# CLASS closedown event

Wednesday 9 September 2015

LCN Fund
Low Carbon Networks

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**Steve Cox**

Head of Engineering

**Welcome and introduction**

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# Housekeeping

Mobile phones

Breaks

Fire alarms

Main Q&A
at end of day

# Agenda

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CLASS
Customer Load Active System Services

| Introduction and CLASS functions | Customer engagement | Technology and trials learning |
|---|---|---|

Lunch

| Research and technical results | What’s next for CLASS? |
|---|---|

# Introducing Electricity North West

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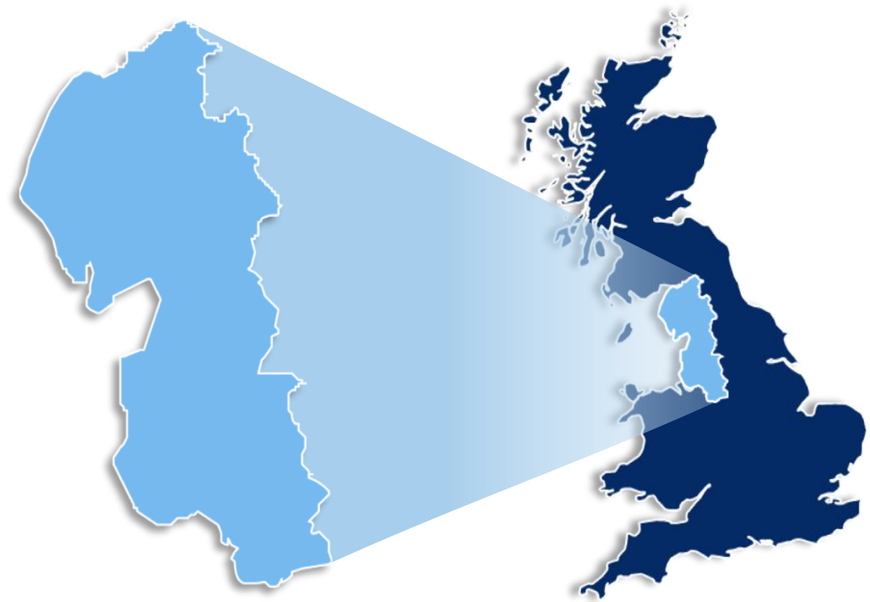
4.9 million

2.4 million

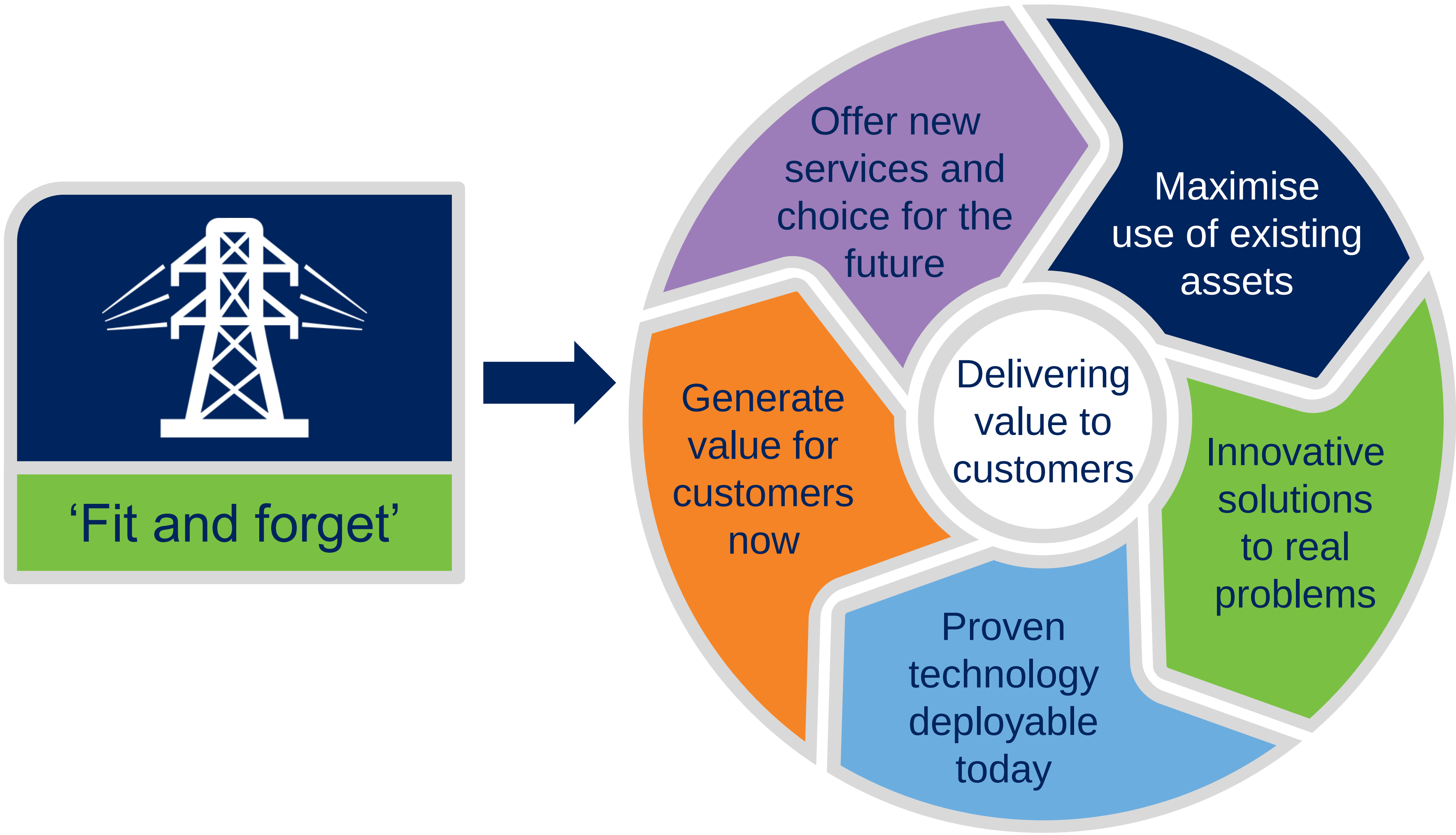
25 terawatt hours



£12 billion of network assets

56 000 km of network ● 96 bulk supply substations
363 primary substations ● 33 000 transformers

# Our innovation strategy



# Our smart grid development

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## Leading work on developing smart solutions

Deliver value from existing assets

Customer choice

LCN Fund Low Carbon Networks — Four flagship products (second tier) £36 million

C2C Capacity to Customers

CLASS

SMART STREET

RESPOND

# CLASS

*Is seeking to demonstrate that*
*electricity demand can be managed*
*by controlling voltage…*

…without any discernible impacts on customers

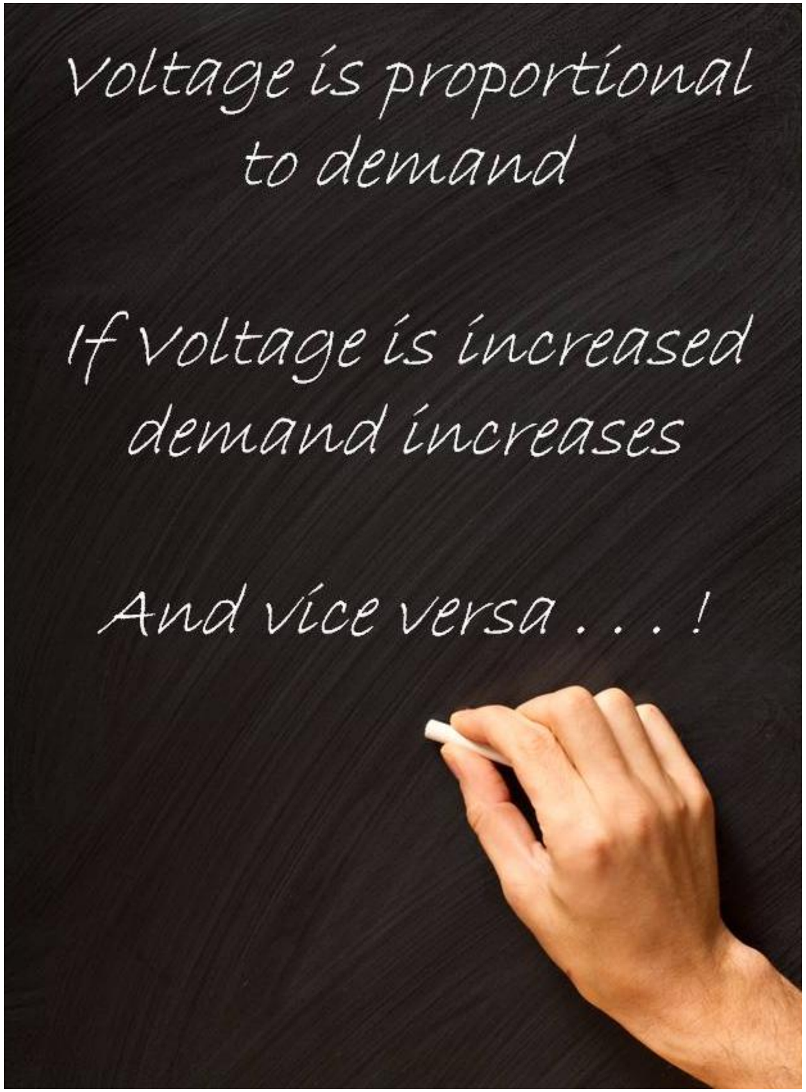
## Customer Load Active Systems Services

# Back to school for a moment…

This fundamental relationship is at the heart of CLASS

But how will it change over time as customers
adopt new devices?

How could we use this relationship in a smart
way to benefit customers?



# How does it work?

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00:03:00

2% ↑ 00:00:08 ↓ 2%

**The cost £ to make your cup of tea is always the same!**

*"A problem shared is a problem halved…"*

**20,000** homes in a town

**200,000** homes in a city

**26** million across the GB

**What problems could we solve ?**

# CLASS aims to harness thousands of tiny changes at just the right time

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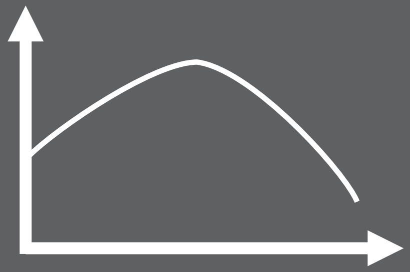
## Today

### High peak demand



Reduces peak demand

Faster LCT connections

Lower network cost

## Tomorrow

### Respond and reserve

Primary and secondary frequency response

Allows more renewable generation

Flexible reactive power absorption

## Future

### Wind following

Facilitates demand boost

Lower energy costs

Mitigates inertia issues

# Summary

Statistical findings are that domestic customers did not notice the CLASS functions

Lessons have been learned during the installation phase, that can be integrated into any future ‘rollout’

CLASS has provided National Grid with the ability to use an ICCP link which provides them with a demand response during a system frequency event

CLASS has shown an approximately linear relationship between voltage and demand

# High level benefits

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- Low cost high speed frequency support
- 3GW demand reduction or boost
- 2GVAr National Grid voltage control
- Reinforcement deferral
- 24/7 voltage/demand relationship matrix

**Paul Turner**

Innovation Delivery Manager

**CLASS functions**

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# The CLASS functions

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| | Objective | Technique |
|---|---|---|
| **Automatic peak reduction** | Reduce demand to within substation capacity | Lower tap position |
| **Demand boost / reduction** | Boost or reduce demand | Lower / higher tap position |
| **Frequency response** | Primary response to reduce demand when frequency falls on the network | Switch out transformer |
| | Secondary response to reduce demand when frequency fails on the network | Lower tap position |
| **Reactive power** | Absorb high voltages that occur on the transmission network | Stagger tap position |

# CLASS system overview

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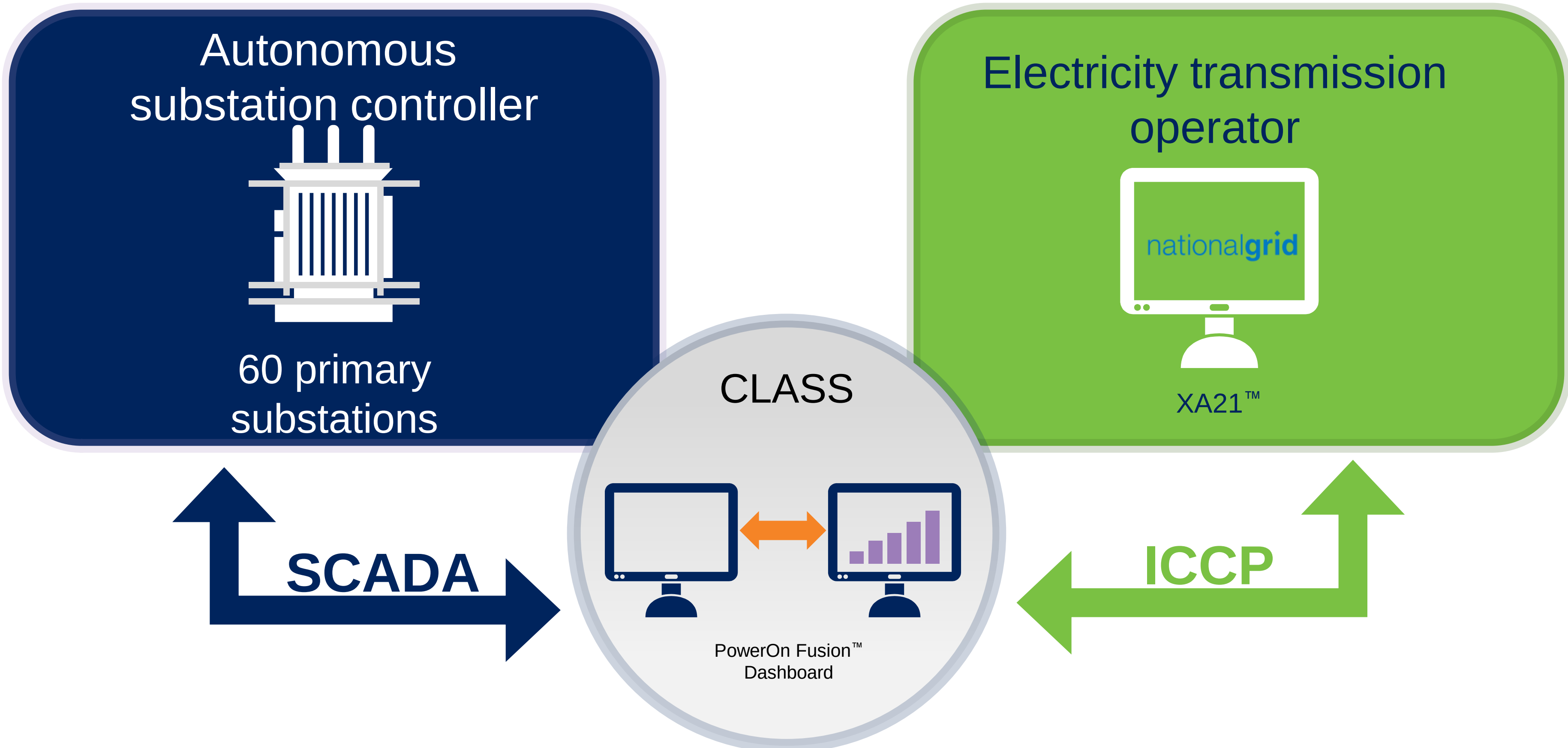
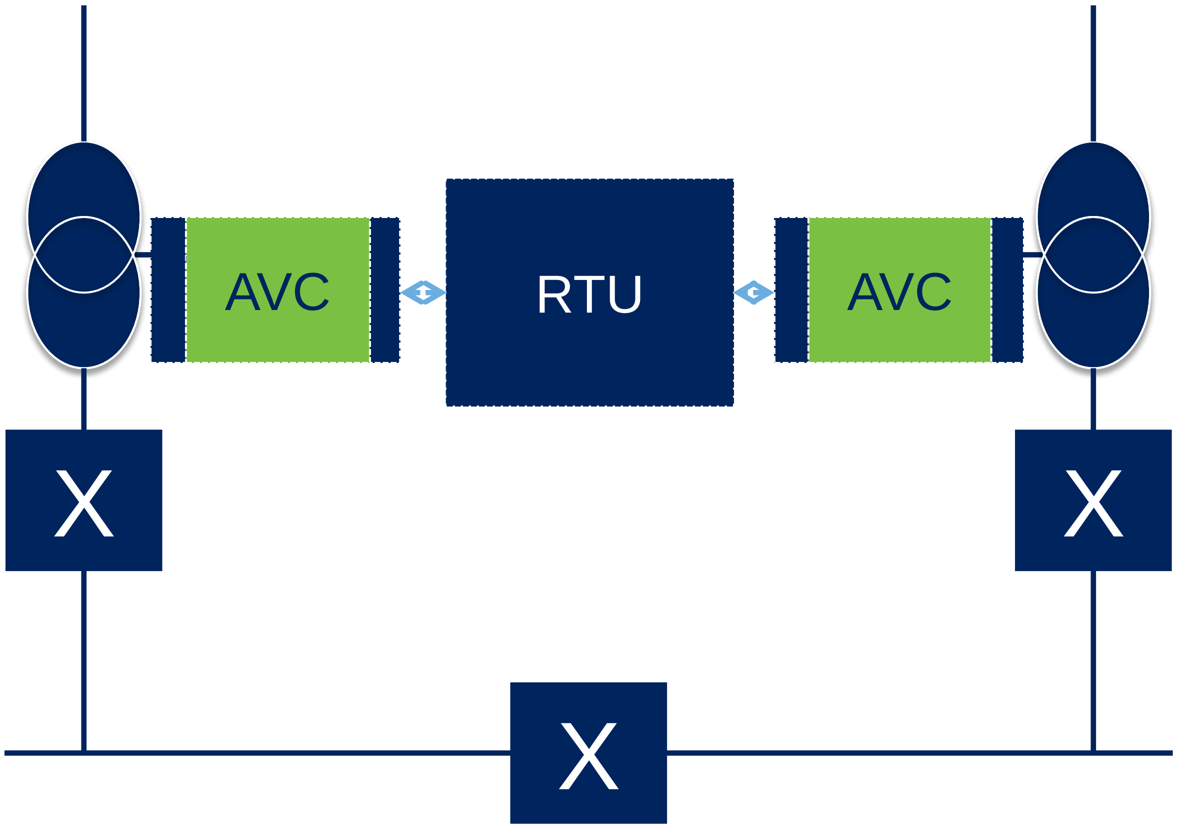



Dashboard forecasts response and allows ‘arming’ of various response services

TSO and DNO both have visibility and control of active and reactive power

# Typical substation overview

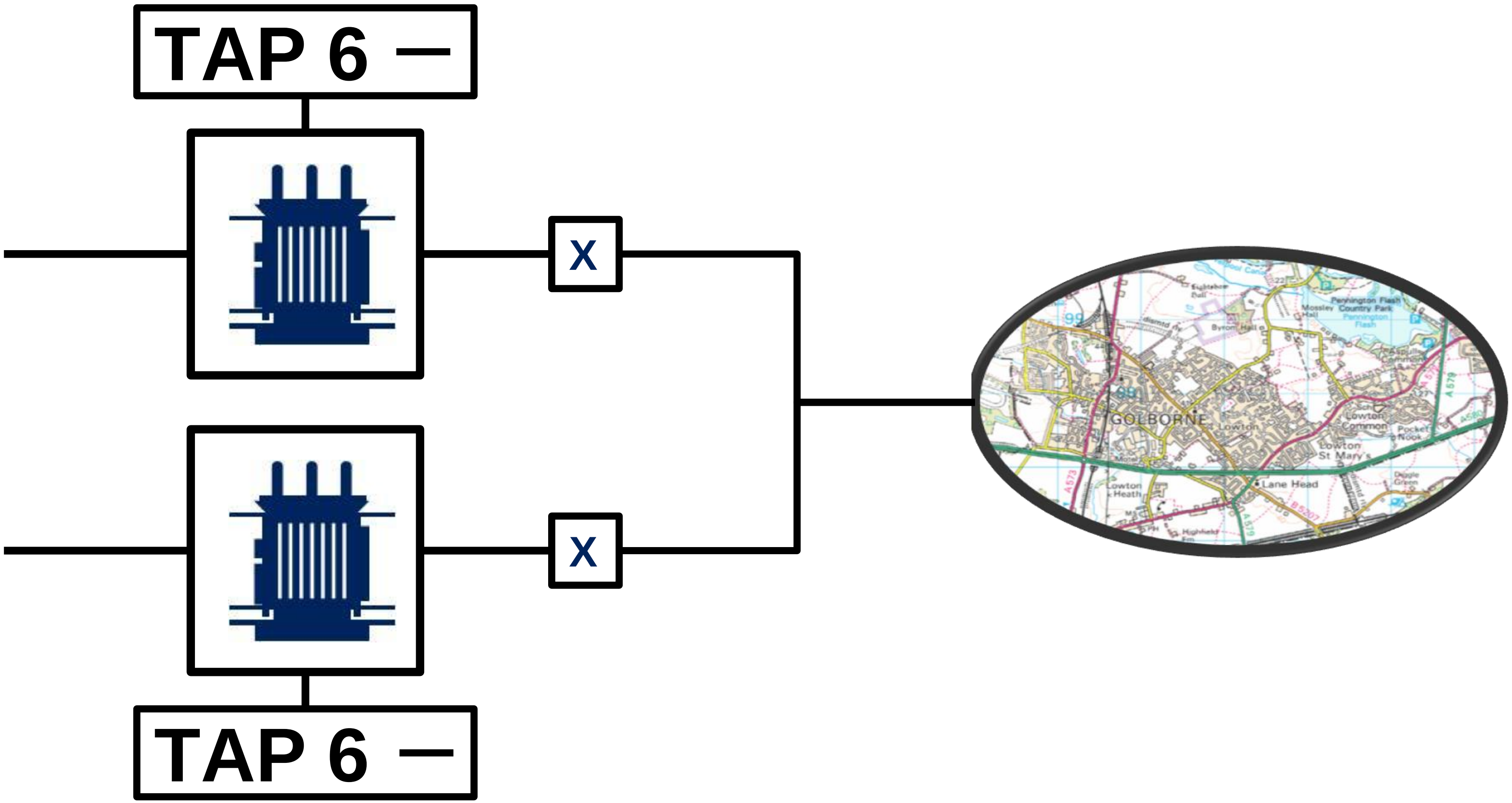


# Typical primary arrangement - Golborne

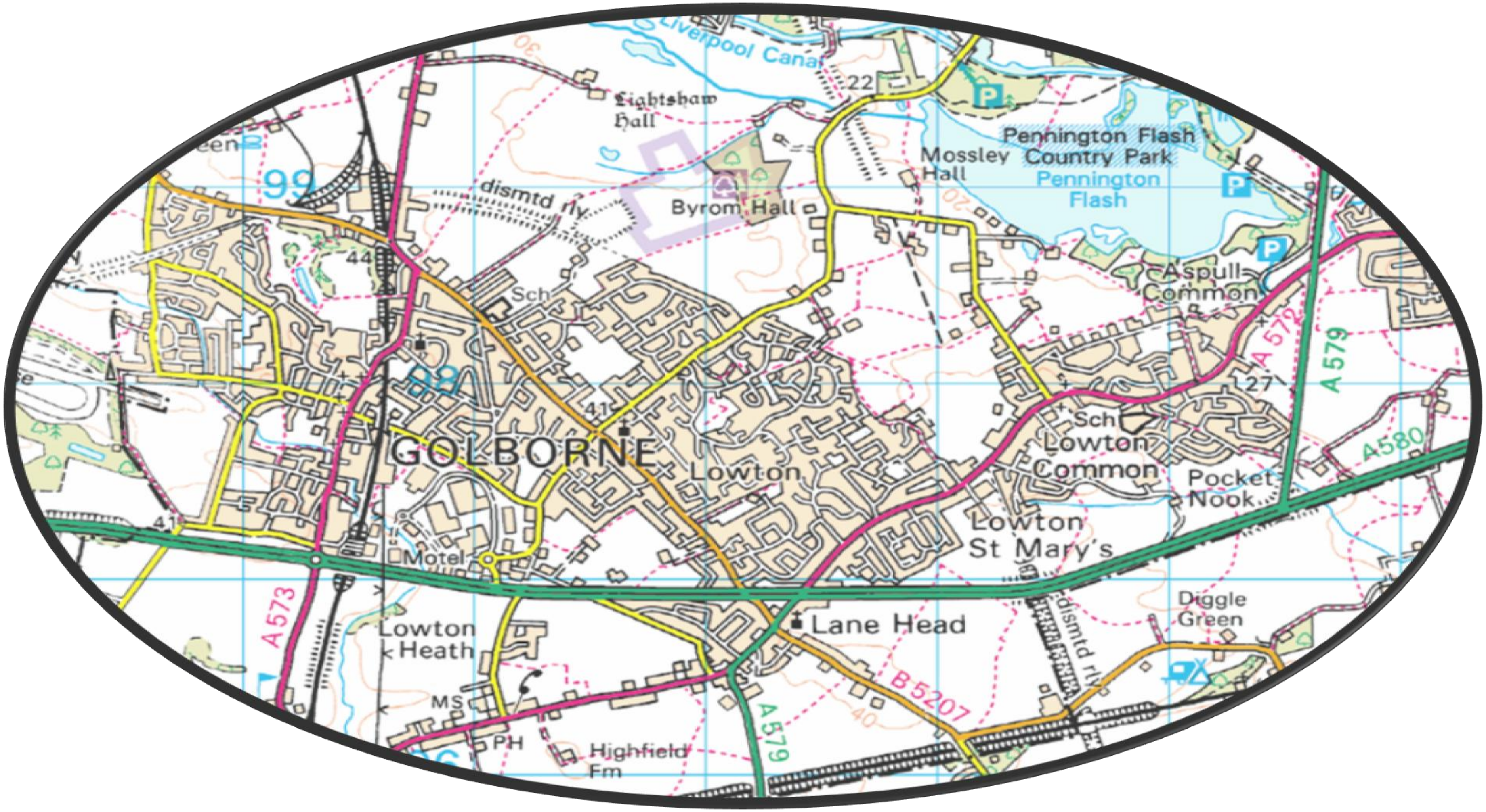


## 33kV

## 11kV

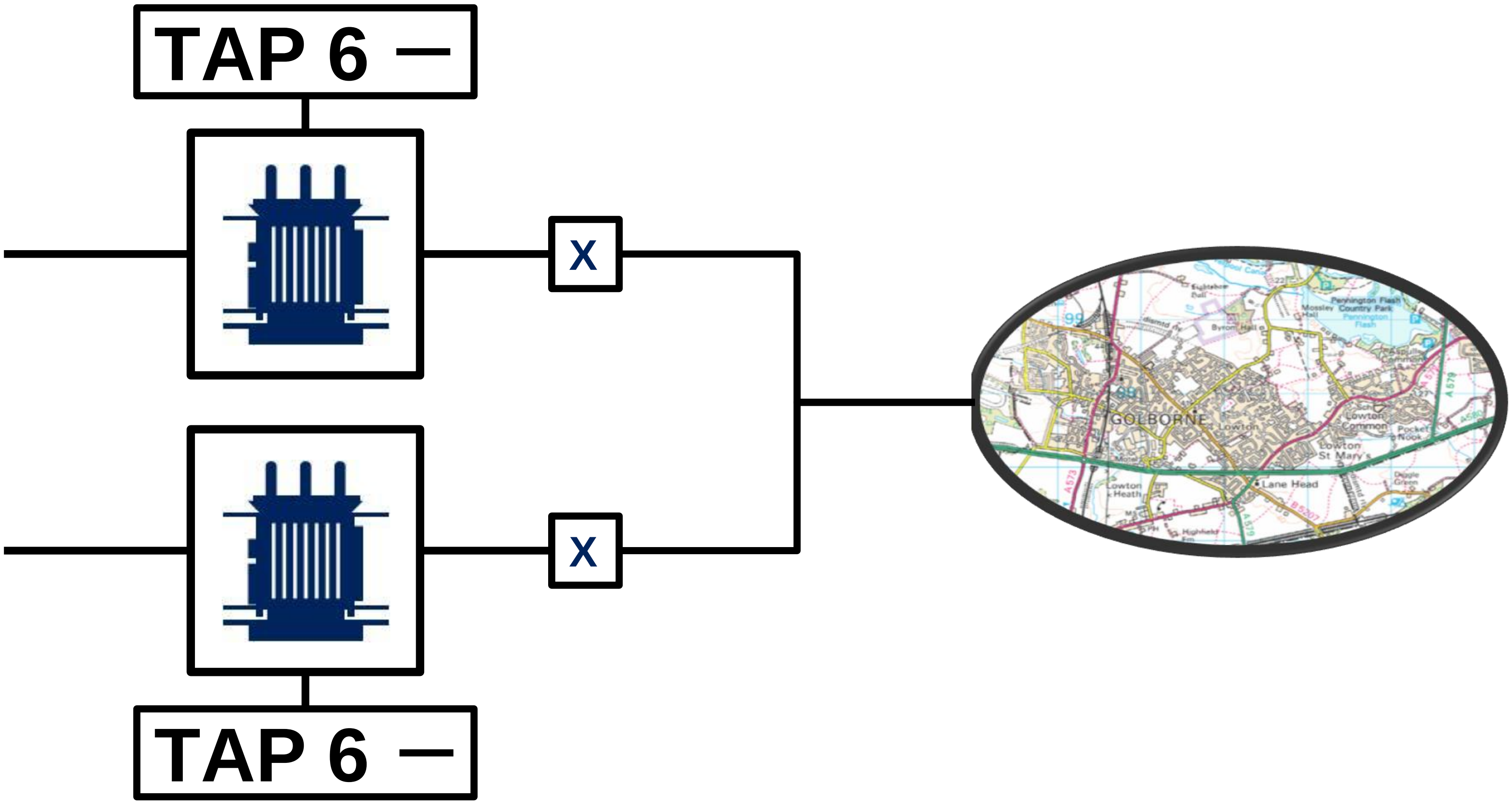


# Golborne area



# Typical primary arrangement - Golborne

**33kV** **11kV**



# Primary transformer

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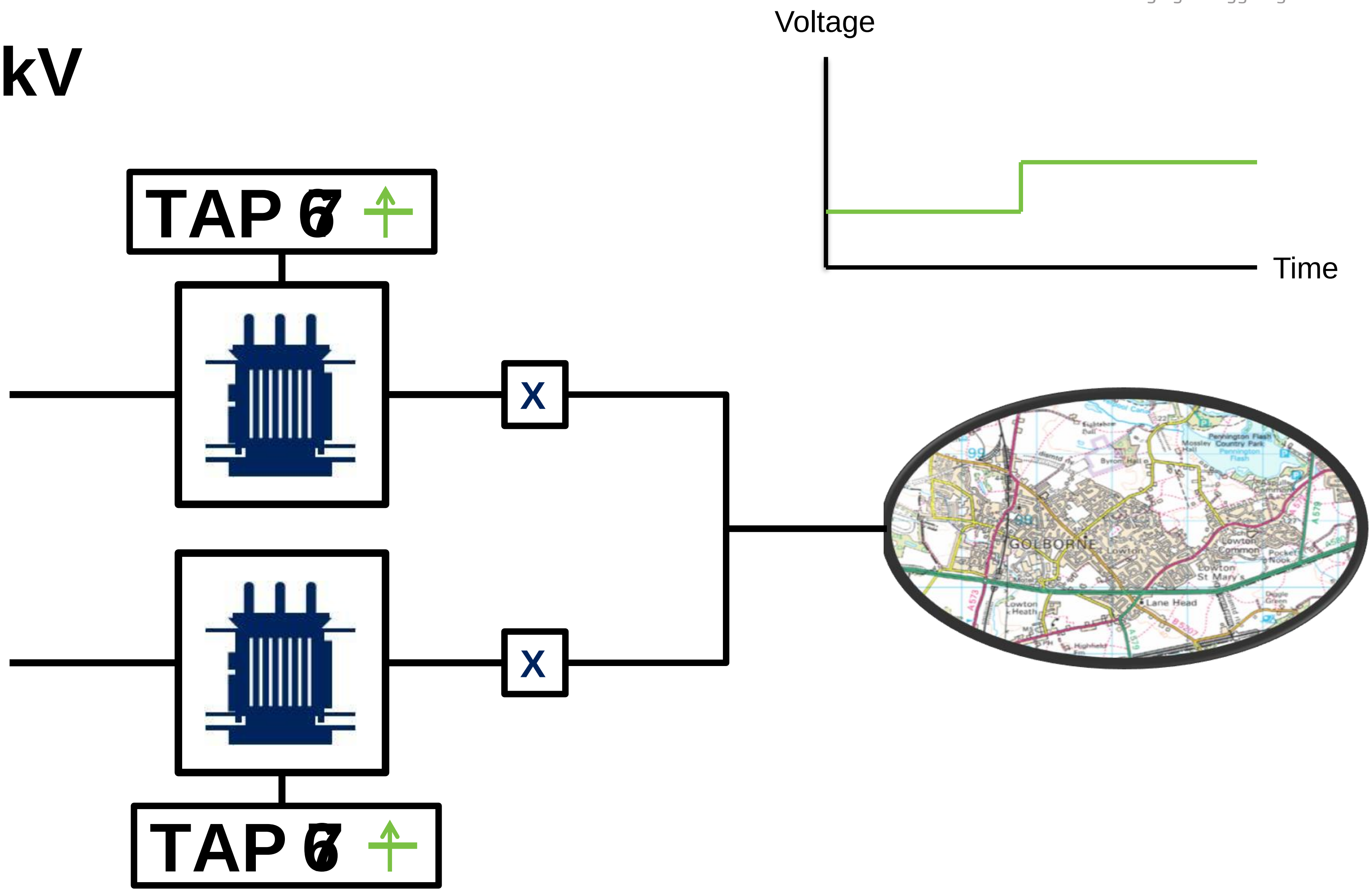
# Typical operation - Golborne

## 33kV

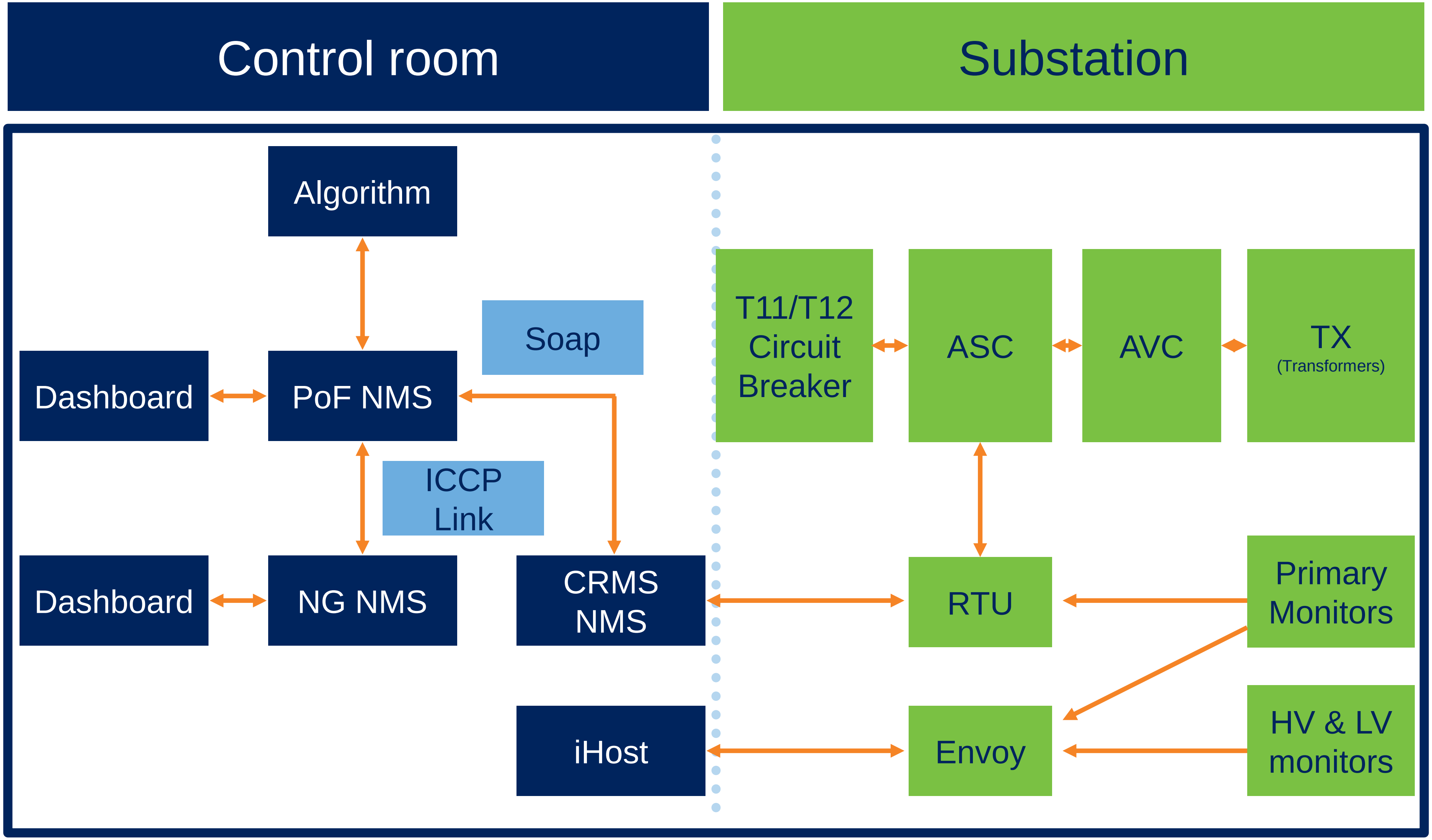


# CLASS project scale

| | |
|---|---|
| Primary sites | 60 |
| Micro tap sites | 52 |
| Argus 8 sites | 8 |
| Primary frequency response sites | 10 |

| | |
|---|---|
| HV locations | 10 |
| 45 new LV locations + 15 existing | 60 |
| Transformers | 3 |

# Complete CLASS system



# Dashboard

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| Group | T11 Tap/Current T12 Tap/Current | NRD | Frequency control MW | | Voltage Control Mvars | | | Demand % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Boost | | Reduction | |
| | | | Stage 1 | Stage 2 | Stage 1 | Stage 2 | Stage 3 | Half | Full | Half | Full |
| South Manc | | Disabled | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | Disabled | Disabled | Disabled | Disabled | Disabled | Disabled | | Disabled | Disabled |
| Trafford 11.1kV | T11 6/400A T12 6/400A | Disabled | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| | | | Disabled | Disabled | Disabled | Disabled | Disabled | Disabled | | Disabled | Disabled |
| Monton 11kV | T11 6/400A T12 6/400A | Disabled | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| | | | Disabled | Disabled | Disabled | Disabled | Disabled | Disabled | | Disabled | Disabled |
| Mount St 10.9kV | T11 6/400A T12 6/400A | Disabled | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** |
| | | | Disabled | Disabled | Disabled | Disabled | Disabled | Disabled | | Disabled | |

# Monitoring

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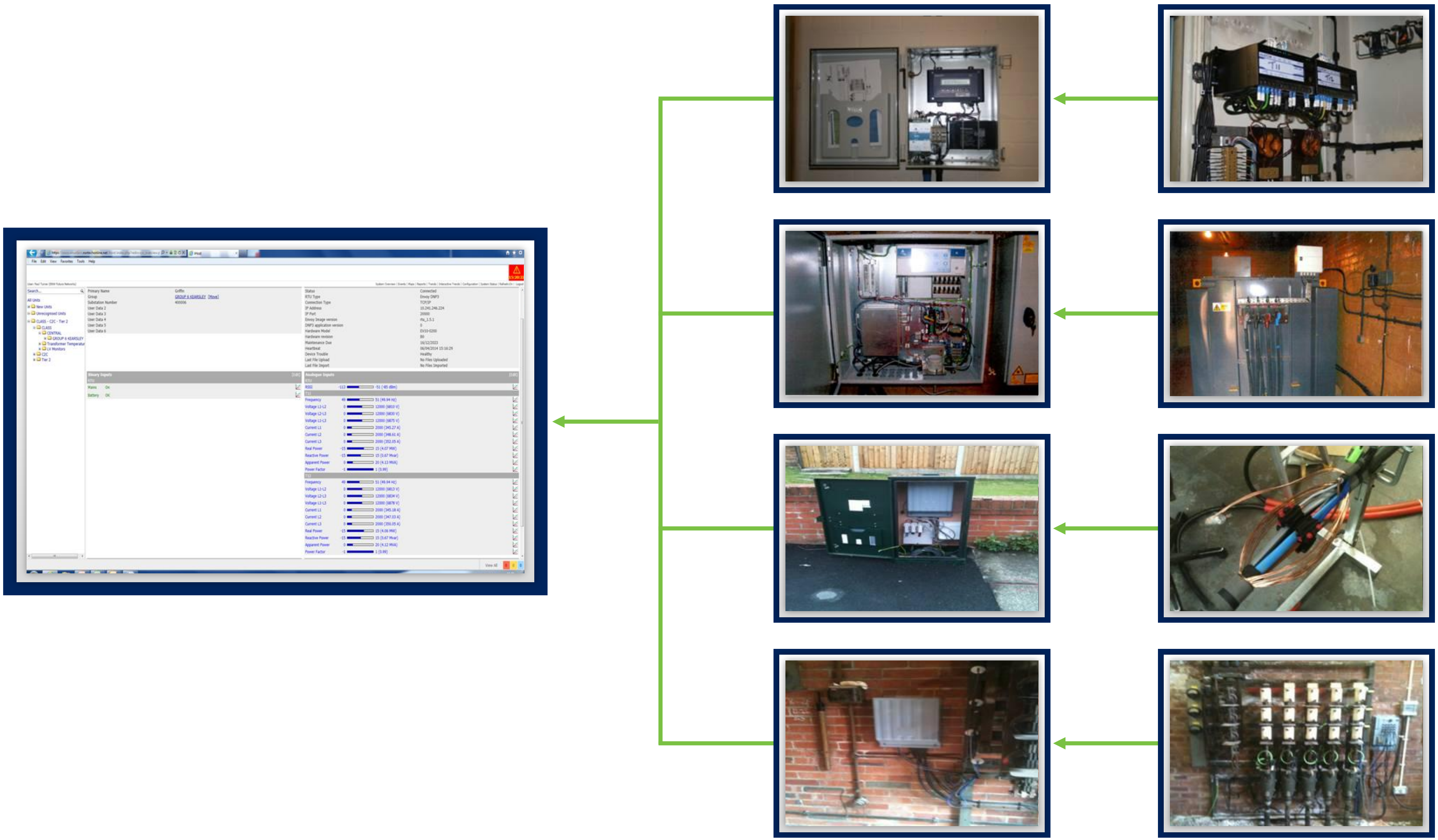

# What is an ICCP link?

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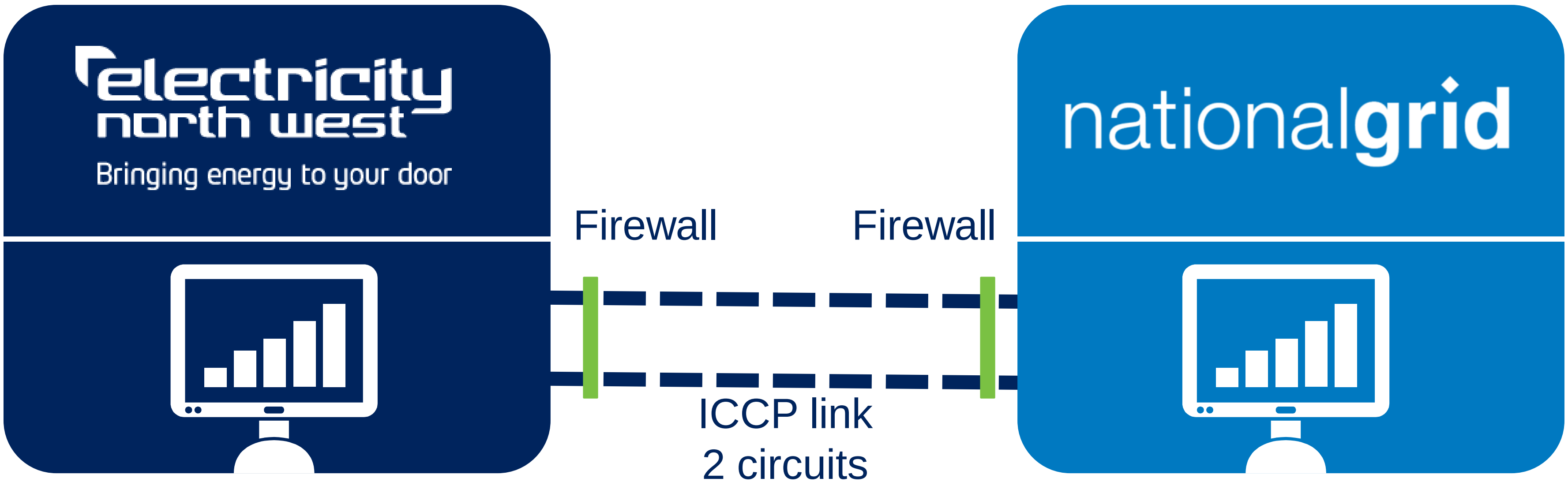
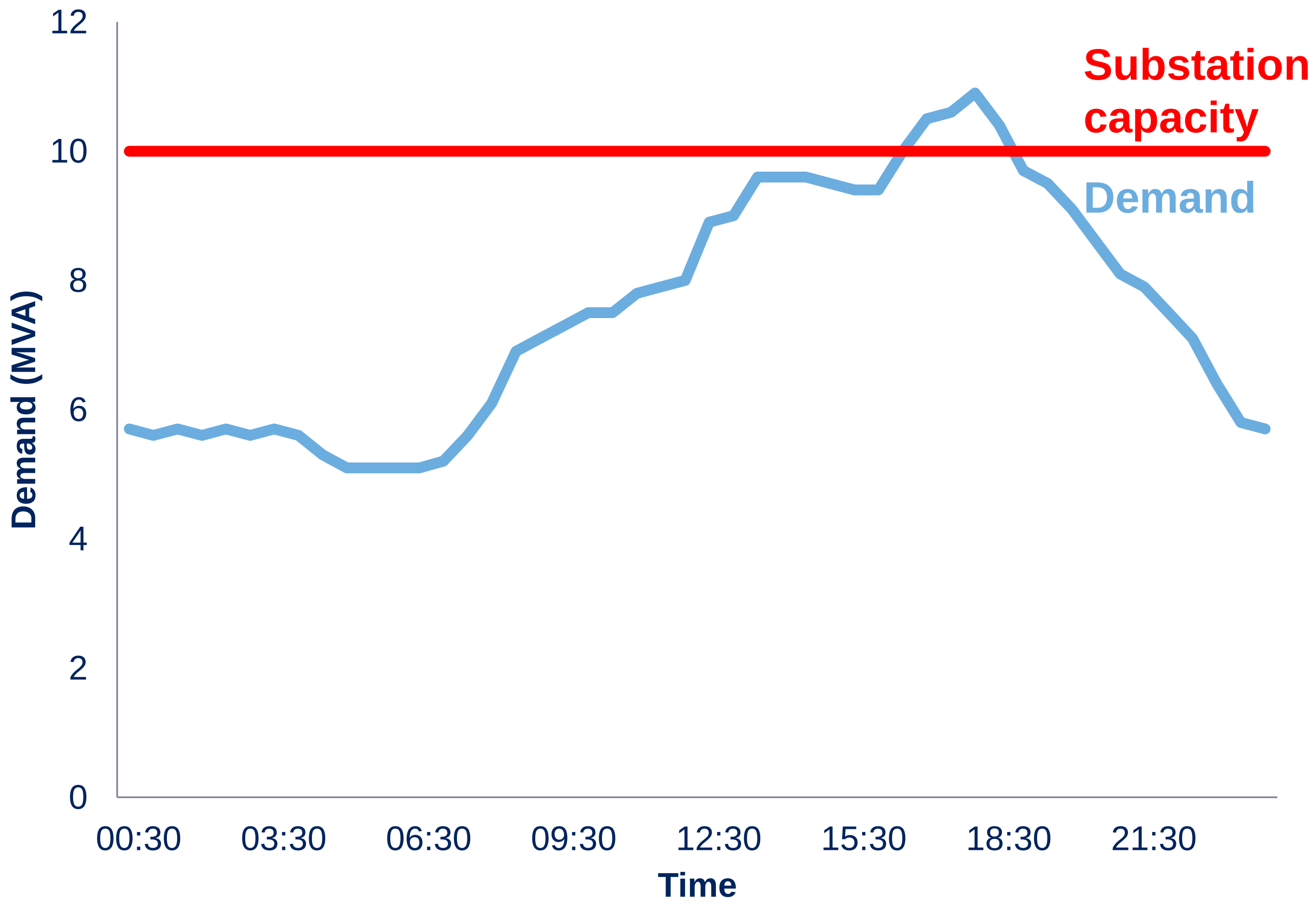



Secure inter control centre protocol is the industry standard

Direct fibre optic connection

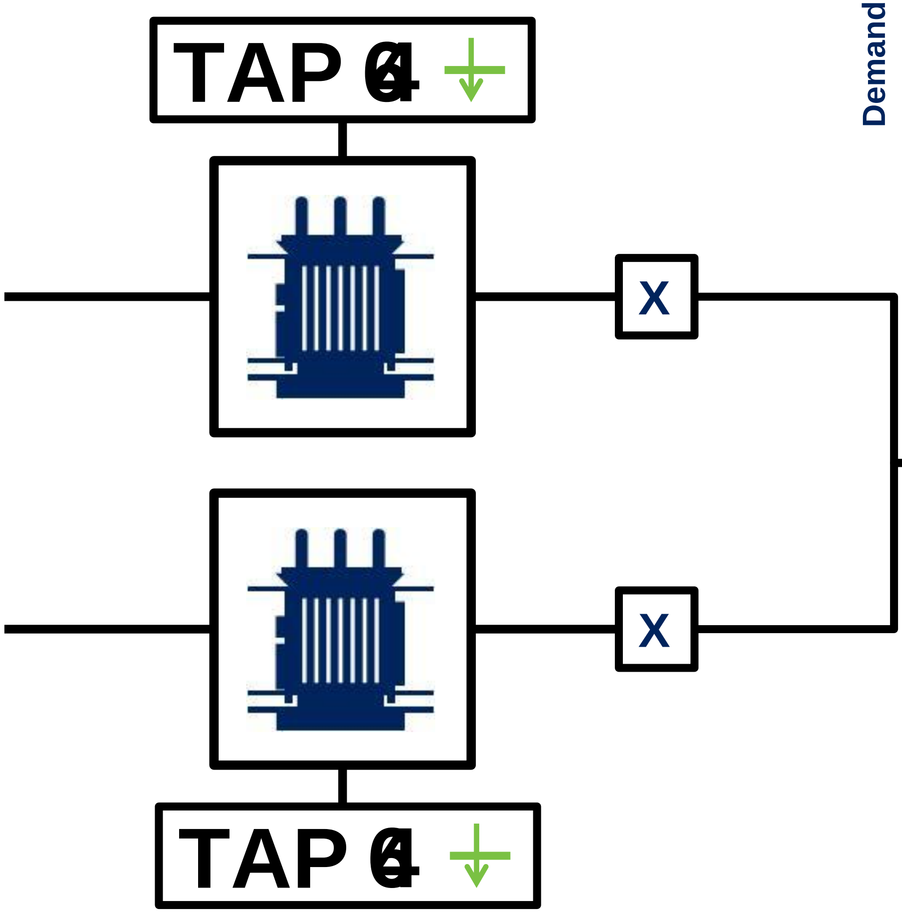
Enables data exchange between energy management systems

# Daily demand curve

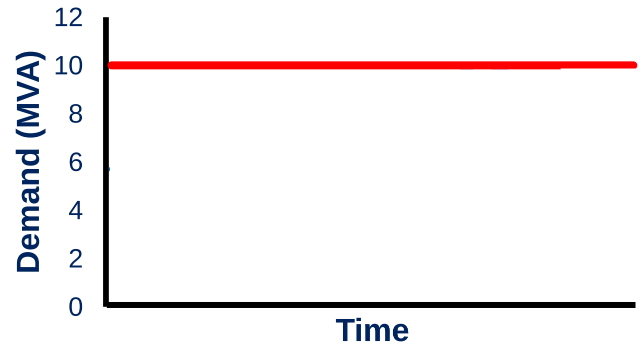


# Peak reduction - Golborne

## 33kV







# Peak reduction - Golborne

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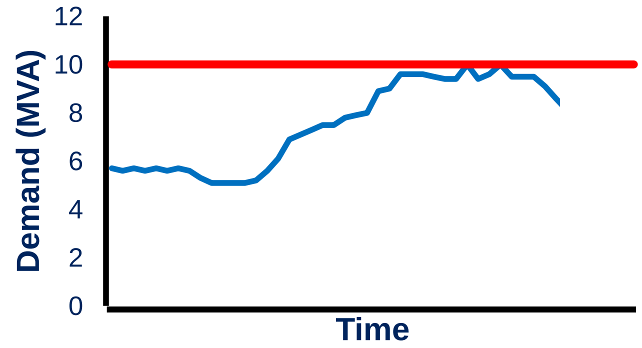
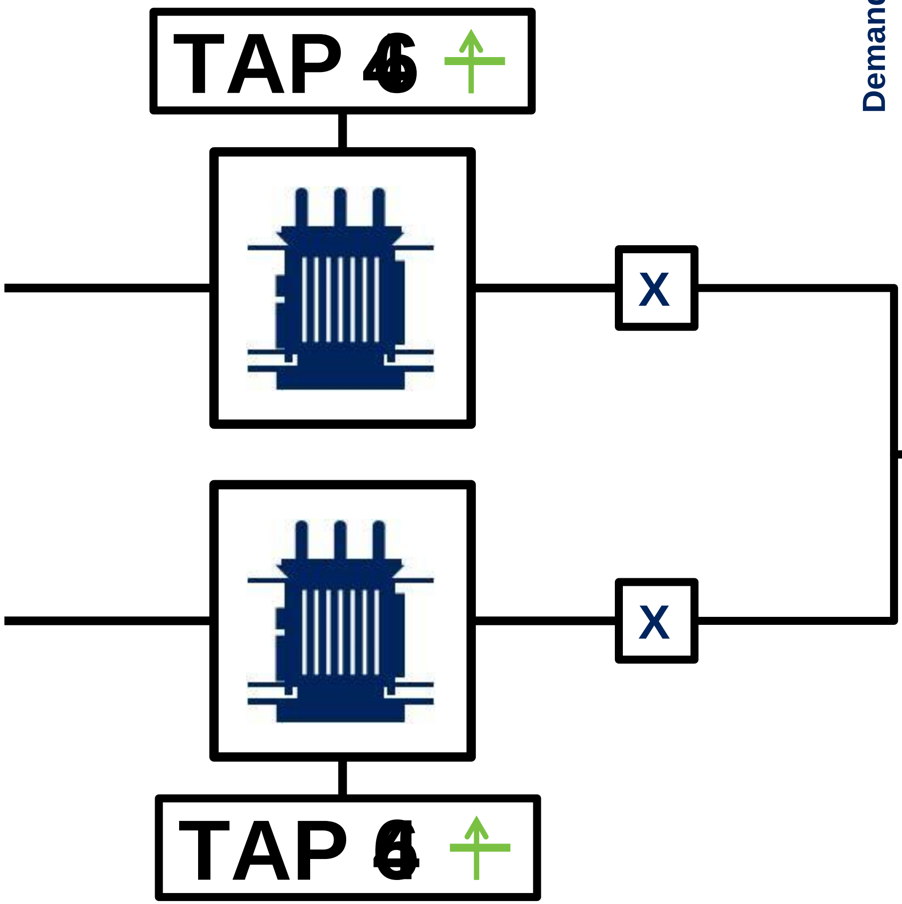
## 33kV




# Primary frequency response - Golborne

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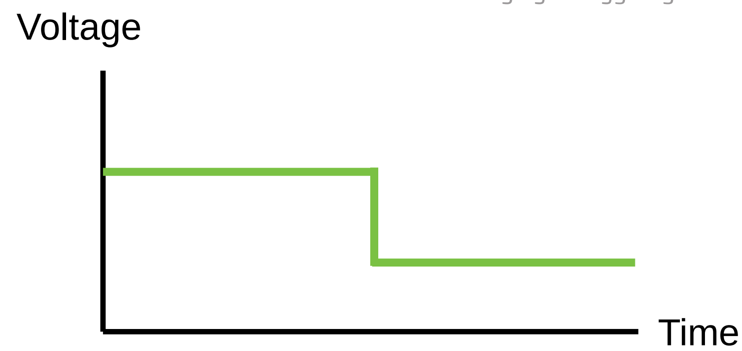
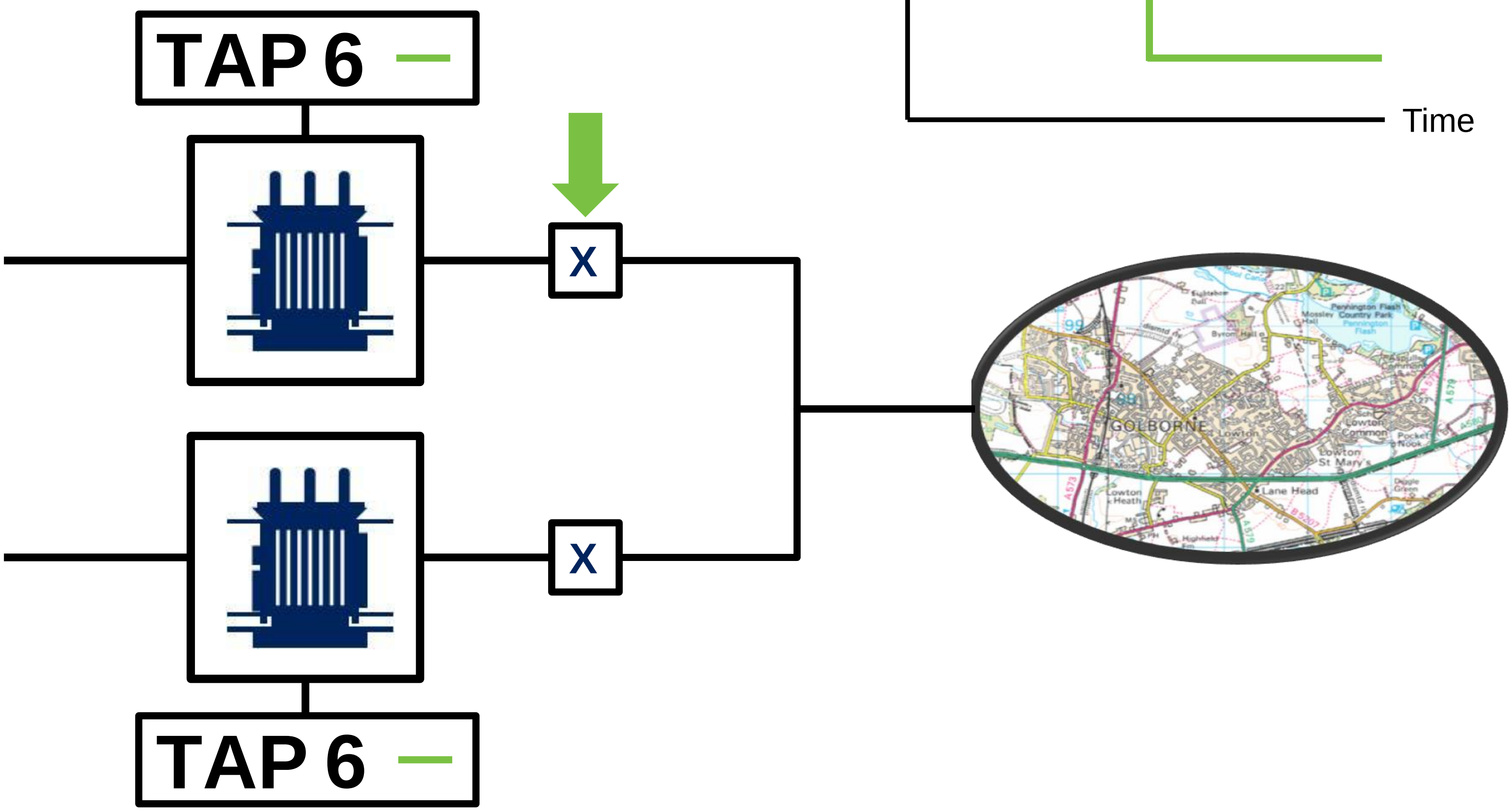
## 33kV



# Secondary frequency response - Golborne

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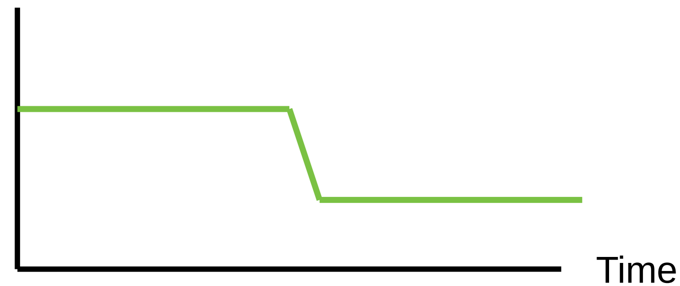
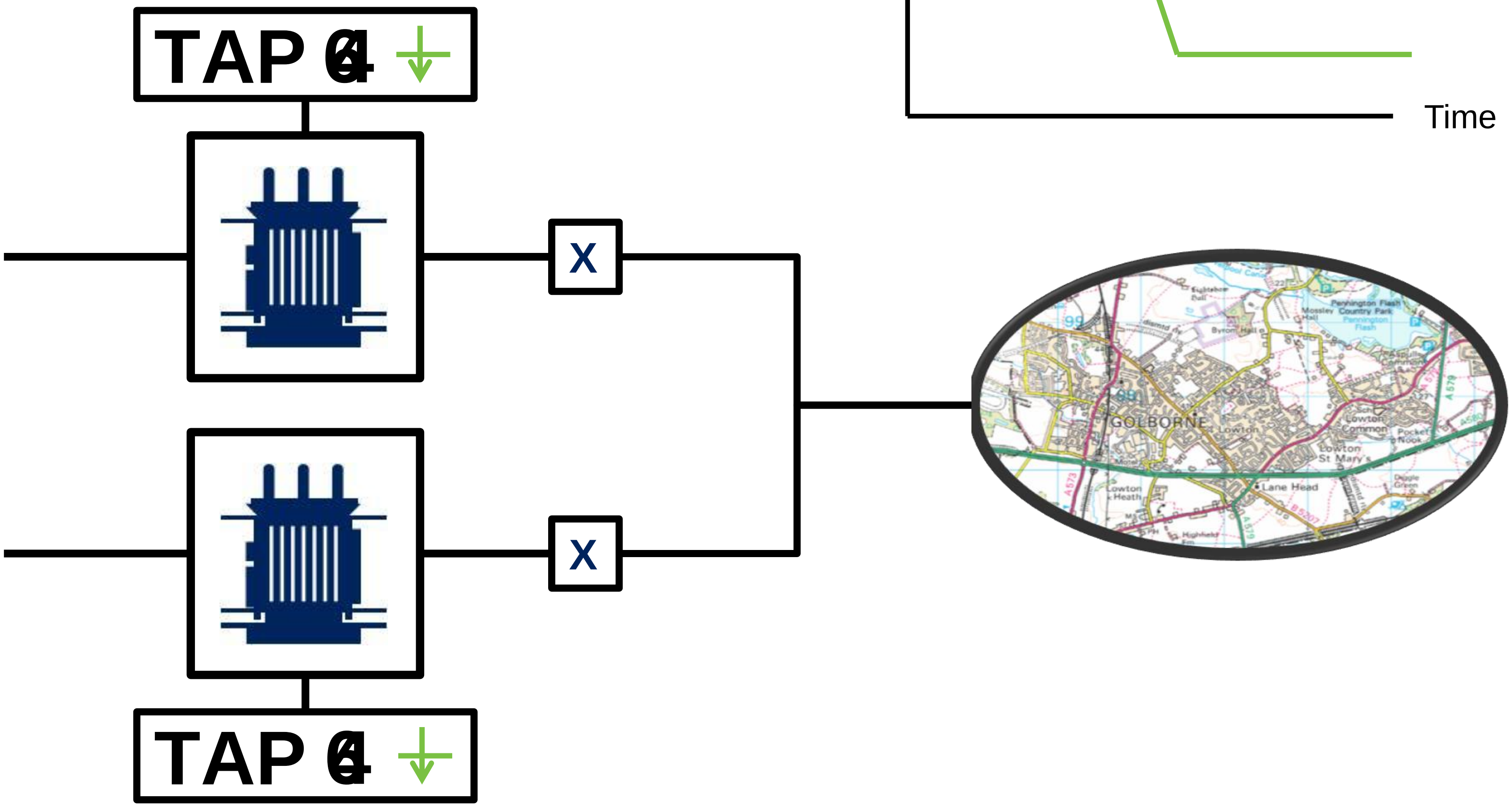
## 33kV



# Reactive power response - Golborne

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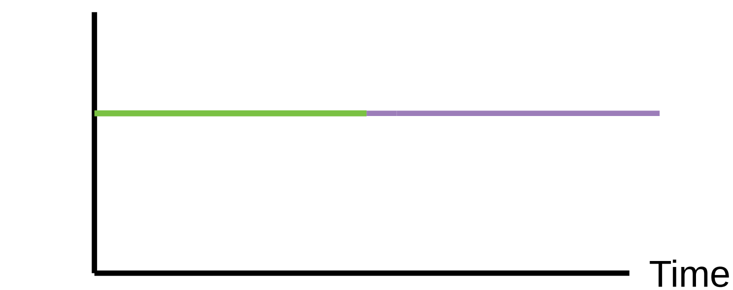
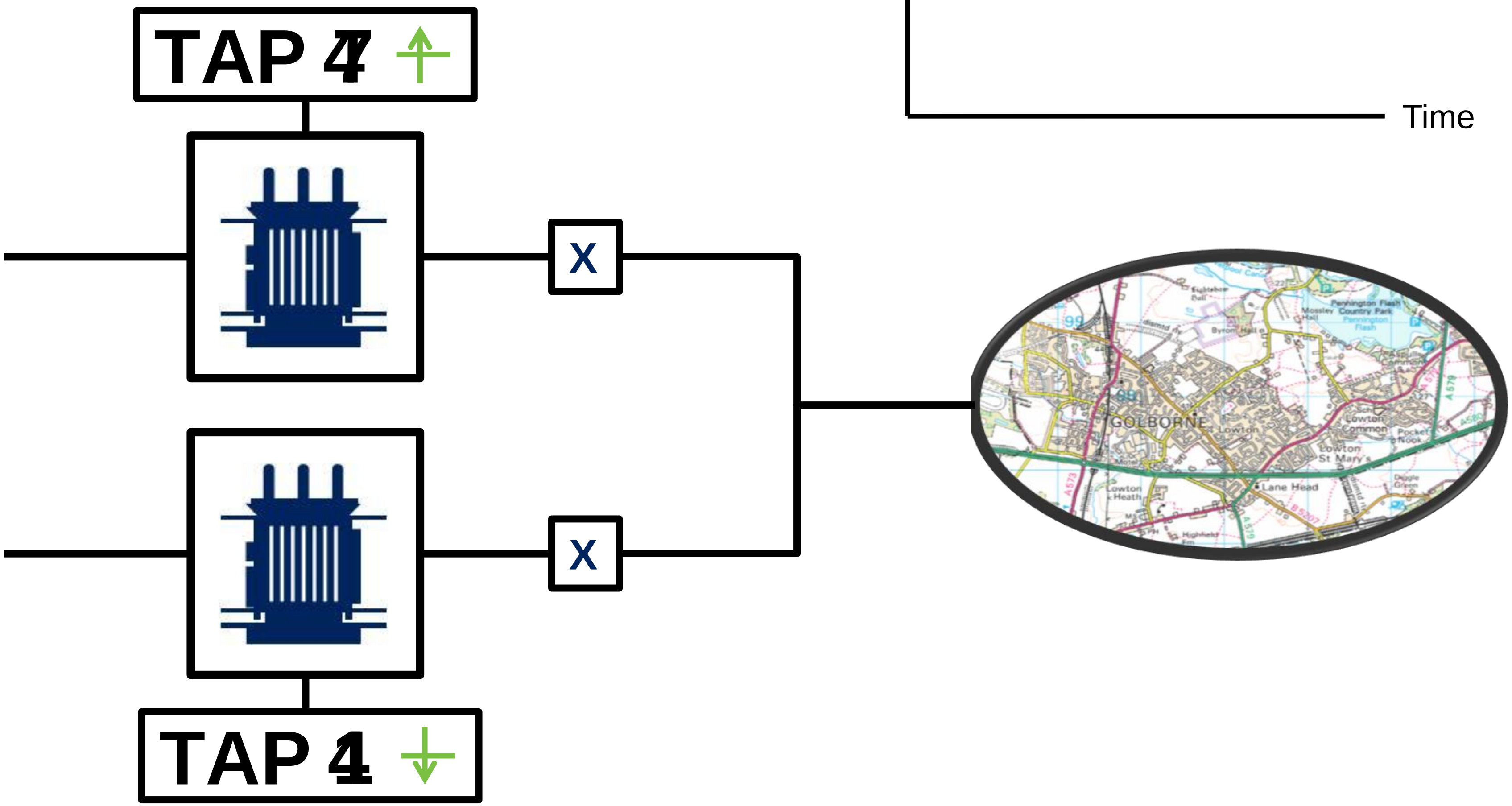
## 33kV



# Demand reduction / boost - Golborne

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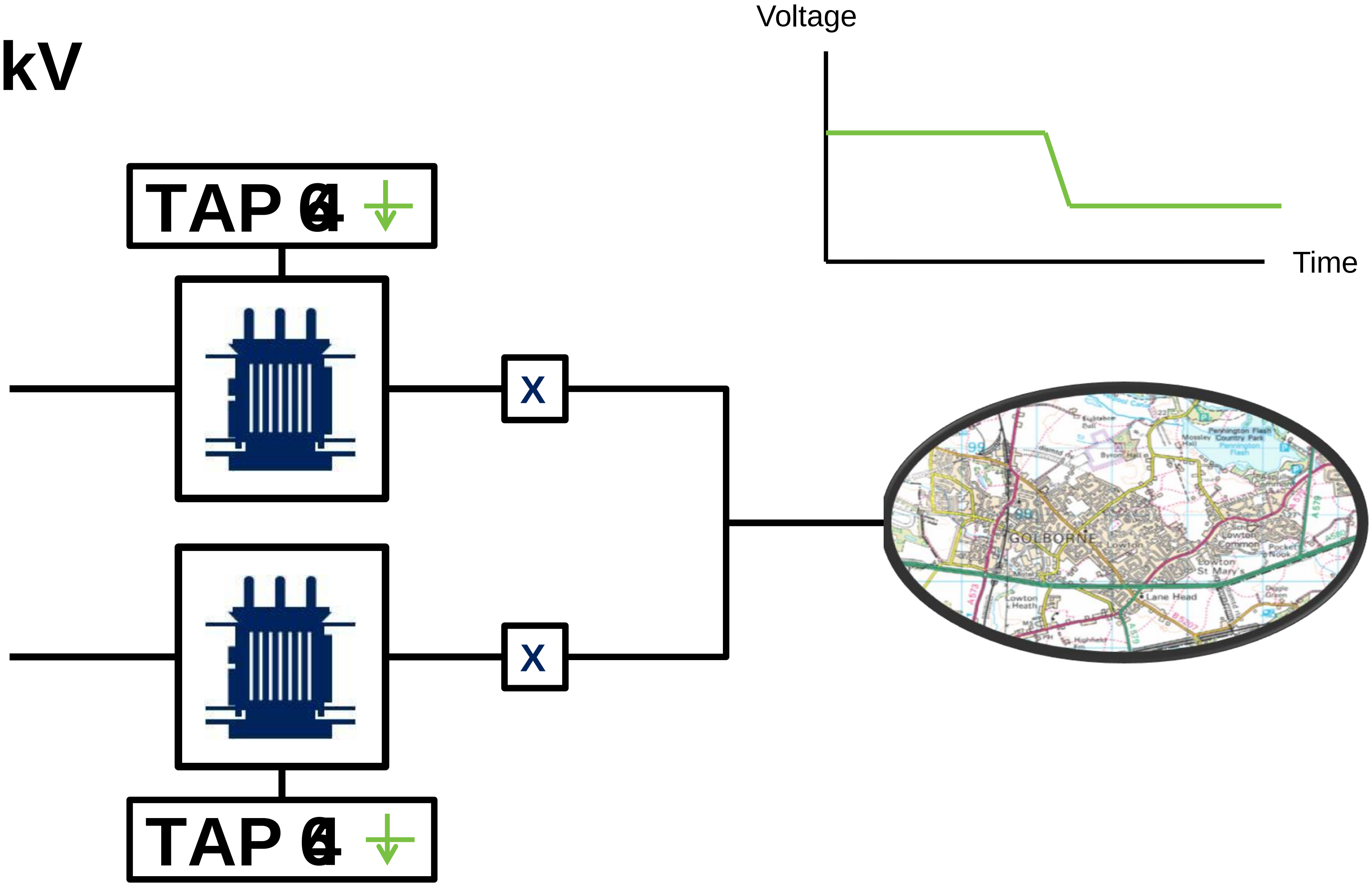
**33kV**



# QUESTIONS

# &

# ANSWERS

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**Kate Quigley**
Innovation Customer Delivery Manager
**Customer Research**

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# Did customers notice CLASS?

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No differences by customer type, trial type, region, vulnerable customers, survey season

No complaints from customers about power quality that could be attributed to CLASS

485,000 customers

Customers did ***not*** notice the CLASS tests

# Customer research methodology

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**"CLASS will be indiscernible to customers"**

Customers will not see / observe / notice an impact on the supply quality when these innovative techniques are applied

**Qualitative**

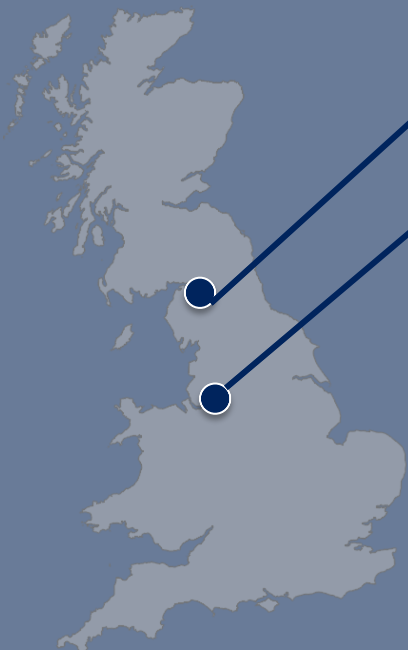
Formulate communications and materials

**Customer research**

**Quantitative**

Compare feedback trial v control

# Engaged customer panel methodology



Carlisle

Manchester

Four meetings as appropriate

Cross section of customers

All I&C panellists had decision-making responsibilities

30 consumers were recruited

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# Engaged customer panel – leaflet

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## How customers get involved in the survey and get the cash reward


Priority Services Register

# Customer leaflet and survey registration

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485,000 customers

3908 registrations

| 111 | 3797 online |
|---|---|
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CLASS website

Due to overwhelming response, registration for trial surveys was closed

Impact Research

Recruitment of 700 participants of a representative mix of customers

# Engaged customer panel lessons learnt

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## Lessons learnt

- DNO/supplier relationship still confusing
- Customers are sceptical of DNOs and suppliers
- Customers need to be educated about the Problem
- With sufficient education customers understand CLASS
- Customers need to be informed about CLASS
- Customers are sensitive to how personal data is handled

**Susie Smyth**
Associate Director,
Impact Research

**Customer Research**

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# CLASS trials overview

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| | | | | |
|---|---|---|---|---|
| Objectives | Reduction of peak demand | Frequency response and voltage support | Voltage and demand relationship | No effect on customers |

**What we did?**

All **485 000** customers in test area received letter
Baseline measure: spring 2014
**696** customers recruited at **baseline**
Test waves: summer 2014 to spring 2015
**1,357 test** interviews

**Customer hypothesis**

**"CLASS will be indiscernible to customers"**
Customers will not see / observe / notice an impact on their supply quality when these innovative techniques are applied

# Summary of the trial surveys

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## Test trial surveys

**Type of trials**

Peak demand voltage reduction at 3% & 5%
Stage 1 frequency response
Stage 2 frequency response

Test & control interviews

Questionnaire

Administered over the phone

**5**

minutes

Had customer noticed any discernable differences in the quality of their supply?

**£25**

reward per interview

# Test and control methodology

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Half took place  a week later than real test

Customers were not informed that they were the test or control group

Half took place a week earlier than real test

Any ‘placebo effect’ from being told that a trial may take place was accounted for by notifying half of the control group and half of the test group before any test or dummy test took place on selected electricity circuits

# Priority service customers

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Project team

485,000 customers

Already registered

Eligible for inclusion

RESULTS

Identify PSR customers and any special needs

Vulnerable customers reside at the property and/or if medical equipment affected

Power quality monitoring

# Changes to appliances or lighting that may or may not have been due to CLASS

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**Baseline population**

21%

**696 surveys**

| | |
|---|---|
| 21.7% | 16.0% |
| 14.4% | 11.6% |

**Test population**

15%

**1357 surveys**

Customers who perceived a change in performance to at least one appliance or to their lighting in the last 7 days was **significantly lower than the baseline**

# Test v control analysis – of the 15%...

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| | NOTIFIED | NOT NOTIFIED |
|---|---|---|
| CONTROL | 5% | 4% |
| TEST | 3% ↓ | 3% ↓ |

***Base**: All seasonal monitoring data = 1357 surveys*

The test sample were **less likely** to have noticed a change in performance than the control sample

# Trial type

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| Planned | Planned | Planned | Unplanned |
|---|---|---|---|
| **Voltage reduction 3%** | **Voltage reduction 5%** | **Stage 1 frequency response** | **Stage 2 frequency response** |
| 13% | 15% | 14% | 22% |

**Baseline 21%**

**Type of test** was not an influencing factor on likelihood to notice a change to power quality

# Customer type

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**Baseline**

21%

**696 surveys**

16%

13%

17%

**Test**

15%

**1357 surveys**

Even **vulnerable** customers who may be more dependent on a constant electricity supply than other customers were no more likely to notice changes than other groups

# Perceived changes that could be due to CLASS

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| | |
|---|---|
| 2% | 1% |
| 3% | 2% |

**Test**

3%

**1357 surveys**

Changes to power quality that **could be due to CLASS** were less than 3% on average

# Customer satisfaction

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| Base | | | | Test | | | |
|---|---|---|---|---|---|---|---|
| 696 surveys | | | | 1357 surveys | | | |
| Noticed a change (144) | 21% | Didn't notice (552) | 79% | Noticed a change (207) | 15% | Didn't notice (1150) | 85% |
| Satisfied | 73% | Satisfied | 93% | Satisfied | 95% | Satisfied | 98% |
| **Overall satisfaction** | | 89% | | **Overall satisfaction** | | 98% | |

# No complaints about power quality

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485,000 customers
in trial areas

Contact centre notified
before each test

= 0

Complaints about power quality or service received at the customer contact centre or to Impact Research team likely to be caused by CLASS trials

# QUESTIONS & ANSWERS

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# Tea break

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**Kieran Bailey**
Innovation Engineer
# Trial Methodology

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# CLASS hypotheses

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Through the application of innovative voltage regulation techniques CLASS will demonstrate…

That a change in voltage will produce a change in demand

Defer network reinforcement by reducing voltage at peak times

Reactive power absorption capabilities

No  detriment to asset health

Customers do not observe any discernible change in quality of supply

# Trial overview and function control

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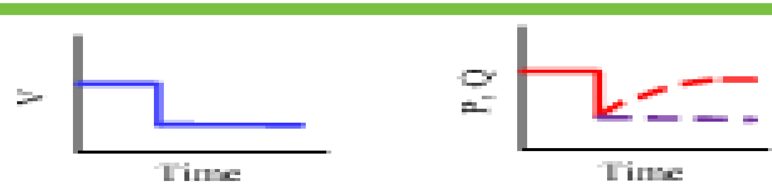
| CLASS trials | | | | |
|---|---|---|---|---|
| Load modelling | Peak demand reduction | Stage 1 frequency response (49.7Hz) | Stage 2 frequency response (49.8Hz) | Reactive power absorption |
| Raise/lower tap position | Lower tap position | Trip CB to switch out transformer | Lower tap position | Stagger transformer taps |

Voltage/demand matrix

| Time | 00:00 | 00:30 | 01:00 | 01:30 | 02:00 |
|---|---|---|---|---|---|
| Kp | 1.01 | 0.98 | 1.1 | 1.05 | 0.95 |
| Kq | 5.02 | 5.06 | 4.9 | 4.8 | 5.2 |




| Group Kearsley | Site Voltage<br>T11 Tap /Current<br>T12 Tap /Current | MPFR | NRD | Frequency control MW | | Voltage Control MVArs | | | Demand % | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Boost | | Reduction | |
| | | | | Stage 1 | Stage 2 | Stage 1 | Stage 2 | Stage 3 | Half | Full | Half | Full |
| Harwood | T11 kV 11<br>T11 Tap position 6<br>T11 Current 241<br>T11 MVAr 1.6<br>T11 MW 4.3<br>T12 kV 11<br>T12 Tap position 6<br>T12 Current 229<br>T12 MVAr 1.5<br>T12 MW 4.1 | 0<br>Disabled | 0<br>Disabled | 0<br>Disabled | 0.8<br>Enabled | NOT AVAILABLE | | | 0<br>Disabled | 0<br>Disabled | 0<br>Disabled | 0<br>Disabled |
| Chamberhall | T11 kV 11<br>T11 Tap position 6<br>T11 Current 337<br>T11 MVAr 2.3<br>T11 MW 6<br>T12 kV 11<br>T12 Tap position 6<br>T12 Current 349<br>T12 MVAr 2.1<br>T12 MW 6.3 | 0<br>Disabled | 0<br>Disabled | 0<br>Disabled | 0.5<br>Enabled | NOT AVAILABLE | | | 0<br>Disabled | 0<br>Disabled | 0<br>Disabled | 0<br>Disabled |
| Lostock | T11 kV 11<br>T11 Tap position 7<br>T11 Current 298<br>T11 MVAr 0.9<br>T11 MW 5.6<br>T12 kV 11<br>T12 Tap position 7<br>T12 Current 315<br>T12 MVAr 1.1<br>T12 MW 5.9 | Inhibit | Inhibited | 0<br>Inhibited | 0<br>Inhibited | 0<br>Inhibited | 0<br>Inhibited | 0<br>Inhibited | 0<br>Inhibited | 0<br>Inhibited | 0<br>Inhibited | 0<br>Inhibited |

# Trial 1 – Developing our understanding of the voltage/demand relationship

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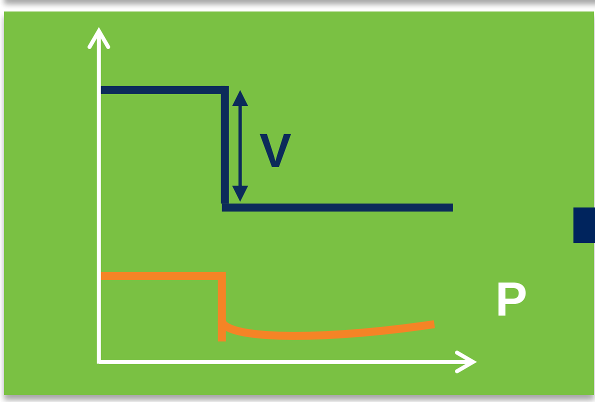
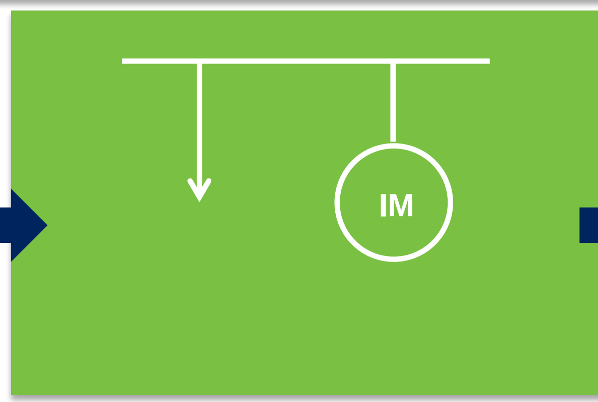
## V ∝ Demand?


| Group | Current Status | Frequency control MW | | Voltage Control Mvars | | | Demand % | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Boost | | Reduction | |
| | | Stage 1 | Stage 2 | Stage 1 | Stage 2 | Stage 3 | Half | Full | Half | Full |
| South manch | | 10 | 10 | 2 | 4 | 6 | 2 | 4 | -2 | -4 |
| | | Enabled | Enabled | Enabled | Enabled | Activated | Disabled | | Enabled | Enabled |
| Kearsley | | 10 | 10 | 1 | 2 | 3 | 2 | 4 | -2 | -4 |
| | | Enabled | Activated | Disabled | | | Inhibited | | Enabled | Enabled |
| 3 | | | | | | | | | | |
| 4 | | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | | | | | | | | | | |

Response of demand

Primary A load model

Voltage/demand matrix

# Trial 1 – Site selection

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MANCHESTER 1824
The University of Manchester

Methodology developed

Ratio of CDCM profile classes at substation peak demand

| Category A | Category B | Category C |
|---|---|---|
| Largely industrial and commercial | Largely domestic | Mixed |

Consideration of additional factors such as geography, socio-economic activity, type of processes for significant I&C customers

# Trial 1 – Determining the test schedule

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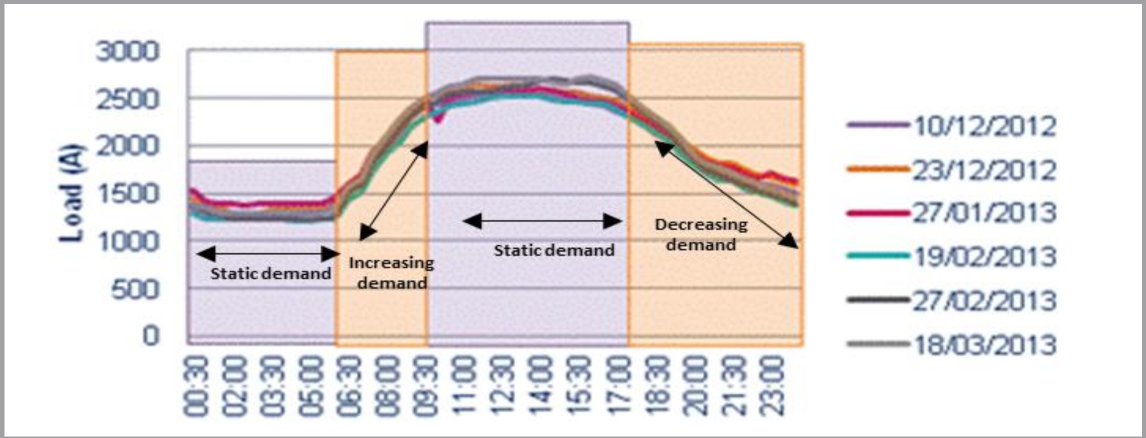
## Typically primary substation demand shows regularity

Example daily profile




Tests can be conducted in representative periods

Quantify the demand/voltage relationship for every half hour across the annual cycle

The planned voltage decrement and increment tests will supplement BAU tap change activity

TEST SCHEDULE

# Trial 1 voltage/demand relationship

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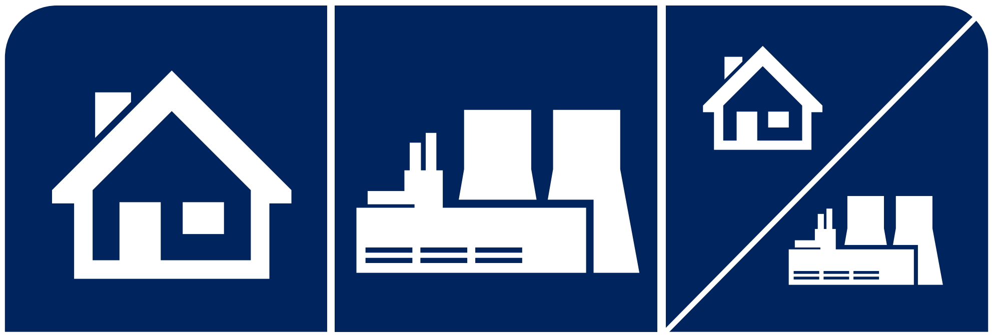

| Mainly domestic | Mainly industrial/ commercial | Mixed |
|---|---|---|
| 1% change in voltage ~ 1.3% change in real power | 1% change in voltage ~ 1.48% change in real power | 1% change in voltage ~ 1.22% change in real power |

# Demand response example

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| | |
|---|---|
| | Primary demand at peak 10MW |
| | 5% voltage reduction = DR of 6.5% |
| Mainly domestic | Demand reduction of 650KW |
| | Equivalent to supply delivered to 300 homes |

# Trial 2 – Reduction in peak demand

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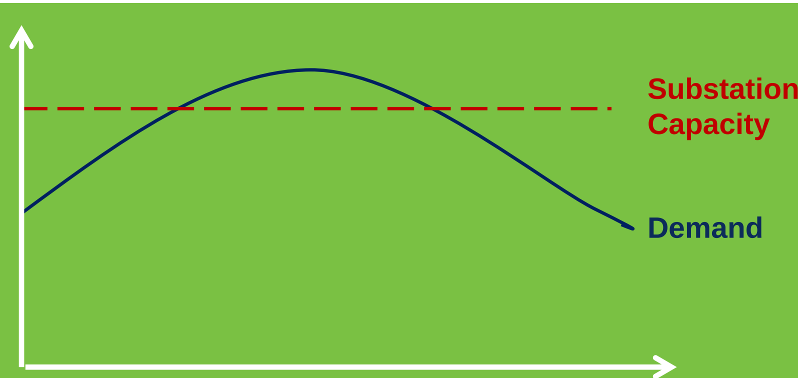
Demonstrate CLASS solution actively reduce peak demands on networks

Avoid or defer network reinforcement

CLASS is a low cost and quickly deployable solution where there is uncertainty in demand forecast




Maximum apparent power reduction that can be sustained

V

3%

5%

Incremental levels of voltage reduction

Historic peak times

120 minute duration

Evaluating customer perception and testing technology

# Trial 2 – Implementing the peak demand reduction

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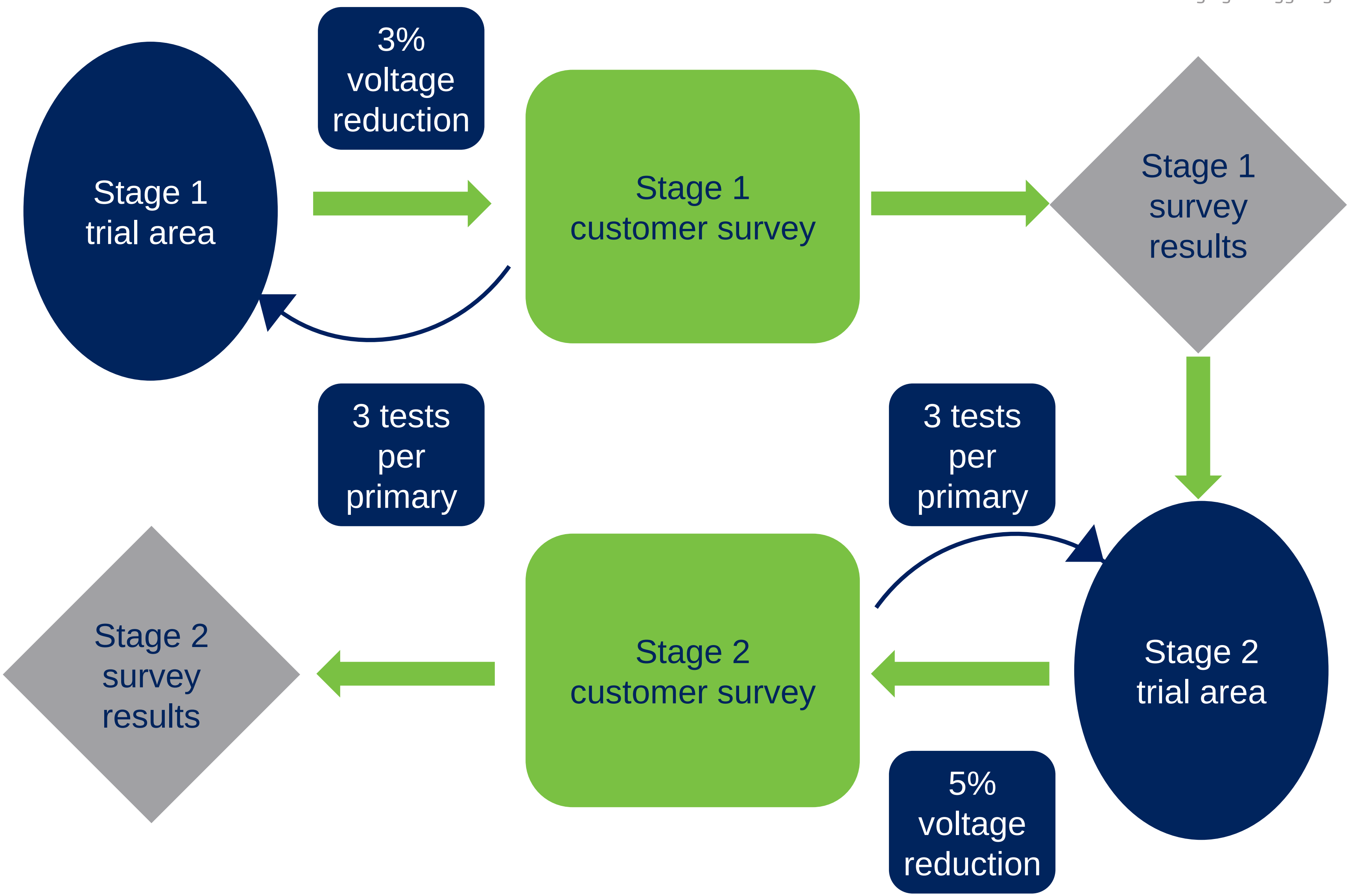
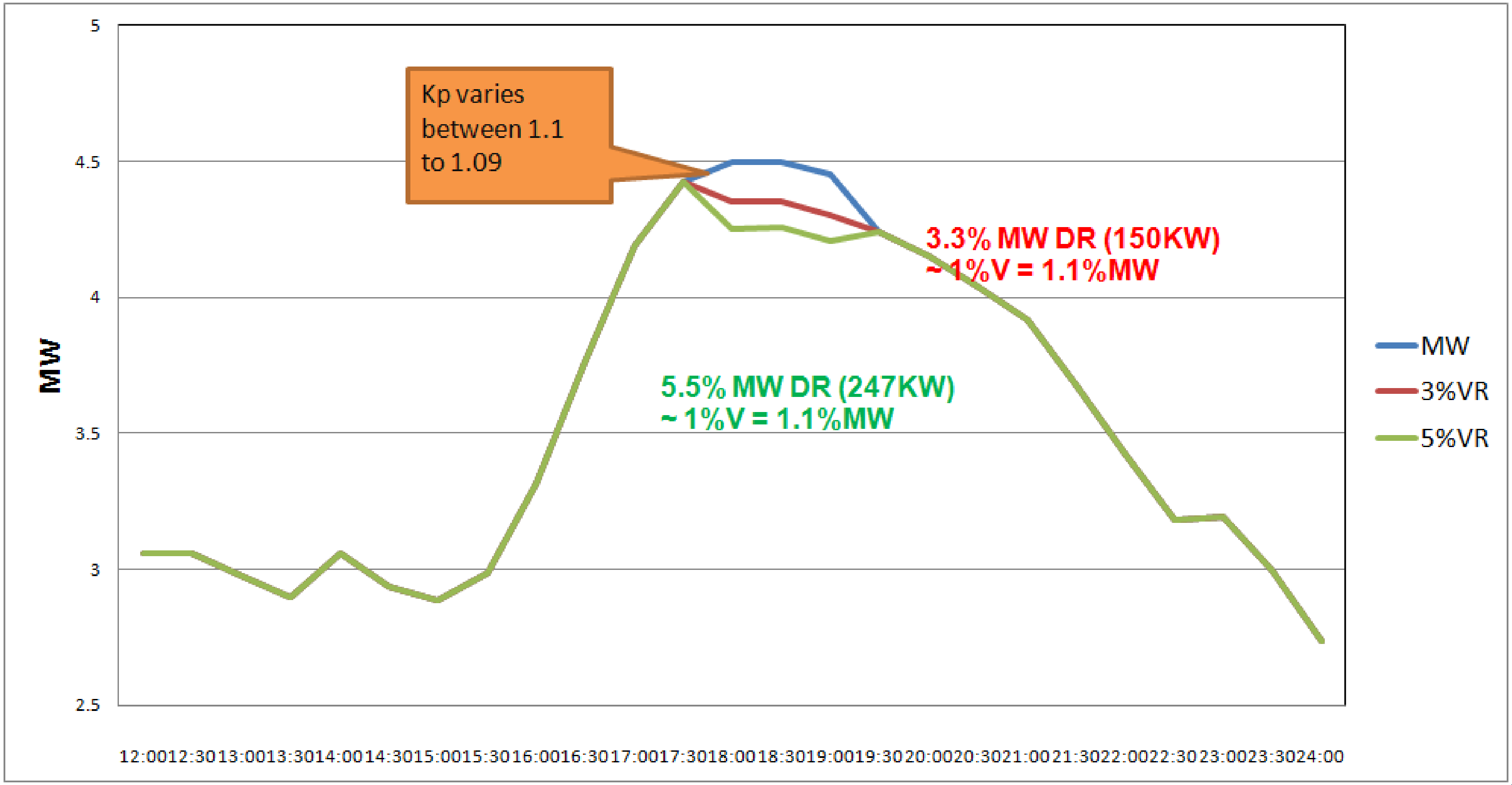


# Demand reduction at peak demand

## Demand reduction – Romiley winter mid-week



# Demand response (DR)

| Electricity North West | | Great Britain 3% VR = 3.6%DR | |
|---|---|---|---|
| Summer minimum demand response = 65MW | Winter maximum demand response = 170MW | Summer minimum demand response = 670MW | Winter maximum demand response = 1890MW |

# Demand response (DR)

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| Great Britain 5% VR = 6%DR | | Great Britain 6% VR =7.2%DR | |
|---|---|---|---|
| Summer minimum demand response = 1120MW | Winter maximum demand response = 3150MW | Summer minimum demand response = 1340MW | Winter maximum demand response = 3780MW |

# Trial 3 – Frequency response

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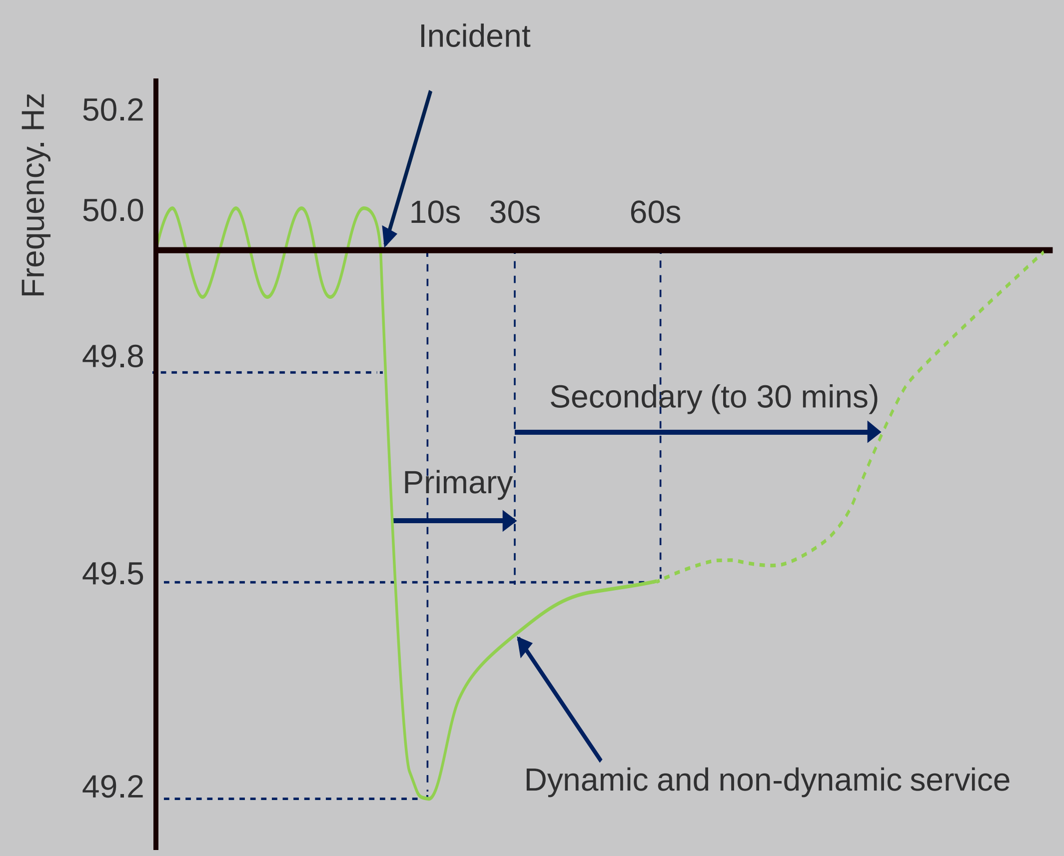


Demonstrate CLASS can be a new mechanism for managing system frequency

Existing reserve services attract a high financial and carbon cost

CLASS has the potential to be a cost effective and flexible solution

# Trial 3 – Utilising our assets

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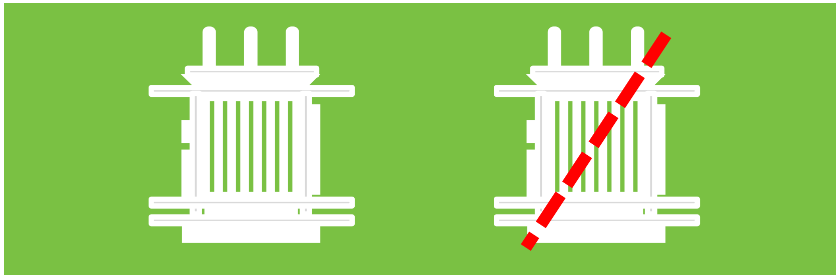
## Stage 1



Detection of a low frequency threshold

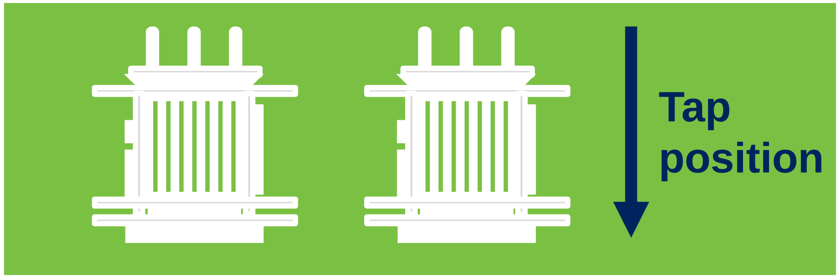
Tripping one of a pair of parallel primary transformer

Instantaneous change in voltage

Response time ~ 2 sec

Duration – 30 minutes

## Stage 2



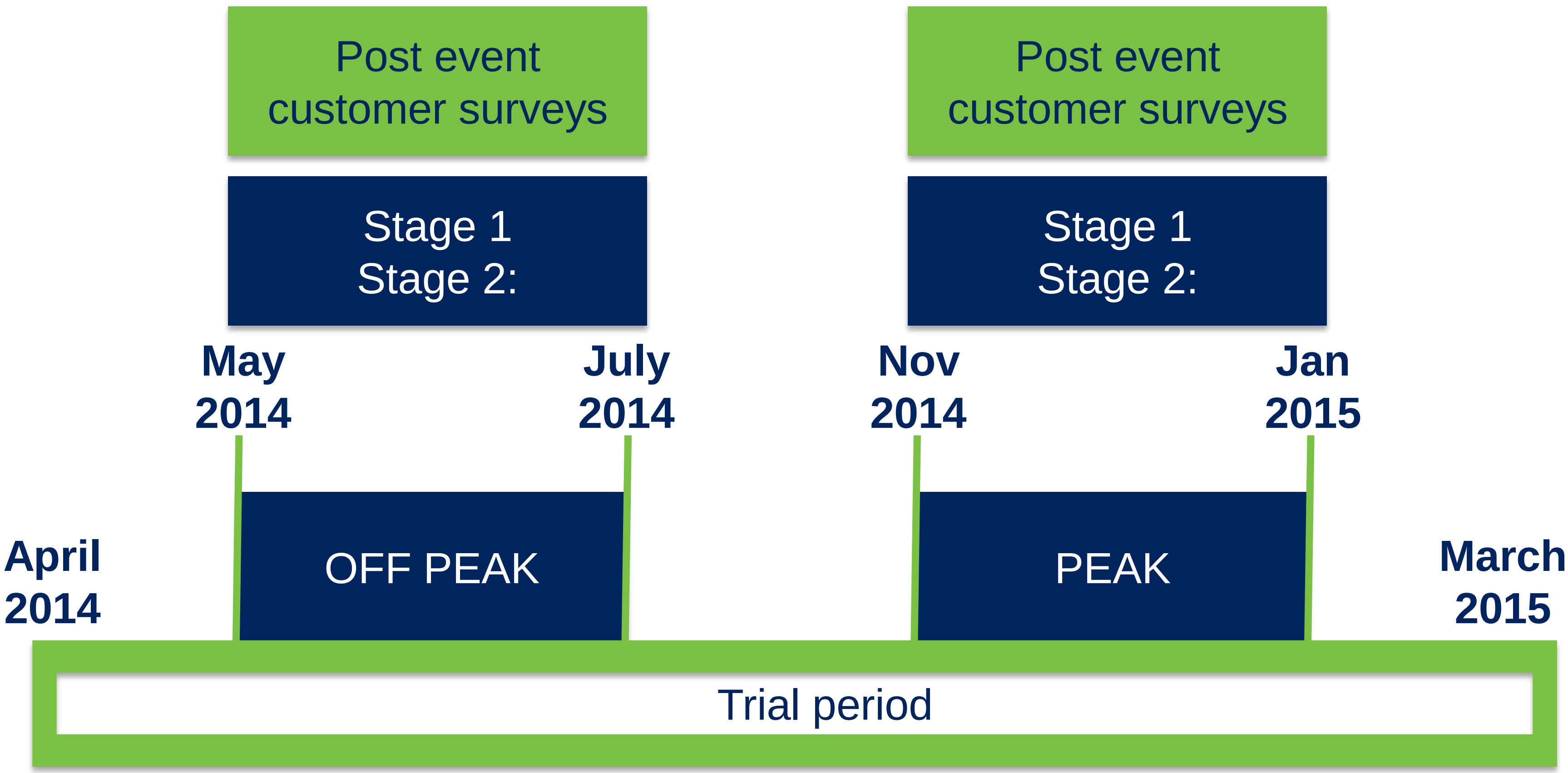

Initiated from dashboard or detection of a low frequency threshold

Reduction in HV voltage through change in tap position

Response time – 30 sec to 2 minutes

Duration – 30 minutes

# Trial 3 – Testing approach



# DR for frequency response events

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| | | | |
|---|---|---|---|
| **Event 1:** | **17/09/2014 20:44** | | |
| **Primary** | | **V change (%)** | **Pchange (%)** |
| Fallowfield | | 1.44 | 2.05 |
| Baguley | | 1.57 | 2.67 |
| **Event 2:** | **15/12/2014 22:43** | | |
| **Primary** | | **V change (%)** | **Pchange (%)** |
| Fallowfield | | 1 | 1.78 |
| Baguley | | 1.7 | 1.9 |

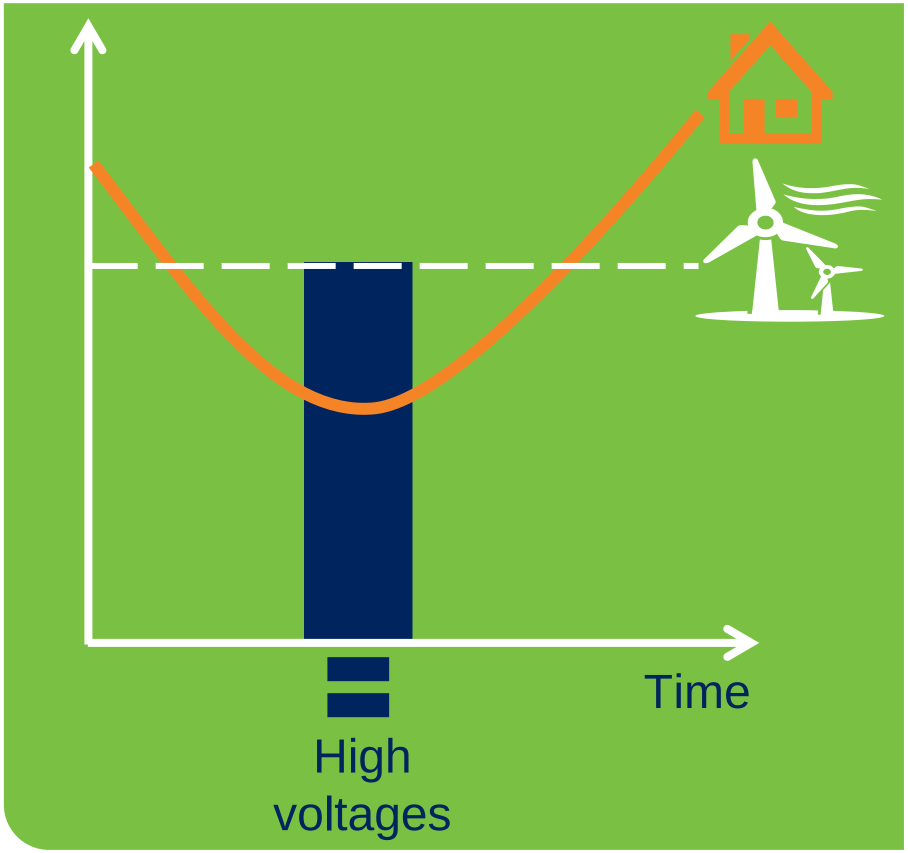
**1% voltage change = 1.78%-1.12%MW DR**

**Equates to**

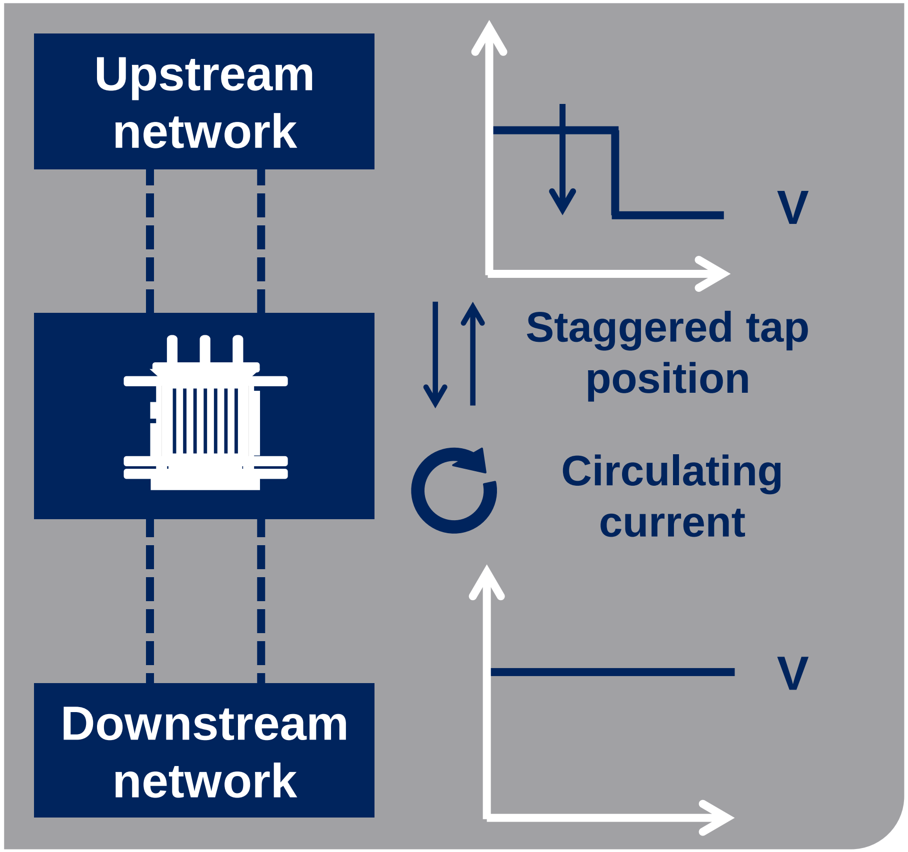
**5% voltage change = 8.9% to 5.6%MW DR**

# Trial 4 – Reactive power absorption

Demonstrate CLASS can be used to manage excessive system voltage typically at times of high generation output but low demand




Method of implementation



# Trial 4 – Approach to testing

Three levels of reactive power absorption capability

NGT high voltage period 2-6am

Electricity North West high voltage period 10pm – 7am

# Reactive power absorption



## Electricity North West area – 6 tap stagger

| Spring | Summer | Autumn | Winter |
|---|---|---|---|
| 129MVAr to 156MVAr | 134MVAr to152MVAr | 132MVAr to159MVAr | 131MVAr to169MVAr |

# Reactive power absorption

| Great Britain | | | |
|---|---|---|---|
| **Spring** | **Summer** | **Autumn** | **Winter** |
| 1419MVAr to 1716MVAr | 1474MVAr to 1672MVAr | 1452MVAr to1749MVAr | 1441MVAr to1837MVAr |

# QUESTIONS

# &

# ANSWERS

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# Lunch

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**Steve Stott**

Innovation Engineer

**Technology and Technical Learning**

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# Academic research

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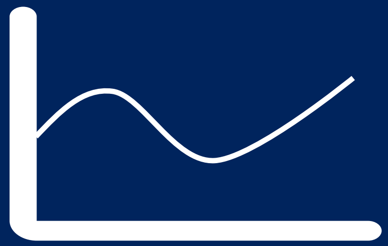

Demand profiles through modelling and validation using trial data

Demand response quantification methodology and results

Q absorption capability and availability study based on EHV network

Asset health


Carbon impact

**Dr Kazi Hasan**
**Prof Jovica Milanovic**

# Demand profiles through modelling and validation using trial data

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# Load modelling methodology

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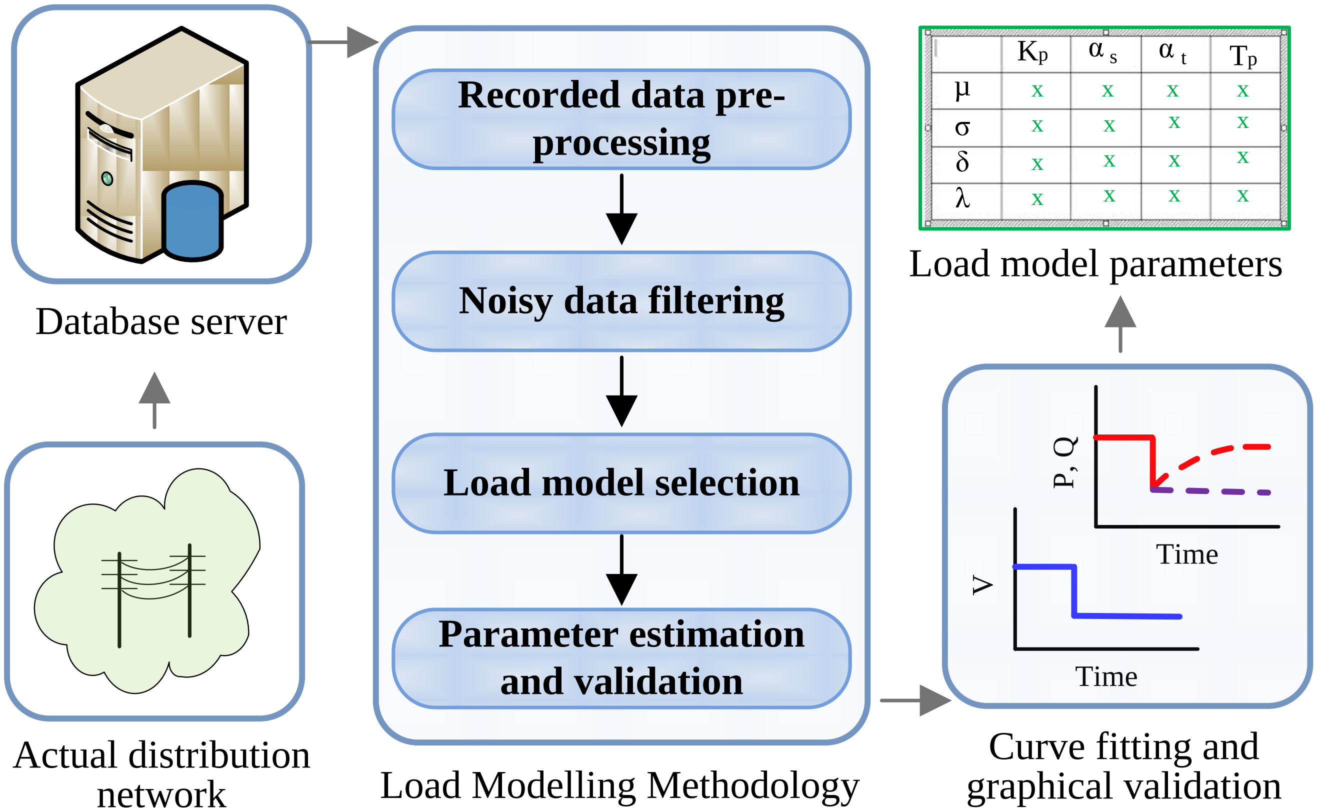


Recorded measurements extraction and processing ● Data filtering ● Load model selection ● Parameter estimation and validation

# Selection of load model

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**ZIP and exponential model parameters for 3 substations**

| Substation | Type | ZIP Model Parameters | Exponential Model Parameters |
|---|---|---|---|
| **Trafford Park North** | Industrial | $Z_p = 0.11, I_p = 0.22, P_p = -708$<br>$Z_Q = 0.41, I_Q = 0.83, P_Q = -0.42$ | $K_p = 1.63$<br>$K_q = 3.67$ |
| **Fallowfield** | Domestic | $Z_p = 0.46, I_p = -0.91, P_p = -3040$<br>$Z_Q = 0.29, I_Q = -0.58, P_Q = -0.29$ | $K_p = 1.55$<br>$K_q = 5.88$ |
| **Victoria Park** | Mixed | $Z_p = 0.22, I_p = -0.44, P_p = -1483$<br>$Z_Q = 0.36, I_Q = -0.73\ P_Q = -0.37$ | $K_p = 0.83$<br>$K_q = 5.32$ |

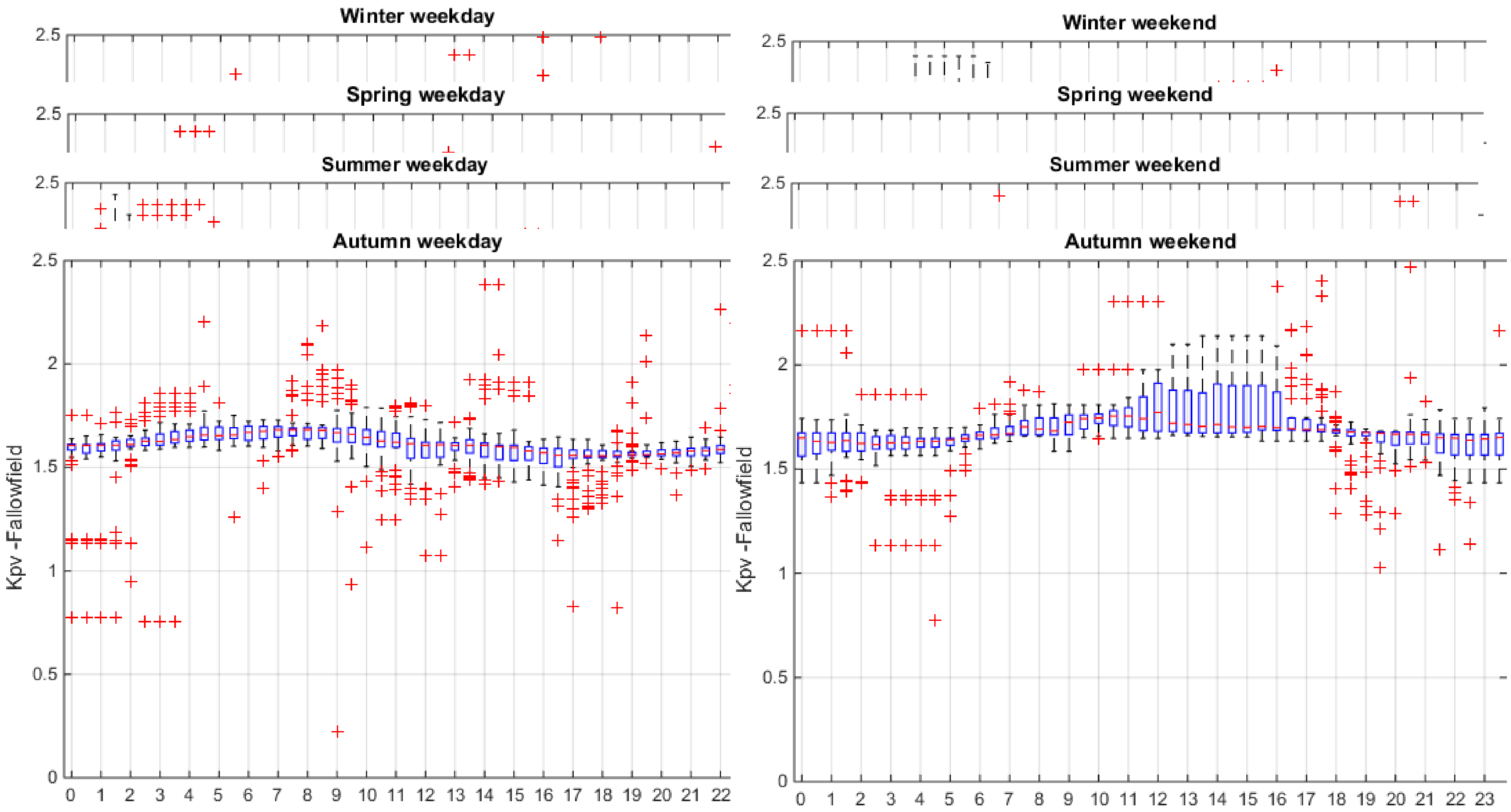
Simplicity: 1 parameter to represent P-V relationship

Persistence: ZIP model is more sensitive to any change

Coherence: Self-explanatory and straightforward

Large-scale application: CLASS concept will roll-over throughout the whole UK. Easily deployable and less computationally intensive

# Voltage-demand matrix development



# Voltage-demand matrix: summary

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| $K_p$ | Mainly domestic | | | Industrial/commercl | | | Mixed | | | Seasonal avg. for all substations |
|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | |
| Winter | 0.87 | 1.33 | 1.93 | 0.86 | 1.47 | 1.85 | 0.70 | 1.23 | 1.91 | **1.34** |
| Spring | 0.83 | 1.32 | 1.86 | 1.02 | 1.39 | 1.80 | 0.80 | 1.20 | 1.68 | **1.30** |
| Summer | 0.72 | 1.25 | 2.11 | 1.02 | 1.52 | 1.97 | 0.70 | 1.20 | 1.58 | **1.32** |
| Autumn | 0.67 | 1.31 | 1.91 | 0.95 | 1.53 | 1.98 | 0.71 | 1.23 | 1.80 | **1.36** |
| Load types' average | **1.30** | | | **1.48** | | | **1.22** | | | |

| $K_q$ | Mainly domestic | | | Industrial/commercl | | | Mixed | | | Seasonal avg. for all substations |
|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | |
| Winter | 3.98 | 5.96 | 7.98 | 3.79 | 5.62 | 6.86 | 4.36 | 5.92 | 6.93 | **5.83** |
| Spring | 4.58 | 6.14 | 8.05 | 4.30 | 5.56 | 6.75 | 3.82 | 5.82 | 7.52 | **5.84** |
| Summer | 3.25 | 5.98 | 7.62 | 3.96 | 5.65 | 7.26 | 4.52 | 5.75 | 6.95 | **5.79** |
| Autumn | 4.41 | 6.16 | 8.06 | 2.41 | 5.49 | 6.79 | 4.26 | 6.10 | 7.58 | **5.92** |
| Load types' average | **6.06** | | | **5.58** | | | **5.90** | | | |

# Conclusions

Seasonal variations of the load model parameters: Seasonal range is [1.30 ~ 1.36] and [5.79 ~ 5.92], for Kp and Kq, respectively. The seasonal variation is negligible

Customer type effect on load model parameters: Kp values for domestic, industrial & mixed substations are 1.30, 1.48 and 1.22, respectively.

Comparison with the literature (reason for higher values of Kp and Kq):

Kp CLASS [0.67 ~ 2.11] and Lit. [0.62 ~ 2.00].
Kq CLASS [2.41 ~ 8.06] and Lit. [0.96 ~ 4.00].

New types of loads are increasing in the power network.
This causes the higher Kp and Kq values.

# Conclusions

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| Load model development | Load model validation | Voltage-demand relationship matrix |
|---|---|---|
| Load models based on 15 Electricity North West primary substations field measurements | Load models based on CLASS trial 1 data across entire annual cycle | 24 hour (48 x ½ hr) matrix for the whole year for 60 primary substations |

# QUESTIONS

# &

# ANSWERS

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**Dr Luis (Nando) Ochoa**
**Andrea Ballanti**

# Demand response quantification methodology and results

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# Outline

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| Voltage-led demand response | Demand response quantification methodology | Demand response results |
| --- | --- | --- |
| Concept | Load modelling<br>Voltage capability | Electricity North West area<br>UK |

# DR quantification: methodology



**Load model & profile**

Load response ($\Delta$P) to a generic voltage variation ($\Delta$V)

$\Delta P = f(\Delta V)$

**Voltage capability**

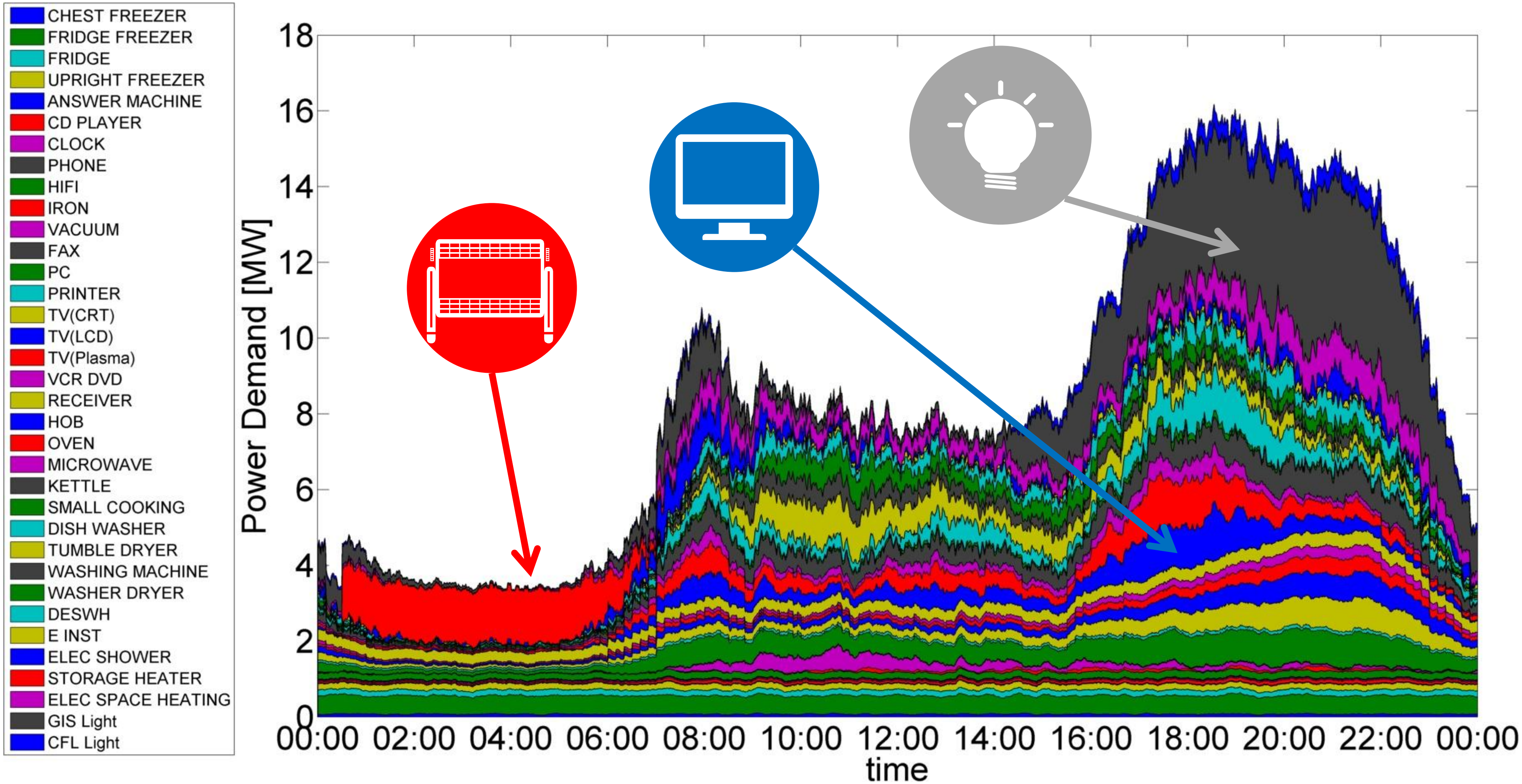
The extent to which the voltage can be changed

$\Delta Vmax$

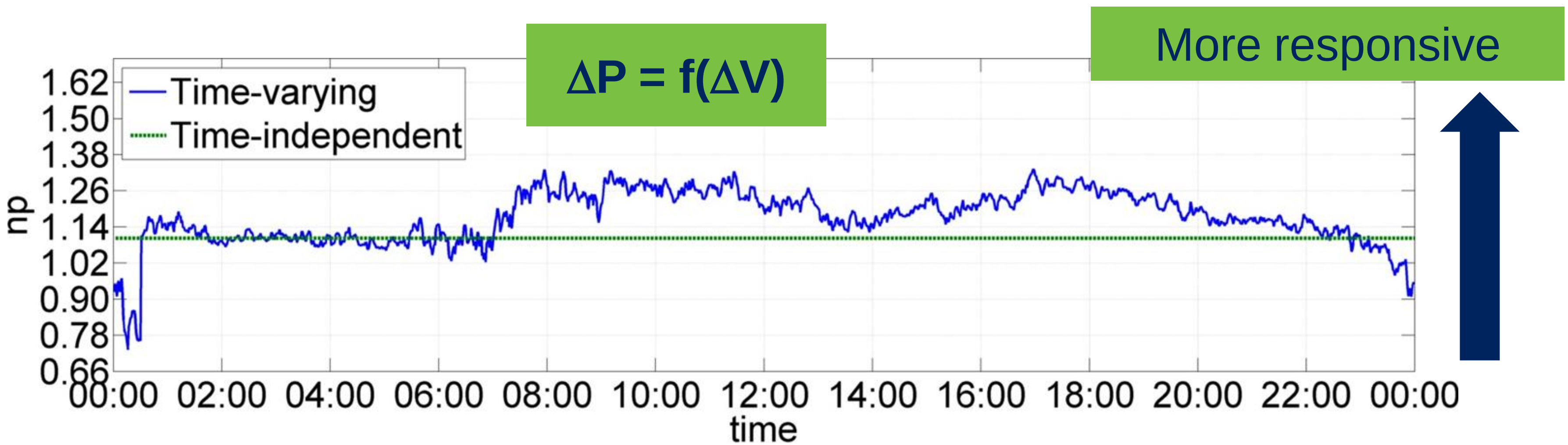
**Demand response**

$\Delta Pmax = f(\Delta Vmax)$

# Aggregated demand profile



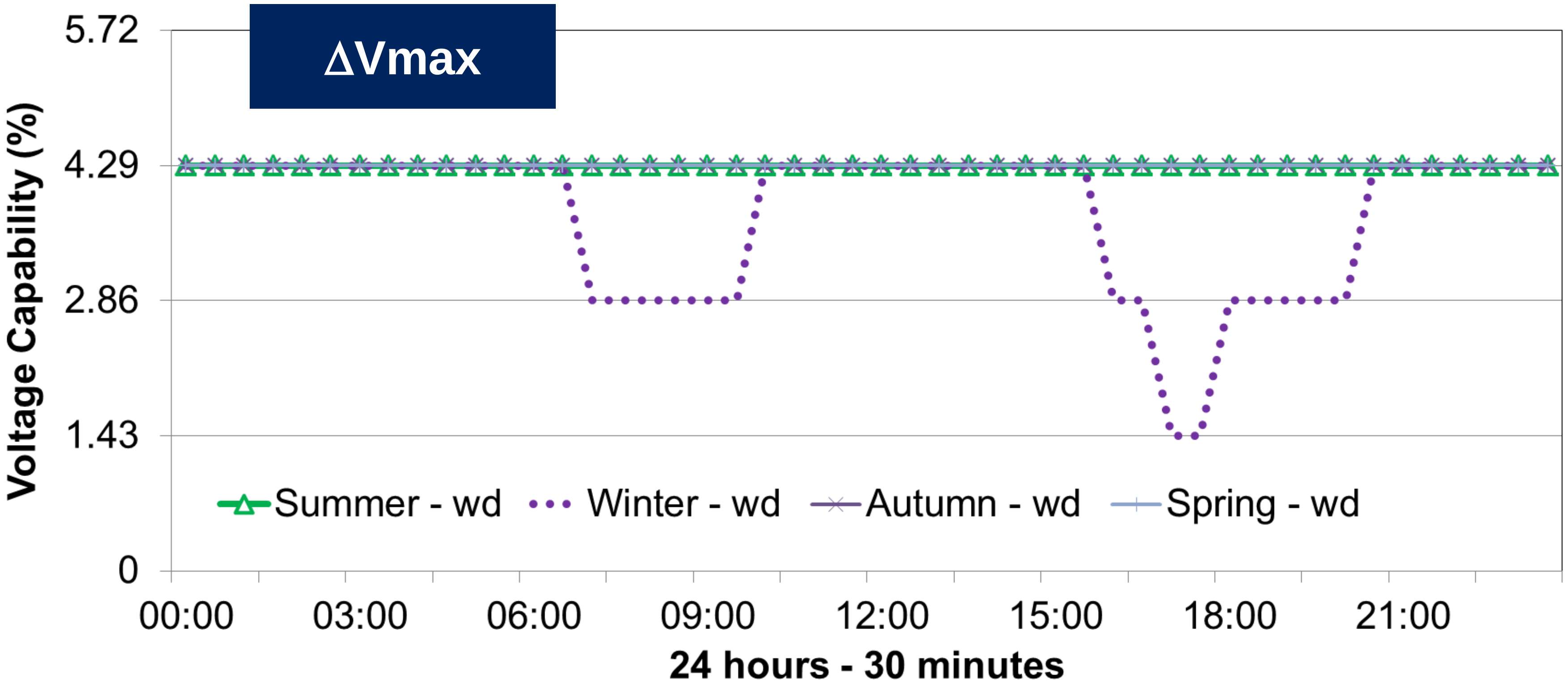
# Aggregated load model




$$P(t) = P_0(t)\left(\frac{V}{V_0}\right)^{np(t)}$$

Load composition varies
→ Responsiveness of the load varies

# Voltage capability: conservative




2.86% and 4.29% voltage reduction

**OK most of the time**

>99% customers compliant

# DR results: ENWL (residential)

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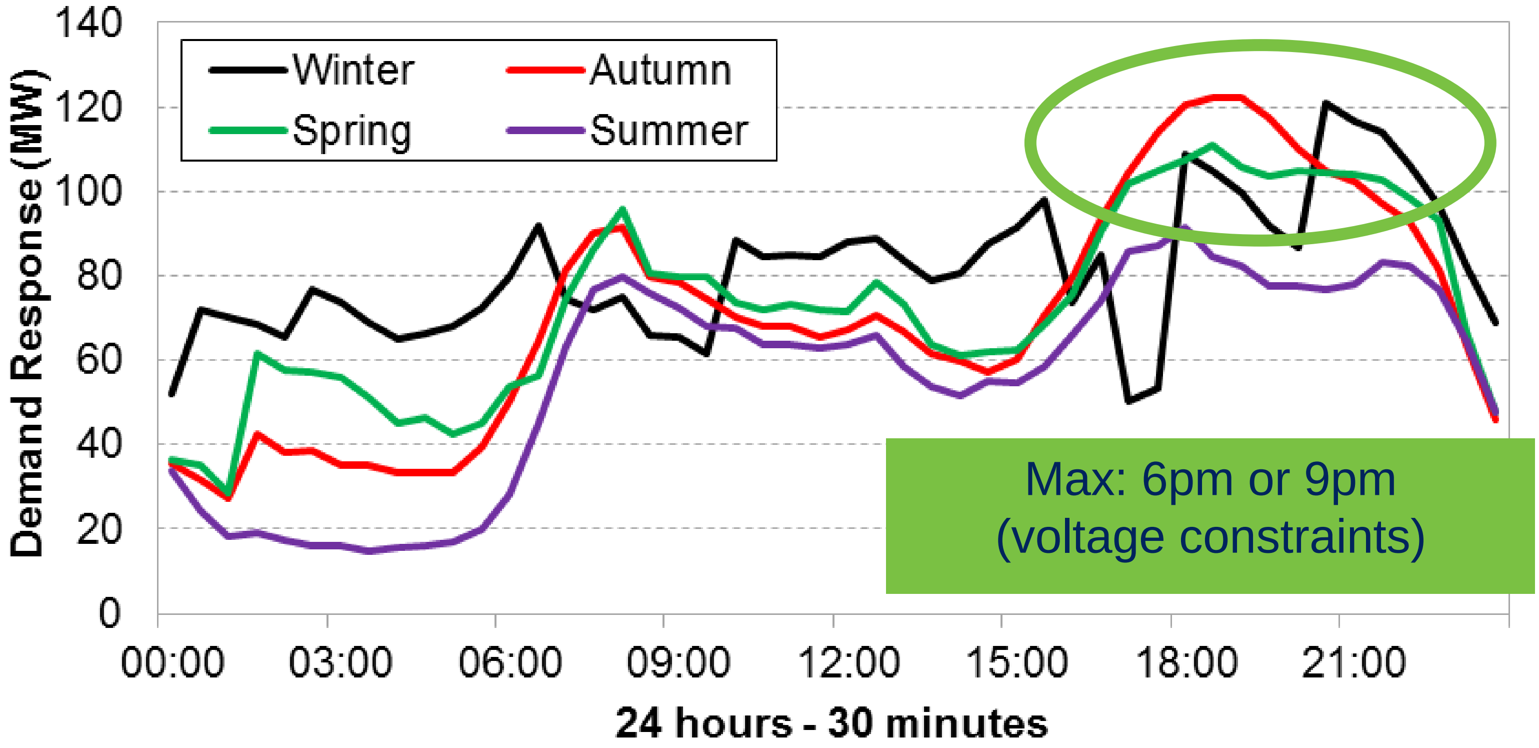
## ENWL (~4 GW) DR 15 to 120 MW




**Conservative** voltage capability
Min. summer night – Max. winter-autumn peak

# DR results: UK (residential)

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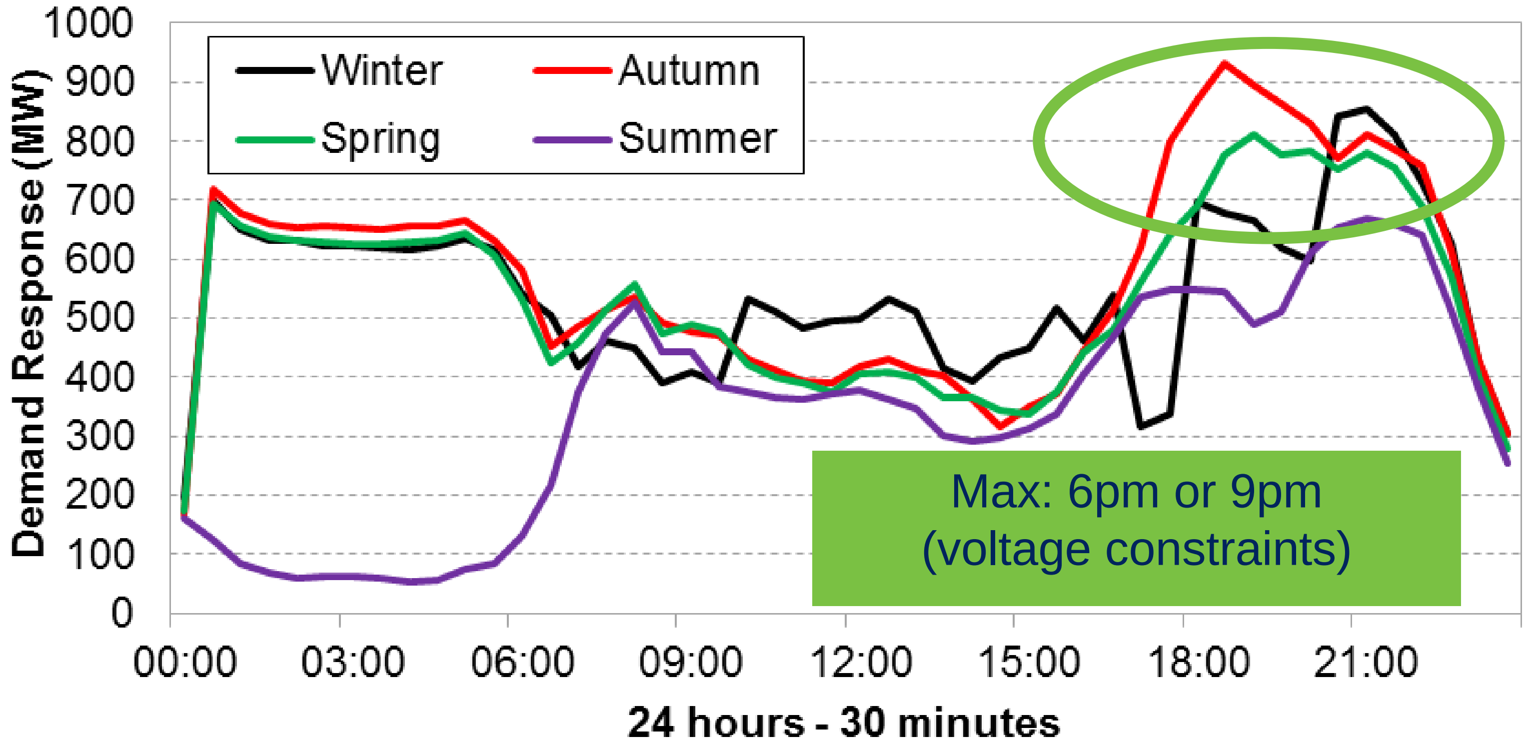
## UK (~60 GW) DR 63 to 930 MW




**Conservative** voltage capability
Min. summer night – Max. winter - autumn

# Measurement-based load models*

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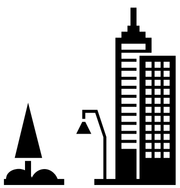

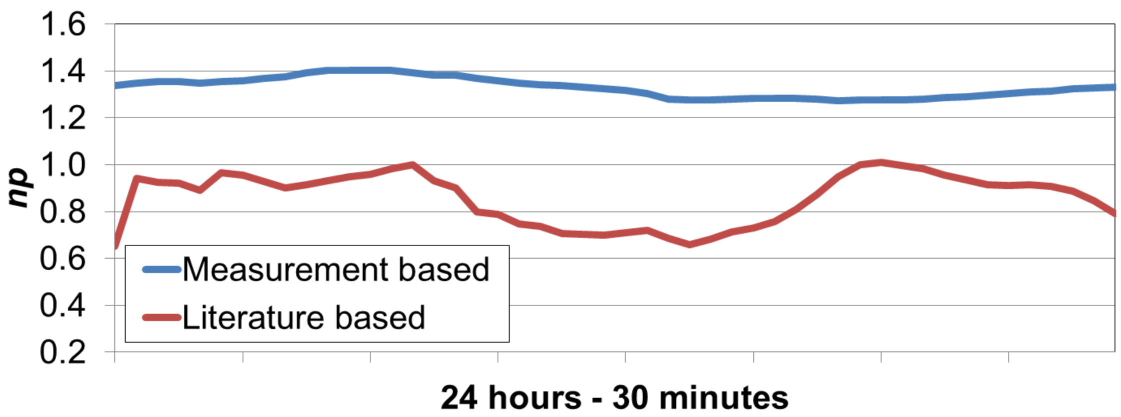


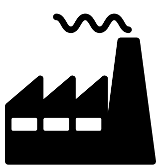

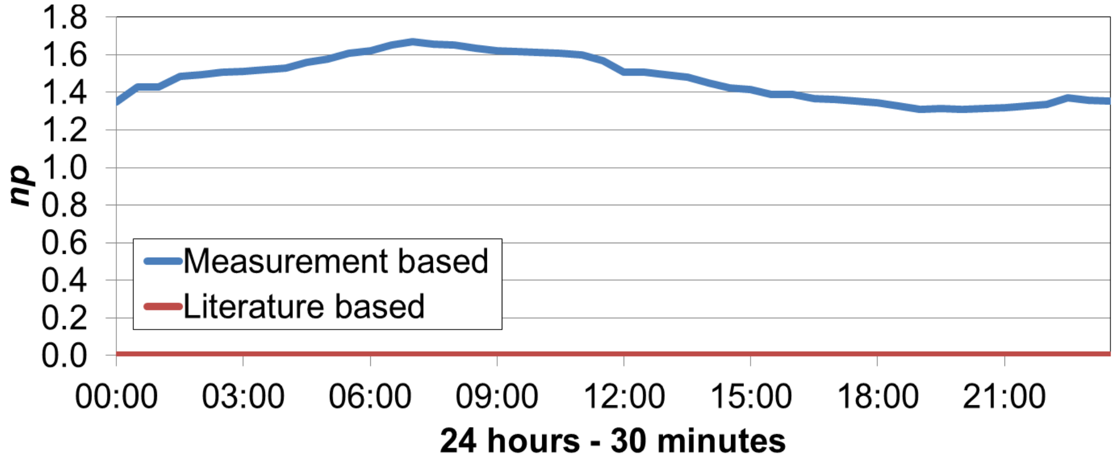


**Residential**

Good consistency

$$P_{pu} = V_{pu}^{np}$$

**Non-residential**

Neglected before

* Load models produced by Work Package 1 of the CLASS Project (Dr Hasan and Prof Milanovic, The University of Manchester)

# DR results: ENWL (full model)

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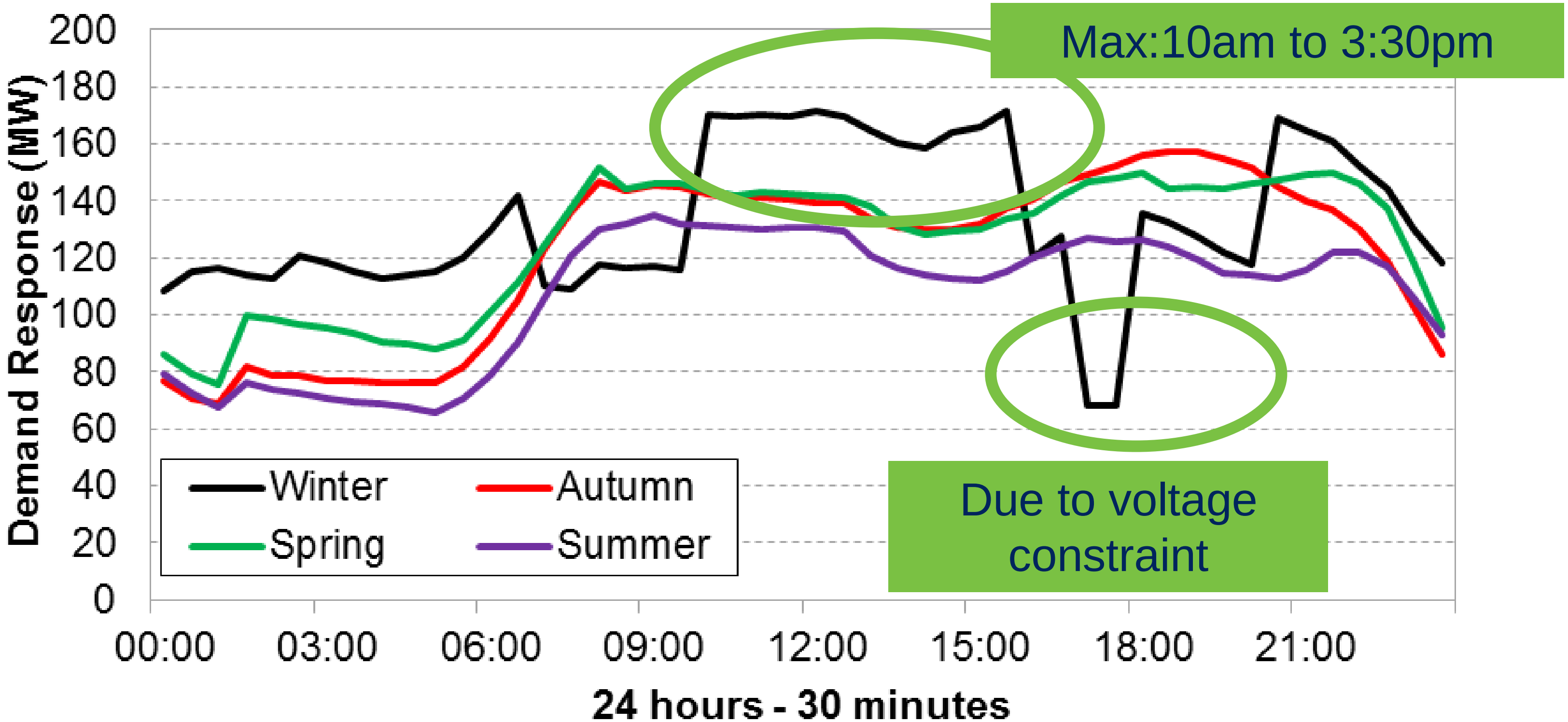
## ENWL (~4 GW) | DR 65 to 170 MW




**<u>Conservative</u>** voltage capability
Min. summer night – Max. winter at noon

# DR results: UK (full model)

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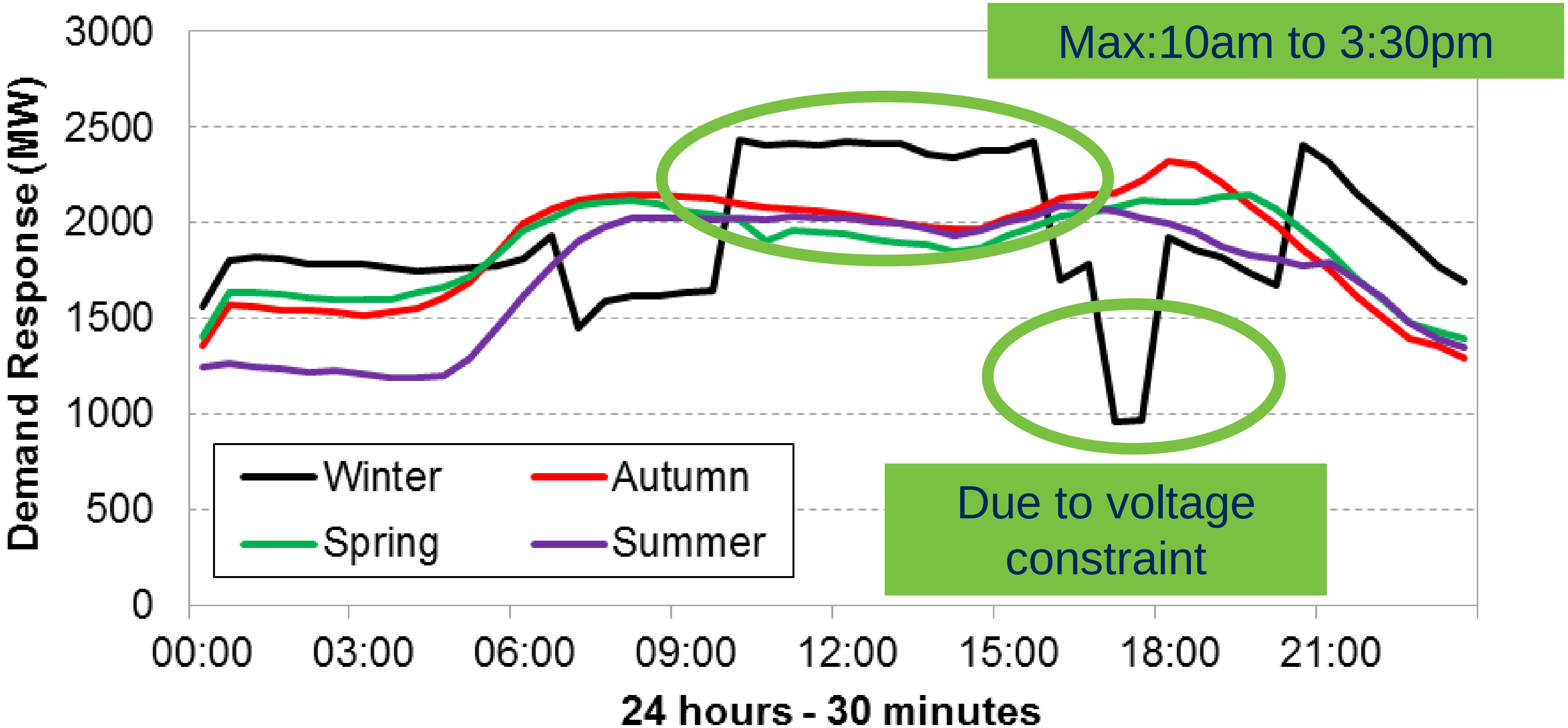
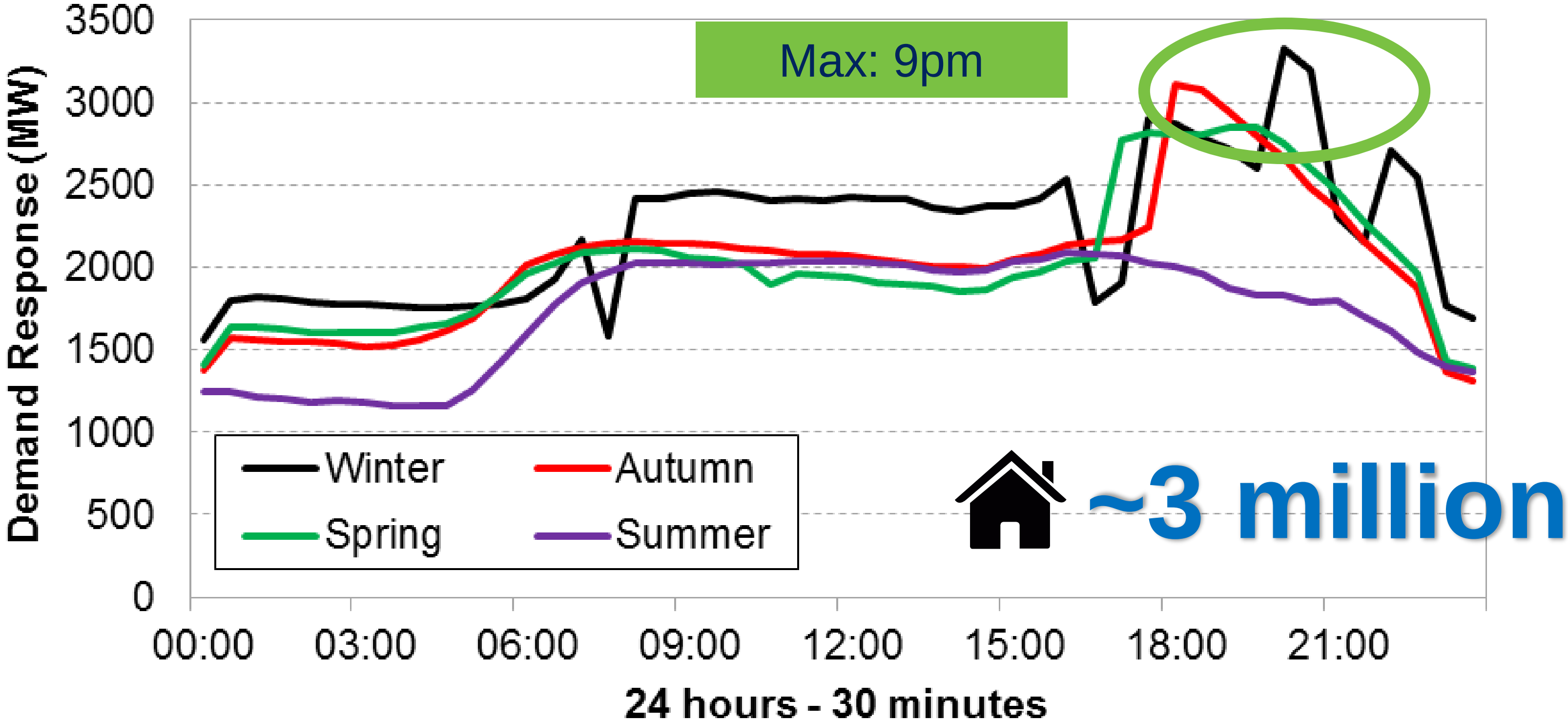
## UK (~60 GW) DR 1 to 2.5 GW




<u>**Conservative**</u> voltage capability
Min. winter ~6pm – Max. winter at noon

# DR results: UK (full model)

**UK (~60 GW)** **DR 1.2 to 3.3 GW**




**Optimistic** voltage capability
Min. summer night – Max. winter late evening

# Conclusions

| Key technical considerations | CLASS demand response can unlock 150MW+ for ENWL and 3 GW+ for the UK |
|---|---|
| Voltage interactions among EHV-HV-LV networks | Max in autumn (~6pm) or winter (~noon) |
| Measurement-based load models (WP1) | Min in summer night (~3-4am) or winter (~6pm) |
| Impacts on LV customers | |

# QUESTIONS

# &

# ANSWERS

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Dr Haiyu Li
Mr Linwei Chen
Mr Yue Guo

# Q absorption capability and availability study based on EHV network

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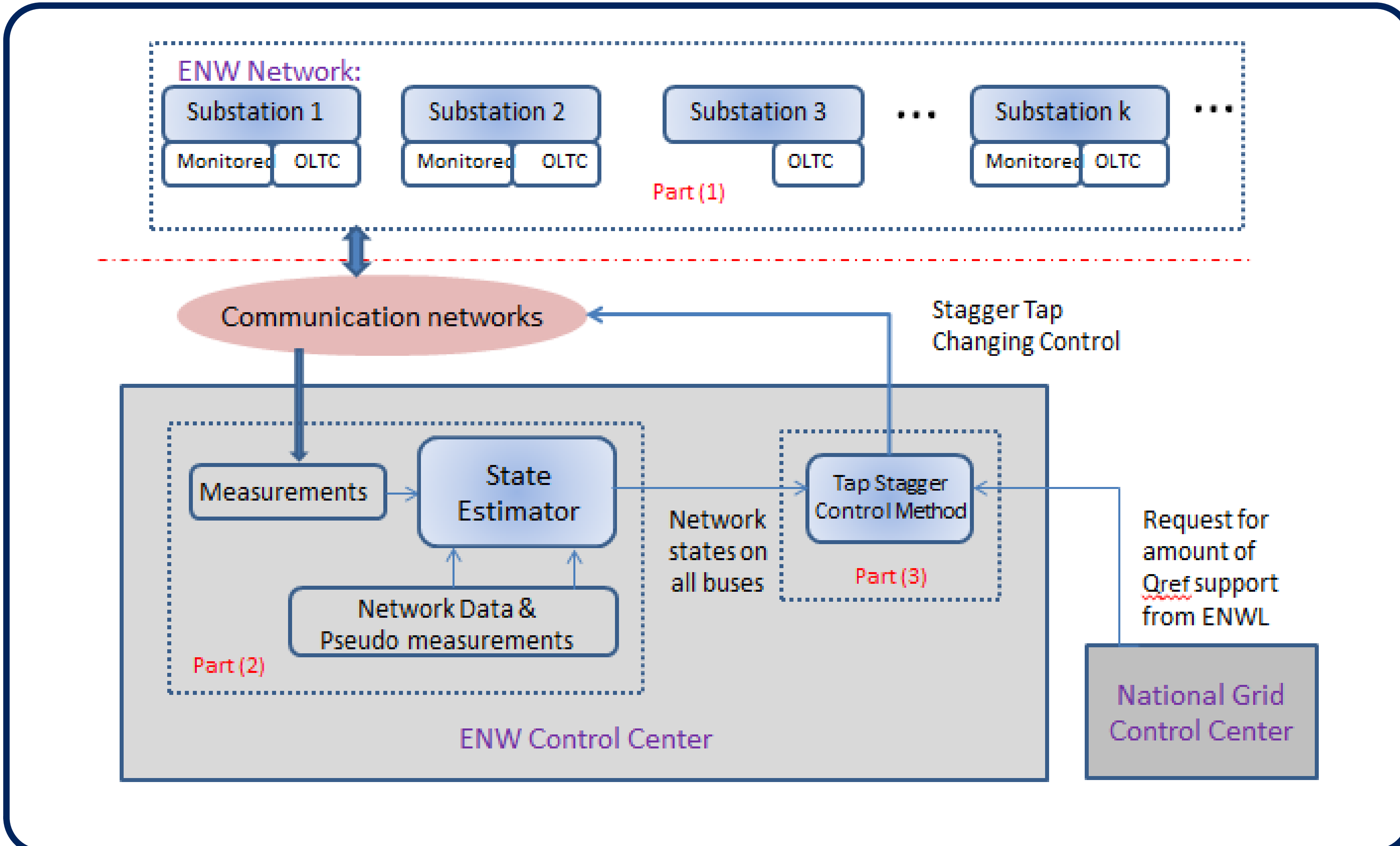
# Executive summary

| Aims | Techniques | Motivations | In addition |
|---|---|---|---|
| :Assess the Electricity North West reactive power absorption capability through the use of the tap staggering technique and validate the estimated results with site trial data | The operation of parallel transformers (at primary substations) with staggered taps can provide a means of absorbing reactive power | The aggregated reactive power absorption from many primary substation transformers could be used to mitigate the high voltage issues in the transmission grid during periods of low demand | Has also estimated and validated the demand reduction capability of the modelled EHV network using the load models |

# Closed-loop control system for the tap staggering operation



# Q capabilities in the two modelled networks

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## Fixed load: all loads of primary substations are set as their ratings

### Q capabilities in South Manchester network

| South Manchester GSP subnetwork consisting of 11 pairs of parallel transformers and 102 load buses | | | | | |
|---|---|---|---|---|---|
| Allowed Maximum Stagger Amount | original | 1 | 2 | 3 | 4 |
| P at 400kV Point (MW) | 164.6614 | 164.698 | 164.801 | 164.971 | 165.208 |
| Q at 400kV Point (MVAr) | 10.1624 | 10.7661 | 12.585 | 15.6134 | 19.8431 |
| Additional P losses (MW) | 0 | 0.0364 | 0.1397 | 0.3096 | 0.5462 |
| Additional Q absorption (MVAr) | 0 | 0.6037 | 2.4226 | 5.451 | 9.6807 |
| P losses per primary sub(MW/Sub) | 0 | 0.00331 | 0.0127 | 0.028145 | 0.04965 |
| Q absorbed per primary sub(MVAr/Sub) | 0 | 0.05488 | 0.22024 | 0.495545 | 0.88006 |

### Q capabilities in Stalybridge network

| Stalybridge GSP subnetwork consisting of 28 pairs of parallel transformers and 222 load buses | | | | | |
|---|---|---|---|---|---|
| Allowed Maximum Stagger Amount | original | 1 | 2 | 3 | 4 |
| P at 400kV Point (MW) | 433.64 | 433.746 | 434.041 | 434.5247 | 435.143 |
| Q at 400kV Point (MVAr) | 208.664 | 210.408 | 215.356 | 223.4832 | 233.842 |
| Additional P losses (MW) | 0 | 0.1057 | 0.401 | 0.8847 | 1.5029 |
| Additional Q absorption (MVAr) | 0 | 1.744 | 6.6923 | 14.8192 | 25.1776 |
| P losses per primary sub (MW/Sub) | 0 | 0.00378 | 0.01432 | 0.031596 | 0.05368 |
| Q absorbed per primary sub(MVAr/Sub) | 0 | 0.06229 | 0.23901 | 0.529257 | 0.8992 |

# Estimated Q capabilities for whole ENWL distribution network

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## Estimation based on South Manchester network

| Estimated Q Absorption Capability for the whole ENWL network based on South Manchester GSP subnetwork study | | | | | |
|---|---|---|---|---|---|
| Allowed Maximum Stagger Amount | original | 1 | 2 | 3 | 4 |
| P loss across ENWL(MW) | 0 | 1.17142 | 4.4958 | 9.963491 | 17.5777 |
| Q Capability across ENWL(MVAr) | 0 | 19.4282 | 77.9637 | 175.4231 | 311.543 |

## Estimation based on Stalybridge network

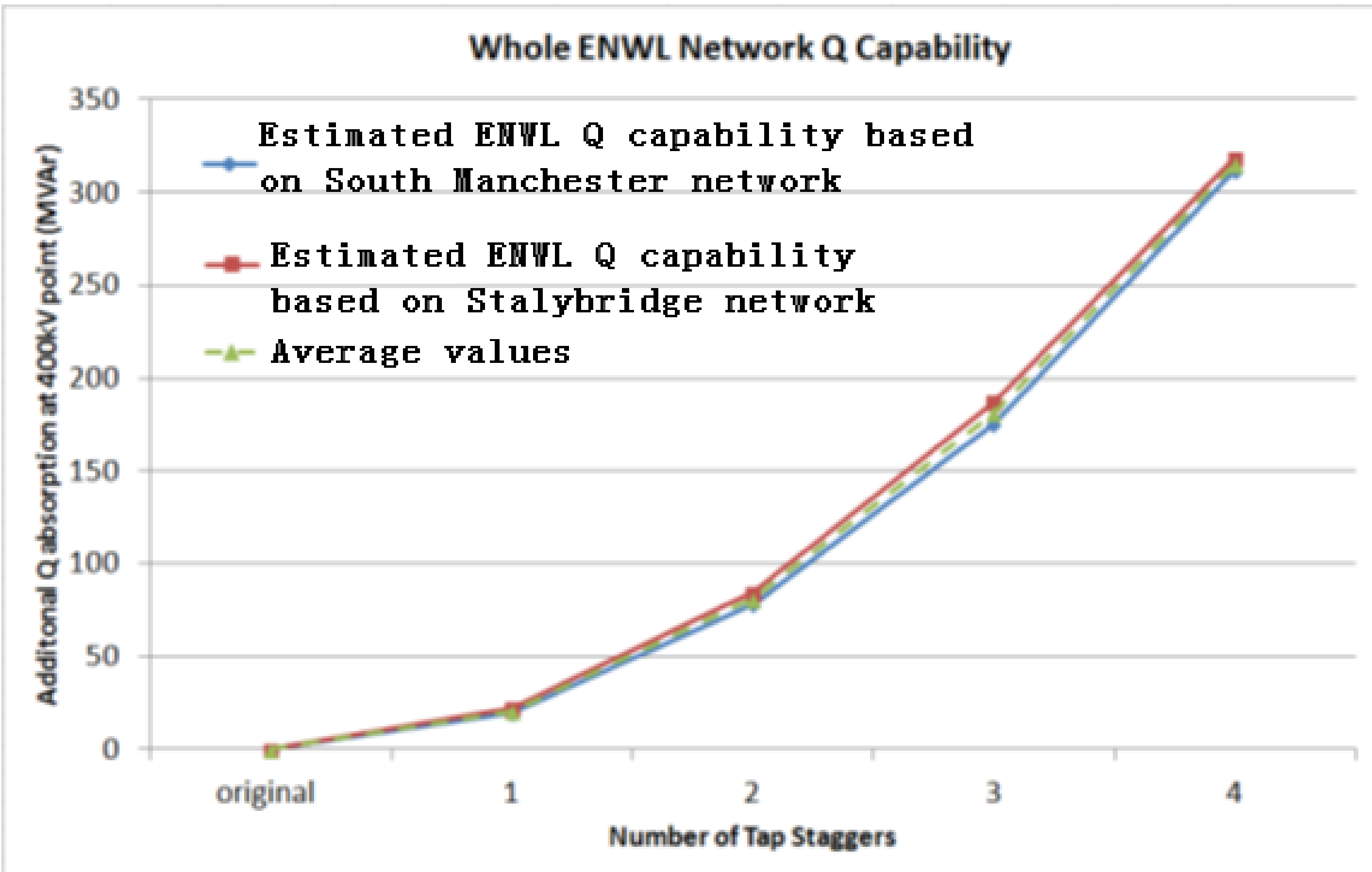
| Estimated Q Absorption Capability for the whole ENWL network based on Stalybridge GSP subnetwork study | | | | | |
|---|---|---|---|---|---|
| Allowed Maximum Stagger Amount | original | 1 | 2 | 3 | 4 |
| P loss across ENWL(MW) | 0 | 1.33635 | 5.06979 | 11.18514 | 19.001 |
| Q Capability across ENWL(MVAr) | 0 | 22.0491 | 84.6098 | 187.357 | 318.317 |

## Estimation based on the average values of the two network

| Averaging the Estimated Q Absorption Capability based on the Two Sub-Networks studies | | | | | |
|---|---|---|---|---|---|
| Allowed Maximum Stagger Amount | original | 1 | 2 | 3 | 4 |
| P loss across ENWL(MW) | 0 | 1.25388 | 4.78279 | 10.57431 | 18.2893 |
| Q Capability across ENWL(MVAr) | 0 | 20.7387 | 81.2867 | 181.3901 | 314.93 |

# Estimated Q capabilities for whole ENWL distribution network

Difference between 3 estimations is very small



# Reactive power capability study with load profiles

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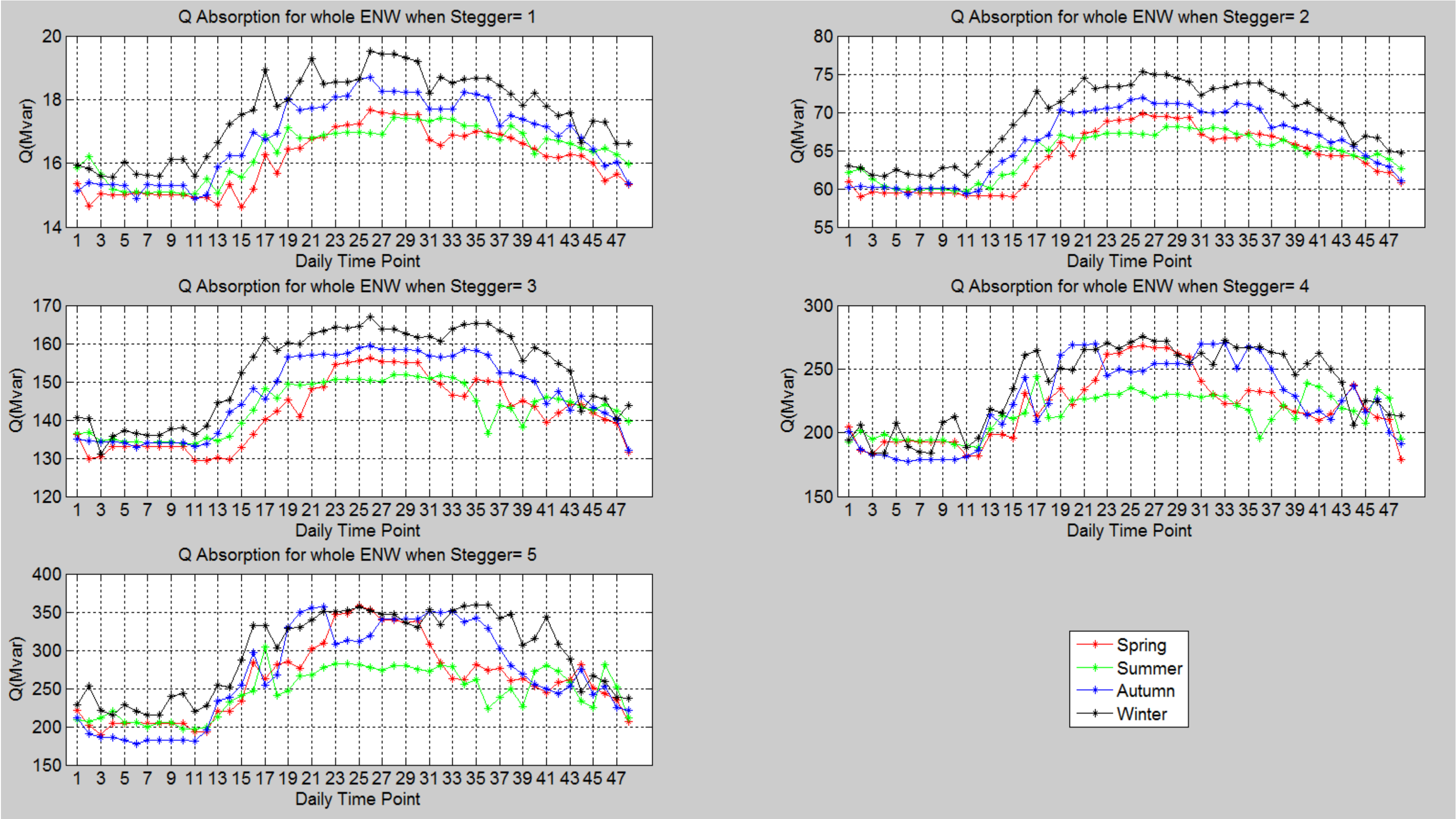
## The Q absorption capability curves of 4 seasons for whole ENW distribution network for the number of tap stagger form 1 to 5



# Reactive power capability study with load profiles

## The minimum and the maximum of Q absorption capability and P losses within a day for four seasons in whole Electricity North West network

**Extra Q absorption caused by tap stagger**

| Max No. of staggered taps | Stagger=1 | | Stagger=2 | | Stagger=3 | | Stagger=4 | | Stagger=5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| (MVAr) | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max |
| Spring | 14.63 | 17.66 | 58.93 | 69.8 | 129.44 | 156.12 | 178.98 | 267.89 | 189.42 | 358.27 |
| Summer | 15.04 | 17.43 | 59.71 | 68.12 | 133.76 | 151.77 | 188.61 | 244.26 | 196.48 | 303.72 |
| Autumn | 14.89 | 18.7 | 59.21 | 71.91 | 132.13 | 159.33 | 177.48 | 270.09 | 177.48 | 356.22 |
| Winter | 15.57 | 19.53 | 61.62 | 75.3 | 131.2 | 166.99 | 184.1 | 275.14 | 215.43 | 359.41 |

**Extra P losses caused by tap stagger**

| Max No. of staggered taps | Stagger=1 | | Stagger=2 | | Stagger=3 | | Stagger=4 | | Stagger=5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| (MW) | Min | Max | Min | Max | Min | Max | Min | Max | Min | Max |
| Spring | 0.504 | 0.675 | 2.656 | 3.218 | 6.397 | 7.619 | 8.732 | 13.438 | 9.803 | 18.015 |
| Summer | 0.539 | 0.705 | 2.72 | 3.16 | 6.535 | 7.426 | 9.433 | 12.03 | 10.156 | 14.691 |
| Autumn | 0.634 | 0.86 | 2.984 | 3.616 | 6.795 | 8.256 | 9.436 | 14.104 | 9.436 | 18.394 |
| Winter | 0.616 | 0.807 | 3.002 | 3.561 | 6.797 | 8.246 | 9.458 | 13.904 | 11.195 | 18.183 |

The Q absorption capability and corresponding P losses for whole Electricity North West network can be expanded to the entire GB level by multiplying a scaling factor of 11.

# Validation using single primary substation

**Objective substation:**
Dickinson St

**Measure points:**
primary side of the transformers

| ΔQ(MVAr) | Stagger=1 | Stagger=2 | Stagger=3 |
|---|---|---|---|
| Trial Data | 0 | 0.2 | 0.4 |
| Model Data | 0.0445 | 0.1780 | 0.4011 |

As for stagger=1, no extra Q absorption has been observed in trial, because the supposed value of 0.0445 MVAr form the model is smaller than the trial measurement resolution (ie 0.1MVAr)

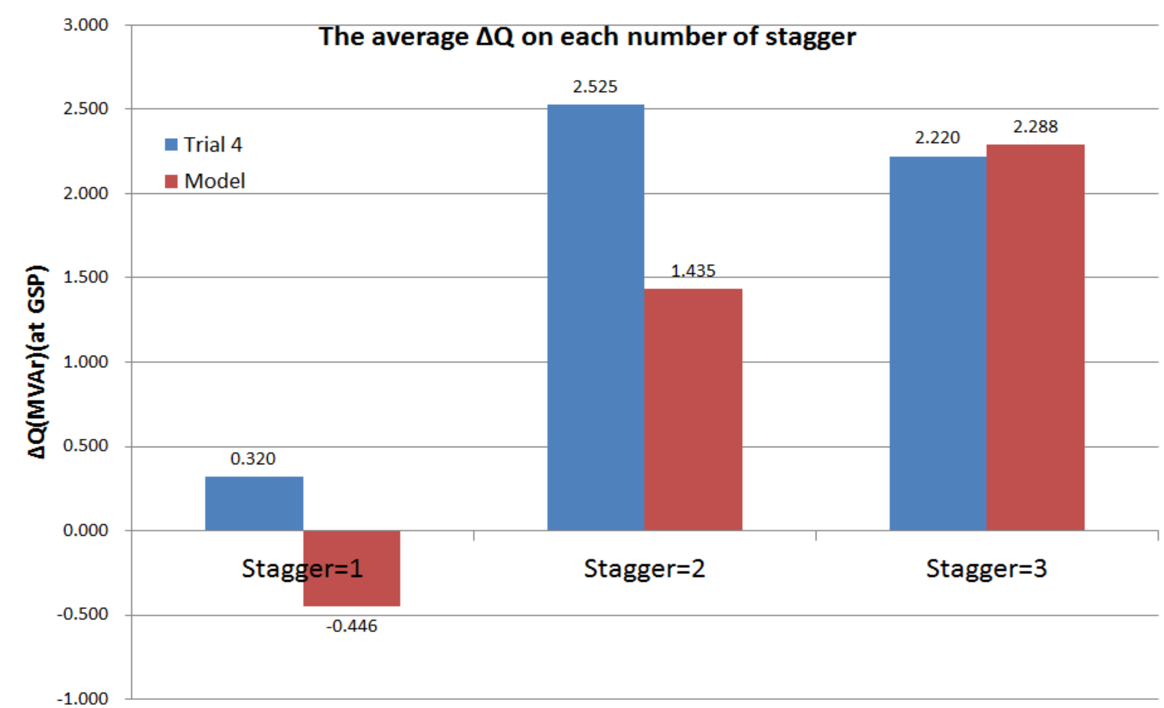
For stagger=2, the model result 0.178 MVAr can round off to 0.2 considering about the site measurement resolution which matches the result from site trial.

For stagger=3, the trial result of 0.4MVAr which matches the model result of 0.4011MVAr with a small error of 0.275%.

# Validation using the whole Stalybridge GSP network

**Objective substations:** 7 CLASS substations in Stalybridge network

**Measure points:** GSP of the Stalybridge network




For stagger =3, the results match very well between trial and model with a small error of 3.06%.

However for stagger=1 and stagger=2, because the extra Q absorption values caused by tap stagger are much smaller than that for stagger=3, the measured Q differences at GSP for these two scenarios will be more badly affected by the base load changes.

# 24-hour 4-season P reduction capability on Stalybridge network

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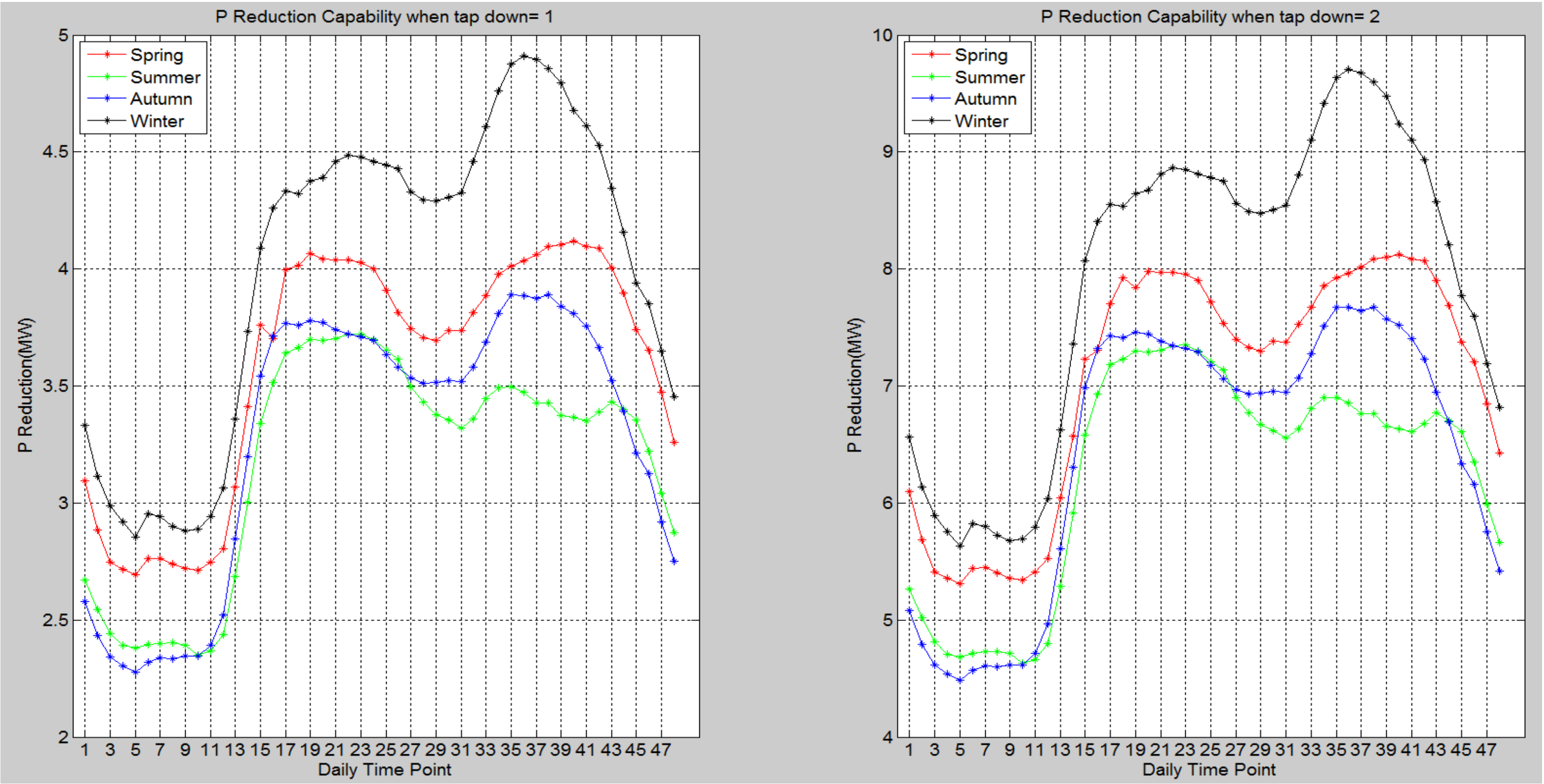
According to the study, in order to avoid violating the voltage at customer side, the maximum of two positions are allowed to tap down




P reduction capability for whole Stalybridge network in four seasons

# Summary of the main achievements

1. A closed-loop control system for the tap staggering operation has been proposed

4. Q absorption capability of the ENW network over the 24-hour (48 × ½ hour) period in a day and in four seasons has been investigated

2. Two representative EHV networks of Electricity North West 'South Manchester GSP' and 'Stalybridge GSP' have been modelled in OpenDSS for simulation

5. The model's simulation results have been validated against the site trial data

3. Annual load profiles for all primary substations in the Stalybridge network have been developed based on real monitoring data

6. In addition, the demand reduction capability of the modelled Stalybridge network has been investigated using the load models

# QUESTIONS

# &

# ANSWERS

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# Tea break

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Prof Joe Spencer
Prof. Zhongdong Wang
Dongmiao Wang

# Asset health

UNIVERSITY OF LIVERPOOL

MANCHESTER 1824
The University of Manchester

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# Aim

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Analyse the impact of CLASS techniques on the health of 33/11 (or 6.6) kV primary substation transformer assets

Transformer assets

| Transformer main tank | Transformer tap changer |
|---|---|
| University of Manchester | University of Liverpool |
| Preliminary work of CLASS trial tests | Installation of monitoring systems |
| Data analysis for main tank | Data analysis for tap changer |
| Assessment of impacts on main tank | Assess impacts on tap changer |

# Assessment of main tank health

| Preliminary work of CLASS trial tests | Data analysis for main tank |
| --- | --- |
| The health of the main tank is only concerned with transformer tripping and tap staggering<br><br>Suggestions on data monitoring and device installation | The current of an operating transformer will double following the trip of the other parallel transformer<br><br>The maximum current difference due to tap staggering is 150A if the load power factor is above 0.9 according to monitoring data<br><br>The analysis of oil data sampled before and after trials shows that it is unlikely to correlate the change of oil test results with CLASS techniques |

# Assessment of main tank health

## Thermal modelling

**Thermal Model Inputs**
- Ambient Temperature
- Load
- Thermal Parameters
- Cooler Setting

**Hot-spot Temperature Calculation**
- Use difference equations in IEC 60076-7 to calculate the hot-spot temperature

**Ageing Rate Calculation**
- Use Arrhenius equation
- Incorporate the paper's ageing mechanism
- Incorporate paper's moisture accumulation effect

**Estimation of Paper Life Expectancy**
- Use DP reduction model
- DP starts from 1000
- DP decrease to 200 as end-of-life criteria

## Health assessment

Calculate paper insulation life expectancies based on worst-case scenarios of future load

Impact of tap staggering on main tanks are negligible as the load increase due to staggered taps can be regarded as the normal variation of load profile

Tripping could be detrimental to main tank health and system safety if happening at high peak load

# Assessment of tap changer health

## Installation of monitoring system

Units installed at three primary substations monitoring vibration, external temperature of the oil tank,

ambient temperature, currents, voltages, power

Oil samples from the tap changer tank were analysed with an optical technique rather than conventional DGA to assess the localised immediate degradation in the oil

An assessment of additional contact wear was also undertaken to determine the impact of the CLASS switching operations

## Data analysis for tap changer

The vibration signals were analysed to extract information from complex signals taken over a number of months. This also allowed comparison of tap events for CLASS and non CLASS. The comparison did not show any adverse effects from the CLASS operations

Pre and post vibration signatures from the transformer did not show any unusual responses. Although there were different vibration signatures noted pre and post tap.

.

# Assessment of tap changer health

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| Data analysis for tap changer | Assessment of impacts on tap changer |
| --- | --- |
| Some degradation in the tap changer oil was found but the overall effect is judged to be negligible<br>An analysis of wear on the contacts within a tap changer mechanism highlighted that provided the current is within “normal” load levels for the tap changer then the extra wear can be included in the normal count for maintenance purposes | Overall the impact of the CLASS type of operation has some effect on the tap changer in that there are additional switching “counts” that need to be noted for wear<br>The worse case situation is when there is additional current flowing due to the CLASS operation, this increases contact wear and further shortens the time between maintenance schedules |

# Recommendations

| For main tank maintenance | For tap changer maintenance |
| --- | --- |
| A loading guide is established by setting a load limit, within which a certain type of transformer can be safely tripped under different ambient temperatures without causing any temperature violations in the substation | To minimise maintenance, ensure that the number of extra tap changes are not significant compared to the number of normal daily tap changes |

# QUESTIONS

# &

# ANSWERS

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**Ruth Wood**

Carbon assessment

TyndallManchester

Climate Change Research

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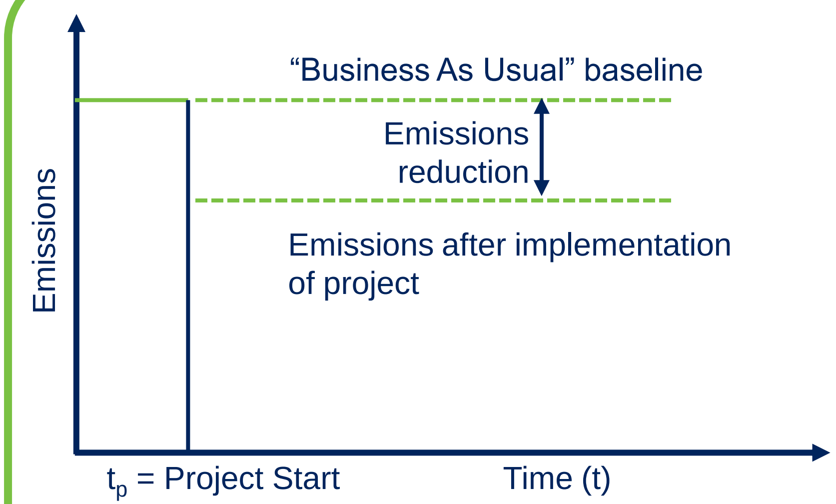
# What are the carbon impacts of CLASS?

Multiple services benefit the network

What are CLASS carbon impacts vs traditional methods?




Approach based on UN Clean Development Mechanism

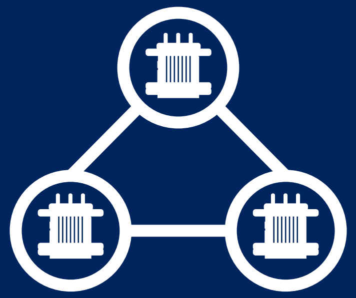
$$CI_{Service} = \sum_{t=t_p}^{n} BE_t - CE_{Service,t}$$

# Business as usual baselines

## How will the three CLASS services be otherwise provided?

**Peak demand reduction**
Reinforce substations with upgraded transformers

**Demand response**
Continue with balancing units available to National Grid



**Reactive power**
Deploy additional STATCOMs (Static Synchronous Compensators) on the network

# Headlines

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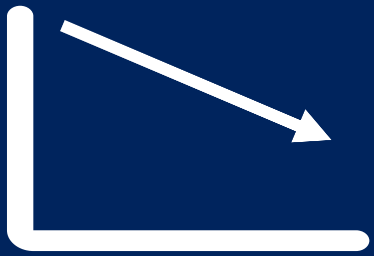
CLASS
Customer Load Active System Services

CLASS could reduce the carbon impact of demand response (DR) and reactive power (RP) provision substantially


The total benefits from both the DR and RP ancillary services could be as much as 116,000 $tCO_{2e}$ per annum



The continuous operations impacts category provides the dominant DR and RP carbon benefit

However, when reinforcement is deferred due to peak demand reduction losses are significant – as is the carbon penalty if the grid margin is provided by CCGTs

# What are the carbon impacts of CLASS?

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## Scope and classification of impacts

**"Asset carbon"**
discrete measure of emissions embodied in materials and construction of the equipment

**"Operations carbon"**
the carbon associated with demand reduction and losses that arise during operation - based on current and projected UK grid carbon intensity (marginal / balancing services)

**"Facilitated reductions"**
indirect benefits from facilitating the uptake of low carbon technologies due to quicker availability of services (see written report)

# Asset carbon profiles

Carbon impact estimated at 33kg $CO_2e$

Four orders of magnitude less than transformer reinforcement

ICE v2.0 emissions factors for consistency

## CLASS autonomous substation controllers

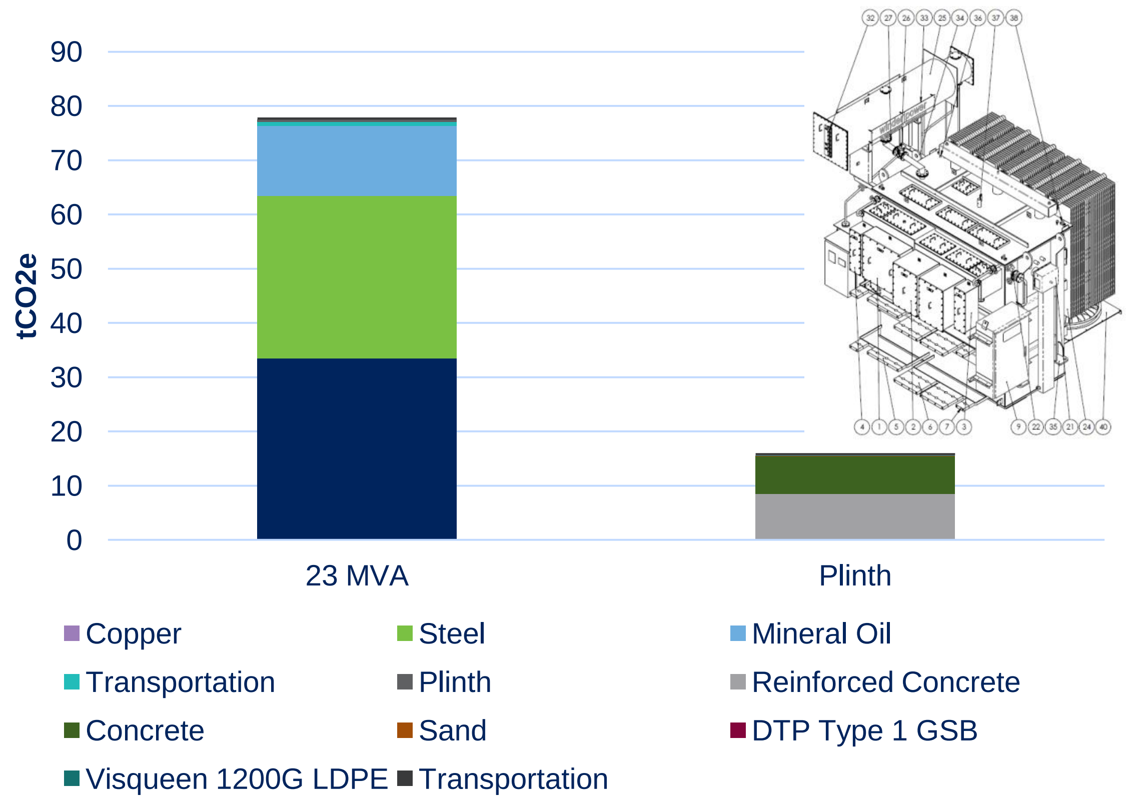
# Asset carbon profiles

Metal content of transformers not the only impact of reinforcement

Impacts comparable to literature estimates Harrison et al (2010) and Turconi et al (2014)

Asset carbon benefits are deferral and not permanent benefit

## PDR: Carbon embodied in 23MVA transformer



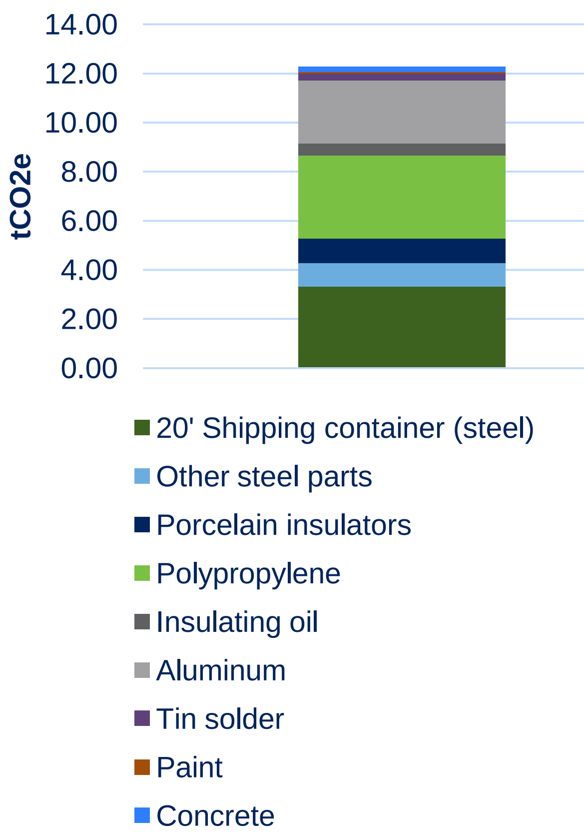
# Asset carbon profiles

No prior example of STATCOM carbon footprint in literature

Proxy developed: HV capacitor bank, Alaviitalaa & Mattila (2015)

ICE v2.0 emissions factors for consistency

## RP: Carbon embodied in containerised STATCOM





PCS 6000 STATCOM: +/- 12.5 MVAr unit

# Asset carbon approach: PDR

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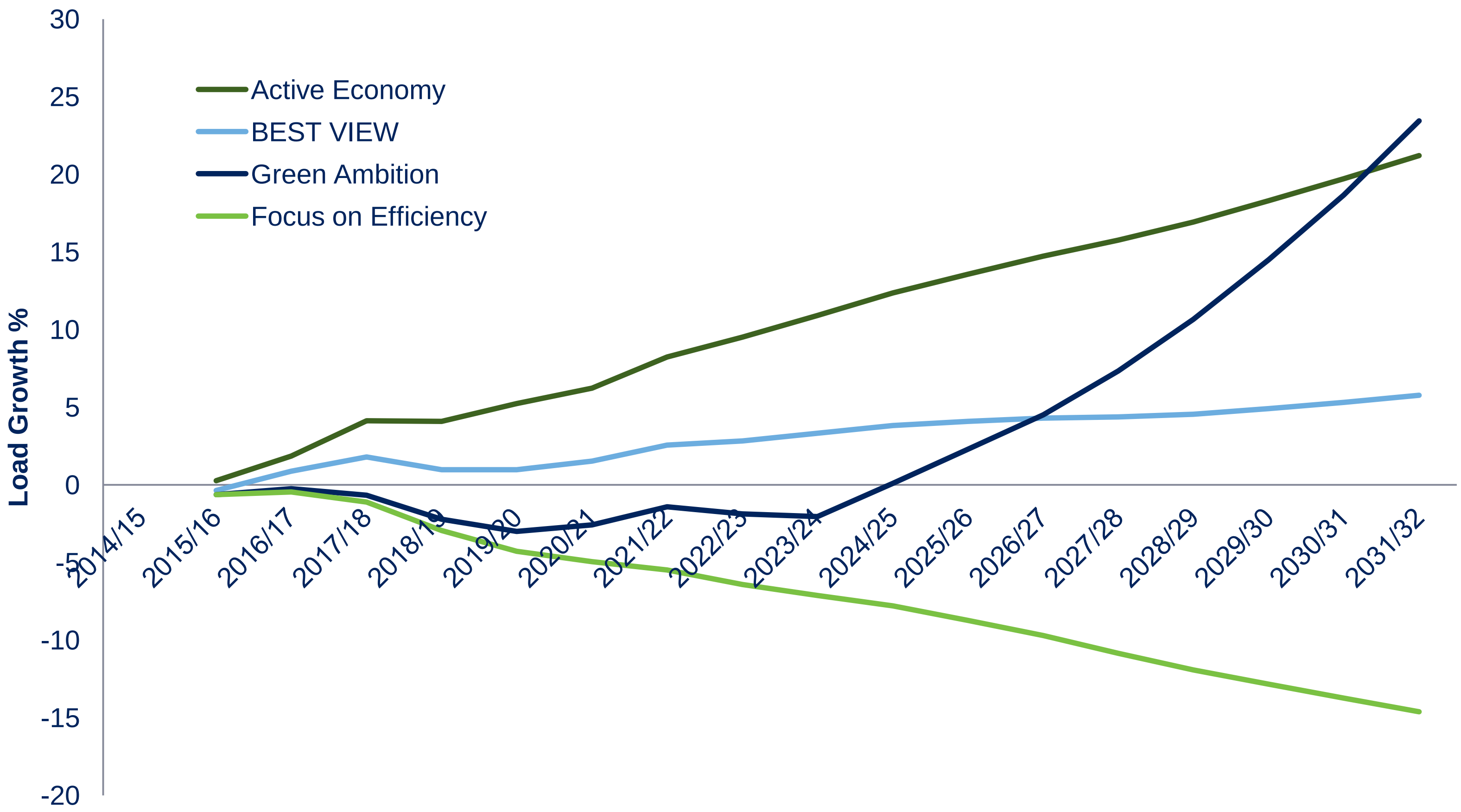
## Load growth scenarios



# Asset carbon approach: PDR

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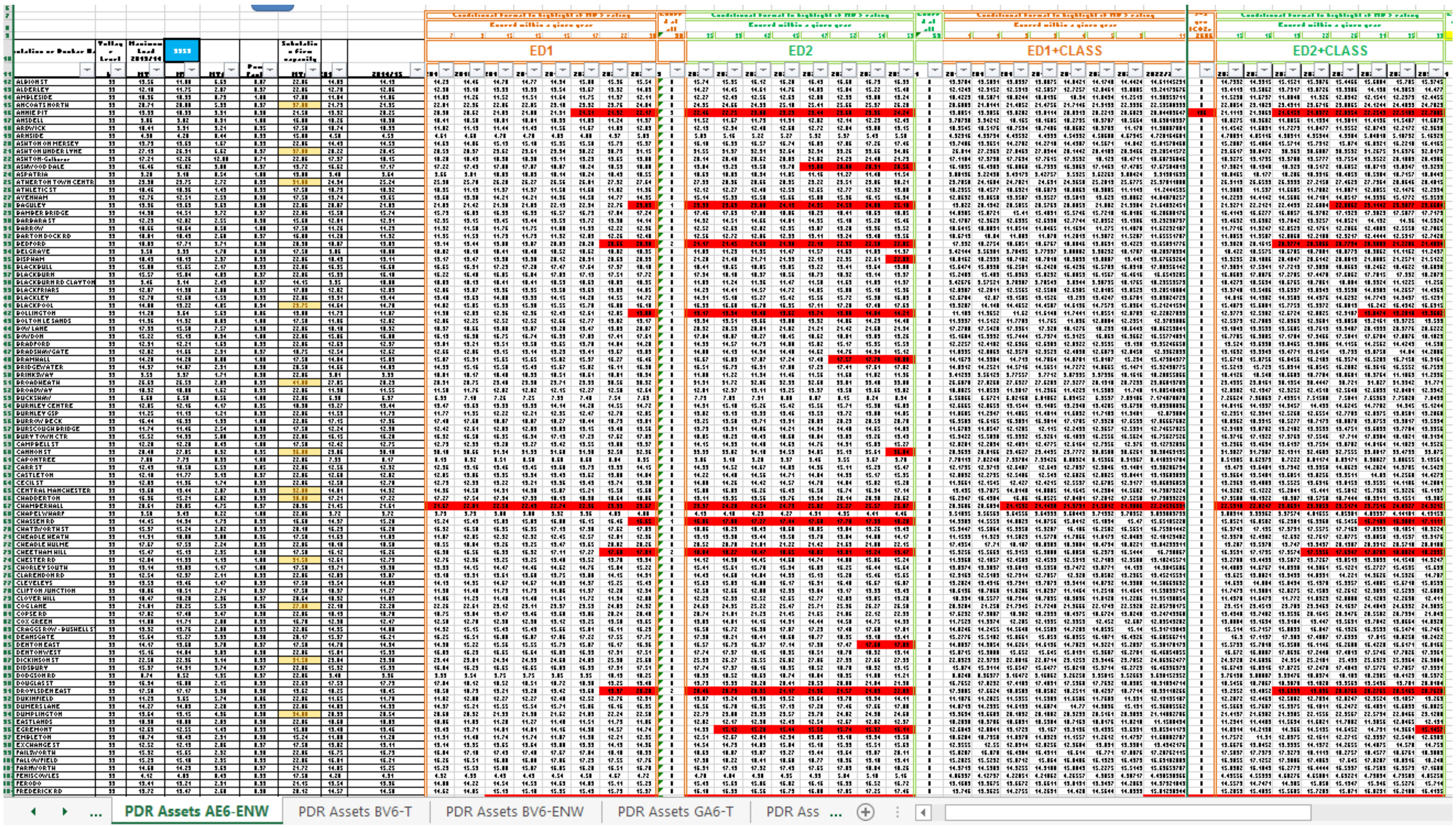
## Reinforcement modelling – Substation reinforcement deferred



# Asset carbon approach: PDR

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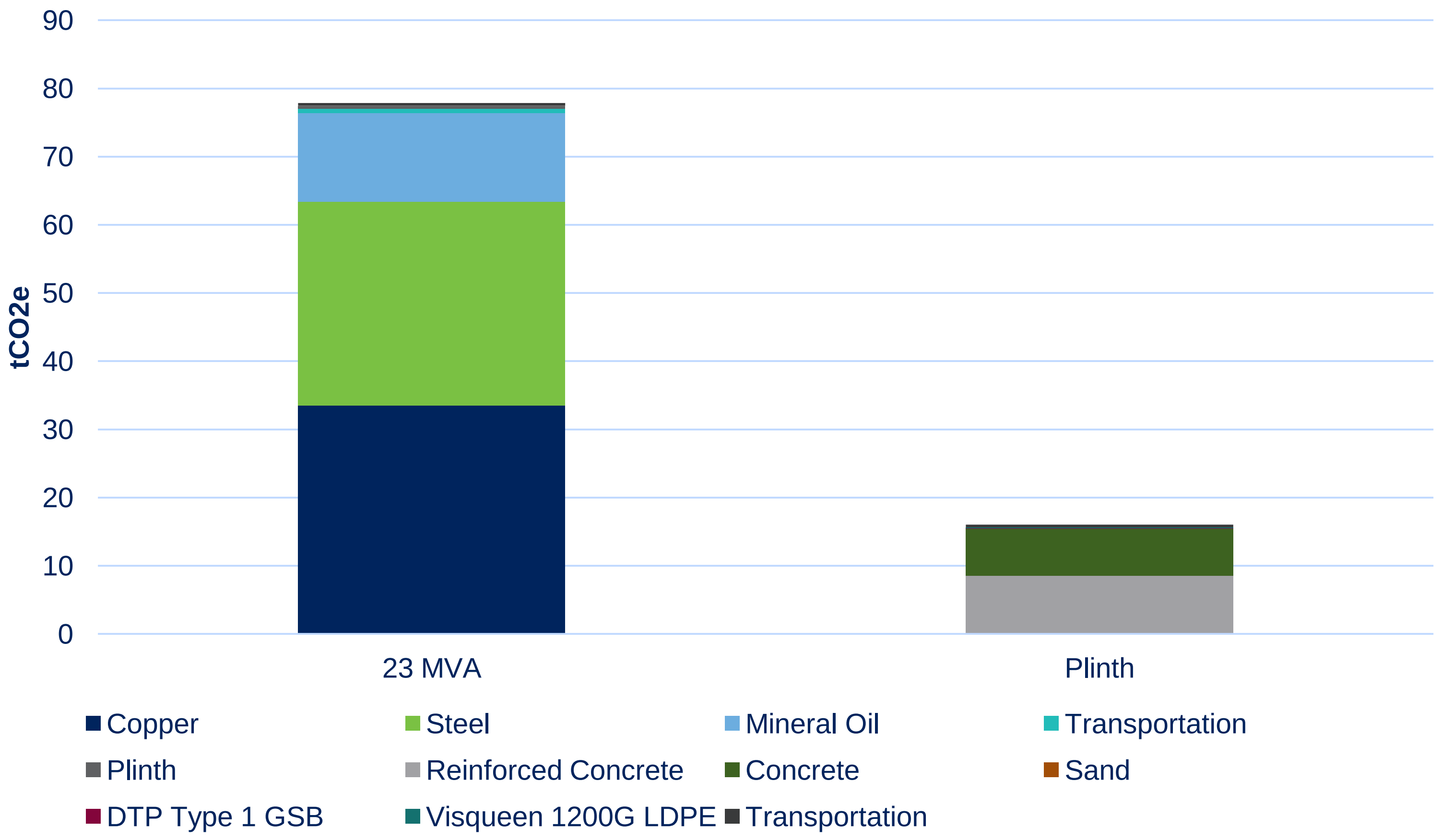
## Carbon embodied in 23MVA transformer installation



# Asset carbon approach: PDR

# Asset carbon findings: PDR

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Across the 60 circuits and four demand growth scenarios, asset carbon deferred for up to 8 years is up to 2600 $tCO_2e$

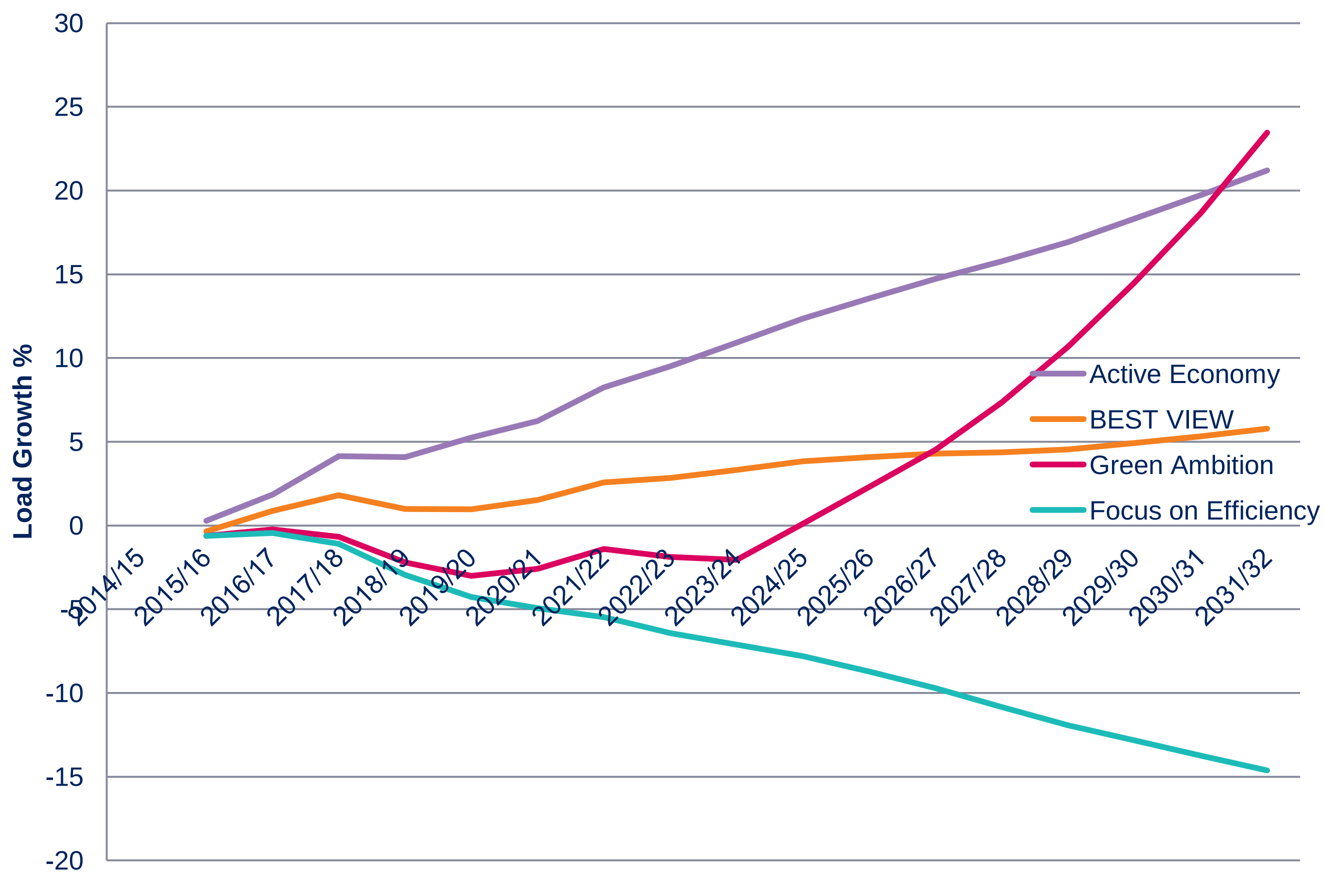
Similar picture for whole ENW network, with greater benefit in ED2

## Peak Demand Reduction: asset carbon deferral

| ED1 | Number of substations where reinforcement is deferred >=3 yrs | Years deferred for >=3 yrs | Deferred assets tCO2e |
|---|---|---|---|
| Active Economy | 5 | 24 | 927 |
| Best View | 3 | 19 | 558 |
| Green Ambition | 1 | 8 | 186 |
| Focus on Efficiency | 1 | 4 | 186 |
| | | | |
| ED2 | Reinforcement Deferred >=3 yrs | Years Deferred >=3 yrs | Deferred assets tCO2e |
| Active Economy | 14 | 66 | 2602 |
| Best View | 4 | 30 | 745 |
| Green Ambition | 3 | 9 | 558 |
| Focus on Efficiency | 0 | 0 | 0 |

# Operations carbon approach: PDR

## Load growth scenarios



# Operations carbon approach: PDR

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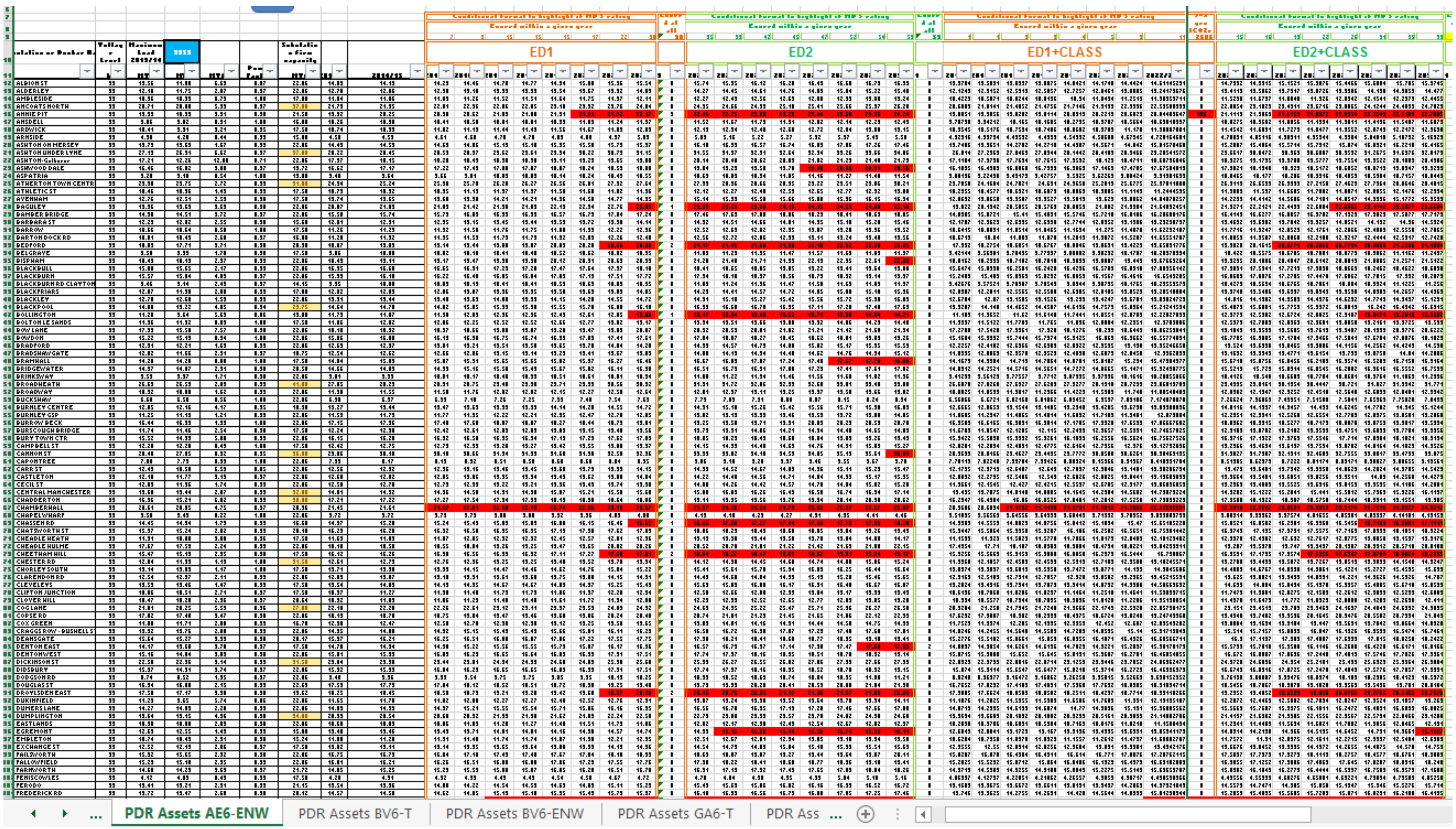
## Reinforcement modelling – Years deferred by CLASS



# Operations carbon approach: PDR

## Losses at carbon content of marginal grid electricity

Photo: 2MW Pembroke CCGT plant under construction, 2011, James Knight CC-BY-3.0

# Operations carbon approach: PDR

Operations Carbon Impact

# Operations carbon findings: PDR

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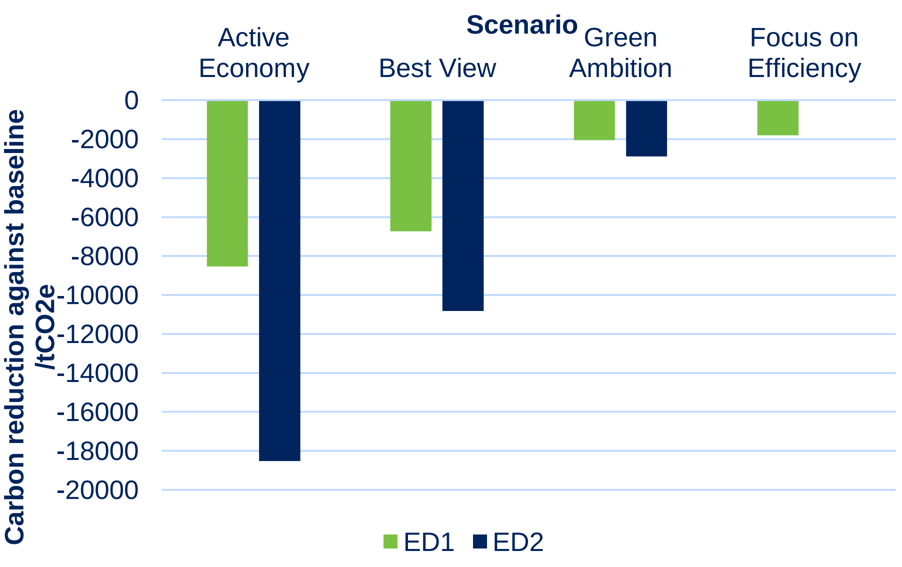
## Carbon penalty from CLASS across the ENW Network

| ENW Network | | | | |
|---|---|---|---|---|
| ED1 | Substation reinforcement deferred >=3 yrs | Years deferred for >=3 yrs | Additional Losses /MWh | Operations tCO2e |
| Active Economy | 14 | 71 | -18659 | -8536 |
| Best View | 8 | 56 | -14717 | -6732 |
| Green Ambition | 3 | 17 | -4468 | -2044 |
| Focus on Efficiency | 4 | 15 | -3942 | -1803 |
| | | | | |
| ED2 | | | | |
| Active Economy | 33 | 154 | -40471 | -18514 |
| Best View | 12 | 90 | -23652 | -10820 |
| Green Ambition | 8 | 24 | -6307 | -2885 |
| Focus on Efficiency | 0 | 0 | 0 | 0 |




304 circuits assessed

# Operations carbon approach: DR

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## CLASS monitoring data

Stage 1 and Stage 2 Frequency events

+

Voltage/Demand response

# Operations carbon approach: DR

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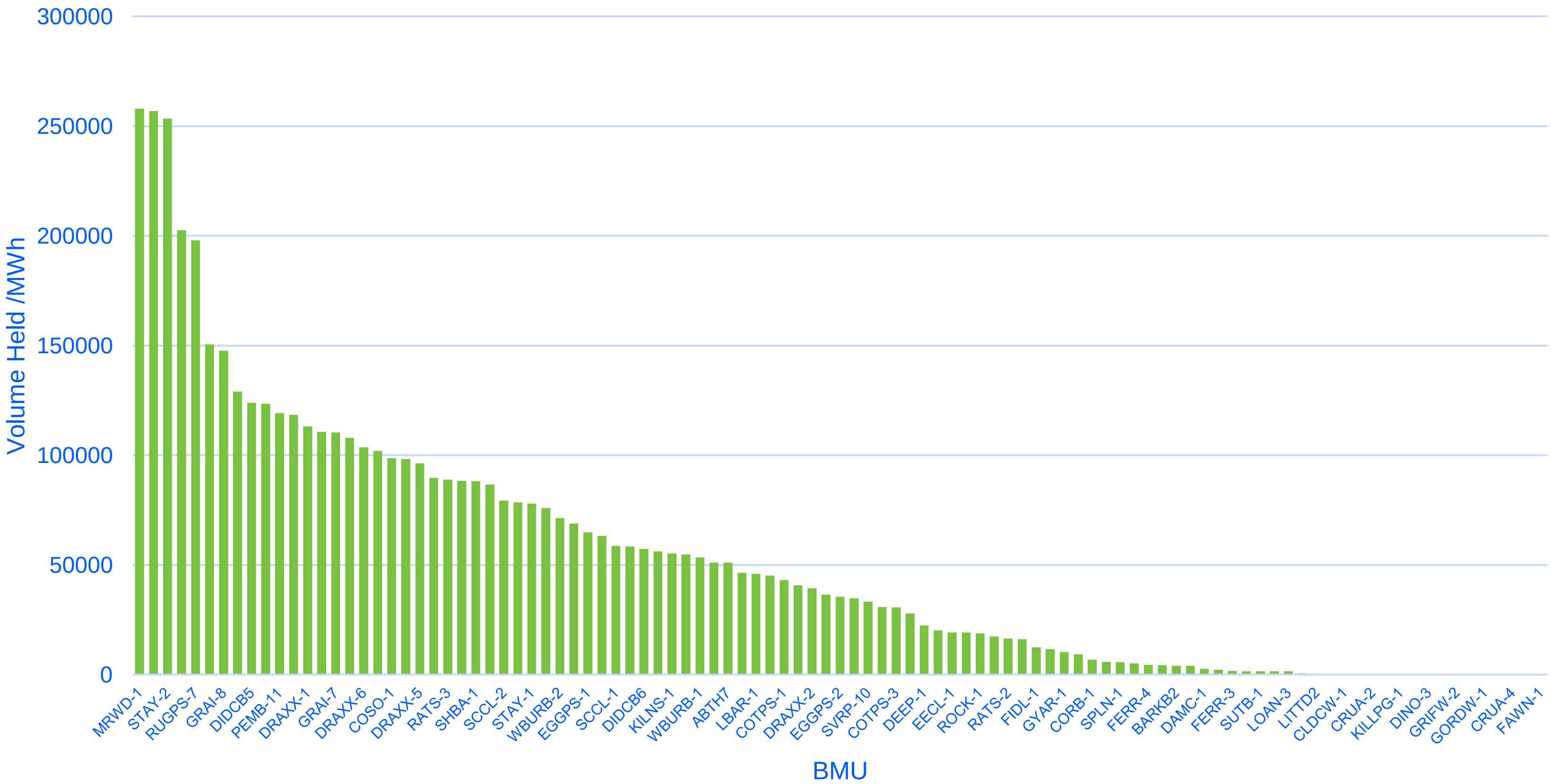
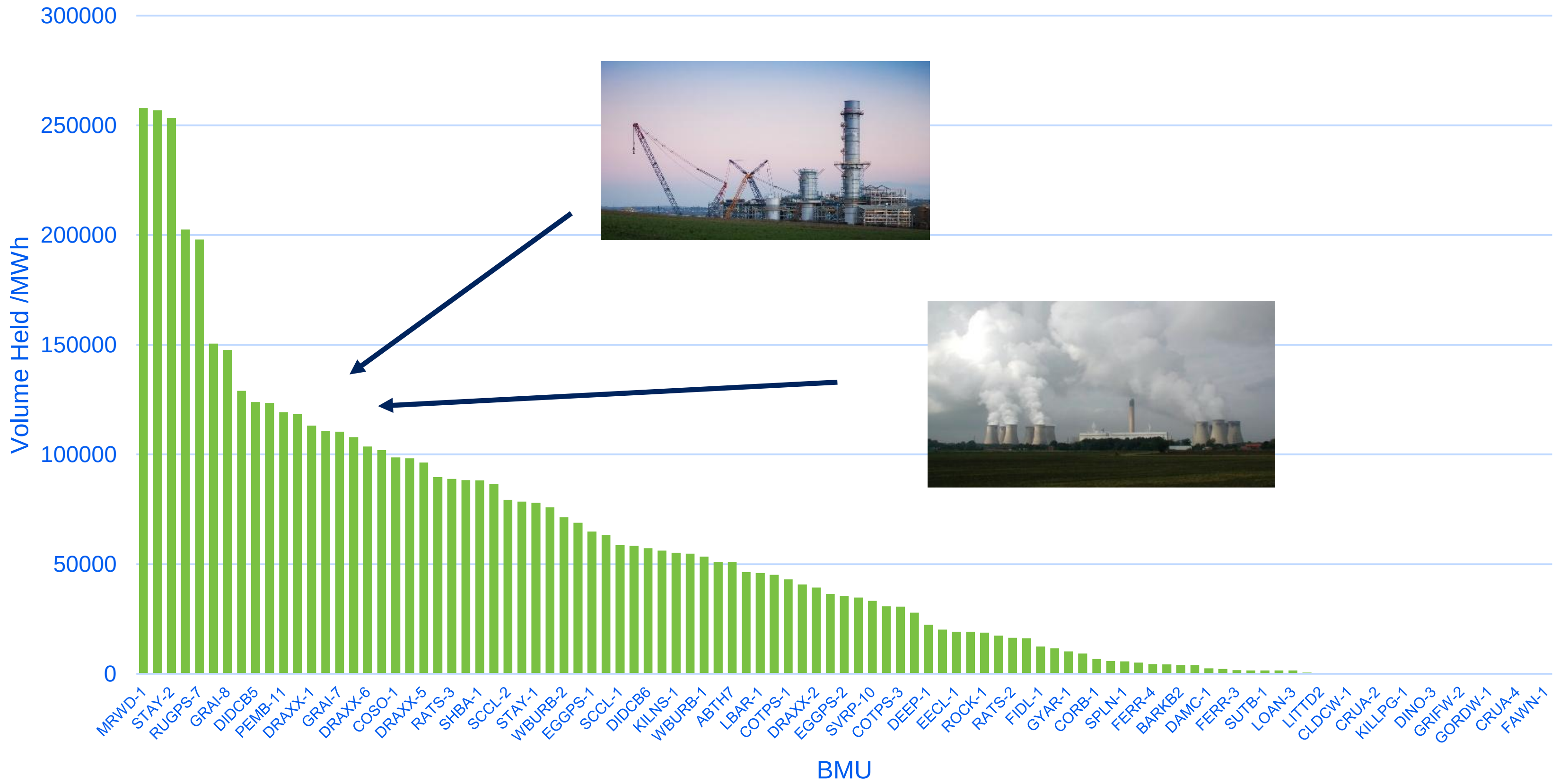
## Frequency response utilisation data 2014/15



# Operations carbon approach: DR

## Composite emissions factor

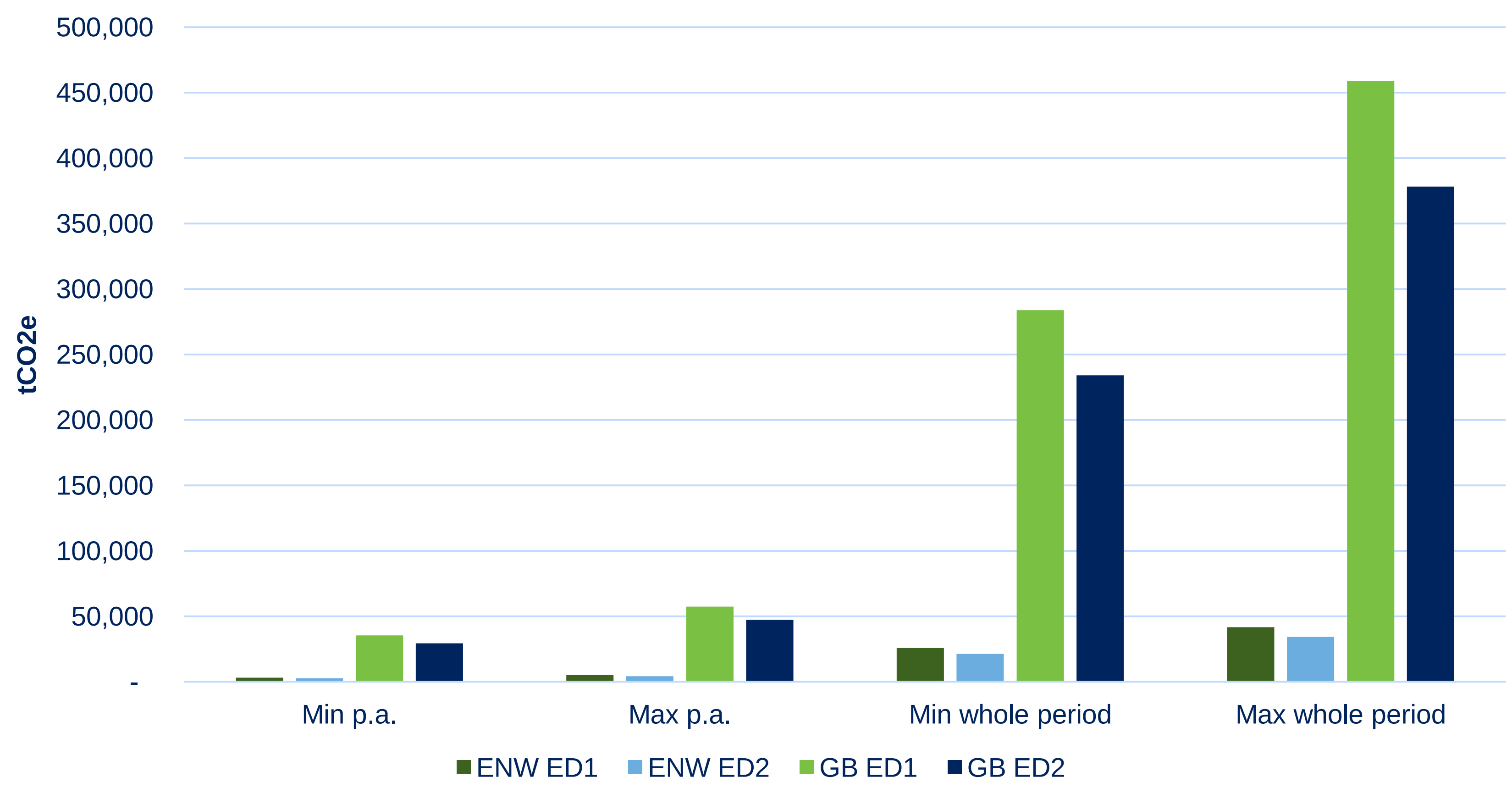


# Operations carbon approach: DR

Operations Carbon Impact

# Operations carbon findings: DR

## Demand response carbon savings – ENW and GB scale



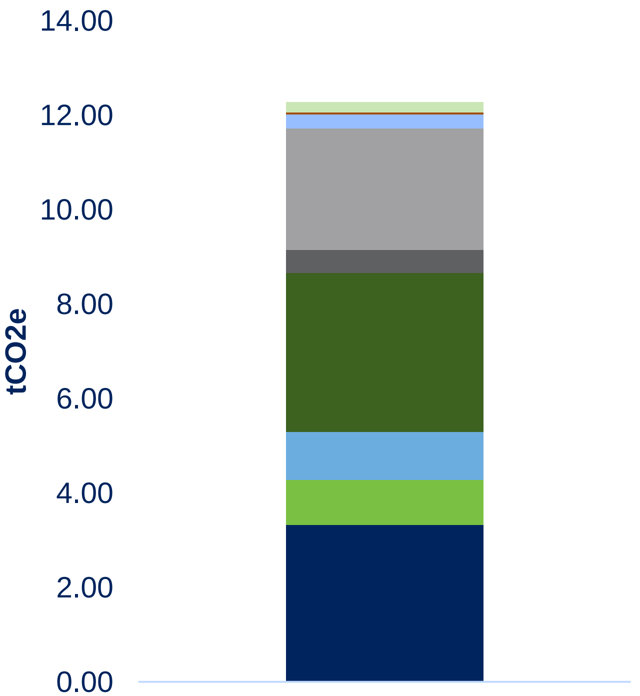
# Asset carbon approach: RP

## Service estimate cf BAU equivalent

CLASS Reactive Power absorption capability

+

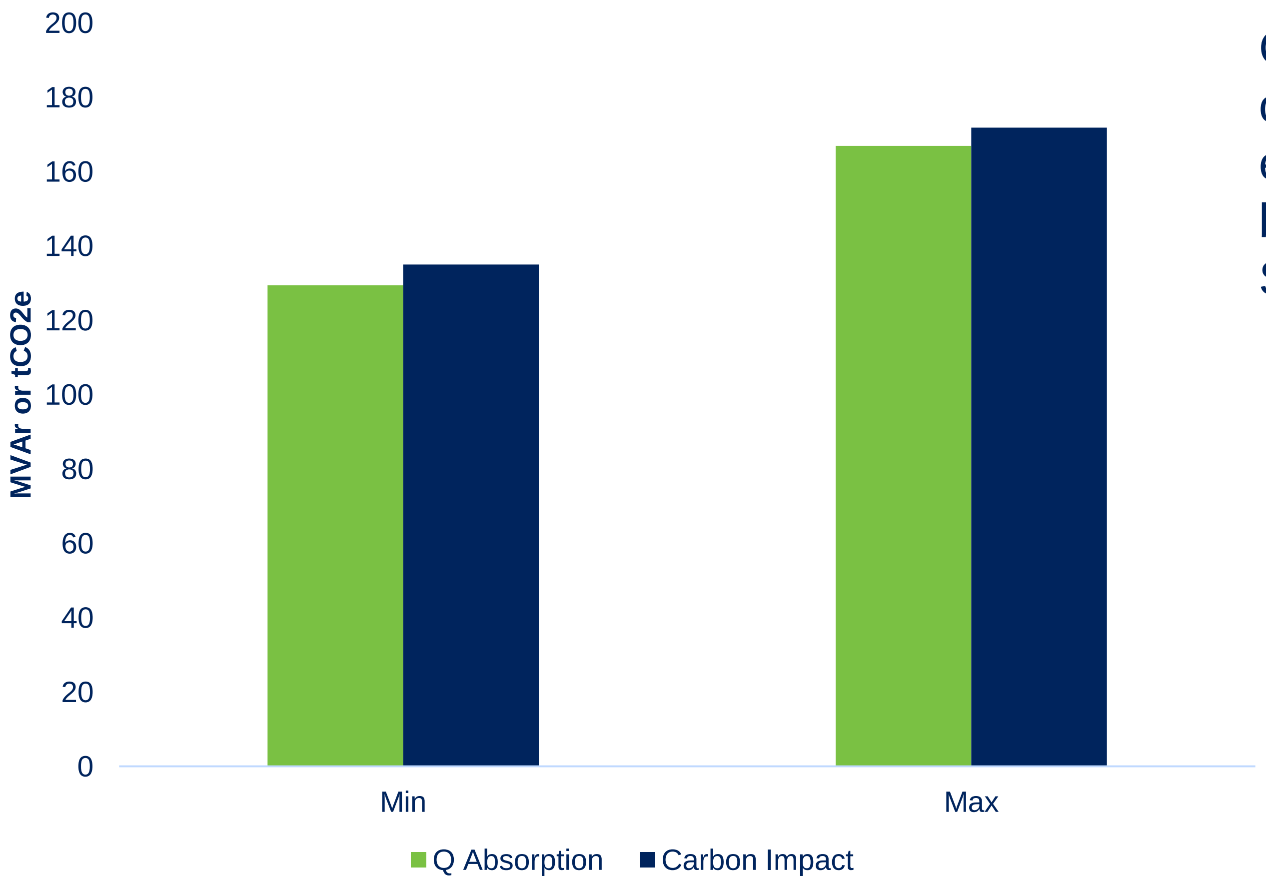
STATCOM embodied emissions per unit - multiplied



# Asset carbon approach: RP

# Asset carbon findings: RP

## Demand response carbon savings – ENW network scale




CLASS RP service on ENW network is equivalent to between 10 and 15 STATCOMs

# Operations carbon approach: RP

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## Powerflow modelling

CLASS reactive power absorption capability

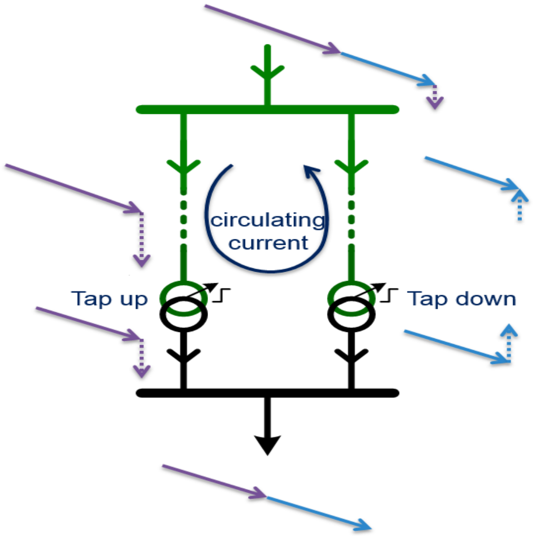
+

Losses in network under new powerflow

# Operations carbon approach: RP

## Usage profiles

Transformer losses increase when tap staggered




STATCOMs continuous "hot standby" consumption


PCS 6000 STATCOM: +/- 12.5 MVAr unit

# Operations carbon approach: RP

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## Losses/consumption at carbon content of marginal grid electricity

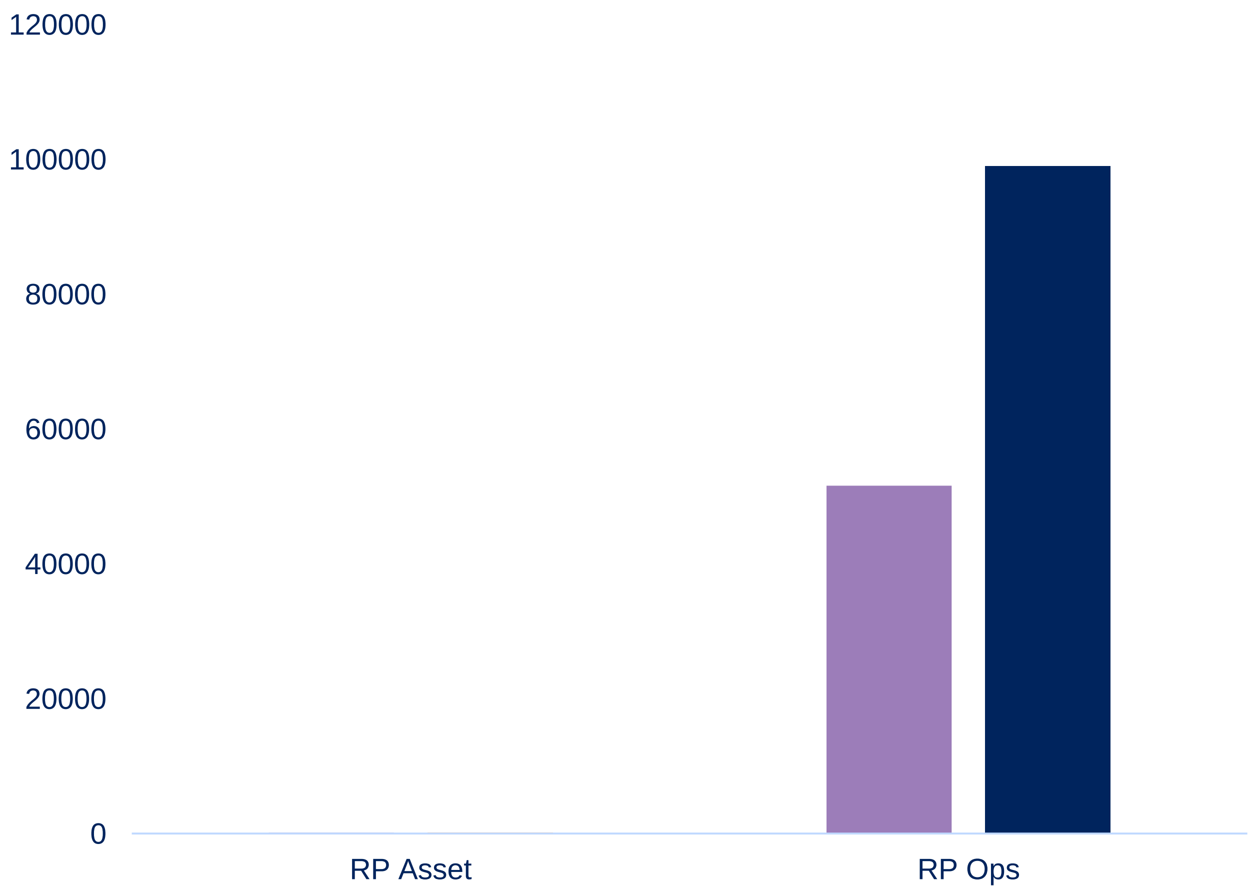
Photo: 2MW Pembroke CCGT plant under construction, 2011, James Knight CC-BY-3.0

# Operations carbon approach: RP

Operations Carbon Impact

# Operations carbon findings: RP

## Reactive power carbon  savings ENW network ED1+ED2




CLASS RP operations save carbon relative to STATCOMs

# Carbon impact summary

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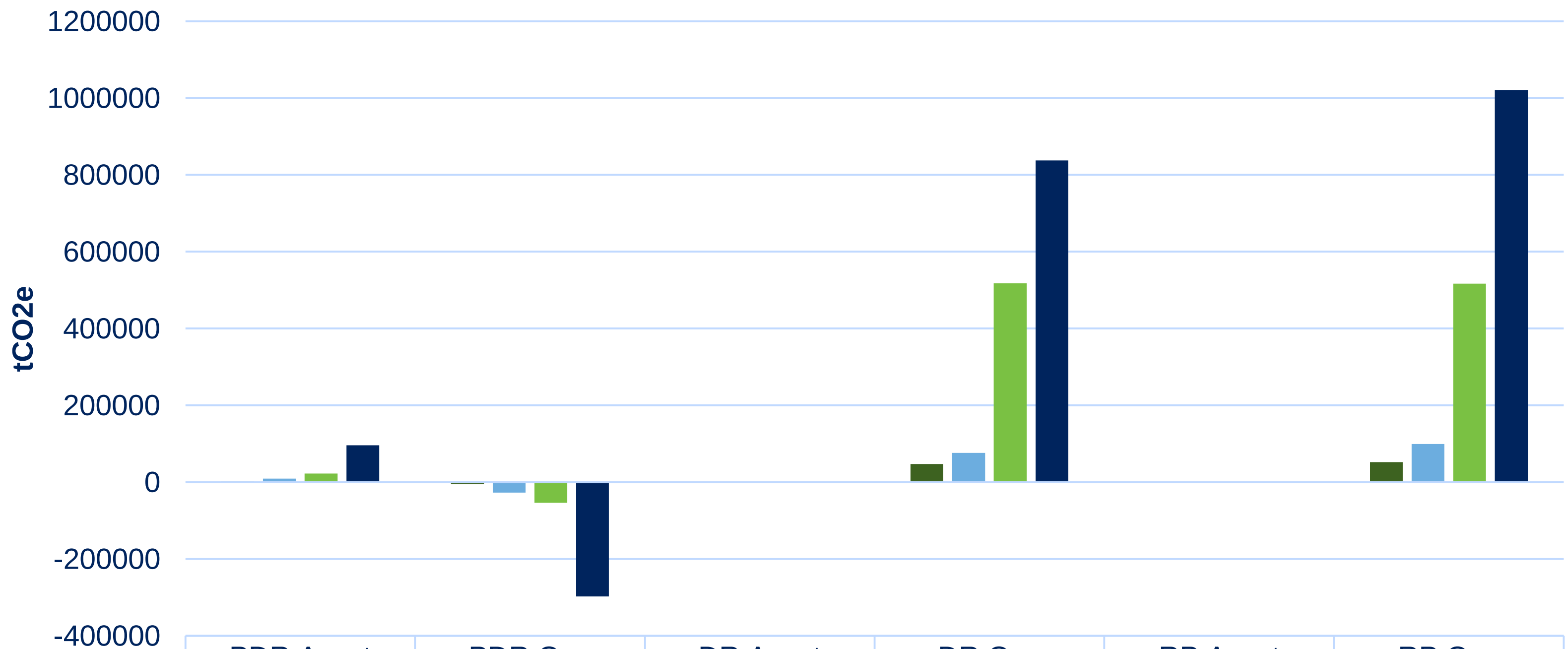
## CLASS carbon impacts over RIIO ED1+ED2




| | PDR Asset | PDR Ops | DR Asset | DR Ops | RP Asset | RP Ops |
|---|---|---|---|---|---|---|
| ENW Min | 2048 | -4929 | | 47081 | 135 | 51616 |
| ENW Max | 8707 | -27050 | -20 | 76112 | 172 | 99007 |
| GB Min | 22525 | -54221 | | 517887 | 1400 | 517049 |
| GB Max | 95781 | -297552 | -220 | 837236 | 1805 | 1021442 |

# Conclusions

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## Substantial potential for carbon reductions in future

CLASS could reduce the carbon impact of demand response (DR) and reactive power (RP) provision substantially

The total benefits from both the DR and RP services could be as much as 116,000 $tCO_{2e}$ per annum

The continuous operations impacts category provides the dominant DR and RP carbon benefit

However, when reinforcement is deferred due to peak demand reduction losses are significant – as is the carbon penalty if the grid margin is provided by CCGTs

Facilitated carbon impact across the trial was found to be very small and highly uncertain.

# QUESTIONS

# &

# ANSWERS

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# Steve Cox
Summary

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# Summary

Statistical findings are that domestic customers did not notice the CLASS functions

Lessons have been learned during the installation phase, that can be integrated into any future 'rollout'

CLASS has provided National Grid with the ability to use an ICCP link which provides them with a demand response during a system frequency event

CLASS has shown an approximately linear relationship between voltage and demand

# High level benefits

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- Low cost high speed frequency support
- 3GW demand reduction or boost
- 2GVAr National Grid voltage control
- Reinforcement deferral
- 24/7 voltage/demand relationship matrix

# Next steps

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| Technical rollout in ENW | Commercial rollout | Monitoring | ICCP link |
| --- | --- | --- | --- |
| Evaluation and selection of best technologies from those identified during the project | Evaluation of best mechanism | Continue with monitoring study | ENW-National Grid ICCP link now part of future NMS |

# QUESTIONS

# &

# ANSWERS

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# Want to know more?

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| | |
|---|---|
| e | futurenetworks@enwl.co.uk |
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# CLASS closedown event

Wednesday 9 September 2015

LCN Fund
Low Carbon Networks

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