WP4-Hardware in the Loop Validation of the EFCC Scheme

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Presentation Outline

- Manchester RTDS Lab
- Hardware in the Loop Building Blocks
- Testing Configuration and RTDS GB Network Model
- Role of Manchester in Testing the GE-MCS Equipment
- Testing and Assessing the GE-MCS
- GE-MCS Testing Summary

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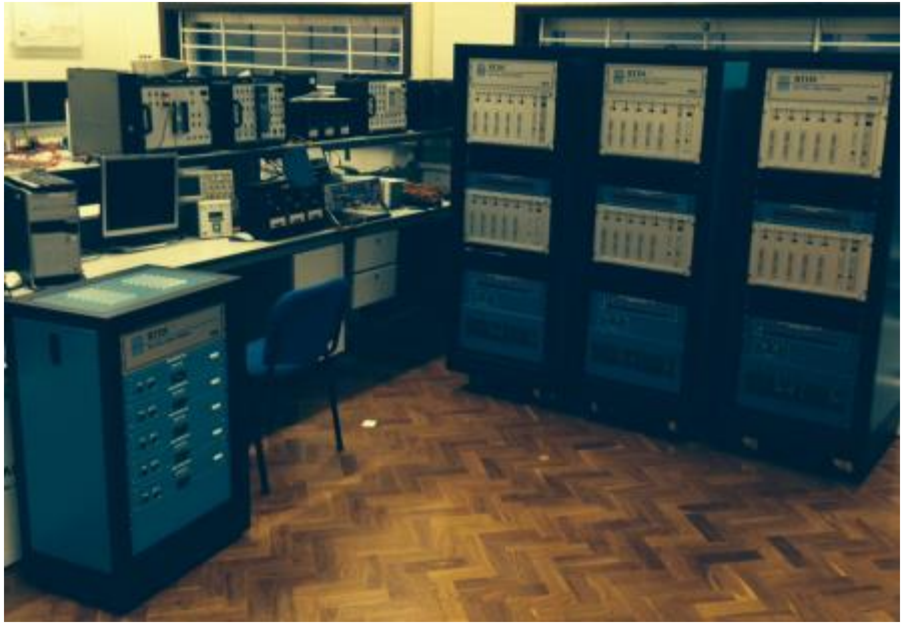
Manchester RTDS Lab

Manchester RTDS Lab

- **Manchester Real Time Digital Simulator (RTDS)** is employed to represent the EFCC physical plant and a variety of future scenarios
- **RTDS** consists of 6 racks with 30 PB5 processor card:
  - GTSync card for synchronisation of the RTDS
  - GTNet cards for high level communication (e.g. IEC 61850, C37.118 and IEC 60870 protocols)
  - GTWIF cards to connect to Admin PC



Hardware in the Loop Building Blocks

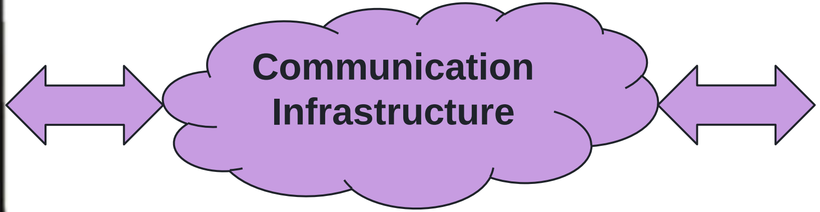
Hardware in the Loop Building Blocks

Hardware in the Loop Building Blocks

RTDS

GE-MCS

Admin PC to control simulation runs and visualise the results



RTDS to perform flexible HiL tests

Evaluating **GE-MCS** hardware components:

a) Regional Aggregators (x2)
b) Local Controllers (x4)
c) Central Supervisor (x1)

Hardware in the Loop Building Blocks

- Using **hardware-in-the-loop (HiL)** simulation to assess the GE-MCS for a range of system cases and operational conditions
- Simulating future power networks with high penetration of Non-Synchronous Generation (NSG) and **variable/reduced system inertia** (expressed in GVAs)
- Representation of **load models** through frequency and voltage dependent models
- Representation of **NSG through high fidelity** models
- Modelling virtual phasor measurement units (**PMUs**) and Information and Communications Technology (**ICT**)
- Rigorous testing of resilience and robustness of the **GE-MCS** connected to the primary plant for a broad range of scenarios

Testing Configuration and RTDS GB Network Model

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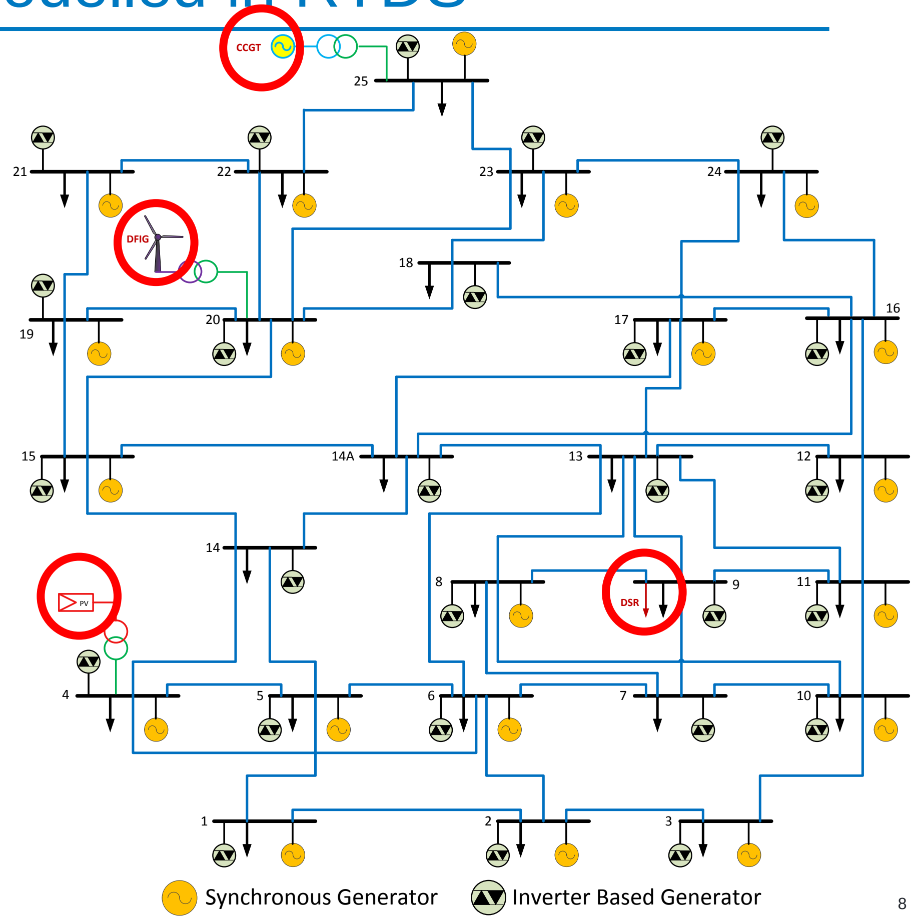
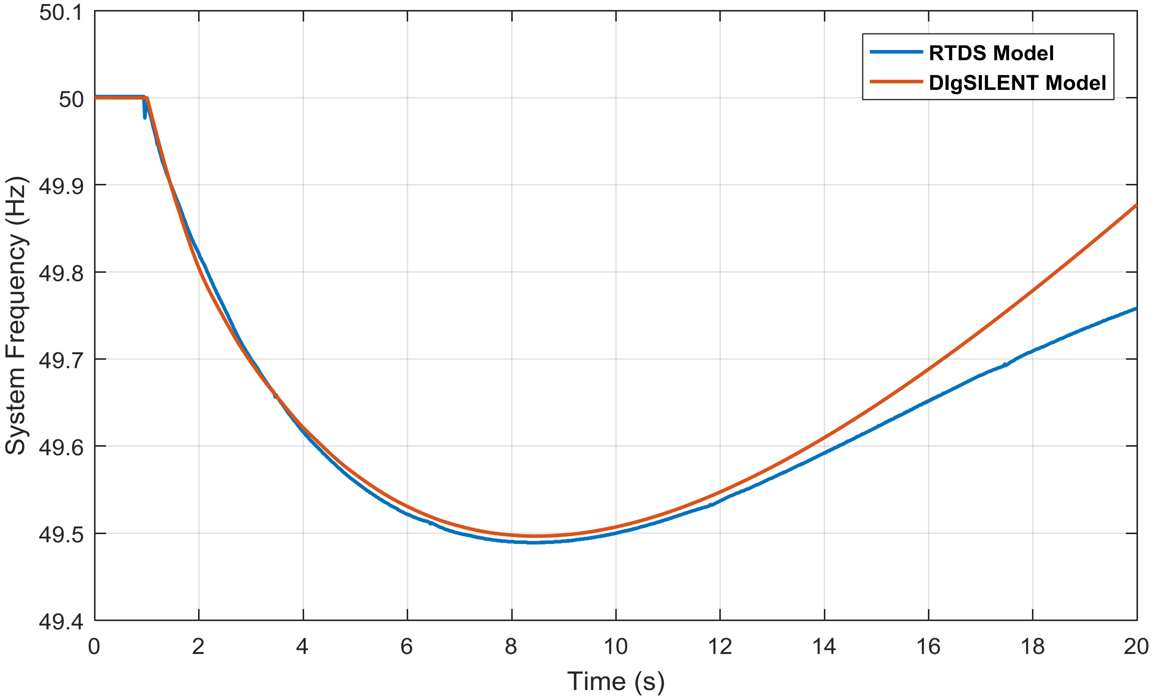
Simplified GB Network Model Modelled in RTDS

- **Use of the 26 Zone GB Network Model, simplified from the 36-zone one, allowing dynamic simulations, but using 2 Racks**
- **The model includes:**
  - 20 synchronous generators,
  - 26 Non-Synchronous generators
  - 26 loads
  - 4 service providers models (circled in red)



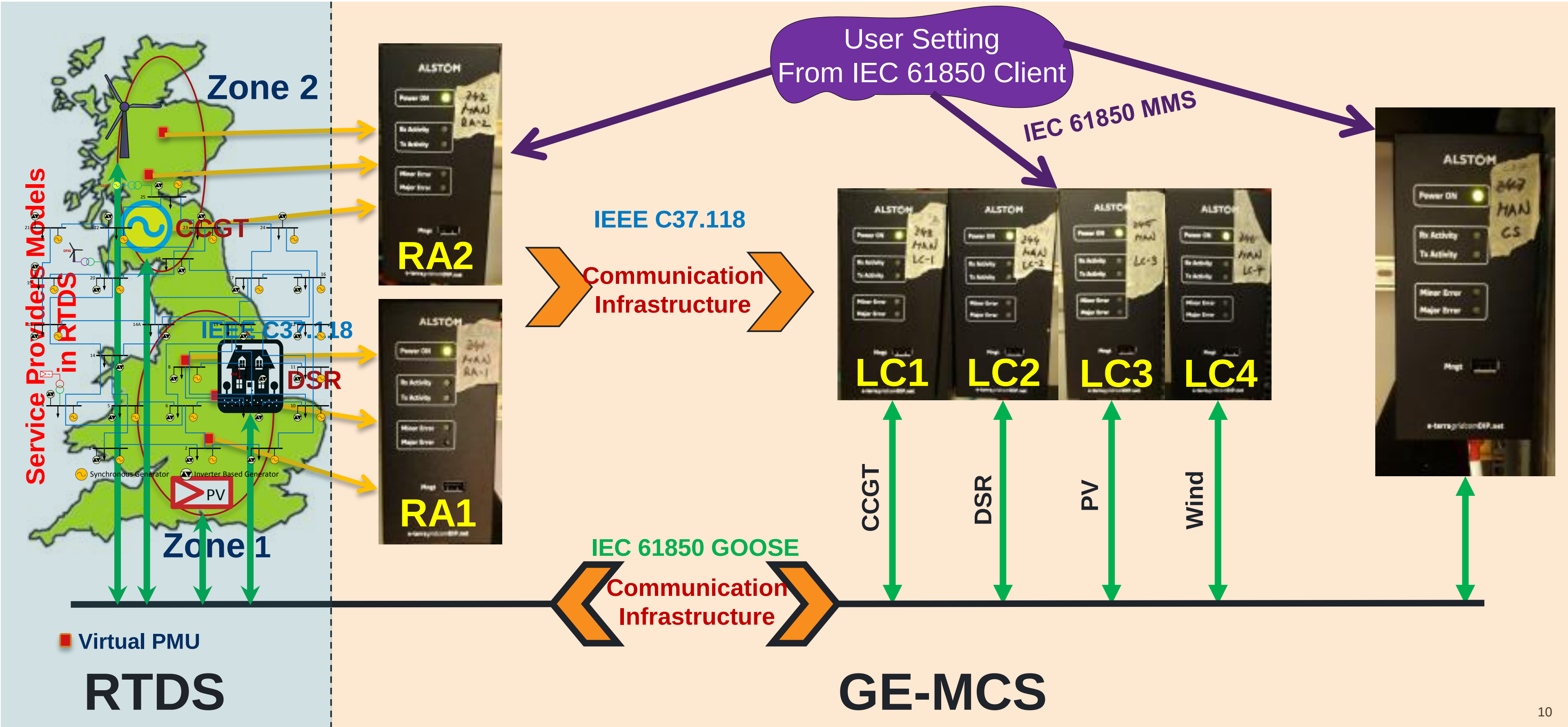
Validation of the Simplified 26 Zone GB Network Model



- Validation of the 26 Zone GB network represented in RTDS against the GB 36 Zone network simulated using PowerFactory (model based on scenario year 2020)
- The total inertia is **82 GVAs**
- **Event:** 750 MW at Bus 1
- The initial response (first 10 seconds) practically the same
- *Conclusion*: the testing using the Simplified GB model justified

System Frequency = Frequency of the equivalent inertia centre (COI frequency) = National Frequency

GE-MCS Hardware Connected to the RTDS GB Model



Role of the Manchester Research Team in EFCC Project

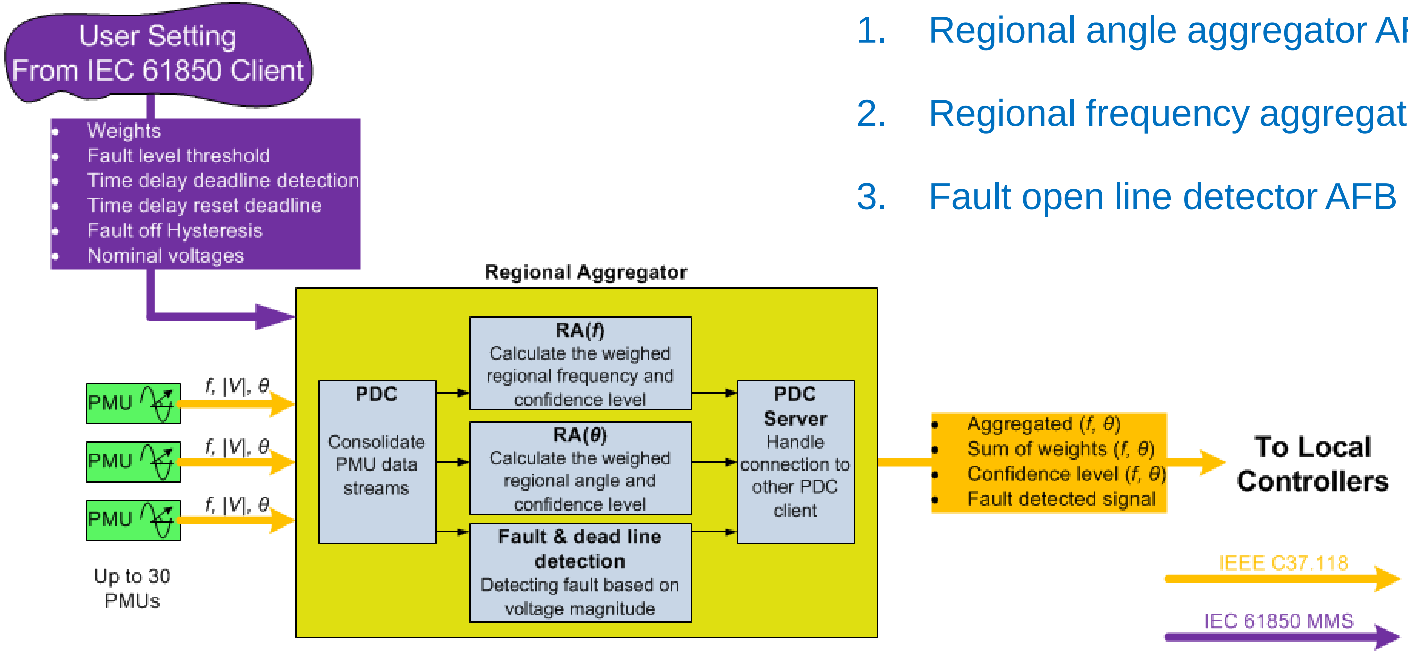
- Focus on the **Wide Area Mode**
- Test network: 26 zone equivalent GB system, including a variety of generators, non-synchronous generators and different level of system inertia. Combination of constant power load (40%), constant current load (40%), and constant impedance load (20%) is deployed in ZIP load model.
- Testing of:
  A. Individual Application Function Block (AFB)
  B. The entire GE-MCS

Role of Manchester in Testing the GE-MCS Equipment

Testing Regional Aggregator, Local Controller and Central Supervisor

Regional Aggregator Testing

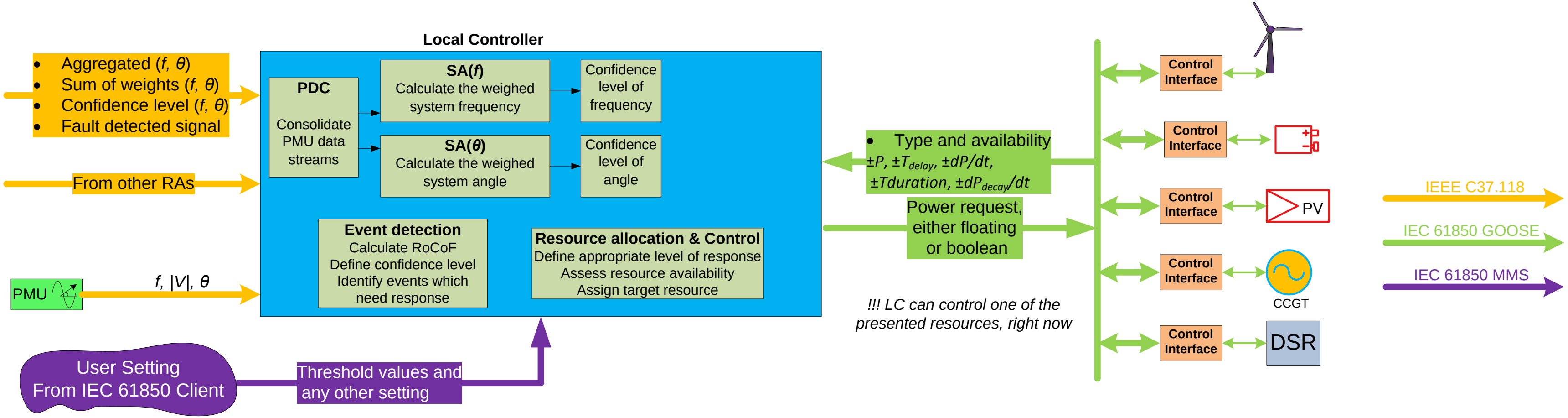
- Its main functionality is to calculate the regional frequency, regional angle and detecting the fault
- A Regional Aggregator consists of the following Application Function Blocks (AFBs):
    1. Regional angle aggregator AFB
    2. Regional frequency aggregator AFB
    3. Fault open line detector AFB



Local Controller Testing

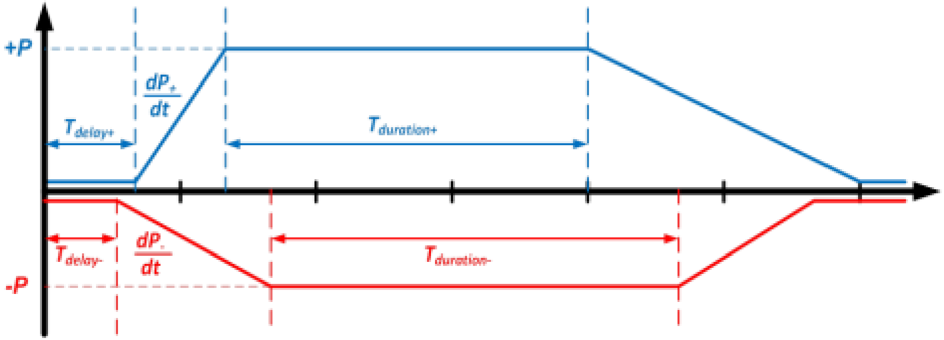
- Local controller (LC) determines a suitable wide-area response which will be allocated to service providers
- Local independent response - a backup solution in case of losing wide-area signals

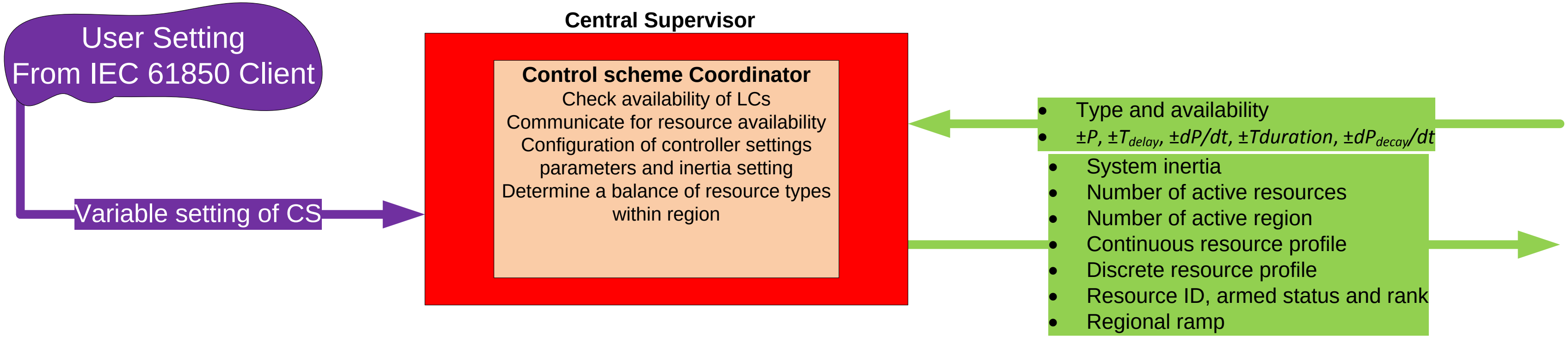
- A LC consists of the following AFBs:
  1. System frequency aggregator AFB
  2. System angle aggregator AFB
  3. Event detection AFB
  4. Resource allocation AFB



Central Supervisor Testing

- Its main functionality is to keep all the Local Controllers updated with the latest status of the controlled service provider
- Represented through a single AFB called optimisation AFB in order to prioritize the service providers of the LCs





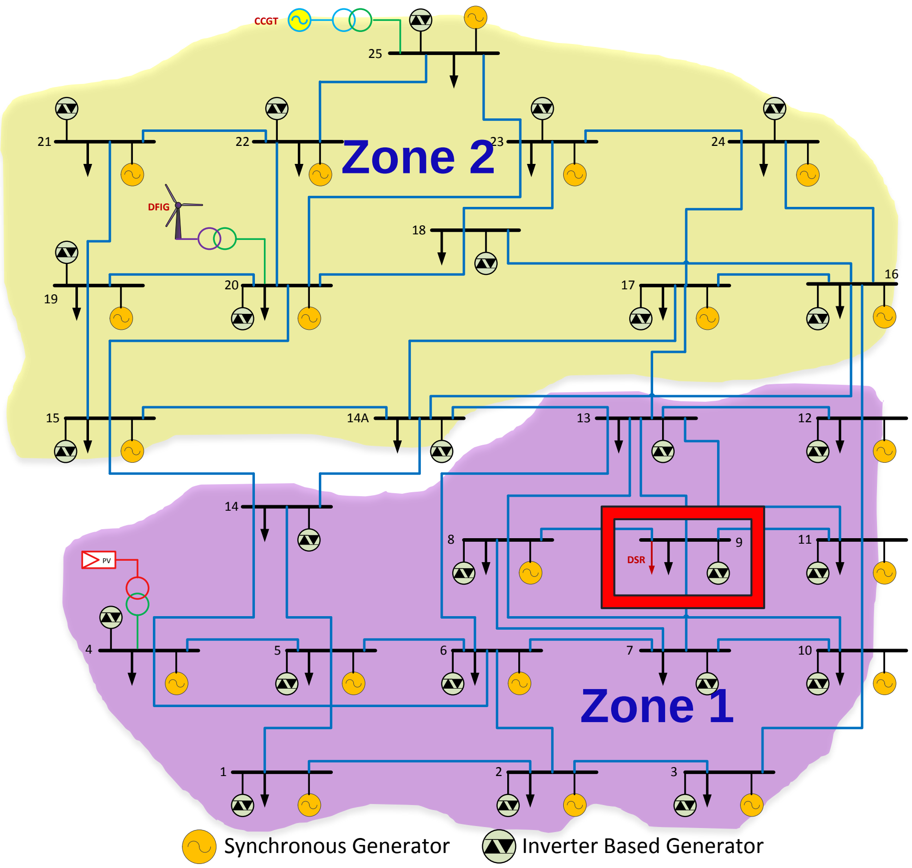
Testing and Assessing the GE-MCS

Review of Test Cases

- The balanced GB power system has the nominal frequency of 50 Hz
- A sudden active power, *P*, mismatch results in an over- or under-frequency deviation
- Disturbances used to cause power mismatch:
  - Sudden load connection (1GW)
  - Sudden load disconnection (1GW)
  - Short circuit fault (generators acceleration leads to frequency increment)
  - Generator disconnection, following a140 ms short circuit (two cascading events)

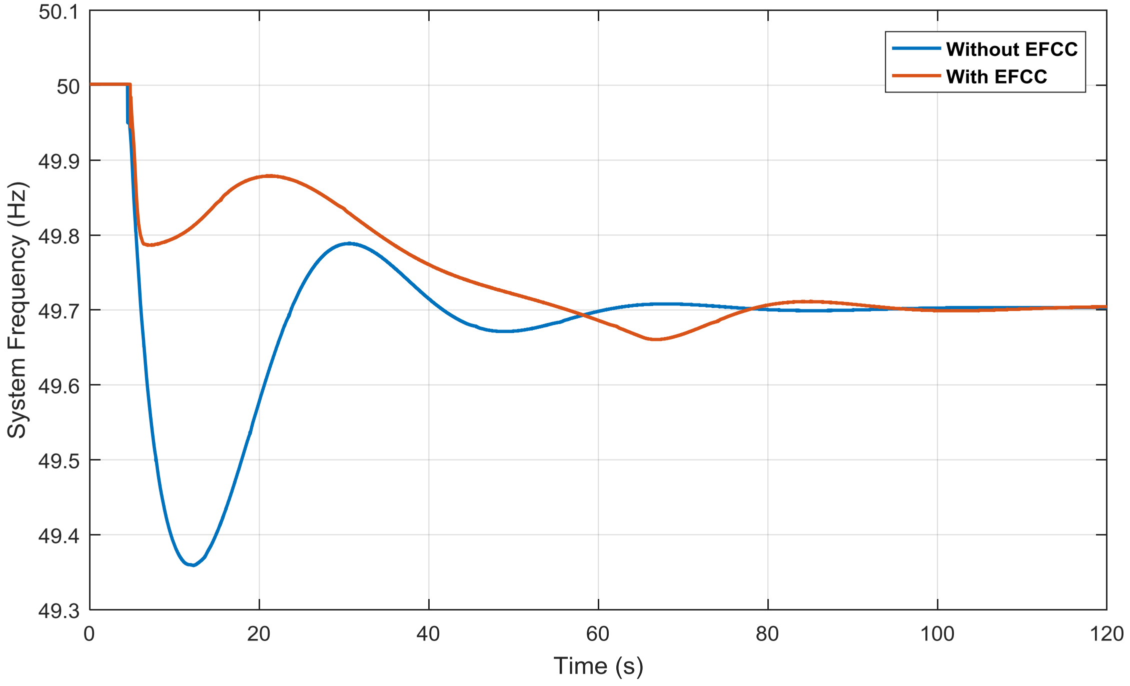
Case 1: Sudden Load Connection (1GW)

- **Demand: 42GW**
- **Inertia: 82 GVA.s**
- **Event: Sudden load connection**
- **Size: 1000 MW**
- **Location: Bus 9**
- **Available Power in zone 1: 1500 MW**



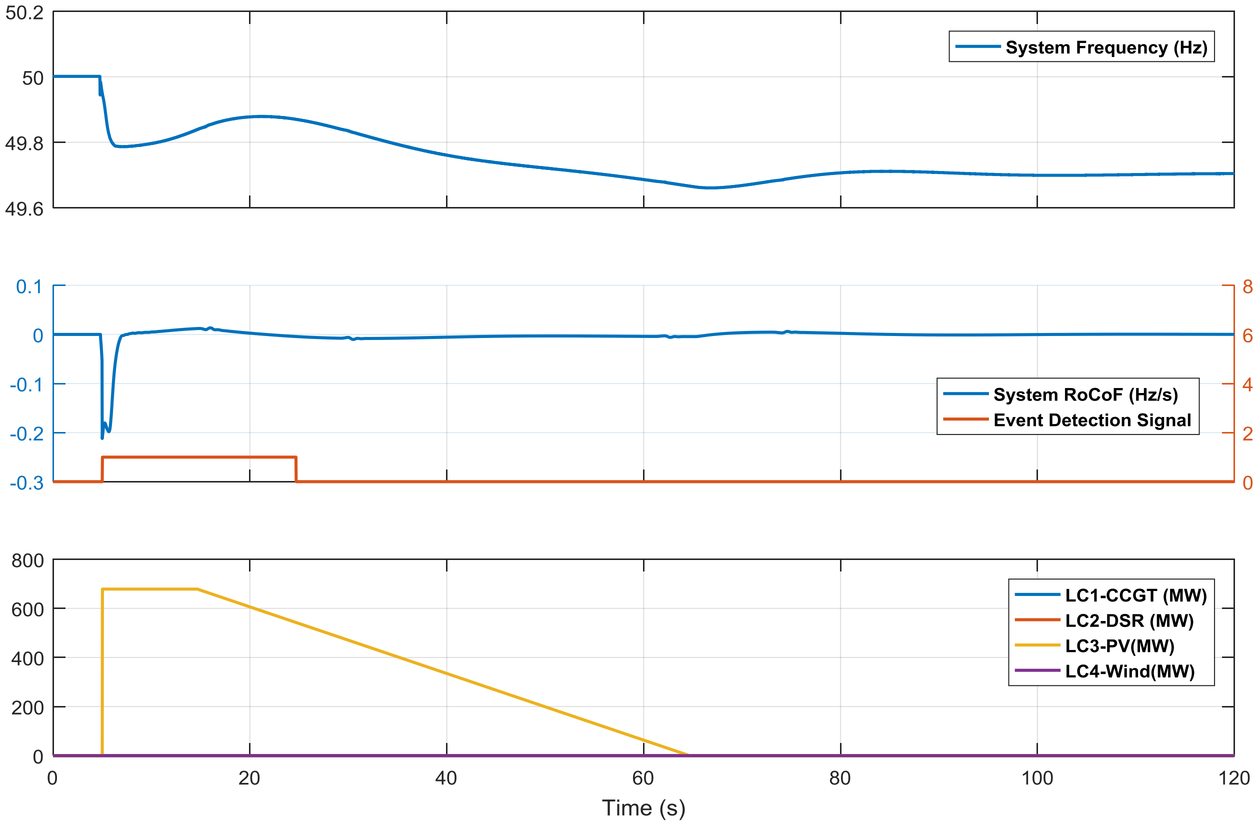
Service Provider	Available Power (MW)
DSR	200
PV	1300
CCGT	200
Wind	300

Case 1: Sudden Load Connection (1GW)



- EFCC delivers a faster and more effective frequency response (Lowest frequency is improved from 49.37Hz to 49.66Hz).

Case 1: Sudden Load Connection (1GW)

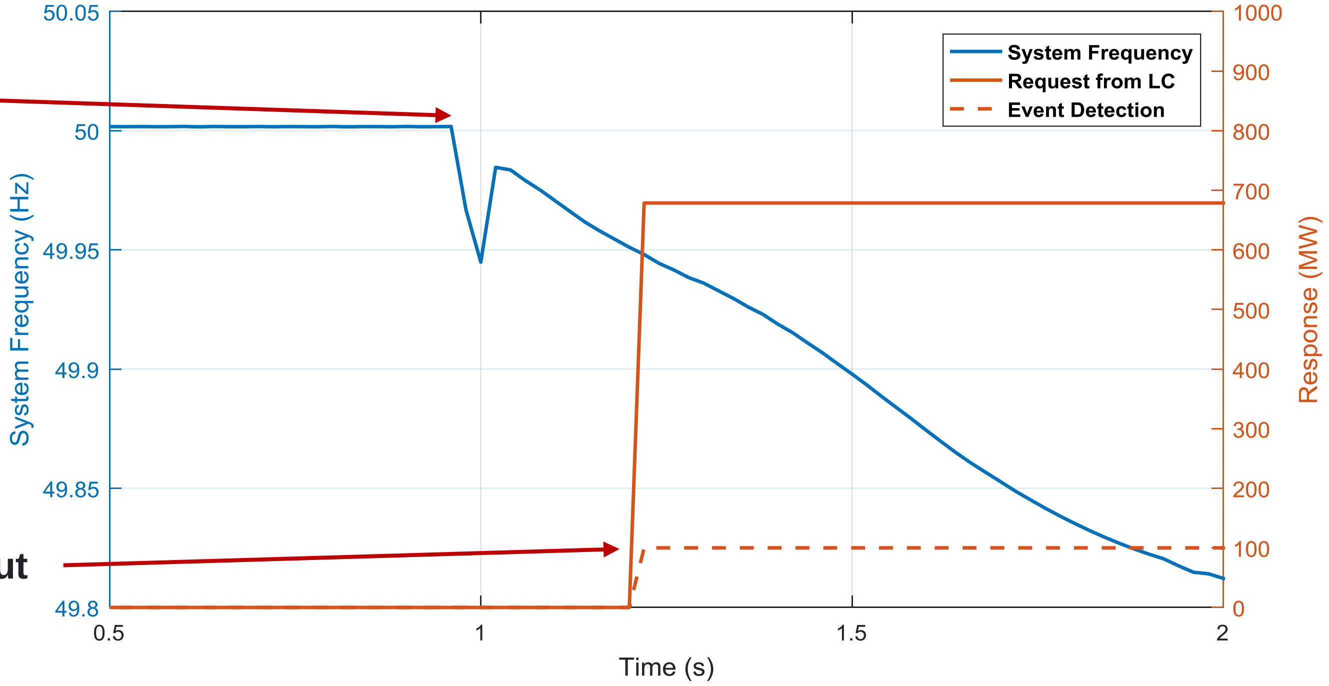


- Measured RoCoF: -0.21 Hz/s
- The event is detected within 500ms in Zone 1.
- Requested response is 600 MW which is calculated based on the measured system RoCoF and system inertia.

Case 1: Sudden Load Connection (1GW)

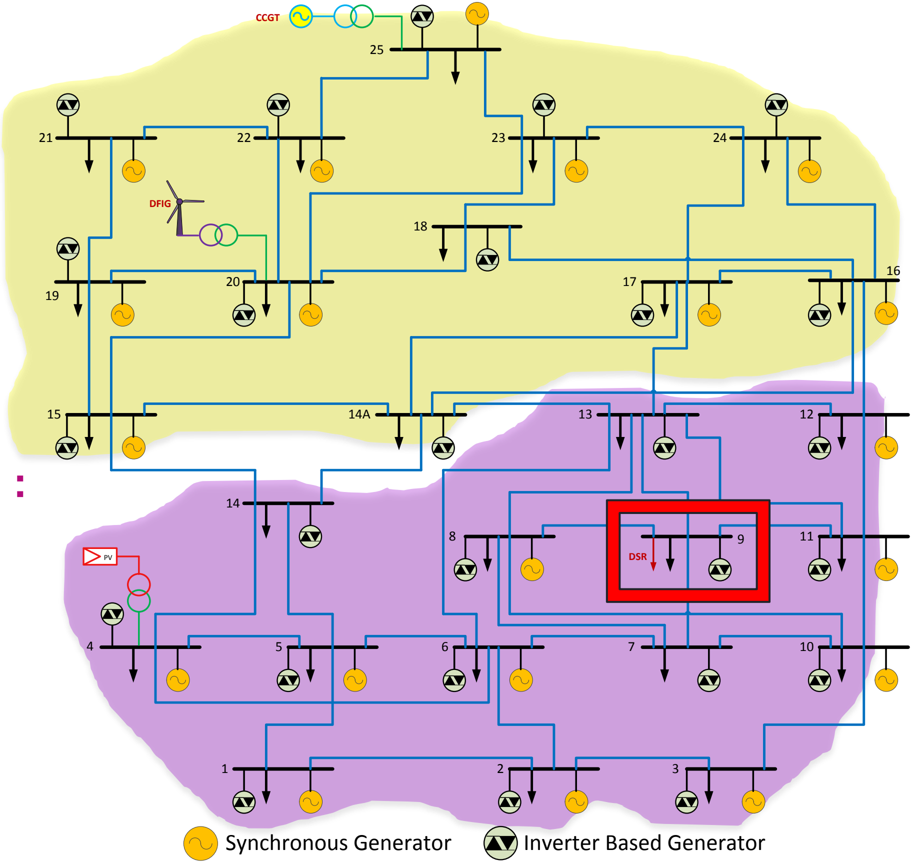
Event starts at 1s

Event detected and response request sent out by EFCC within 0.23s



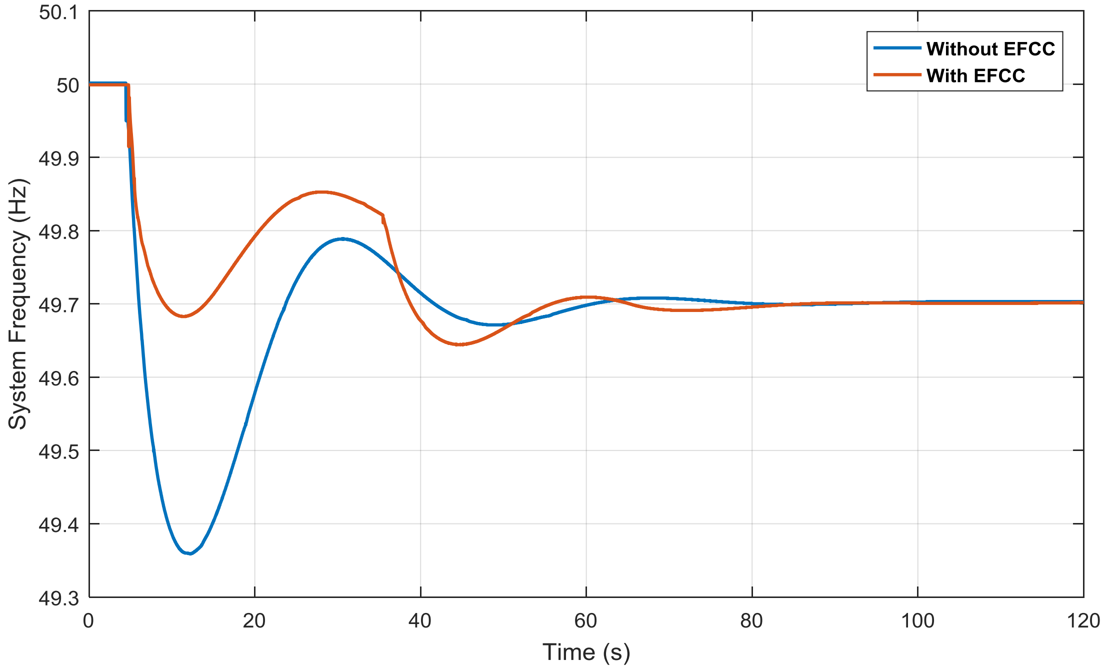
Case 2: Sudden Load Connection (1GW), Less Resource Availability

- **Event: Sudden load connection**
- **Size: 1000 MW**
- **Location: Bus 9**
- **Resource availability : Just 500MW to challenge the EFCC scheme**



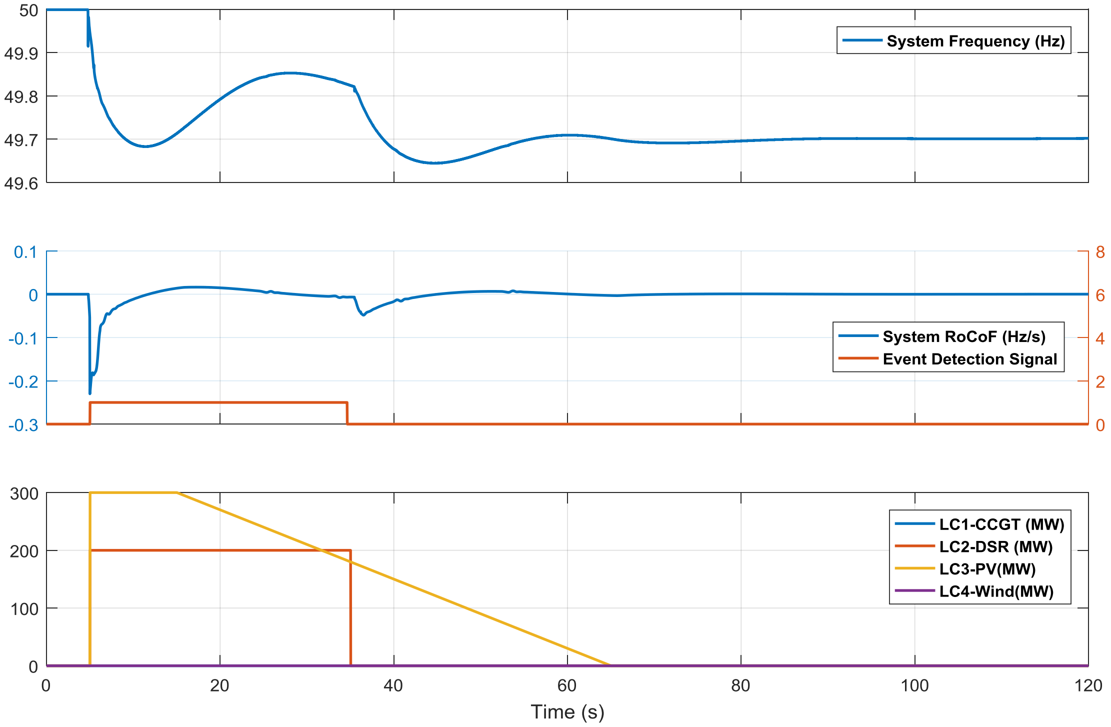
Service Provider	Available Power (MW)
DSR	200
PV	300
CCGT	200
Wind	300

Case 2: Sudden Load Connection (1GW), Less Resource Availability



- The lowest frequency is changed from 49.37Hz to 49.65Hz.
- It is lower than that of case 1.

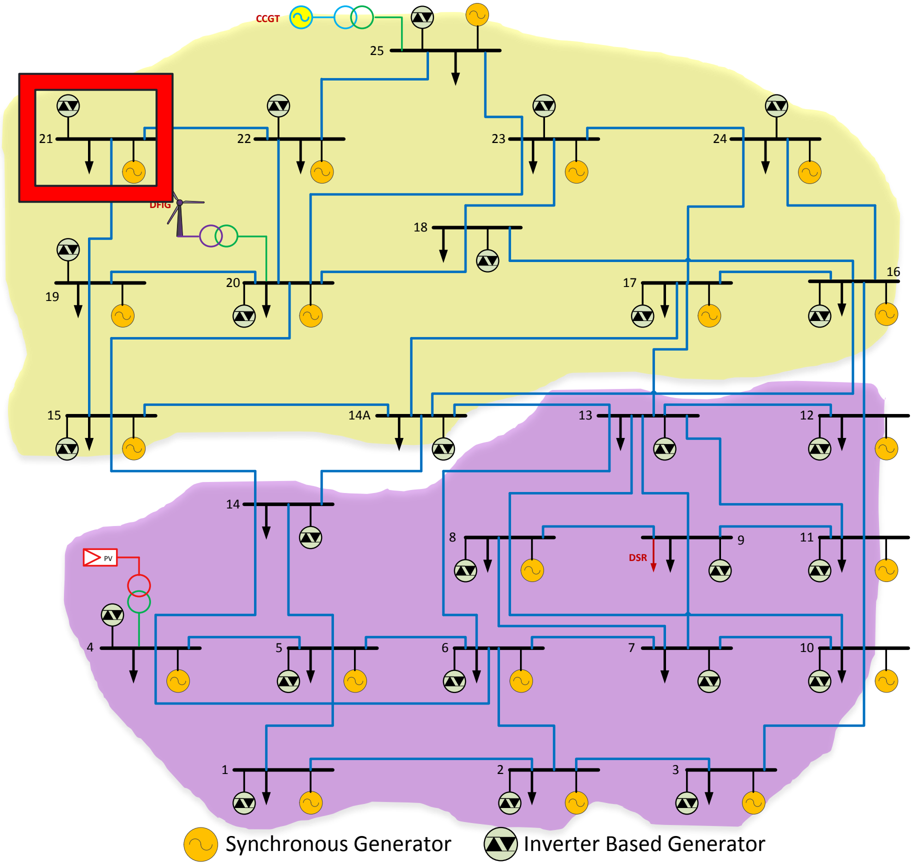
Case 2: Sudden Load Connection (1GW), Less Resource Availability



- Measured RoCoF: -0.23 Hz/s
- Requested response is 500 MW as the event size is beyond the maximum availability.
- Two service providers, PV and DSR, are involved.

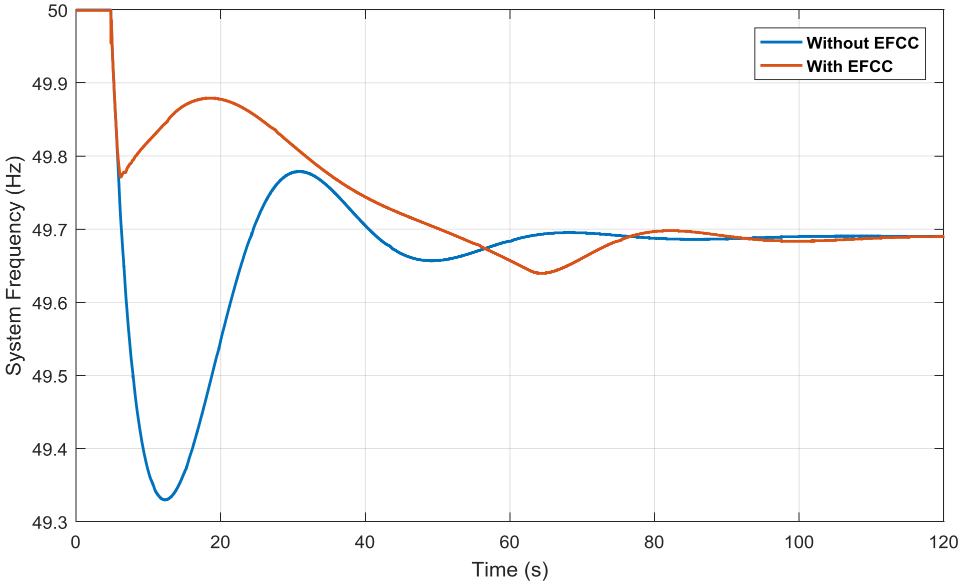
Case 3: Sudden load Connection (1GW) (at another location)

- **Event: Sudden load connection**
- **Size: 1000 MW**
- **Location: Bus 21**
- **Resource availability: 1500MW**



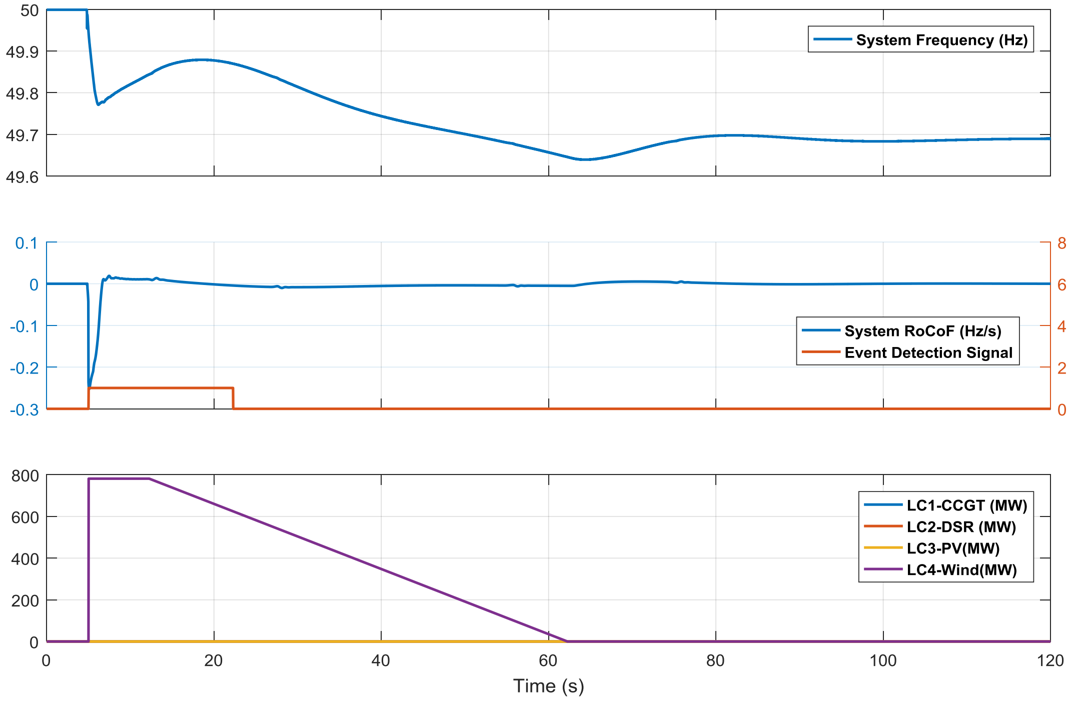
Service Provider	Available Power (MW)
DSR	200
PV	300
CCGT	200
Wind	1300

Case 3: Sudden load Connection (1GW), At Different locations



- The lowest frequency is improved from 49.33 Hz to 49.64 Hz

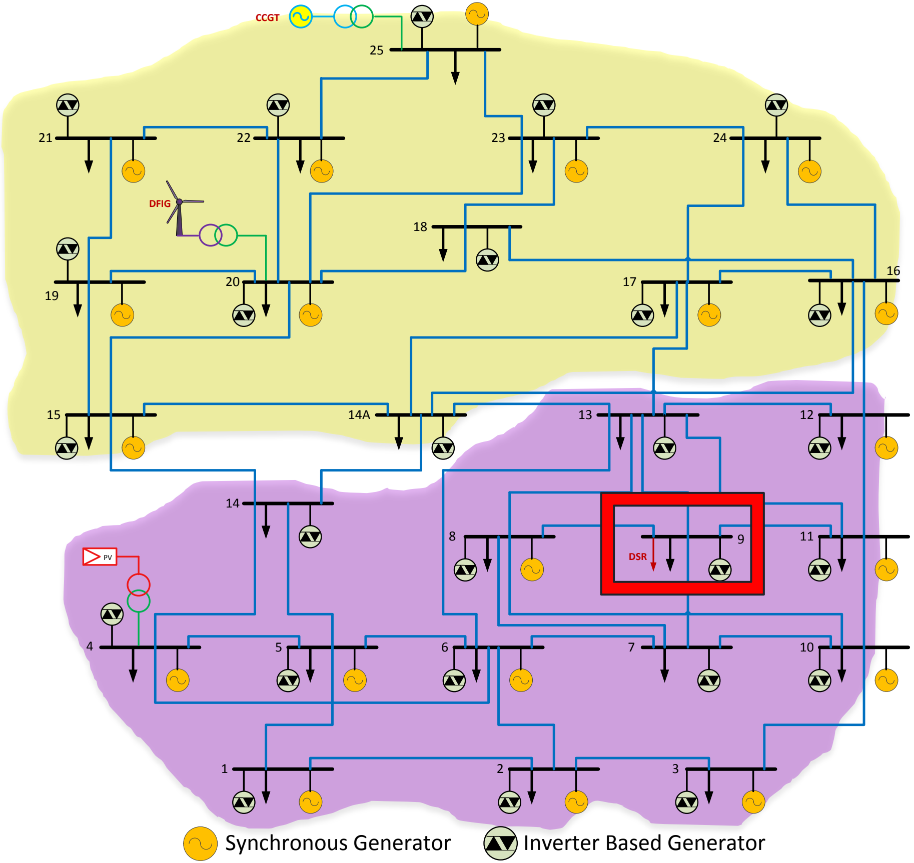
Case 3: Sudden Connection of Load (1GW), Different location



- Measured RoCoF: -0.25 Hz/s
- The event is detected within 500ms in Zone 2.
- Requested response is 790 MW which is calculated based on the system RoCoF and inertia

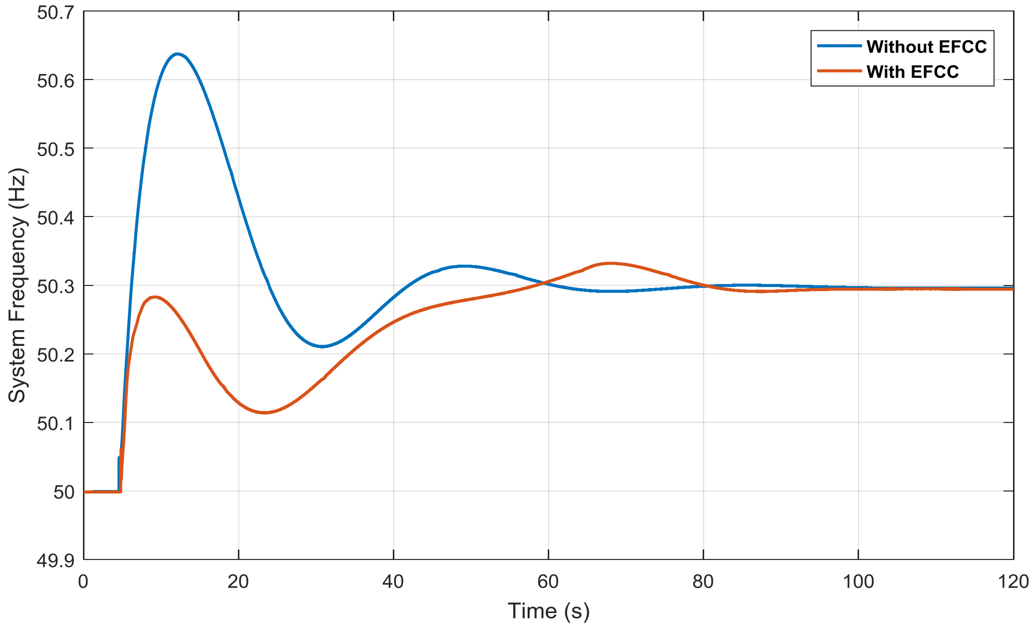
Case 4: Sudden Load Disconnection (1GW), less resource availability

- **Event: Sudden load disconnection**
- **Size: 1000 MW**
- **Location: Bus 9**
- **Resource availability: Just 500MW to challenge the EFCC scheme**



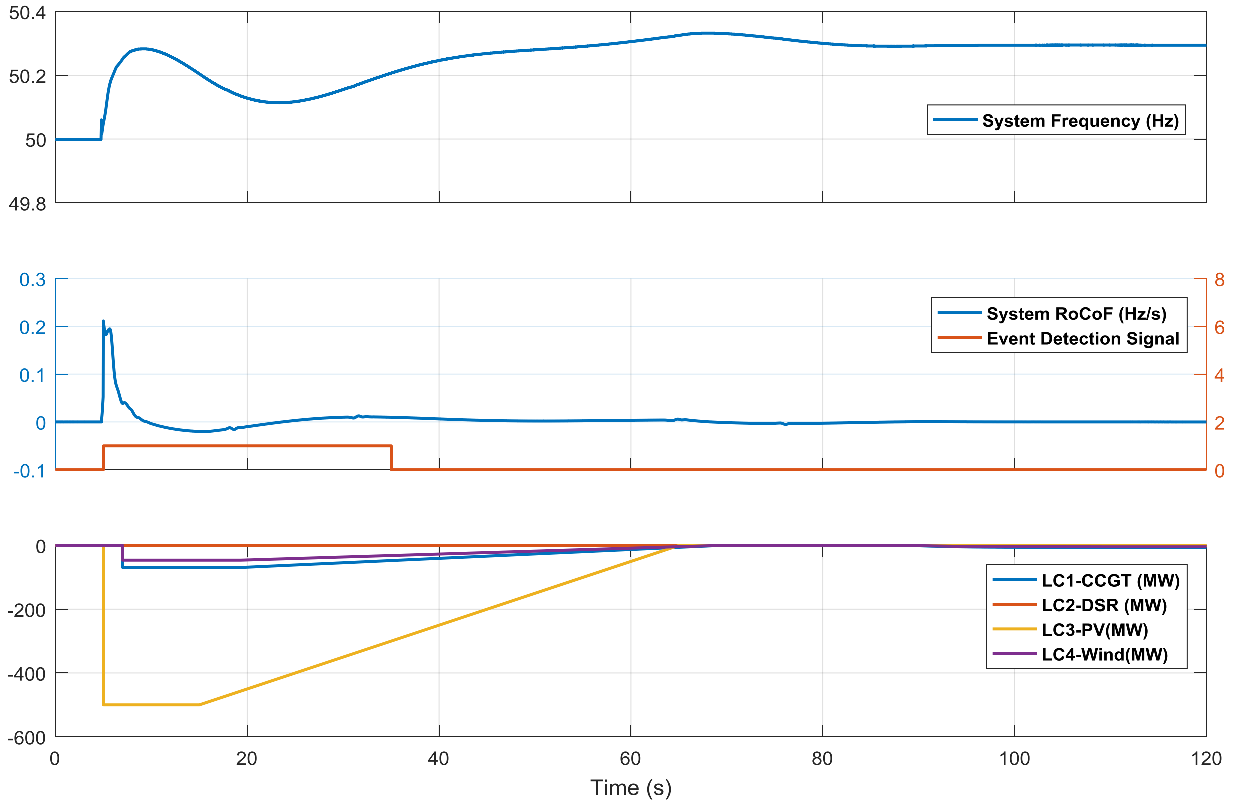
Service Provider	Available Power (MW)
DSR	0
PV	500
CCGT	200
Wind	300

Case 4: Sudden Load Disconnection (1GW), less resource availability



- The highest frequency is enhanced from 50.63 Hz to 50.33 Hz

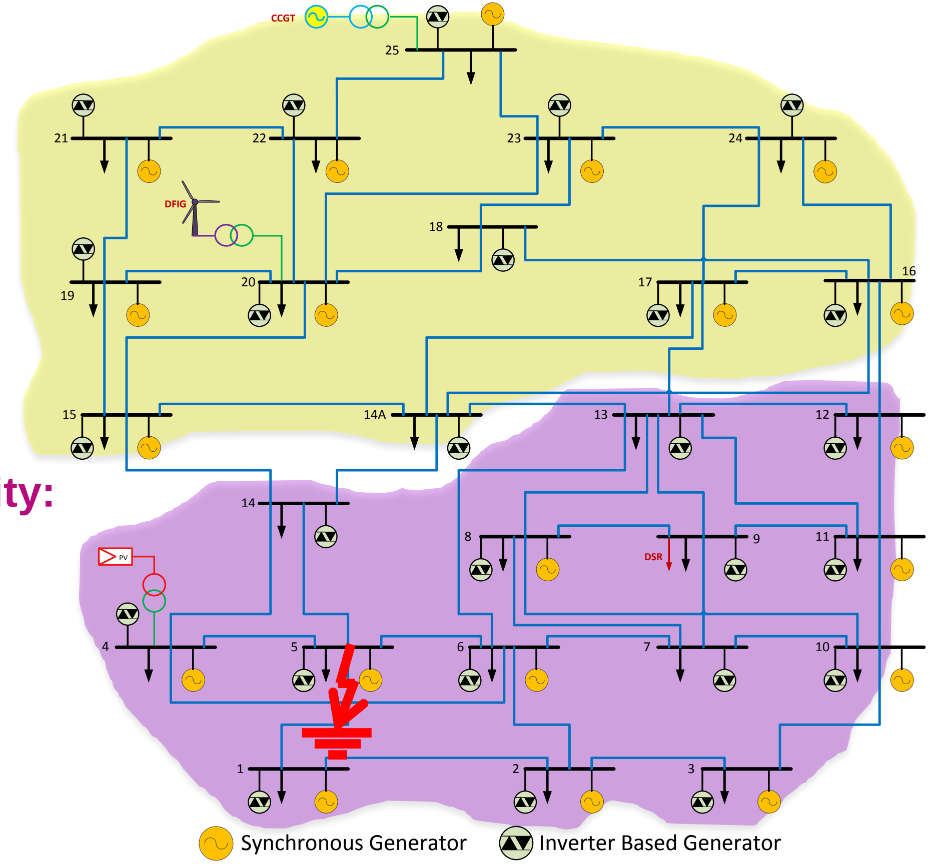
Case 4: Sudden Load Disconnection (1GW), limited resources available



- Measured RoCoF: 0.20 Hz/s
- The event is detected within 500ms in Zone 1
- Requested responses are:
  - 500 MW from Zone 1 (Wide Area Mode)
  - 100 MW from Zone 2 (Local Coordinated Mode)

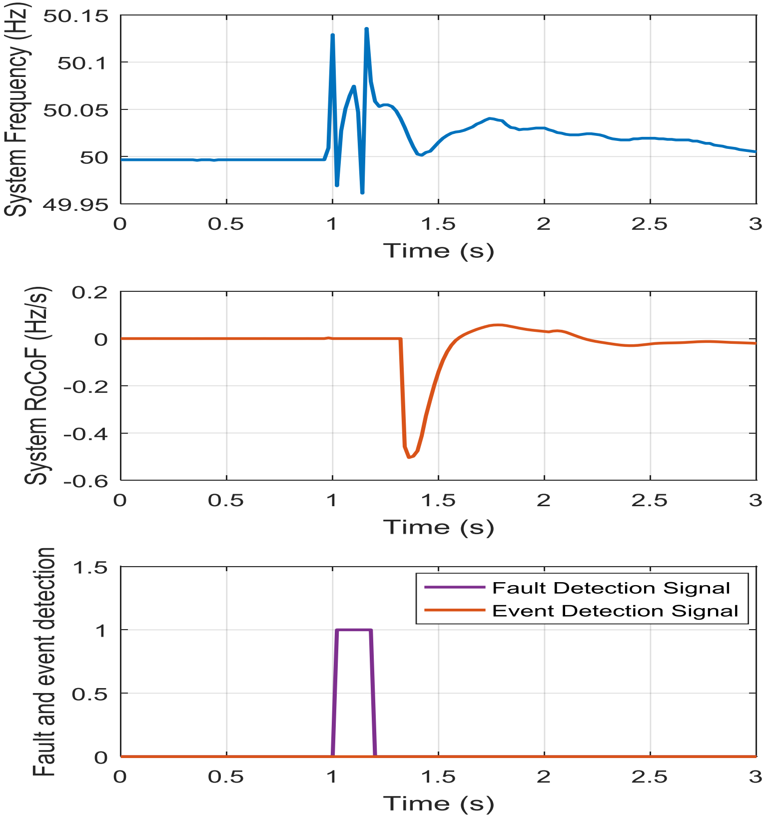
Case 5: Single-Phase to Ground Fault

- **Event: 1-phase to ground fault**
- **Length: 140 ms**
- **Location: Bus 5**
- **Resource availability: 1500MW**



Service Provider	Available Power (MW)
DSR	200
PV	1300
CCGT	200
Wind	300

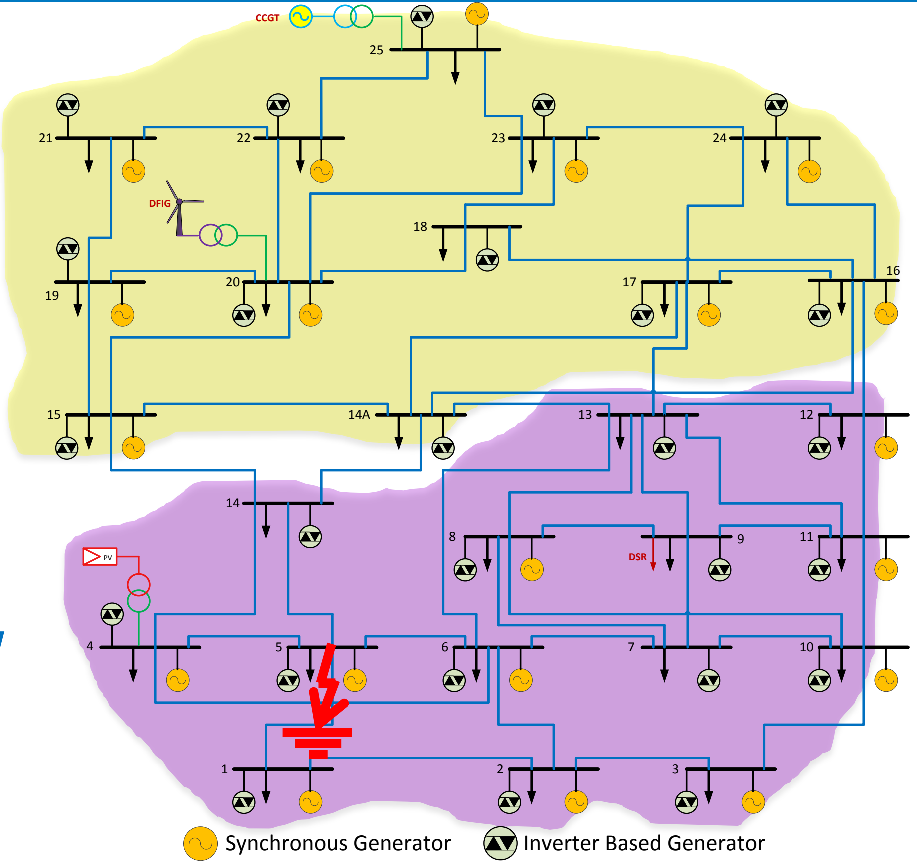
Case 5: Single-Phase to Ground Fault



- During the fault, the monitored system frequency is highly distorted, so that the MCS should be blocked in this period.
- The fault event is detected and disturbance detection is blocked. Thus, the event detection is extended for the fault period by extra 120ms to ensure the system is settled down.
- The measured maximum system RoCoF doesn’t trigger the event detection module, because the frequency is in the permissible range ±0.05Hz.

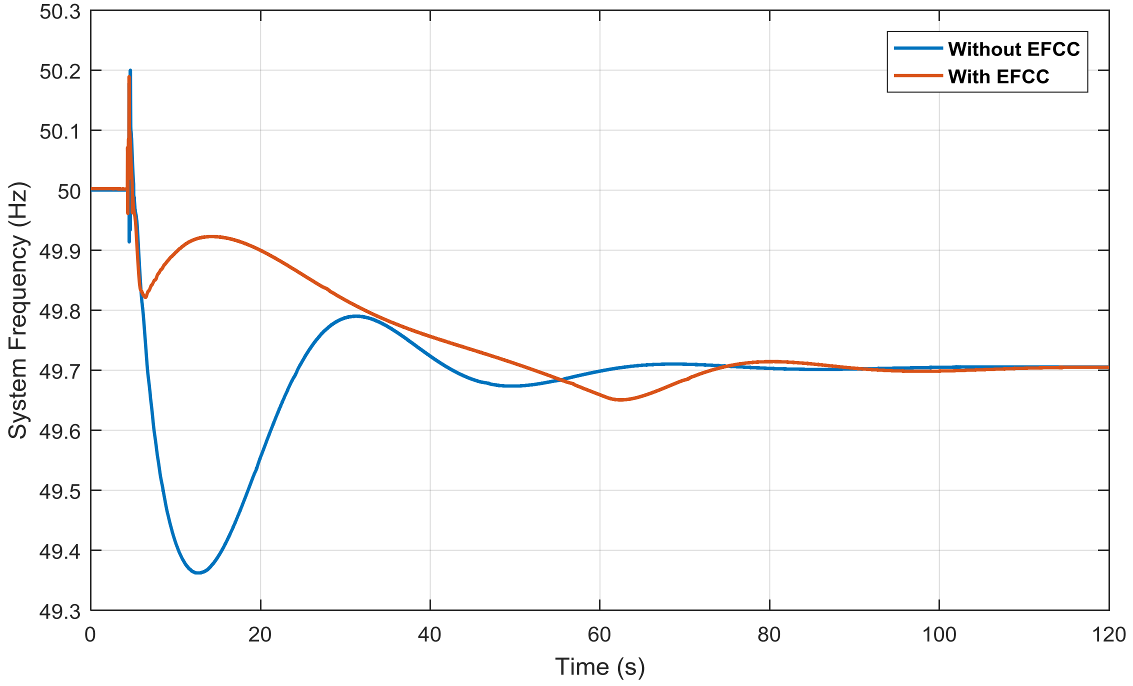
Case 6: 1 GW Generator Tripping Following a Short Circuit Fault

- **Event: Generator tripping after a fault**
- **Size: 1000 MW with 140ms 1phG fault**
- **Location: Bus 5**
- **Resource availability: 1500MW**



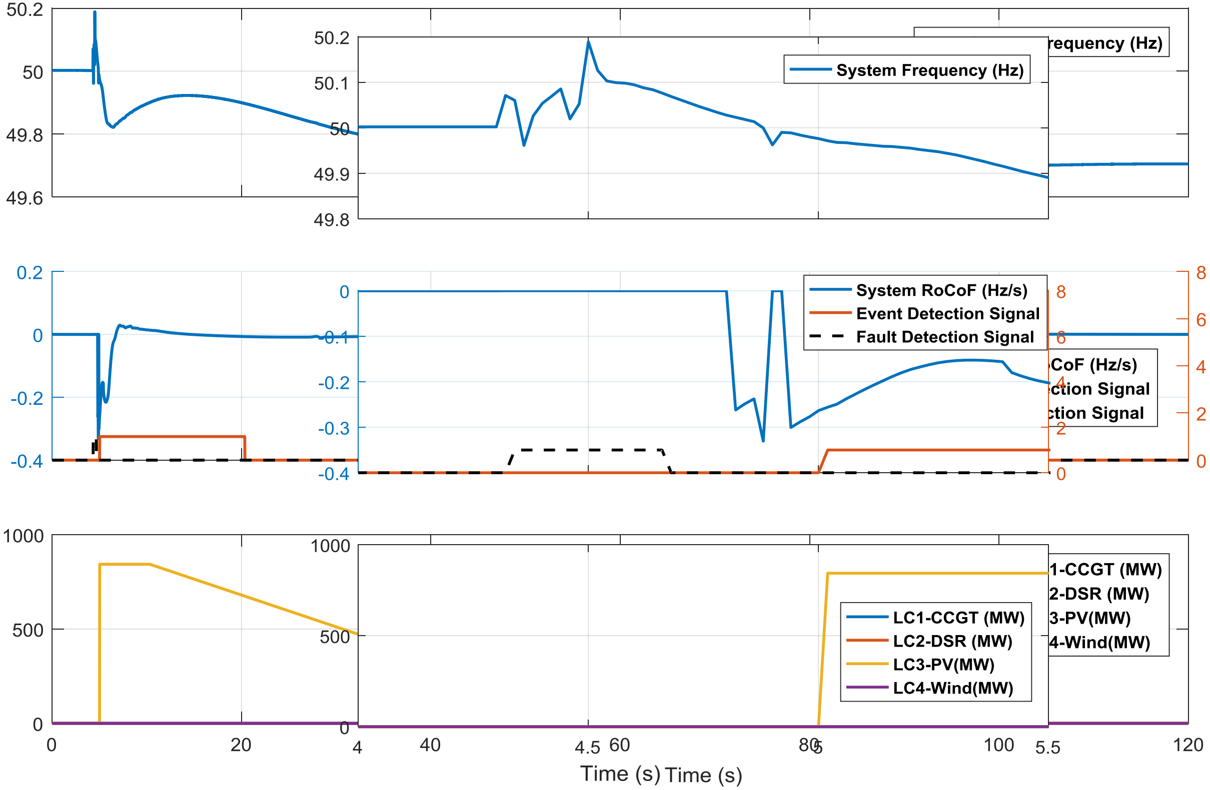
Service Provider	Available Power (MW)
DSR	200
PV	1300
CCGT	200
Wind	300

Case 6: 1 GW Generator Tripping Following a Short Circuit Fault



- The generator tripping is successfully detected after the fault.
- The lowest frequency was moved from 49.36 Hz to 49.65 Hz

Case 6: 1 GW Generator Tripping Following a Short Circuit Fault



- Fault event is detected, blocking by this the event detection is extended with a fault period to ensure the system is settled down.
- The generator tripping is successfully detected after the fault. The response is 800 MW and not affected by the distorted information during the fault.

GE-MCS Testing Summary

GE-MCS Testing Summary

- Frequency event caused by the system load increment/decrement in the low system inertia conditions can be successfully detected.
- Event detection and resource allocation modules respond within the designed time
- Wide-area based RoCoF calculation and loss of generation estimation are accurate.
- Fault event can be successfully detected and event detection module is intentionally blocked for a defined period of time
- With fast coordinated response of the scheme, a moderate amount of fast service response can effectively counteract the frequency contingencies
- The scheme is efficient in scenarios with the reduced system inertia

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