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
Main facilities at PNDC

- Urban cables
- Overhead lines
- Control room
- Primary substation and MG set
- Mock impedance
Main features of PNDC

- 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
The SFC scheme and the role of PNDC

- Wind farms
- DSR
- PV
- Energy storage
- CCGT
- Zone 1
- Zone 2
- Zone 3
- PMUs

Fast, coordinated response closest to the disturbance
The SFC scheme and the role of PNDC

- RTDS model
- Zone 1
- Zone 2
- Zone 3
- Motor-generator (MG) set
- Monitoring and control signals
- Power-Hardware in Loop (P-HiL)
- SFC Scheme
PNDC Tests: two stages

Stage 1: Open-loop test

Simulated regional PMU streams

IEEE C37.118

Regional Aggregators

Local Controller

PNDC network

SFC hardware

Resource information

Control actions

Communication interface

Response of local controller is verified against expected behavior
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.
Demand Response.
Delivered.

Smart Frequency Control
Developing demand response methods
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
Saturday 3rd January 2009

STOR call received at 16:38
Flexitricity started generation in same minute; full power by 16:43

Day peak 17:15 - 17:20
STOR cease received at 17:46

Nuclear power station failed at 16:34;
632MW generation lost
Demand-side frequency response

National mains frequency falls rapidly to 49.6Hz

IFA single bipole failure at 14:03:19

Frequency fall detected – site responded in one second

Site reconnected after 30 minutes
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
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
Spinning Reserve

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

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

- Site controller
  - Run/stop
  - Site data

- Outstation
  - Encoded operating rules
  - Continuous monitoring
  - 1-2s updates

- Central
  - Encoded operating rules
  - Continuous monitoring
  - 10s updates

- Messages

- Monitoring and control

- Flexitricity operator

- Site control
- Flexitricity control

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

![Statistics Graph](image-url)
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

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

© Energie-Museum Berlin
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
Prequalification: Alt Daber battery park

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

Active power [kW] vs. Δf [Hz]

Frequency response with battery

- Active power [kW]
- Δf [Hz]
- SoC [%]
- Time [h]
Why fast Batteries?

- Strathaven
- Deeside
- Langage
- Keadby
- London
- Spalding North

© Alstom / Psymetrix
How fast are batteries?

55 ms from request to full response
Using fast Batteries

RoCoF response with fast battery

<table>
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<tr>
<th>Active power [kW]</th>
<th>Δf [Hz]</th>
<th>SoC [%]</th>
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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.
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,...
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
Solar farm in the UK
Distributed control power

Solar power

Battery storage

No frequency response

Positive and negative response

SoC 50%
Distributed control power

Solar power

- No frequency response
- Negative response with PV

Battery storage

- SoC 50%
- Positive and negative response
- SoC 100%: higher response capability
- Positive response with battery

www.belectric.com
Distributed control power

Solar power

No frequency response

Negative response with PV

Positive response with battery

Battery storage

SoC 50%

Positive and negative response

SoC 100%:

higher response capability

Reduction of irradiation:
change SoC to 50%

Day chart
Belectric deployment
Belectric deployment

[Diagram of a power system with a battery and solar panels, labeled PMU.]

www.belectric.com
Belectric deployment

IEEE C37.118 PMU Control
Belectric deployment

1. IEEE C37.118 PMU Control
2. IEC 61850 GOOSE (MMS)
3. IEC 61850 GOOSE
Belectric deployment

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

<120 ms response time

IEEE C37.118 PMU Control
IEC 61850 GOOSE (MMS)
IEC 61850 GOOSE
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
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
BELECTRIC
## Synchronous machine vs. battery

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BELECTRIC – The better electric.

Headquarters Germany:
BELECTRIC, Wadenbrunner Str. 10, 97509 Kolitzheim,
Telefon: +49 9385 9804 – 0, Email: info@BELECTRIC.com
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

Typical 500 MW CCGT Running Profile

- Load Factor (%)
- Number of Starts

Graph showing the load factor (%) and number of starts from 2007 to 2015.
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!

Reactive Utilisation From Large Coal PS (MVARh)
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 losing 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

Diagram showing various control system elements and connections.
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
-0.5Hz ramp over 20 seconds
Maximum of P or D Response

[Diagram with control system elements and parameters, including:
- Target Load Setpoint MW
- Speed (Frequency) Measurement RPM: 3000
- Speed (Frequency Target) Setpoint RPM: 3000
- Frequency Injection test Signal RPM
- EFCC External Demand MW
- EFCC External Demand Limiter
- EFCC Demand Limiter
- Kdf / dt filter
- Grid Frequency File
- Damped I/P
- CC and Turbine MW
- Net Power MW
- Measurement Damping MW
- P Base
- P Min
- P Max
- K
- Kdf
- OF
- UF
- Static DB
- Hz
- % Scale
- RPM / Hz
- Ts
- Ke
- KdF
- Droop Gain MW/Hz
- K
- df
- Rate Limiter
- Hold
- Reset
- Select Noise
- Select EFCC Demand MW
- Select EFCC Ext.
- Delay
- File
- Liner]

[Additional annotations and labels for control parameters and settings]
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

- Battery, 888
- Diesel/Battery, 40
- Flywheel, 56
- DSR, 100
- Supercapacitor, 25
- Interconnector, 150
- CAES/LAES, 2
- DRUPS, 50
- Power to Gas, 1
- Thermal, 50
- Battery/DSR, 9

Total Capacity 1370(MW)
Enhanced Frequency Response
Enhanced Frequency Response

- Pre-fault frequency control
- Post-Fault frequency containment
- Existing services will still be required
- Enhanced Frequency Control Capability
- Enhanced Frequency Response

Primary, Secondary, High