University of Strathclyde

Validation of the EFCC scheme at the Power Networks Demonstration Centre (PNDC)

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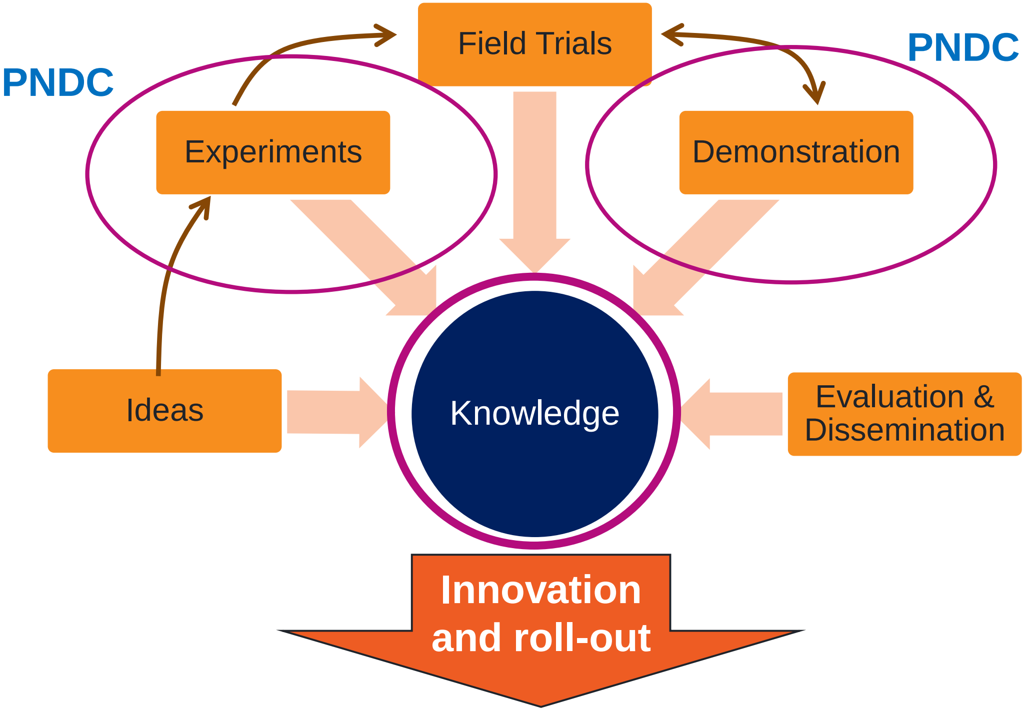
Overview

- Brief introduction to PNDC
- Role of PNDC in the testing of the EFCC scheme
- Testing configurations and test results
  - Wide area mode tests
  - Communication impact tests
  - Local mode tests
- Key learnings and findings
- Conclusions and future work

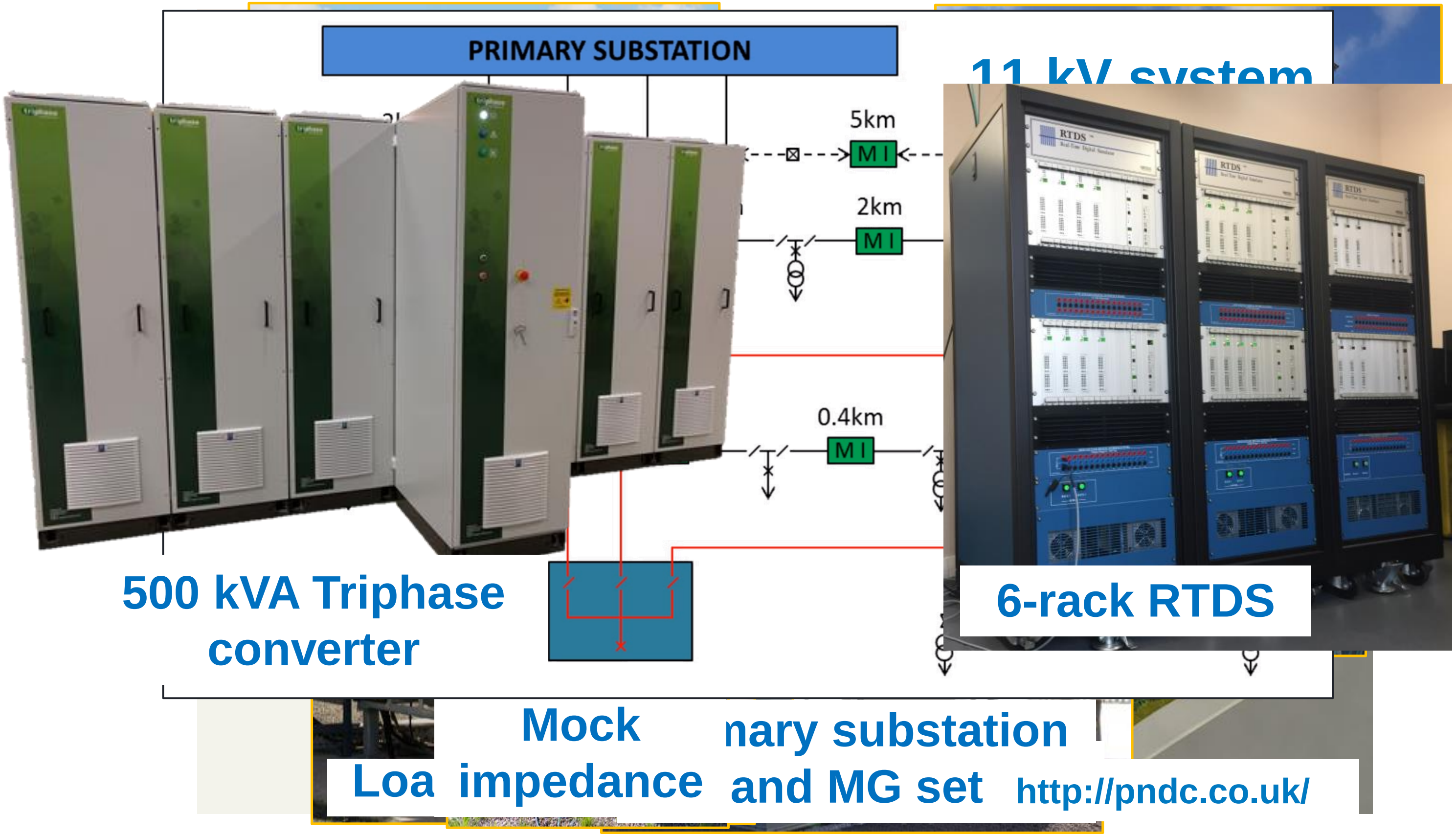


PNDC – what we do?

Provide a realistic and flexible platform for the accelerated testing of smart grid innovations

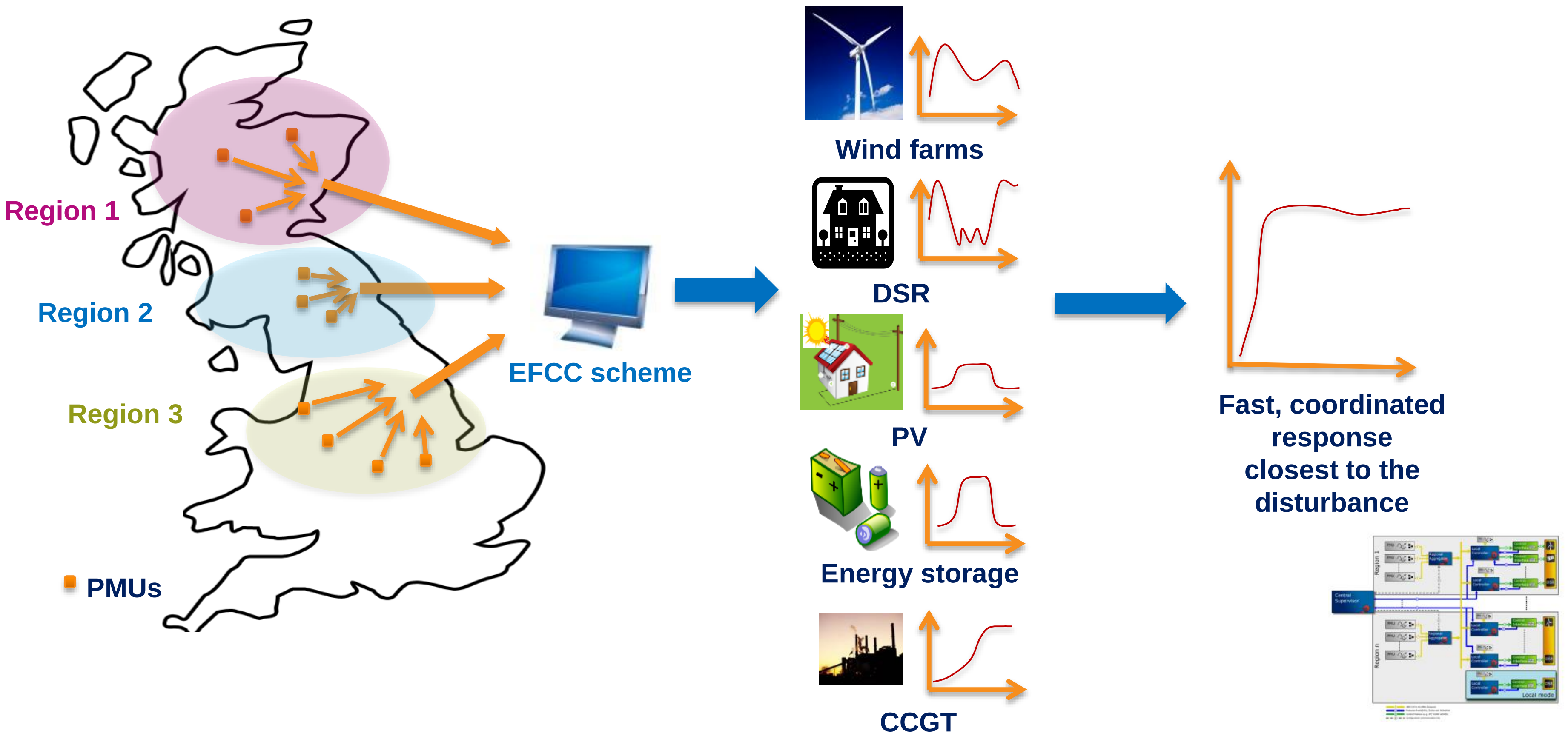


Main facilities at PNDC



http://pndc.co.uk/

Overview of the EFCC scheme



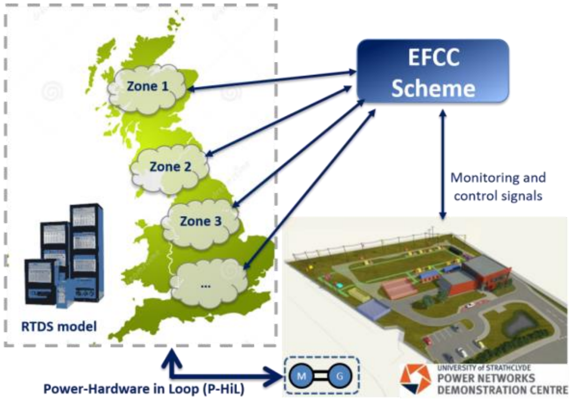
Role of PNDC in the EFCC project

Tests at the University of Manchester:

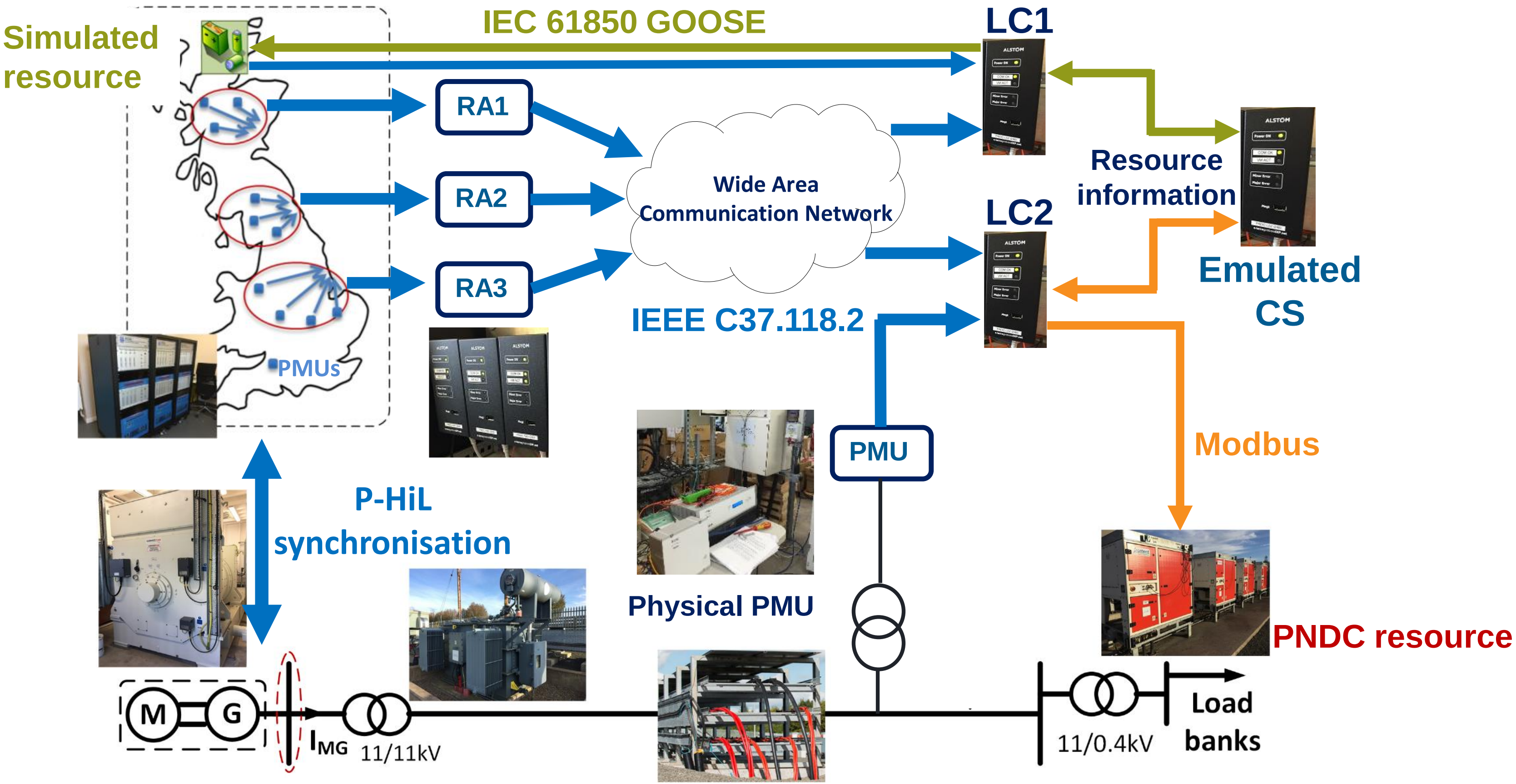
EFCC controllers connected to pure simulated signal sources

Tests at the University of Strathclyde (PNDC):

- Controllers interfaced with physical network and an actual PMU unit
- Both wide-area and local back up modes are tested
- Performance of the EFCC scheme evaluated under different communication quality conditions

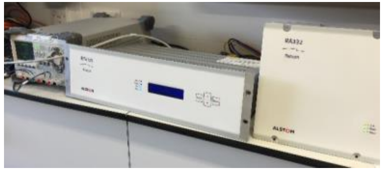


Wide area mode test setup:



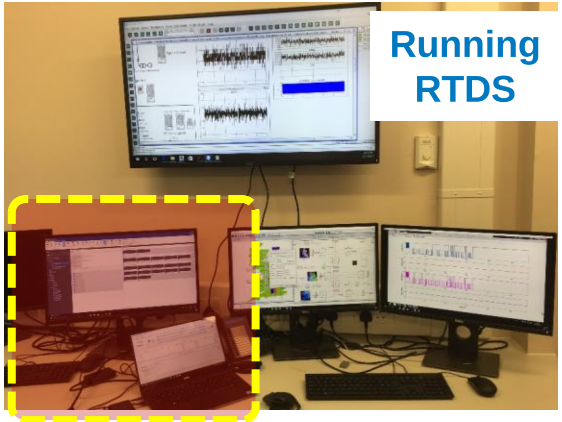
PNDC setup

EFCC controllers



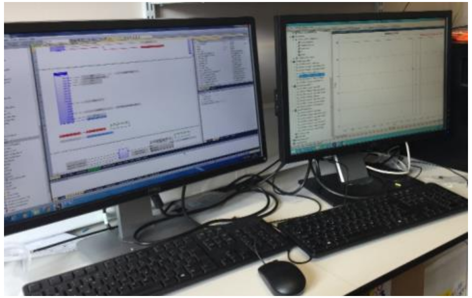
PMU

Injection using amplifier



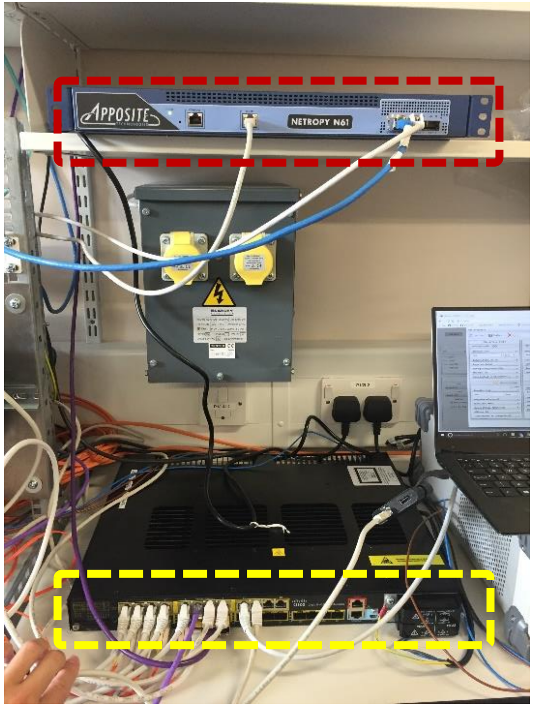
Running RTDS

Configuration using IEC 61850



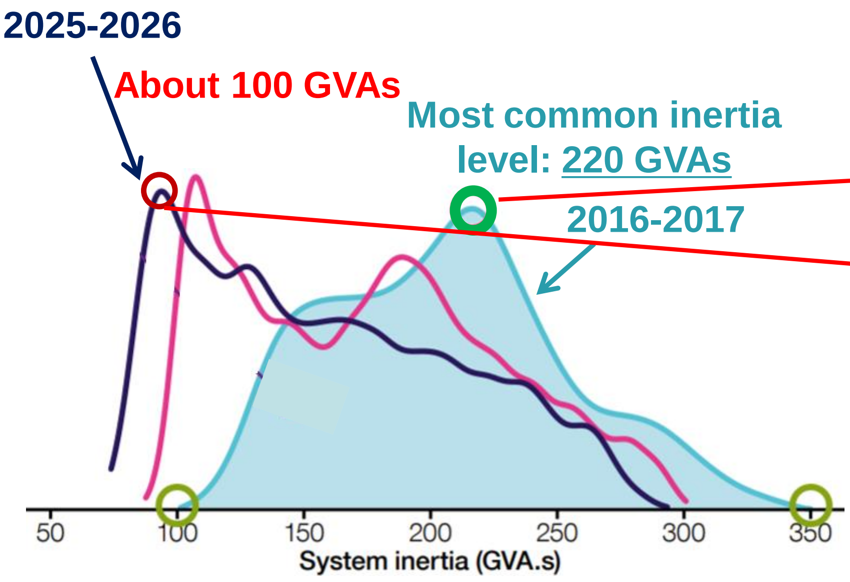
Straton and PhasorPoint

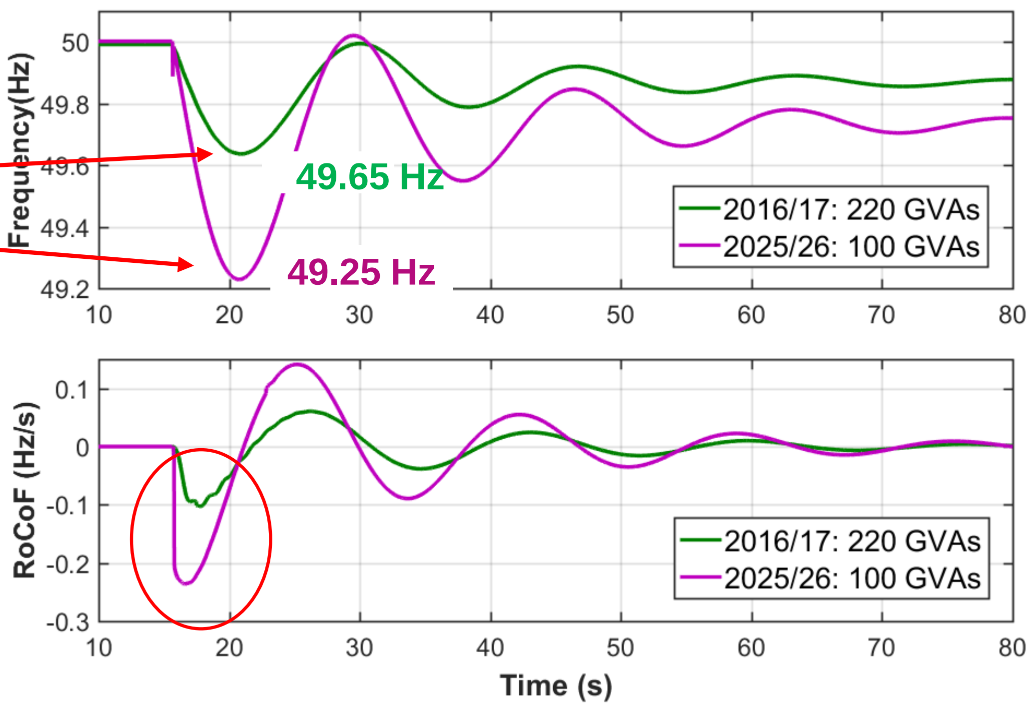
Communication emulator



Communication switch

Wide area mode test cases:





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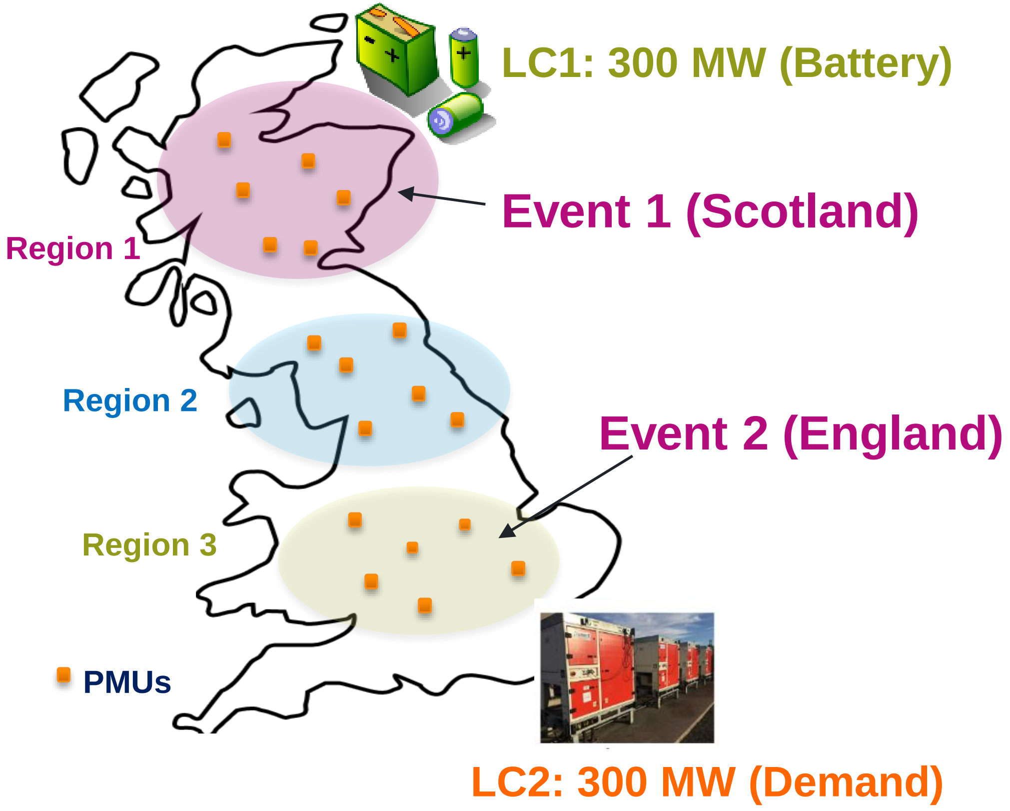
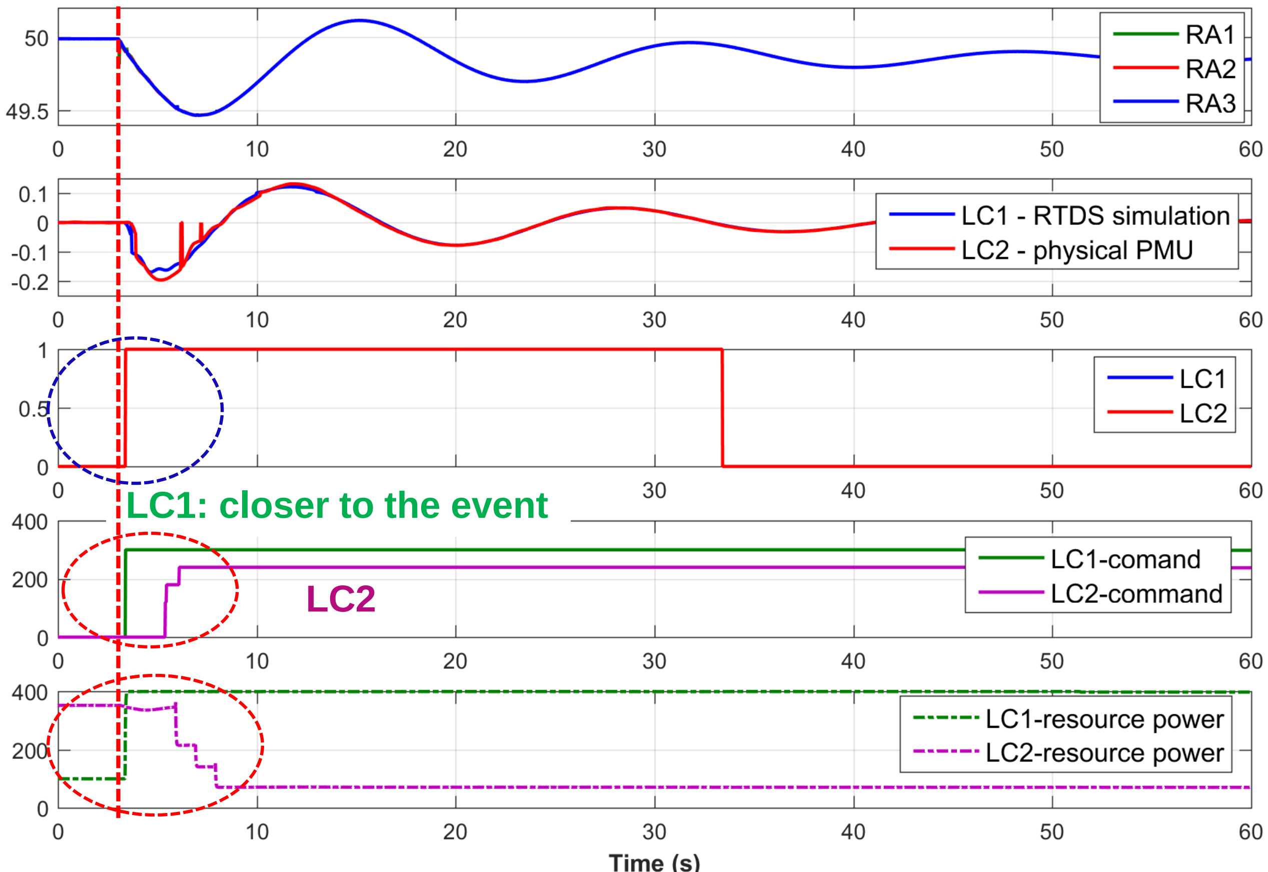
Wide area mode test cases:



- Inertia level: 100 GVAs
- Event: loss of generation
- Size: 1000 MW
- Testing effectiveness of fast frequency response from EFCC
- Evaluating EFCC’s response to events at different locations

Case 1: 1 GW loss, Region 1 (LC1 location), 100 GVAs



Frequency (Hz)

Local RoCoF (Hz/s)

Event detection

Power command (MW)

Resource Power (MW)

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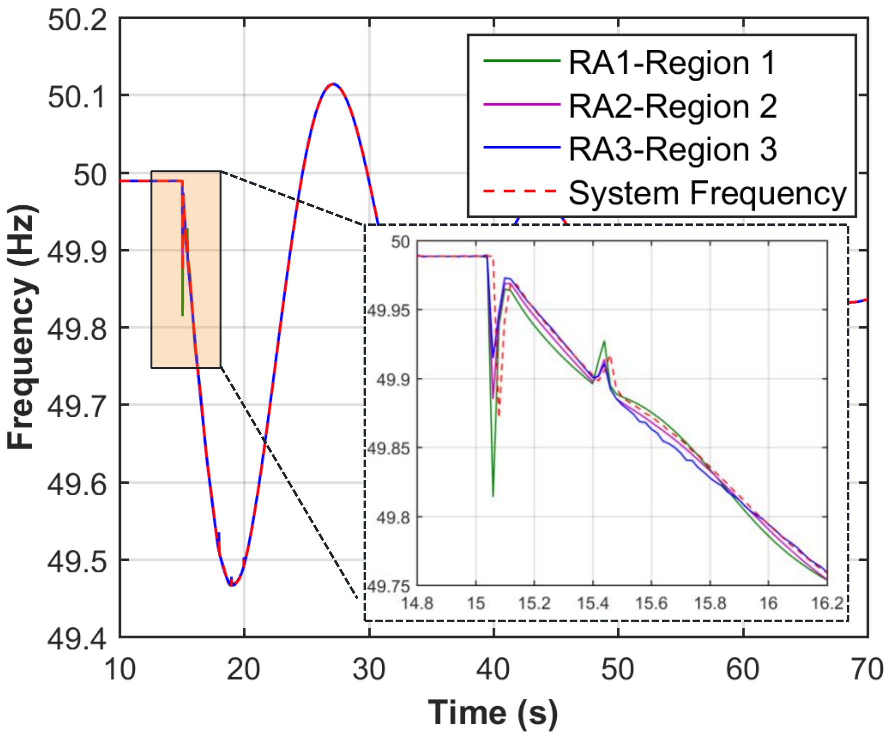
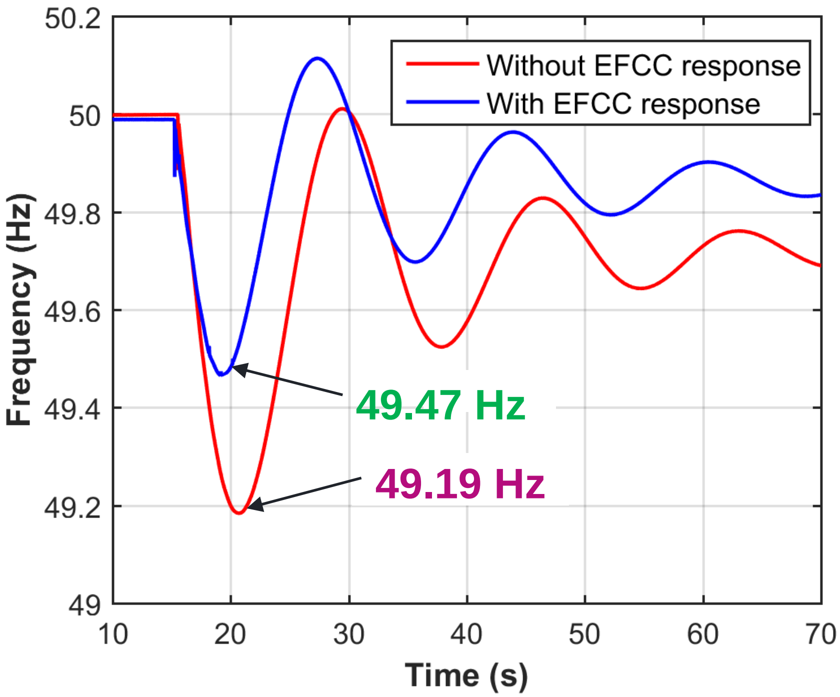
Case 1: 1 GW loss, Region 1 (LC1 location), 100 GVAs

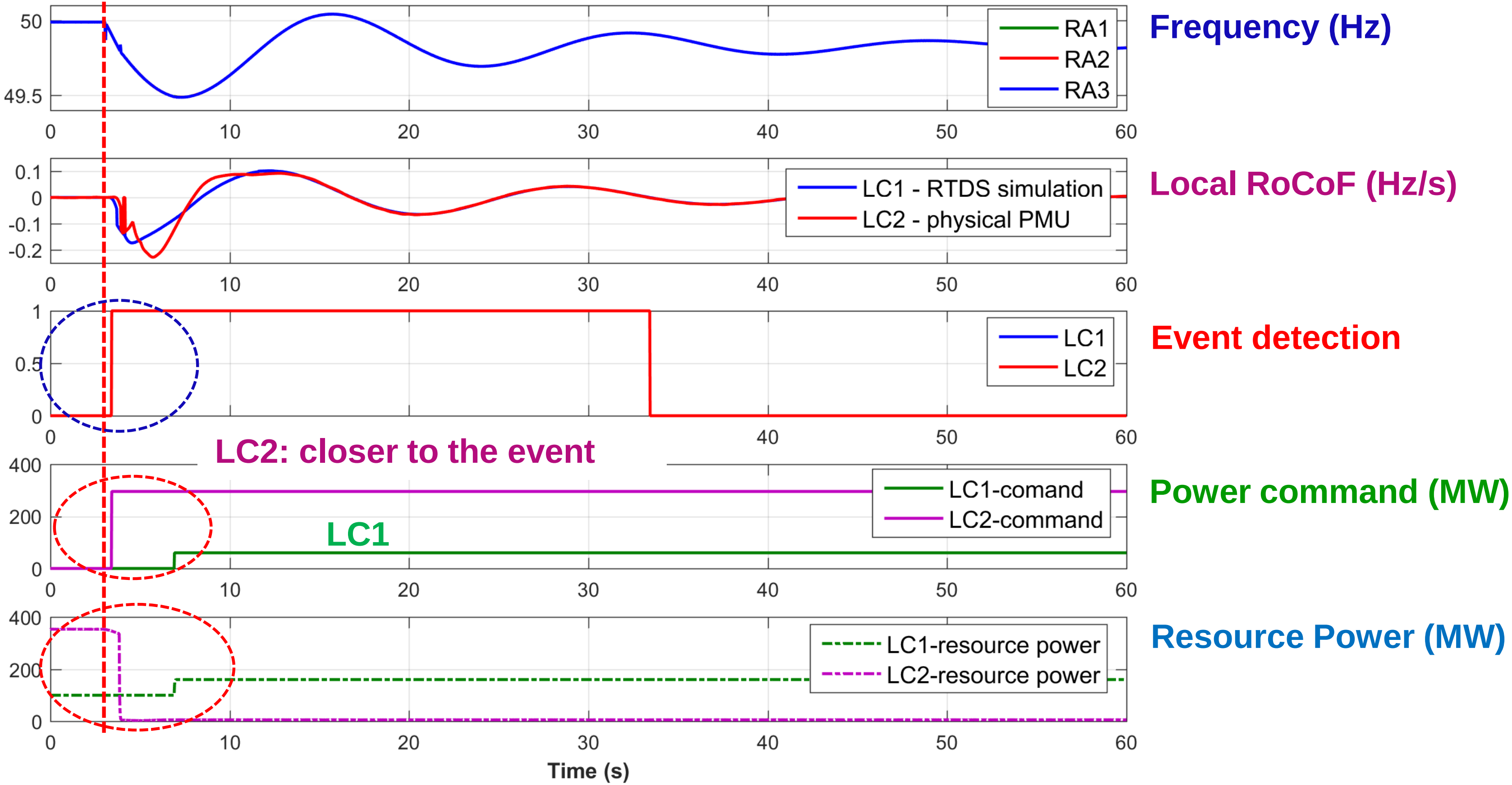


Frequency measured in RAs

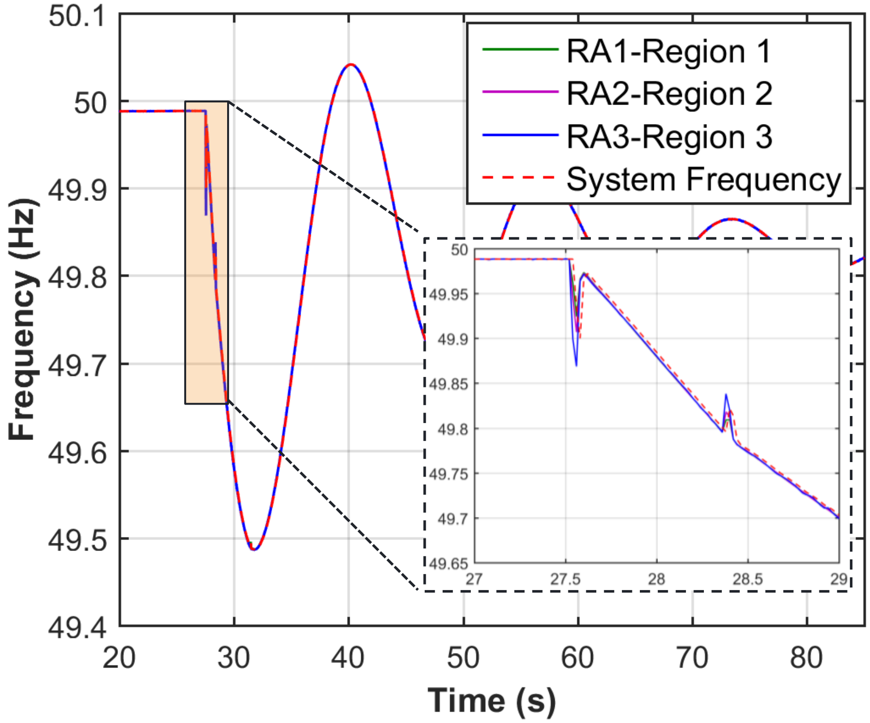


Comparison: with and without EFCC response

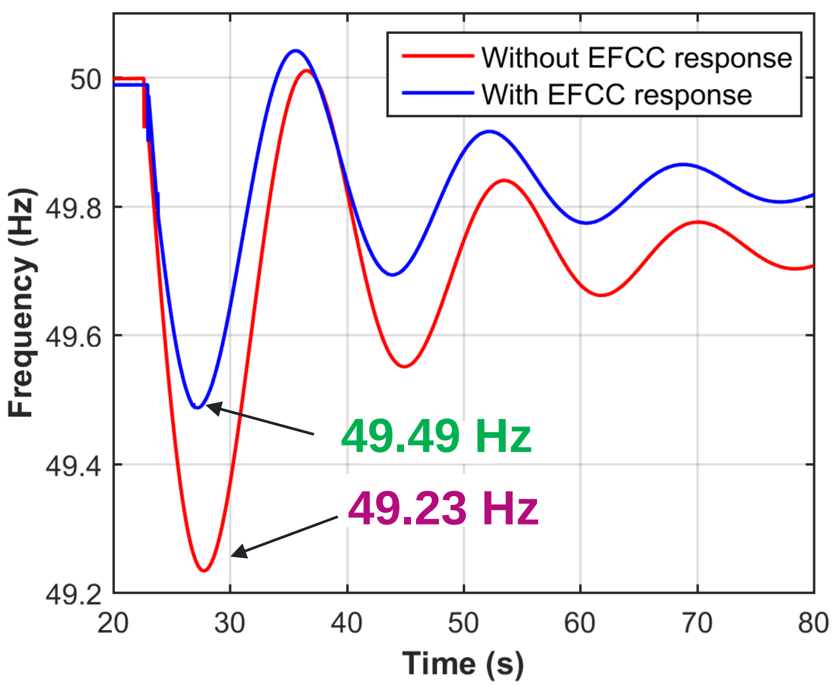
Case 2: 1 GW loss, Region 3 (LC2 location), 100 GVAs



Case 2: 1 GW loss, Region 3 (LC2 location), 100 GVAs



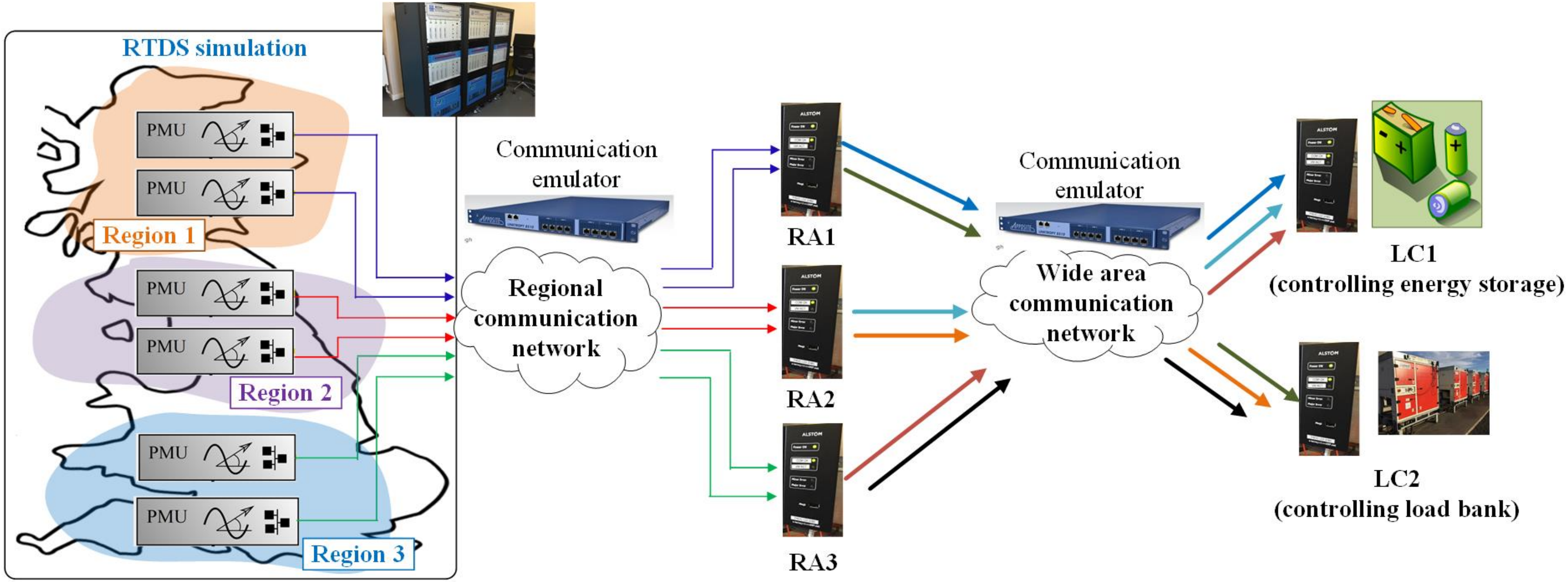
Frequency measured in RA



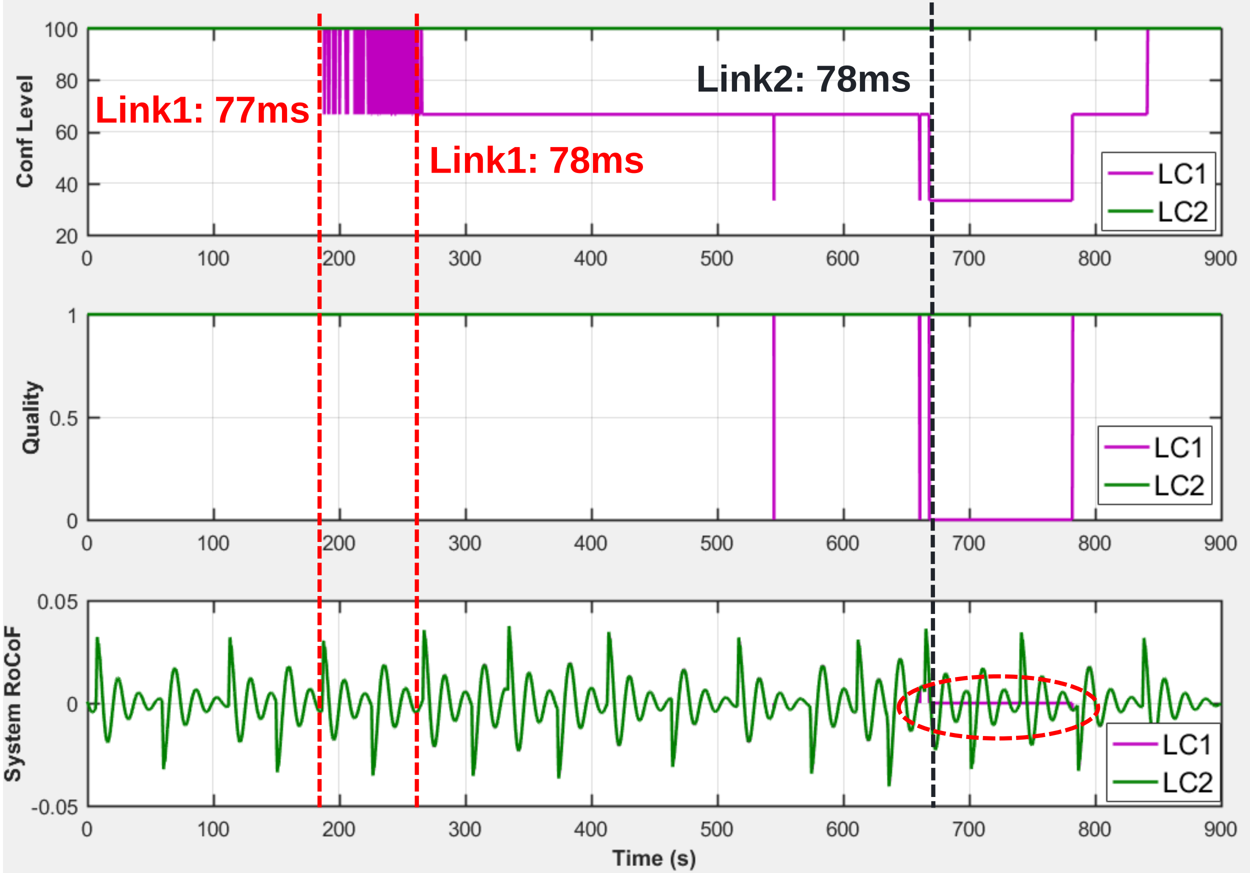
Comparison: with and without EFCC response

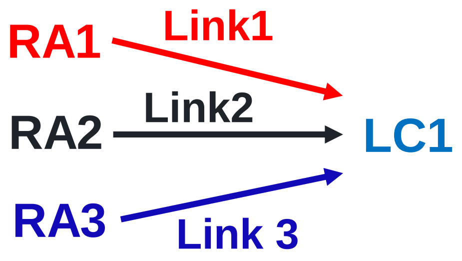
Communication tests

- Aimed at evaluating the impact of communication performance of the operation of the EFCC scheme
- EFCC tested under different levels of latency (delay), jitter (variation in delay), loss of packet, bit error rates, etc.



Impact of communication latency (delay)

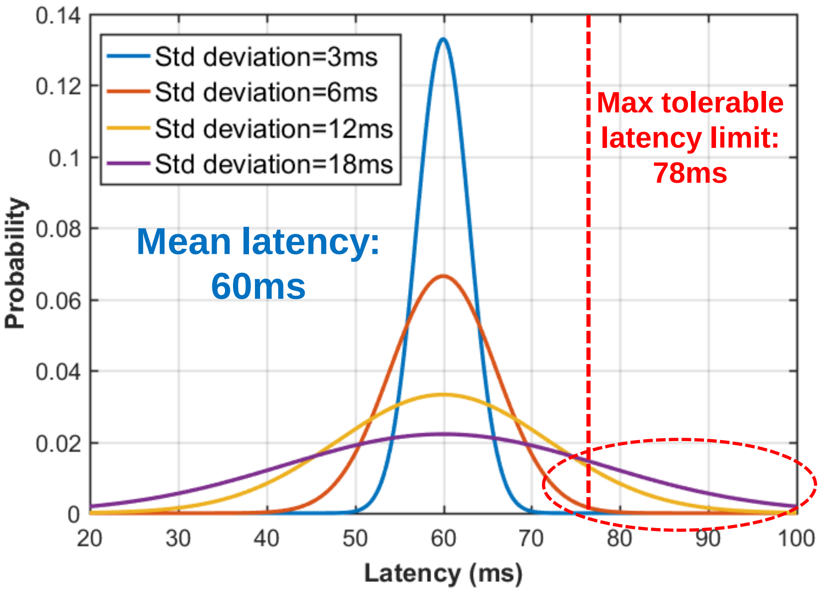




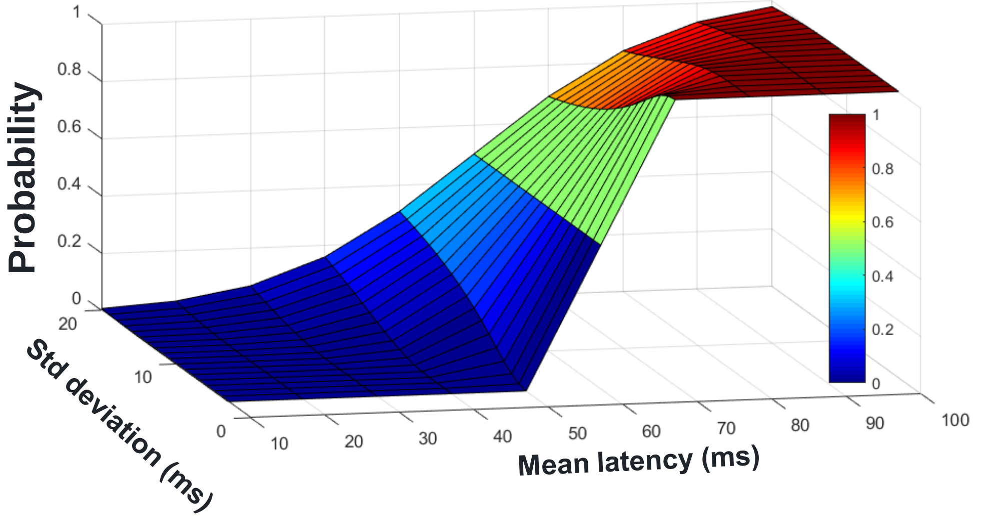
- Maximum tolerable latency 78ms for 100ms buffering window
- Latency larger than the limit will lead to packets being discarded, i.e. risking in loosing wide-area visibility

Impact of communication jitter

- Jitter is the change in communication delay
- Higher jitter levels could lead to higher risks of the violating maximum tolerable latency limit



Normal distribution of latency level



Probability of latency larger than the max limit

Latency with jitter tests

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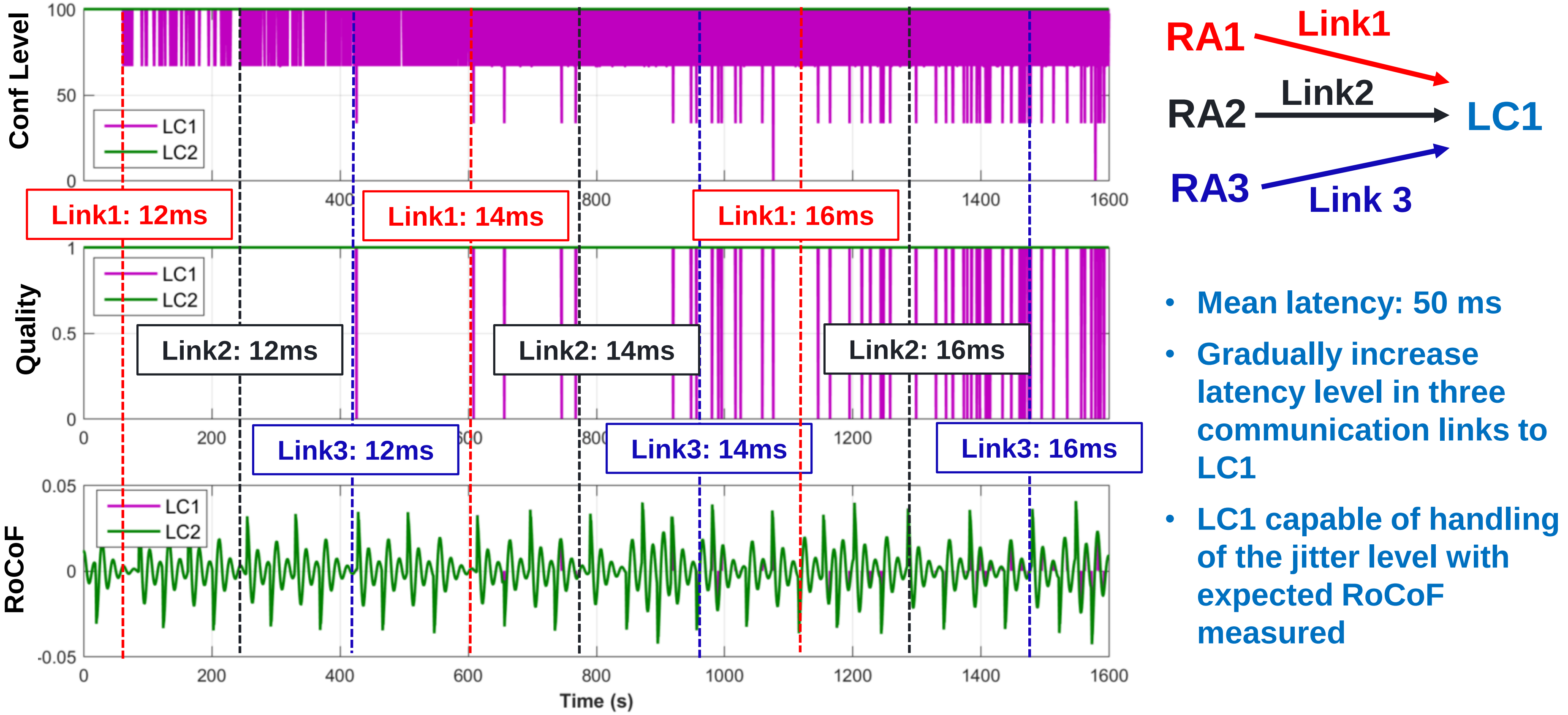
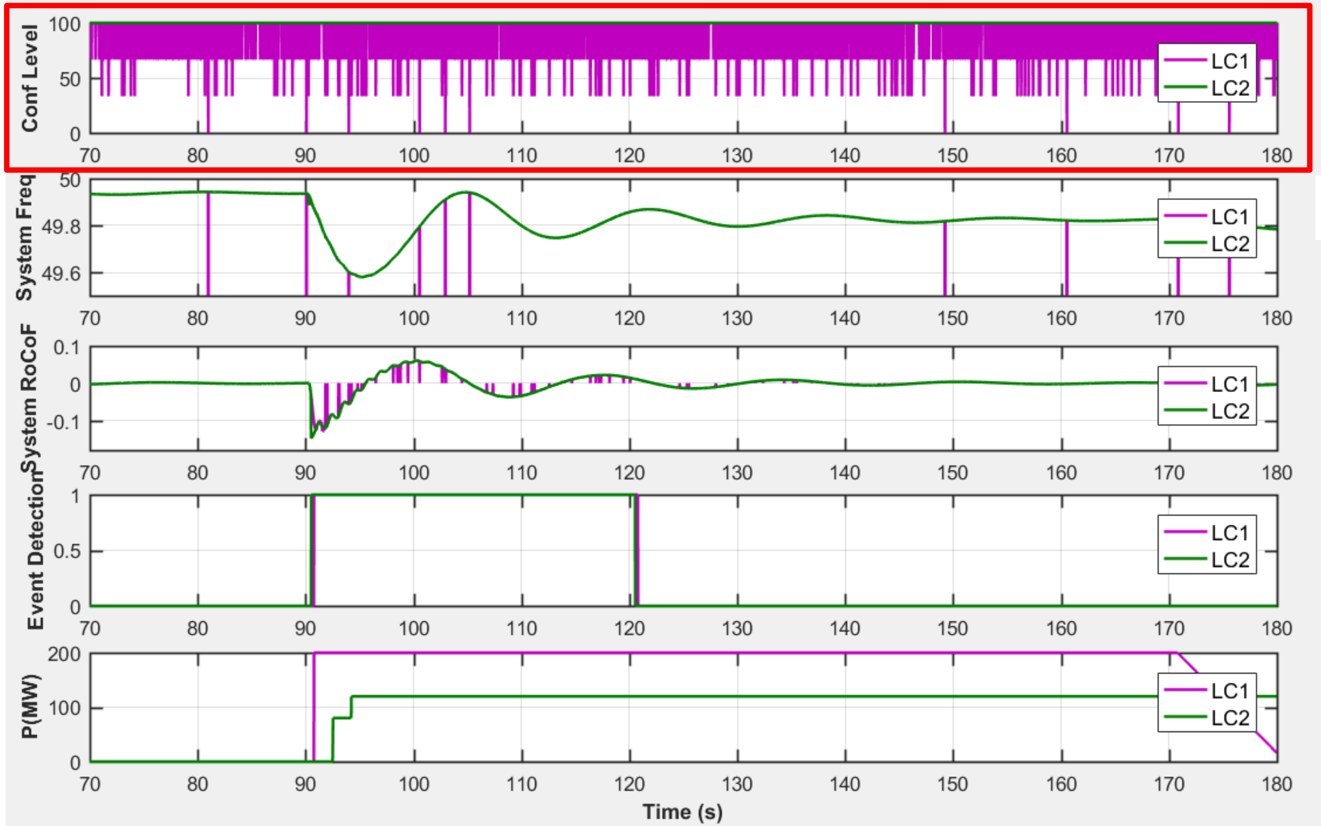


- **Mean latency: 50 ms**
- **Gradually increase latency level in three communication links to LC1**
- **LC1 capable of handling of the jitter level with expected RoCoF measured**

EFCC operation with mean latency 60 ms and 18 ms jitter



Loss of Packets/delay exceeding threshold

Frequency (Hz)

RoCoF (Hz/s)

Event detection

Power command (MW)

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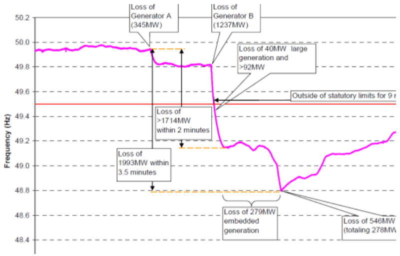
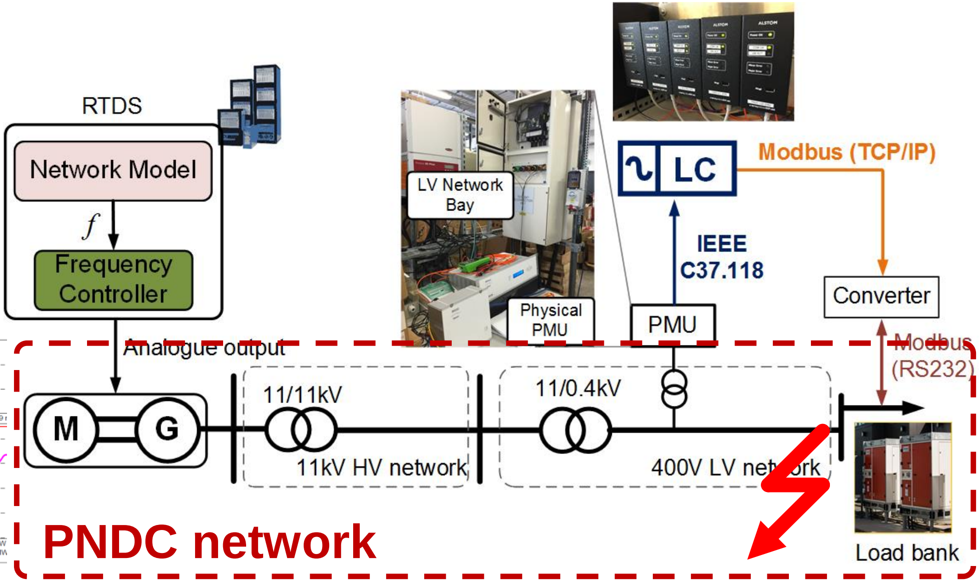
Local mode operation:

- **Local mode: used when wide-area connection is lost or data quality is not sufficiently high for wide-area operation mode**
- **Acting as backup mode – only using local measurement**

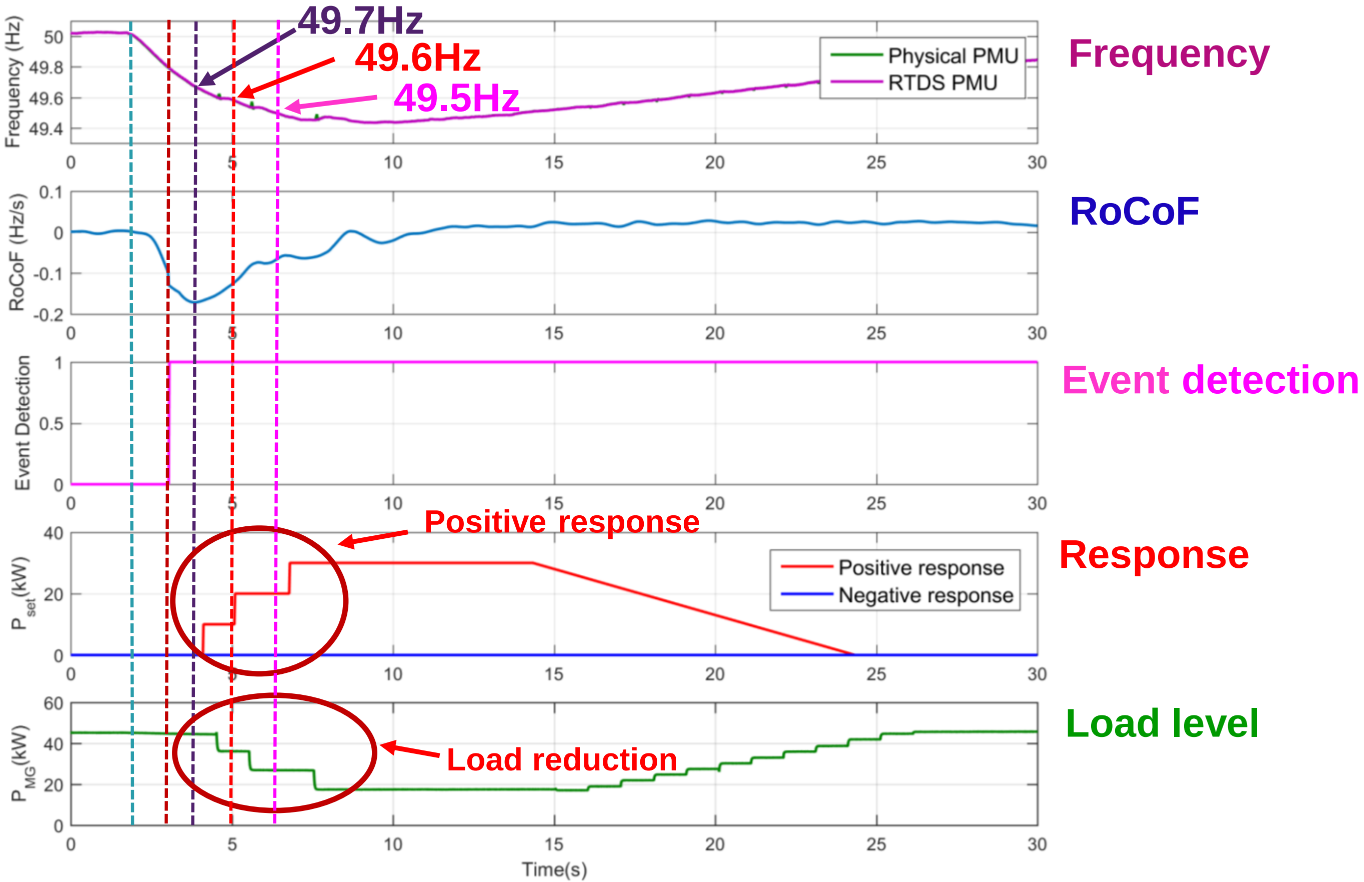
Test setup:

- Motor-Generator (MG) set controlled to emulate frequency disturbances
- Actual faults are also applied in the physical network





Under-frequency event :



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Fault tests:

- Actual faults have been applied in the physical network

- Testing the LC's capability to remain stable to the faults

- Fault types tested:
    - Ph-E
    - Ph-Ph
    - Ph-Ph-E
    - 3Ph-E

Fault thrower

Fault resistors

Fault control

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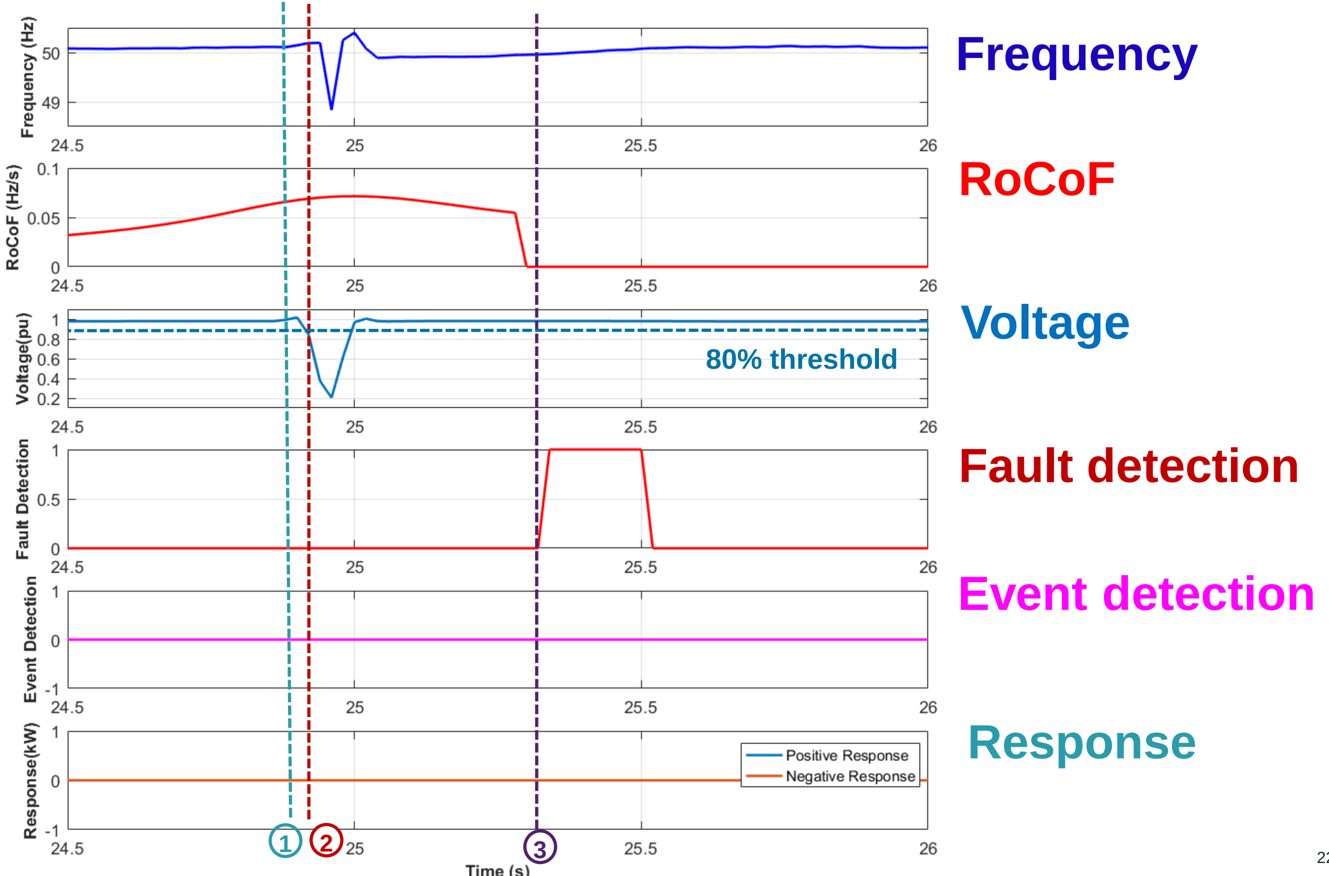
Fault tests in local mode: 3Ph-E fault

Associated settings

- Voltage threshold: 80%
- Event detection RoCoF threshold: 0.1Hz/s
- Event detection frequency threshold: 49.7 Hz



Fault details

- Bolted fault
- Fault duration: 150ms

Key learnings and findings

Wide area mode tests:

- Location of disturbances and the response power both have impact on the frequency profiles – electrical distances and regional inertia.
- Frequency and RoCoF are different at different parts of the network, thus important to have wide-area visibility for fast frequency control
- Fast frequency response: more effective compared to the same volume of conventional primary response
- RoCoF measurement can be significantly different with different PMUs, so testing the scheme using actual PMU in physical network before actual implementation is essential
- EFCC scheme capable of instructing fast, coordinated response in the tests – effective in enhancing frequency control in a low-inertia system

Key learnings and findings

Communication tests:

- Size of data buffering window directly determines EFCC's capability to handle degraded communication performance
- Increasing buffering window can mitigate the risk of loosing packets, but can compromise the response speed
- At the PNDC tests, the requirements for communication performance has been quantified
- EFCC scheme appears to be robust in degraded communication conditions

Local mode tests:

- Essential in case of wide area communication failure
- Action should be slower compared to wide area mode due to lack of wide-area visibility

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Conclusions and future work

- **PNDC's role: comprehensive validation of the EFCC scheme using the established realistic testbed**
- **The EFCC scheme have been tested under a wide range of operating conditions and disturbances**
  - wide area mode
  - impact of communication performance
  - local mode as backup
- **EFCC scheme capable of instructing fast and coordinated response to enhance frequency control in low-inertia systems**
- **Future work**
  - finish wide-area mode and communication tests
  - knowledge dissemination