The Power Networks Demonstration Centre and its role in testing EFCC scheme performance

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Overview of Presentation

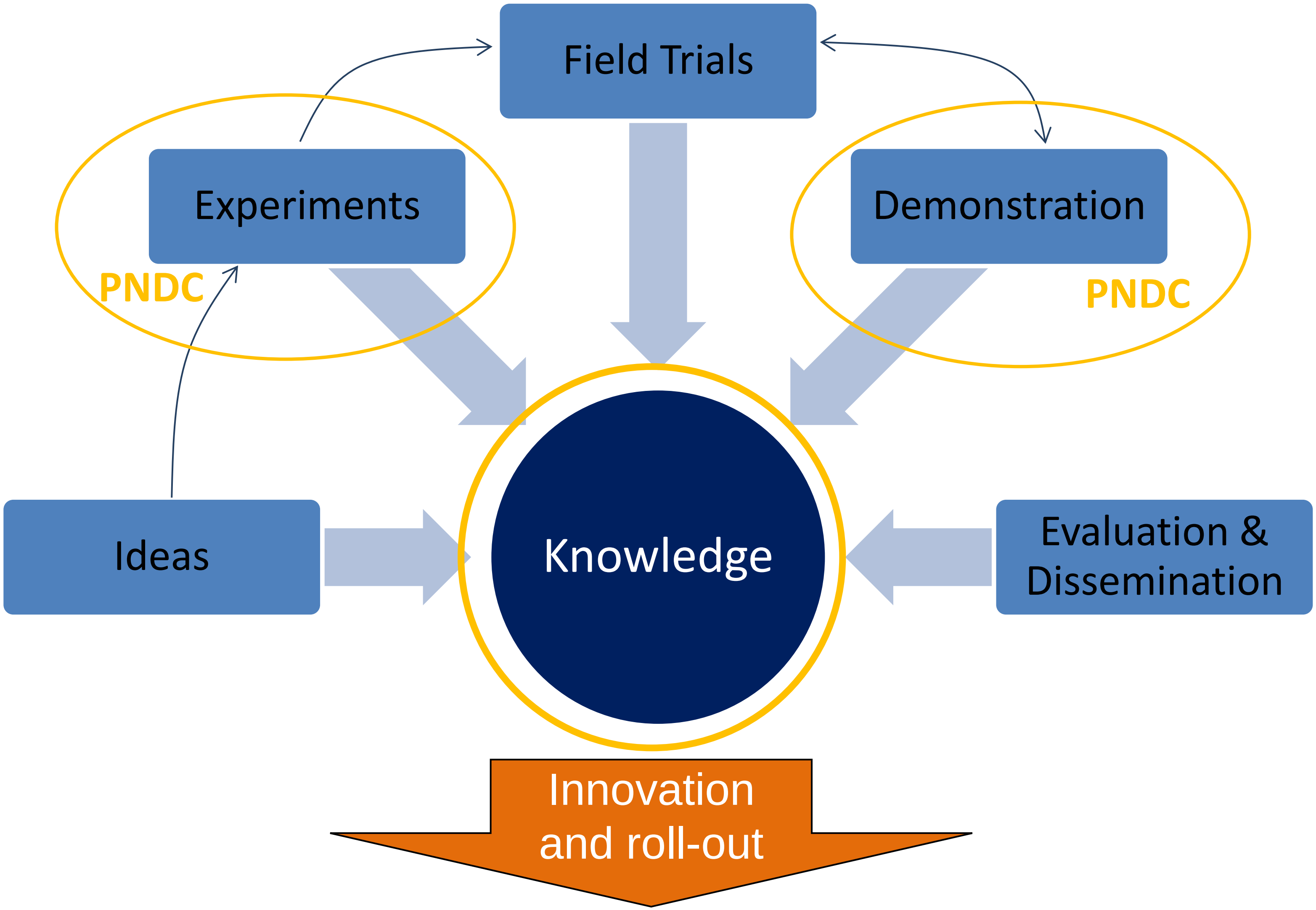
1. Introduction to the PNDC
2. Role of PNDC in the testing of EFCC
3. Proposed testing configurations
4. Where we are and next steps




Innovation

UNIVERSITY of STRATHCLYDE
POWER NETWORKS
DEMONSTRATION CENTRE

University of Strathclyde Glasgow



Main facilities at PNDC

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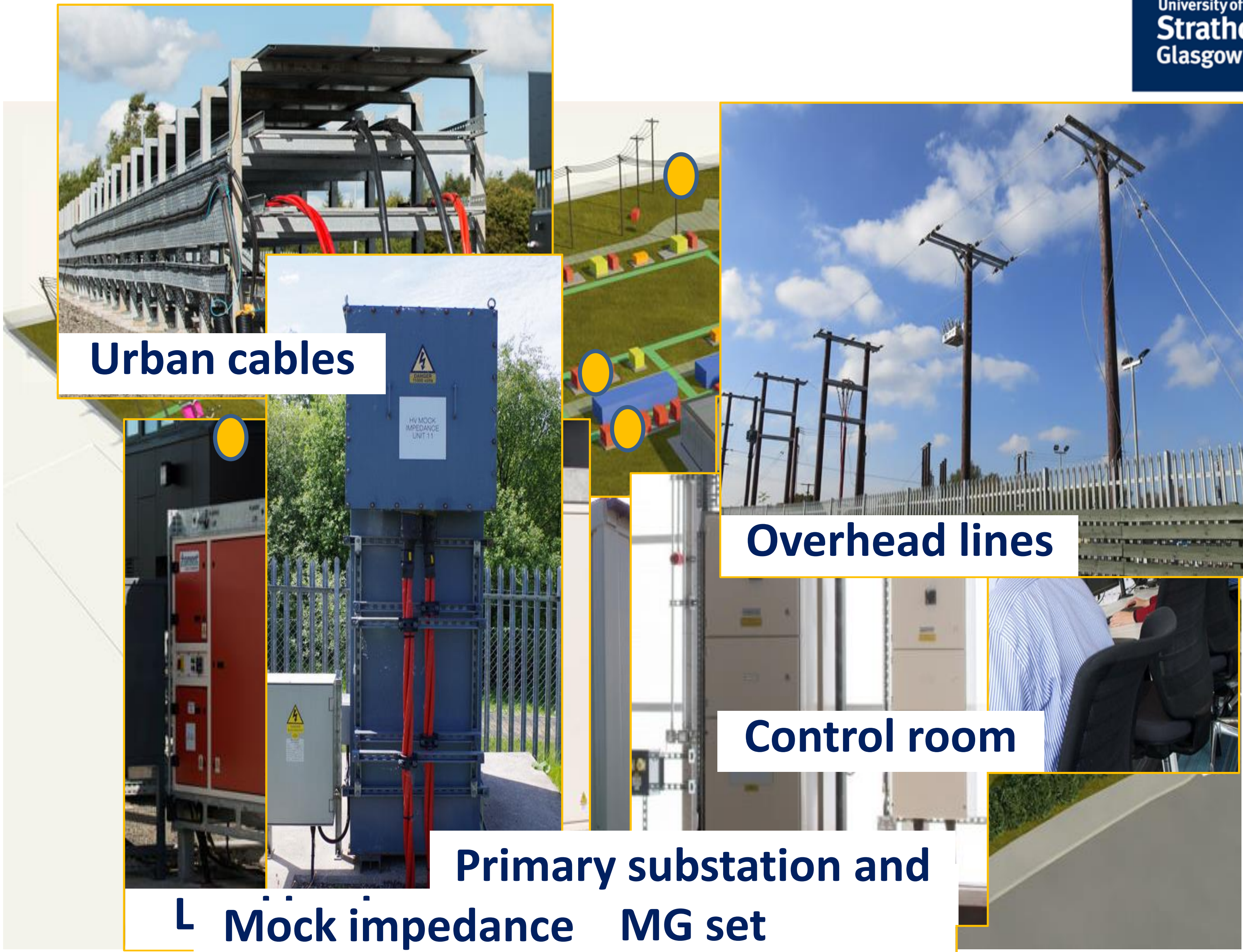

Main features of PNDC

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- Realism
- Flexibility
- Control room, industry-standard SCADA system, laboratories

- Accelerated testing (voltage, frequency, unbalance, power quality, faults…)
- Enhanced instrumentation and recording

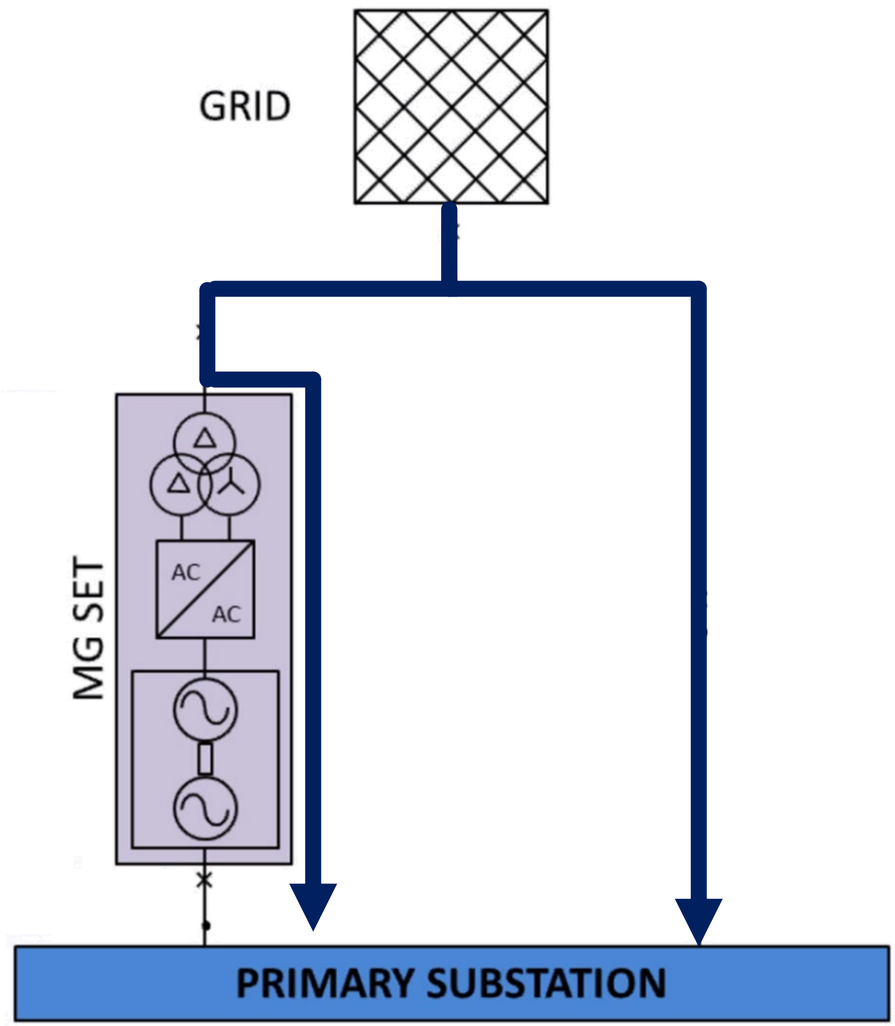
Grid/islanded modes of operation

Grid connected mode:

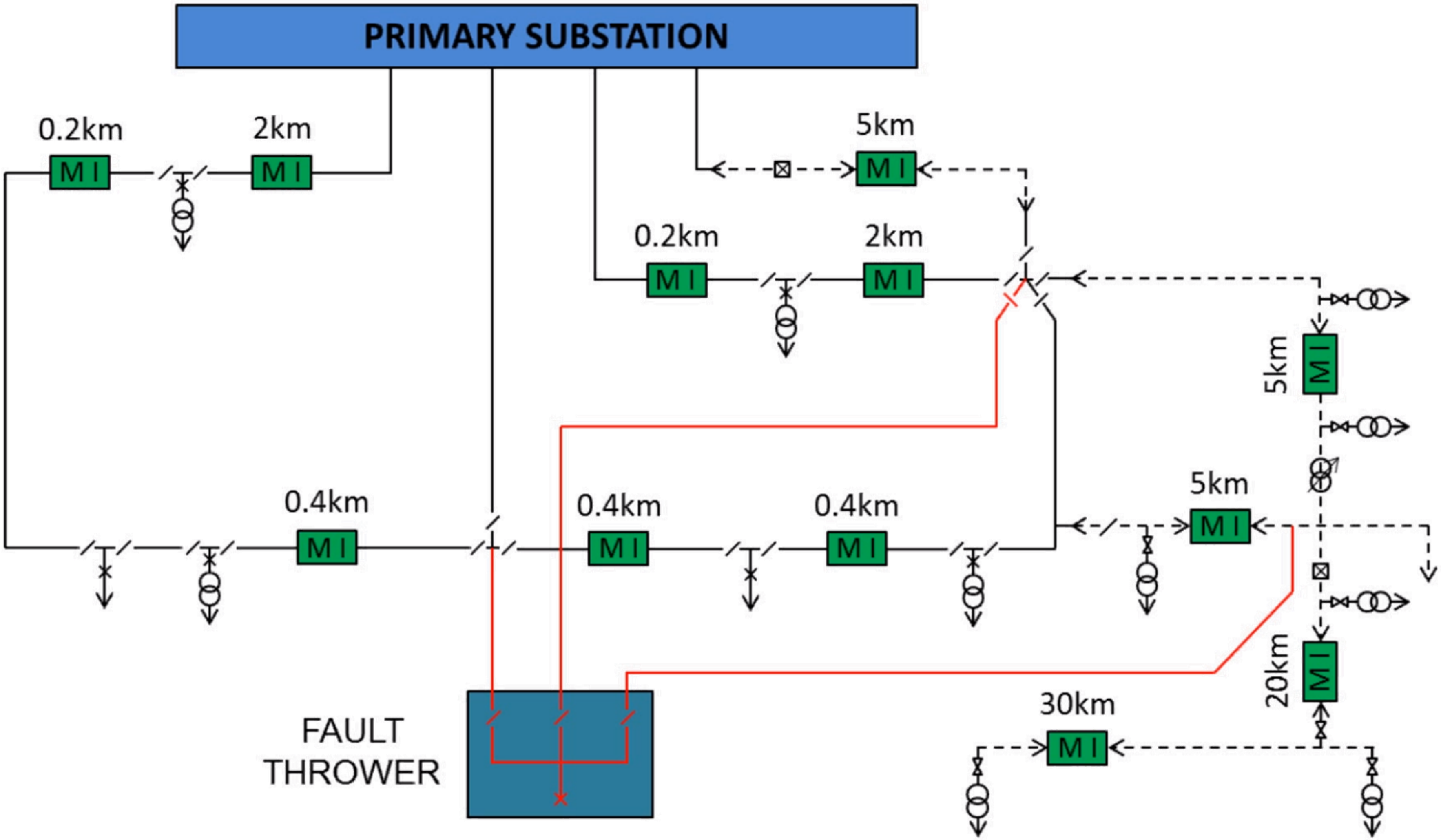
- Connected to 11kV distribution network.
- Supplied through an 11/11kV isolation transformer.

Islanded mode:

- The network is supplied from a 5MVA motor/synchronous generator set.
- Allows for voltage and frequency disturbances to be applied.

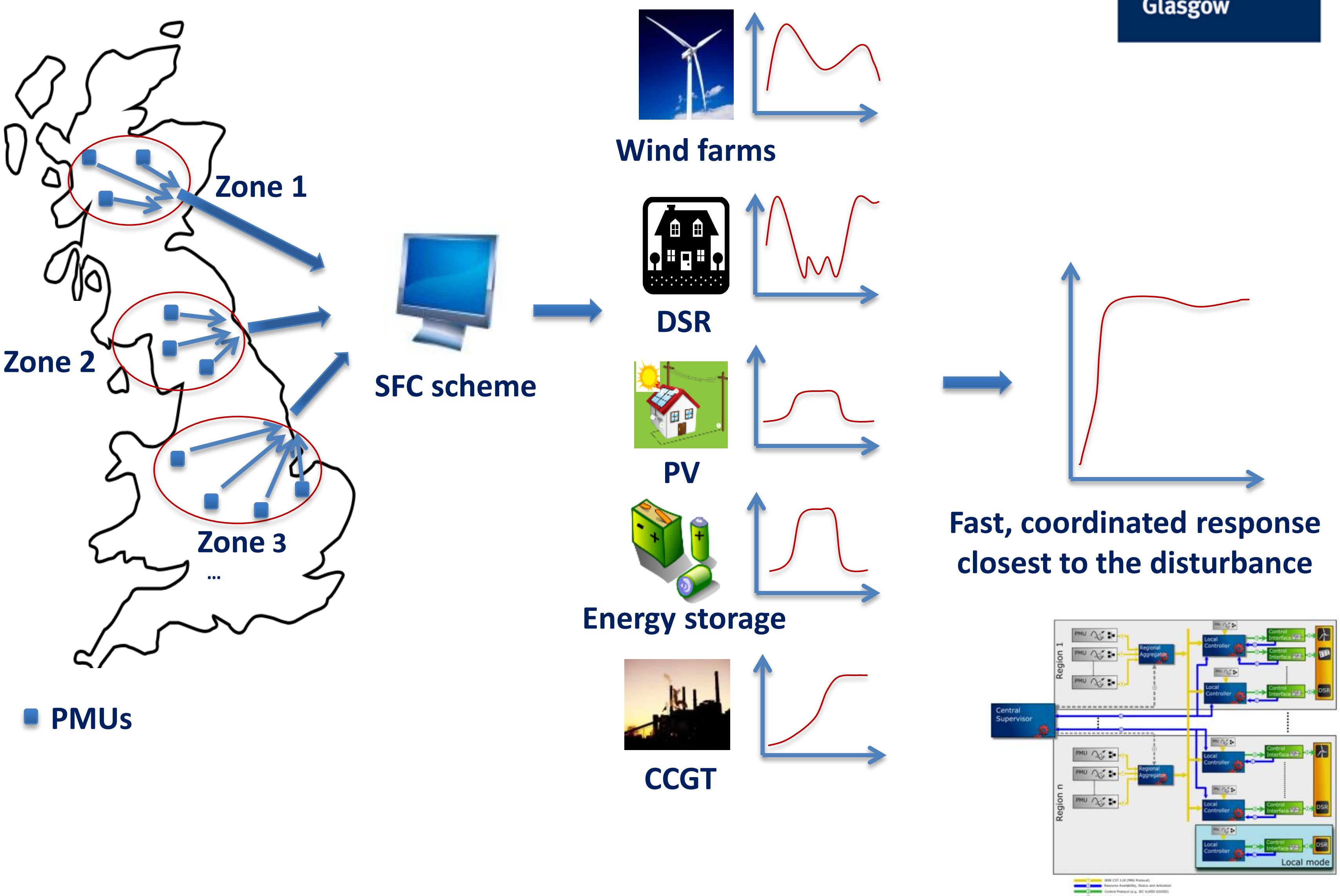


11 kV system

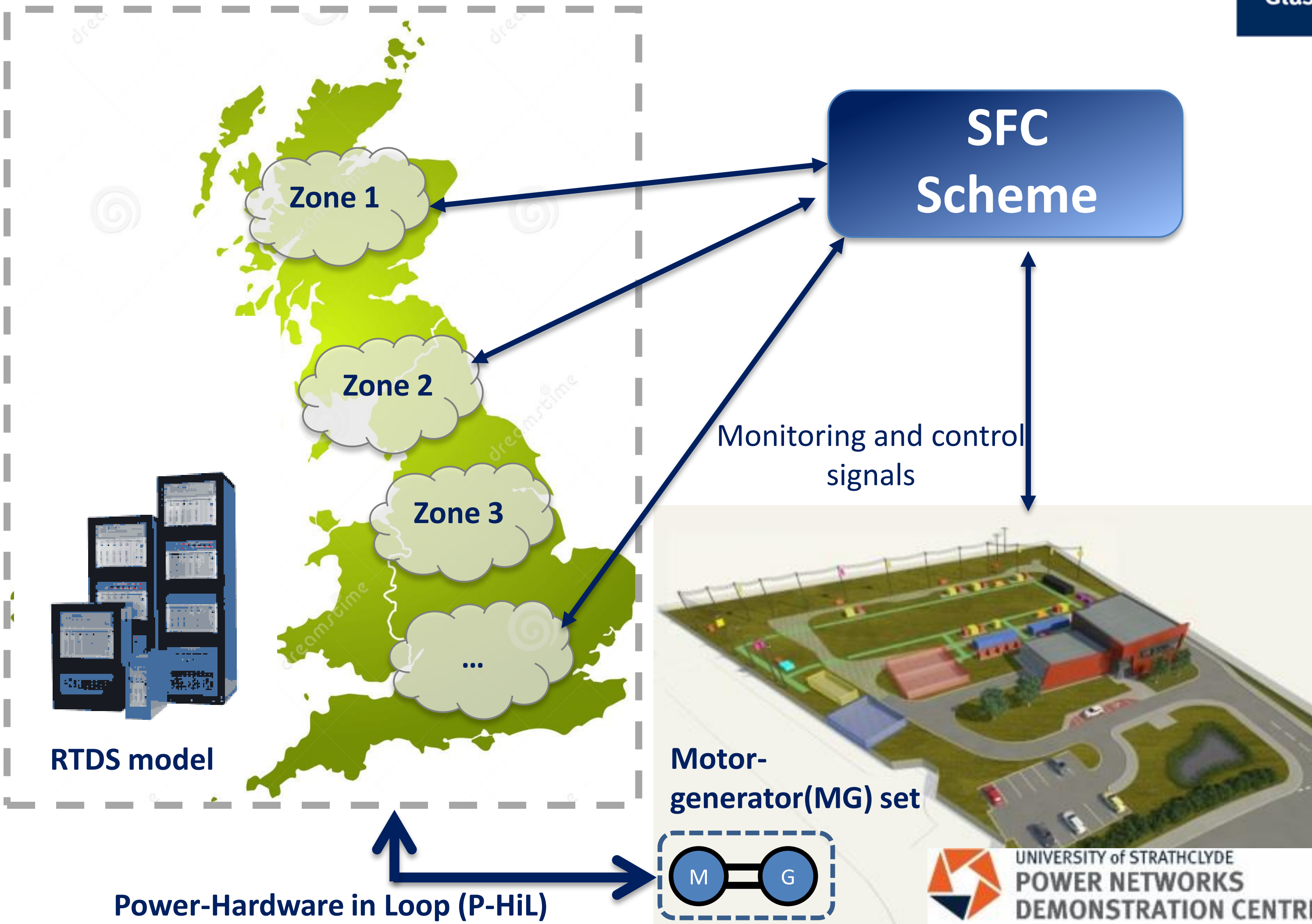


PRIMARY SUBSTATION
0.2km
2km
MI
5km
0.4km
20km
30km
FAULT
THROWER

The SFC scheme and the role of PNDC

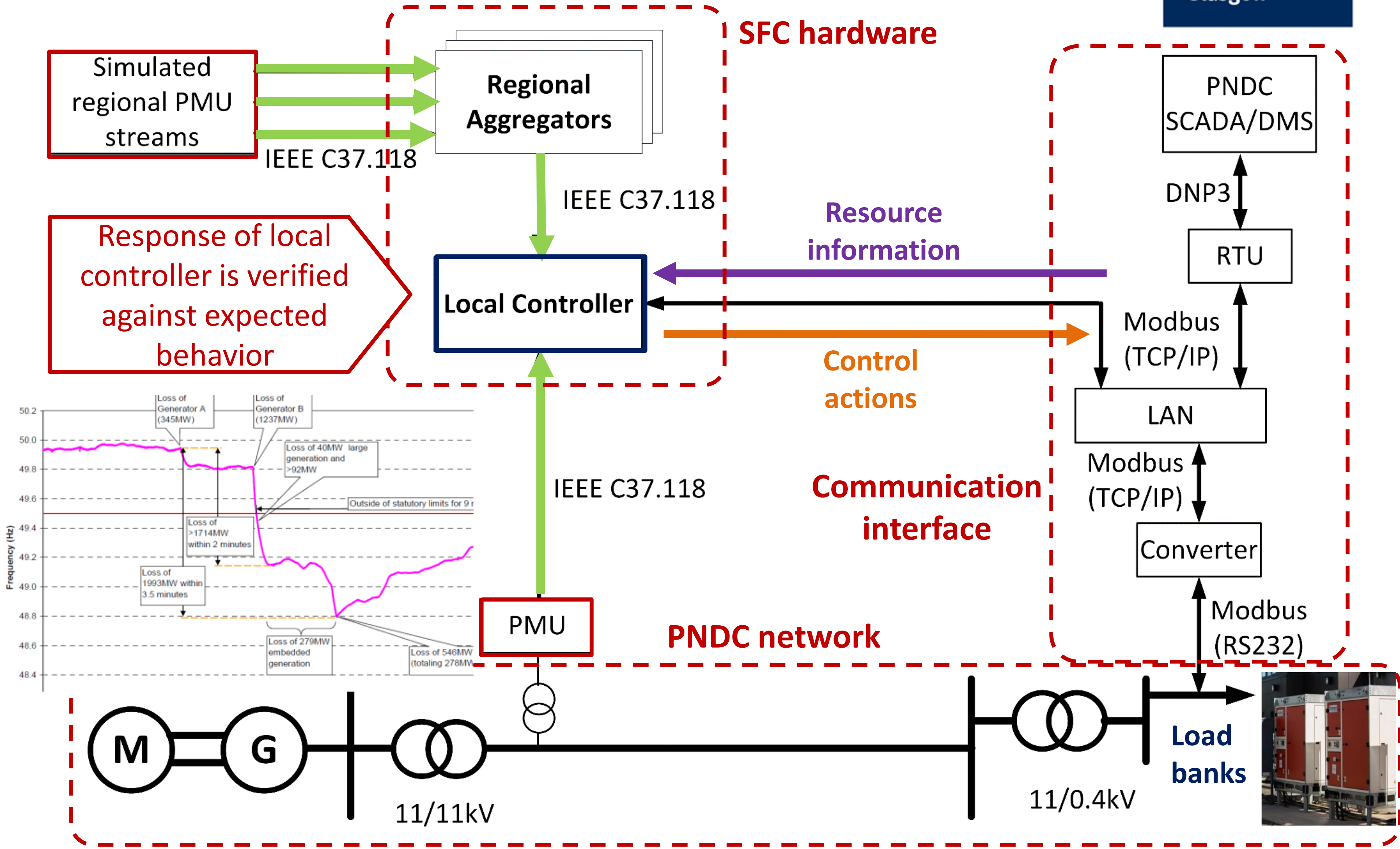


The SFC scheme and the role of PNDC



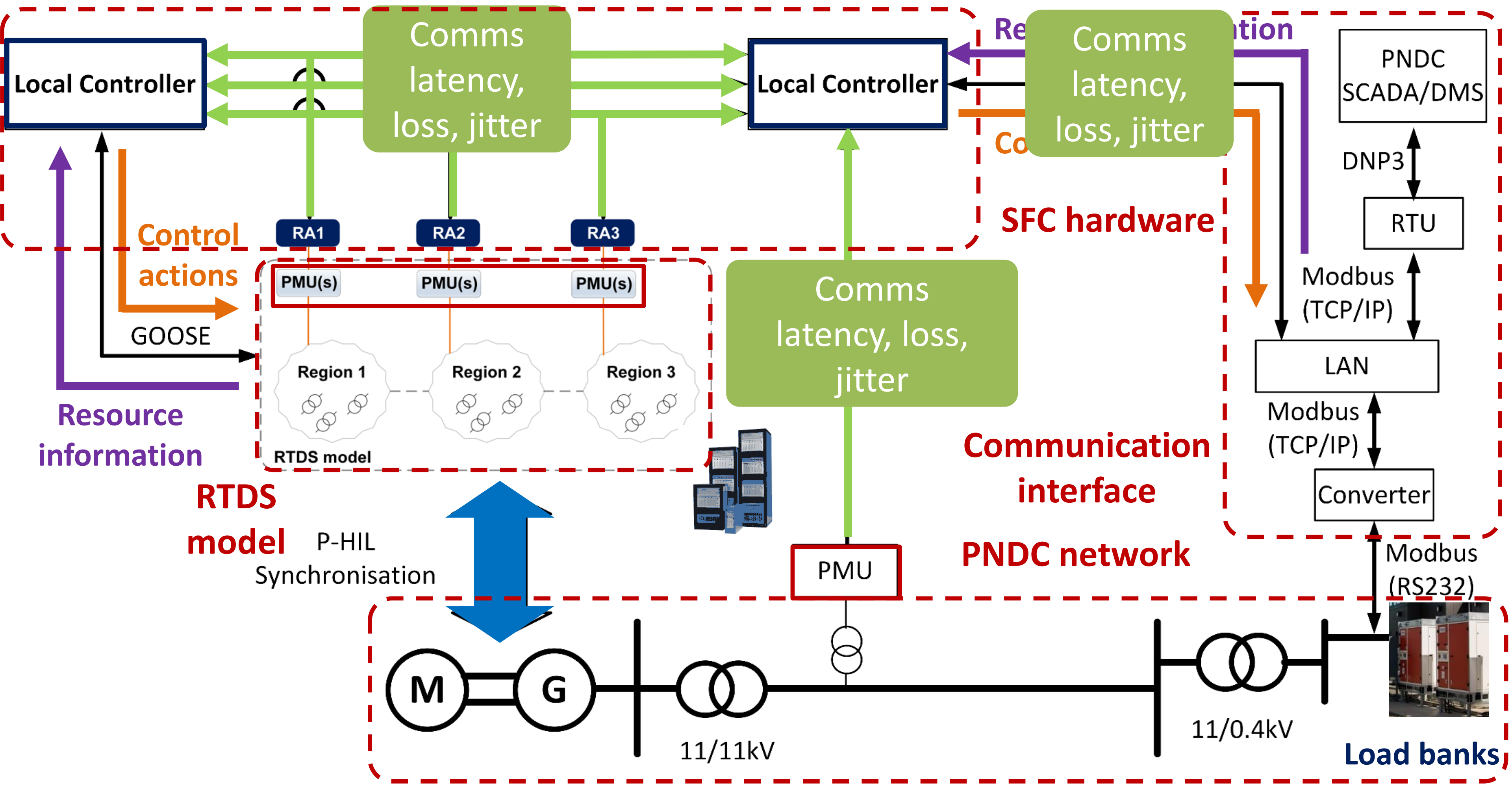
PNDC Tests: two stages

Stage 1 : Open-loop test

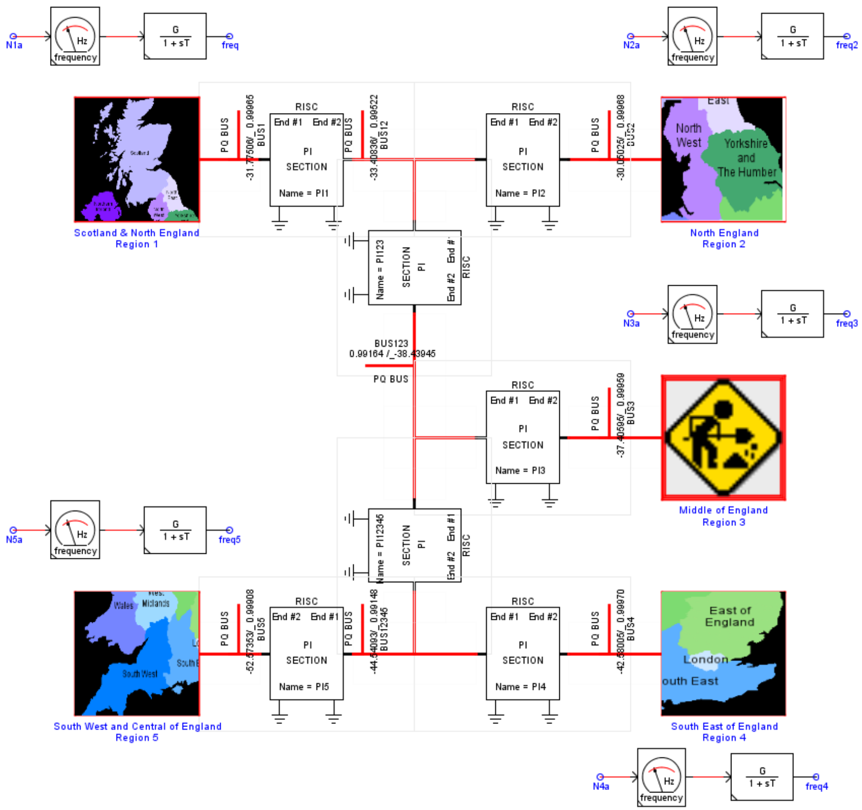


Stage 2: Closed-loop test: P-HiL simulation

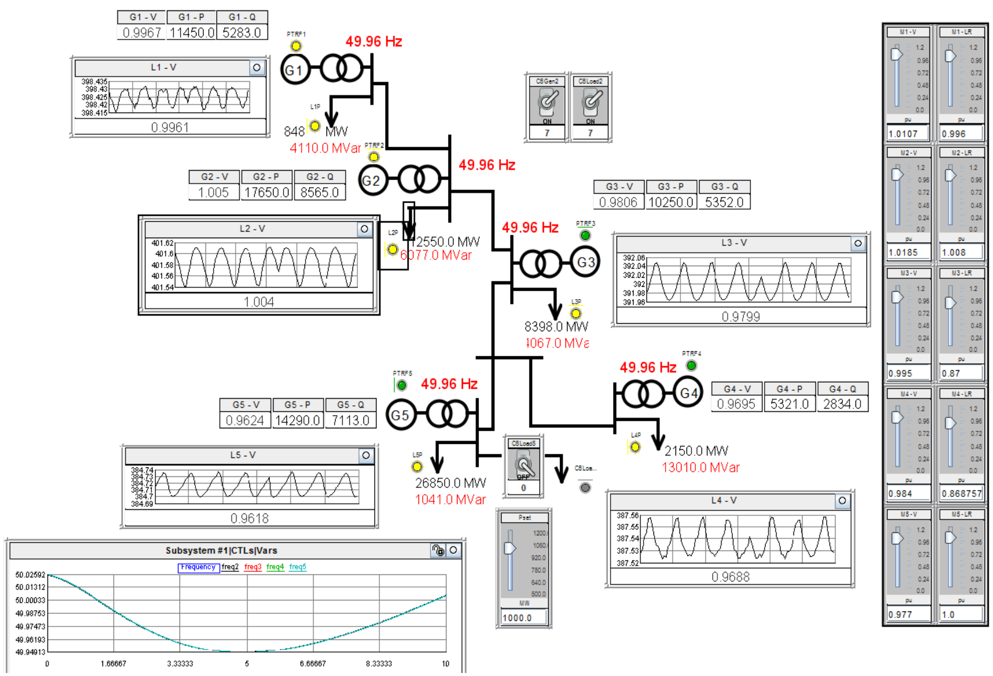
- Tests dependability and security of the SFC scheme
- Replace part of RTDS network with PNDC network
- SFC control over PNDC load(s)
- Emulation of latency & jitter to investigate the impact of communication issues



RTDS model being developed



Network model with 5 regions



Simulation using the model

Progress

- Comprehensive test plan developed.
- 5-bus RTDS model developed and being refined.
- PMU at PNDC and accurate voltage measurements in place.
- Simulation of various disturbances event using PowerFactory on-going.
- In the process of developing detailed specific test implementation plans and preparation of associated activities.
- …

Next steps

- Finalise specific test implementation plans and P-HiL arrangement at PNDC.
- Initial “pre-testing” activities – frequency and voltage transients.
- Investigate the impact of communication systems performance on the SFC scheme.
- …

Points to consider

- Ensuring a comprehensive list of credible events that allows intensive testing of the capability of SFC scheme under a wide range of scenarios.
- The requirements for the P-HiL arrangement to form a testbed with sufficient accuracy, repeatability and capability.
- Definition and quantification of realistic communications performance parameters and ranges to be tested.

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Demand Response.
Delivered.

Smart Frequency Control
Developing demand response methods

Flexitricity

Flexitricity in a nutshell

- Leader in I&C demand response
- >6,400 demand response events
- Industrial, commercial, public sector
- CHP, load, diesel, hydro, UPS
- 100kW to 24MW
- 24-hour operations
- Fully automated
- 1s to 30 minute response
- Innovative

The zoo of demand response activities

STOR

Frequency response

Wind following

Capacity market

Energy trading

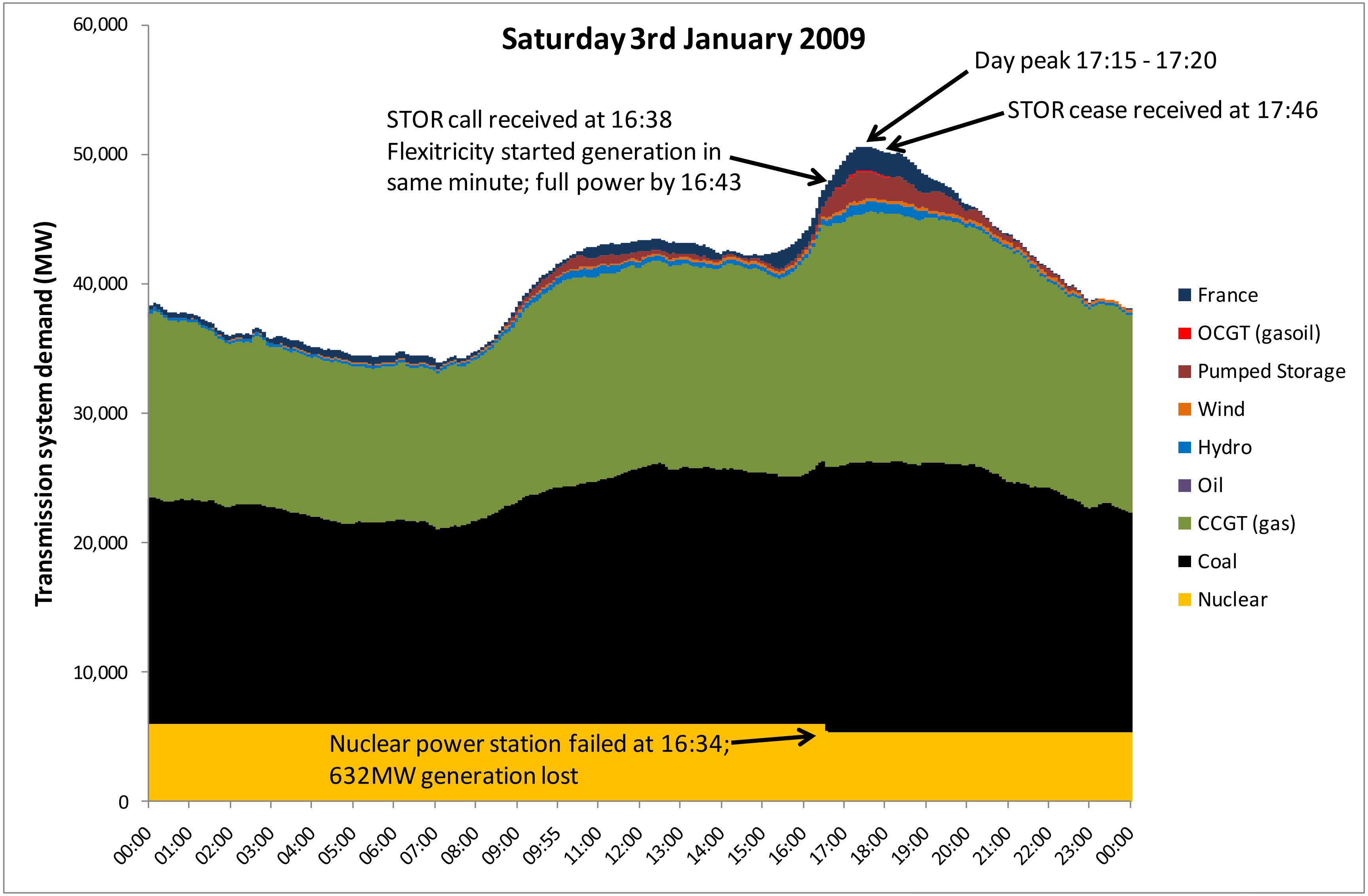
Distribution constraints

New network challenges

Voltage support

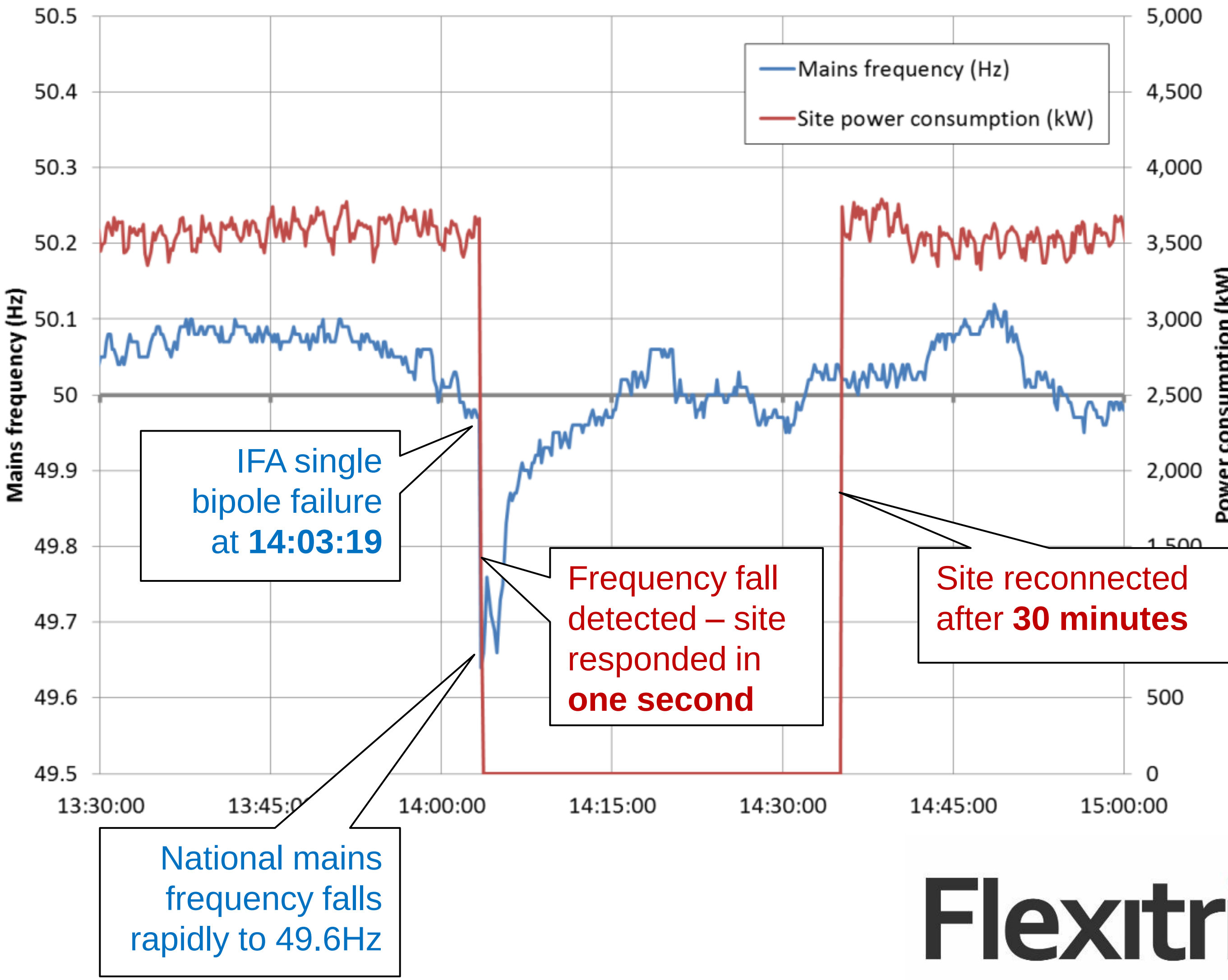
Peak reduction

Flexitricity



Flexitricity

Demand-side frequency response



Smarter Frequency Control

- **Objective:**
  - Can demand response help solve the inertia problem?
    - Providing a safety net?
    - Providing more synchronous spinning metal?
    - Adjusting load dynamically when frequency events occur?
  - Can it do this economically and efficiently?
  - Which resource types are best for which service?

Smart Frequency Control

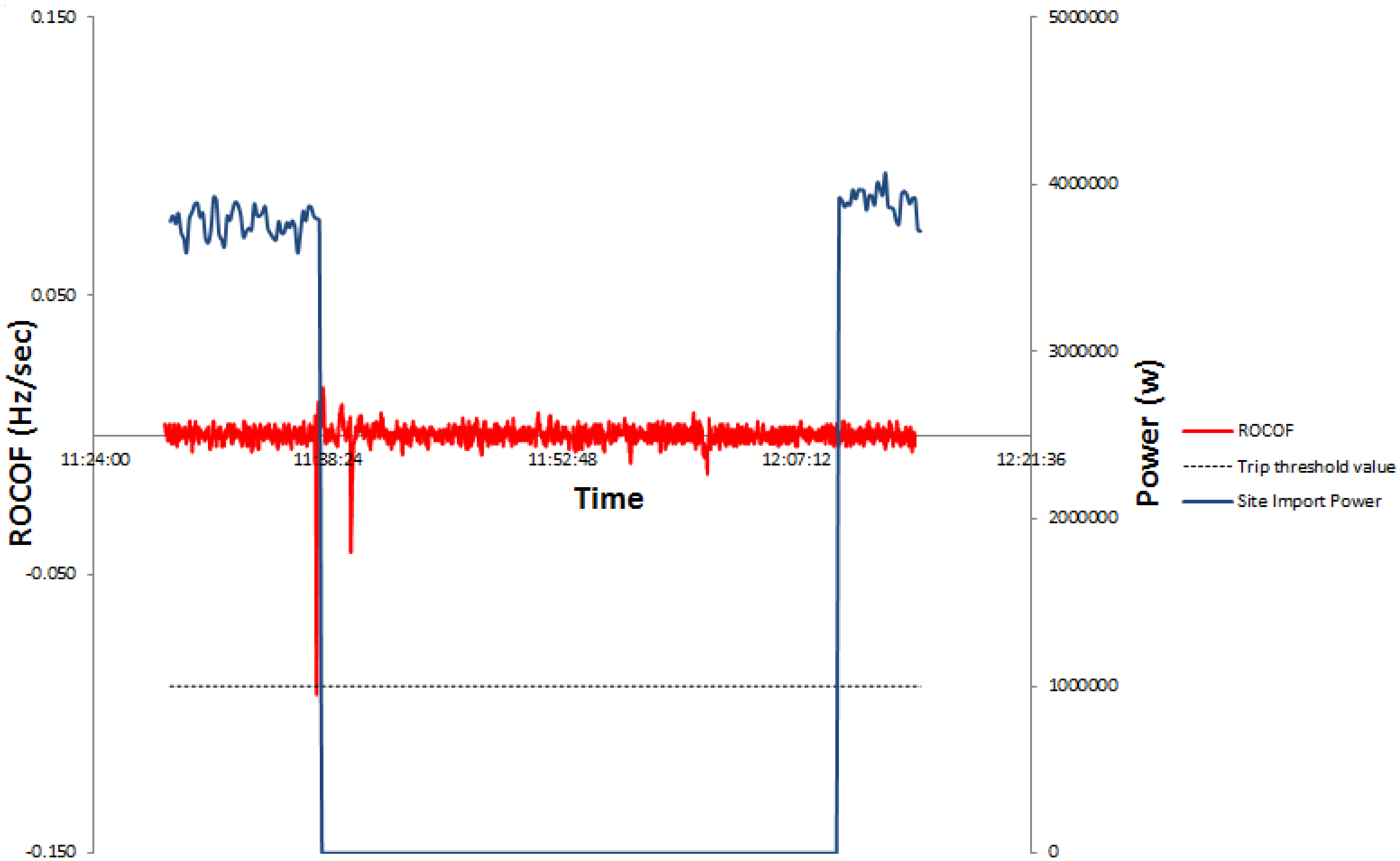
- Flexitricity works with 3rd party sites to provide MW capacity for demand side management
- Capacity will be provide for SFC in 3 ways:
  - Static RoCoF
  - Spinning Reserve
  - Dynamic RoCoF

Flexitricity

Static RoCoF

- Delivers full capacity for 30mins.
- Trips at threshold RoCoF value
- Responds within ~0.5-1.0 sec.
- Generation or load management
- Similar to FCDM

Flexitricity



Flexitricity

www.flexitricity.com 0131 221 8100

Spinning Reserve

- Maintain frequency by increasing inertia
- Rely of use of CHP units
- More spinning metal = more inertia
- Participating site will need => 2 CHP units

Flexitricity

+

+

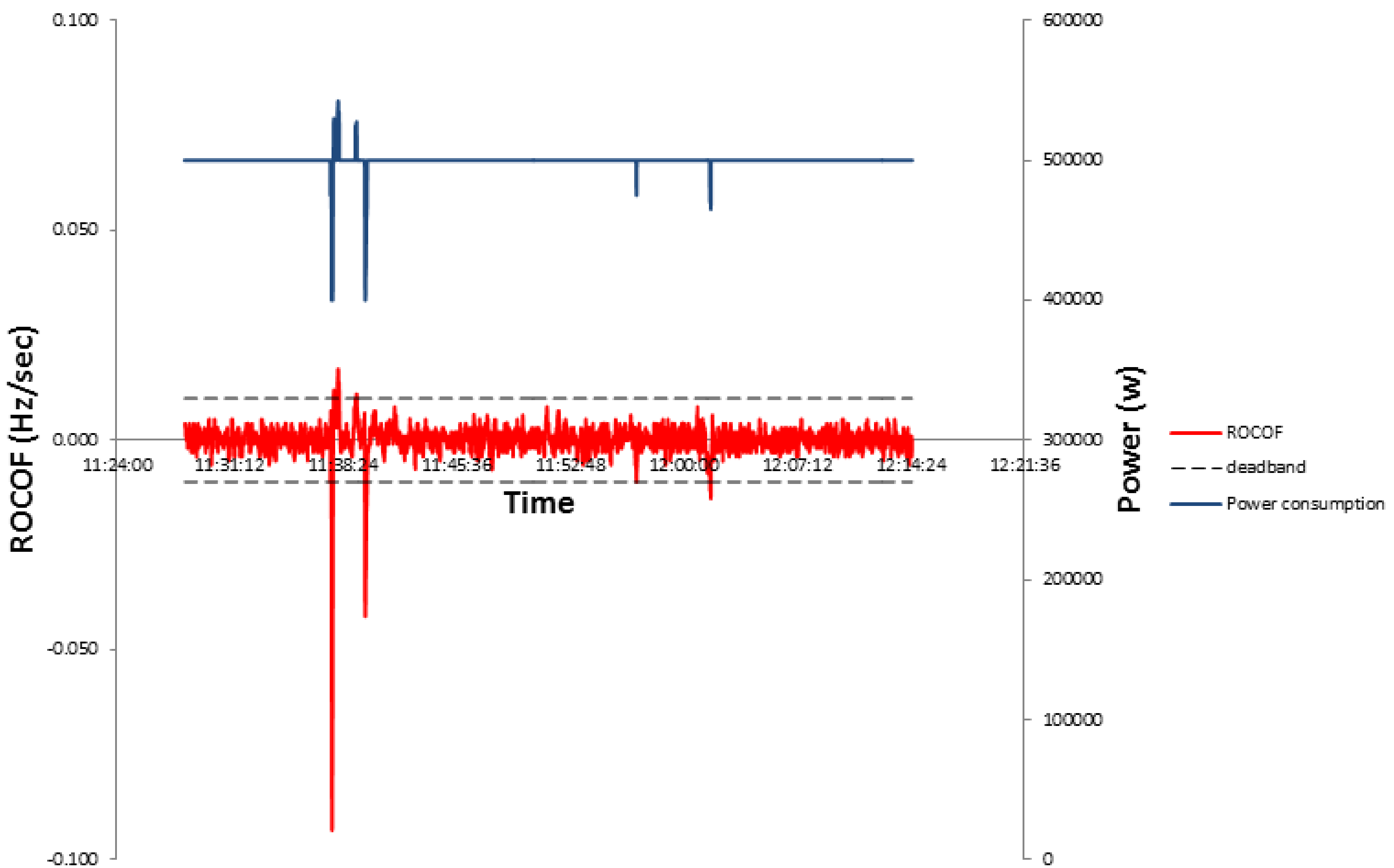
=

Flexitricity

Dynamic RoCoF

- For site with variable loads
- Load varies in response to changes to rate of change of grid frequency
- Uses variable speed drives

Flexitricity



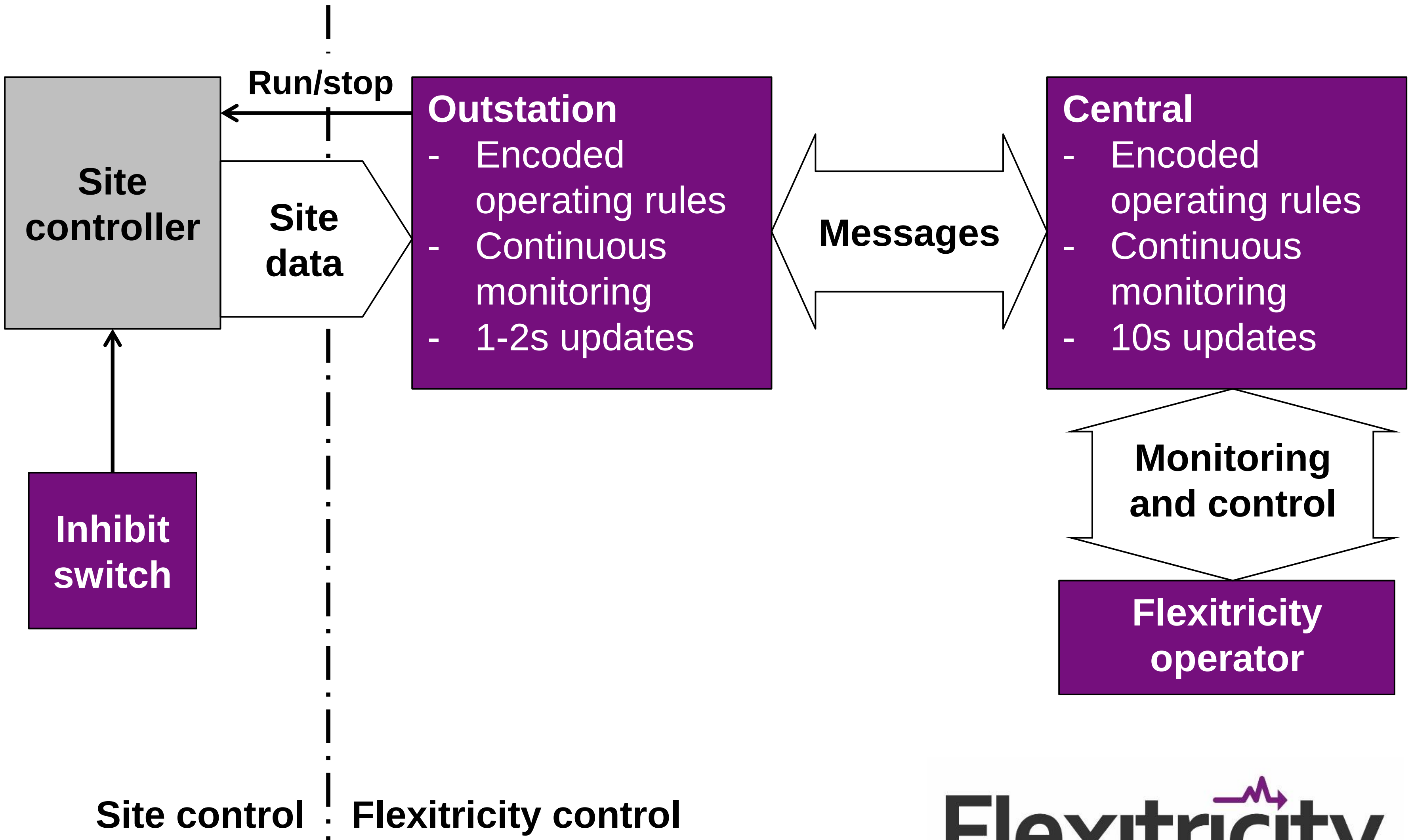
Flexitricity

What customers should expect

- No disruption
  - Production unaffected
  - Customer in control
  - Defensive engineering
- Worth it
  - We pay for hardware
  - Flat fee for trials
  - Sites proven for enduring service

Flexitricity

Defensive engineering



Flexitricity

Rules of engagement

- Customer in control
  - Sets operating rules
  - Sets schedules of availability
  - Opt out at any time
  - Hard and soft opt-out
- Limitations
  - Total number of events
  - Period between events
- Ensuring trial success
  - Engaging with site engineers
  - Detailed measurement
  - Ensuring events occur

Timeline

- Setting up for trials
  - Resource identification and appraisal: now
  - Solution design: spring 2016
  - Commissioning: summer 2016
  - Ready for trials from late 2016
  - Trials completed by October 2017
- Hitting the milestones
  - Defensive engineering takes time
  - Talk to us **now**

Flexitricity

Flexitricity operates the largest and most advanced demand-response portfolio in Britain. Join us today. Call **0131 221 8100.**

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National Grid – Dissemination event

”Distributed response: PV & Battery Storage”

EFCC – Enhanced Frequency Control Capability

BELECTRIC: Company profile

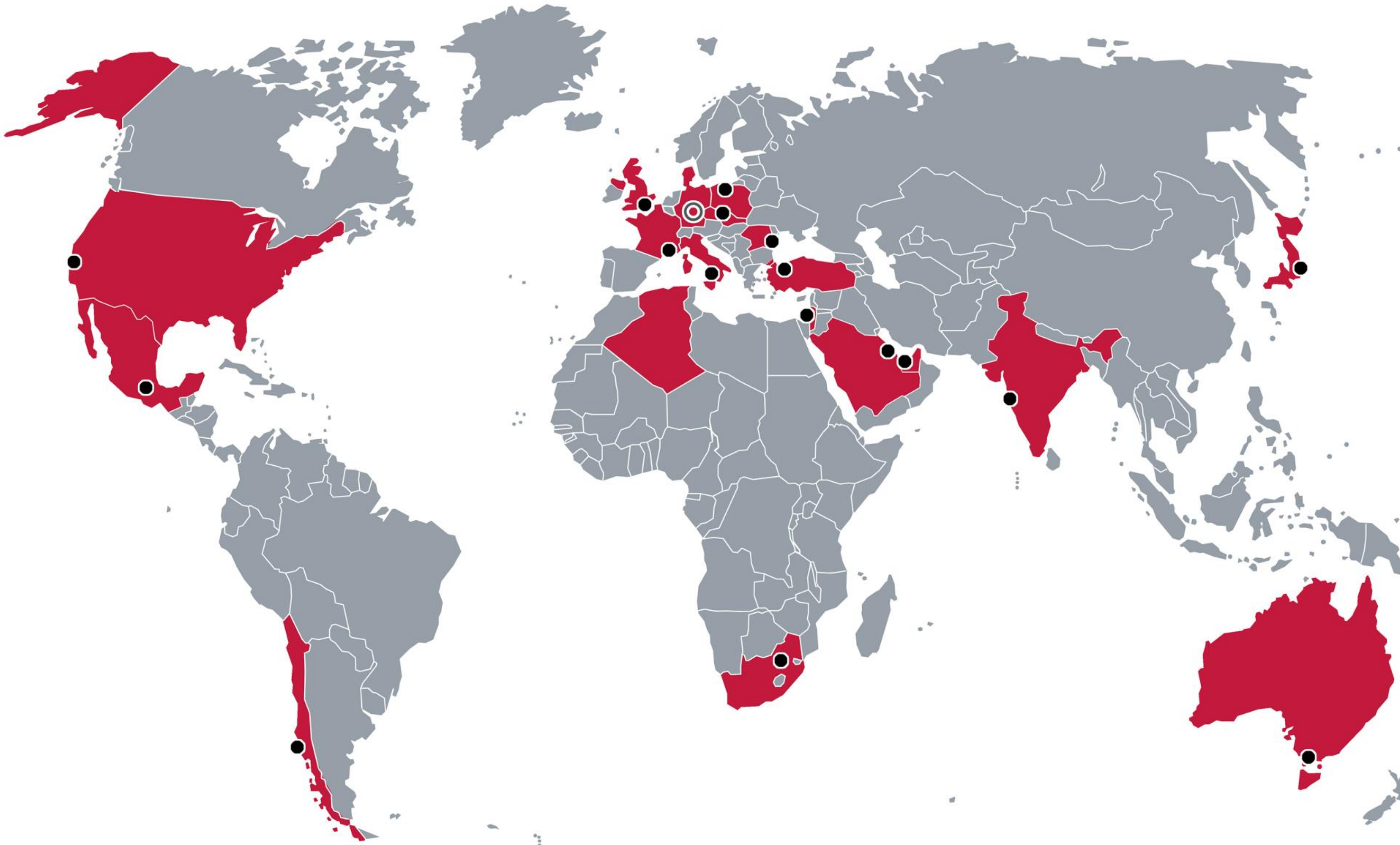
- Yearly total revenue of **550M EUR**
- More than **1,200 employees** in **20 countries**
- **Over 120 patents** registered since 2001
- **Technology leader** in the utility-scale solar power business

12+ YEARS OF EXPERIENCE

500+ CONSTRUCTION WORKERS WORLDWIDE

1500+ MWp WORLDWIDE INSTALLED SOLAR POWER

BELECTRIC: International



BELECTRIC Headquarters: Germany - Regional offices: Australia, Chile, Czech Republic, Denmark, France, Greece, India, Italy, Japan, Malaysia, Mexico, Poland, Romania, Saudi Arabia, Switzerland, Turkey, United Arab Emirates, United Kingdom, USA

Agenda

Batteries: state of the art

- EFCC: Advantages of Batteries
- EFCC: Combined frequency response from PV and Battery
- EFCC: Challenges of the transformation to renewables

Battery Energy Storage in Steglitz 1986-1994

One of 12 battery rooms:

- Operational scheme: frequency response
- Power: 17 MW, 14 MWh
- Lead acid batteries, total cycles after 7 years of operation: ~ 7000
- Max. power gradient limit: 12 MW/s
- Payback time: 3 years

Battery standalone: Alt Daber battery park

- Technology: Advanced Lead Acid
- Capacity: 1,9 MWh
- Power: 1,3 MW (1,6 MW) at a 68 MW PV solar farm
- Frequency response
- Commercially operating – equals the spinning reserve of a 25MW conventional PP
- Alt Daber/Germany

BELECTRIC®

Prequalification: Alt Daber battery park

Press release and articles about the commissioning and the **successful prequalification** of the Energy Buffer Unit in Alt Daber.

BELECTRIC®

Press Release
Friday, 8 May 2015

Energy Storage System BELECTRIC EBU prequalified for frequency response

BELECTRIC EBU meets the prequalification requirements and is thus able to provide most important balancing service for the electric grid

Berlin/Kolitzheim: Formally inaugurated last November at the Solar Power Plant Alt Daber in Brandenburg, BELECTRIC's Energy Buffer Unit (EBU) has been successfully prequalified for 1.3MW frequency response by the transmission network operator (TNO) 50Hertz. The Energy Buffer Unit is thus officially approved for the provision of the most important ancillary service for grid operation: frequency response. From the Alt Daber location, the BELECTRIC EBU will assist in Germany-wide frequency control in the high voltage grid. Equipped with the latest storage technology, it constitutes a necessary component for a reliable grid operation, one that is increasingly influenced by renewable energies.

To be prequalified, a technical unit must demonstrate that it meets the TNO's requirements for security of the supply of frequency response. New ground was broken for capacity-limited units (i.e. battery storage) and, in close cooperation with the TNO, appropriate test specifications were defined. Evidence has thereby been provided that battery storage improves the safety of transmission network operation, even during heavy fluctuations like a generator or interconnector trip. Now that the BELECTRIC EBU has successfully passed prequalification, Vattenfall can market the Alt Daber energy storage system as part of its frequency response pool. Services from the EBU will be offered on the frequency response market on a weekly basis. Due to rising prices in this market over the last three years, attractive business models are now appearing for the use of energy storage therein.

With its Energy Buffer Unit, BELECTRIC delivers a state-of-the-art battery based energy storage system in a container solution. The EBU is shipped with power inverter and medium voltage transformer and features a nameplate power between 800kW and 1400kW, depending on configuration. It has a storage capacity of 948 kWh and is available starting at 560,000 EURO. It can be prequalified for frequency response on the German transmission network with up to 650 kW, taking into account reserve capacity required by the German TNOs. The advanced lead-acid batteries were developed for a long service life and high cycling stability for high performance applications. Thanks to standardization, the serially produced BELECTRIC EBU is the most cost-effective utility scale energy storage system currently available on the market for frequency response and other cyclic applications.

Photo: BELECTRIC EBU at the solar power plant Alt Daber, Germany

About BELECTRIC: BELECTRIC is one of the most successful enterprises in the realization of free-field solar power plants and utility-grade energy storage systems. Through its joint venture partners and subsidiaries BELECTRIC operates worldwide. Its sophisticated system expertise is the result of the high degree of vertical integration in the development and manufacturing processes. The reconciliation of economic efficiency and ecology forms the basis for the company's sustainable success. With numerous patents and innovations, BELECTRIC has proven its technological leadership in the industry. Complementing its solar power generation capabilities BELECTRIC Drive® manufactures intelligent charging products for electric vehicles.

Publication and reprint free of charge; specimen copy is requested.

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Battery standalone: WEMAG battery park

- Technology: Samsung SDI lithium-ion
- Capacity: 5 MWh
- Power: 3,8 MW (5 MW)
- Frequency response
- Commercially operating
- Schwerin/Germany

WEMAG

Battery standalone: DREWAG battery park

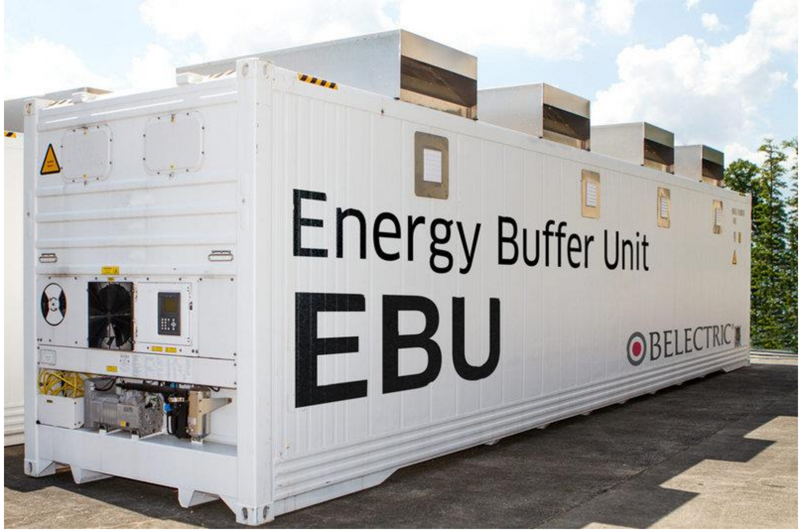
- Technology: LG Lithium-Polymer
- Capacity: 2,7 MWh
- Power: 1,8 MW
- Frequency response
- Commercially operating
- Dresden/Germany

Battery standalone: UPSIDE battery park

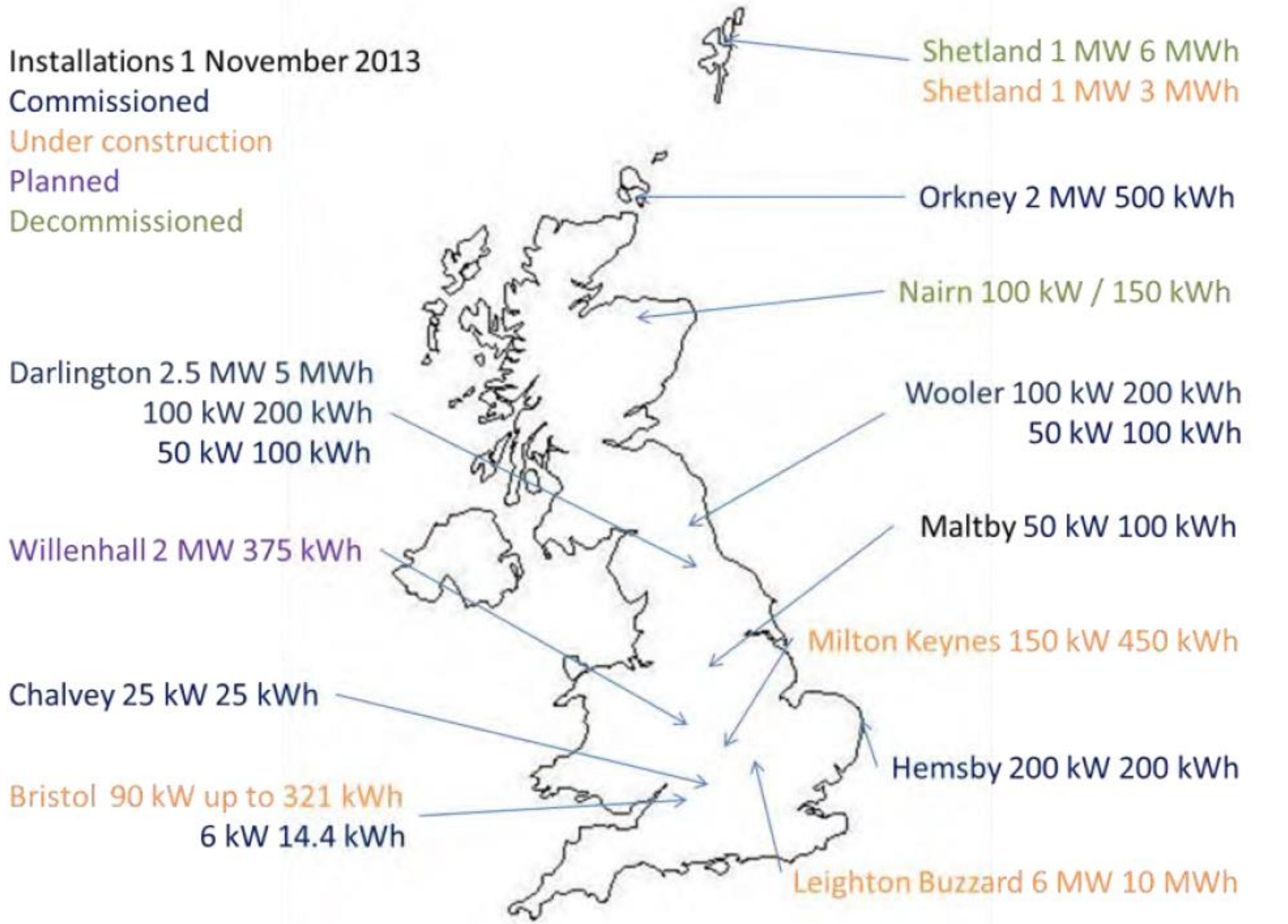
- Technology: lithium-Ion
- Capacity: 5 MWh
- Power: 5 MW
- Frequency response
- Commercially operating
- Neuhardenberg/Germany

Hybrid System: Battery Innopark Kitzingen

- Main revenue stream: ancillary service
- Battery in combination with diesel Genset and PV
  - Peak shaving
  - Self consumption
  - Increasing prequalified power for ancillary services
- Island grid test field



Battery Projects: UK



Practical Example: Leighton Buzzard

- Technology: lithium-ion NMC, Samsung SDI
- Capacity: 10 MWh
- Power: 6 MW
- DNO Peak shaving / ancillary services including frequency response in preparation
- Commercially operating
- Leighton Buzzard/UK, operated by UKPN

Practical Example: Rise Carr, Darlington

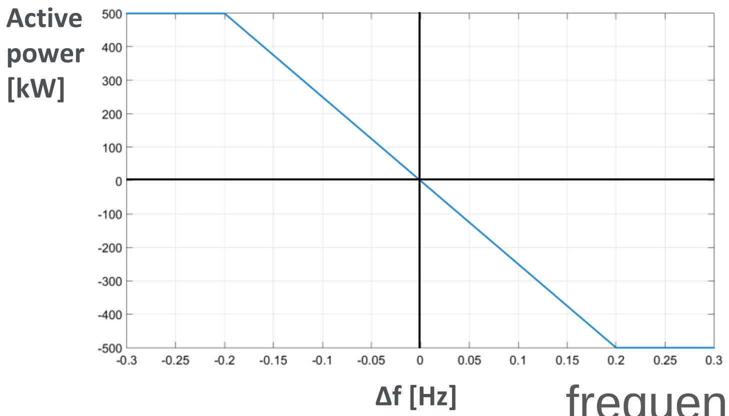
- Technology: 123 sytems Inc., Lithium Iron Nanophosphat
- Capacity: 5 MWh
- Power: 2,5 MW
- DNO Peak shaving / voltage support
- Commercially operating
- Rise Carr, Darlington/UK, operated for Northern Powergrid

Agenda

- Batteries: state of the art
- **EFCC: Advantages of Batteries**
- EFCC: Combined frequency response from PV and Battery
- EFCC: Challenges of the transformation to renewables

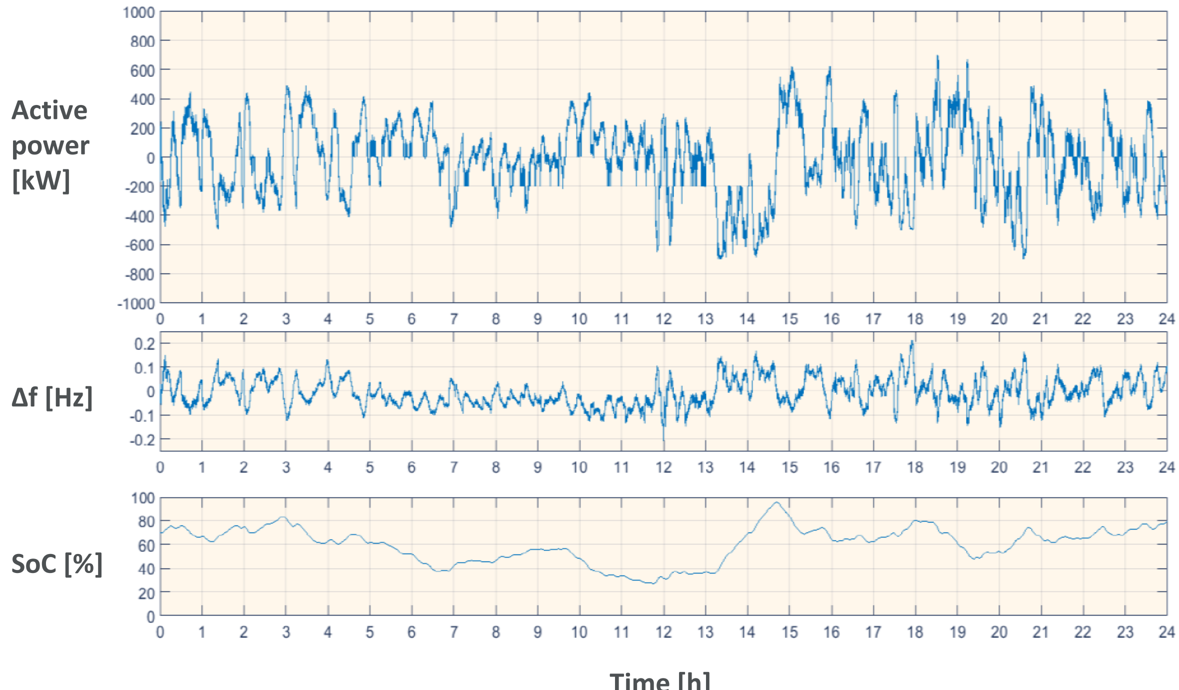
Firm Frequency response

P(f)-diagram for frequency response in UK

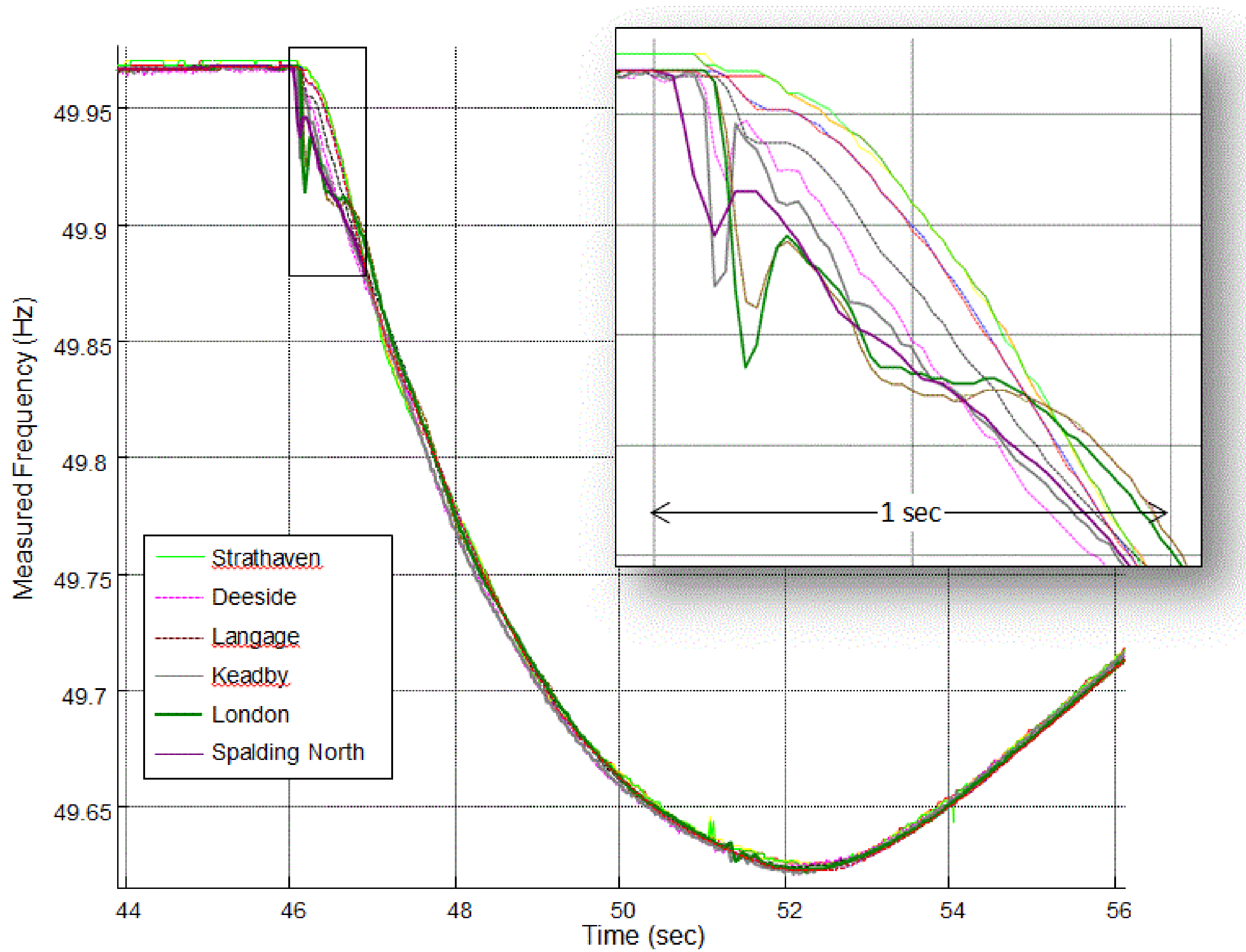


- Frequency-dependent rapid deployment of power(Δf)
- Option df/dt behavior like synchronous machine

frequency response with battery



Why fast Batteries?



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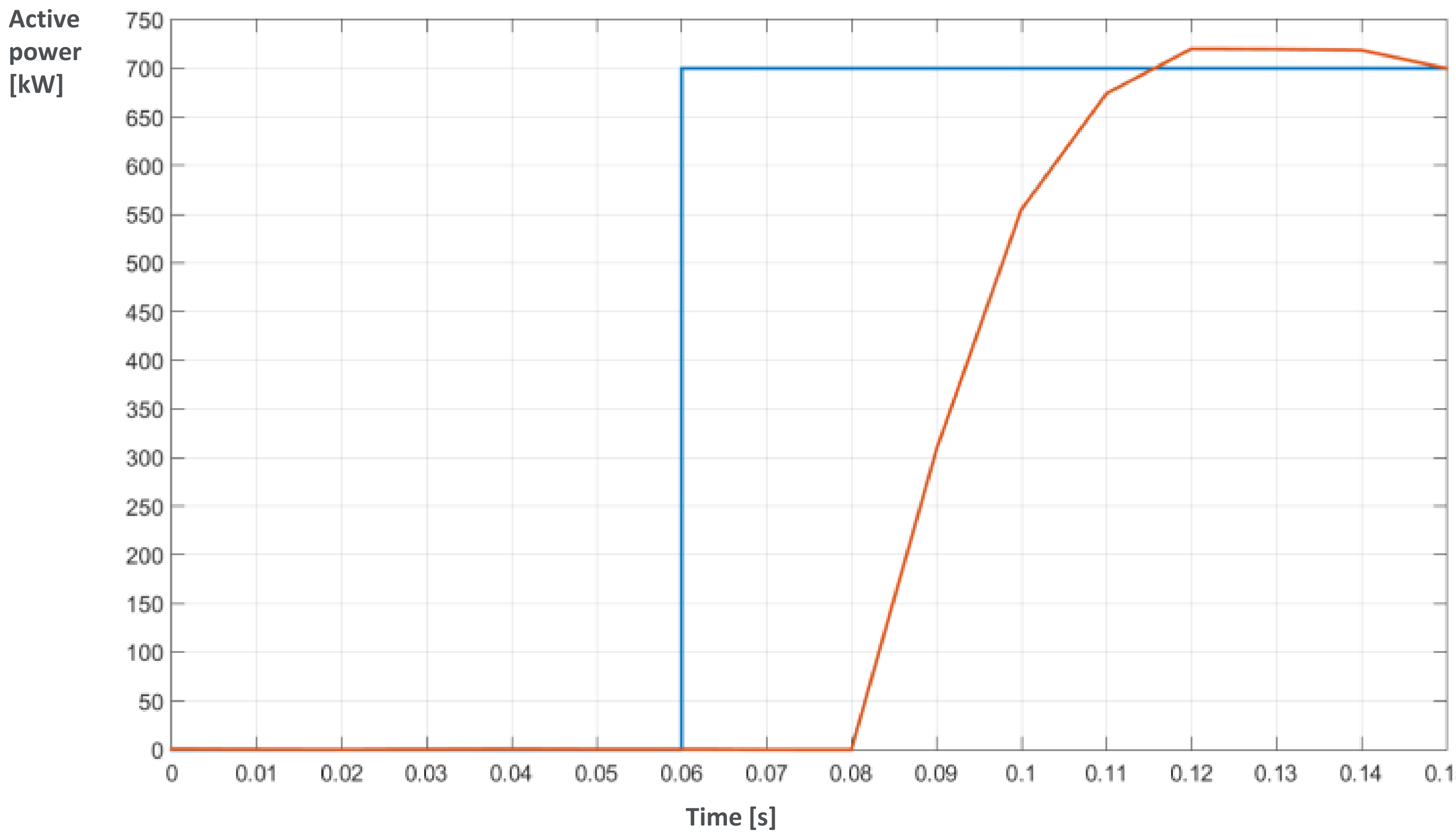
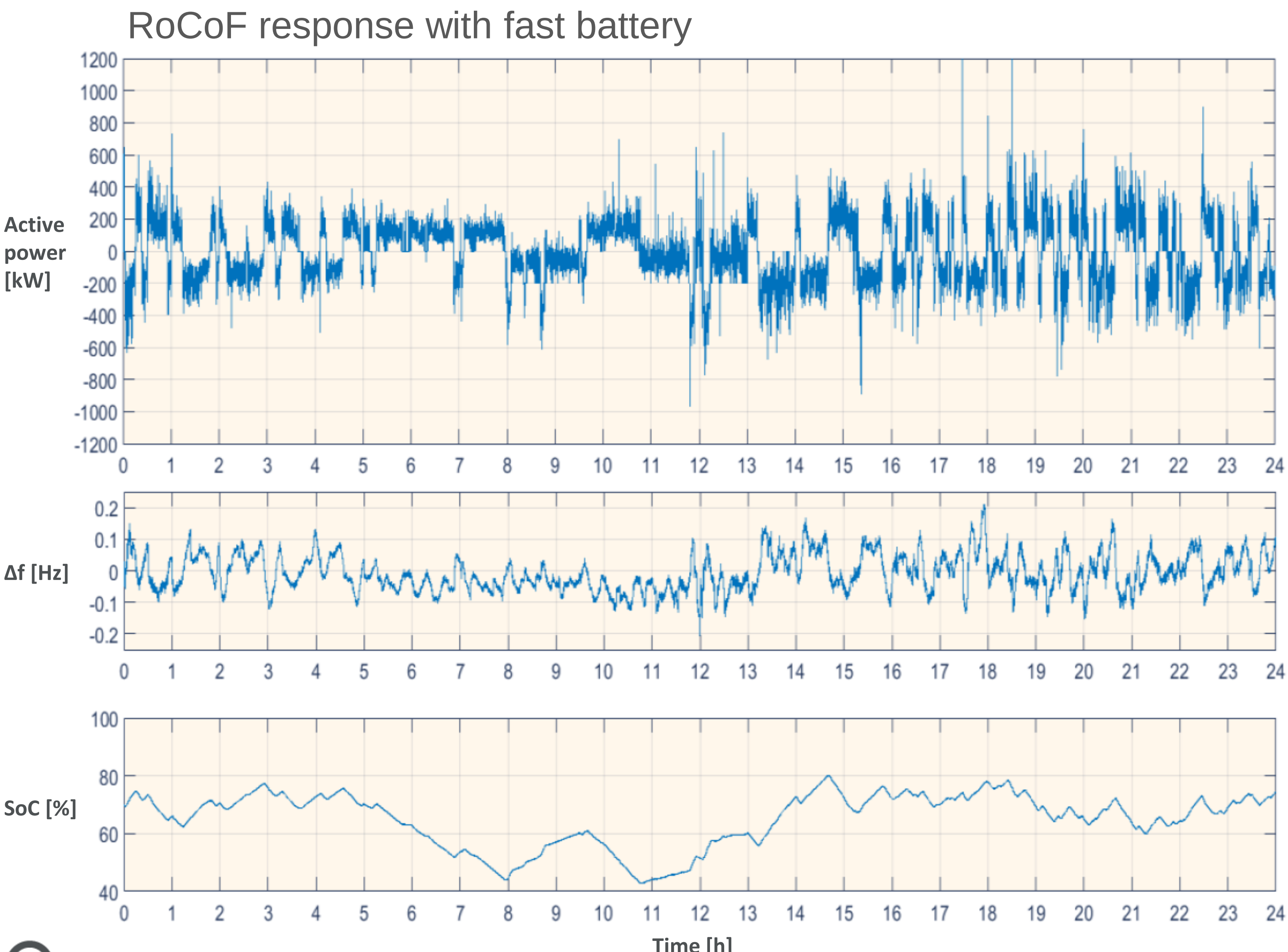
How fast are batteries?



55 ms from request to full response

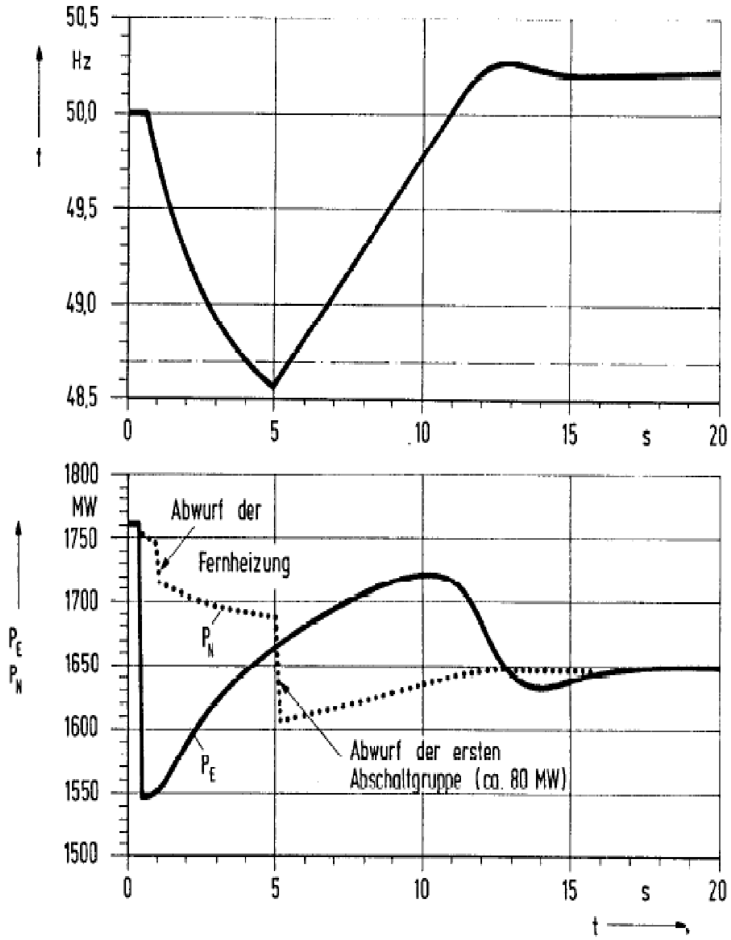
Using fast Batteries



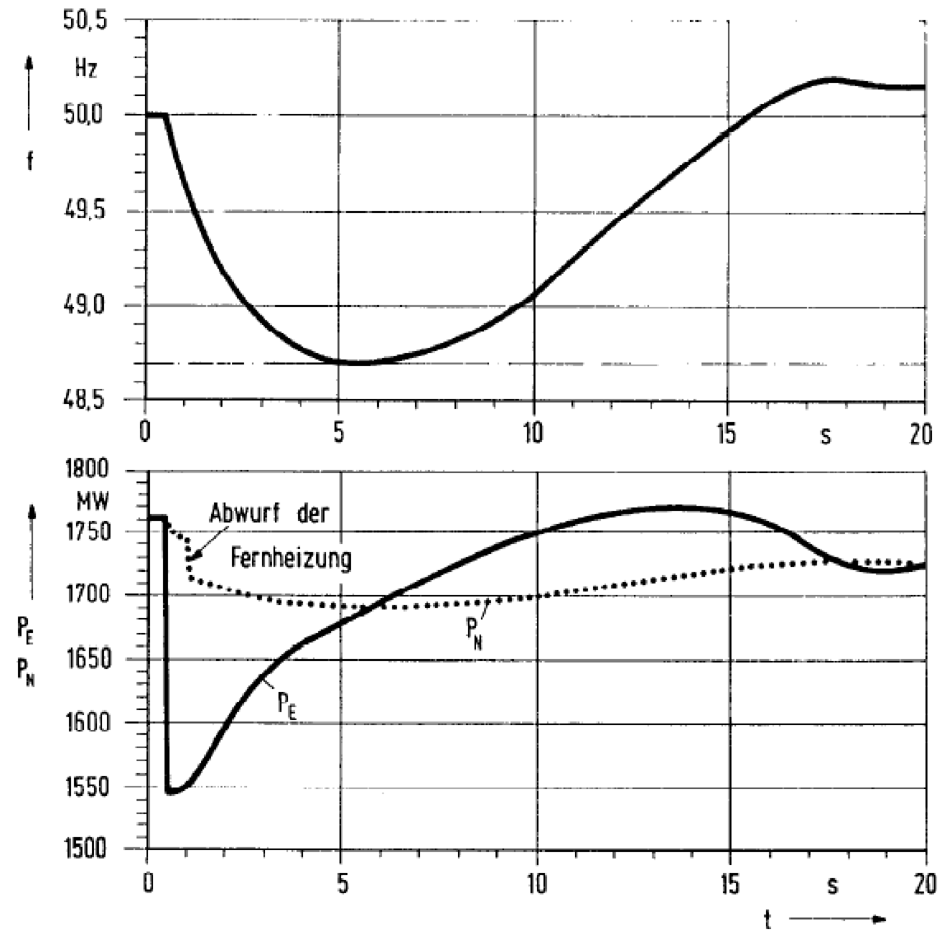
Using fast Batteries

Failure simulation (217 MW / 1760 MW)

without storage

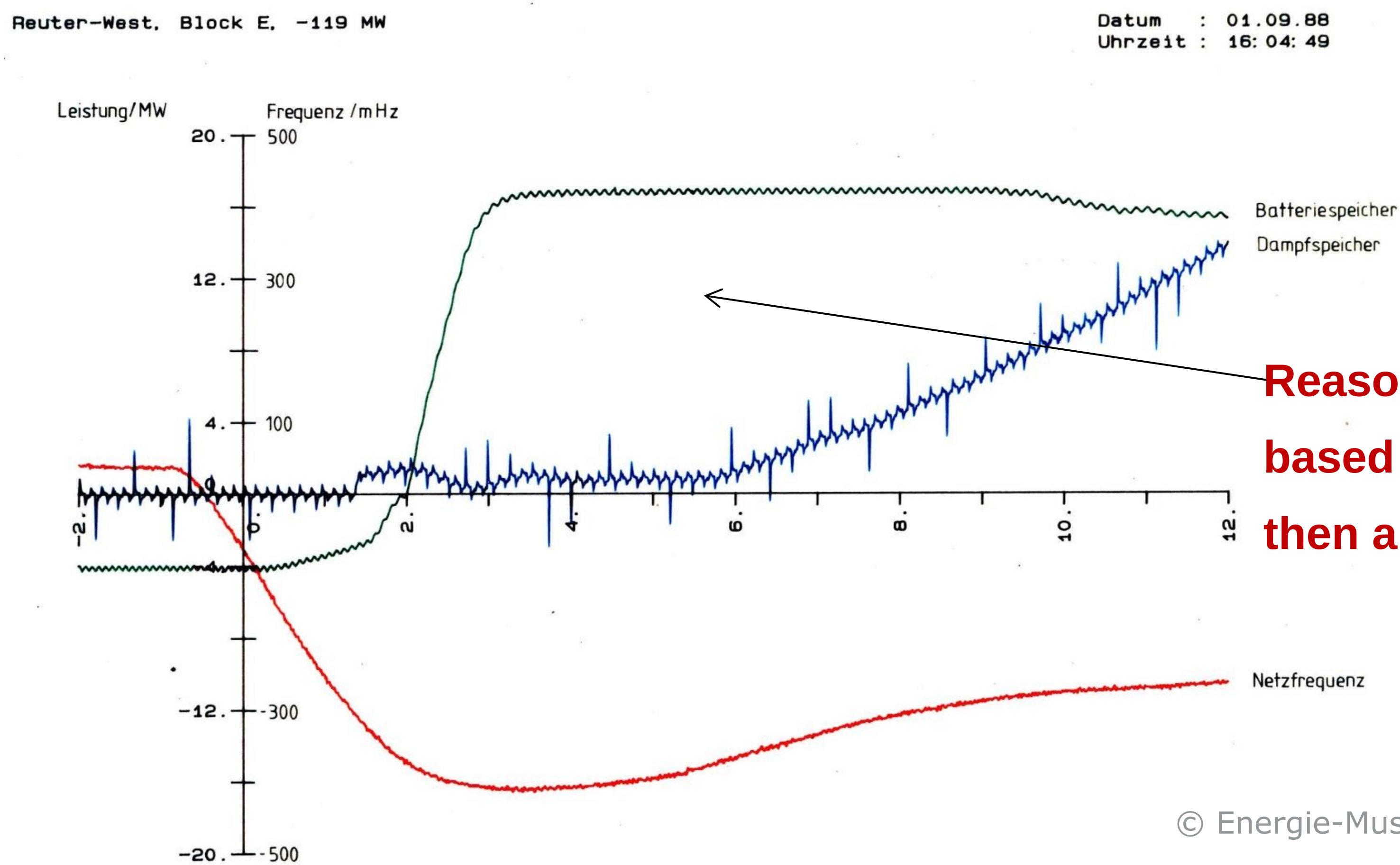


with storage (20 MW)



Using fast Batteries

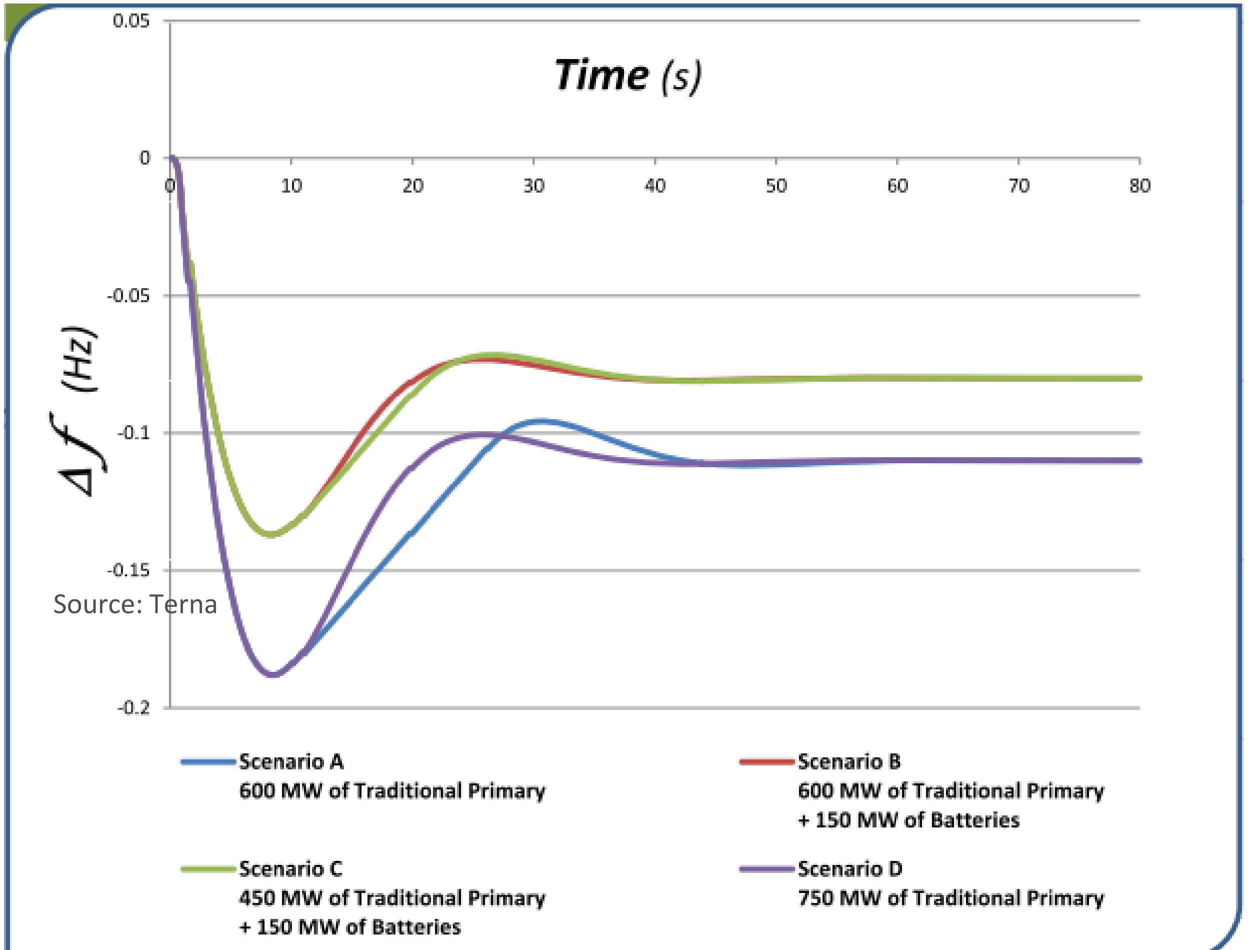
Operation mode of instant reserve



Reason for battery based response, then and today.

Does physics change over time?

- TERNA, Italy, 2014:



Activation time is equally important as pure power :

→ Short response times reduce total power needed for frequency response

→ Savings for the customer

System: **"Pay as performed", RoCoF-Following, EFR, EFCC,…**

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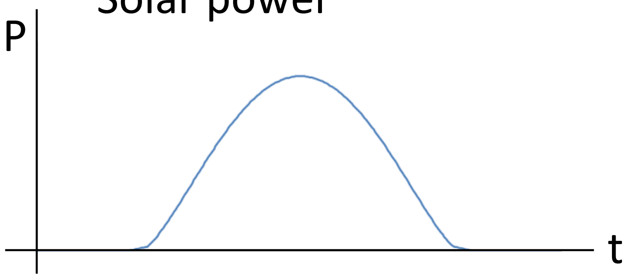
Solar farm in the UK

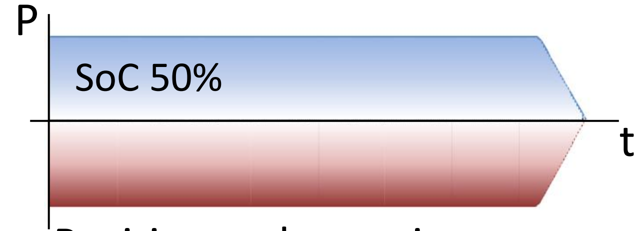
Distributed control power

Solar power



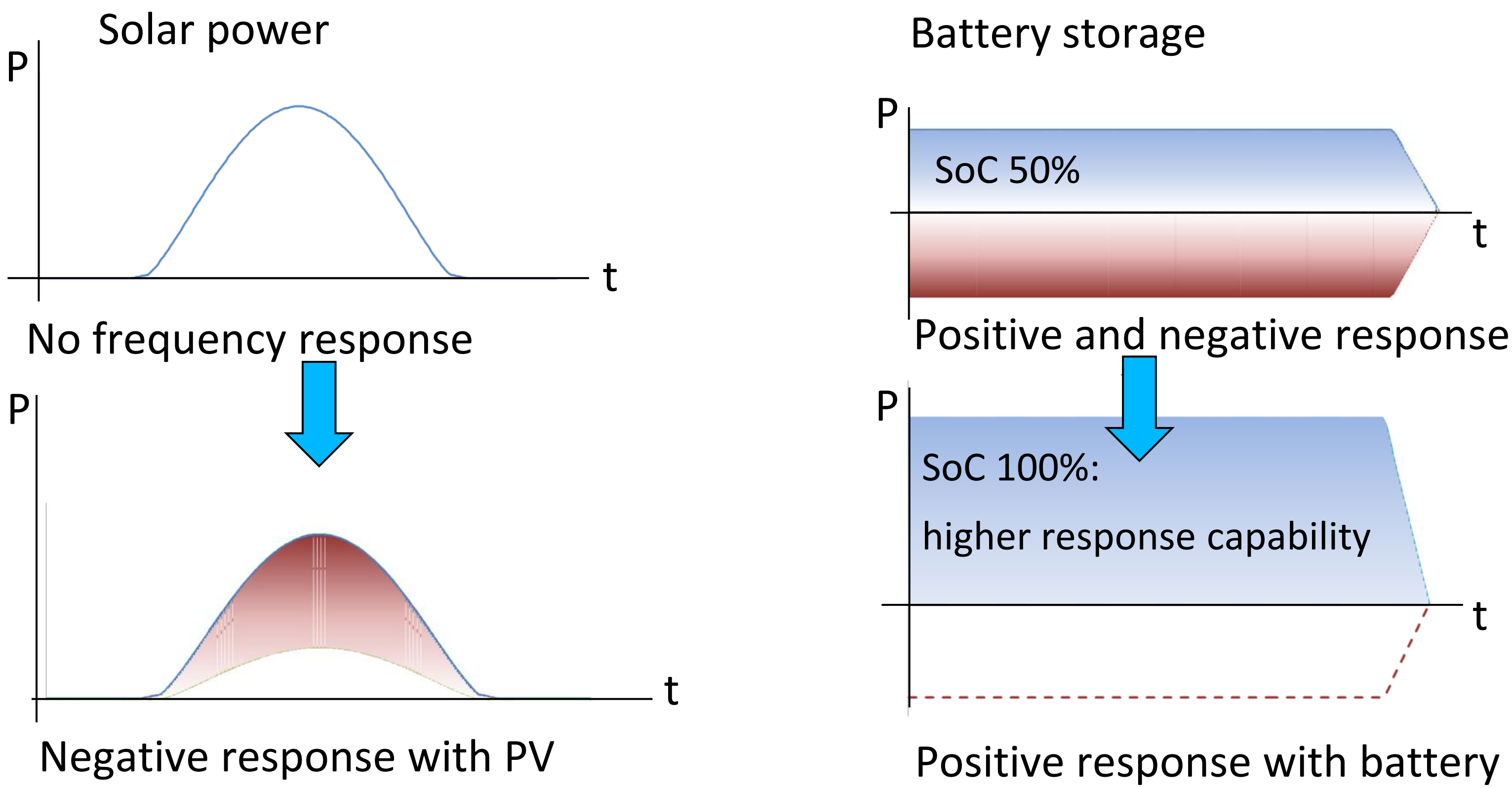
No frequency response

Battery storage

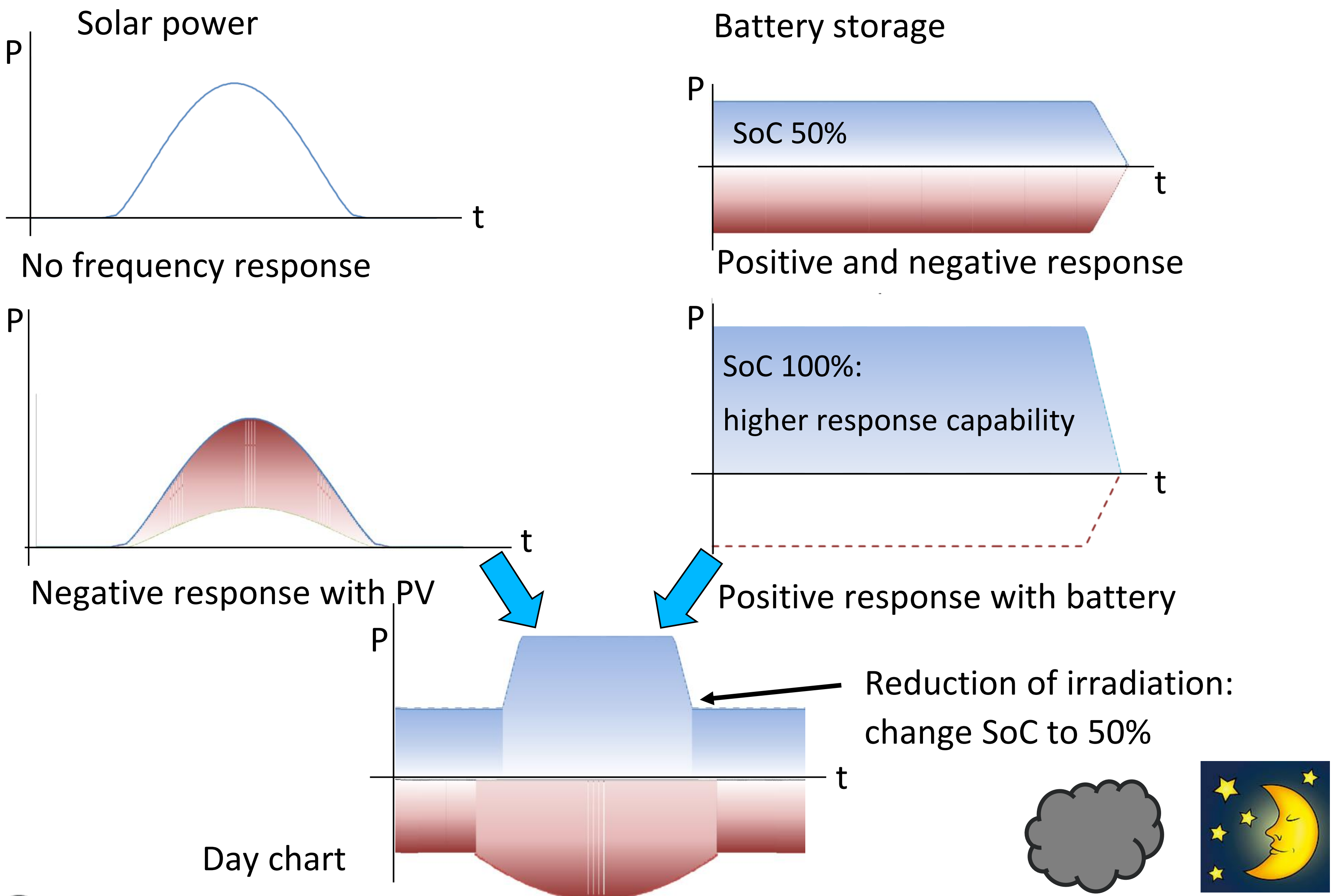


Positive and negative response

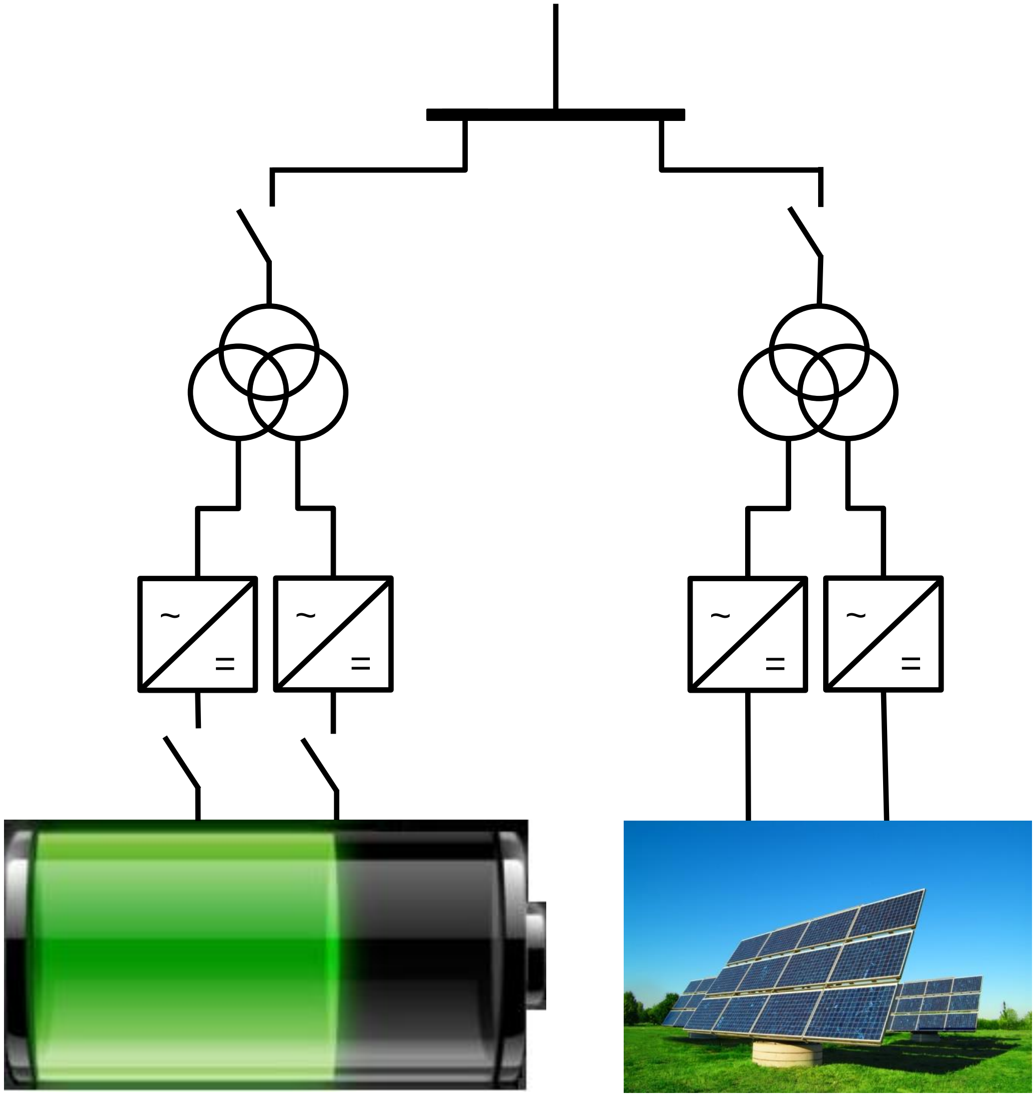
Distributed control power



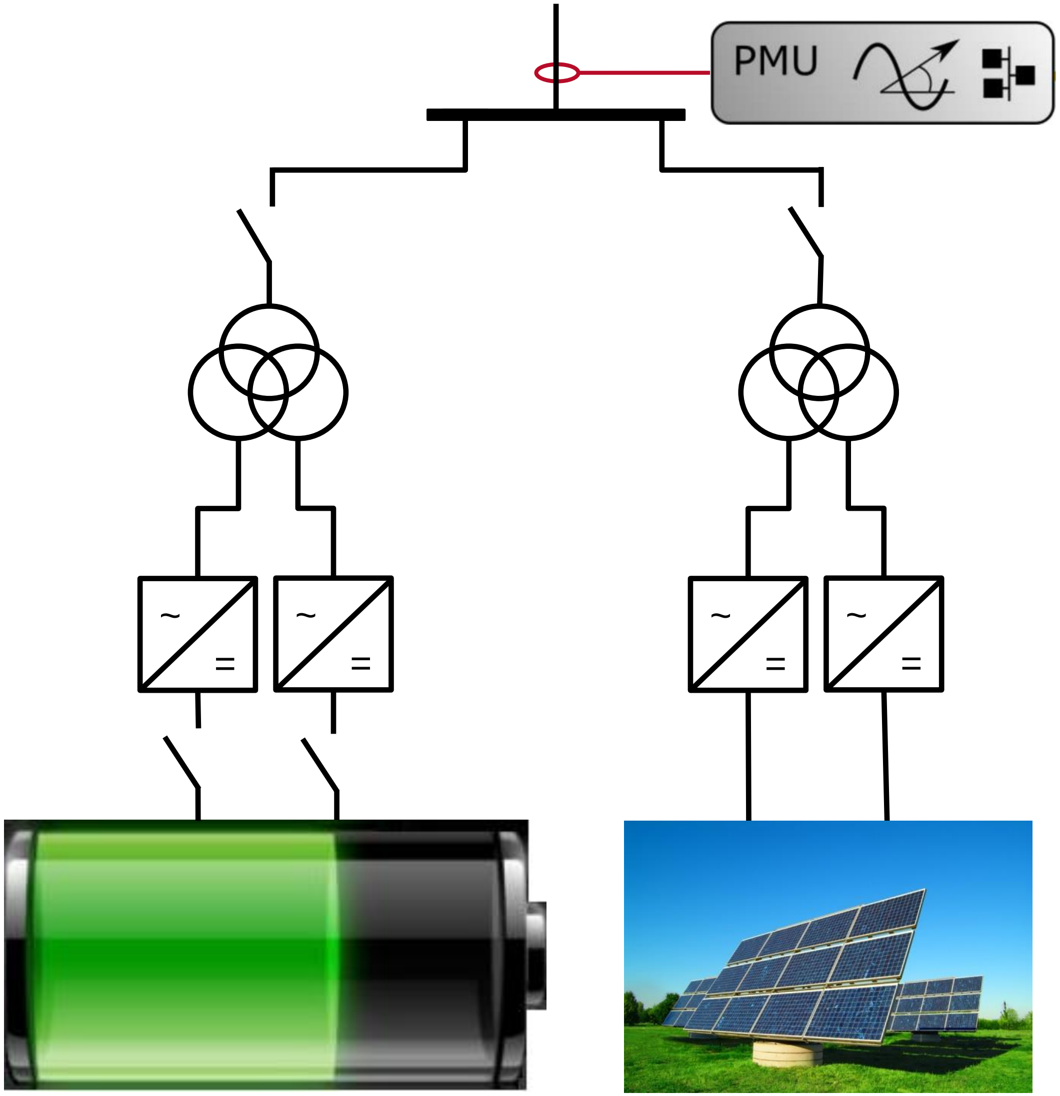
Distributed control power



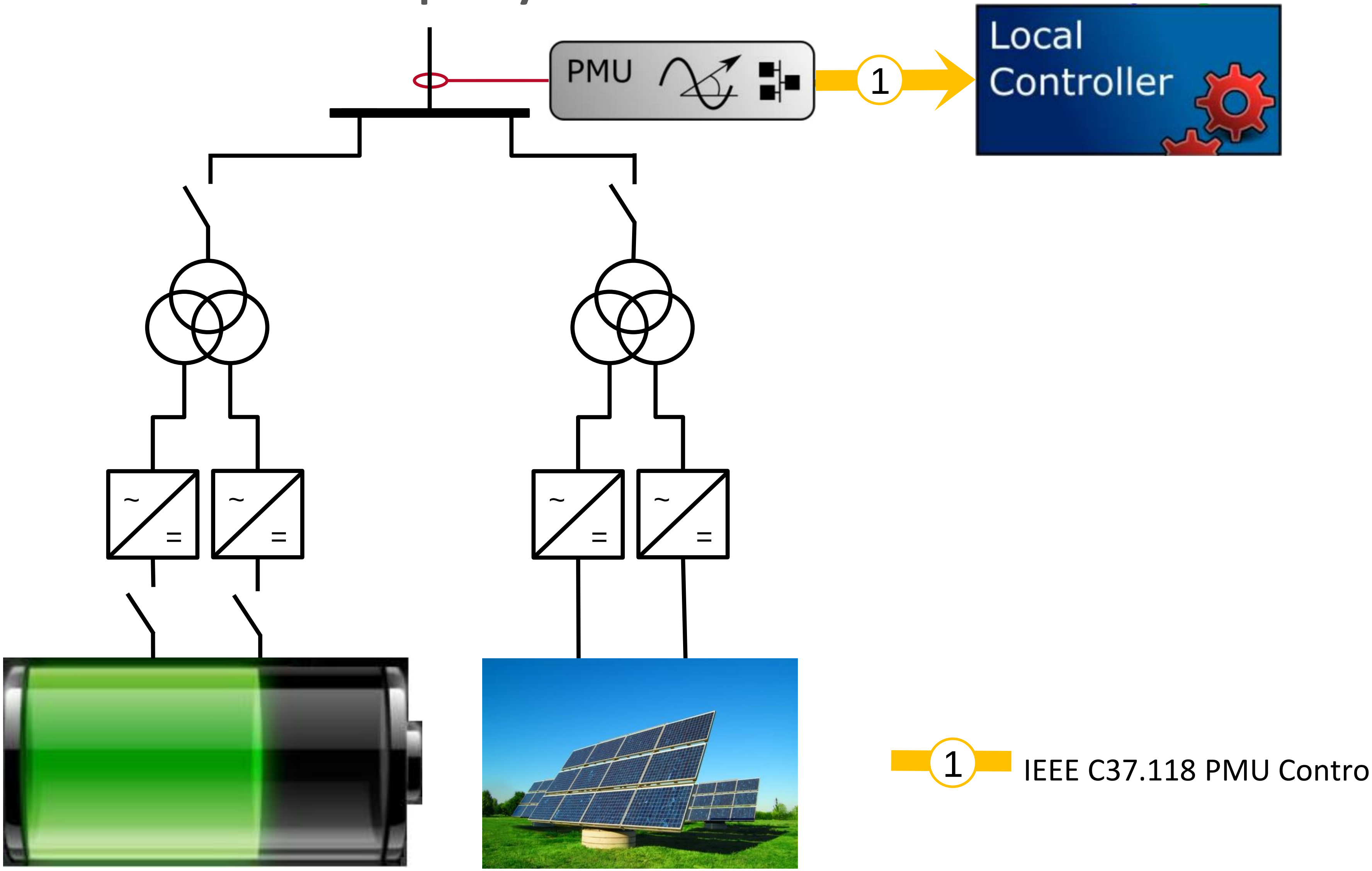
Belectric deployment



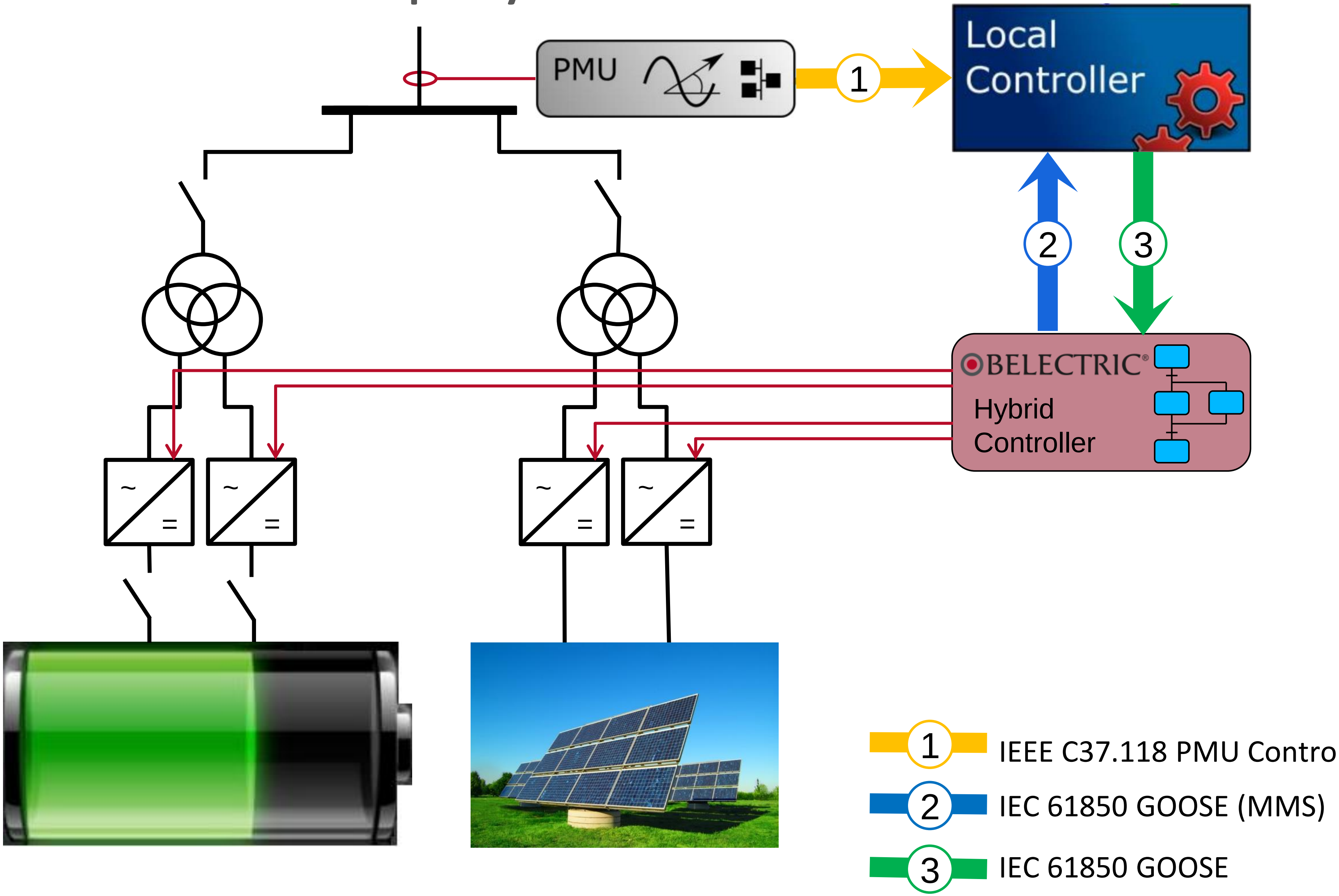
Belectric deployment



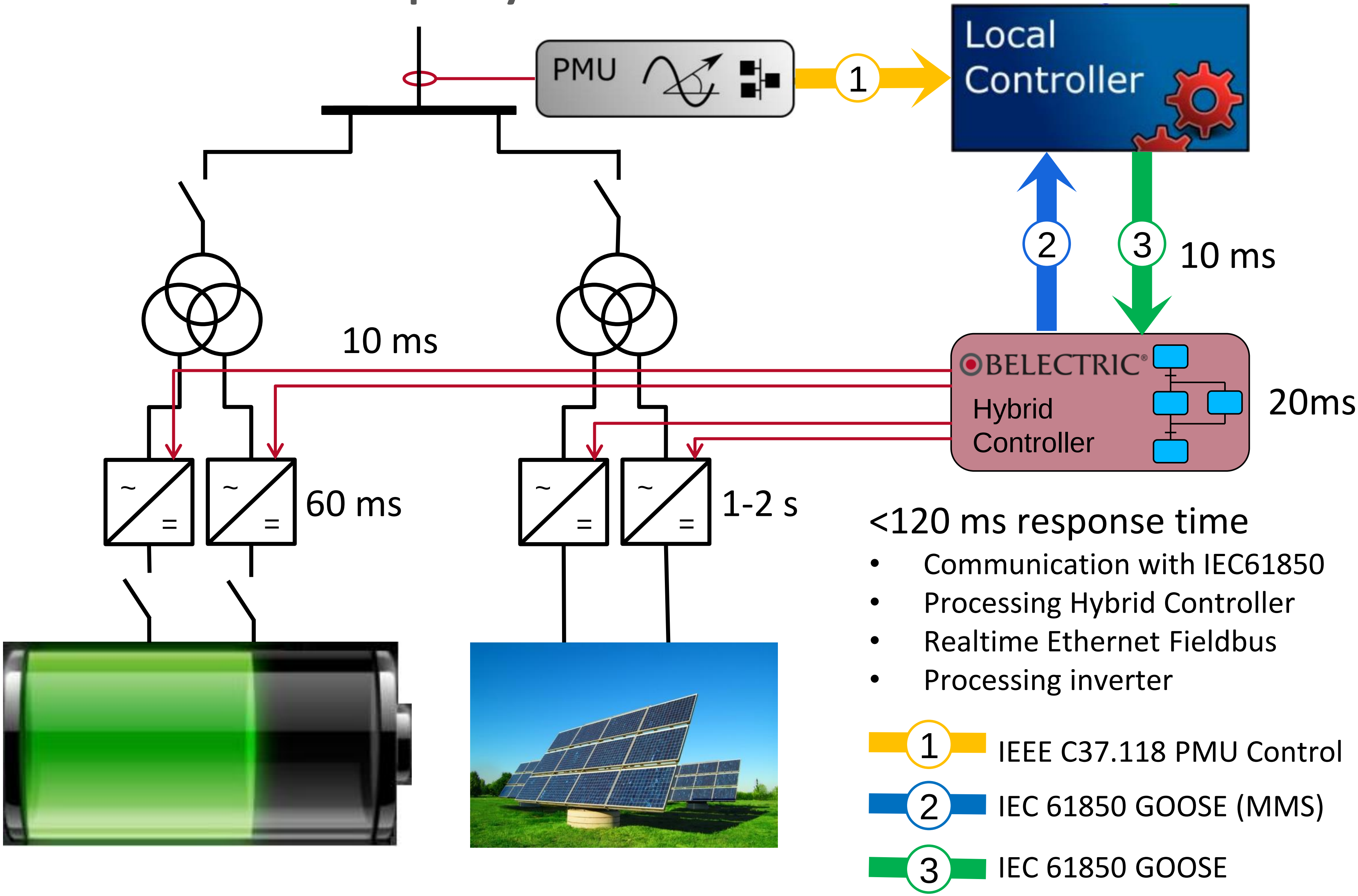
Belectric deployment



Belectric deployment



Belectric deployment



<120 ms response time

- Communication with IEC61850
- Processing Hybrid Controller
- Realtime Ethernet Fieldbus
- Processing inverter

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- EFCC: Combined frequency response from PV and Battery
- **EFCC: Challenges of the transformation to renewables**

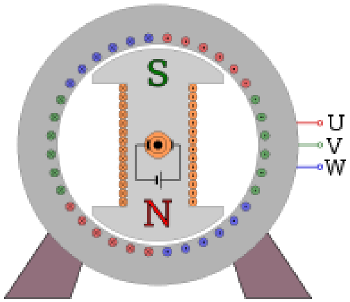
Transformation from synchronous generators to inverter-based response

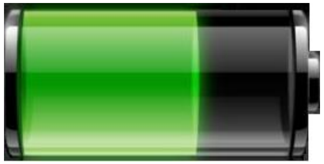
Turbogenerating set of steam turbine (yellow) with synchronous generator (red)
Source: Siemens

Central inverter
© *GE Power Conversion*

Fraunhofer ISE

Synchronous machine vs. battery

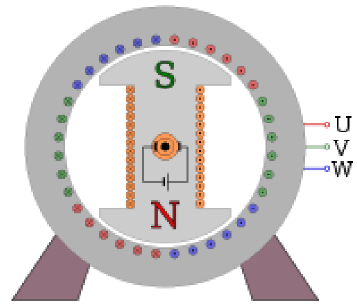


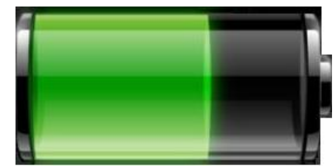


© Wikipedia

Category	Synchronous Machine	Battery storage
Grid building	Intrinsic ✔	Electronic ✔
Resonance frequencies and synchronization fault	Is an issue	Not an issue due to lack of mechanical inertia
Distributed response	Mostly centralized units	Distributed units possible
Inertia	Intrinsic	Electronically simulated
Over current capability	Very high	Usually 20-30%
Response from "idle state"	No	Yes

Synchronous machine vs. battery





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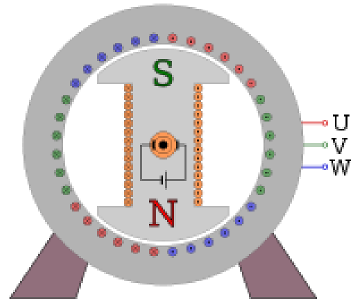
Category	Synchronous Machine	Battery storage
Grid building	Intrinsic	Electronic
Resonance frequencies and synchronization fault	Is an issue	Not an issue due to lack of mechanical inertia
Distributed response	Mostly centralized units	Distributed units possible
Inertia	Intrinsic	Electronically simulated
Over current capability	Very high	Usually 20-30%
Response from "idle state"	No	Yes

Synchronous machine vs. battery



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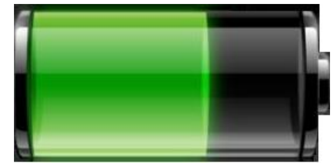

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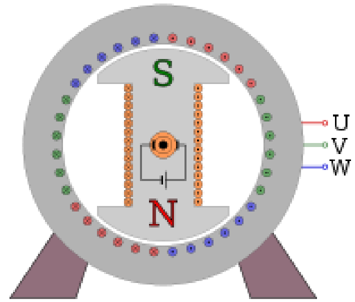

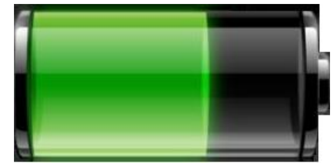

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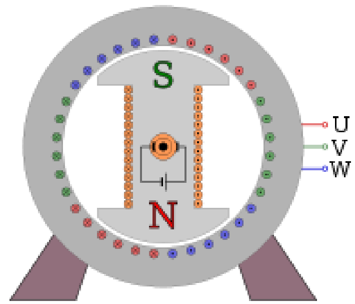
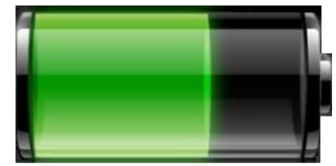
Category	Synchronous Machine	Battery storage
Grid building	Intrinsic ✔	Electronic ✔
Resonance frequencies and synchronization fault	Is an issue !	Not an issue due to lack of mechanical inertia ✔
Distributed response	Mostly centralized units ✘	Distributed units possible ✔
Inertia	Intrinsic ✔	Electronically simulated !
Over current capability	Very high	Usually 20-30%
Response from “idle state”	No	Yes

Synchronous machine vs. battery





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Category	Synchronous Machine	Battery storage
Grid building	Intrinsic ✓	Electronic ✓
Resonance frequencies and synchronization fault	Is an issue !	Not an issue due to lack of mechanical inertia ✓
Distributed response	Mostly centralized units ✗	Distributed units possible ✓
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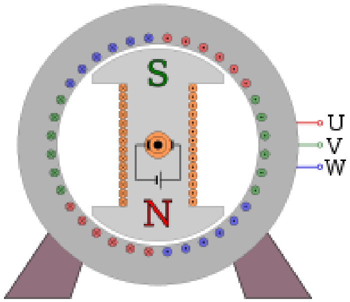
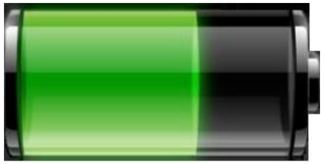
Response from "idle state"	No	Yes

Synchronous machine vs. battery





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Role of CCGTS in Enhanced Frequency Response

Christopher Proudfoot & Peter Wilkinson
Centrica, 25/02/16

Agenda

- How the system has changed in 27 years?
- Role of CCGTs
- Gas Turbines and frequency response
- What are the options for faster response?
- Simulation Results

How the system has changed in 27 years?

- The demand for Scotland, England and Wales at 1030 hours on Saturday 24 June 1989 was:-

  A) 24, 500 MW

  B) 26, 500 MW

  C) 29, 000 MW

How the system has changed in 27 years?

- The demand at 0930 hours on Saturday 25 June 2016 (seasonal normal temps, decent breeze and reasonable sunshine) is predicted (no guarantees!) to be:-

A) 26, 000 MW

B) 28, 000 MW

C) 30, 000 MW

How the system has changed in 27 years?

- At 1030 hours on Saturday 24 June 1989, the number of generators synchronised to the transmission system is estimated at:-

  A) 82

  B) 99

  C) 111

How the system has changed in 27 years?

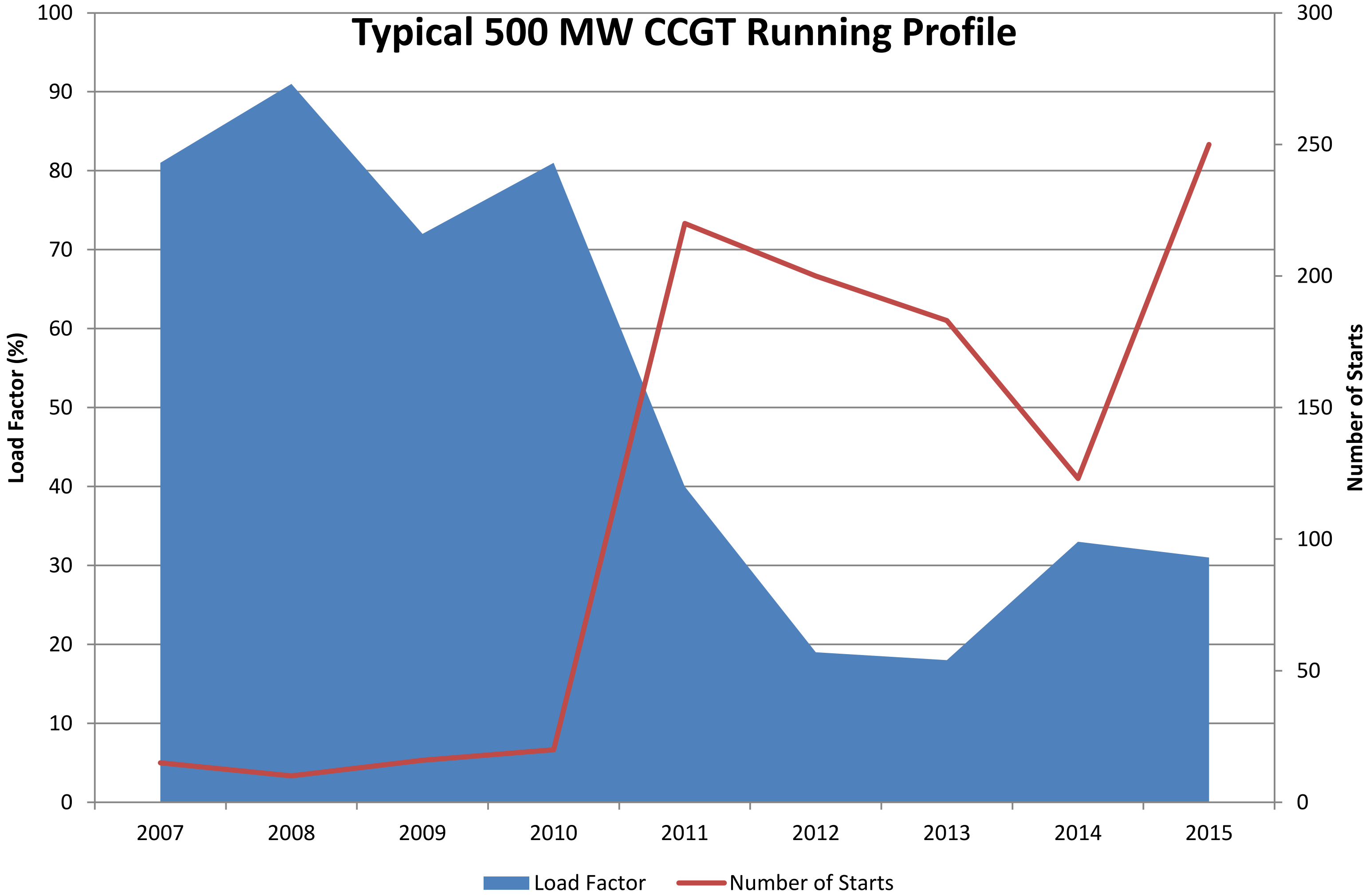
- At 0930 hours on Saturday 25 June 2016 the number of generators estimated to be synchronised to the transmission system is:-

A) 54 (45% reduction)

B) 61 (38% reduction)

C) 68 (31% reduction)

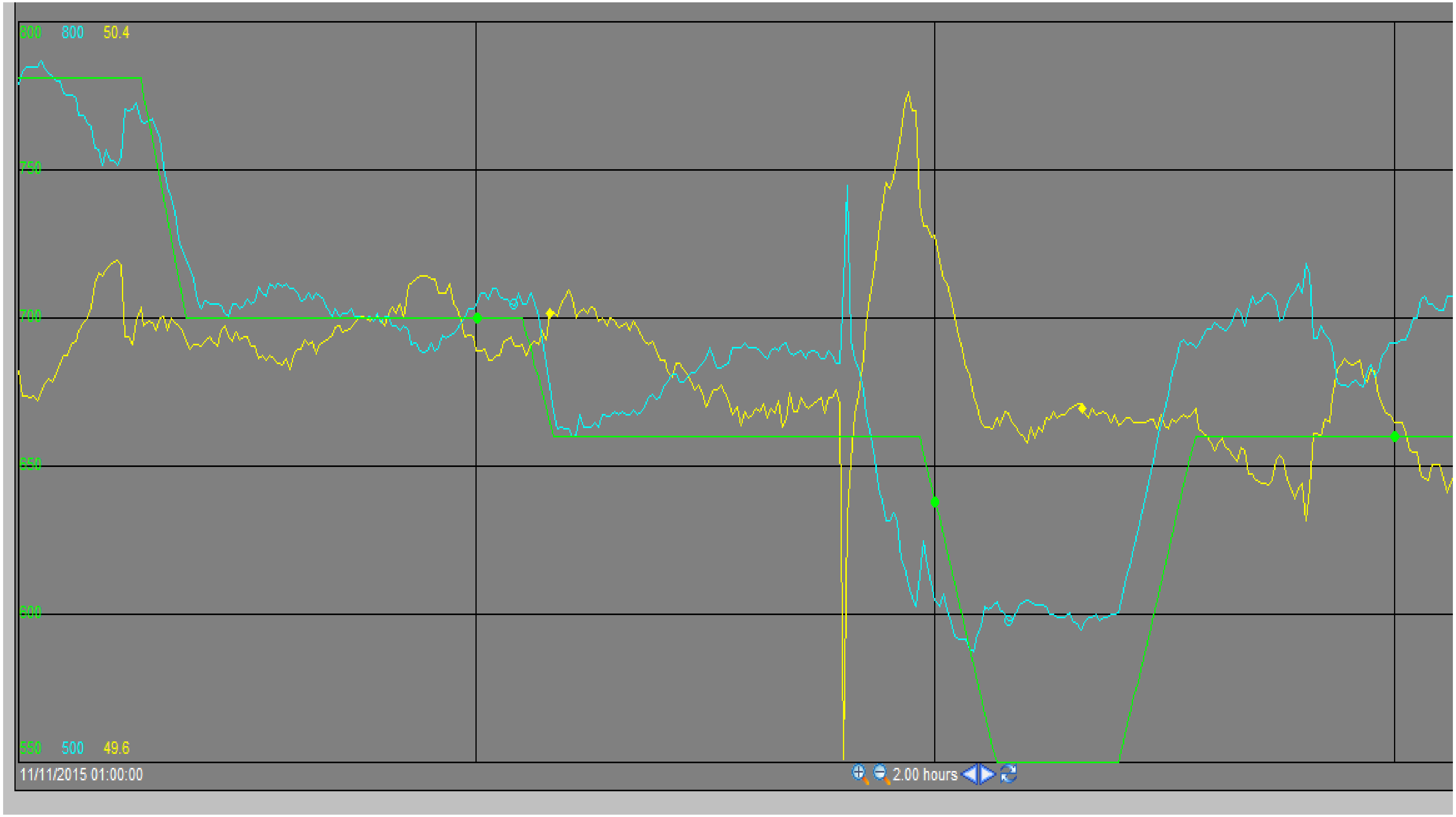
Role of CCGTs



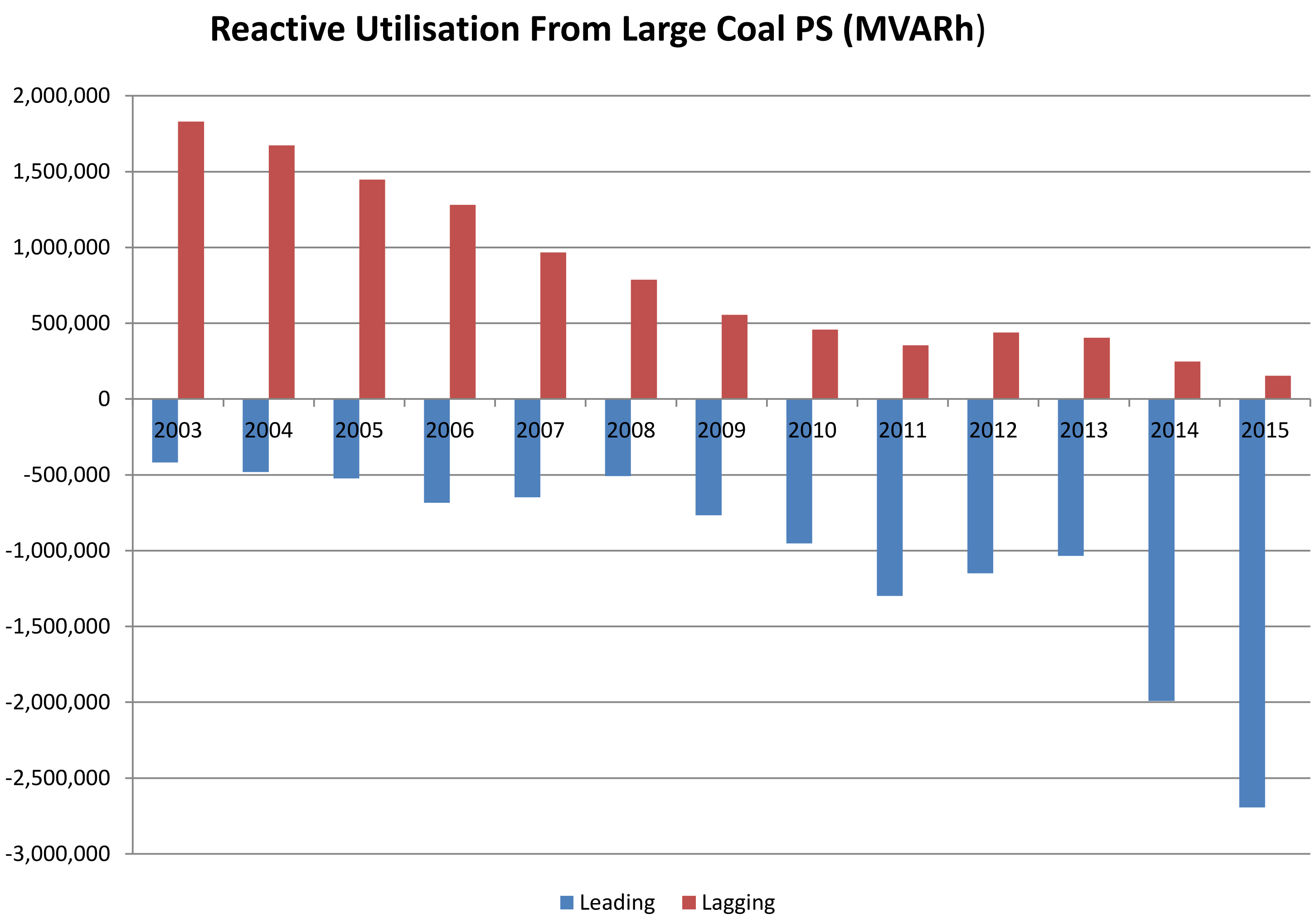
Role of CCGTs

https://www.youtube.com/watch?v=VQ6oXQ4tFow

Role of CCGTs – a recent frequency excursion



Just to prove the system really has changed!



Gas Turbines and Frequency Response

Primary Response:-

- Provided by the Gas Turbine(s)
- ST provides only minor contribution
  - Response time of the HRSG is the limiting factor

- Large Gas Turbines – Modern Strategy
  - Store energy and use ST to reduce initial response time
  - Grid compliance requires less than 2 seconds to react

- Response is scheduled by frequency error (dF) multiplied by a gain factor (K)

Gas Turbines and Frequency Response

Secondary Response:-

- Provided by both GT and ST
- Can be greater than Primary
- Alternate strategies can reduce GT output as ST rises
- Response sustained as long as the deviation is present

Gas Turbines and Frequency Response

- Frequency response capacity can be calculated based on ambient conditions, design curves and active power

- Maximum delivery gradient is governed by machine limits defined by the Original Equipment Manufacturer (OEM)

- For a gas turbine faster response comes at a cost in terms of material life due to cyclic thermal stresses

What are the options for faster response?

- Change to existing control strategies - traditional proportional response to frequency error

- Rate of change of frequency based response
  - Potential indication of the event severity
  - Reduced undershoot and deviation from target frequency
  - External demand for response e.g. GE (Psymetrix)

What are the options for faster response?

- How would we integrate that into a traditional GT DCS without loosing the benefits of traditional compensation?

- How could we utilise the response capacity available?
  - Commit response to one or more than one strategy?

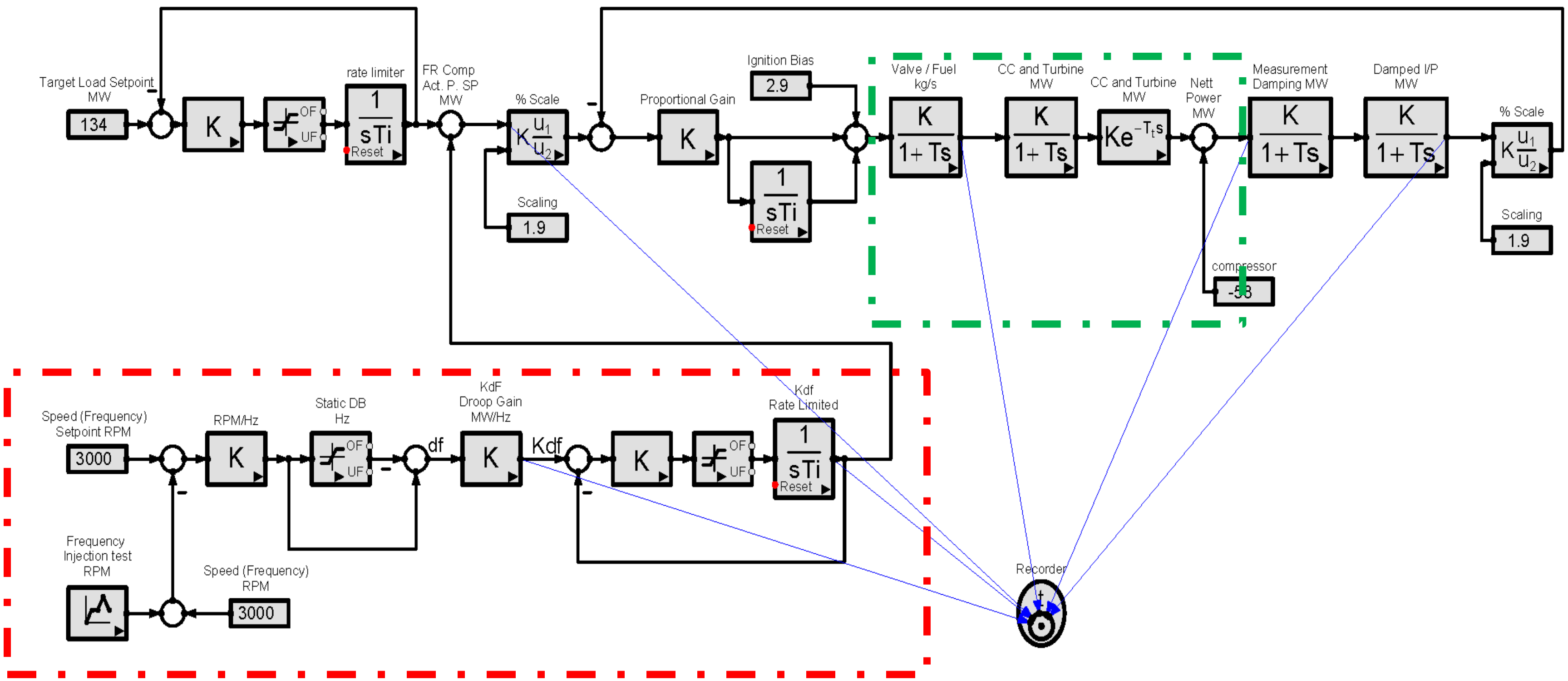
- How would the response behaviour look?

SimApp Workstation Testing

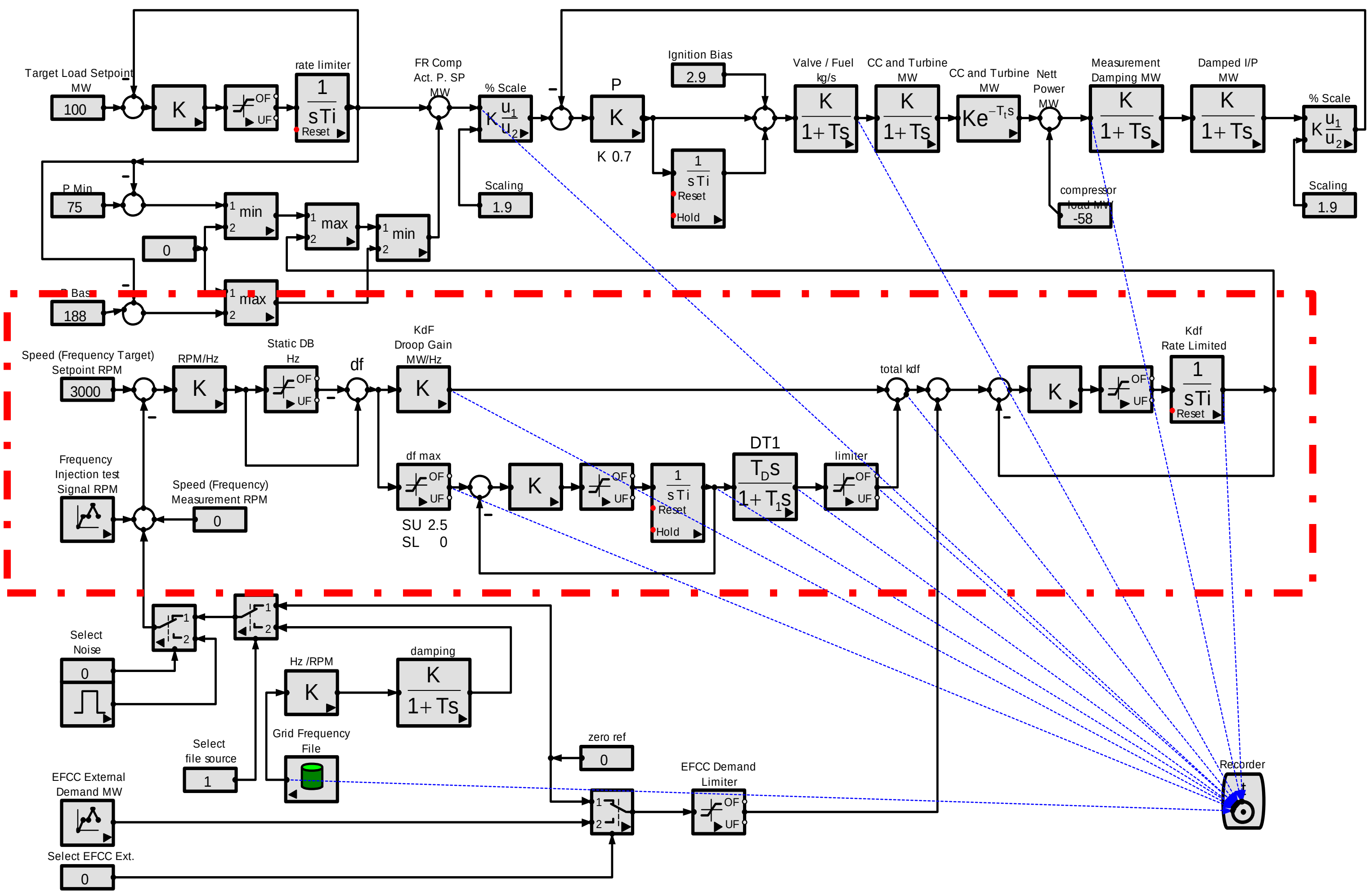
- Option A – Proportional + Derivative Response
  - Summating traditional response demand with the derivative of the frequency signal (ROCOF)

- Option B – Maximum of Proportional or Derivative
  - Responding to the maximum demand from all strategies
  - Optimising for speed of response

GT Power / Frequency Controller Simulation



P + D Response



Target Load Setpoint MW
100
K
OF
UF
rate limiter
1
sTi
Reset
FR Comp Act. P. SP MW
% Scale
Scaling
1.9
P
K
K 0.7
Ignition Bias
2.9
1
s Ti
Reset
Hold
Valve / Fuel kg/s
CC and Turbine MW
CC and Turbine MW
Nett Power MW
compressor load MW
-58
Measurement Damping MW
Damped I/P MW
% Scale
Scaling
1.9
P Min
75
min
max
min
0
P Bas
188
max
Speed (Frequency Target) Setpoint RPM
3000
RPM/Hz
Static DB Hz
df
KdF Droop Gain MW/Hz
total kdf
Kdf Rate Limited
Frequency Injection test Signal RPM
Speed (Frequency) Measurement RPM
0
df max
SU 2.5
SL 0
DT1
limiter
Select Noise
0
Hz /RPM
damping
Grid Frequency File
Select file source
1
zero ref
0
EFCC External Demand MW
EFCC Demand Limiter
Select EFCC Ext.
0
Recorder

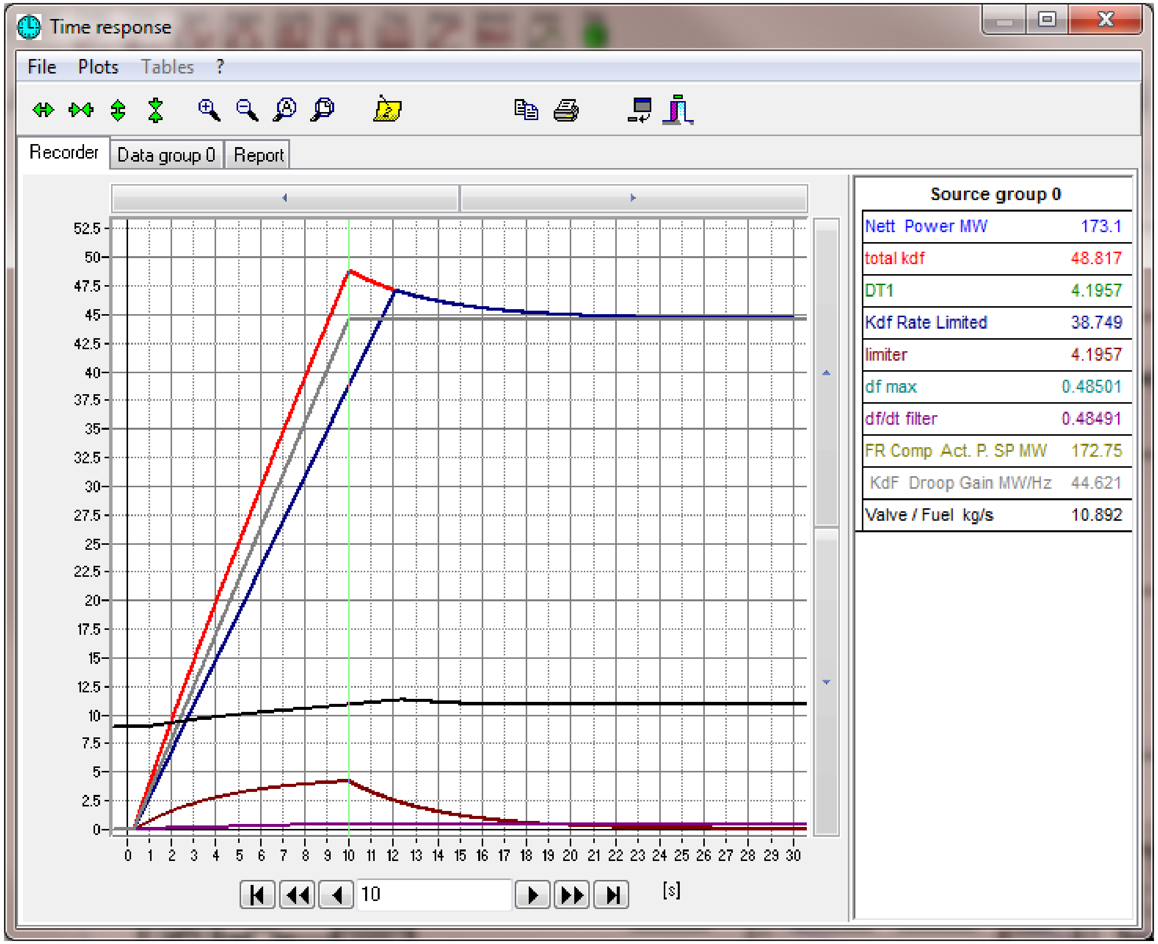
Proportional + Rate of Change of Frequency

- In theory extra response is scheduled against the rate of change

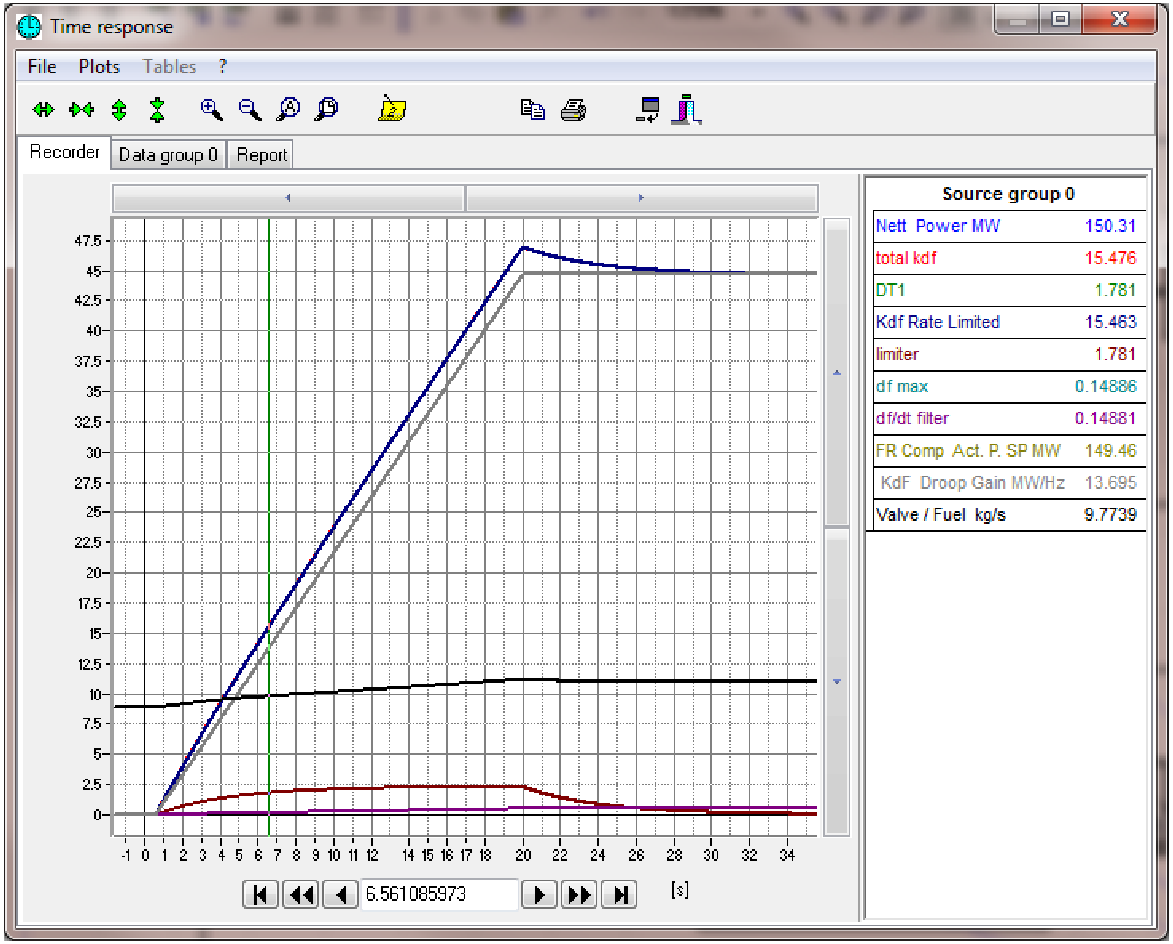
- Once the frequency stabilises the additional response decays to zero

- In fast deviations the benefit is usually lost due to the dynamic limits of Gas turbine performance imposed by the OEM

-0.5Hz ramp over 10 seconds



-0.5Hz ramp over 20 seconds



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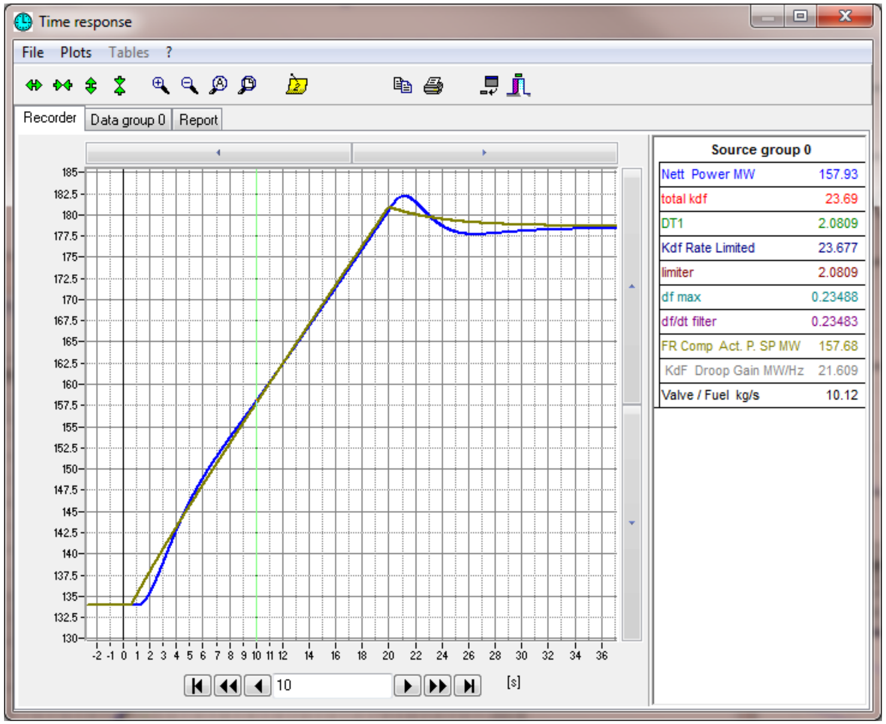
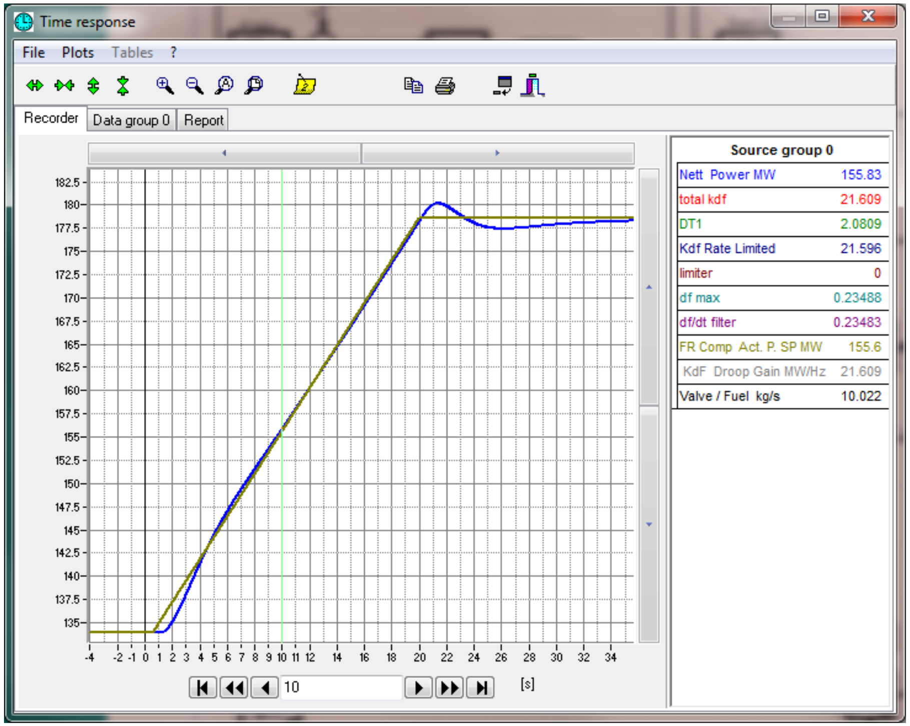
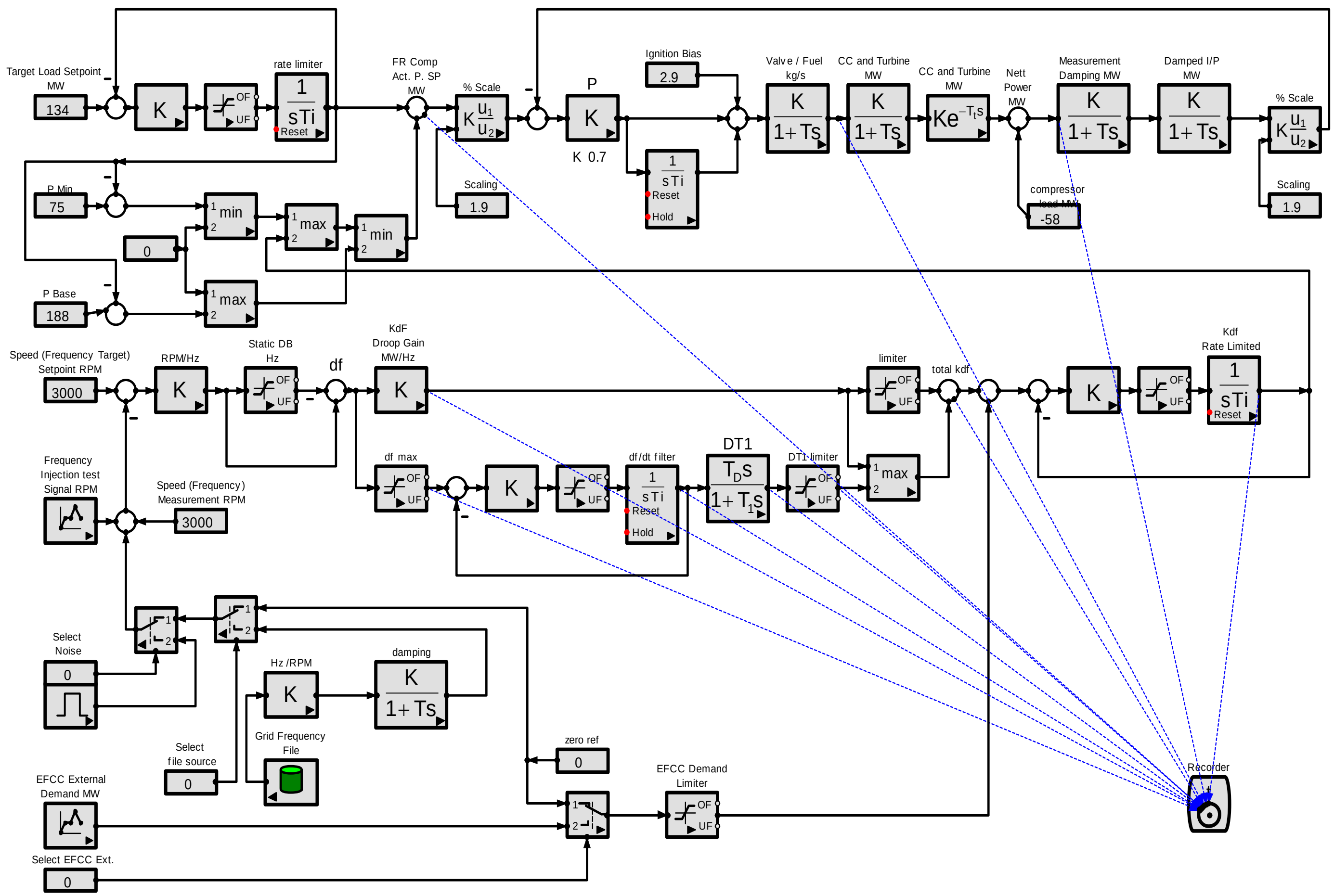




Maximum of P or D Response

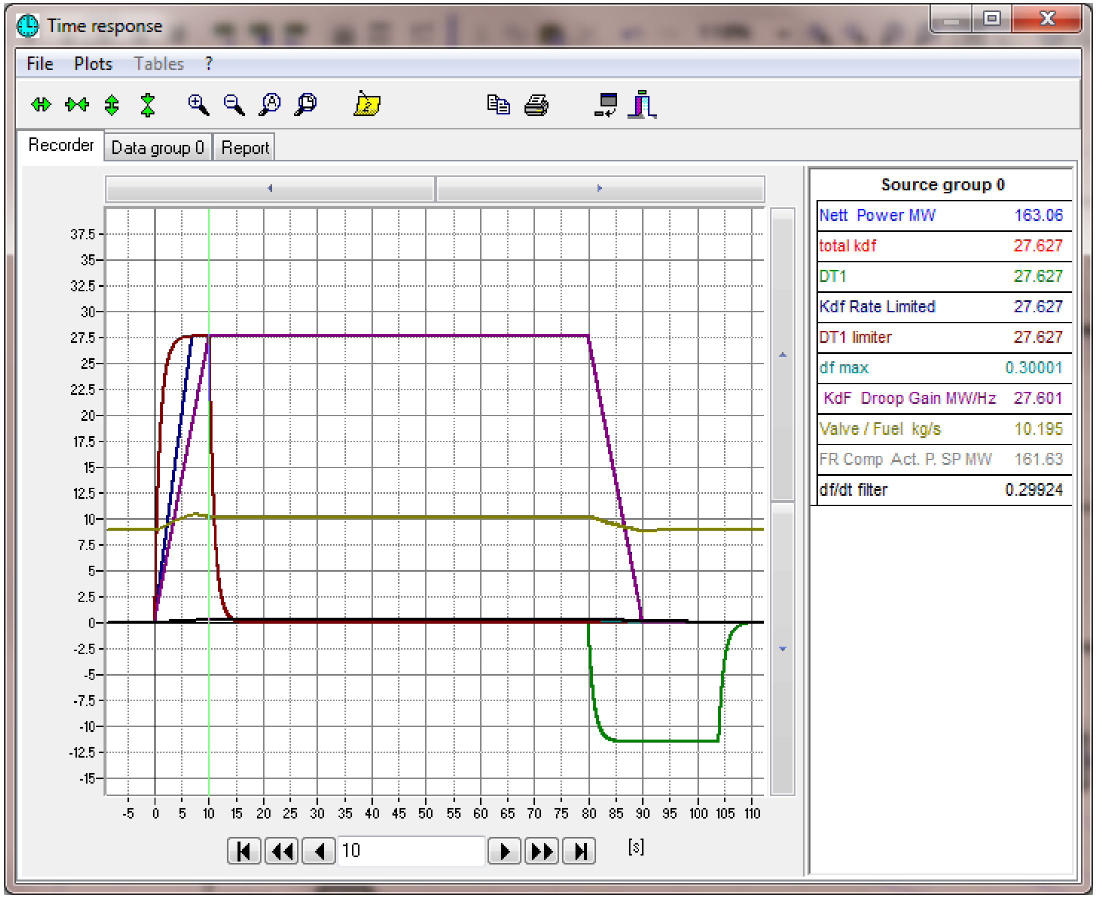


Maximum of P or D Response

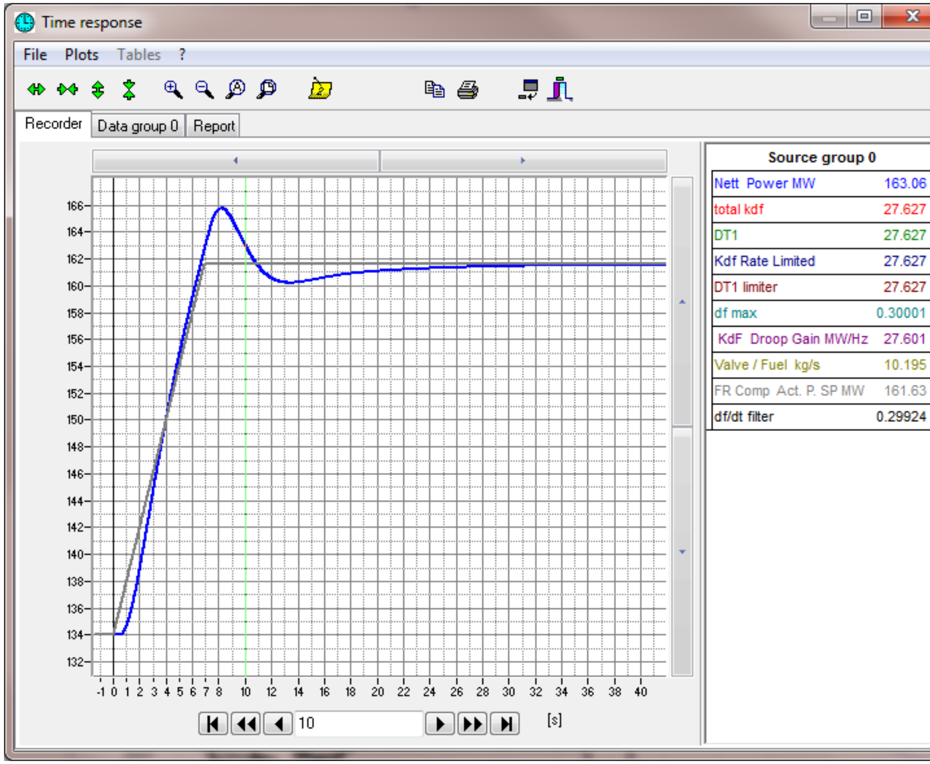
- Provide the correct proportional level of response at the maximum loading rate

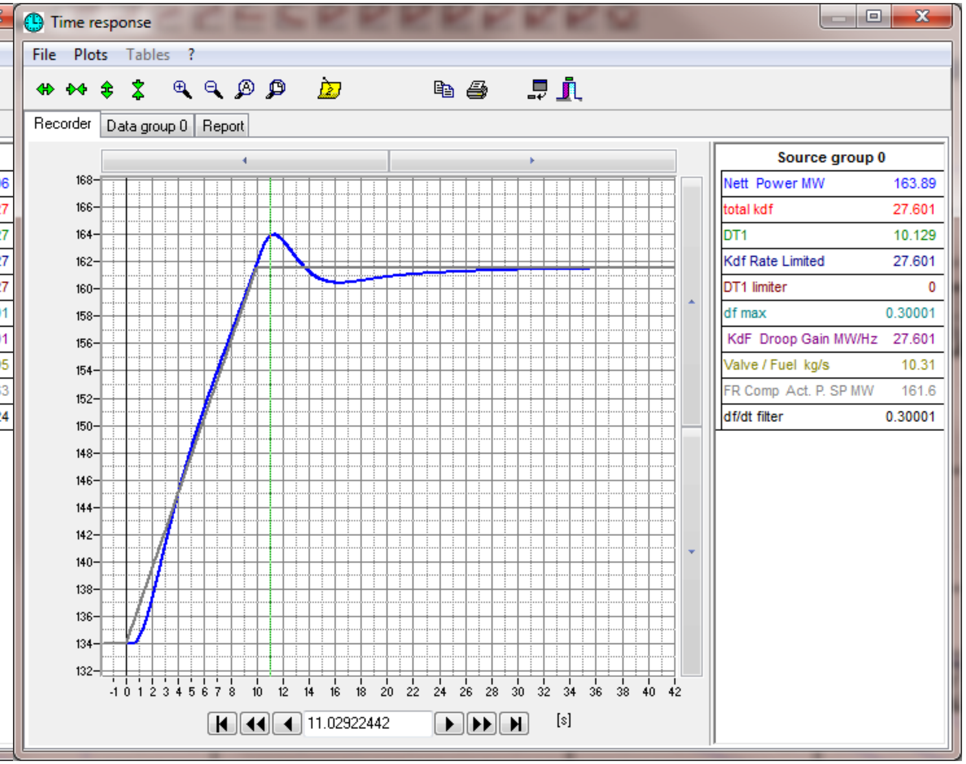
- Anticipates the actual level of response that will be required based on the rate of change of falling frequency

-0.3Hz ramp over 10 seconds Max (P, D)

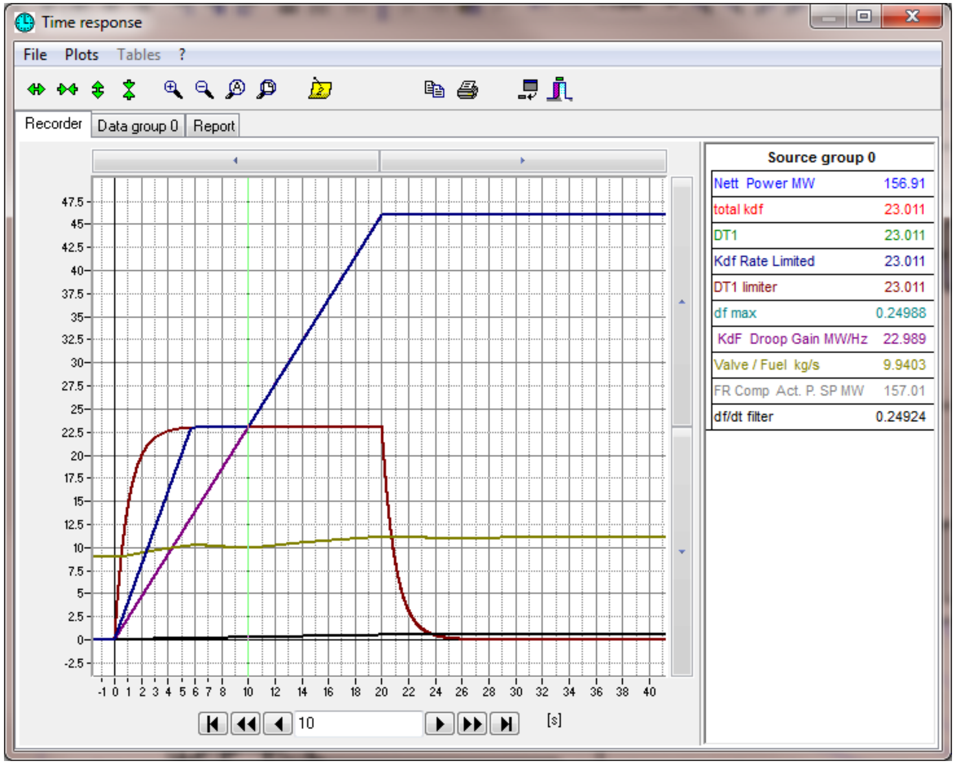


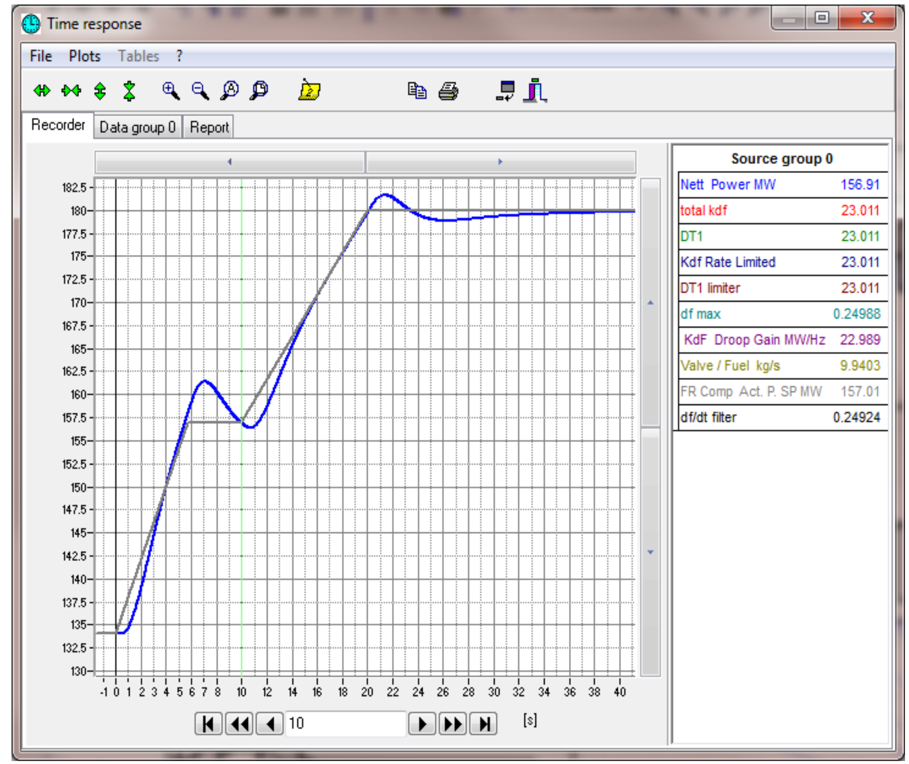
-0.3Hz ramp over 10 seconds Max (P, D)





-0.5Hz Ramp over 20 seconds





Questions?

Enhanced Frequency Response

Adam Sims
Senior Account Manager

Enhanced Frequency Response

Size

- Increase of potential largest infeed loss

Speed

- System inertia forecast to reduce by 15%-25% by 2020

Source

- Decrease in “traditional” frequency response providers

Enhanced Frequency Response

New Service Opportunity Identified – Summer 2015

- Continuous dynamic frequency response delivering in 1s from a deviation
- Aim to procure approximately 200MW, with a cap of 50MW per Applicant

Invitation for Expressions of Interest – October 2015

- Over 60 submissions received
- Over 1.3GW of capacity proposed

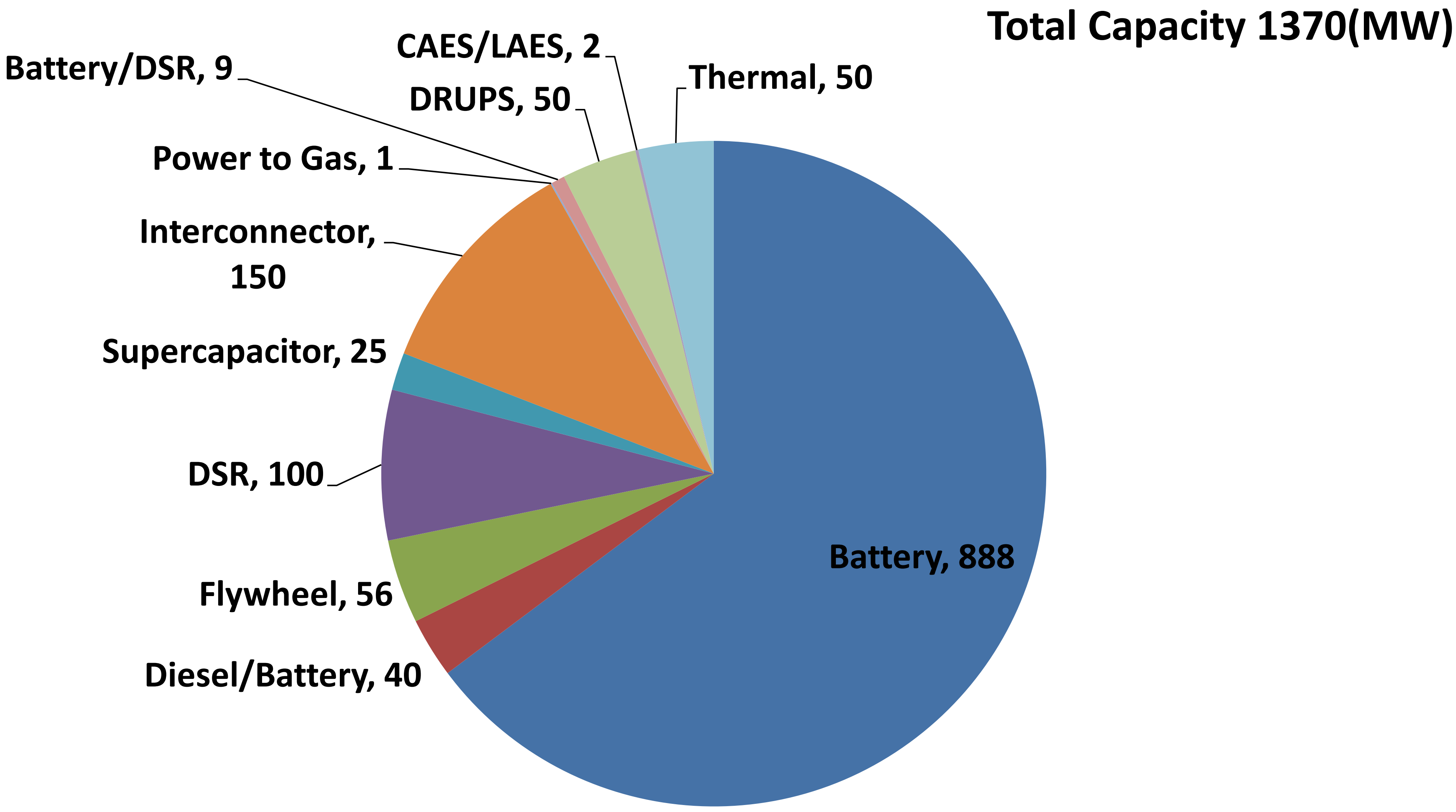
Finalise Invitation to Tender Pack – April 2016

- Aim to include application process, technical description, assessment criteria, value periods, contract drafting

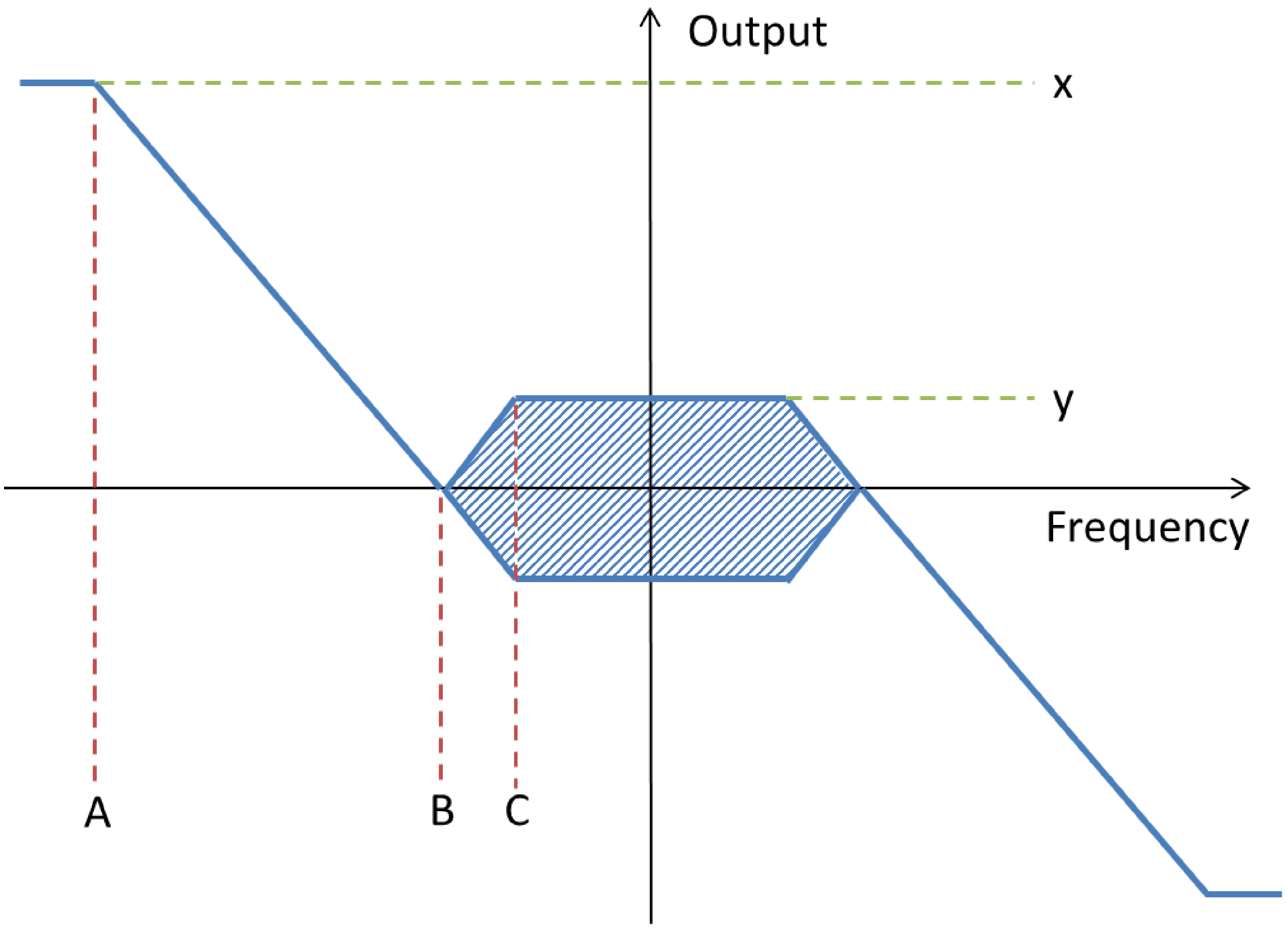
Tender Event – June 2016

- Aim to assess tenders by end of July
- Service delivery 18 months after tender award

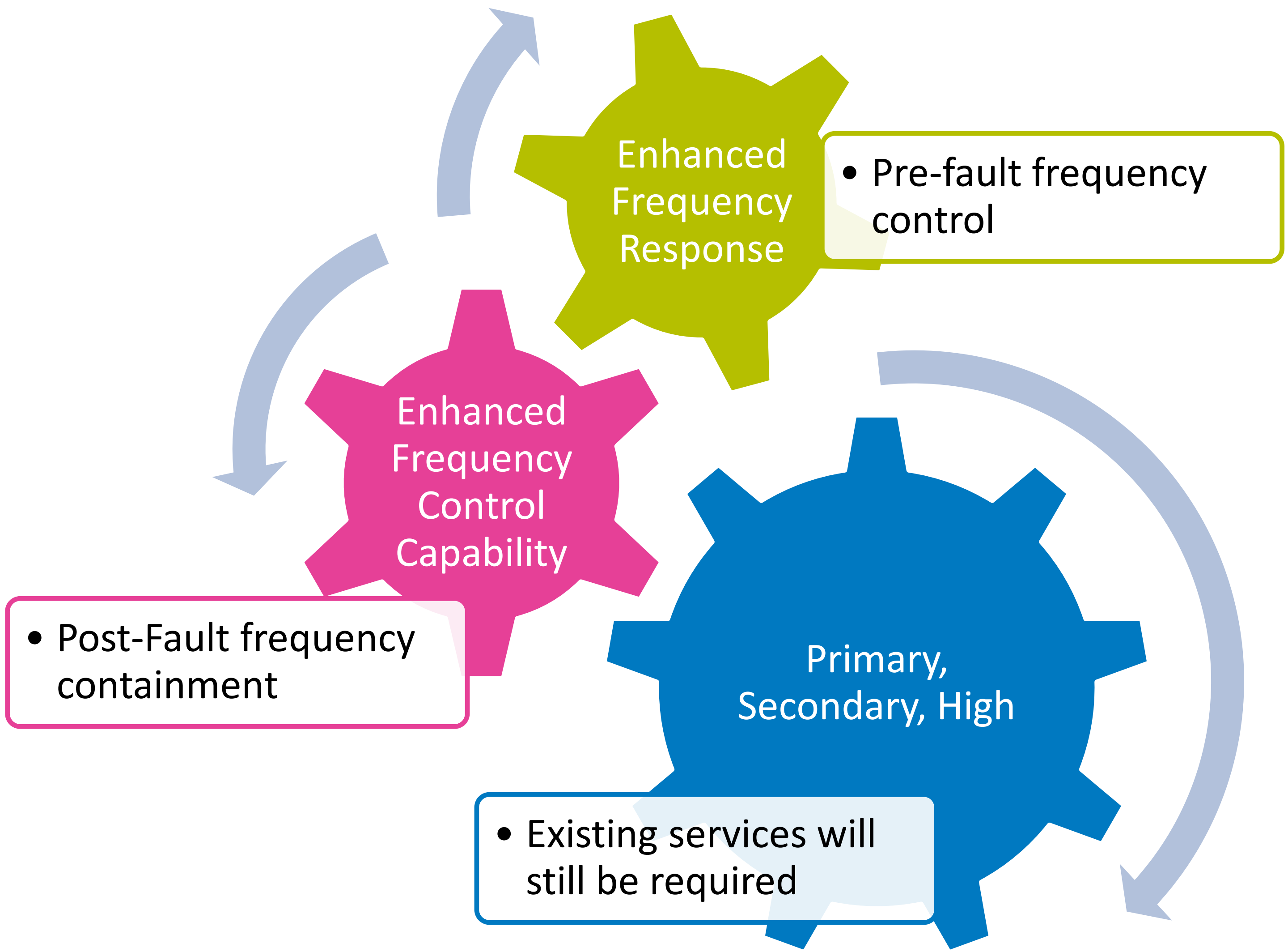
Enhanced Frequency Response



Enhanced Frequency Response



Enhanced Frequency Response



Enhanced Frequency Response

Minimum System Inertia Including Contribution from Embedded Generation