Visor Close Down Event 2018

VISOR

Agenda

13:30	Welcome address
13:35	Introduction to VISOR
13:50	What was done
14:50	Tea and coffee break
15:05	Project conclusion presentations
16:05	Questions
16:20	Closing remarks

FUTURE NETWORK INNOVATION

1 | Innovating to Deliver the Electricity Network of the Future

We own and maintain the network that carries electricity to homes and businesses. Providing safe and reliable electricity supply 24 hours a day, 365 days a year.

SP Energy Networks owns and maintains three UK networks

- SP Transmission PLC (SPT)
- SP Distribution PLC (SPD)
- SP Manweb PLC (SPM)

"Innovation is at the core of SP Energy Networks. We have the ambition and capability to lead the industry by innovating in the best interest of our customers and wider stakeholders"

Colin Taylor
Director of Engineering Services

Colin F. Taylor

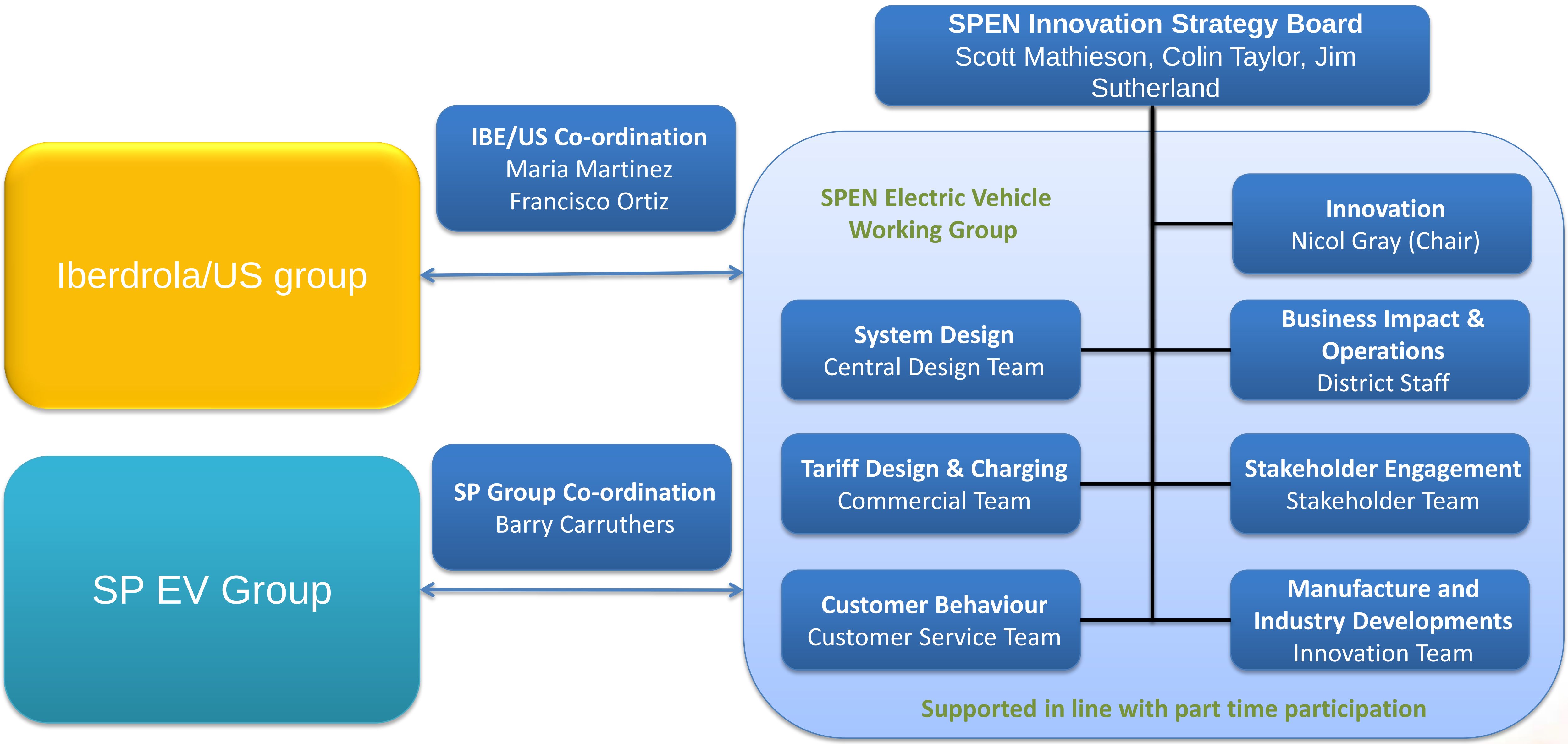
2 | Future Networks

Iberdrola Network Business Innovation Committee

- Contacts with Corporate Innovation:
- Chaired by Maria Martinez Yañez

Task	Contact organization	Contact
Global Coordination	GIC / SMADE	Maria Martinez / Irene Cirujano
Spain	Local Innovation Committee	Jose Maria Mira
UK	Local Innovation Committee	James Yu
US	Local Innovation Committee	Christian Bilcheck
Brazil	Local Innovation Committee	Luiz Flavio

UK – SPEN Cross Functional Electric Vehicle Team



- Understand the **potential network impact** of the EV rollout in the UK across a range of rollout scenarios
- **Lobby key stakeholders** on the implications and options for EV rollout in the UK
- **Inform our customers** of the potential cost and lifestyle impact of wide-scale EV rollout

Requirement to understand the impact and influence key stakeholders

2 | Future Networks

Effective and efficient innovation, in the best interest of our customers, has never been more important when you consider the challenges that today's energy system faces.

At SP Energy Networks, our focus is on innovating to put the customer at the centre of a smart, flexible energy system. The future networks team make this possible.

Innovation is about more than technology – it's about people thinking and acting differently to realise benefits to customers.

Future networks team

The future networks team are leading the industry in delivering innovative projects and changing the landscape for low carbon technologies to benefit local communities.

Their hard work and dedication has seen them jump to the forefront of their field, winning numerous awards and a massive increase in government-awarded funding.

As a team, they have achieved more, which is only possible with the support of the Iberdrola group – but it doesn't stop here. They continue to innovate and bring this innovation into business as usual.

3 | Flagship Innovation Projects

3 | Flagship Innovation Projects

ARC £8.4m

- Use of Technical and Commercial Innovation to accelerate network access for renewable generation.
- Connections are facilitated around constraints.

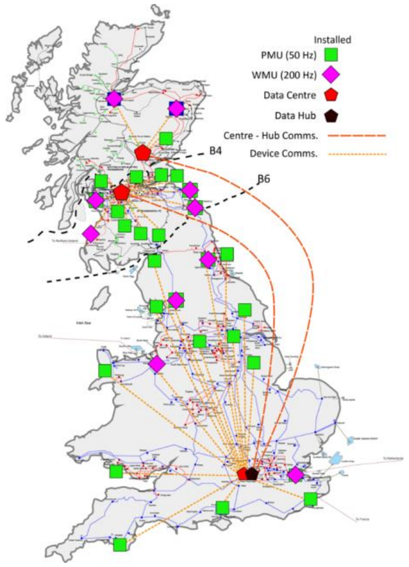
ANGLE-DC £15m

Secures a Power Corridor between Anglesey and North Wales, creating headroom in capacity.

A Demonstration of a novel network reinforcement technique using DC operation.

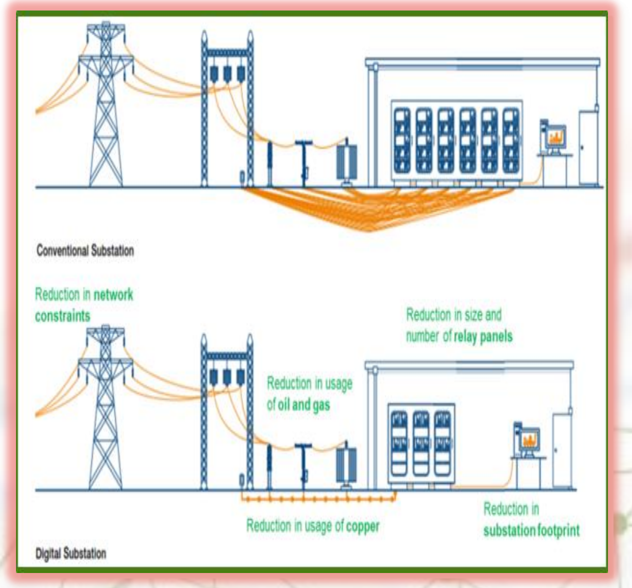
VISOR £7.4m

- Aims to establish the first national Wide-Area Monitoring System on the Transmission Network.
- New Phasor Measurement Units deployed to understand the real-time network dynamics.



FITNESS £9.5m

- Improving transmission substation design, protection and control using digital communications.
- Increasing efficiency of asset use with standardised monitoring.



3 | Flagship Innovation Projects

OPEN INNOVATION £700K

•Looking inside SPEN for the challenges we have in our day-to-day business

•Looking for solutions outside SPEN's normal supply chain, and working with small, agile businesses.

FUSION £6m

•Trial of a commoditised local demand-side flexibility market framework.

•Demonstration of how DNOs can harness flexibility networks to manage modern networks

FUSION

LV ENGINE £8.4m

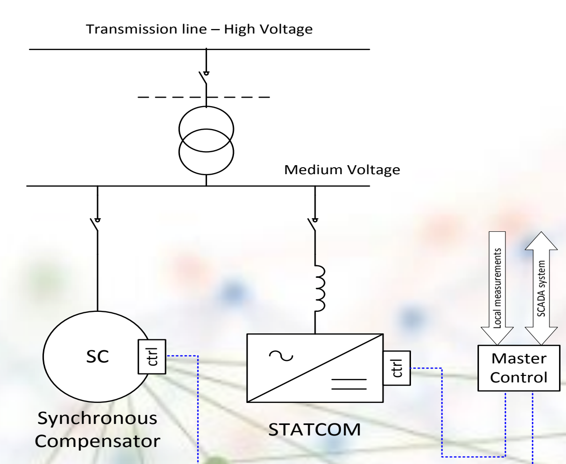
•A trial of Solid-state transformers at secondary substations

•Increasing network flexibility and releasing capacity on the LV network

LV ENGINE
A SMARTER ELECTRICITY NETWORK

PHOENIX £19.5m

•The Demonstration of the design, deployment and control of a synchronous Compensator combined with a STATCOM to address system issues which risk security of supply.



Visor Close Down Event 2018

VISOR

VISOR Introduction

The VISOR project: Jan 2014 – Dec 2017

- Funded through Ofgem's Network Innovation Competition (NIC)
- First NIC proposal awarded under RIIO-1 framework

Objectives

- Create the first integrated GB Wide Area Monitoring System (WAMS) across 3 GB TOs and SO
- Deploy Phasor Measurement Units (PMUs) and the first ever Waveform Measurement Units (WMUs)
- Demonstrate the concepts and tangible benefits of new WAMS capabilities to system planning, real-time operation and post event analysis

Managing Risk & Events | **Maximising Assets** | **Reducing Uncertainty**

Electricity Transmission Regulatory Framework

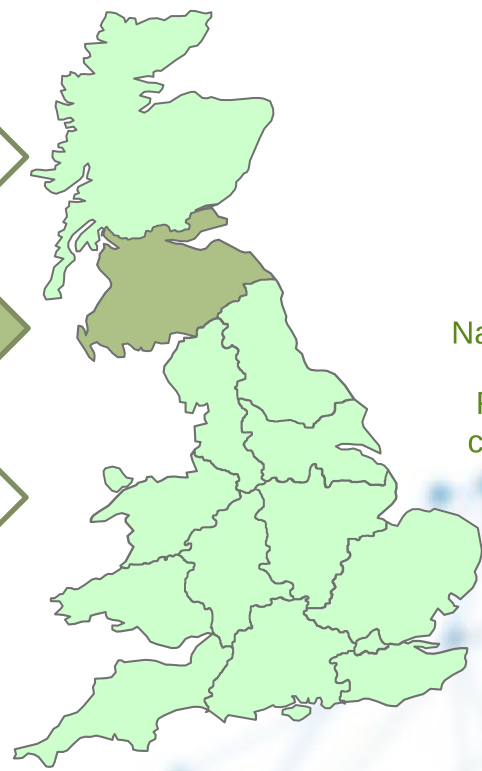
SP Transmission is responsible for delivering an economic, efficient and co-ordinated system of electricity transmission, to meet the needs of GB consumers, in accordance with its Statutory Duties

Three Onshore Transmission Owners

Transmission Licensees

Statutory Duty to develop and maintain an efficient, coordinated and economic system of electricity transmission

- SHE Transmission (SHET)
- **SP Transmission (SPT)**
- National Grid (NGET)



Single GB System Operator

National Grid Electricity Transmission (NGET)

Responsible for market / system operation, charging and contractual interface with users

Enhanced responsibilities for planning

SP Transmission Investment Plan (RIIO-T1)

£2.7bn Investment Plan (2013-2021)

Delivery is Key to Energy Policy Objectives

£1.8bn (~ 65%) provides connections and capacity for wind generation

- Large Increase in wind generation, connect an additional 2.5 GW
- Investment delivers MW and increase in transmission boundary capacity
- Increased import capacity to Scotland will enhance security of supply

£0.9bn (~ 35%) needed to modernise the network by 2020

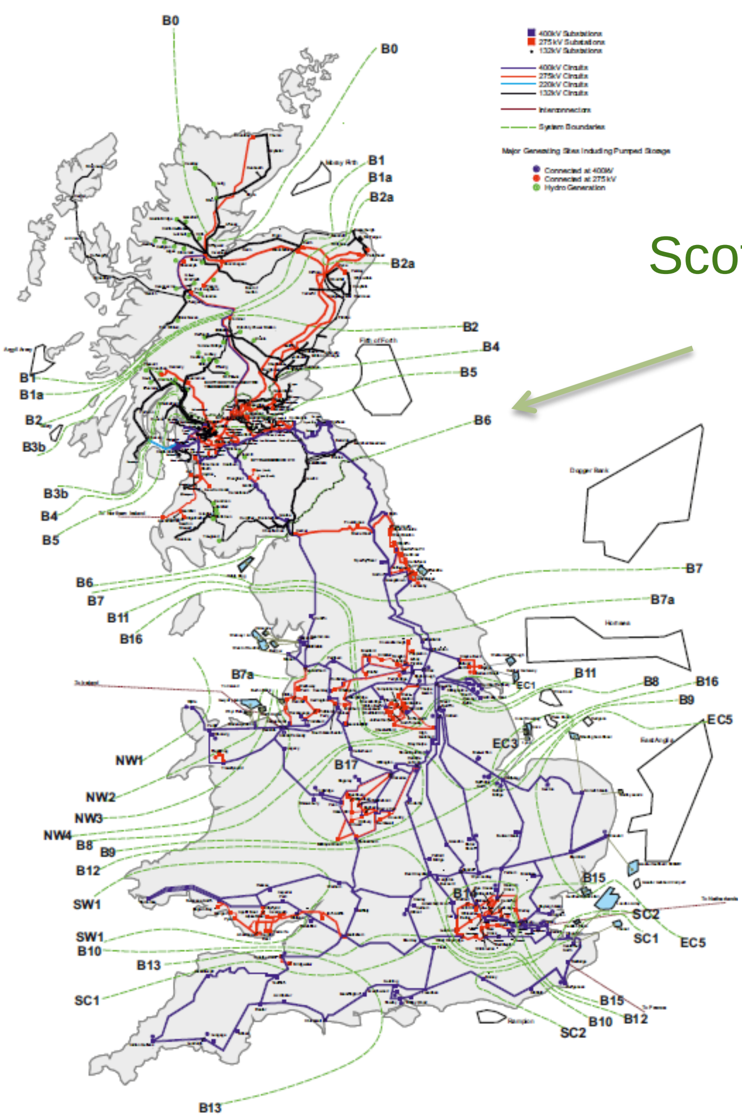
- Majority of 275 kV network over 40 years old
- Significant sections of 132 kV network over 60 years old
- Renew 15% of substation assets, replace over 800 circuit km of overhead line

Strong Incentives to Deliver Outputs

- Innovation embedded throughout investment programme
- Numerous projects are first of a kind in the UK, and, in the case of Western HVDC Link, the world.

System Boundaries

Figure A3: GB Transmission System Boundaries



Scotland-England
“Cheviot”
B6

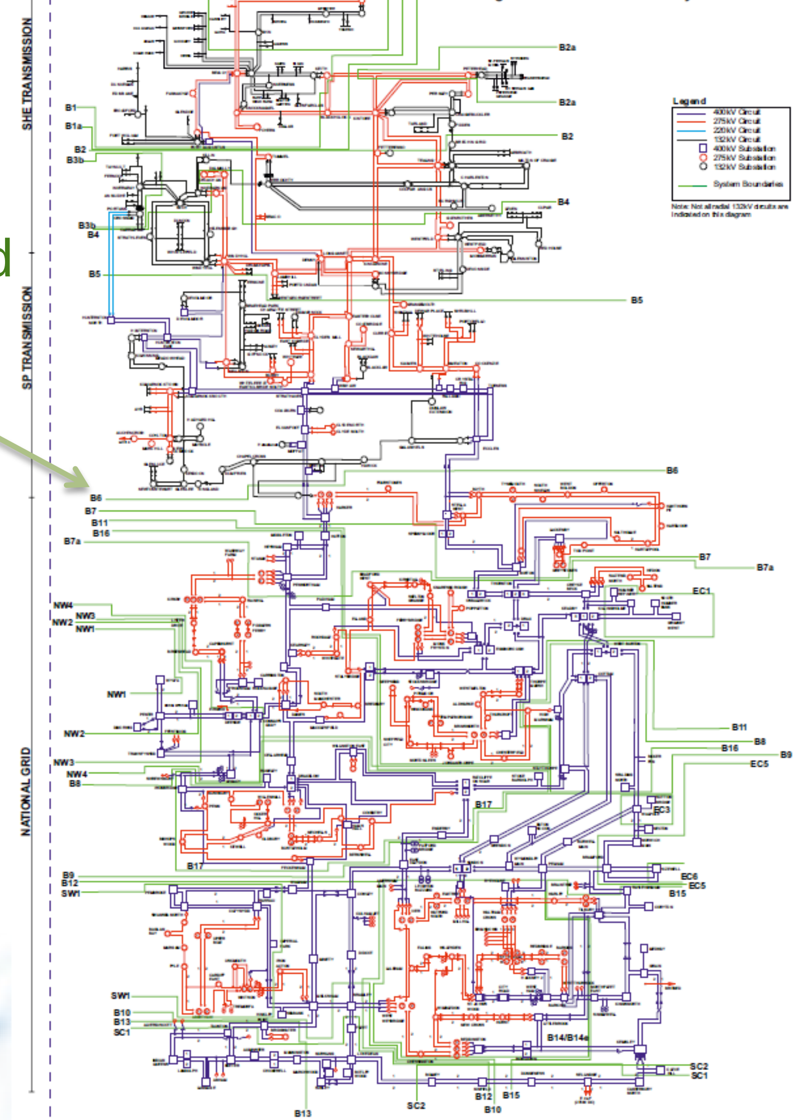
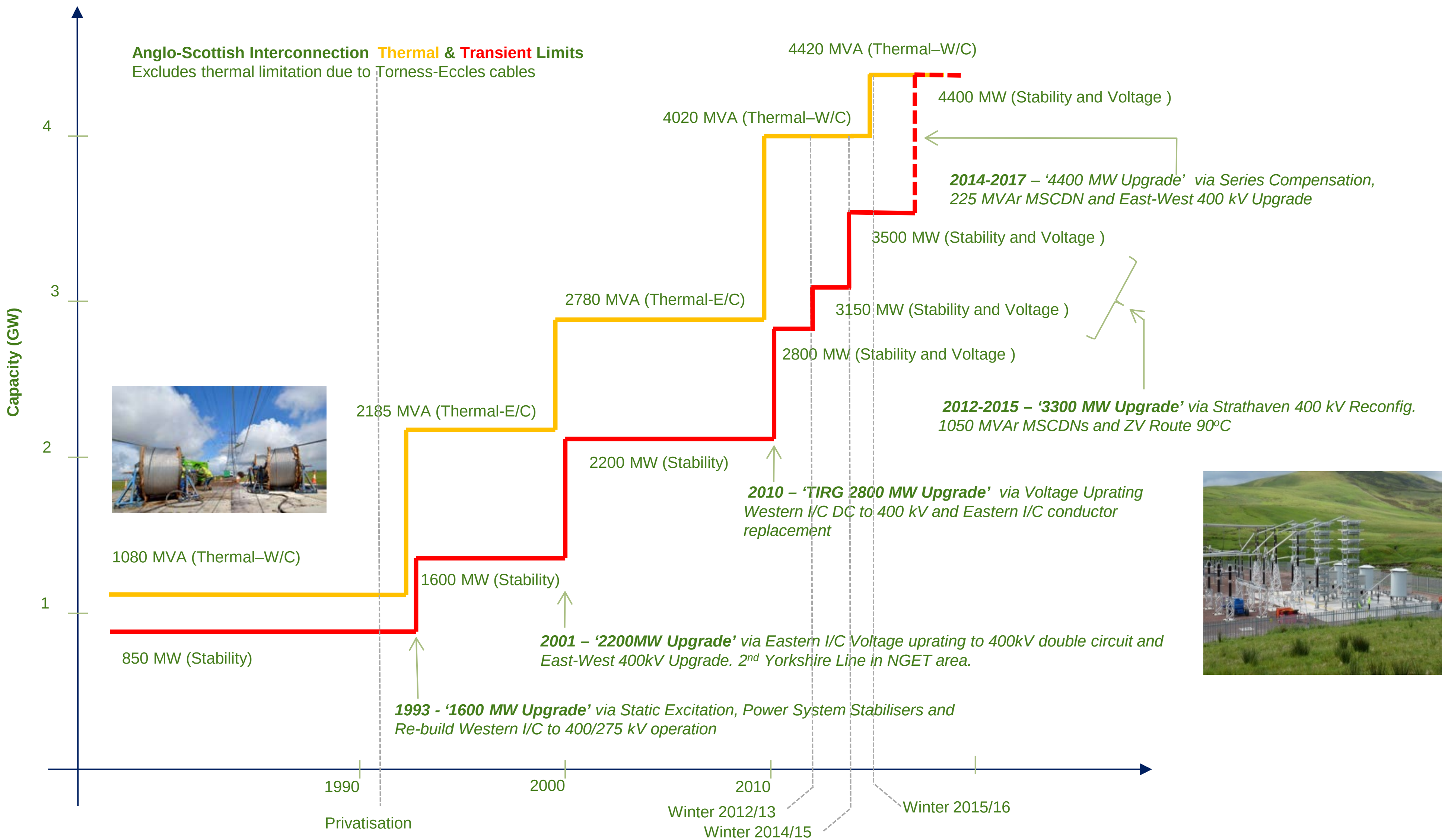


Figure A6: GB Transmission System Boundaries

B6 Export Upgrades



8

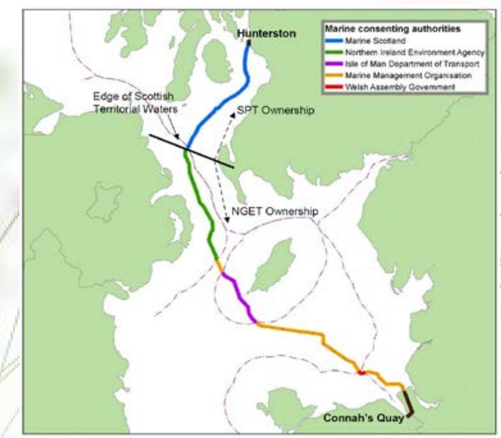

MAP OF THE TRANSMISSION SYSTEM
LEGEND
NUCLEAR POWER STATION
FOSSIL FUEL POWER STATION
HYDRO POWER STATION
132kV SUBSTATION
275kV SUBSTATION
400kV SUBSTATION
HIGHEST BUSBAR VOLTAGE INDICATED
132kV TRANSMISSION CIRCUIT
275kV TRANSMISSION CIRCUIT
400kV TRANSMISSION CIRCUIT
SCOTTISH HYDRO-ELECTRIC TRANSMISSION
SP TRANSMISSION LTD.
NGC
Dalmally
CRUACHAN
SLOY
To Braco/Errochty
To Kintore/Tealing
To Tealing
Cupar
Leven
Glenrothes
Westfield
Redhouse
Devonside
Dunfermline/Townhill
KINCARDINE
Glenniston
Mossmorran
Stirling
LONGANNET
Bainsford
Grangemouth
Whistlefield
To Dunoon
Helensburgh
Strathleven
Spango Valley
INVERKIP
Devol Moor
Erskine
Windyhill
Lambhill
Bonnybridge
Cumbernauld
GREENGAIRS
Broxburn
Bathgate
Livingston
Newarthill
Kaimes
Smeaton
COCKENZIE
Dunbar
CRYSTAL RIG
Crystal Rig
TORNESS
Neilston
Hunterston Farm
HUNTERSTON
HAUPLAND MUIR
Saltcoats
Kilwinning
Busby
Strathaven
DUNLAW
Berwick
Marshall Meadows
Linnmill
STONEBYRES
BONNINGTON
EMLY BANK
ROUGHSIDE
Eccles
Eccles
(Stella No.1 and 2 Circuits)
Meadowhead
Kilmarnock Town
Kilmarnock South
Coalburn
HAGSHAW HILL
Galashiels
Ayr
Coylton
Elvanfoot
Degree of Compensation
30~35% End to End
Hawick
HAREHILL
GALLOWRIGG
Maybole
Moffat
Moffat
(Harker Circuit)
KENDOON
CARSFAD
EARLSTOUN
GLENLEE
Undersea Cables To Northern Ireland
Auchencrosh Convertor Station
Dumfries
Ecclefechan
Chapelcross
Gretna SCE
(Elvanfoot Circuit)
Blyth
Stella
Harker
Newton Stewart
Glenluce
TONGLAND
SP TRANSMISSION
Map of the Interconnected Transmission System

Incremental Onshore

- B6 to ~4400 MW
- Capex ~ £350m (SP~£170m)
- East-West 400 kV Upgrade
- Reconductor Harker-Hutton
- Shunt compensation at Cockenize
- **Series Compensation**

Western Link HVDC

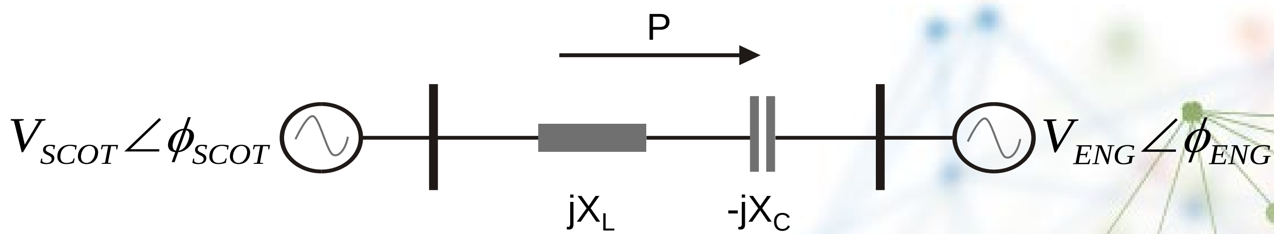
- B6 to ~6600 MW
- Capex ~ £1bn
- 600 kV HVDC
- 2250 MW
- Bidirectional
- Subsea



Series Compensation

- Series compensation is the addition of capacitor banks in series with a circuit
- Reduces circuit reactance, improving stability and voltage performance, allowing the thermal capacity of the SPT-NGET interconnection to be exploited

- Employed worldwide for decades to improve long distance power transfer and defer / avoid the requirement for new circuits
- First application in the UK: Four units in SPT, Two in NGET

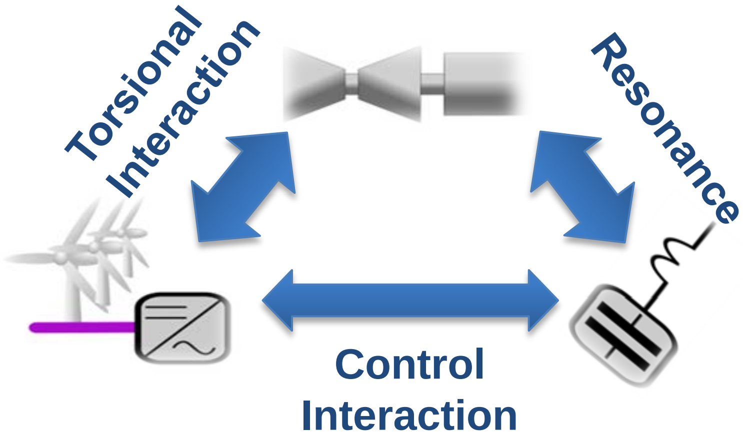


$$P_{B6} = \frac{V_{SCOT} V_{ENG} \sin\left(\varphi_{SCOT} - \varphi_{ENG}\right)}{X_L - X_C}$$

Increased Risk of Sub-Synchronous Oscillations

Bruce English, "Reactive Power Solutions, Subsynchronous Oscillations (SSO): Risk Analysis, Protection, and Mitigation Techniques", GE Digital Energy. Available: http://www.slideshare.net/GEEnergyConsulting/v5-ssr-ssciwebinar

Hole burnt in shaft after SSR event: Mojave desert, USA 1970



Fatal failures: Siberia's hydro disaster
IET E&T Magazine, 11 July 2011 By Fabia Acker

- The network needs to support big export and big import, sometimes in the same day!
- Heavily constrained boundaries
- New technologies
  - Intra-network HVDC, new HVDC interconnectors, series compensation and wind farm controllers
- Changing Energy Landscape…

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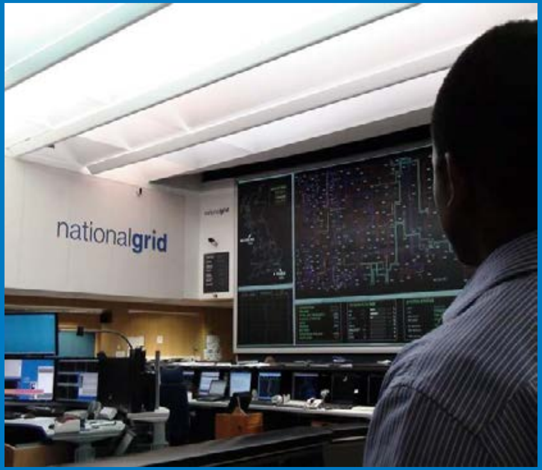
The Development of Wide Area Monitoring Systems - NGESO



Dr Phil Ashton – Future Control Strategy

Monday 12th March 2018

phil.ashton@nationalgrid.com

Changing Energy Landscape

Power Station Closures

≈25%

of total capacity by 2020 vs 2010 levels

Decarbonise Electricity

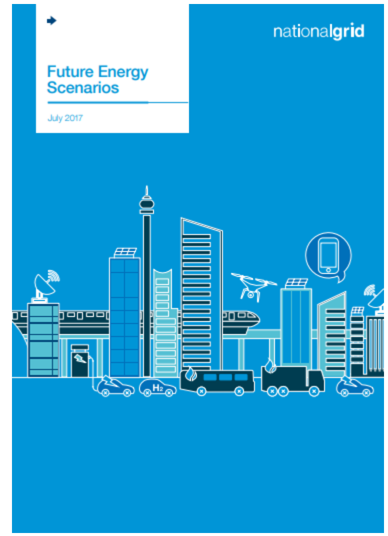
80%

CO_2 reduction by 2050

Energy from Renewables

≈15%

of total supplies by 2020



Energy needs based on stakeholders views of the future energy landscape

Challenges and Opportunities. Developing measures to ensure the operability of future networks

Future Energy Scenarios 2017, National Grid. http://fes.nationalgrid.com/

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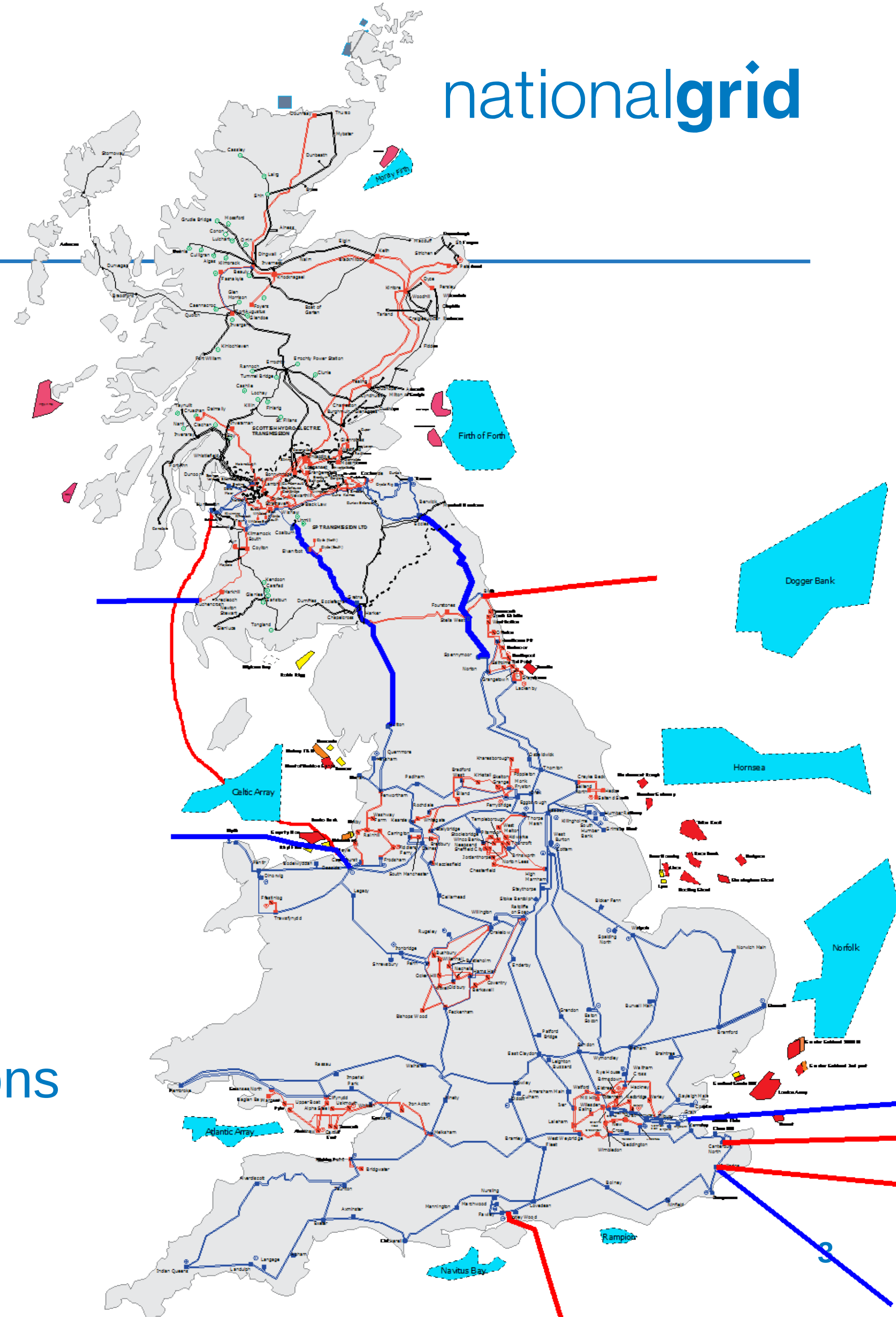
Network Challenges

- Increased Interconnection
  - ELEC Link 1000MW
  - NEMO 1000MW
  - IFA2 1000MW
  - NSN 1400MW
- Series Compensation
  - TCSC and FSC
- Intra-Network HVDC
  - Western Link
- Power Electronics
  - Statcoms, SVC's etc
- Multiple Models
- Increased Dynamic Interactions
- SSO
- System Stability Issues?



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SO VISOR Research Objectives

- First “Full GB” WAMS
  - What’s under the bonnet?
  - X-ray to MRI
- What do we do with all the data?
  - How best to represent it to operators?
  - Post-event analysis requirements
- How much is it going to cost?
  - What do we need and where?
  - Who owns it / is responsible?

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Electricity Transmission Owner VISOR Deployment Experience

Mark Osborne March 2018

Perform/Compete/Grow/ETO

Background for System Monitoring

Why do Transmission Operators need system monitoring?

- Networks are changing faster than utilities can respond
- We need to:
  - Quantify the phenomena on the system (harmonics, sub-synchronous oscillations, unbalance & control interactions)
  - Need to characterise generation & load response to network perturbations
  - Validate network modelling and assumptions to prediction future contingencies
  - Prepare for changes in regulation and grid code requirements which may require the networks to be managed differently “Connect & Manage”
  - Measure the impact of changing network conditions on asset performance.

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Wide Area Monitoring Systems

How will Transmission Owners use WAMS?

- Improve network observability to measure and monitor the performance of an increasingly complex system
- identify opportunities for marginal capacity improvement
- Underpin the control philosophy for network automation to address transient & voltage stability issues
- Improve post-event analysis, including accurate fault location
- Improve asset monitoring and protection
    - Optimising asset maintenance
    - Facilitate Risk Management

VISOR Monitoring devices

Waveform Measurement Unit

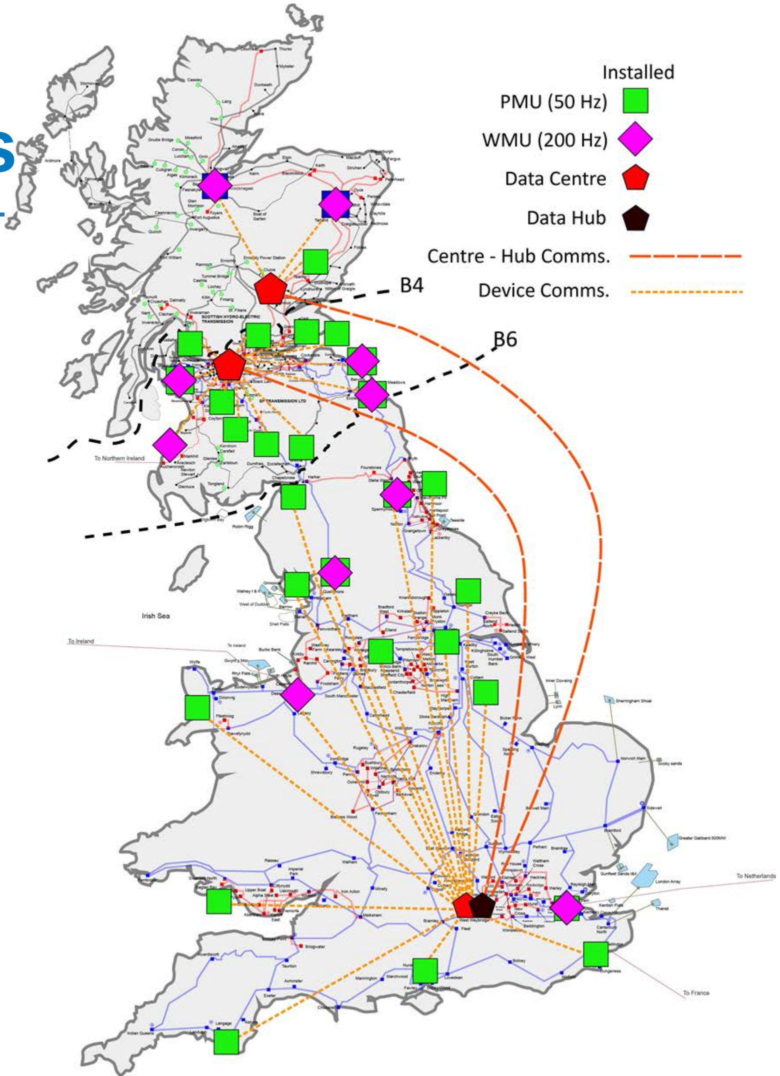
- New: **1st demonstration under VISOR**
- Streams time-synchronised waveforms at **200 samples/s**
- Sent as **IEEE C37.118** (PMU) stream "analogs" – fully compliant
- Implemented within **Reason RPV311**
  simultaneous PMU, WMU, DFR and 800fps continuous recording

RPV311
Central Unit

RA33x
Acquisition Unit

VISOR monitoring locations

#	VISOR Partner	Locations (circuits)
4	SP Transmission	Eccles (Stella West 2) Torness (Eccles 2) Hunterston (Inverkip 2, to be Strathaven) Auchencrosh (Coylton)
8	National Grid	Hutton (Harker 1 & 2) Stella West (Spennymoor 1 & 2) Deeside/Connah’s Quay (Circuits 1 & 2) Grain (Circuits 1 & 2)
2	Scottish Hydro Electric	Kintore Beauly
1	The University of Manchester	Manchester



VISOR WMU Installations

- Stand alone installation – to avoid impact on other substation services
- Utilising the existing business LAN (RAMM) until fully proven for migration onto more resilient Optel
- Establishing Settings & Configuration files
- Also utilise existing PMU population
- Connection to substation 110V DC supplies for resilience

Lessons learned during the Project

- Installation took longer than anticipated
  - Piggy backing onto outage restrictions – resource coordination required
  - Internal design assurance and commissioning checks – should get better in time
- Instrument transformers
  - Availability of 3 phase VT signals only on feeder circuits. (Busbar is only single phase)
  - Availability of spare CT cores
- Communication issues
  - RPV 311 uses UDP, cyber security requires TCP
- GPS antennae performance affected by rain - replaced
- Firmware upgrades – these can be achieved remotely – (benefit of standalone units)
- Existing/converted PMUs where not adequately designed to output to multiple PDCs – these will be upgraded/replaced in time.
- Difficult to free up internal resource to support innovation – heavily reliant on external resource for analysis and support.

VISOR Project: Applications

Stuart Clark
GE Grid Solutions

VISOR Close-Down Event

12th March 2018

VISOR Project: Visualisation of real time system dynamics using enhanced monitoring

Presentation Outline

- **Background:** power system oscillations
- **VISOR applications:** context & overview
- **VISOR application highlights**
  - **Functionality:** *what was demonstrated*
  - **Learning** *gained from the project*

BACKGROUND:
POWER SYSTEM OSCILLATIONS

Background: Power System Oscillations

Oscillations are inherent in the Grid, due to network + plant

Usually present but well damped – by design & running of network, tuned plant controls

Risk: poor damping due to *interaction, plant malfunction* or *conducive conditions*

"VLF"

Governor
Common
0.1 Hz

"LF"

Electro-Mechanical
Inter-Area / Local / Plant
2 Hz

"SSO" – *SSR, SSTI, SSCI*

Control *voltage, power electronics*
4 Hz

Torsional *turbine mechanical*

Grid Resonance *capacitor + network*

50 / 60 Hz

Reliable, accurate* observability** ***~10 Hz

50/60 fps PMU data

Tools & Capabilities before VISOR

Monitoring

Source Location

SP ENERGY NETWORKS nationalgrid Scottish & Southern Electricity Networks MANCHESTER 1824 The University of Manchester RIIO NIC NETWORK INNOVATION COMPETITION

VISOR Project: Visualisation of real time system dynamics using enhanced monitoring

Extending Oscillatory Visibility: the WMU

GE RPV311 Digital Recorder

11+ WMUs
monitoring 22 circuits across GB

Waveform Measurement Unit

Point-on-wave samples at 200fps

- Uses **standard hardware:** PMU / DFR platform
- Uses **standard protocol:** IEEE C37.118
  200fps rate is atypical, but encouraged by standard
- **New signal processing** is **straightforward to standardise**
  Simple downsampling: filter requirements easy to define
  "Clever bit" is in single phase conversion, bad data detection, etc.
- **Uses existing infrastructure:** PDCs, communications networks
  Increased communications bandwidth and PDC software enhancement may be needed for atypical 200fps data rate

VISOR APPLICATIONS

VISOR Applications: Context

Demonstrate the **concepts, capabilities** and **tangible benefits** of **WAMS** to business-as-usual grid **planning**, real-time **operation** and **analysis**

Risks & Events

Disturbances & oscillations

- **Monitor expected behaviour**
- **Capture unexpected** behaviour
- **Tools** for real-time awareness & post event analysis

Maximising Assets

- **Angle** as a **constraint** metric

Reducing Uncertainty

- **Line parameters**
- Oscillatory behaviour
- Response to disturbances

Managing Risk & Events

Oscillation Monitoring & Source Location

Mode	Frequency
Governor & Common	**0.002 Hz**
Electromechanical & Voltage Control	**0.1 Hz**
Resonance, Control & Torsional interaction	**4 Hz**
	46 Hz

Disturbance Detection, Location & Characterisation

Maximising Assets

Angle-Based Constraints

WAMS Infrastructure
Requirements, Evaluation & Rollout Recommendations

Online Demo
WAMS software module

Offline Study

Reducing Uncertainty

Hybrid State Estimation

Impact of Uncertainty
On Security Margins

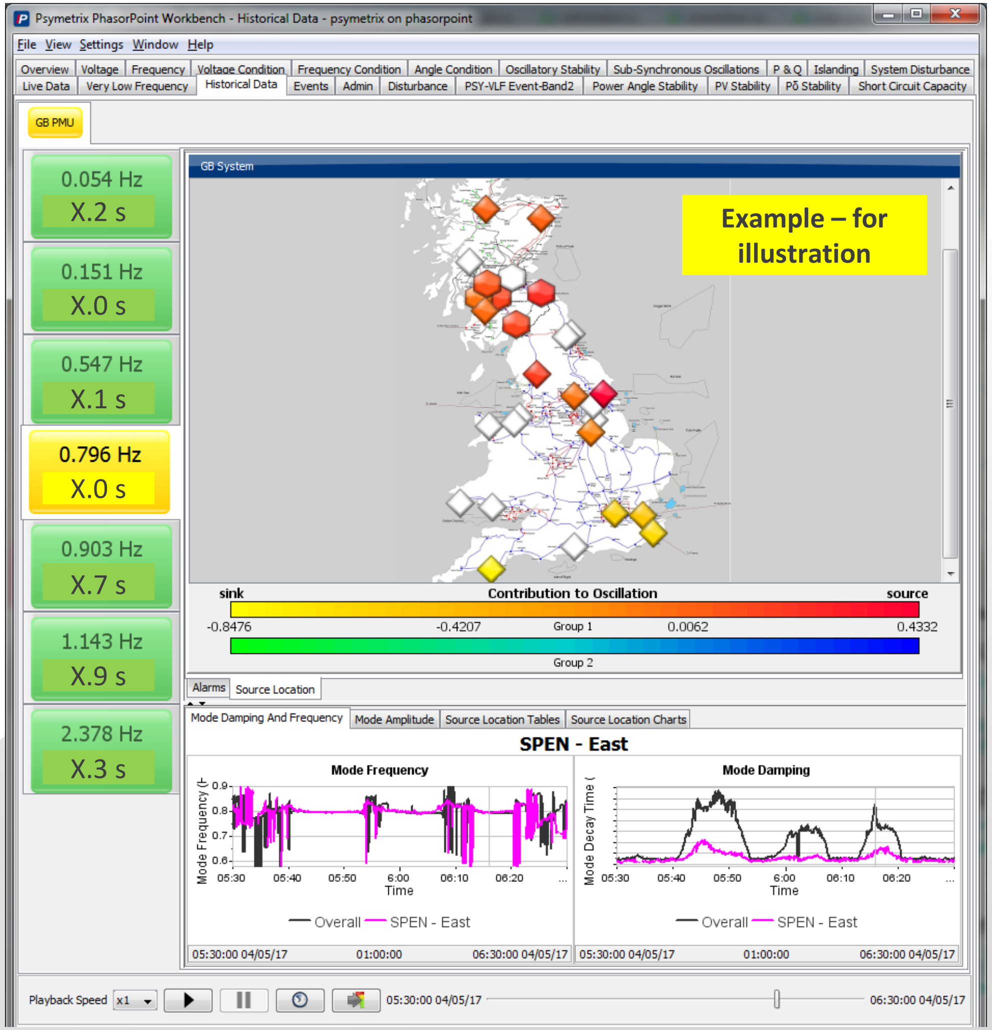
Dynamic Model Validation

Robust Line Parameter Estimation

VISOR Applications: Oscillatory Stability Management

What has been demonstrated:

- **Full visibility** *of VLF, LF and SSO (0.002 - 46Hz)*
- **Real-time monitoring** *map display, alarms*
- Results stored for **historical review**
  Charts, display replay, export
- Flexible **frequency banding**
  For visualisation, alarms & investigation
- **Source Location** *analysis & display*
- **Reports**
  Review behaviour over days, weeks, year
  Experimented with automation

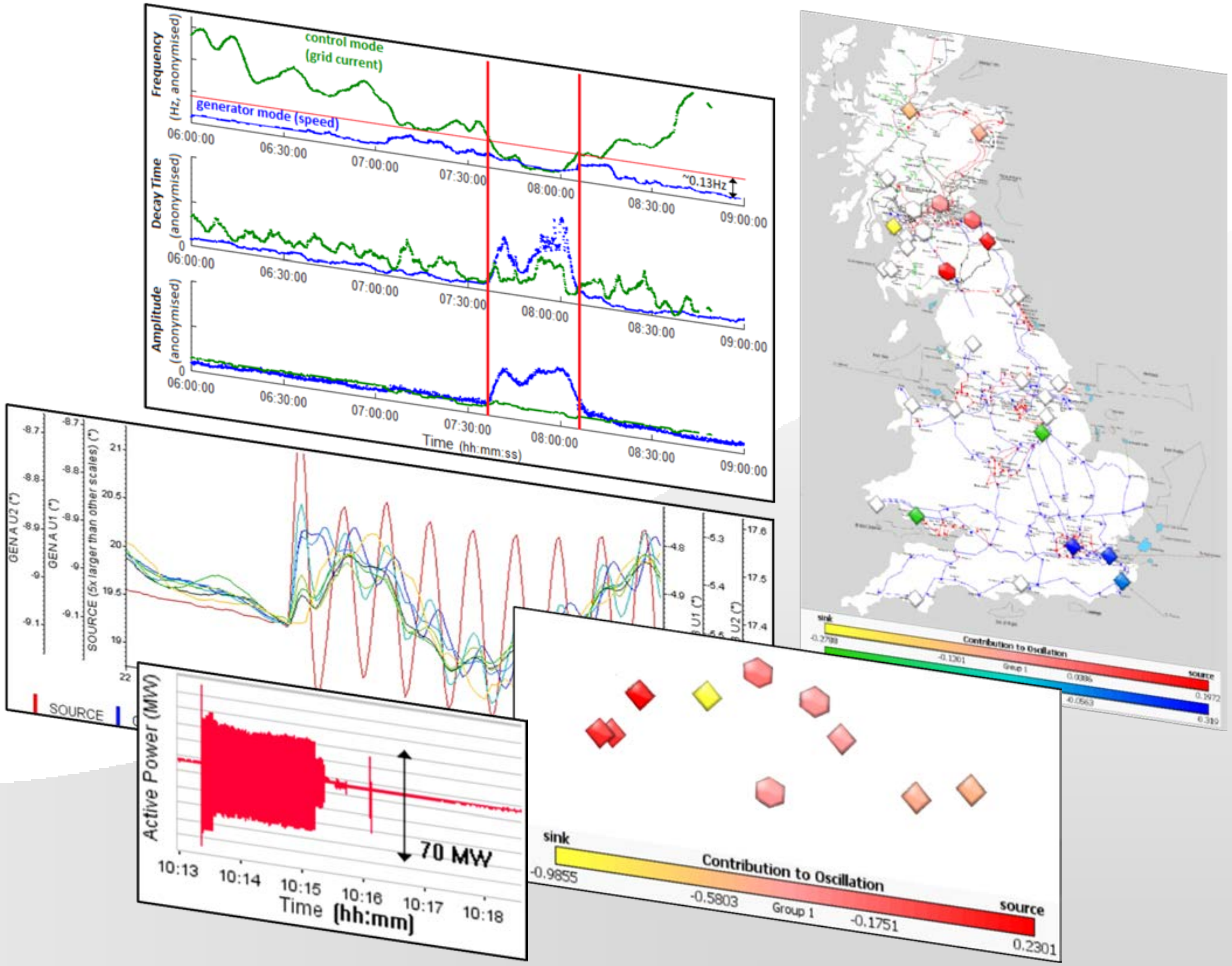


VISOR Project: Visualisation of real time system dynamics using enhanced monitoring

VISOR Applications: Oscillatory Stability Management

What has been learnt:

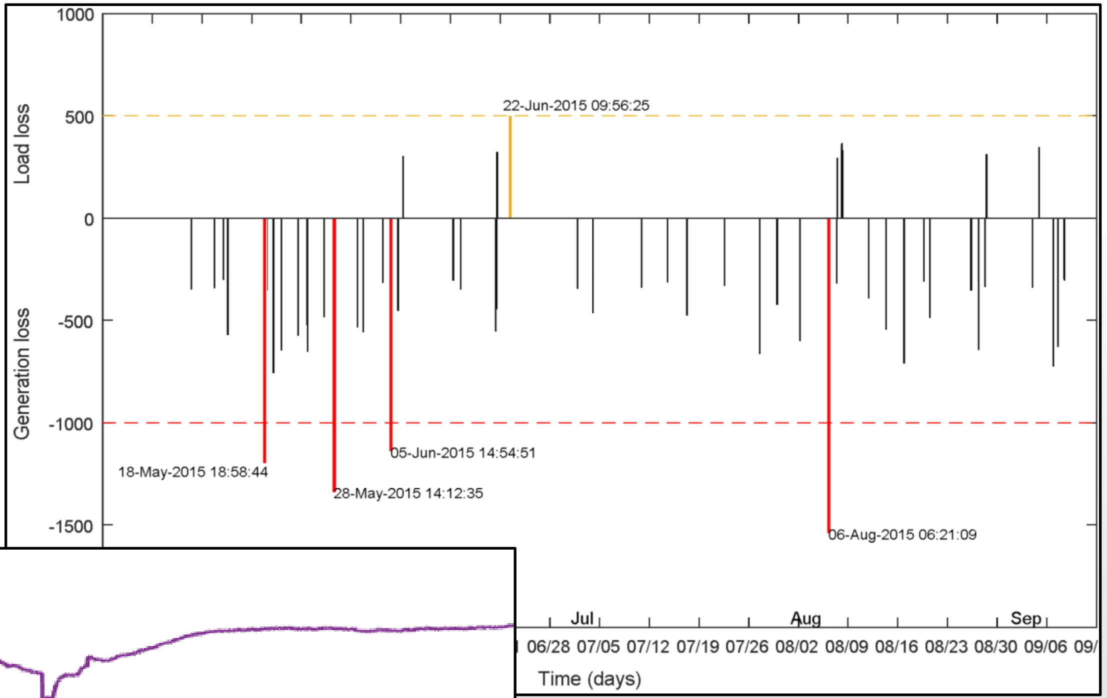
- **GB system modes characterised**
  To a level never achieved before
- **Localised behaviours identified**
  Informs future studies
- **Low-level interactions observed**
- **Significant events detected**
  VISOR data & tools aided investigation
  System response captured

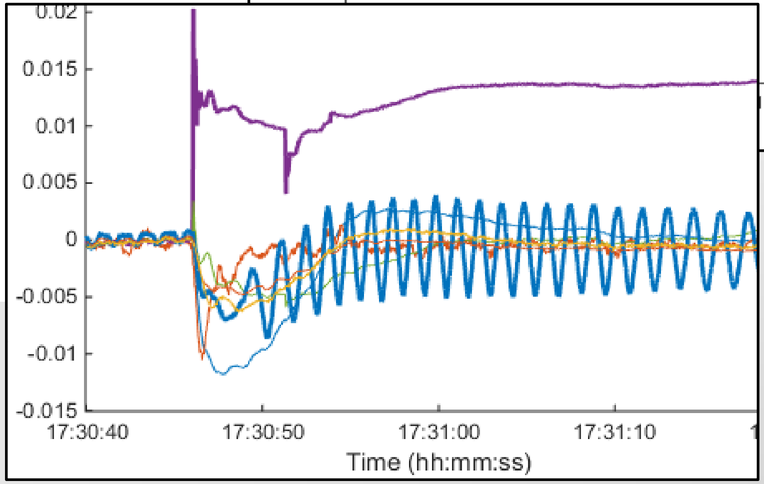


VISOR Applications: System Disturbance Management

What has been demonstrated:

- **Detection & classification** of disturbances
  Generation / load / line loss
- **Location to the nearest PMU**
- **Characterisation** of the impact:
  - **Static** (step) and **Dynamic** (wobble)
  - **Global:** event significance, risk
  - **Local:** most affected site, non-compliant response
- **Review whole system response**
  Experimented with automated reports





SP ENERGY NETWORKS nationalgrid Scottish & Southern Electricity Networks MANCHESTER 1824 The University of Manchester RIIO NIC NETWORK INNOVATION COMPETITION

VISOR Applications: Line Parameter Estimation

Theory:

With voltage and current measured at both line ends, line parameters can be estimated

Challenge:

Measurement error compensation

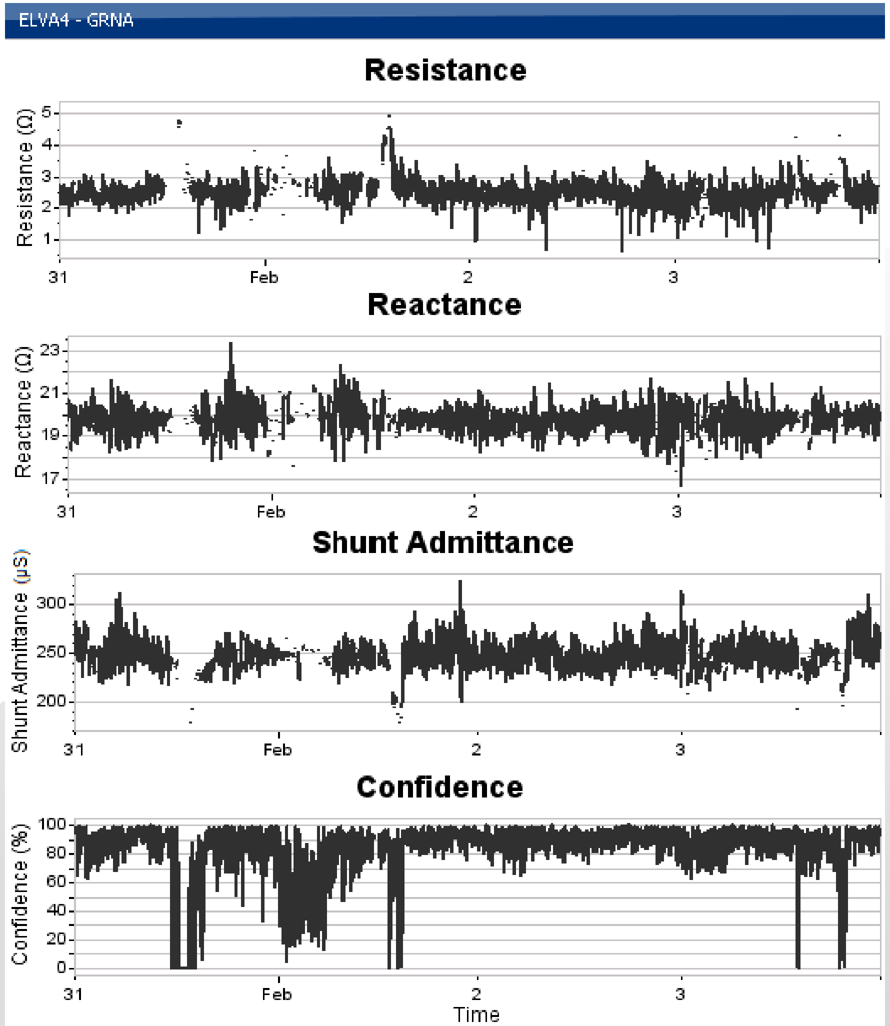
*Primary CT/VT, wiring, PMU – noise **and** systematic*

What has been demonstrated:

Robust LPE algorithm deployed

Some high confidence results

Lower confidence on other lines

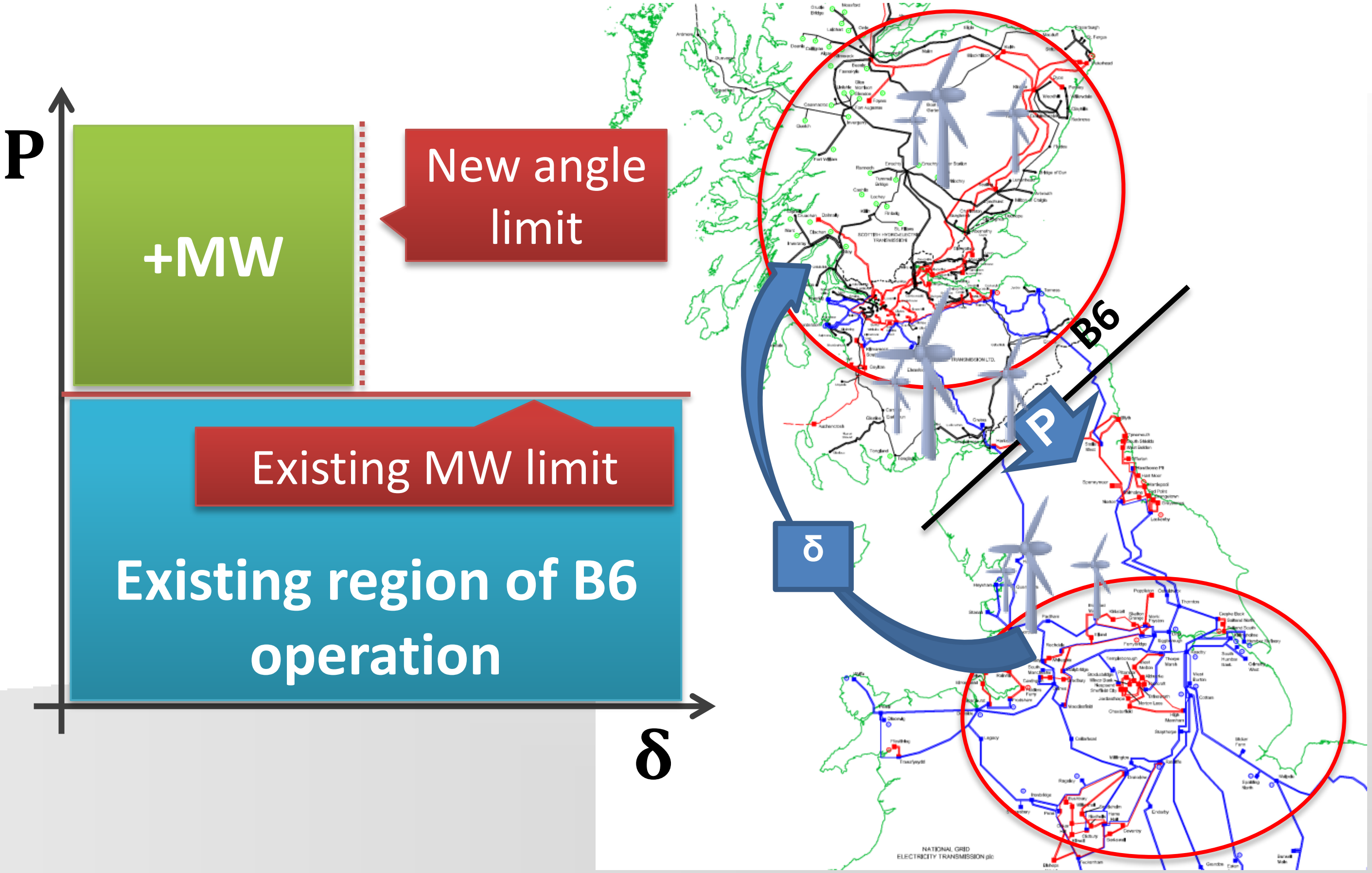


VISOR Applications: Power-Angle Boundary Display

Thesis: wind generation adds to MW flow across a transmission boundary but has less effect on stability

Proposed new constraint:

- **Existing MW limit**
- **"Centre of Angle" difference** between Scotland and N. England



Application demonstrated:

Weighted Centres of Angle calculation for Scotland & England

Next step: incorporate real-time network & generation data

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The University of Manchester

VISOR Research

Close Down Event
12/03/2018, IET London

Vladimir Terzija (The University of Manchester)
vladimir.terzija@manchester.ac.uk

MANCHESTER
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The University of Manchester

Overview of VISOR Project

1. UoM Motivation
2. PMU Placement
3. Hybrid State Estimation
4. Subsynchronous Resonance
5. What’s Next

Related Projects

VISOR has been part of the new drive for innovation in power systems, in which the UoM has been a key player.

VISOR is an enabler of all NIC projects listed below.

1.	Ofgem NIC VISOR Project	(£8m)
2.	Ofgem NIC EFCC Project	(£10m)
3.	Ofgem NIC FITNESS Project	(£12m)
4.	MIGRATE, EU HORIZON2020	(£16m+)

UoM Role in VISOR

UoM

- Study of subsynchronous oscillations and interactions
- Full GB dynamic model validation using synchrophasors
- Optimal PMU placement
- Study the potential role of Hybrid State Estimation (HSE) in GB

MANCHESTER 1824
The University of Manchester

PMU Placement

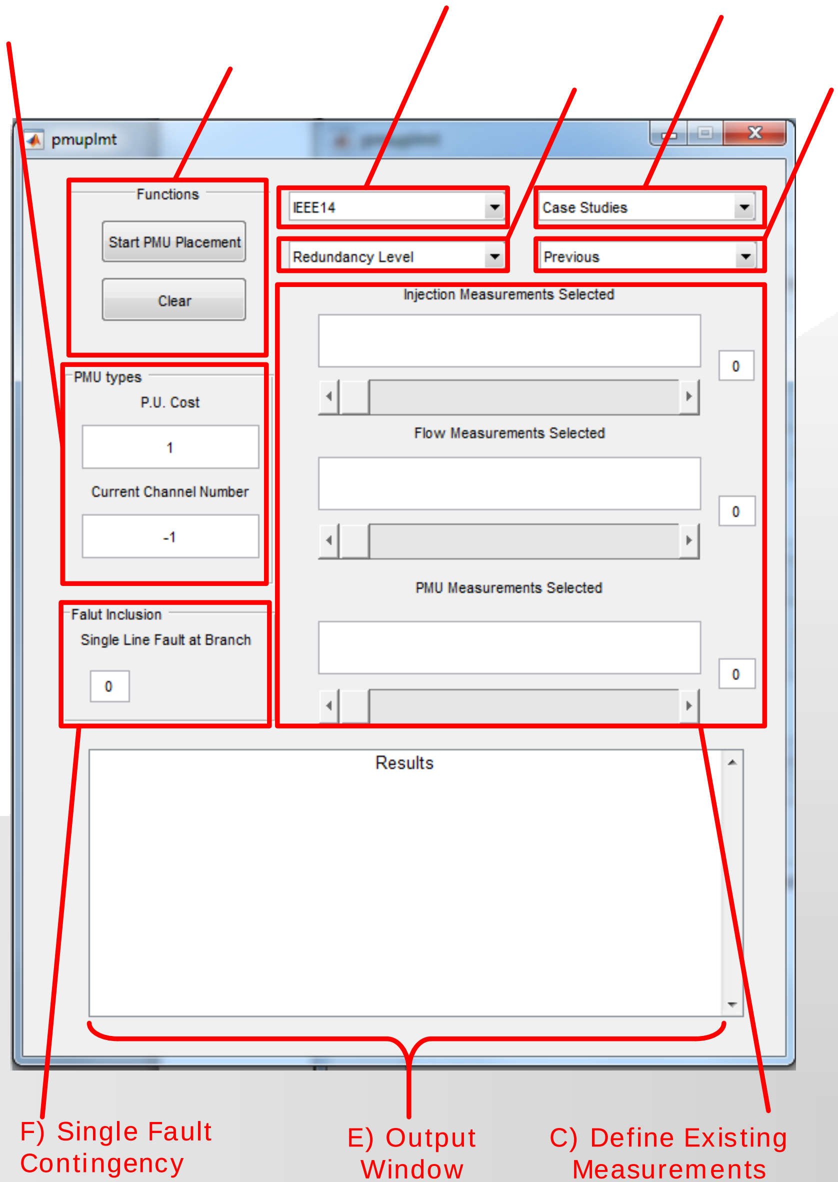
Vladimir Terzija (The University of Manchester)
vladimir.terzija@manchester.ac.uk

Why PMU Placement?

- The performance of Wide Area Monitoring System relies on the performance of its Monitoring Devices
  - This includes their measurement performance (static/dynamic) and where these measurements are taken (their *placement*)
- The monitoring applications developed for VISOR are dependent on receiving the right measurements from the right places
  - Where are the right places and where best to place PMUs to monitor them?
- PMU Placement entails selecting the buses and feeders to monitor
- How do we define ‘best’ ?
  - Cost, performance, level of reliability/redundancy, measurement quality

PMU Placement Tool

- Tool developed at UoM
- Solves:
  - Optimal Placement for full observability from PMUs
  - At minimum PMU cost
- Subject to:
  - Measurement redundancy
  - Existing measurements
  - Line outage contingencies
  - Channel limits
- Assumes
  - 1 PMU per bus



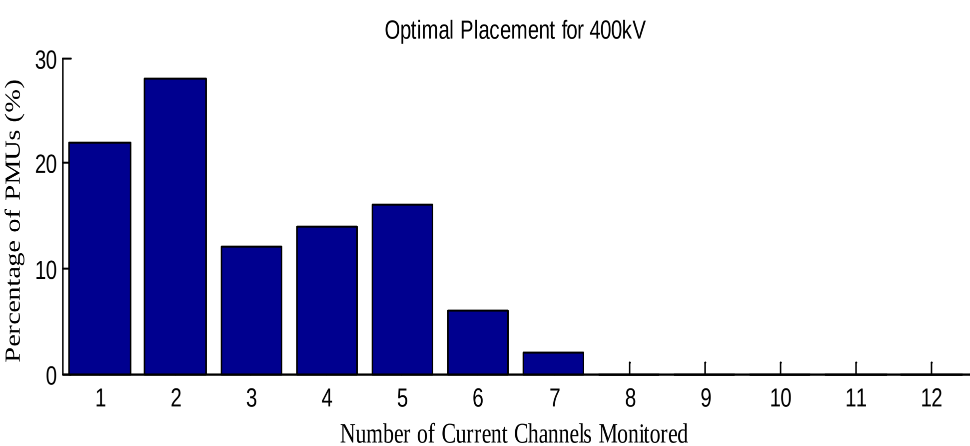
GB Topology

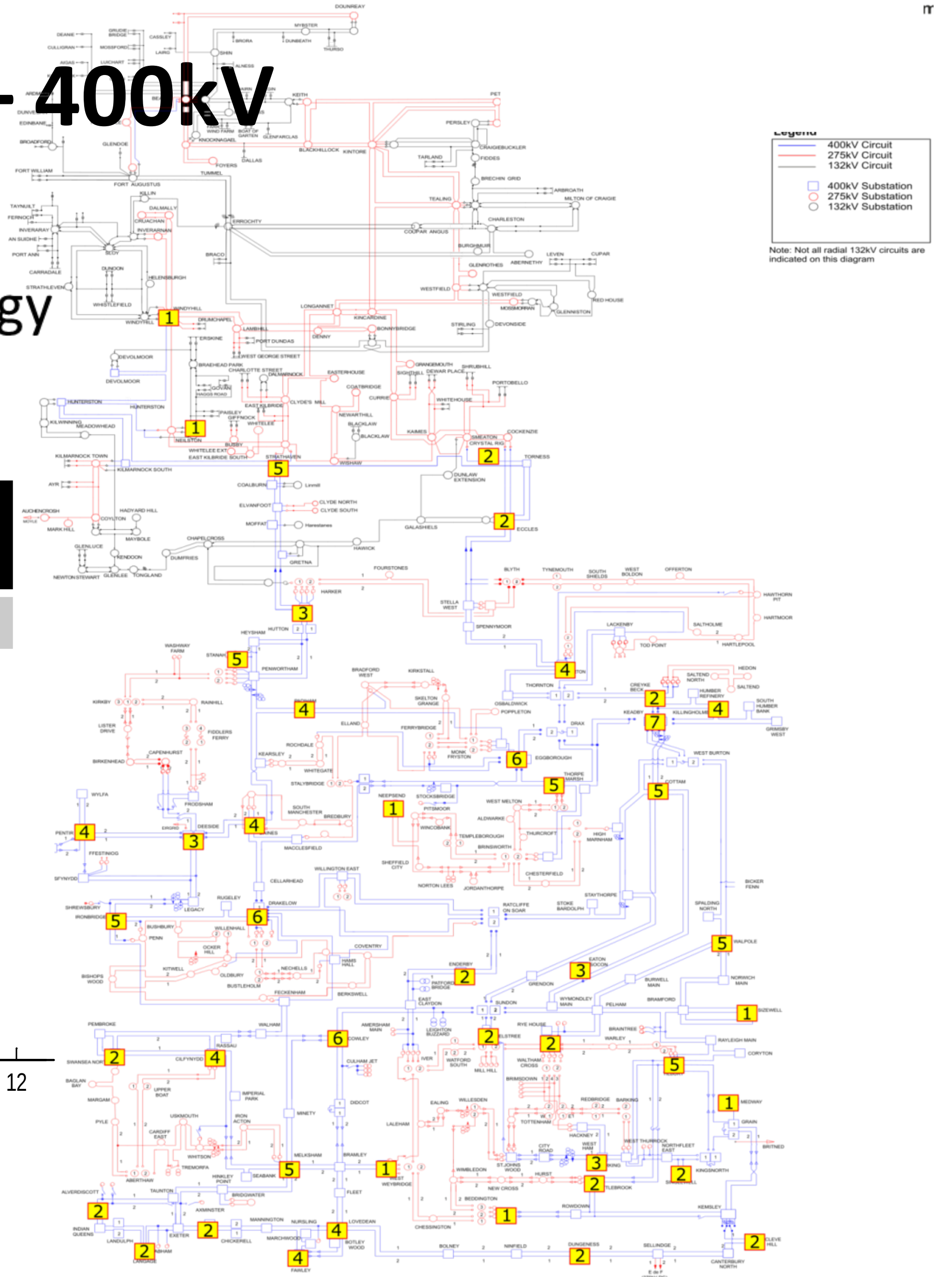
- GB transmission topology extracted from data made available in the appendices of the Electricity Ten Year Statement (ETYS)
  - Branch list used to build incidence matrix
- Topologies include 400kV, 275kV and 132kV transmission network
- Cross checked with system schematics from the ETYS
- Assumptions made to solve placement problem:
  - Single busbar at each substation
  - Busbar common to all voltage levels (i.e. no transformers)

Placement Solution – 400kV

- Applied tool to 400kV topology

PMUs Placed	Buses Equipped with a PMU (%)	Feeders Monitored
50	30	150



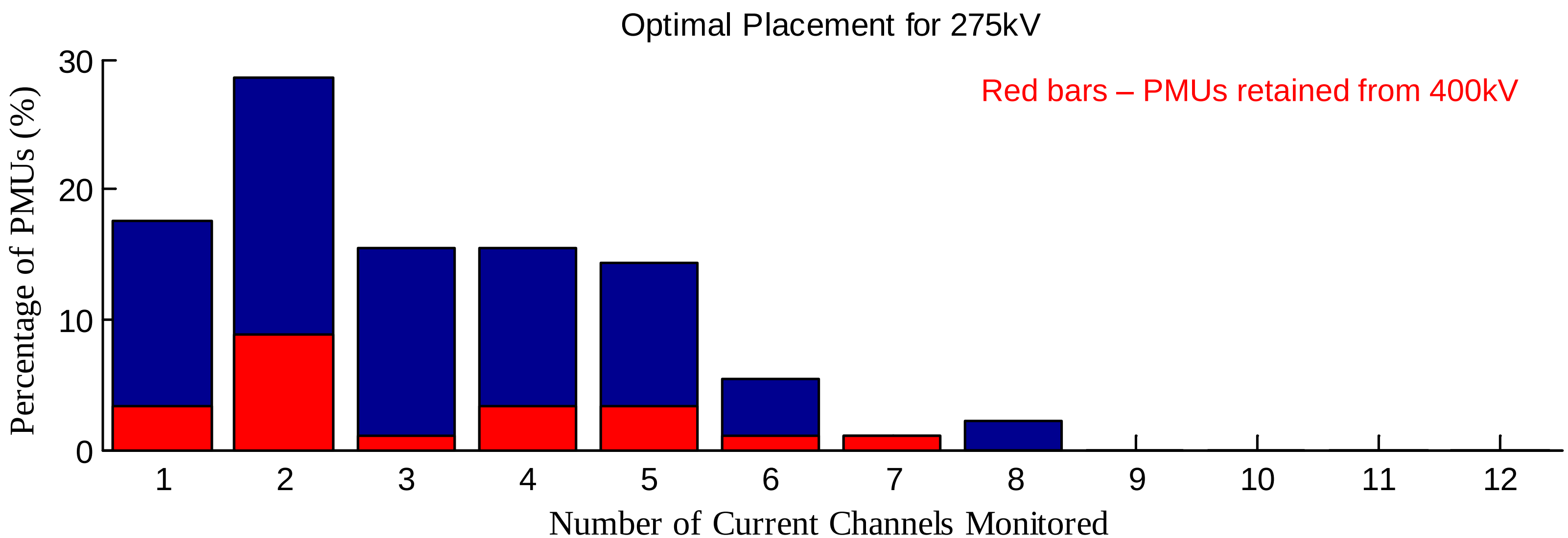


Placement Solutions – 275kV

- Placement tool applied to combined 400 and 275kV system

PMUs Placed	Buses Equipped with a PMU (%)	Feeders Monitored
91	29	284

PMUs in 400kV Solution	Identical PMU placements	Same location, more feeders	PMUs Removed	New Locations
50	19	10	21	62



Learning Generated

- Optimal PMU placement algorithms can be applied efficiently to full transmission system topologies
- Long term planning of PMU deployment should radically reduce the number of the devices that must be installed
- Device number not the best way to capture the cost of PMU deployment
- The solution of most existing optimal placement algorithms is not directly applicable to an actual transmission system
- The focus should be shift towards operational cost of PMU deployment rather than focusing solely on capital costs

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Hybrid State Estimation

Vladimir Terzija(The University of Manchester)
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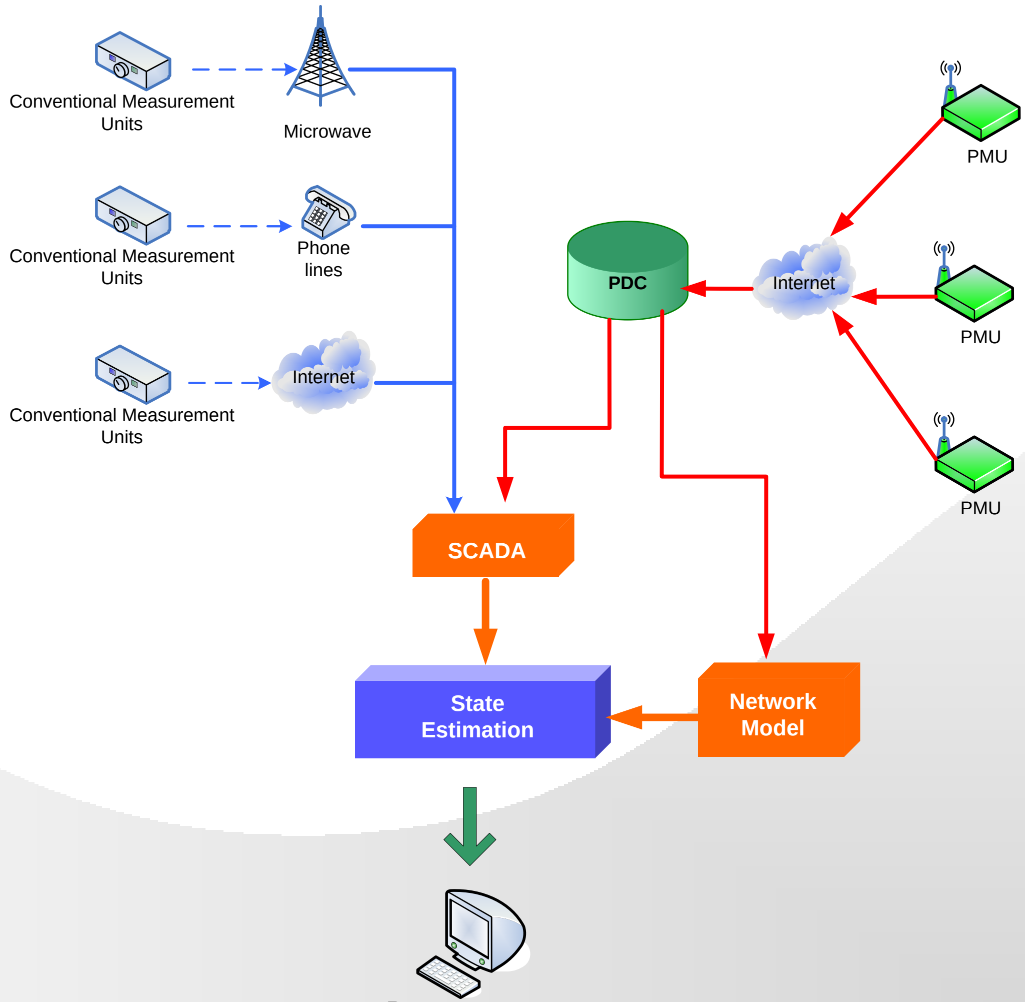
Hybrid State Estimation (HSE)

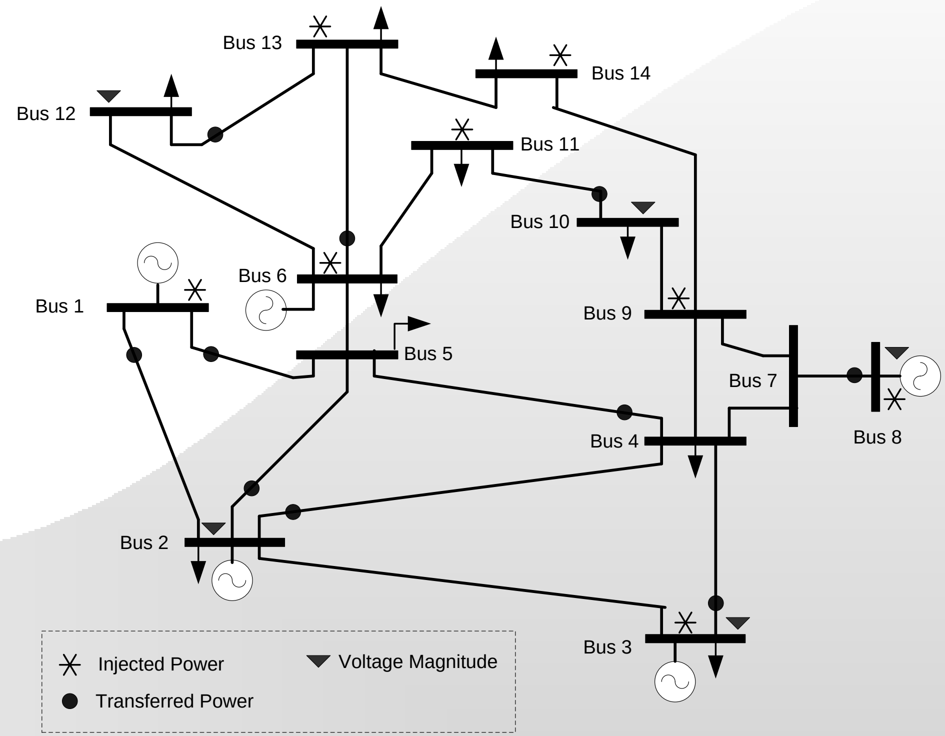
- PMUs directly measure the state of the bus they are placed at
- Can provide observability of neighbouring buses using current measurements between the buses and known impedance
- Synchronisation is critical to the role of PMUs
  - Allows angle measurements to use a common time reference
  - Angles from remote locations can be directly combined in calculations
  - PMU measurements are more accurate than RTU measurements
- UoM implemented five HSEs and compared their performance for the IEEE 14 and 118 bus test systems

Hybrid State Estimation (HSE)



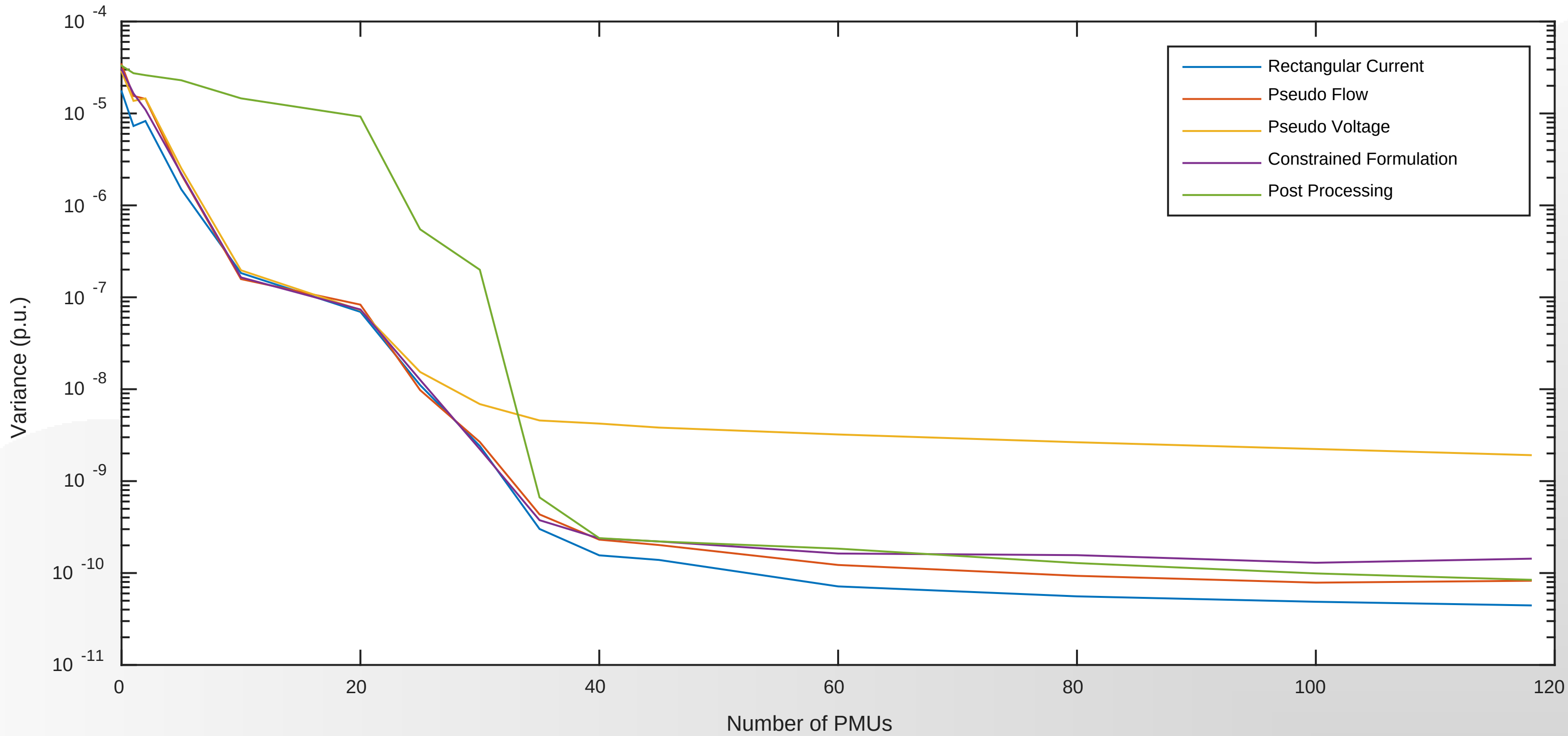
IEEE 14 Bus Test System

- Small test system commonly used for state estimator studies
- Each of the 5 HSEs implemented were applied to this system to compare their performance
  - Gaussian errors included in the RTU and PMU data



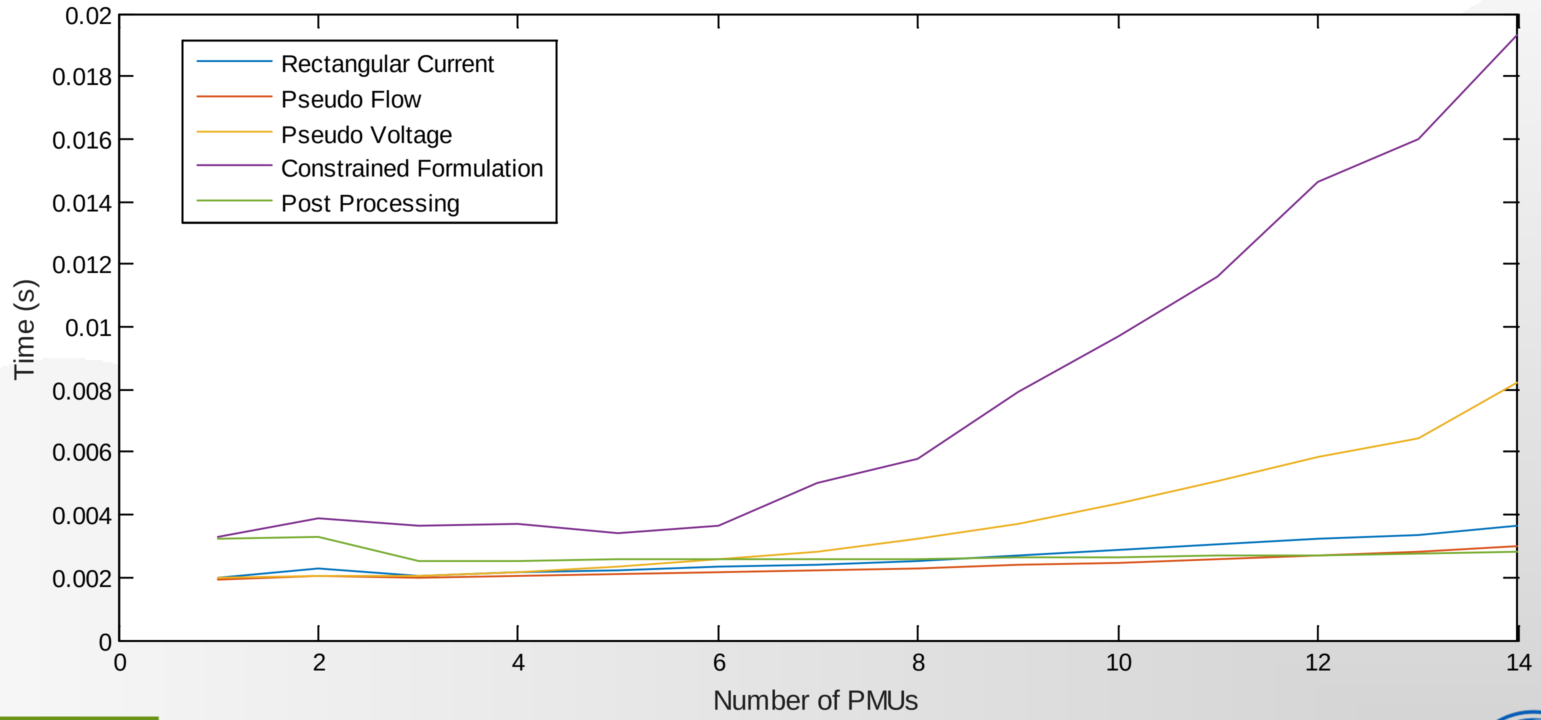
Results: IEEE 118 Bus

- Assessed Accuracy using the variance of the states
- Clear knee point for all HSE at about 37 (about 1/3 of the total number)
- RC is most accurate and PV/PP least accurate



Results: IEEE 14 Bus

- Assessed performance using convergence time
- As PMU number increases the HSEs slow down
- CF has the most significant increase in execution time
  - This formulation increases the number of states



Hybrid State Estimation (HSE)

- All HSE better than CSE by several orders of magnitude

- If HSEs are best when the system is fully observable,
  why not consider going straight to Linear State Estimator (LSE)?

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Subsynchronous Resonance

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What is SSR?

SSR is defined by IEEE as "the electrical power system condition where the electric network exchanges energy with a turbine generator at one or more of the natural frequencies of the combined system below the synchronous frequency of the system"

[Source: IEEE SSR Working Group, "Proposed Terms and Definitions for Subsynchronous Resonance", IEEE Symposium on Countermeasures for Subsynchronous Resonance, IEEE Pub. 81TH0086-9-PWR, 1981, p 92-97]

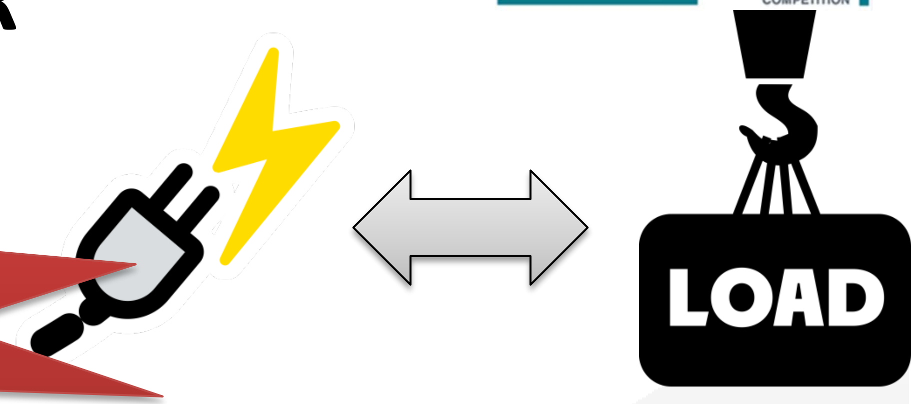
Why Research SSR?

For GB network, compensation is new…….
New technology, means new risks…….

- First ever series capacitor installation in GB network by SPEN in 2015, TCSC installation by NG in 2014
- Torsional protection may also be required for high rated power electronic converters that are near to turbine-generators.
- HVDC is especially of concern, due to typically high power ratings.
- Large motor drives and SVC can also be a problem, typically for smaller turbine-generators nearby

Impact of Loads on SSR

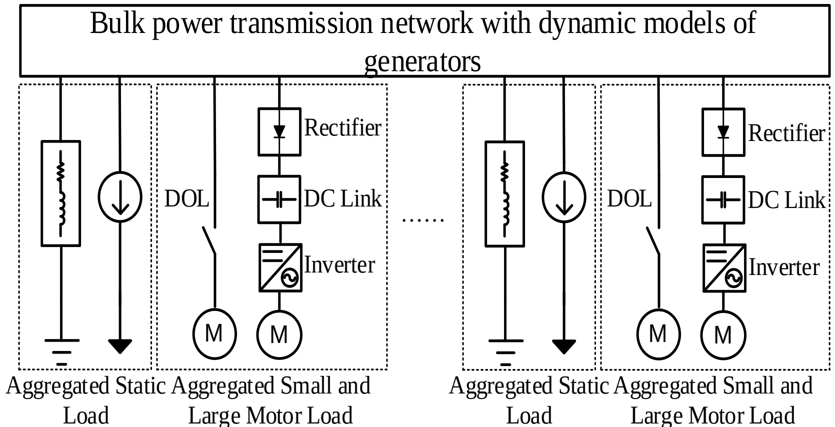
Conservative studies may lead to unnecessary capital expenditures or operational constraints to mitigate non-existent problems



For analysis of SSR impact of LOADS is either neglected (IEEE Benchmark models) or assumed as constant Impedance (STATIC) models (throughout the years of SSR research)

In the absence of appropriate load models, simulations may **over or underestimate the risk of SSR**, which may cause the protection or mitigation to be **over/ under-designed**

Loads and SSR Damping



Aggregation of loads at the transmission level

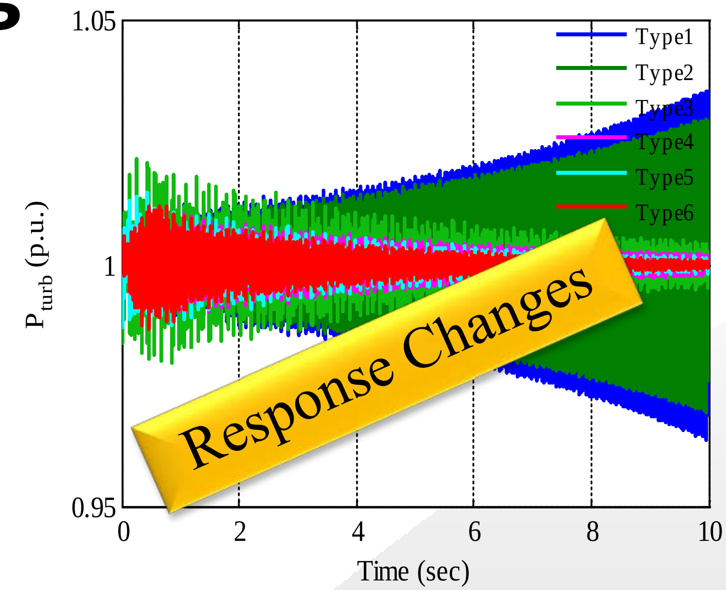


Table I. List of load types considered

Load Type	Description
Type 1	Loads neglected
Type 2	100% Constant Impedance
Type 3	50% Direct on Line (DOL) and 50% VFD based Motor loads
Type 4	100% DOL connected Motor load
Type 5	30% Const. Impedance 30% Const. Current 40% DOL connected Motor load
Type 6	50% Constant Impedance 50% DOL connected

unstable for Type 1 and 2

stable for Types 3, 4, 5 and 6

Conservative results impact decisions

- at the planning stage (regarding location and/or degree of compensation)
- during operation (setting improper thresholds for online alarms against dangerous interactions).

Can We Exploit Load Interactions?

Protection involves forced tripping (removal of generator or series capacitor), which is disruptive for a system that is already in a weakened state due to outages and is generally *recommended as a backup means of defence*.

VS.

Mitigation involves reducing the exposure of the system to the risk of SSR and thus allowing the vulnerable resources to continue operating, even when outages result in stronger electrical coupling between a generator and a series capacitor. In many cases, mitigation may also be able to completely eliminate the risk of SSR.

Can We Exploit Load Interactions?

New Mitigation Concept

- A novel SSR mitigation solution - Auxiliary Damping Controller (ADC)
- Uses existing resources, like 11 kV VFD based auxiliary power plant loads to provide effective damping for torsional oscillations
- Effective SSR mitigation right at the generator using a simple, easy to tune linear feedback compensator (tested for IEEE FBM and 68 Bus systems)
- VFD based auxiliary power plant loads (e.g. pumps and fans) present a significant proportion of plant generation capacity e.g. 3.6 % in fans and 7.2 % in pumps
- Critical role of fans and feed water pumps ensures availability

Conclusions

- Demonstrated the importance of modelling dynamic loads for the correct assessment of SSR risks by showing the sensitivity of torsional damping to dynamic motor load location and aggregated motor load inertia
  - This is contrary to the intuitive expectation that dynamic loads will improve the damping of SSR
- Developed a new form of SSR mitigation
  - The proposed ADC uses the existing auxiliary power plant 11 kV VFD interfaced induction motor loads that are available locally, right at the generation centre
  - Motor speed control systems used to provide the required damping, which incurs little to no additional costs and ensures easy deployment
  - It does not need additional communication or dedicated monitoring ensuring straightforward maintenance
  - Ensures reliability and high availability due to redundancy
  - When the VFD is operating at, or close to, its full load capacity the proposed ADC will not be able to provide satisfactory damping

Final Thoughts

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Final Thoughts

- PMU Placement algorithms must be problem led through collaboration with industry
  - Define the problem then find the solver
- Linear State Estimation is the best next step for using PMUs to enhance state estimation
- SSR should not be allowed to be a barrier to Series Compensation
  - SC is an affordable, effective, scalable and quick to deploy means to enhance the capacity of critical corridors
- Model validation is a complex task, requiring more attention
- Academic/Industrial collaboration needs strong, early engagement, to help ensure that researchers are addressing the right questions

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Questions???

Close Down Event
12/03/2018, IET London

Vladimir Terzija(The University of Manchester)
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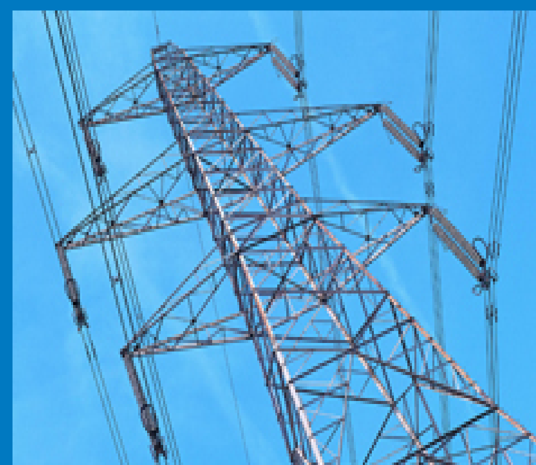
The Development of Wide Area Monitoring Systems - NGESO



Dr Phil Ashton – Future Control Strategy
Monday 12th March 2018
phil.ashton@nationalgrid.com

Overview

- VISOR project benefits
  - Increased observability of the system
  - Enhanced post-event analysis
  - System performance investigations
- Importance of IS infrastructure
  - Robust Resilient Reliable!
- Future plans
  - System Performance Monitoring TASKFORCE

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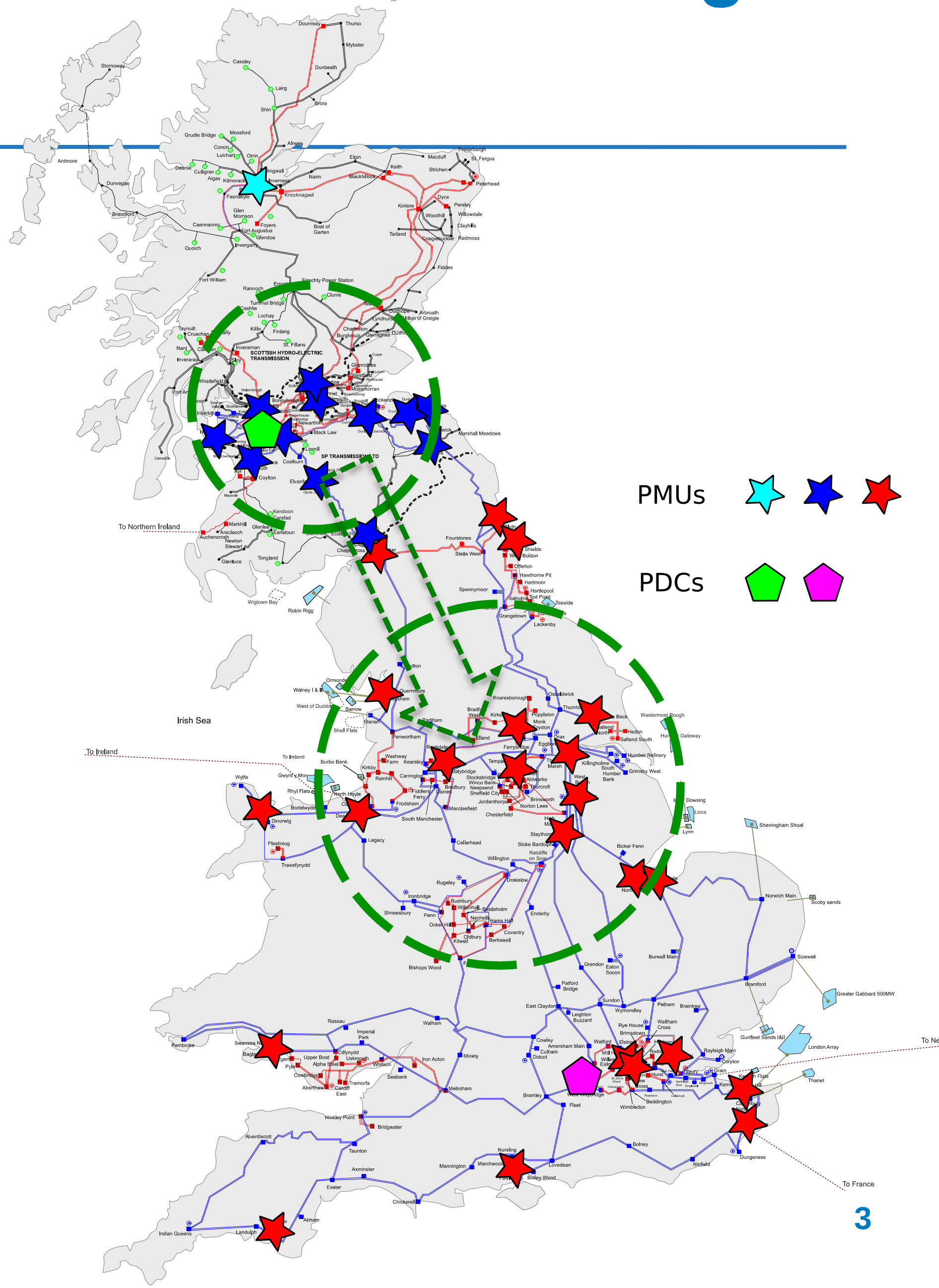
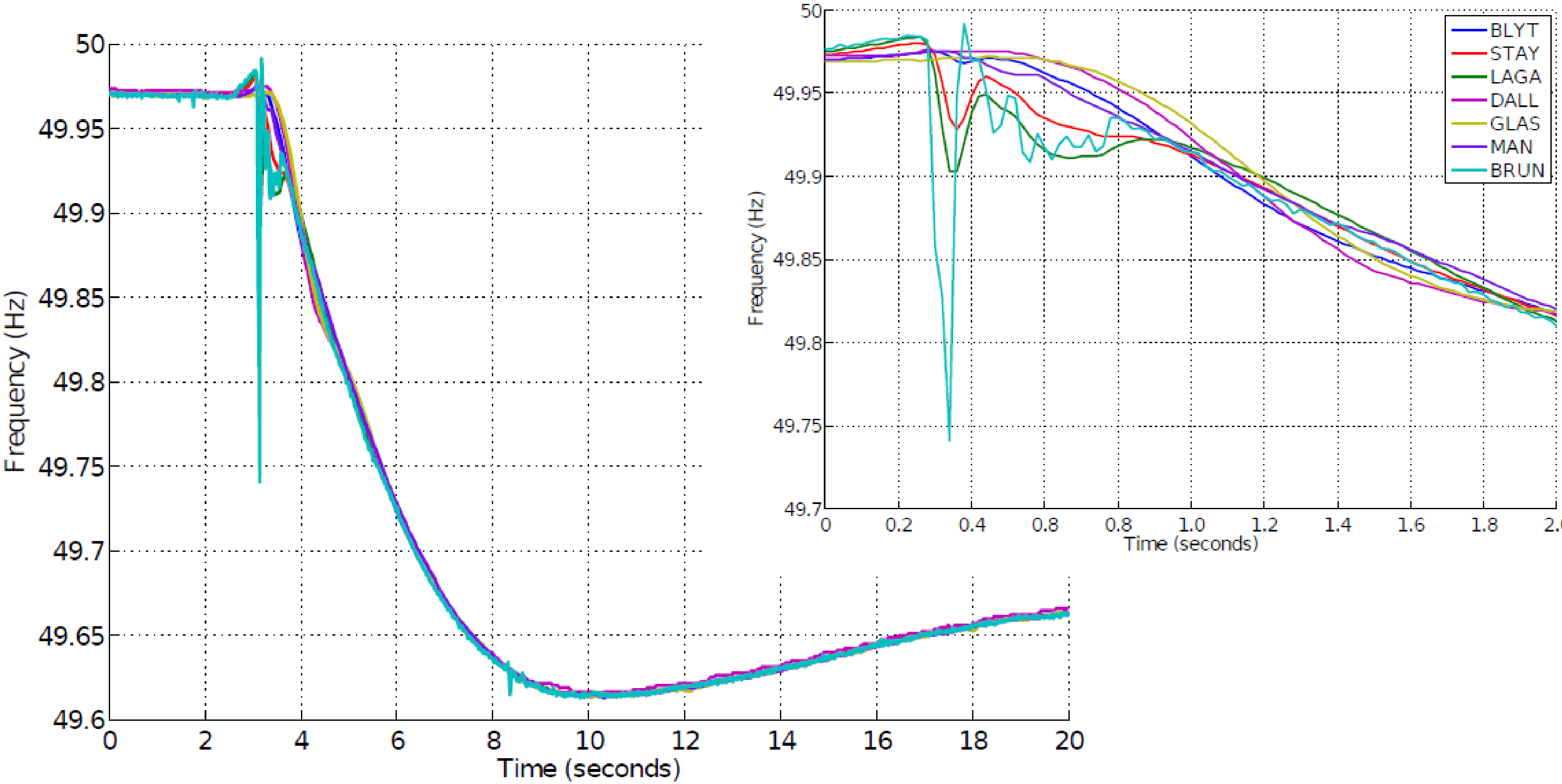
WAMS Experience

- Other TSOs have responded to blackouts
  - Spending > $100million’s
- Unprecedented Bottom-up approach
  - Upgraded DFRs
  - BLAN
- Good geographical system visibility
- Improved understanding of the system
  - Dynamic and
  - Transient performance
- Just scratched the surface!
  - More resilient monitoring
  - Define application requirements
- Importance of IT infrastructure
- Collaboration is key



Synchrophasor data is now vital!

Post-event analysis – only opportunity to assess the systems performance



Actively used to assess post event frequency behaviour, oscillatory behaviour and baseline system performance

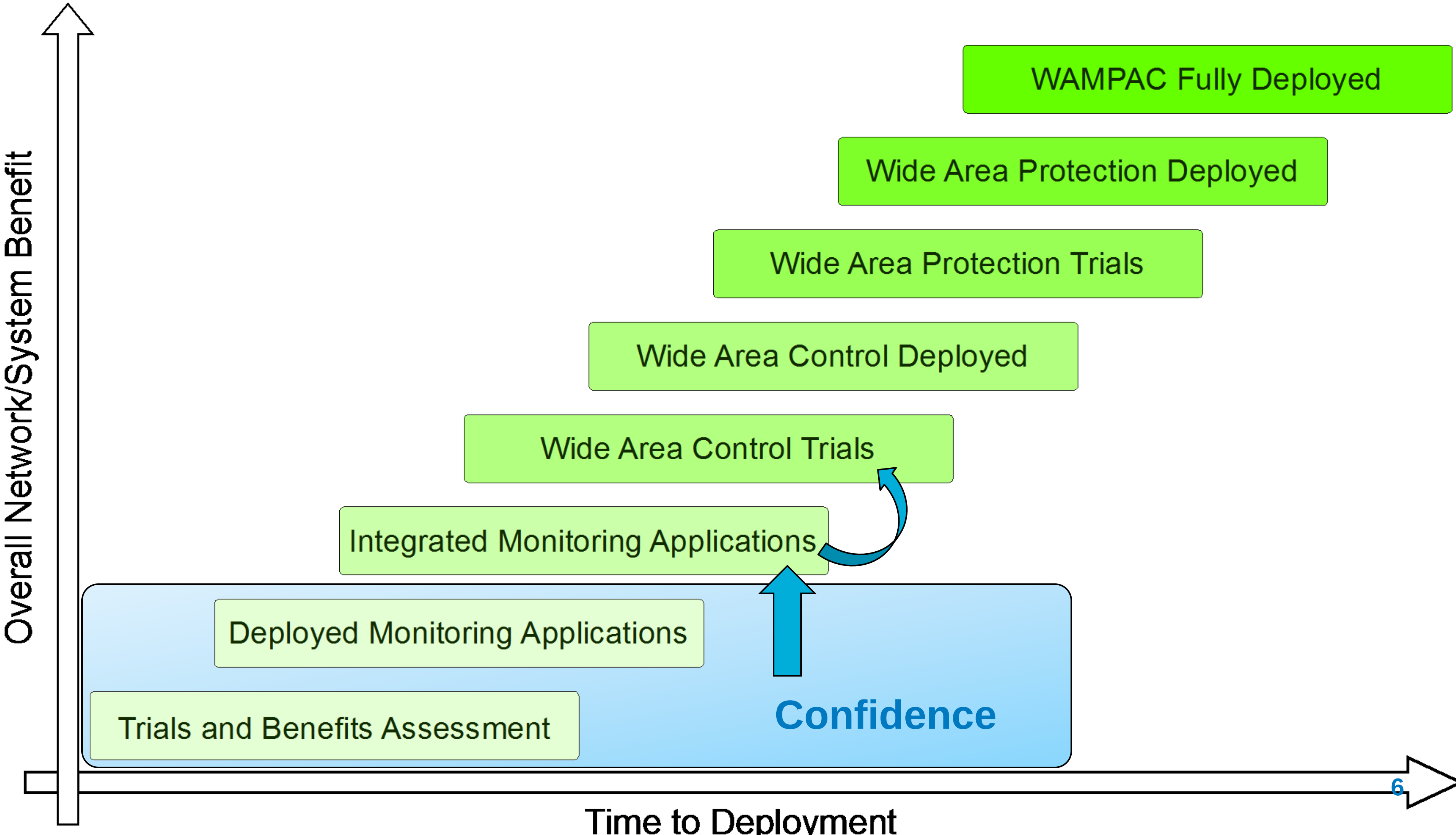
Post Event Analysis

Voltage Excursions	Analysing transient dips/swells in voltage, which resulted in disturbances on NETS and 3rd party interfaces.
Frequency Events	Assessing loss of in-feed events and other system faults, which impact the systems frequency.
RoCoF and Vector Shift	Frequency events leading to loss of embedded generation. The larger piece here is inertia analysis and system strength studies
Operational & Statutory Limits	Performance of contracted frequency response providers: FFR, Static, Dynamic, P, S, H, EFR etc
Ancillary Services	Performance of contracted response providers
Transient / Dynamic Stability	VLF, LF and SSO: Source location and system wide impact assessment – PQ / QoS too

Data to be used for comparisons with models for ongoing validation and systems base-lining.

This will build up confidence to inform the thresholds for Real-time control/operator actions.

Just getting started…



In Summary

- Growing complexities on the GB system
  - *Network Changes*
  - *Generation Mix*
  - *Potential for Increased Interactions – System Dynamics*
- Increased monitoring now required
  - *Existing Systems becoming unsuitable*
  - *Greater Visibility of System Dynamics + SSO*
  - *Rapidly Growing Data Volumes*
- Motivation for WAMS
  - *Increased Visibility*
  - *Real-time / Post Event Applications*
- Just getting started
  - *Confidence in monitoring applications*
  - *Post-event analysis informs real-time operations*

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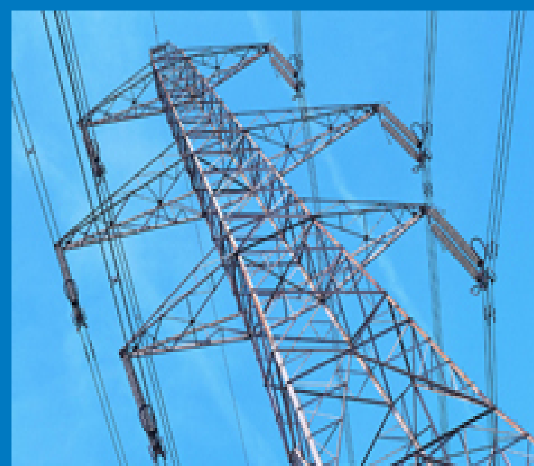
IT Infrastructure

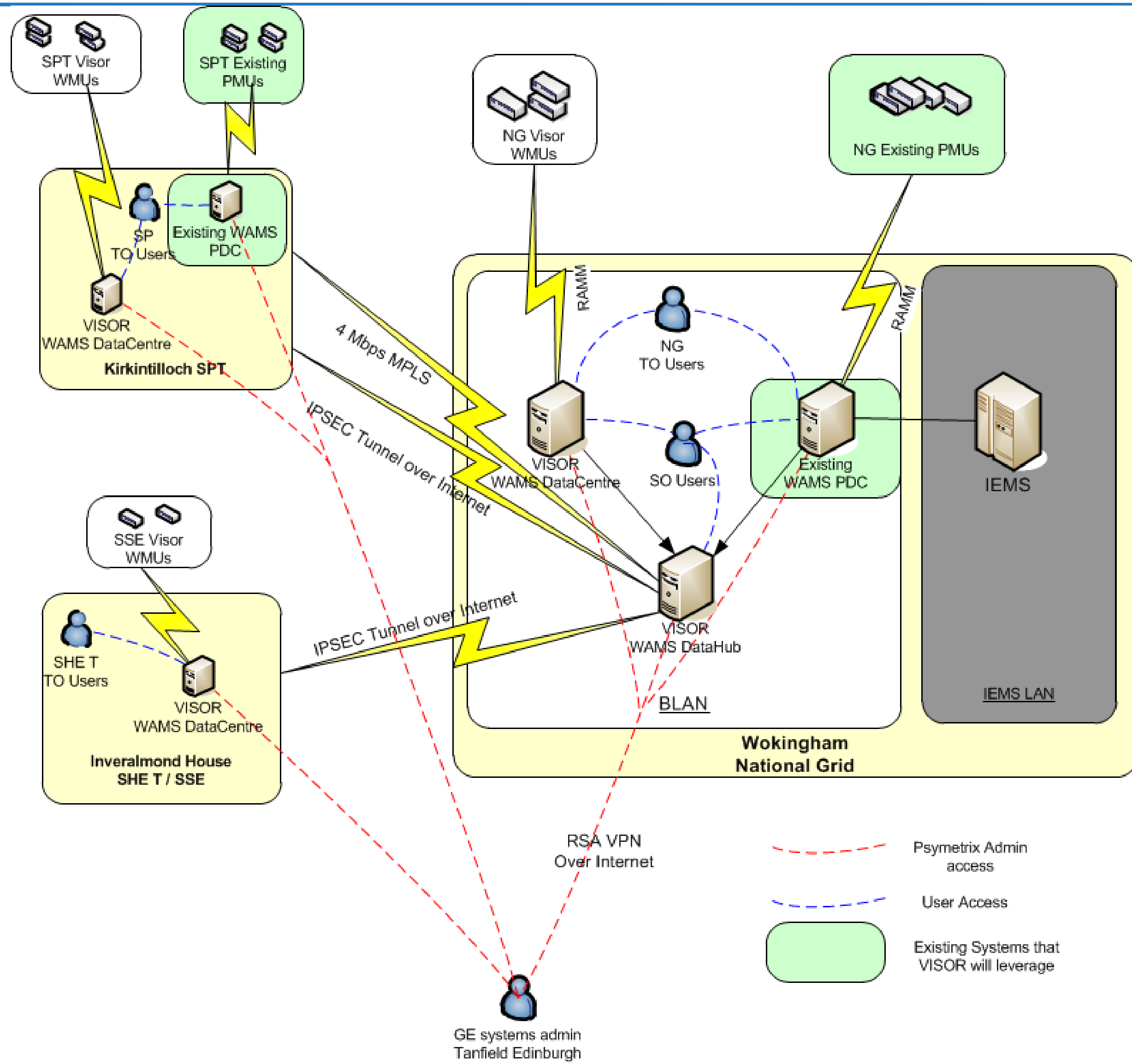


Nick Hird

VISOR Setup

- Tried to make use of existing PMUs and their Data
  - But not affect existing production systems
- Simplified system without DR or HA
  - Within VISOR there was an inherent resilience sufficient enough to support the project
- Focussed upon proving the concepts rather than the implementation of an extensive WAMS roll out

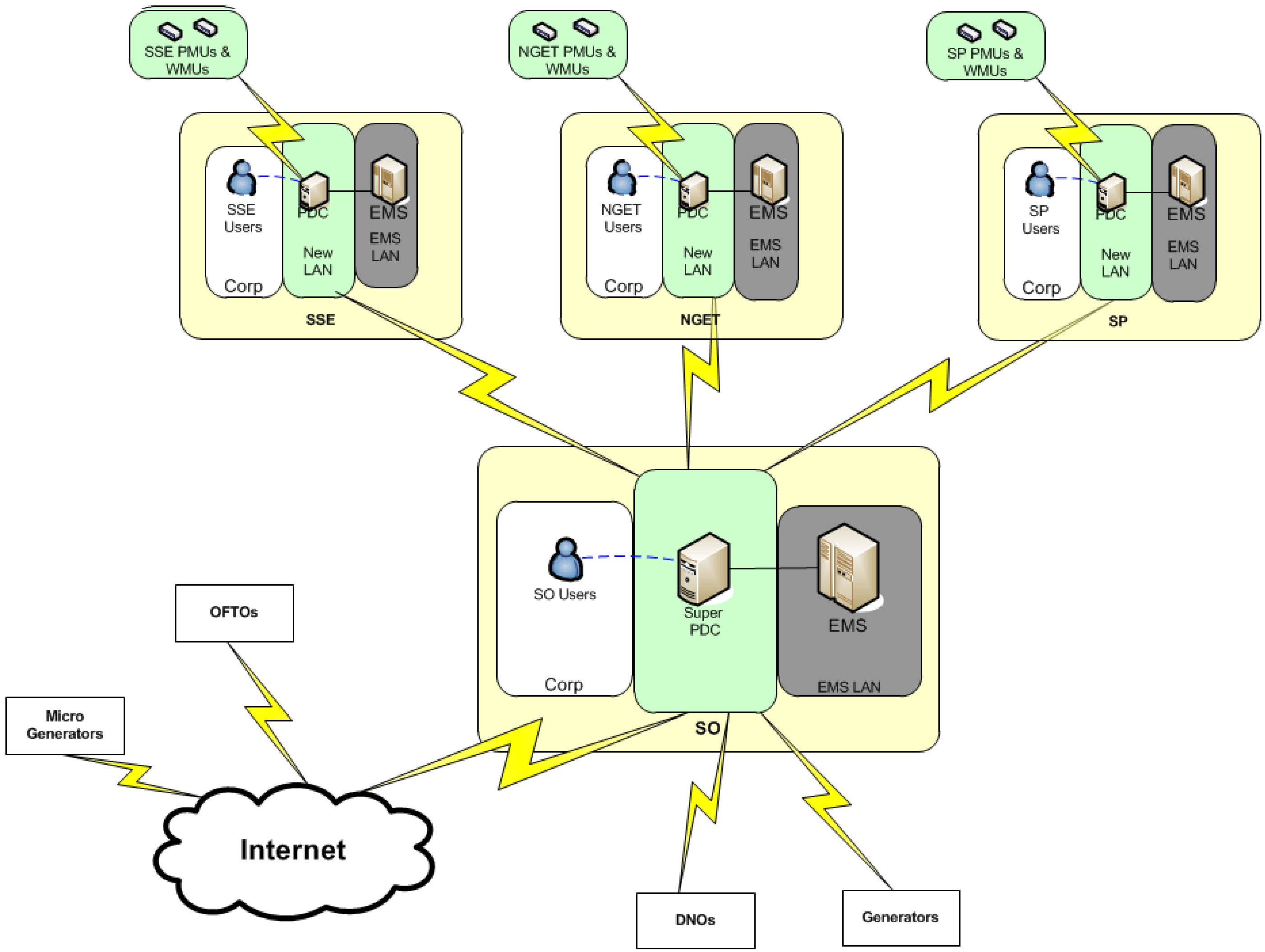
Network For Visor



Problems with the VISOR Setup

- WMU Communication uses UDP, not TCP
  - OK for current location, and setup, but will not work if this moves to a secure zone.
- Not in the correct place
  - More Important than Corporate
  - Not quite classified as CNI
- WAN Network is not resilient
- No HA or DR, No Backups
- Cannot be made a production system.

Possible Future Network



Future Considerations

- Where will the WAMS network sit?
  - All TOs and SO need to agree, as it has security implications
- How Critical is it? SLAs etc?
- Test or Non Production Environments? This won’t be the last NIC or NIA project
- How will it expand out to OFTOs, DNOs, Micro Generators?
- What else will it or could it be used for?

Costs

- 1 PMU ~£30K. How many more will we need?
- VISOR currently has 20TB of storage
  - This is high compared to other systems.
- Resilient WAN between PDCs, and between PDCs and PMUs?
  - Black start compliant?
  - This is reaching control network specifications
- Annual Costs – Increase in OPEX
  - Network Bandwidth, Firewalls, Routers, Intrusion detection
  - Software
  - Support Contracts
  - Server Infrastructure, OS, AV, Monitoring, Storage

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Electricity Transmission Owner WAMS Strategy

Mark Osborne March 2018

Perform/Compete/Grow/**ETO**

Next Steps for VISOR….

Interim strategy for the VISOR trial application up to end of RIIO T1 (2018 – 2021)

- Put support in place to embed the VISOR solution into Business as Usual
  - Articulate the Business case for WAMS as BAU
  - Upgrade VISOR to be adequately Robust, Resilient and Reliable for the business to adopt it – Revise Specification
  - Justify resources to provide this ongoing support
- Evolve VISOR towards an 'end to end' service for the TO and SO
  - Establish a GB Policy which defines the general requirements for TOs to provide System Monitoring services to the SO and at the interface responsibilities between neighbouring utilities and generators
- Communication services
  - Continue to utilise RAMM as communication platform for WAMS
- Cyber security
  - Identify suitable Resilience level
  - Need to be hardened where automated services are established
- Enduring Asset maintenance & replacement strategy
  - Replace on fail
  - Appropriate redundancy levels
  - Suitability for Multiple function system monitoring (Power Quality, System Disturbance monitors and Fault recorders)

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Emerging strategy for WAMS

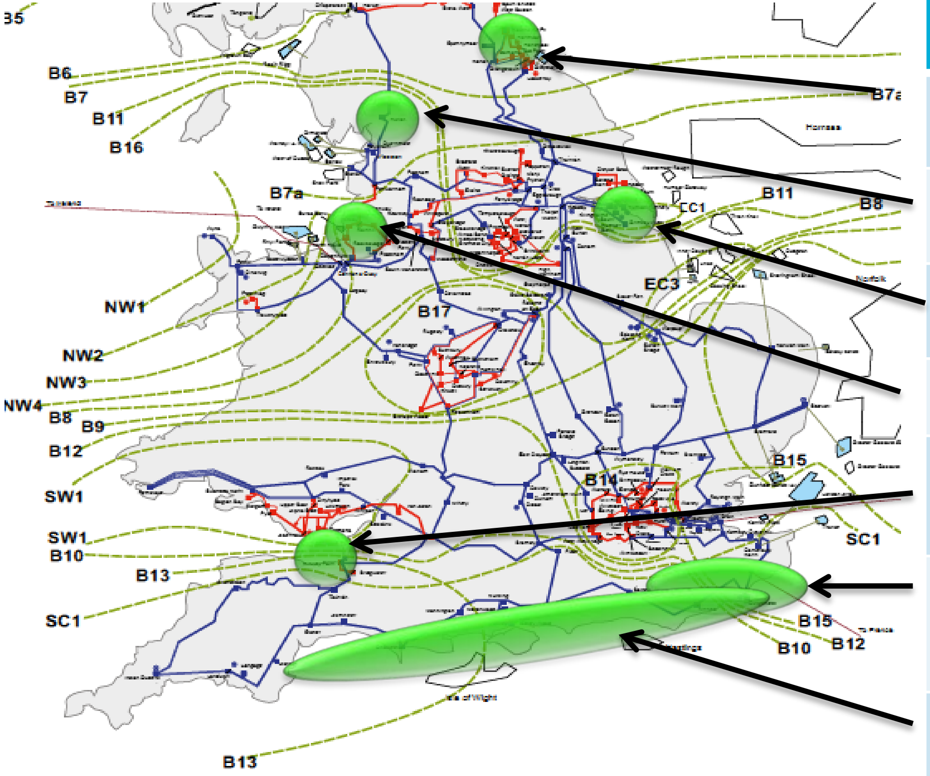
Establish ‘Fit for Purpose’ WAMS

Timely provision of information to inform decisions

Develop ‘end to end’ resilient services

- WAMS is an enabling function which underpins solutions that can deliver RIIO benefits
- No specific funding mechanism in place (typically needs to be directly linked to a RIIO incentive/outcome – difficult for a National scheme
- Need a range of monitoring services to meet internal & customer’s needs
- Need a GB wide System monitoring Policy which defines basic functional requirements for WAMS.
- VISOR has not solved all the issues - still work in progress – to review the infrastructure and technology for WAMS
- Require fully supported ‘end to end’ process
- Additional specialist resources required to manage the services.
- Robust asset management strategies still need developing
- Utilities need establish suitable environment and skills to develop and support WAMS analytics & tools.

Potential Applications for WAMS



Scheme Opportunities
Blyth HVDC connection - stability
Hutton Series Compensation - 2015
Humber Offshore wind - thermal
Western link HVDC SSO 2016
Hinkley Point to Seabank double circuit stability
Voltage stability Static & dynamic reactive compensation - 2018
South Coast OTS upgrade - stability

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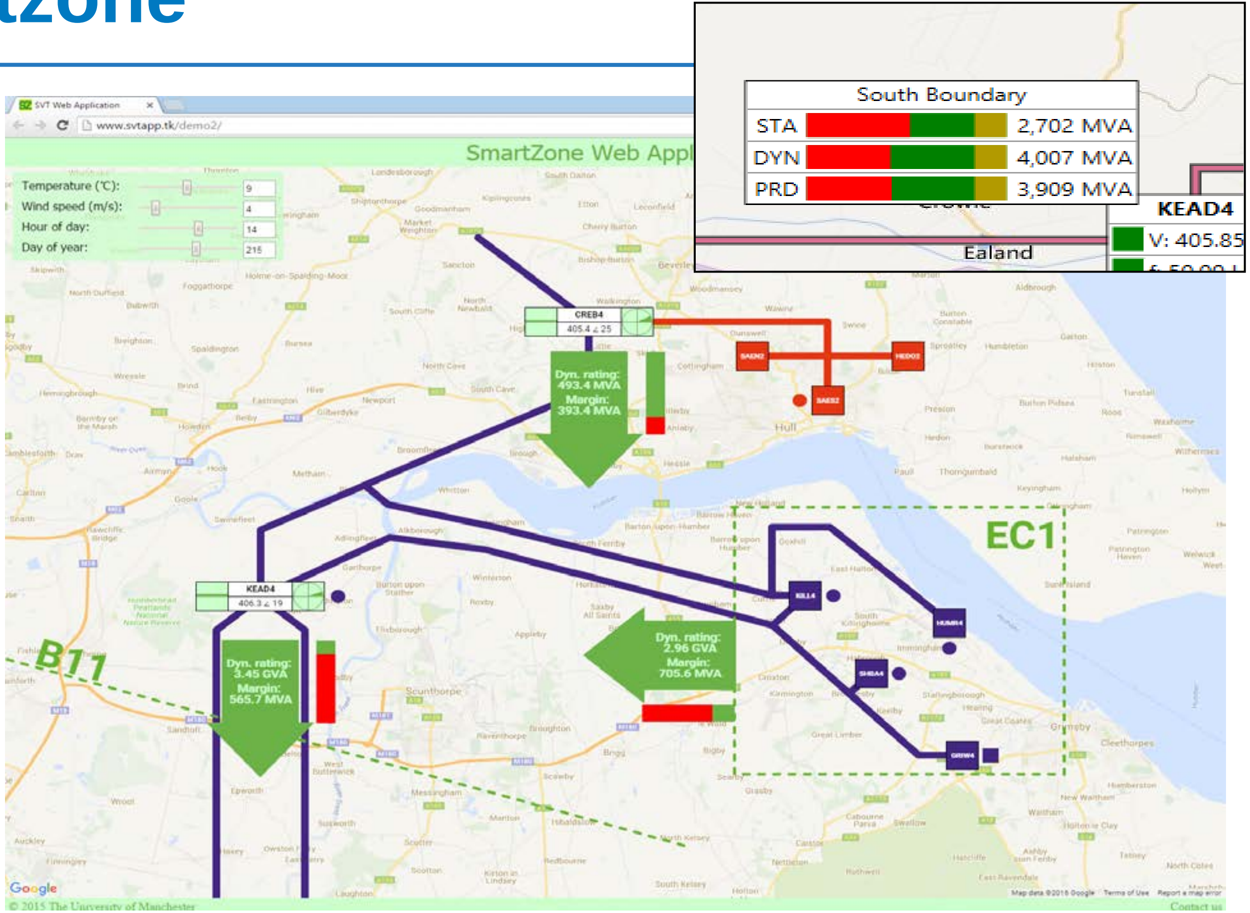
Humber Smartzone

- Accommodating Offshore wind
- Visualising real time and predicted Boundary capacity
- Compares Dynamic, real-time and predictive ratings.
- Evaluate marginal boundary capacity using situational awareness data
- PMU based application.



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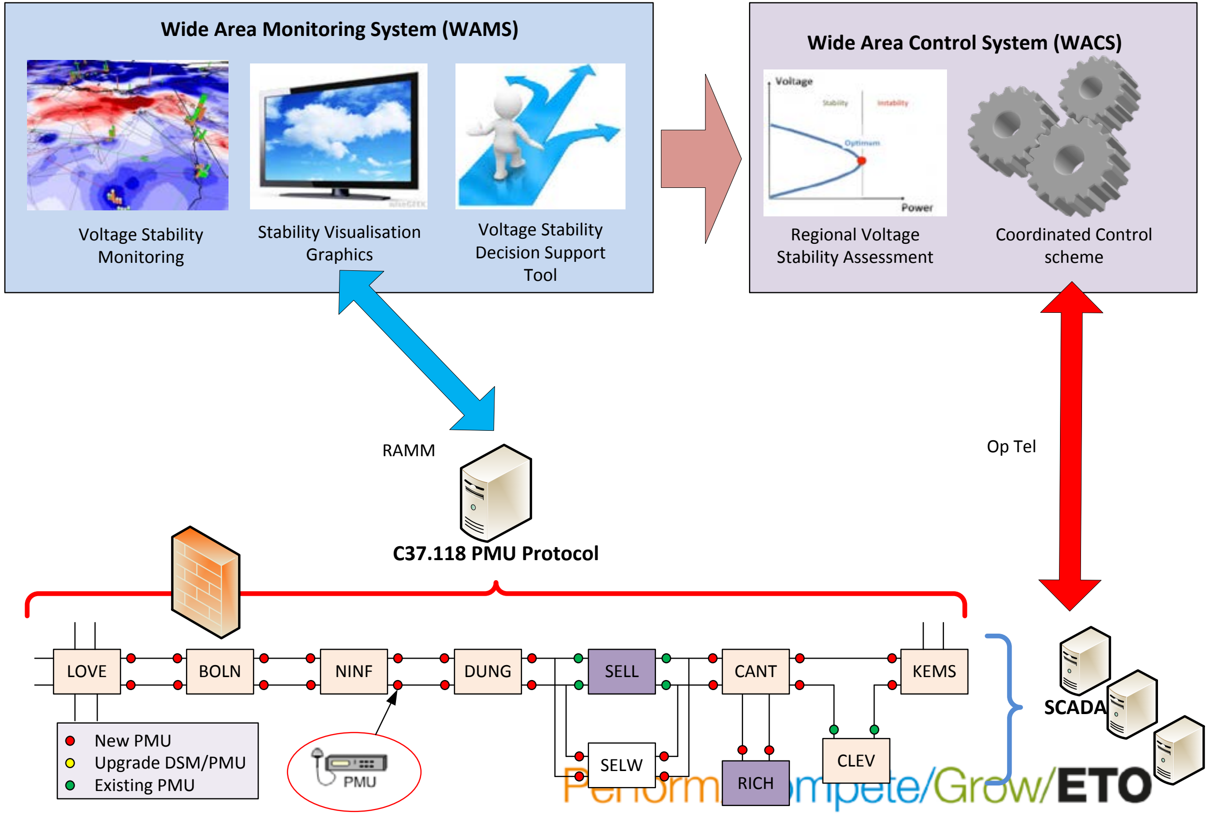
South East WAMS

- South East complexity
  - Multiple HVDC connections
  - Significant embedded generation
  - Control interaction risks
- Regional dynamic voltage stability
- WAMS prequalification to a Regional Wide area Control scheme (WACS)
  - Performance monitoring of dynamic systems
  - Optimise the response from STATCOMs & MSCDNs
  - Awareness of South coast OTS



Concluding remarks

Need a National strategy for WAMS …

- Underpin resilience and identify & manage risk on the system as it gets more complex to understand
  - Meet emerging government policy requirements to deliver a low carbon network,
  - provide network visibility and
  - minimise the potential for major system disturbances and Black-outs.

WAMS can also help to create value through developing the capability to;

- measure and improve network performance
- Visualise and enable situational awareness of issues developing in the networks and optimise constraints
- Police design compliance around asset interaction, control interaction, stability etc..
- Automate and improve system disturbance and post event analysis reporting
- Support model validation to improve boundary capability.

WAMS on its own will not directly deliver the solution, <u>but</u> will be an critical and integral part of the solution

VISOR

Future Plans and Summary from SSEN

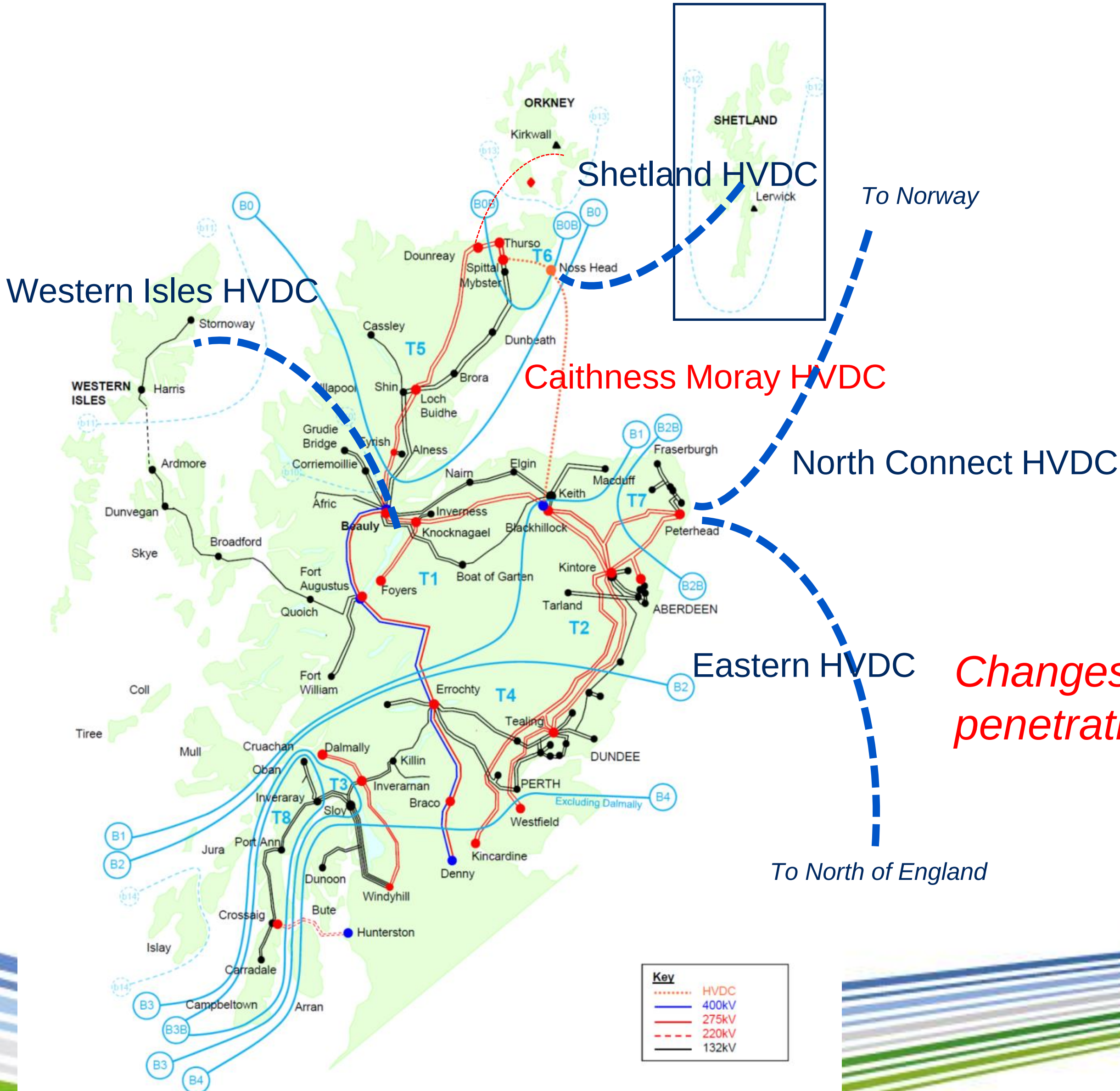
12th March 2018

David Wang
david.wang@sse.com
Transmission Planning

Scottish & Southern Electricity Networks

Scottish & Southern Electricity Networks

The owner of transmission networks in North Scotland



- Offshore + onshore wind 7.5GW by 2028

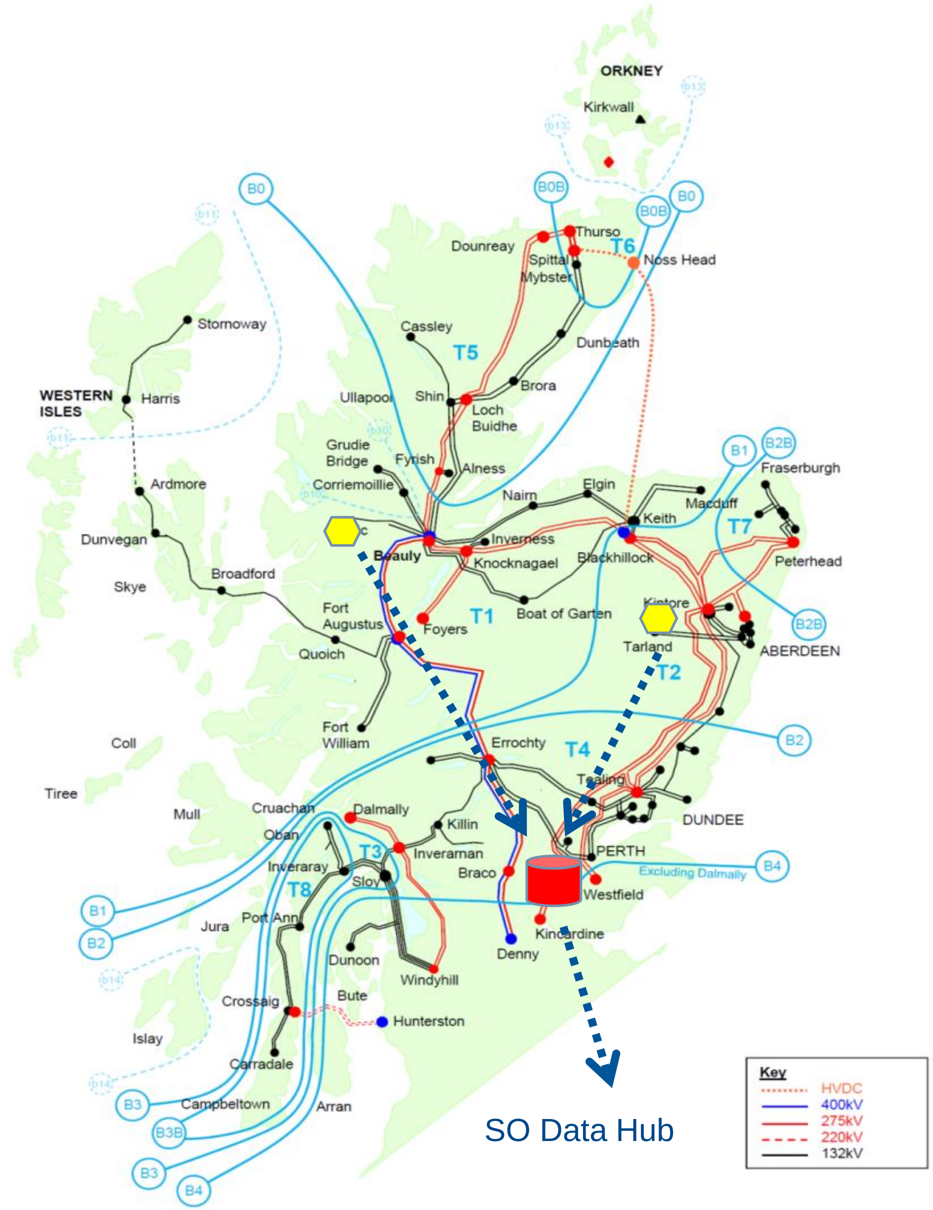
- HVDC
  - Caithness Moray HVDC
  - Shetland Multi-terminal Link
  - Eastern Link
  - North Connect
  - Western Isles HVDC Link

Changes in system dynamics due to increase penetration of power electronics devices

Scottish & Southern Electricity Networks

SSEN Role in VISOR

- Install PMU/WMU pair at Beauly & Kintore substations
- Install data centre (DC) at SSE's headquarter, Perth
- Establish communication links between PMU/WMU pairs and DC
- Sending data from SSE DC to a data hub at GBSO



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SSEN Objectives in VISOR

- To explore the potential benefits phasor data and WAMS can offer to the business

WAMS Applications	SSEN Expectation	SSEN Comments
Oscillation Detection and Location	High	Improve our knowledge on how the system behave dynamically
Disturbance Detection and Locations	High	Add extra layer of information on post-event (fault) analysis
B6 Power-Angle Boundary Constraint	Medium	Questions over the method using aggregated angles
Line Parameter Estimation	Medium	Concern over accuracy and application limitation

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Main Uses of WAMS during VISOR

- Oscillation Observation
  - Increase awareness of types of oscillations existing in the system.
  - 0.04-0.1 Hz, 0.62-0.9 Hz, 1.05-1.7Hz
  - long decay time (20-25s) but small amplitude (10 – 20 mHz)

- Post-event Analysis
  - Help to investigate fault events by providing additional information/evidence
  - WAMS useful to analyse event impact on wider networks and CB tripping sequence

- Dynamic Model Validation
  - Compare simulated oscillations to those observed in WAMS

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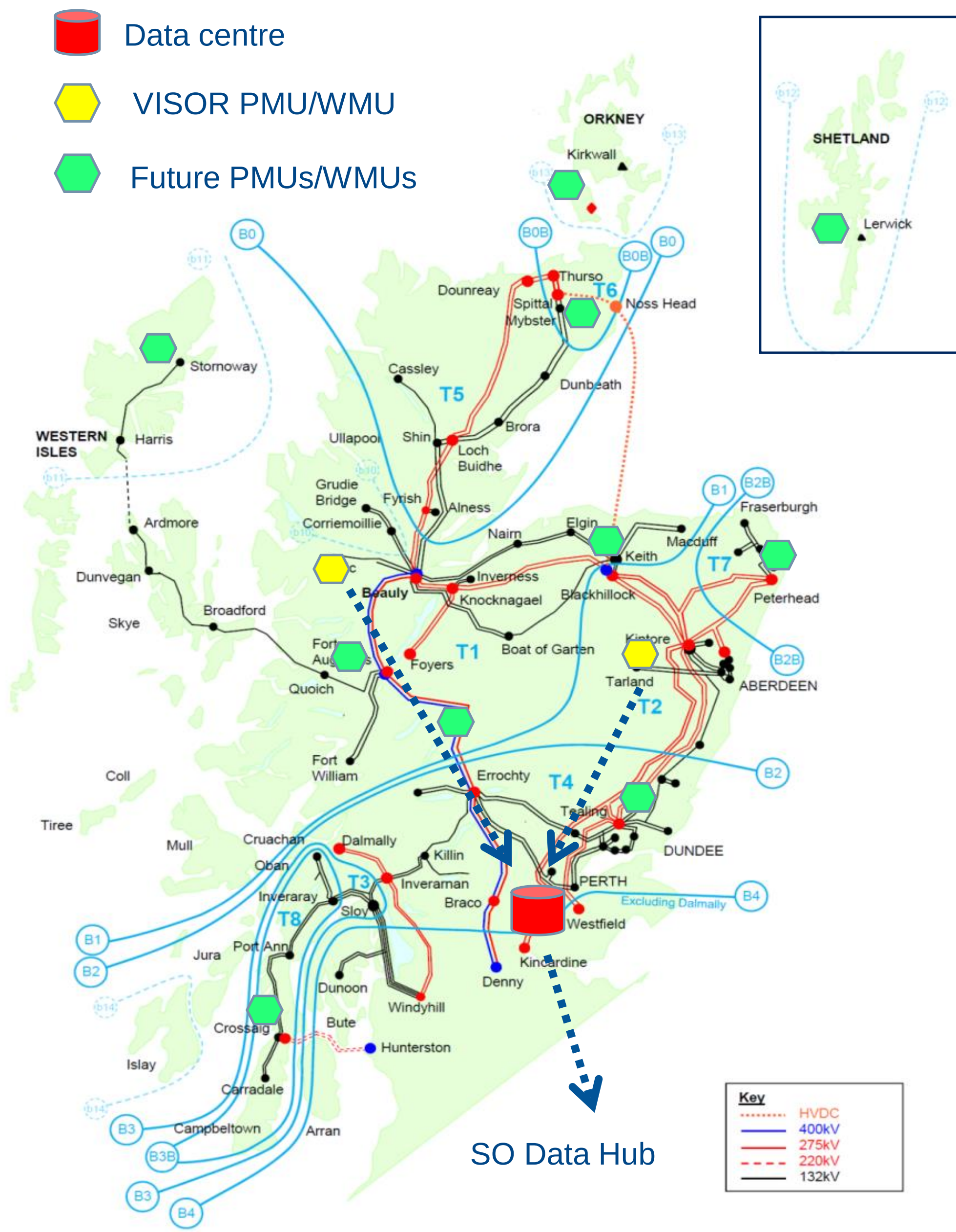
Roadmap

- Install more PMUs/WMUs
  - Budget tied with projects
- Establish robust communication links and servers for WAMS
  - Move from temporary to permanent comm link
  - Require clear funding mechanisms
- Data sharing agreement with TO and SO
  - Key information feedback from SO to TO as an alternative



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Lessons Learnt from VISOR

- WAMS benefit to Transmission Owners realised/confirmed
  - Benefits to Planning and Protection in post-event analysis and mode validation
  - Stronger business cases needed for integrating WMAS real-time applications into Control Room

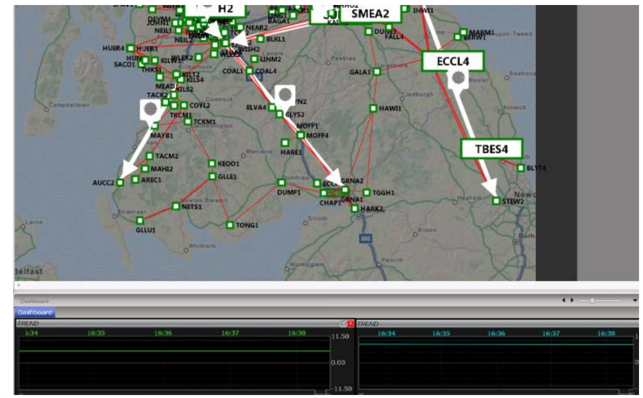
- Require dedicated IT resources for WAMS
  - Engage IT since earliest stage and throughout the whole process

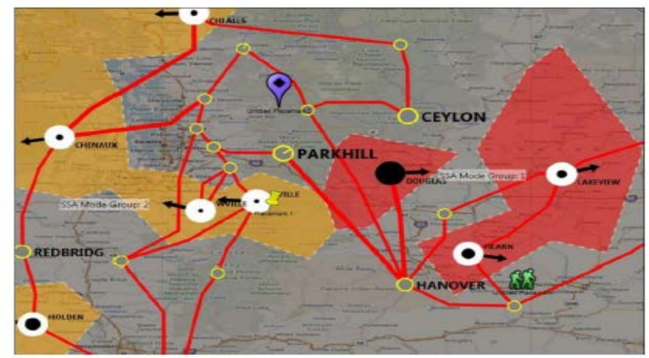
- Continue exploring WAMS benefits as more applications become ‘matured’
  - E.g. Islanding/Black-start, Hybrid Estimation etc.
  - Dedicate WAMS team in-house to keep WAMS technology on track
  - Continue to work with other TOs and SO

Visor Close Down Event 2018

Use Cases for Integrating WAMS with Energy Management System (EMS)

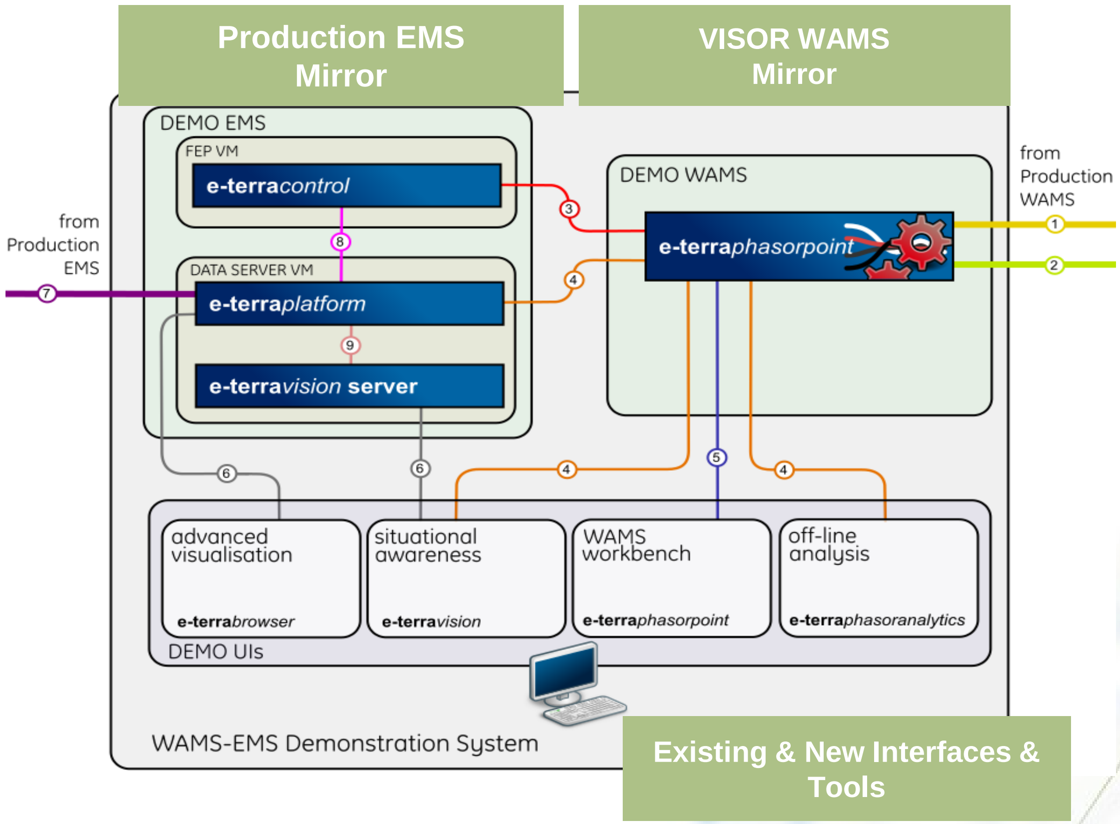
- Maximise the capacity of existing assets
- Blackstart procedures
- Model validation & post-event analysis
- Improved State Estimation
- Alarms in EMS



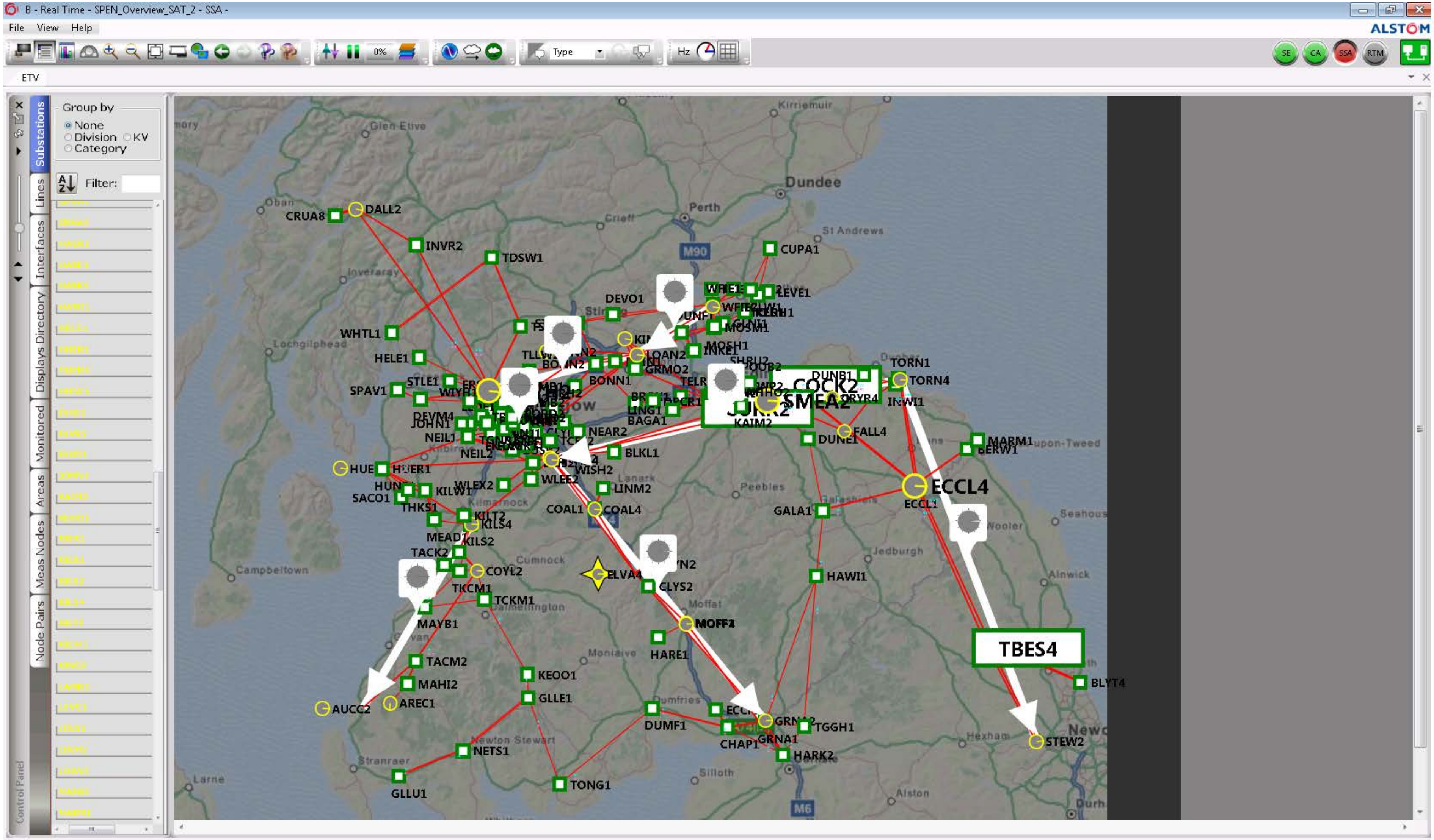


WAMS-EMS Demonstration System “Sandbox”

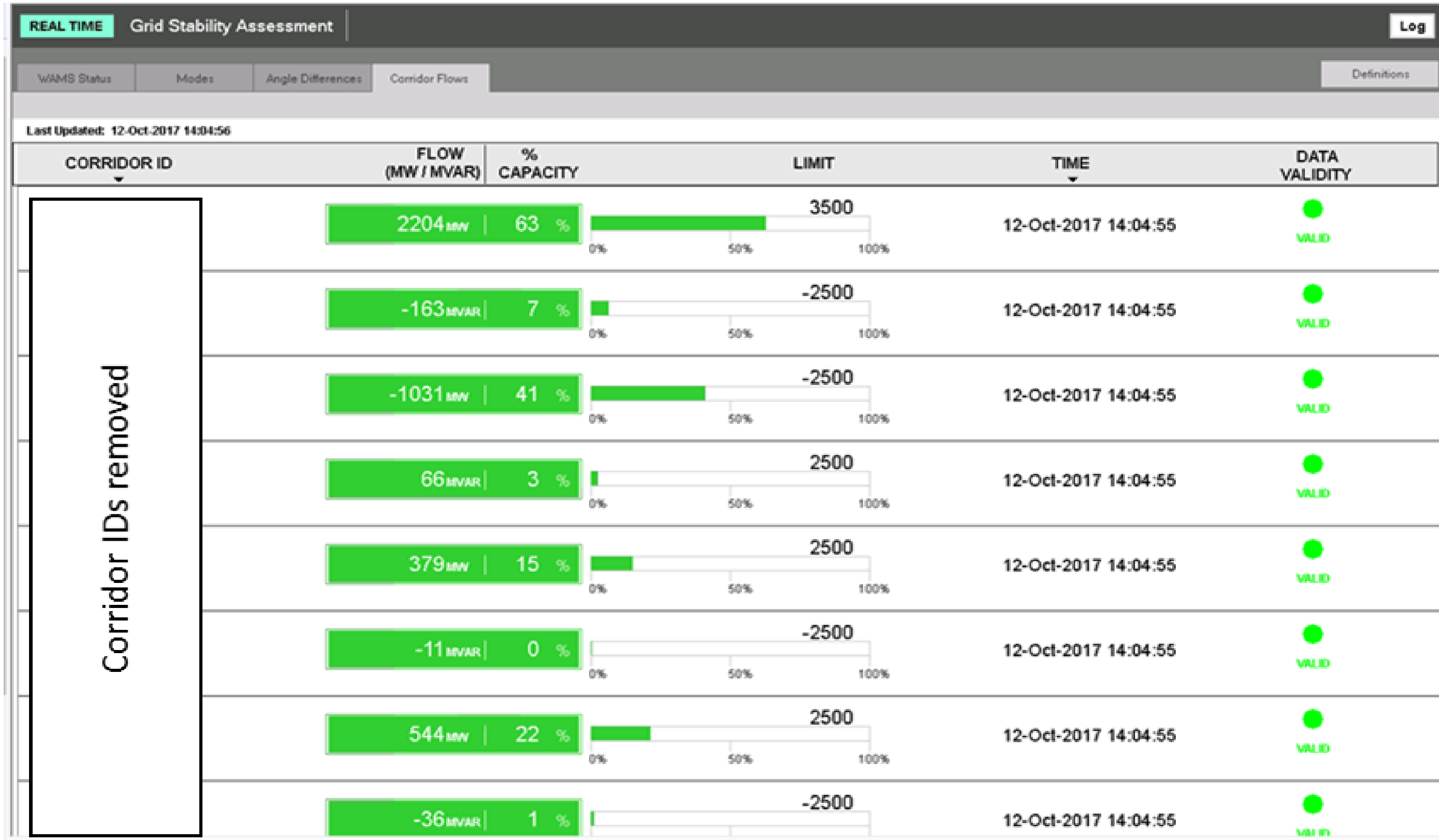
Demonstrate immediate advantages of WAMS integration with operational tools & practices, and **explore further phases** of development and improvement – in a control room environment but **without risk to operation or security**



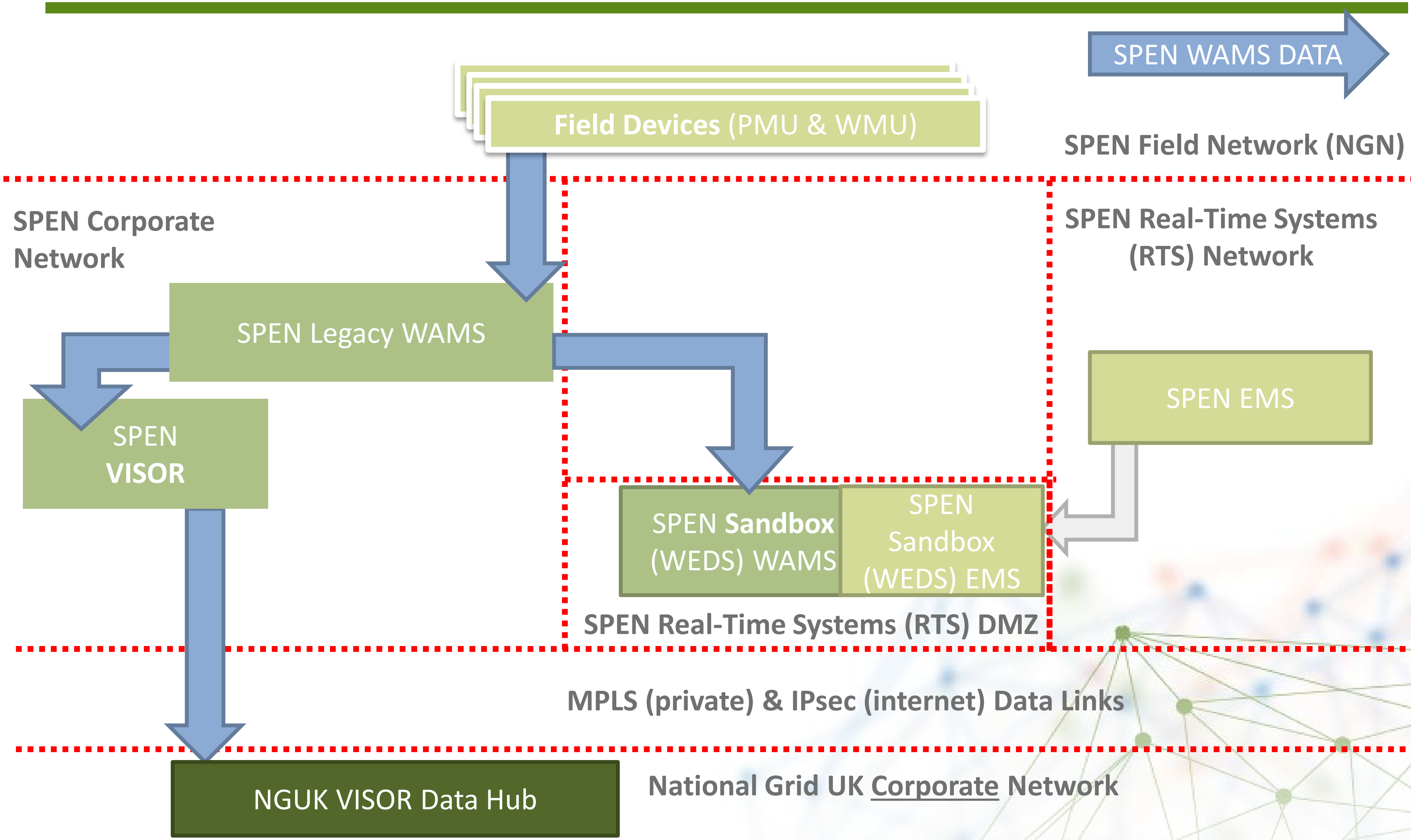
WAMS-EMS Situational Awareness



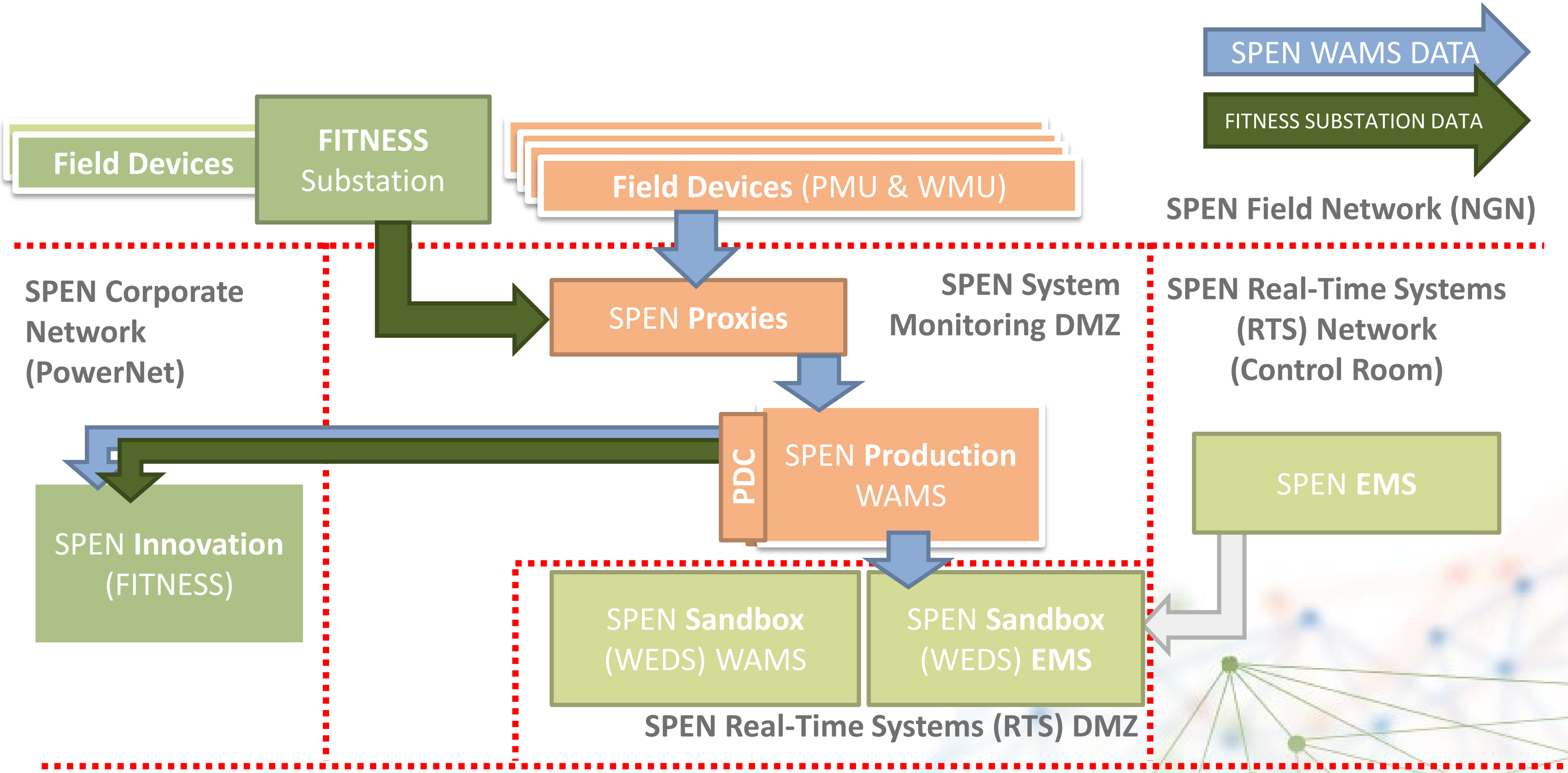
WAMS-EMS Grid Stability Application



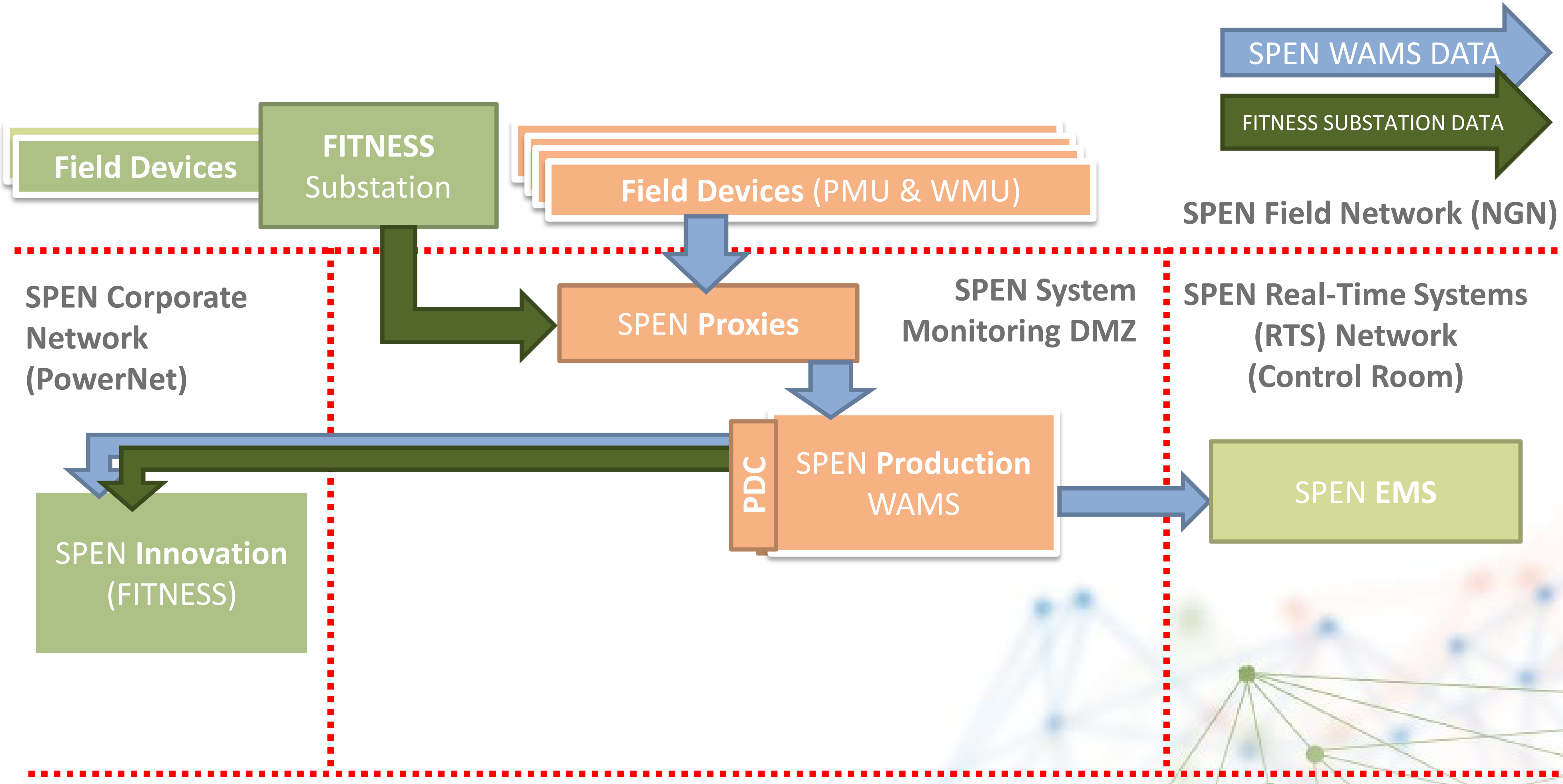
SPT WAMS - Present Arrangement



SPT WAMS - 2018 Arrangement



SPT WAMS - Post-2018 Arrangement



SPT Next Steps

- WAMS-EMS update based on feedback
- Install and commission new WAMS production system
- Upgrade existing PMUs to improve data quality
- Guaranteed Quality of Service for PMUs
- RIIO-T2

VISOR Conclusion

The VISOR project: Jan 2014 – Dec 2017

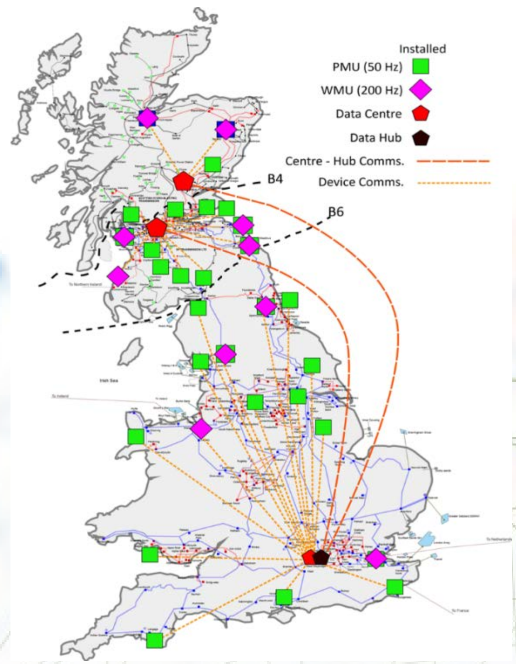
- Successfully created the first integrated GB Wide Area Monitoring System across 3 GB TOs and SO
  - Leading to visibility of sub-synchronous oscillations, and oscillation source location
- Deployed PMUs and the first ever Waveform Measurement Units
- Demonstrated the concepts and tangible benefits of new WAMS capabilities to system planning, real-time operation and post event analysis
- Substantial performance improvement in WAMS performance over the course of the project
- Informed the requirements for a production grade system

SP ENERGY NETWORKS

nationalgrid

Scottish & Southern Electricity Networks

MANCHESTER 1824
The University of Manchester



Questions?

Thank you!

Closing Remarks