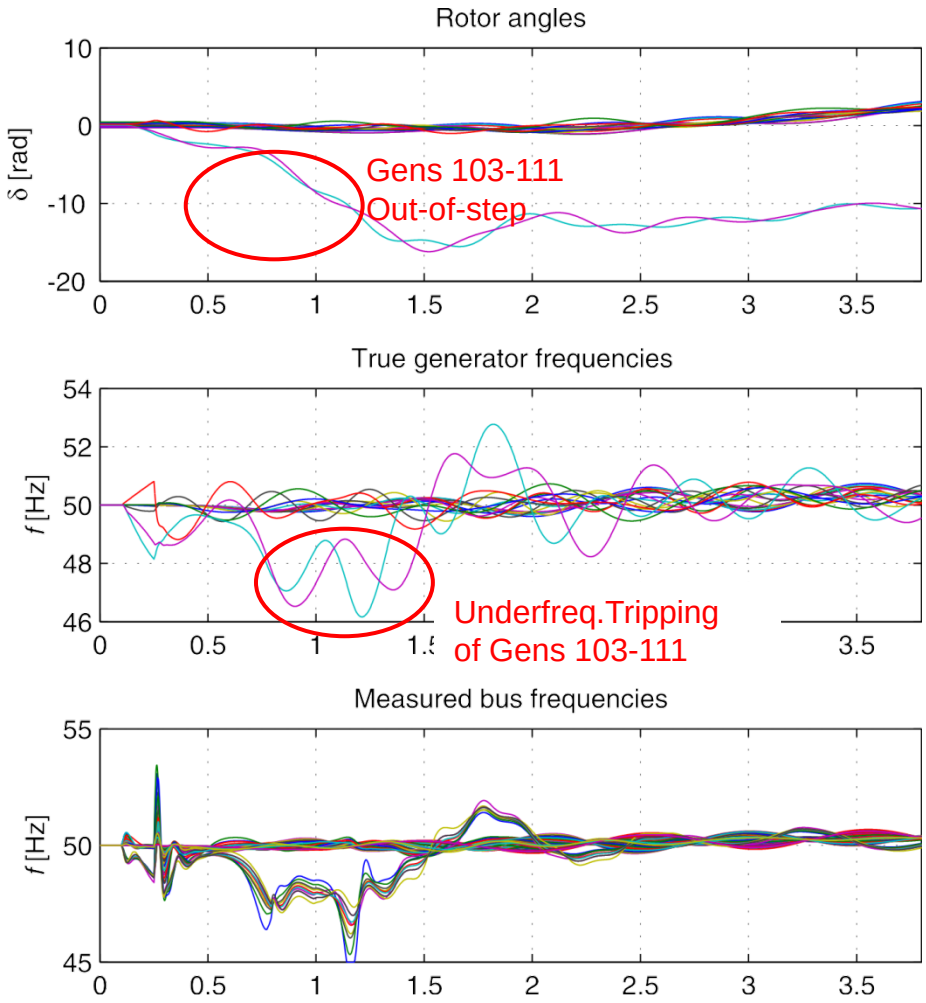


Case 1: Only Conventional Load Shedding

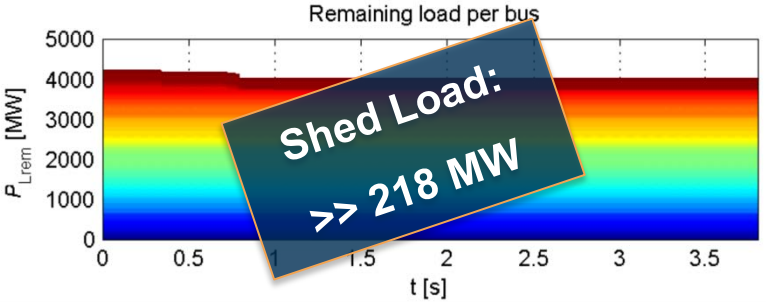
Threshold	Detection Delay	Tripping Delay	% Shed
49.0 Hz	0.10 s	0.05 s	15 %
48.7 Hz	0.10 s	0.05 s	15 %
48.4 Hz	0.10 s	0.05 s	15 %
48.1 Hz	0.10 s	0.05 s	15 %
		Total:	60%

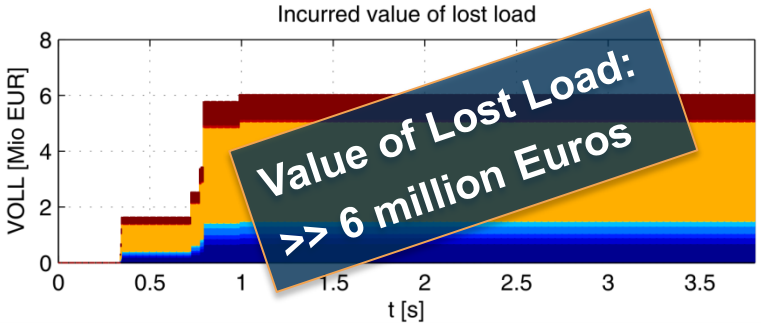


Case 1: Only Conventional Load Shedding



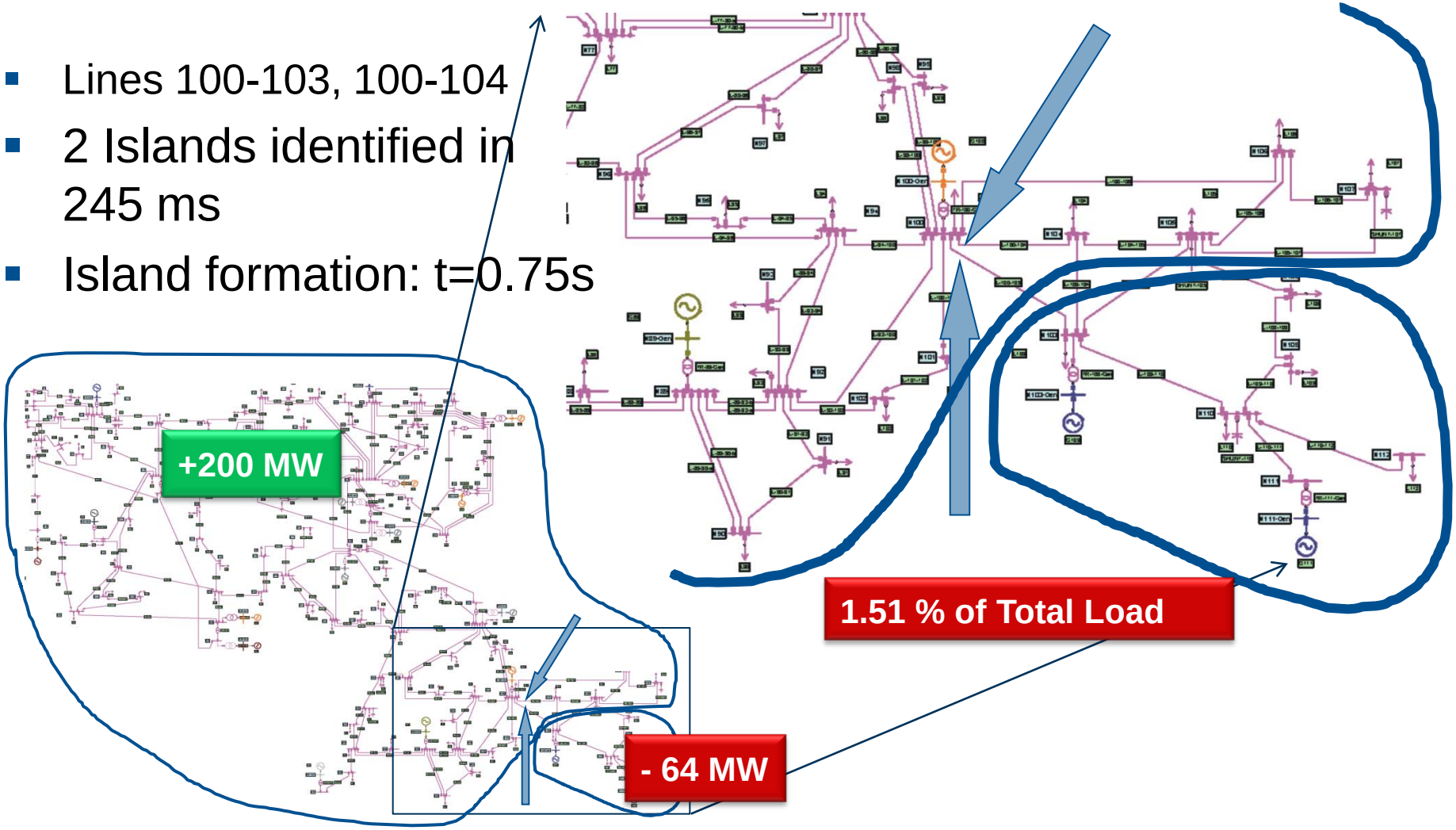
- Generator Tripping:
  Gens 103, 111
  < 47.5 Hz



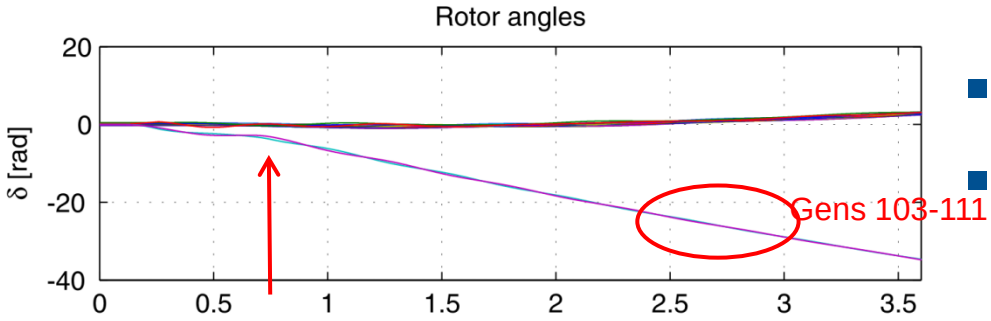


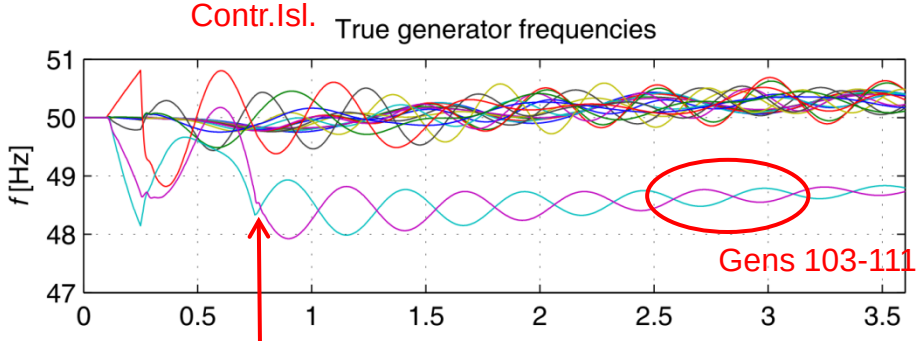
Controlled Islanding (Cases 2, 3, 4)

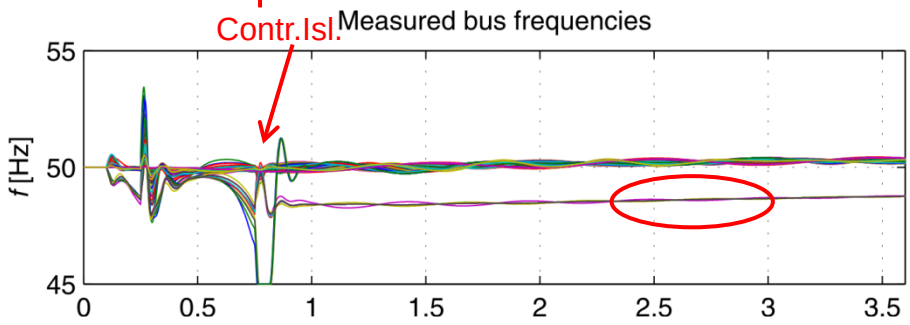
- Lines 100-103, 100-104
- 2 Islands identified in 245 ms
- Island formation: t=0.75s



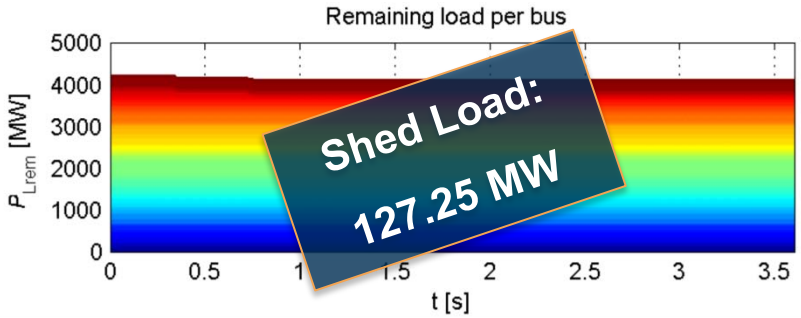
Case 2: Controlled Islanding and Conventional Load Shedding

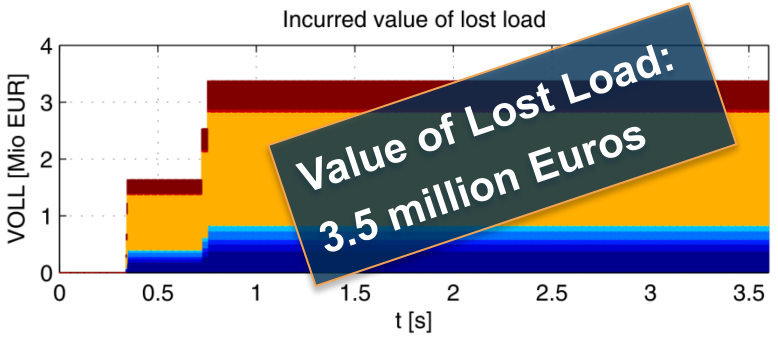






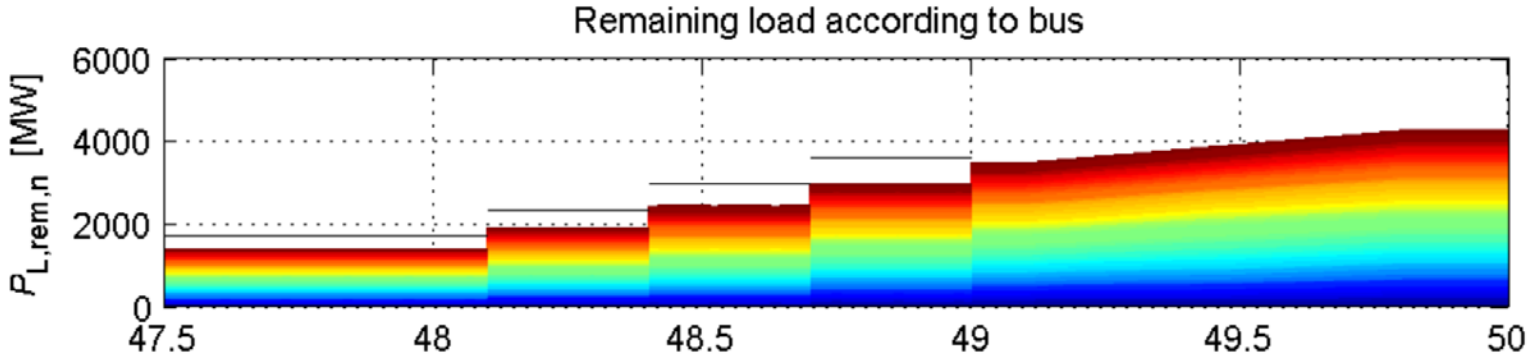
- No generator tripping
- >1 Hz deviation



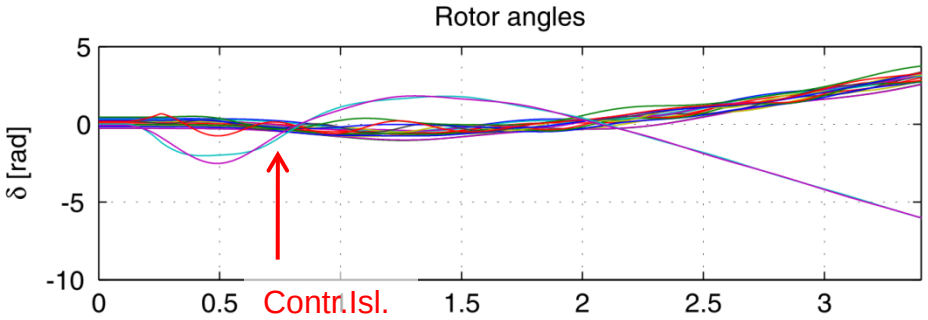


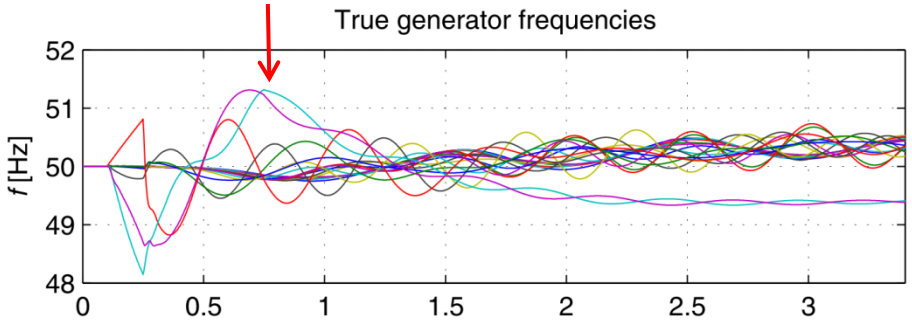
Customer Level Load Shedding (Cases 3, 4)

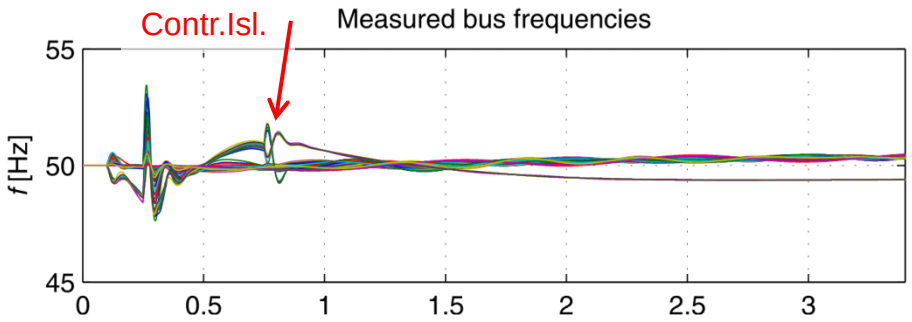
Controllable Loads	Frequency Thresholds	
	Ramp Start (Hz)	Ramp End (Hz)
Residential Heating	49.800	49.776
Residential Warm Water	49.776	49.664
Residential Cooling	49.664	49.487
Industrial Interruptible	49.487	49.449
Commercial Heating	49.449	49.304
Commercial Cooling	49.304	49.196
Residential Washing	49.196	49.100



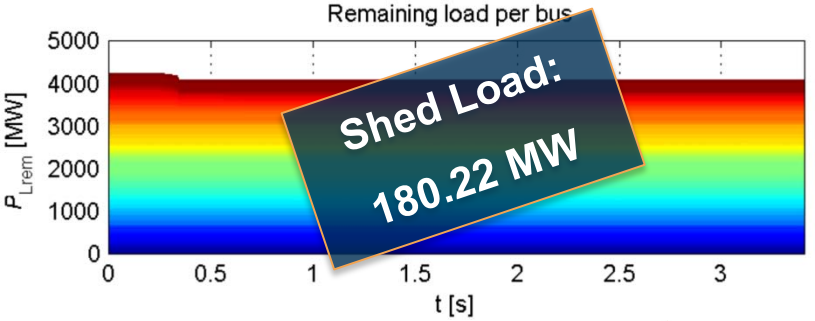
Case 3: Controlled Islanding, Customer-Level Load Shedding and Conventional Load Shedding

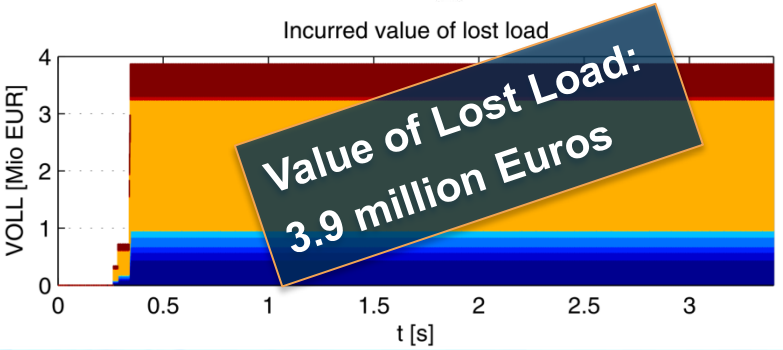




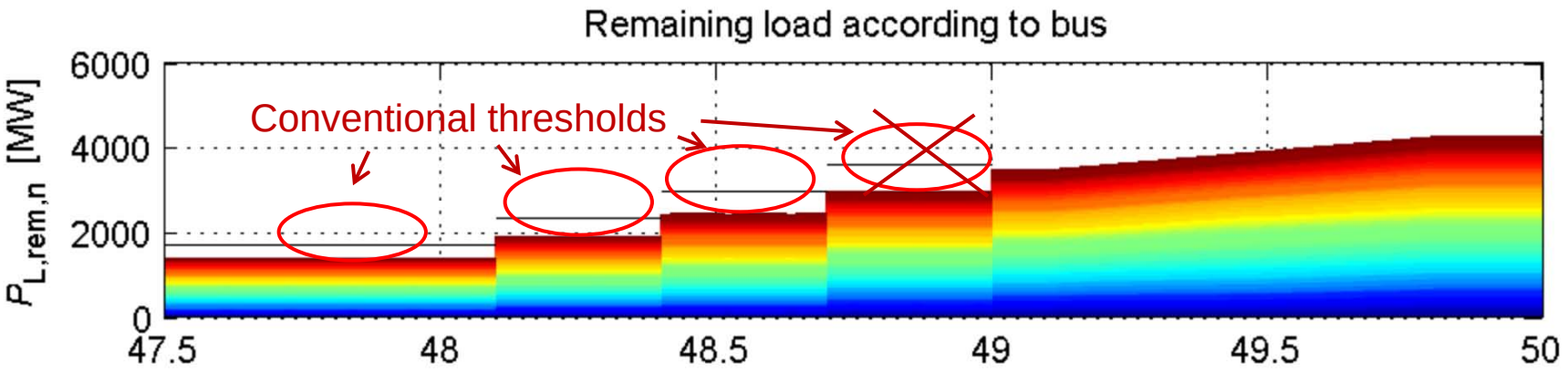


- ~0.6 Hz frequency deviation

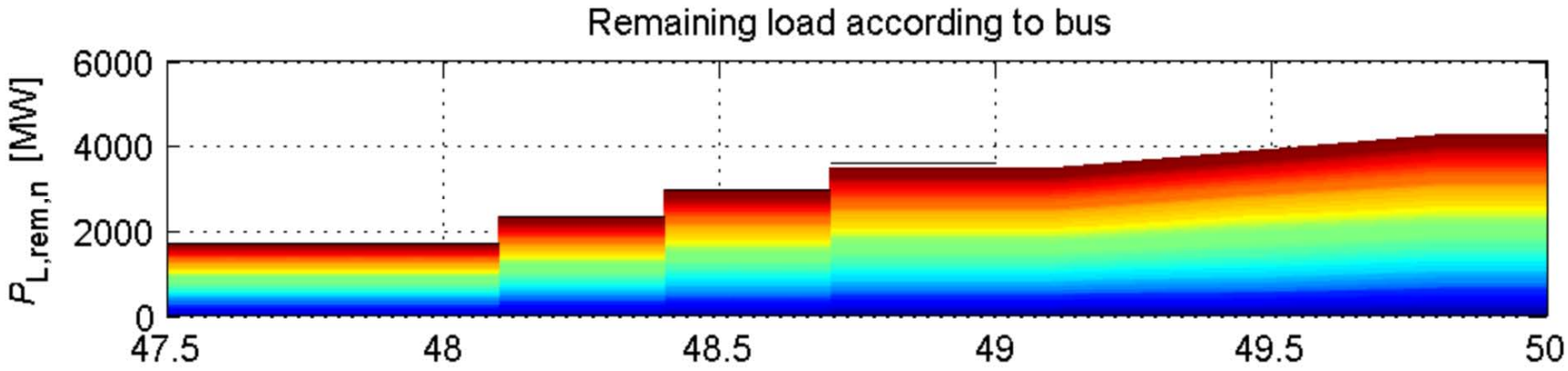




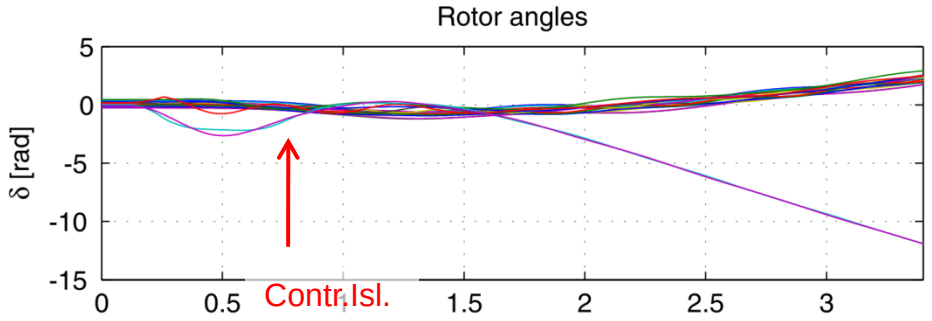
Case 3: Customer Level and Conventional Load Shedding

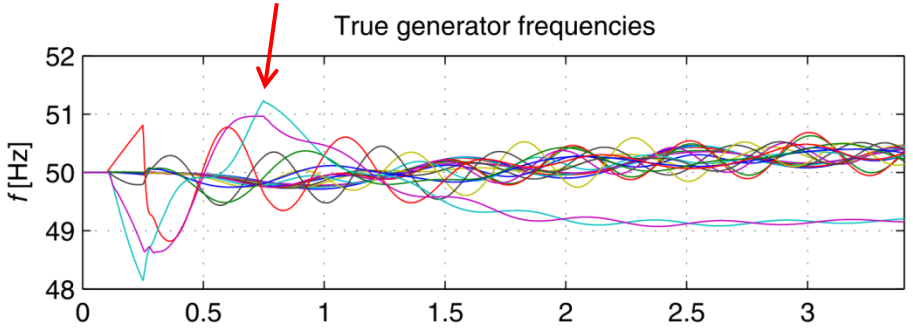


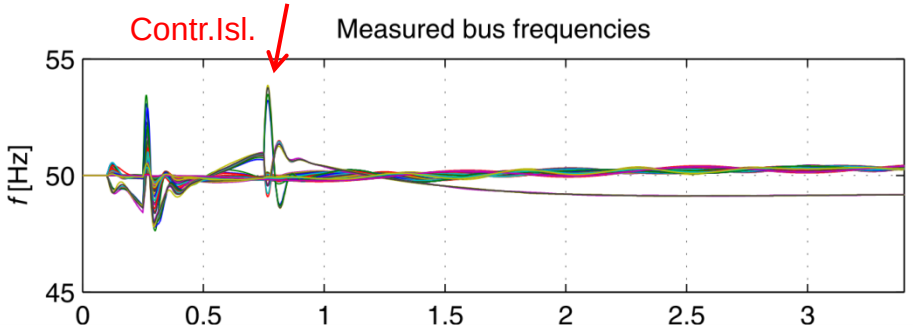
Case 4: Customer Level and *Modified* Conventional Load Shedding



Case 4: Controlled Islanding, Customer-Level Load Shedding and *modified* Conventional Load Shedding

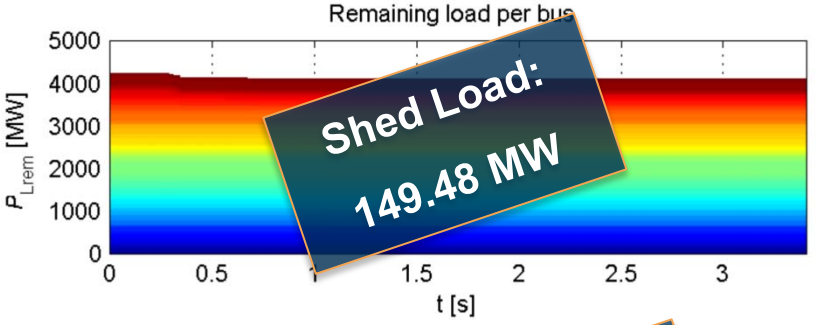


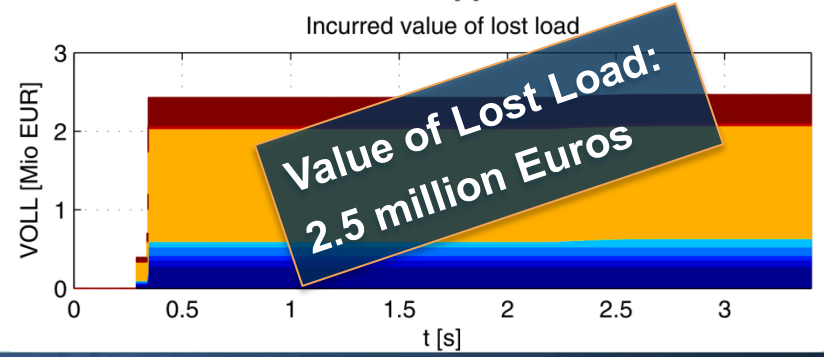




- Substantially smaller value of lost load

  (> 60% less than case 1)





Conclusions

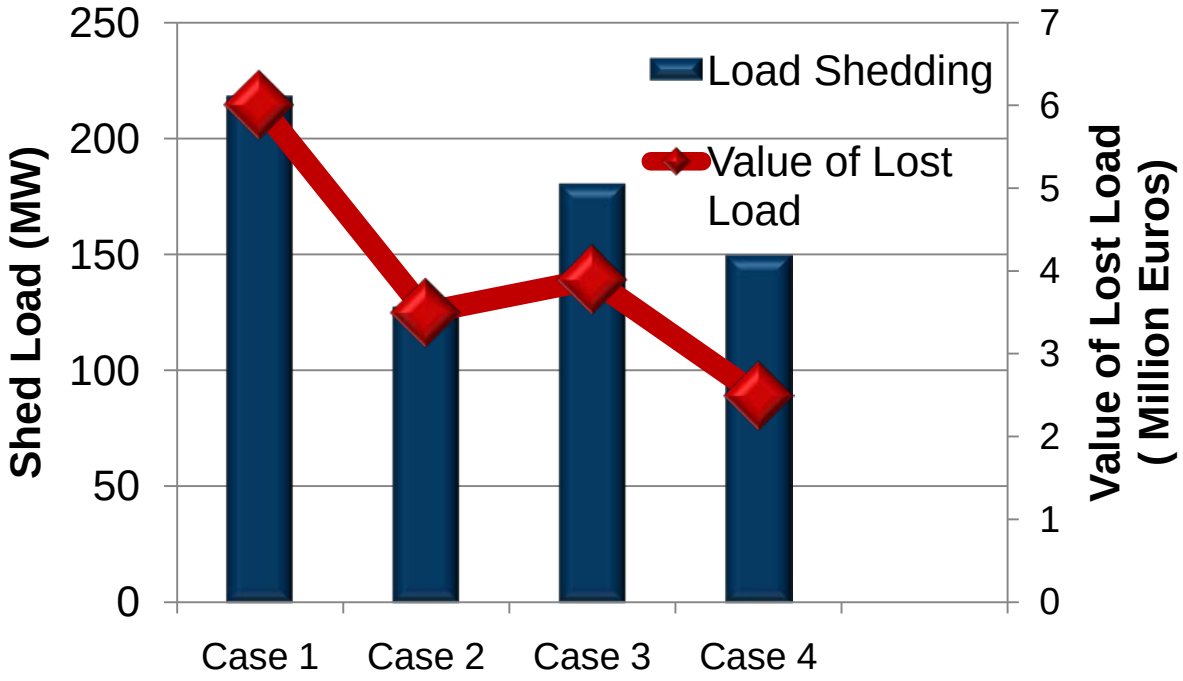
- k-means Controlled Islanding can potentially perform well in real-time

  → variable and intermittent generation can be taken into account

- Customer Level Load Shedding results in:

→ The Intermittent Generation feeders are not disconnected

→ Less Value of Lost Load



Acknowledgements

- Dr. Turhan Demiray
  - for his help and support in the implementation of the power system dynamic model.

- IRENE-40 EU-FP7 project: www.irene-40.eu

- VIKING EU-FP7 project: www.vikingproject.eu

Thank you!

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