

### **CLASS closedown event**

### Wednesday 9 September 2015



Steve Cox Head of Engineering Welcome and introduction U.



#### Housekeeping

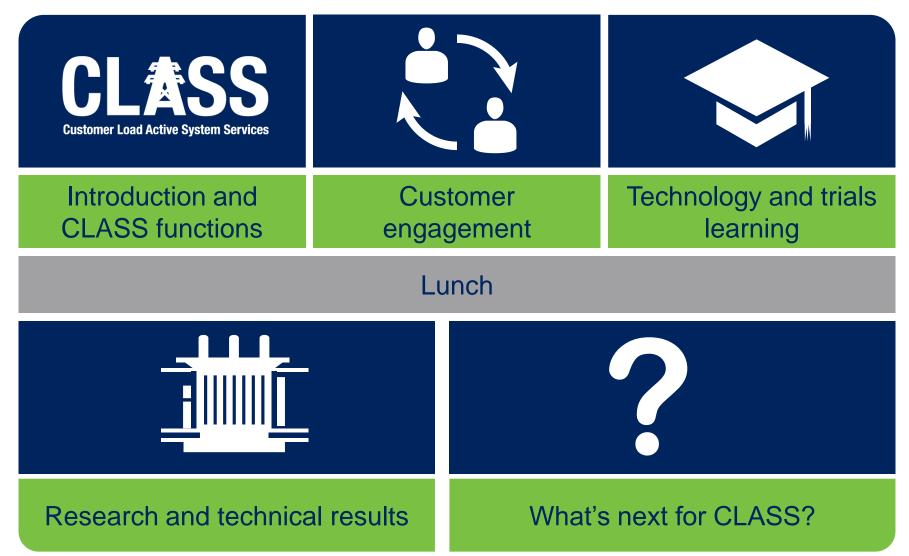


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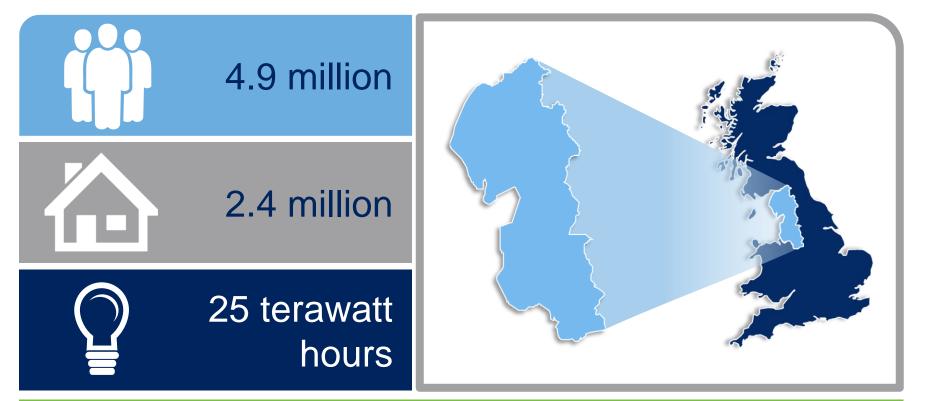


#### Introducing Electricity North West





Bringing energy to your door



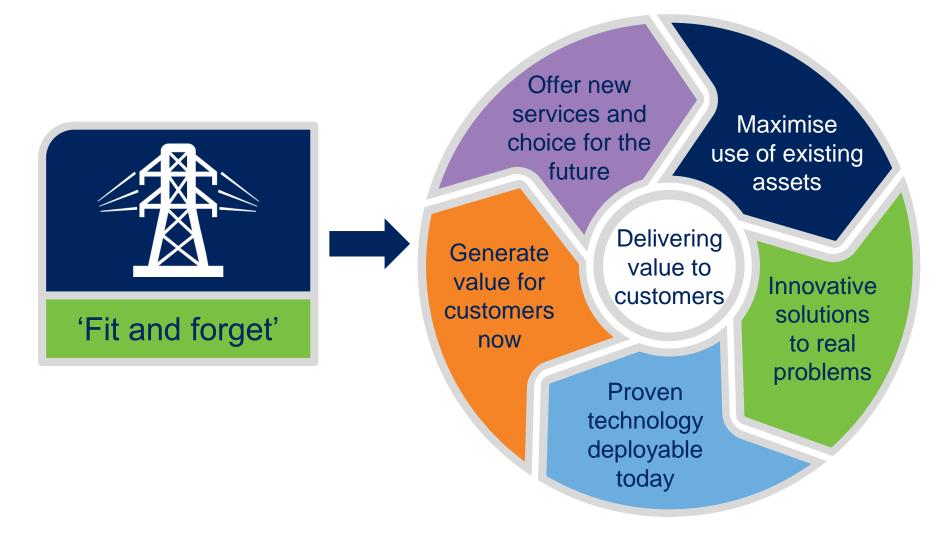
#### £12 billion of network assets

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

#### Our innovation strategy



Celectricity



#### Our smart grid development



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#### Leading work on developing smart solutions





#### **Customer choice**

**EXAMPLE A Four flagship products (second tier)** £36 million



#### CLASS



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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...





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### 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? *voltage is proportional to demand* 

If Voltage is increased demand increases

And vice versa . . . !

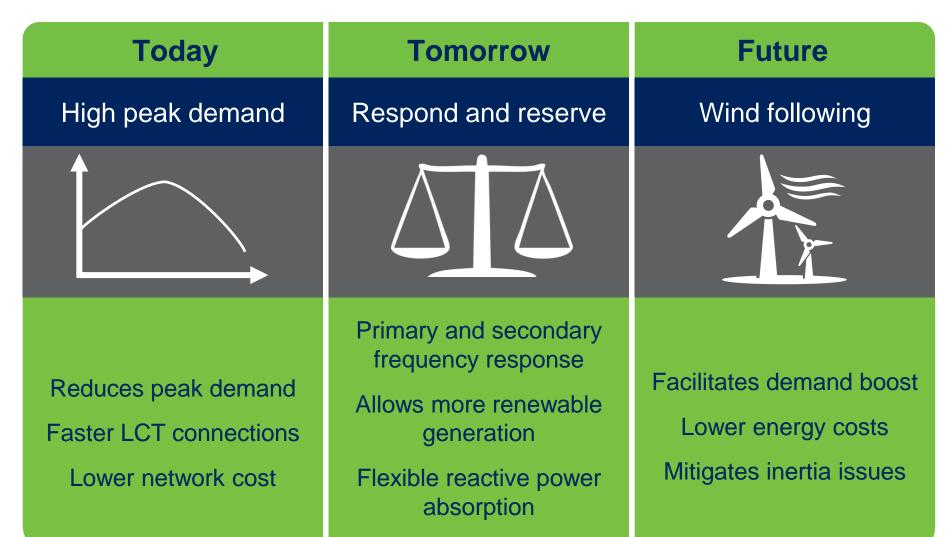


What problems could we solve ?

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



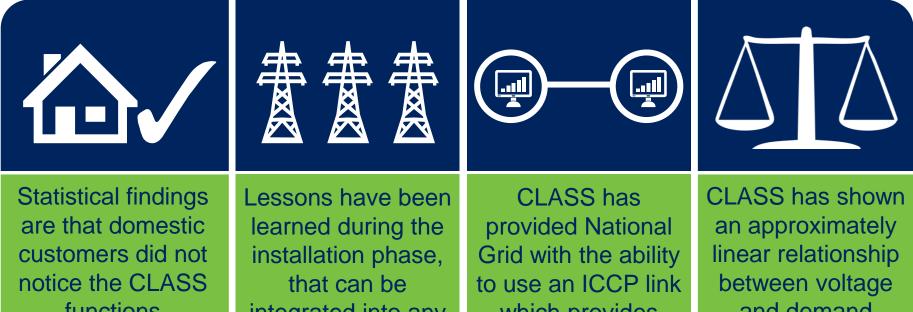




#### Summary



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functions

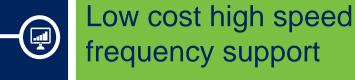
integrated into any future 'rollout'

which provides them with a demand response during a system frequency event

and demand

#### High level benefits







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 U.



#### The CLASS functions





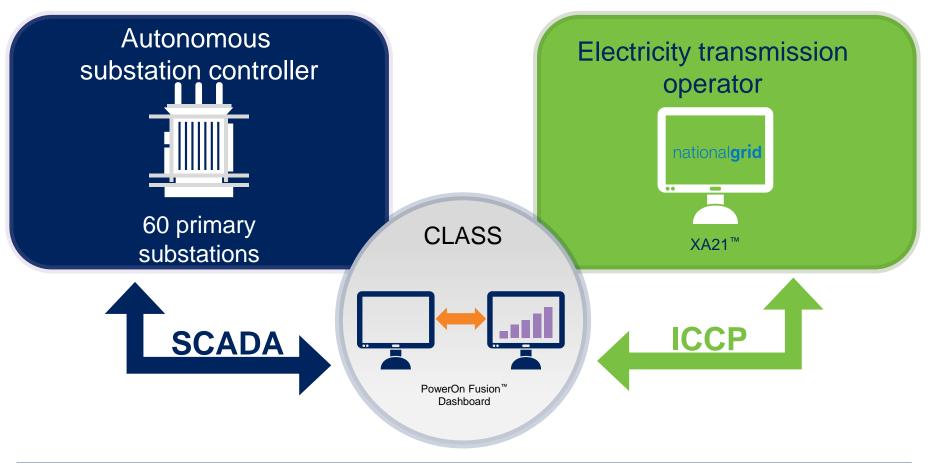
	Objective	Technique			
Automatic peak reduction	Reduce demand to within substation capacity	Lower tap position			
Demand boost / reduction	Boost or reduce demand	Lower / higher tap position			
Frequency response	Primary response to reduce demand when frequency falls on the network	Switch out transformer			
	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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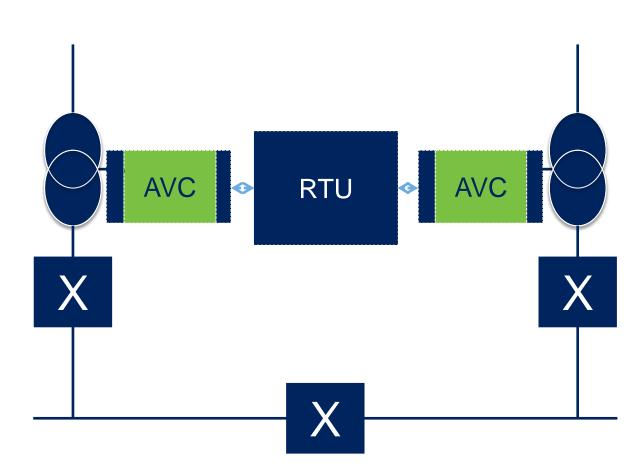
Dashboard forecasts response and allows 'arming' of various response services

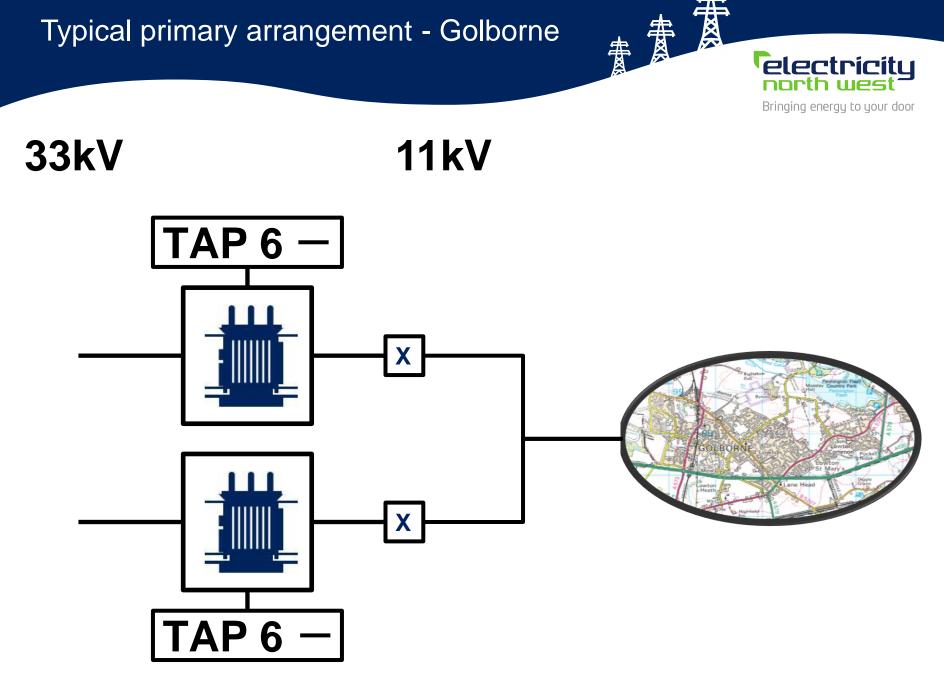
TSO and DNO both have visibility and control of active and reactive power

#### Typical substation overview





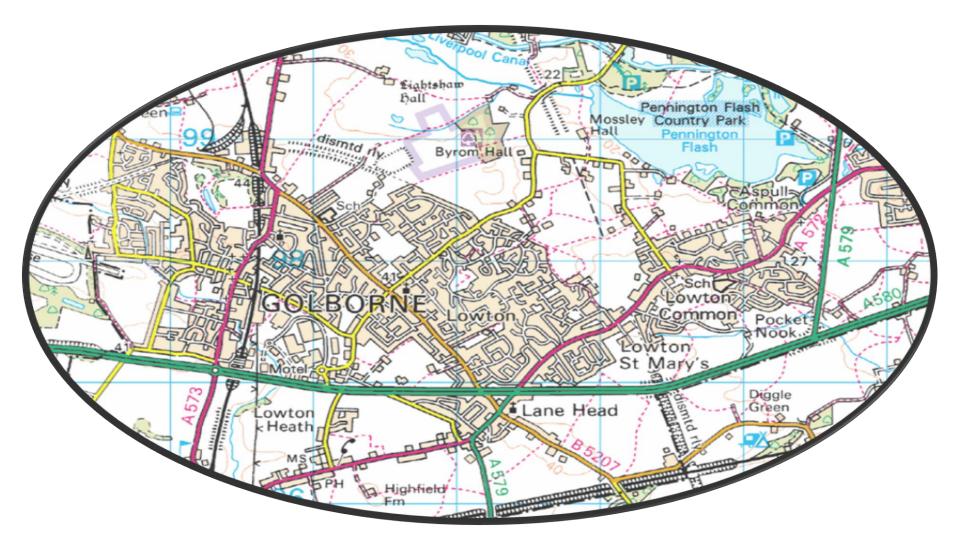


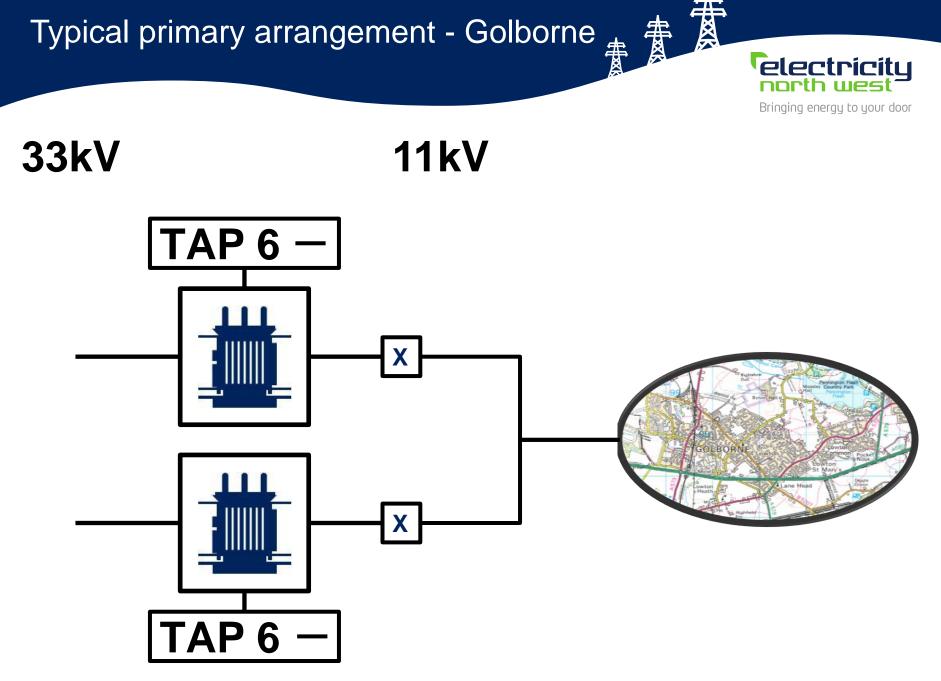


#### Golborne area



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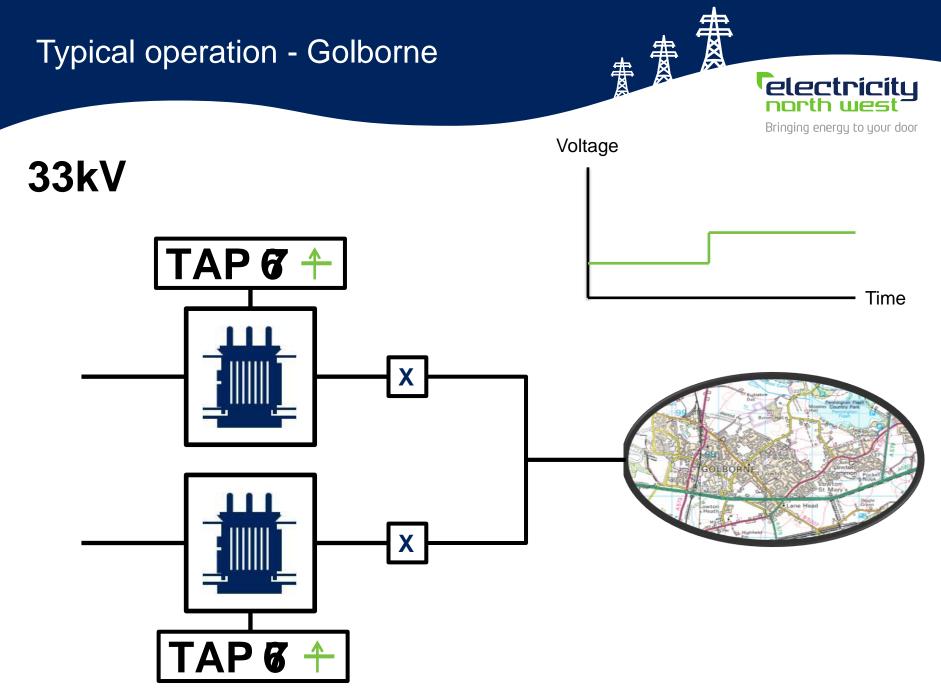


#### Primary transformer



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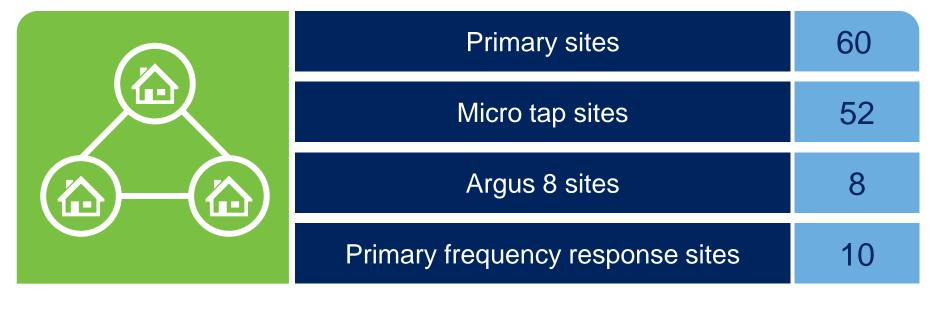




#### CLASS project scale





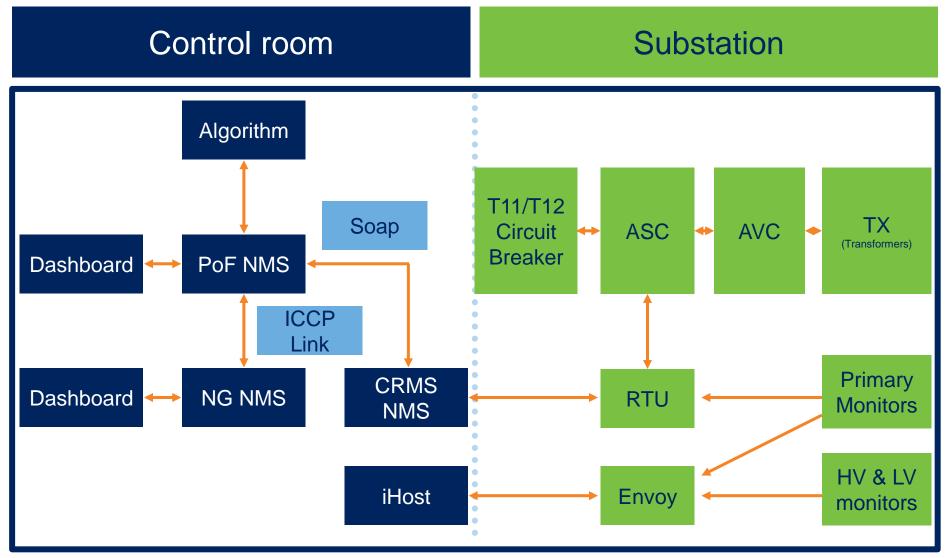


HV locations	10
45 new LV locations + 15 existing	60
Transformers	3

#### Complete CLASS system







#### Dashboard



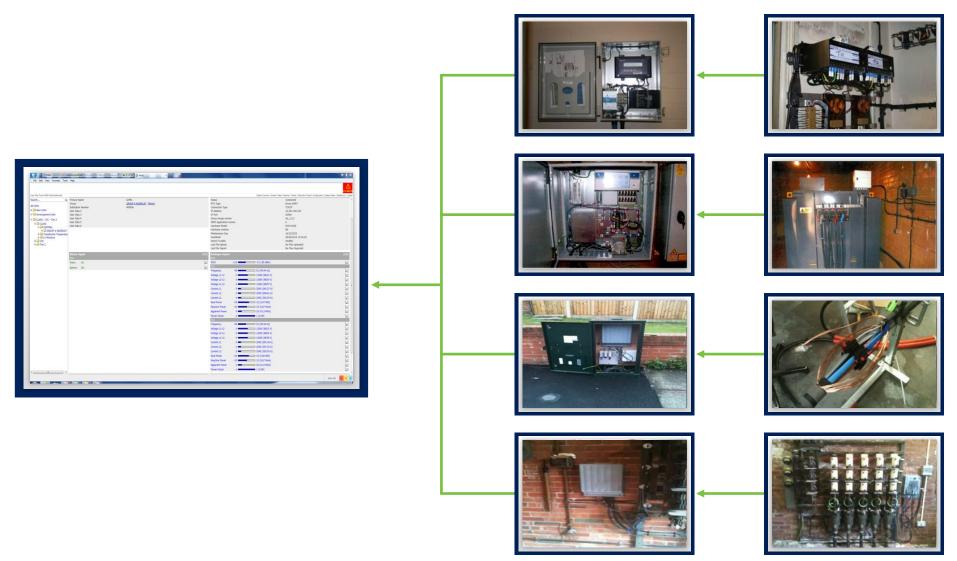


Group	T11 Tap/Current T12 Tap/Current	NRD	Frequency control MW		Voltage Control Mvars		Demand %				
							Boost		Reduction		
			Stage 1	Stage 2	Stage 1	Stage 2	Stage 3	Half	Full	Half	Full
South Manc		Disabled	0	0	0	0	0	0	0	0	0
			Disabled	Disabled	Disabled	Disabled	Disabled	Disa	bled	Disabled	Disabled
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		0	0	0	0	0	0	0	0	0
		T12 Disabled	Disabled	Disabled	Disabled	Disabled	Disabled	Disa	bled	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





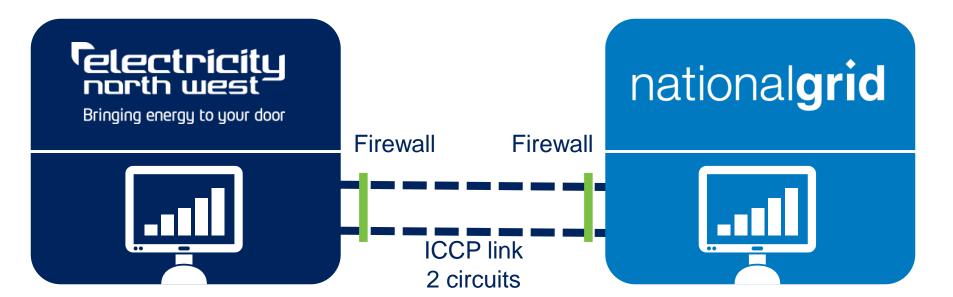


#### What is an ICCP link?





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Secure inter control centre protocol is the industry standard

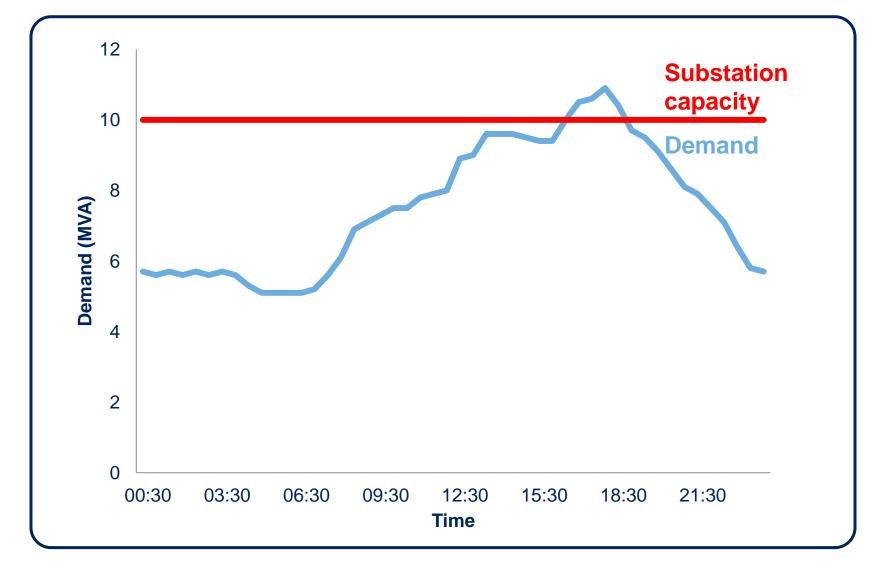
Direct fibre optic connection

Enables data exchange between energy management systems

#### Daily demand curve



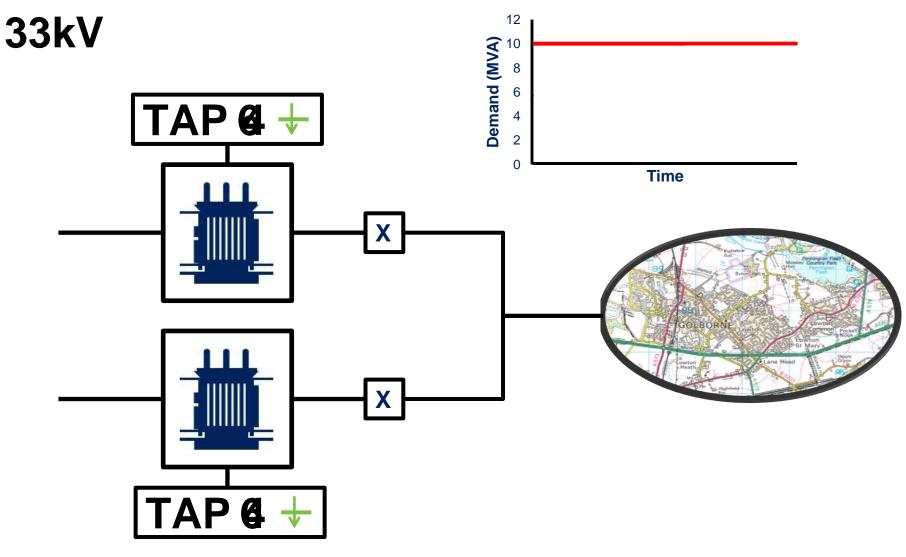




#### Peak reduction - Golborne





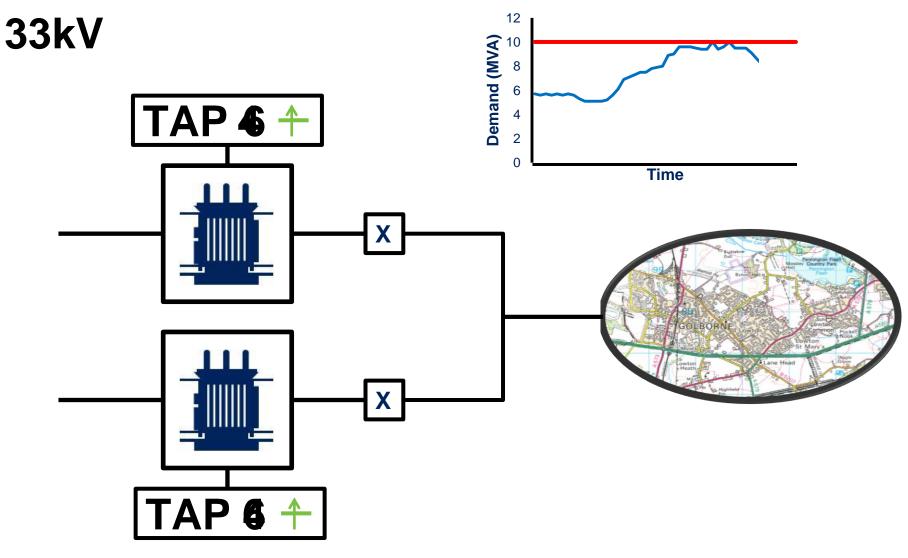


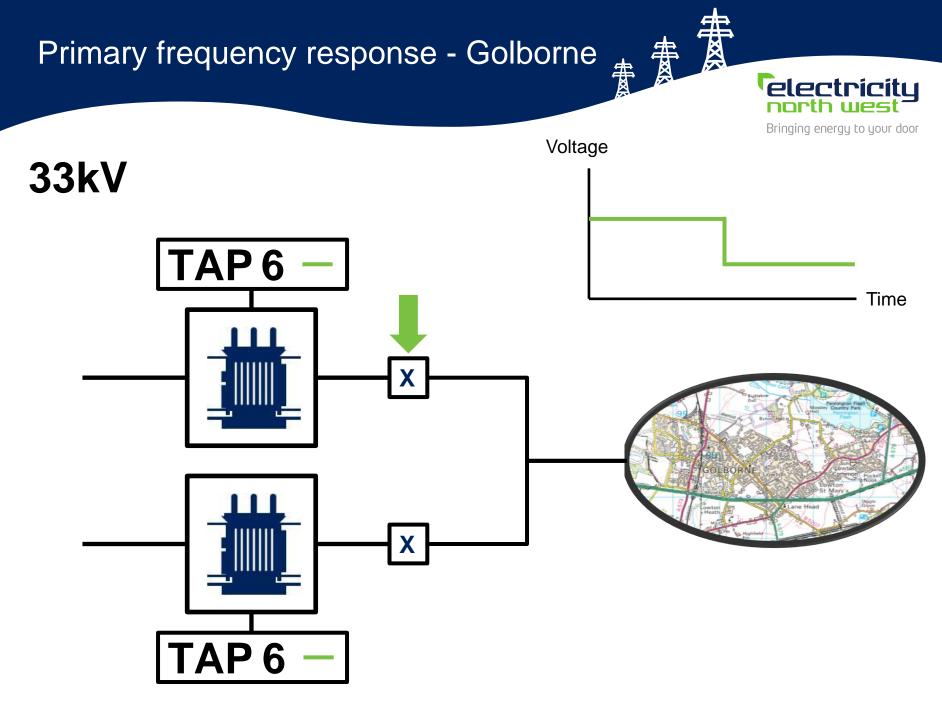
### Peak reduction - Golborne

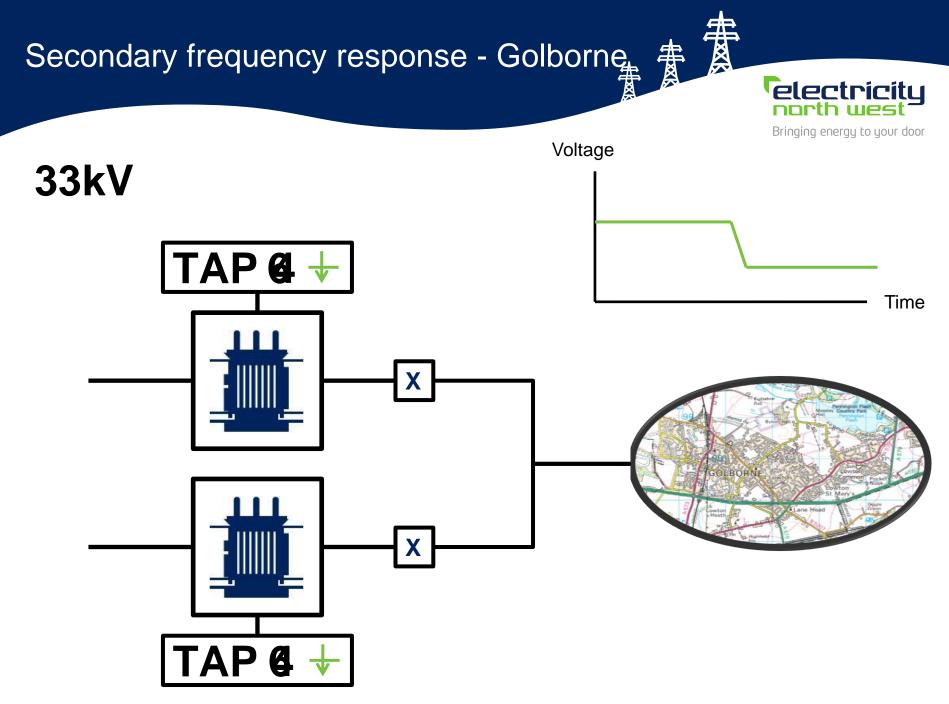


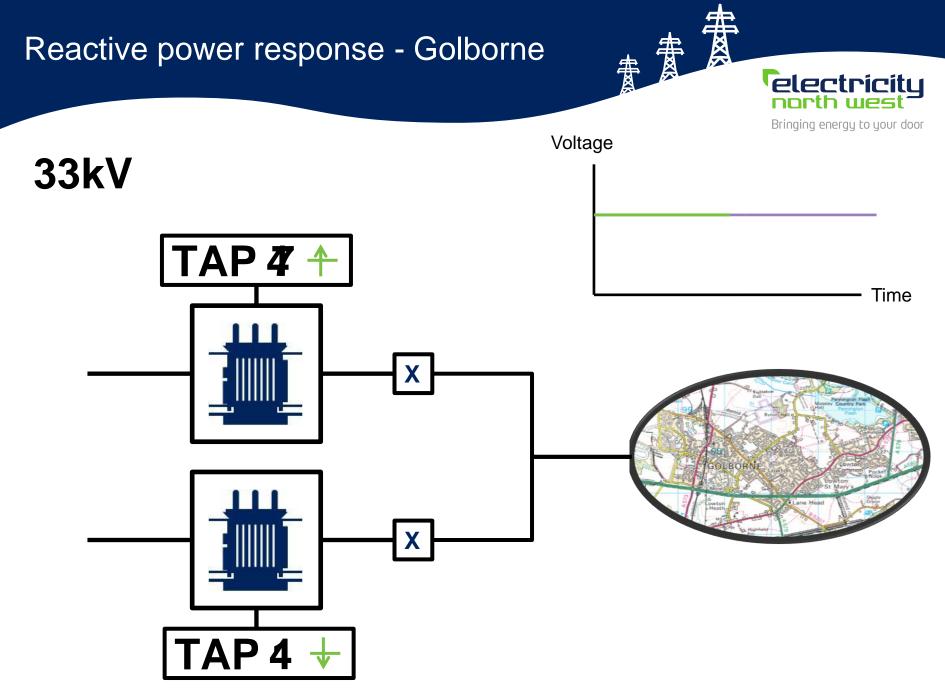
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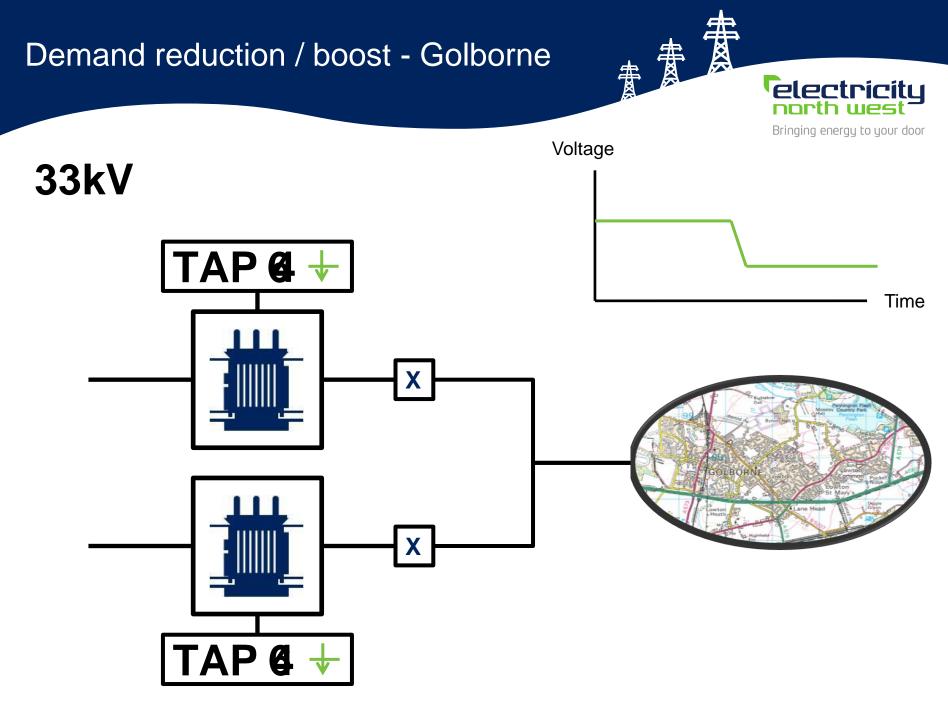












## QUESTIONS

# ANSWERS



Kate Quigley Innovation Customer Delivery Manager Customer Research

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# Did customers notice CLASS?

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485,000

customers

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

Customers did not notice the CLASS tests



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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



# Engaged customer panel methodology





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# Carlisle

# Manchester

Four meetings as appropriate

Cross section of customers

All I&C panellists had decisionmaking responsibilities

30 consumers were recruited

# Engaged customer panel – leaflet





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



electricity

Released to your door

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Help us meet the electricity needs of the future

Earn cash rewards by taking part in our survey





Priority Services Register Customer leaflet and survey registration





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Recruitment of 700 participants of a representative mix of customers



electricitu

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Engaged customer panel lessons learnt

DNO/supplier relationship still confusing

Customers are sceptical of DNOs and suppliers

Customers need to be educated about the Problem

Lessons learnt

With sufficient education customers understand CLASS

Customers need to be informed about CLASS

Customers are sensitive to how personal data is handled

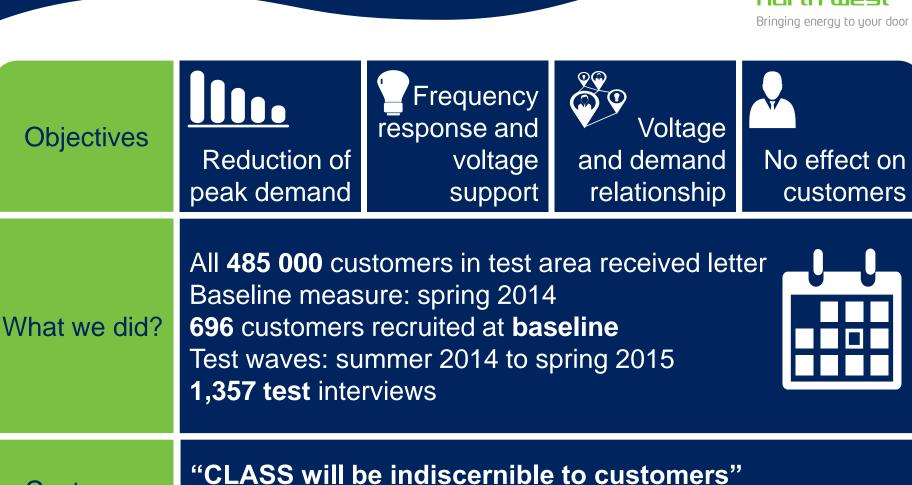
Susie Smyth Associate Director, Impact Research Customer Research



# **CLASS** trials overview

Customer

hypothesis



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

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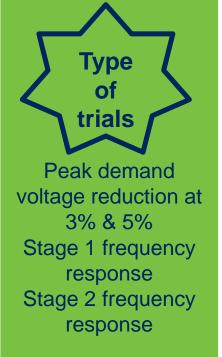
# Summary of the trial surveys





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#### Test trial surveys



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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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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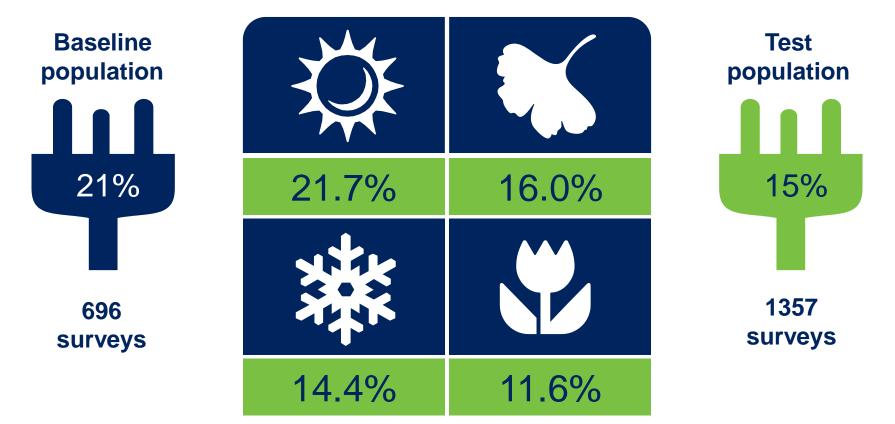
Identify PSR customers and any special needs Vulnerable customers reside at the property and/or if medical equipment affected Power quality monitoring

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





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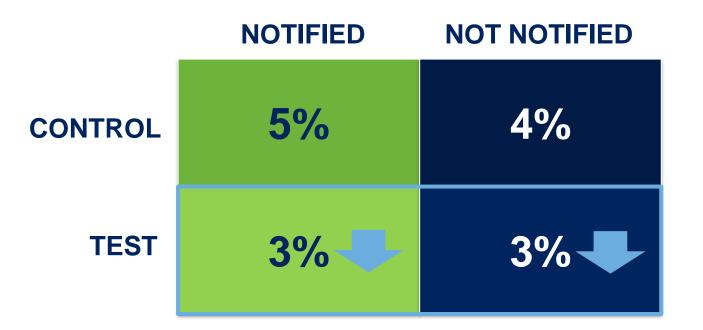


Customers who perceived a change in performance to at least one appliance or to their lighting in the last 7 days was significantly lower than the baseline Test v control analysis – of the 15%...





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

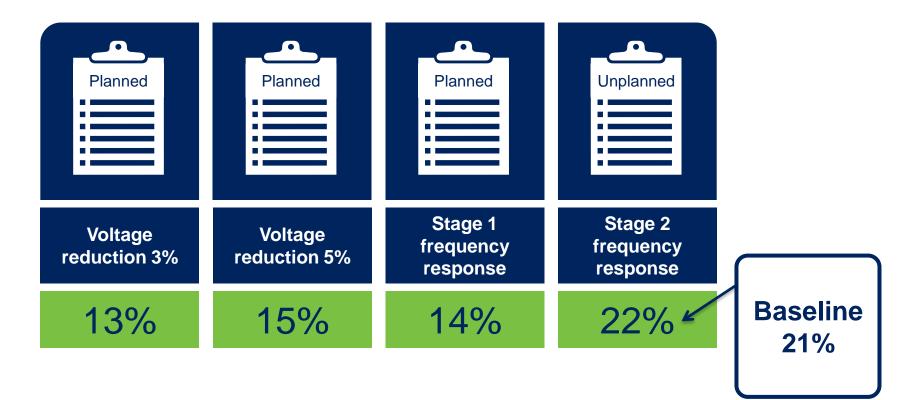
The test sample were **less likely** to have noticed a change in performance than the control sample

# Trial type

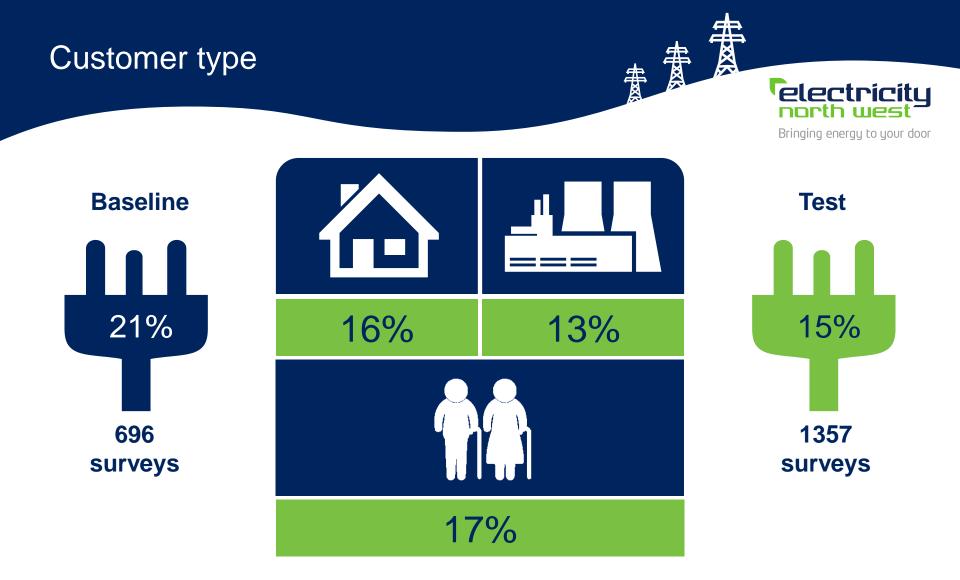


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**Type of test** was not an influencing factor on likelihood to notice a change to power quality

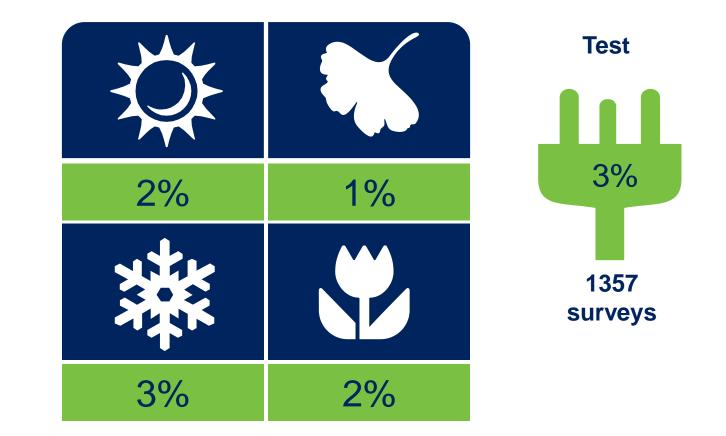


Even **vulnerable** customers who may be more dependent on a constant electricity supply than other customers were no more likely to notice changes than other groups

# Perceived changes that could be due to CLASS



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

# **Customer satisfaction**





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

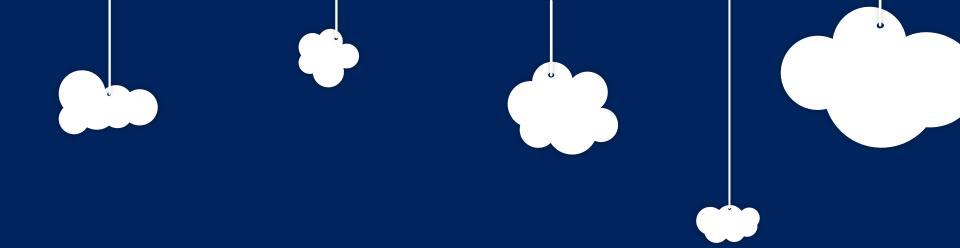


Complaints about power quality or service received at the customer contact centre or to Impact Research team likely to be caused by CLASS trials

# QUESTIONS

# ANSWERS





# **Tea break**



Kieran Bailey Innovation Engineer Trial Methodology

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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

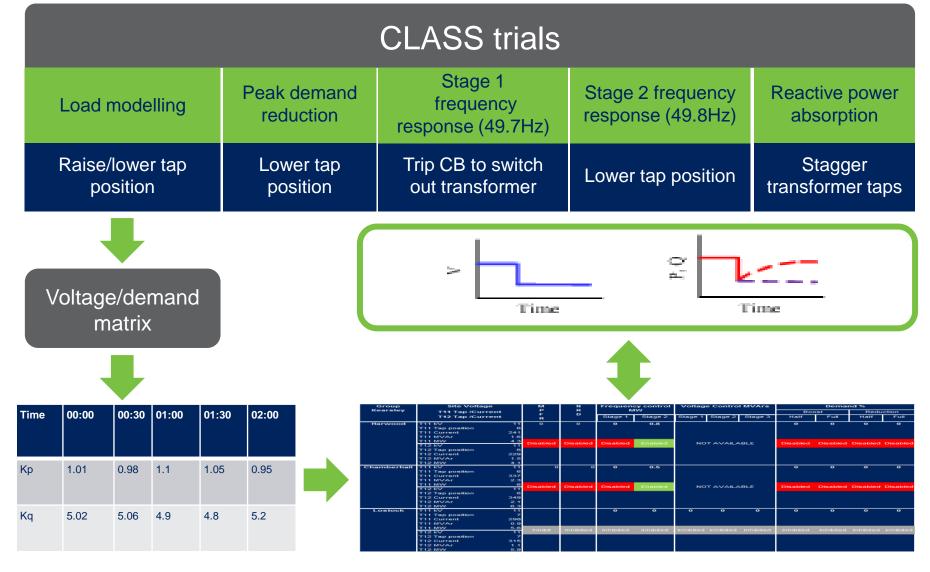
No detriment to asset health

Customers do not observe any discernible change in quality of supply

# Trial overview and function control







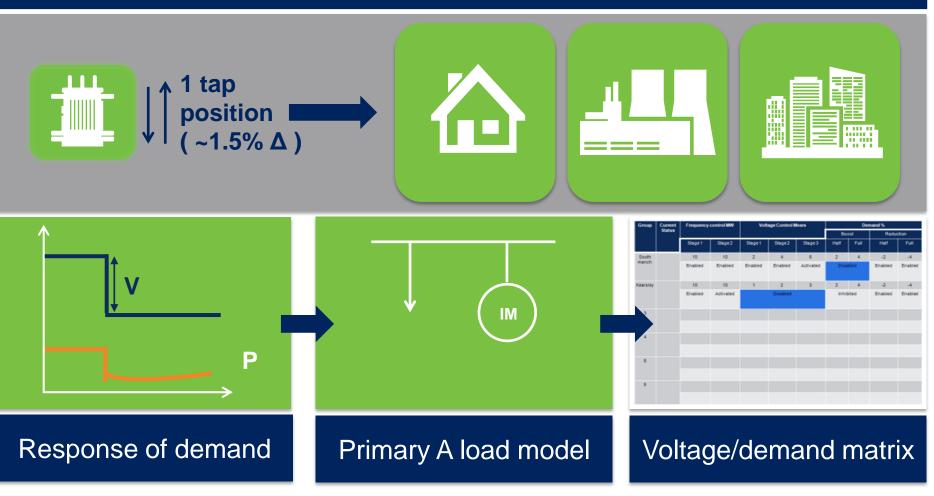
Trial 1 – Developing our understanding of the voltage/demand relationship





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# $V \propto Demand?$



# Trial 1 – Site selection



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# Methodology developed

Ratio of CDCM profile classes at substation peak demand

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

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

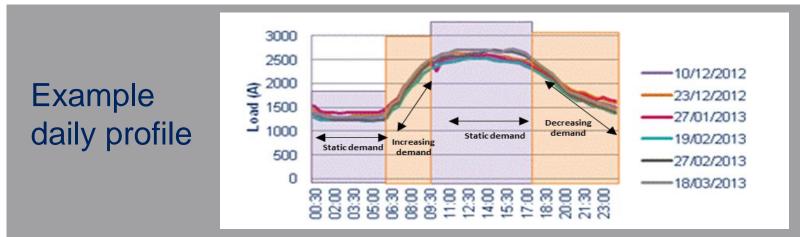
# Trial 1 – Determining the test schedule





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### Typically primary substation demand shows regularity

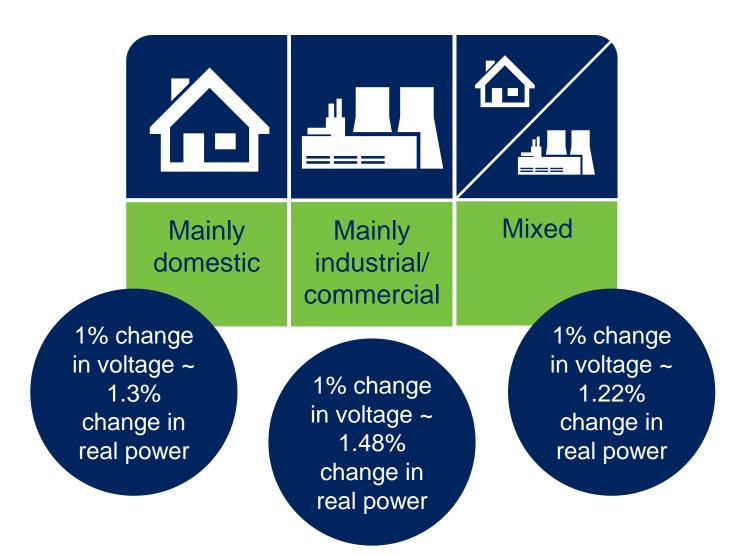


Tests can be conducted in representative periods Quantify the demand/voltage relationship for every half hour across the annual cycle The planned voltage decrement and increment tests will supplement BAU tap change activity

# Trial 1 voltage/demand relationship

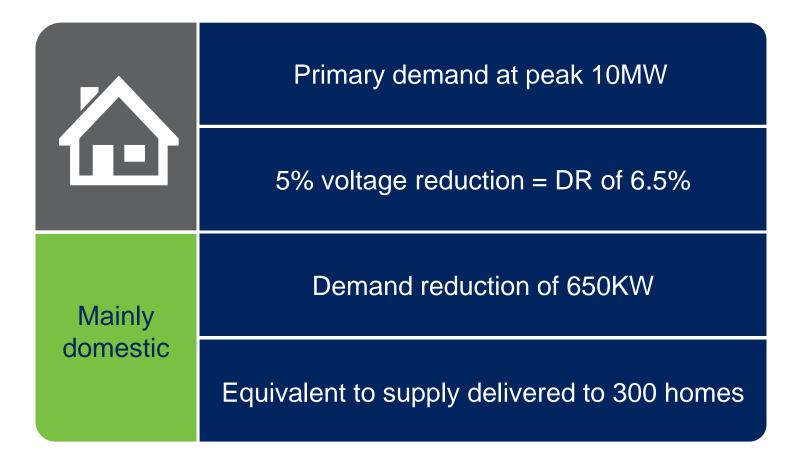






### Demand response example

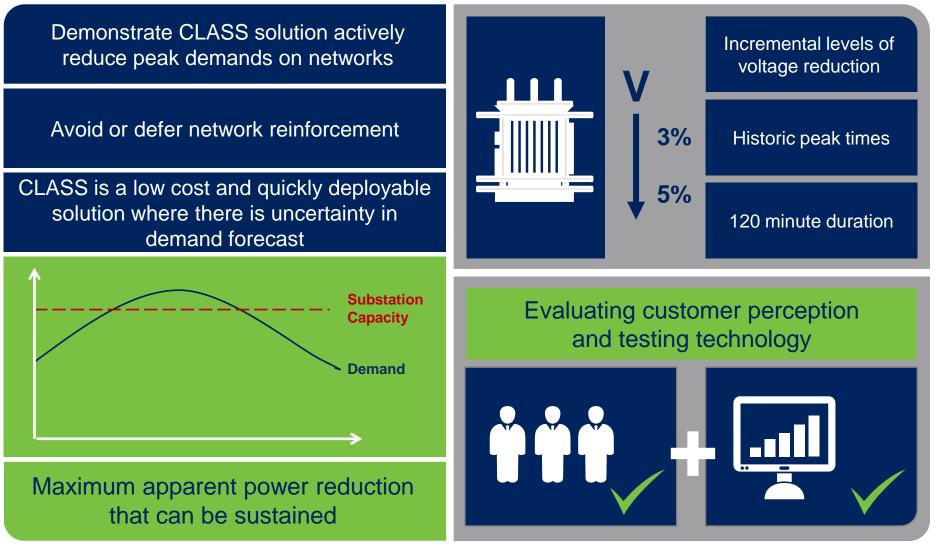




# Trial 2 – Reduction in peak demand







Celectricity Bringing energy to your door 3% voltage reduction Stage 1 Stage 1 Stage 1 survey customer survey trial area results 3 tests 3 tests per per primary primary Stage 2 Stage 2 Stage 2 survey trial area customer survey results 5% voltage reduction

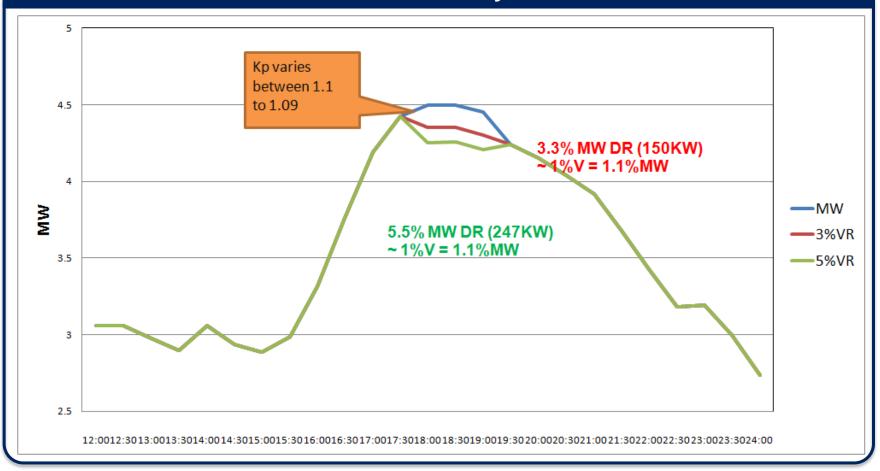
# Trial 2 – Implementing the peak demand reduction

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# Demand reduction at peak demand

#### **Demand reduction – Romiley winter mid-week**



# Demand response (DR)



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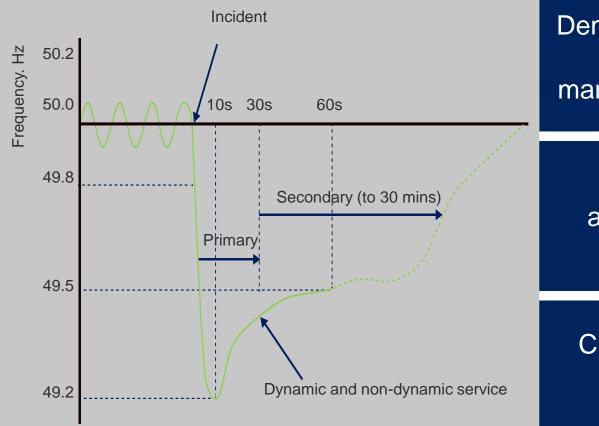
	Britain = 6%DR	Great Britain 6% VR =7.2%DR		
Summer minimum demand response = 1120MW	Winter maximum demand response = 3150MW	Summer minimum demand response = 1340MW	Winter maximum demand response = 3780MW	

# Trial 3 – Frequency response





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Demonstrate CLASS can be a new mechanism for managing system frequency

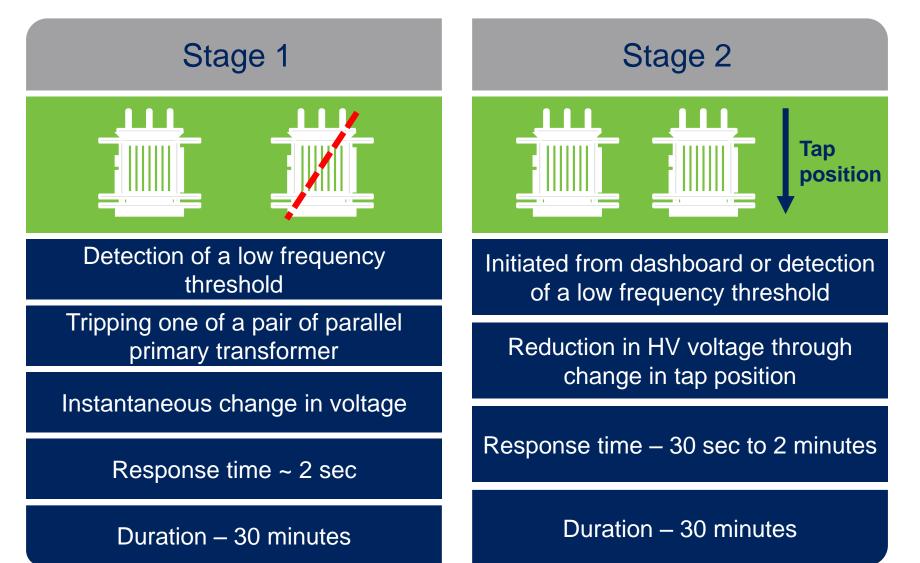
Existing reserve services attract a high financial and carbon cost

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

# Trial 3 – Utilising our assets

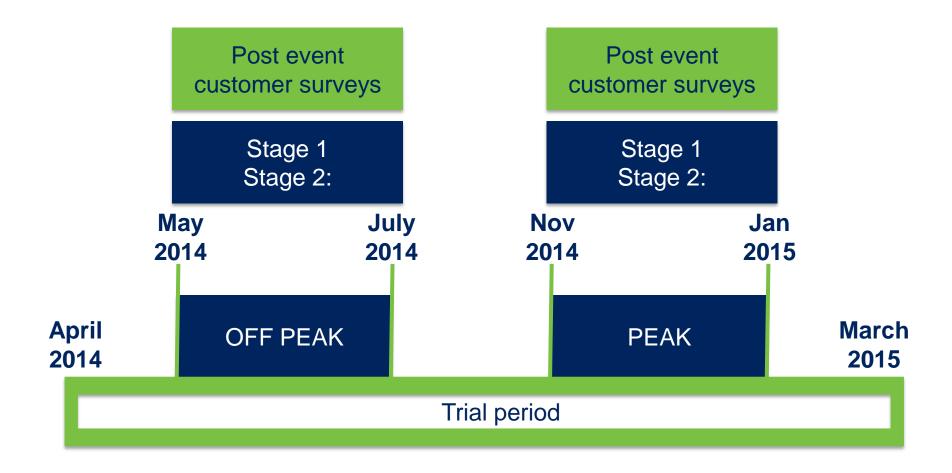






# Trial 3 – Testing approach









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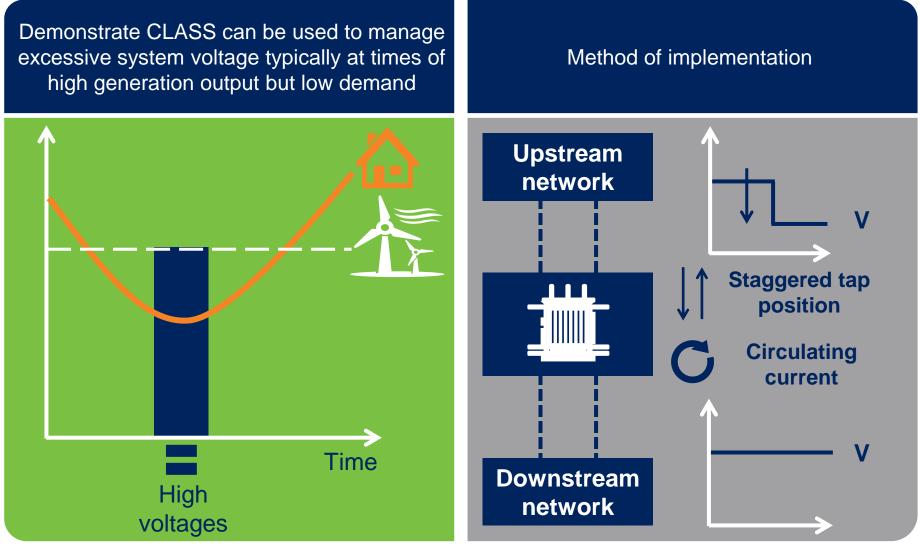
Event 1: 17/09/	2014 20:44	
Primary	V change (%)	Pchange (%)
Fallowfield	1.44	2.05
Baguley	1.57	2.67
Event 2: 15/12/	2014 22:43	
Primary	V change (%)	Pchange (%)
Fallowfield	1	1.78
Baguley	1.7	1.9

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







#### Trial 4 – Approach to testing



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### Three levels of reactive power absorption capability

### NGT high voltage period 2-6am

Electricity North West high voltage period 10pm – 7am

#### Reactive power absorption





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#### 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



### Lunch

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Steve Stott Innovation Engineer Technology and Technical Learning

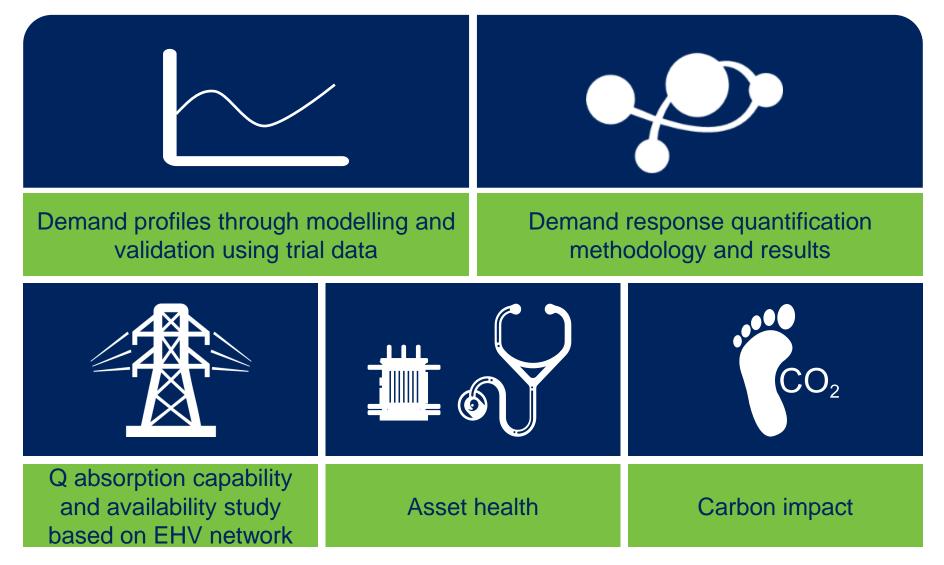
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#### Academic research







Dr Kazi Hasan Prof Jovica Milanovic Demand profiles through modelling and validation using trial data



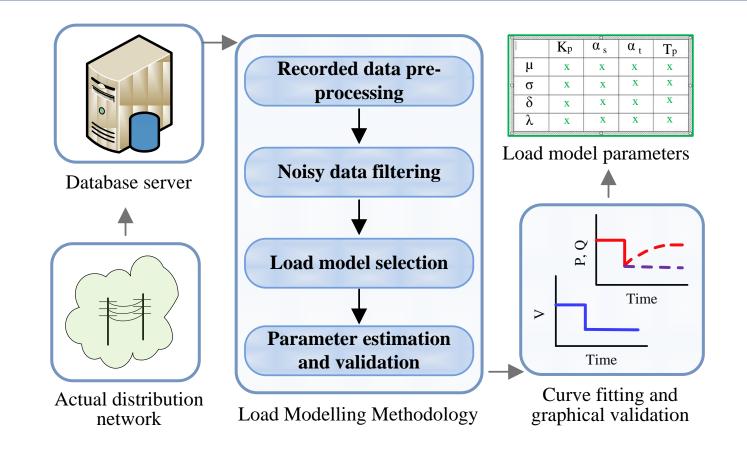
The University of Manchester



#### 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

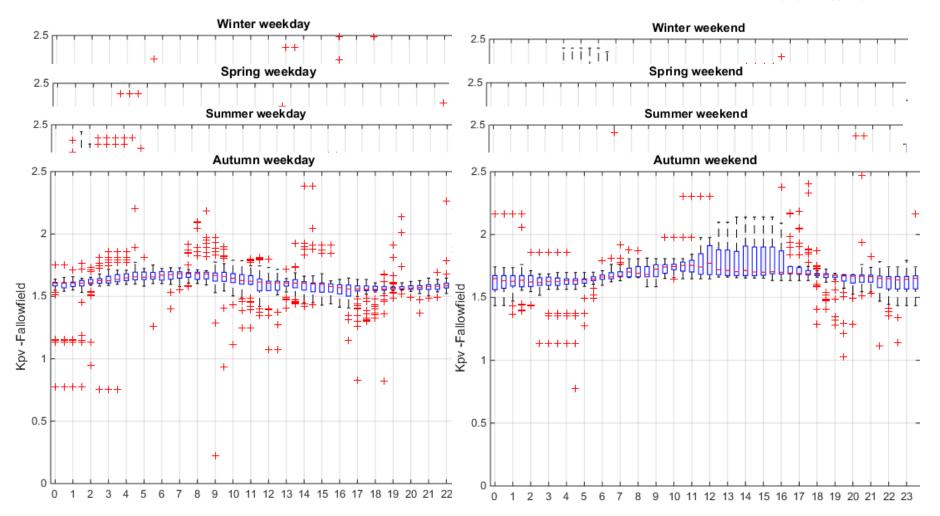


$\frown$	ZIP and exponential model parameters for 3 substations								
	Substation	Туре	ZIP	Model Parameters	Exponential Model Parameters				
	Trafford Park North	Industrial	r	1, $I_p = 0.22$ , $P_p = -708$ 1, $I_Q = 0.83$ , $P_Q = -0.42$	$K_p = 1.63$ $K_q = 3.67$				
	Fallowfield	Domestic	$Z_p = 0.46, I_p = -0.91, P_p = -3040$ $Z_Q = 0.29, I_Q = -0.58, P_Q = -0.29$		$K_p = 1.55$ $K_q = 5.88$				
	Victoria Park	Mixed	$Z_p = 0.22, I_p = -0.44, P_p = -1483$ $Z_Q = 0.36, I_Q = -0.73 P_Q = -0.37$		$K_p = 0.83$ $K_q = 5.32$				
Simplici	Simplicity: 1 parameter to represent P-V relationship				ZIP model is mo to any change	re			
Coherence: Self-explanatory and straightforward			concept will roll whole UK. Easily	opplication: CLAS -over throughout deployable and onally intensive	t the				

#### Voltage-demand matrix development







#### Voltage-demand matrix: summary





K <sub>p</sub>	Mainly domestic			Industrial/commercl			Mixed			Seasonal avg. for
	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	all substations
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 <sub>q</sub>	Main	Mainly domestic Industrial/commercl Mixed			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



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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].

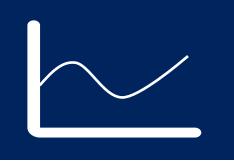
New types of loads are increasing in the power network. This causes the higher Kp and Kq values.

#### Conclusions



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Load model development

Load models based on 15 Electricity North West primary substations field measurements Load model validation

Load models based on CLASS trial 1 data across entire annual cycle Voltage-demand relationship matrix

24 hour (48 x ½ hr) matrix for the whole year for 60 primary substations

## QUESTIONS

# ANSWERS



Dr Luis (Nando) Ochoa Andrea Ballanti Demand response quantification methodology and results



The University of Manchester



#### Outline

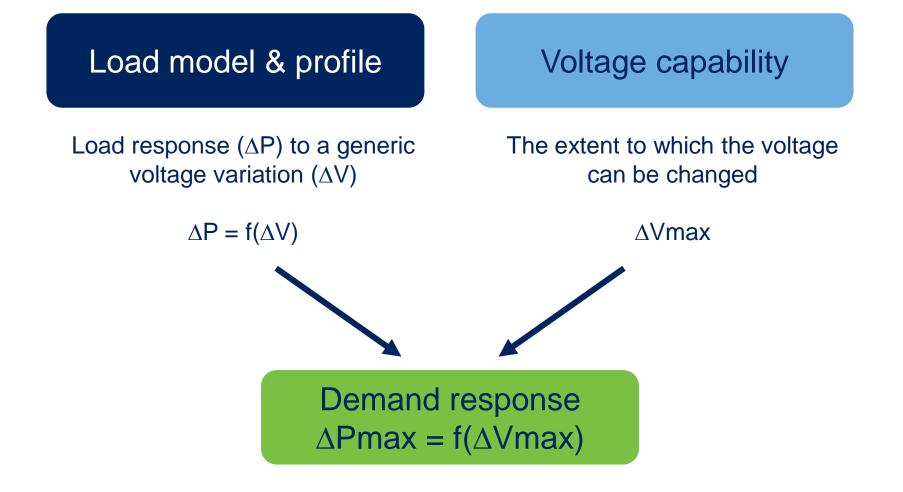


Voltage-led demand response	Demand response quantification methodology	Demand response results
Concept	Load modelling Voltage capability	Electricity North West area UK

#### DR quantification: methodology

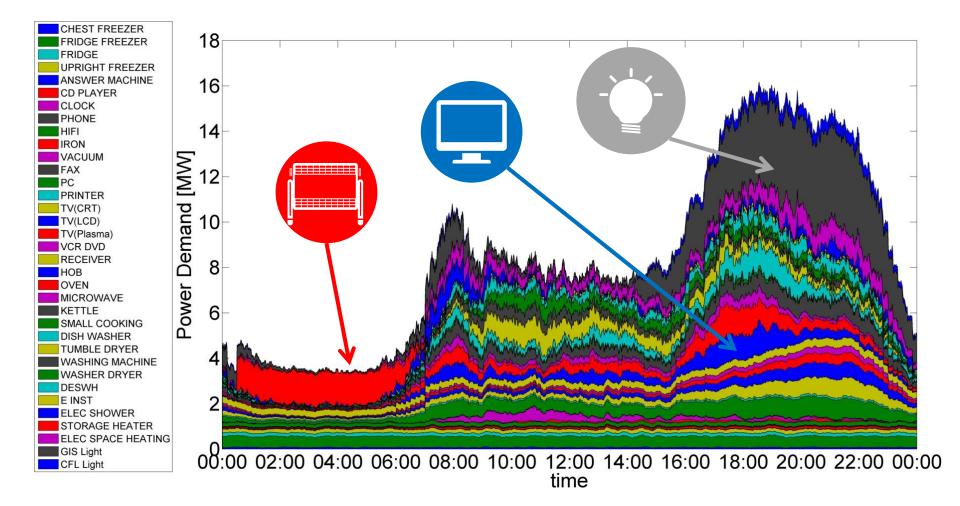






#### Aggregated demand profile



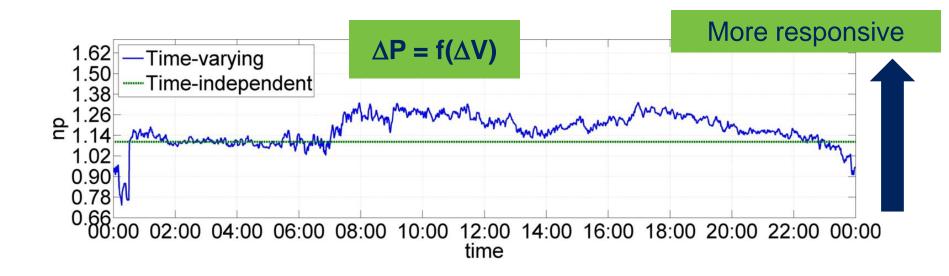


#### Aggregated load model



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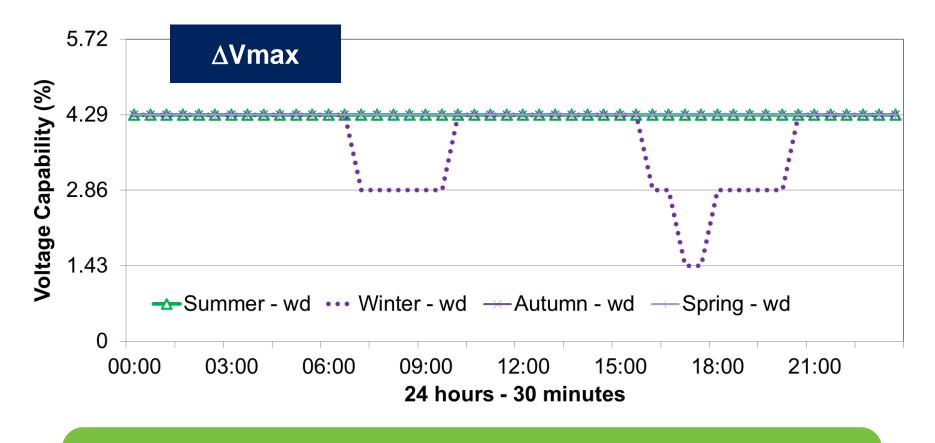


$$P(t) = P_0(t) \left(\frac{V}{V_0}\right)^{np(t)}$$
Load composition varies  
 $\rightarrow$  Responsiveness of the load varies

#### Voltage capability: conservative



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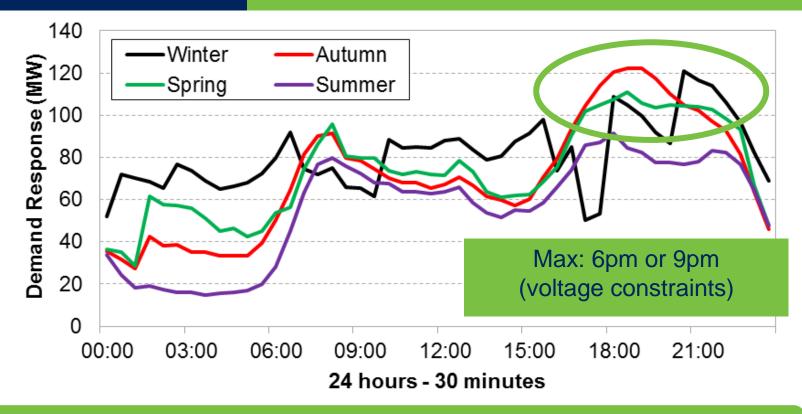
2.86% and 4.29% voltage reduction OK most of the time

>99% customers compliant



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



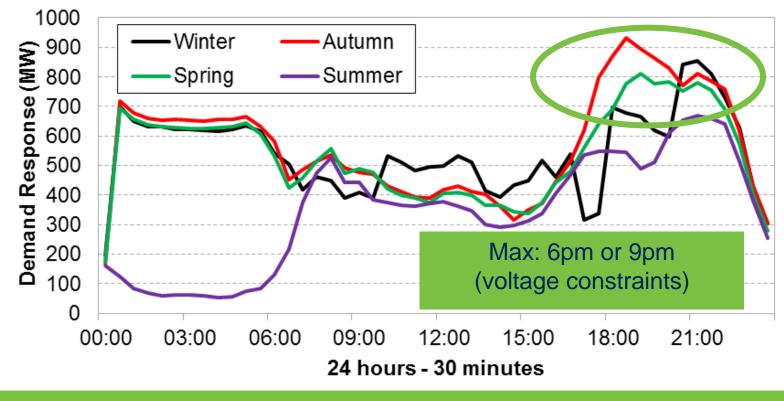
**Conservative** voltage capability

Min. summer night – Max. winter-autumn peak



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



Conservative voltage capability

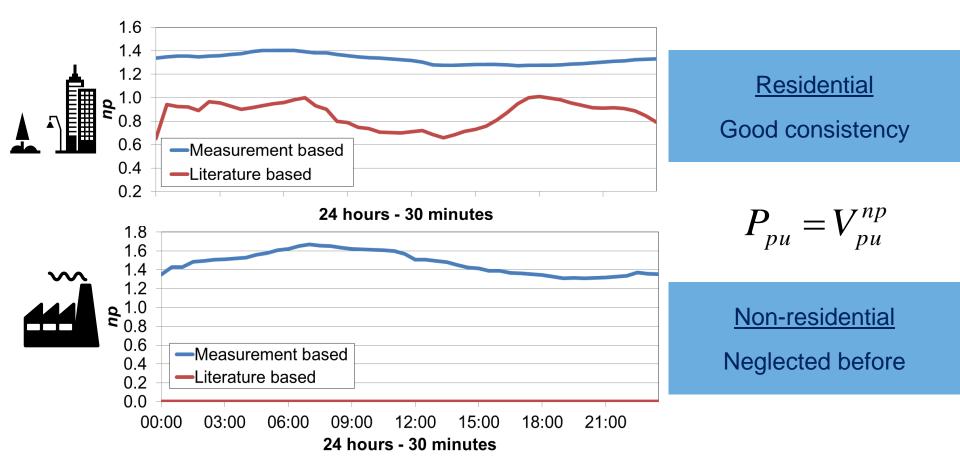
Min. summer night – Max. winter - autumn

#### Measurement-based load models\*





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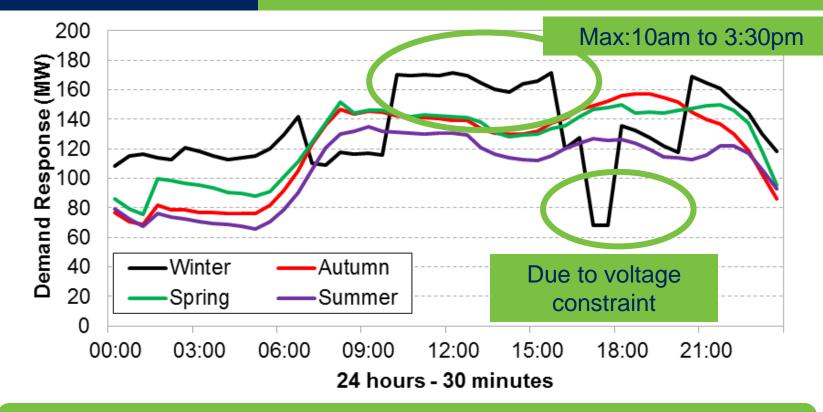
\* Load models produced by Work Package 1 of the CLASS Project (Dr Hasan and Prof Milanovic, The University of Manchester)





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



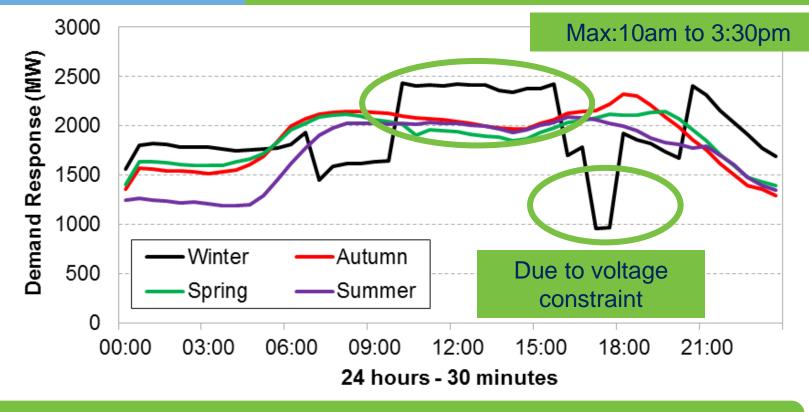
Conservative voltage capability

Min. summer night – Max. winter at noon



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



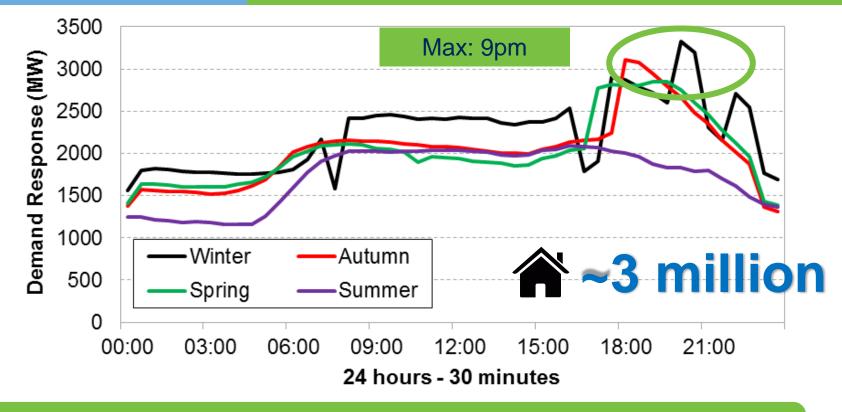
**Conservative** voltage capability

Min. winter ~6pm – Max. winter at noon





### 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	Max in autumn (~6pm)
EHV-HV-LV networks	or winter (~noon)
Measurement-based load	Min in summer night
models (WP1)	(~3-4am) or winter (~6pm)
Impacts on LV customers	

## QUESTIONS

# ANSWERS



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



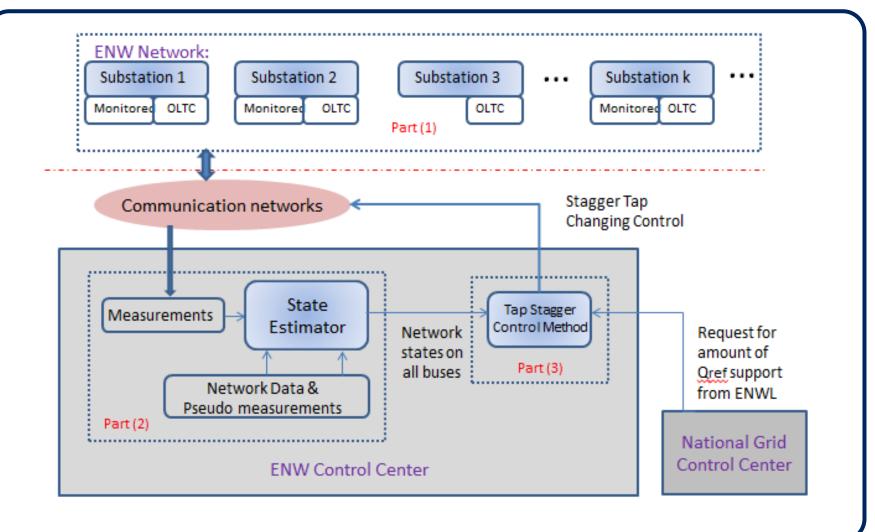


Aims	Techniques	Motivations	In addition
Assess the Electricity North West reactive power absorption capability through the use of the tap staggering technique and validate the estimated results with site trial data	The operation of parallel transformers (at primary substations) with staggered taps can 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









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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				

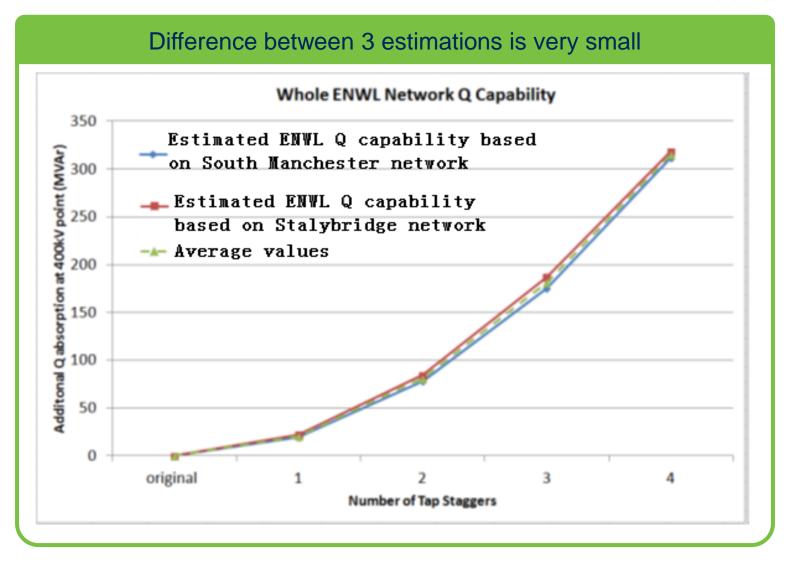
#### Estimation based on the average values of the two network

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



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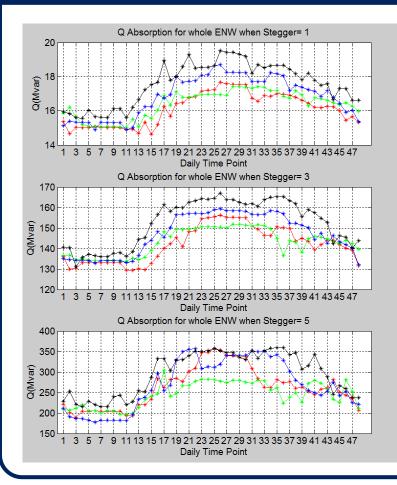


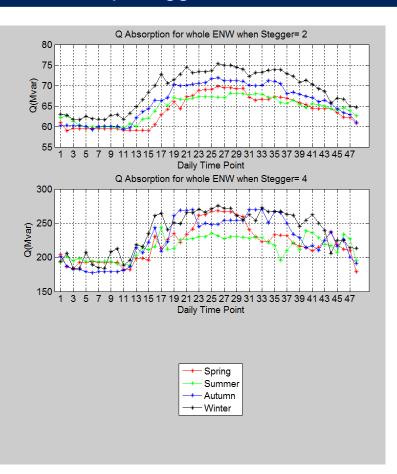
# Reactive power capability study with load profiles



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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





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

	Max No. of staggered	Stagger=1		L	Stagger=2			Stagger=3		Stagger=4		Stagger=5	
Extra Q absorption	taps (MVAr)	Min	Ma	x 1	Min Max		N	Min Max		Min Max		Min	Max
caused by tap stagger	Spring	14.63	17.	66 5	8.93	69.8	12	9.44	156.12	178.98	267.89	189.42	358.27
	Summer	15.04	17.	43 5	9.71	68.12	13	3.76	151.77	188.61	244.26	196.48	303.72
	Autumn	Autumn 14.89		.7 5	9.21	71.91	13	2.13	159.33	177.48	270.09	177.48	356.22
	Winter 1		/ 19.	53 6	1.62	75.3	13	1.2	166.99	184.1	275.14	215.43	359.41
	Max No. of staggered taps		Stagger=		St	tagger	=2	Stag	gger=3 Sta		ger=4	Stagger=5	
	(MW)	W) 1		Max	Mi	n N	⁄Iax	Min	Max	Min	Max	Min	Max
Extra P losses	Spring	0	.504	0.675	5 2.6	56 3.	.218	6.397	7.619	8.732	13.438	9.803	18.015
caused by tap stagger	Summer	0	.539	0.705	5 2.7	2 3	.16	6.535	7.426	9.433	12.03	10.156	14.691
	Autumn	0	.634	0.86	2.9	84 3.	.616	6.795	8.256	9.436	14.104	9.436	18.394
	Winter	0	.616	0.807	7 3.0	02 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





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<b>Objective substation:</b> Dickinson St	ΔQ(MVAr)	Stagger=1	Stagger=2	Stagger=3
Measure points:	Trial Data	0	0.2	0.4
primary side of the transformers	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

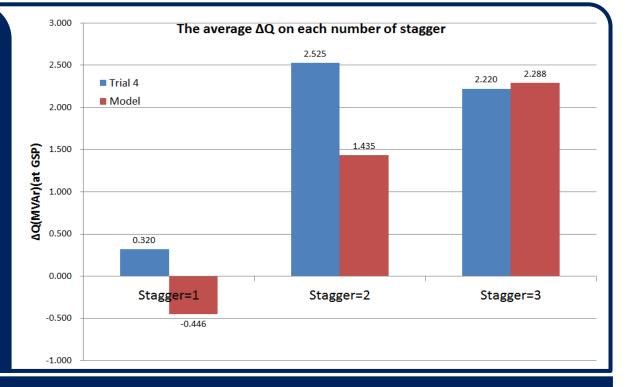




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**Objective substations:** 7 CLASS substations in Stalybridge network

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%.

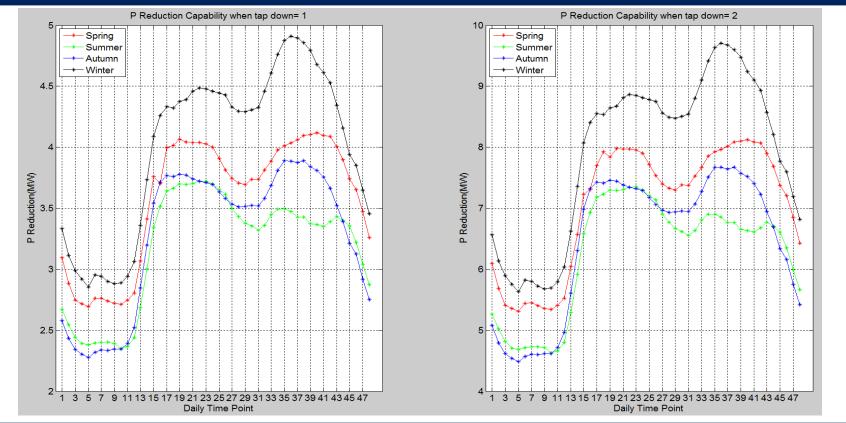
However for stagger=1 and stagger=2, because the extra Q absorption values caused by tap stagger are much smaller than that for stagger=3, the measured Q differences at GSP for these two scenarios will be more badly affected by the base load changes.

# 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





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

 Q absorption capability of the ENW network over the 24-hour (48 × <sup>1</sup>/<sub>2</sub> hour) period in a day and in four seasons has been investigated

 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

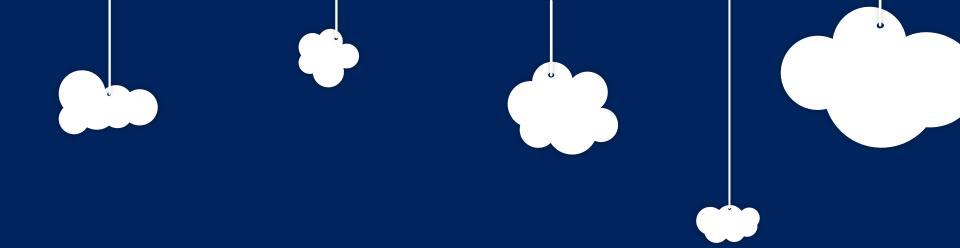
3. Annual load profiles for all primary substations in the Stalybridge network have been developed based on real monitoring data 6. In addition, the demand reduction capability of the modelled Stalybridge network has been investigated using the load models

# QUESTIONS

# ANSWERS



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# **Tea break**



Prof Joe Spencer
 Prof. Zhongdong Wang
 Dongmiao Wang
 Asset health





The University of Manchester



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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 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





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# Preliminary work of CLASS trial tests

The health of the main tank is only concerned with transformer tripping and tap staggering Suggestions on data monitoring and device installation Data analysis for main tank

The current of an operating transformer will double following the trip of the other parallel transformer The maximum current difference due to tap staggering is 150A if the load power factor is above 0.9 according to monitoring data

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

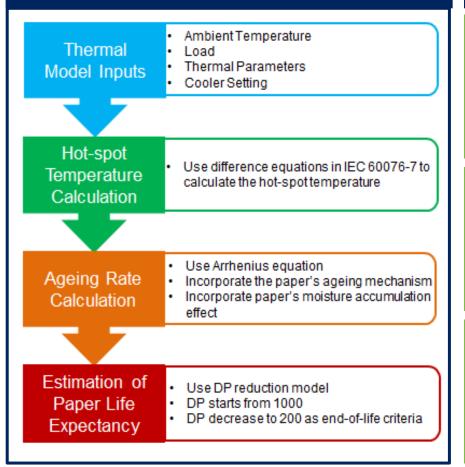
# Assessment of main tank health





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# Thermal modelling



# 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





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## 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



# Assessment of tap changer health





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### 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 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 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



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# 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

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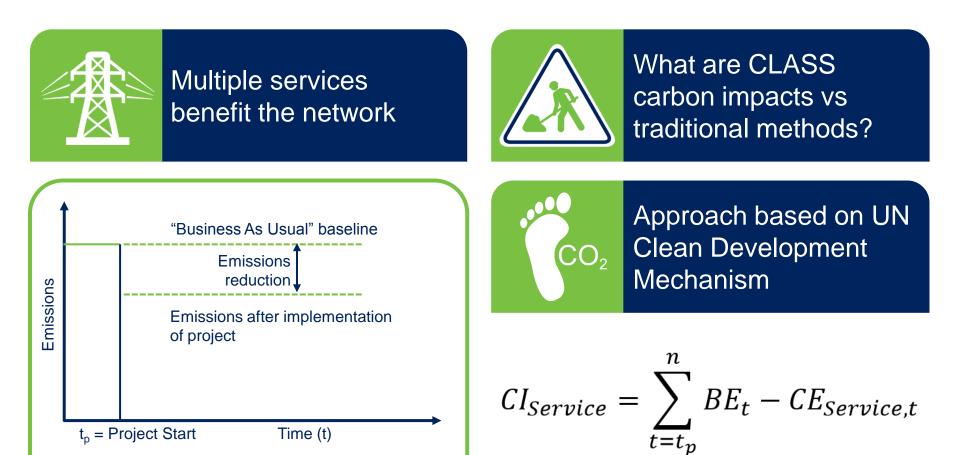
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## What are the carbon impacts of CLASS?





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# Business as usual baselines

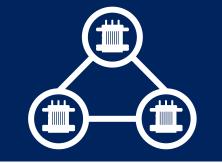


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### How will the three CLASS services be otherwise provided?







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 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<sub>2e</sub> 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







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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



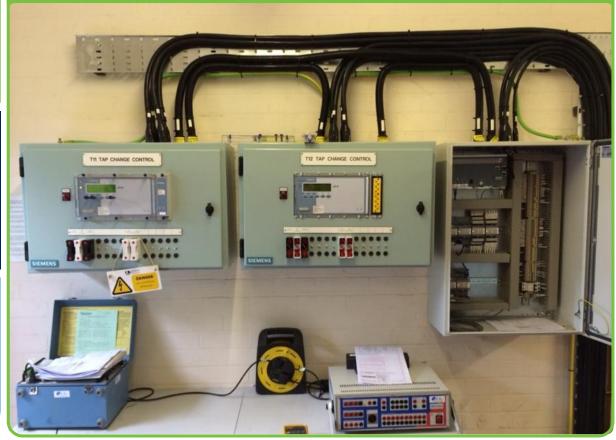
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### Carbon impact estimated at 33kg CO<sub>2</sub>e

### Four orders of magnitude less than transformer reinforcement

# ICE v2.0 emissions factors for consistency

#### **CLASS** autonomous substation controllers



# Asset carbon profiles



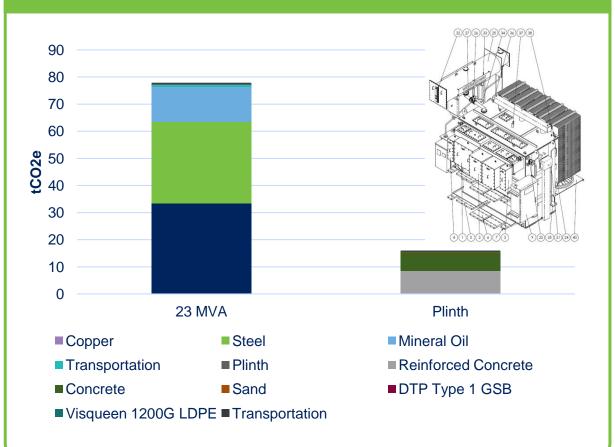
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Metal content of transformers not the only impact of reinforcement

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



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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**

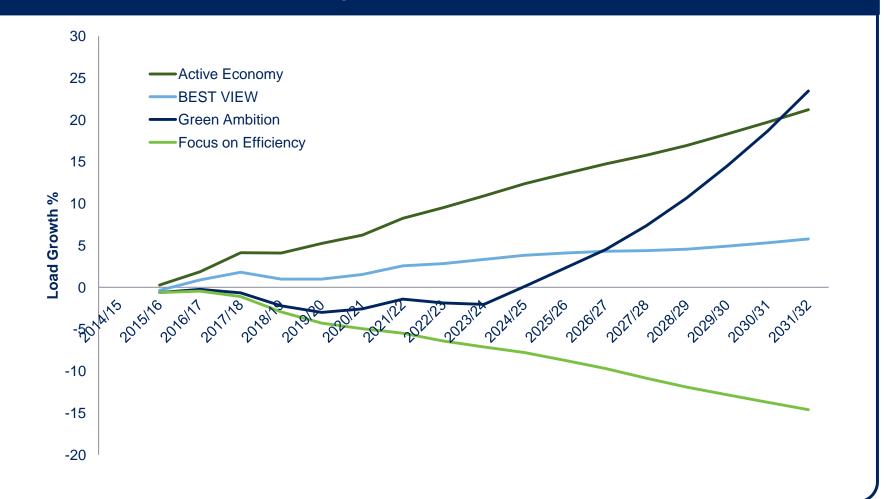






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### Load growth scenarios





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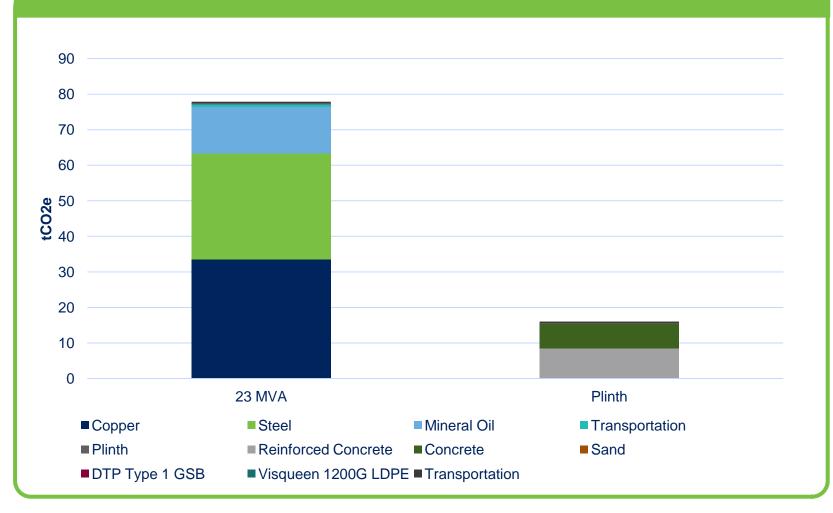
### Reinforcement modelling – Substation reinforcement deferred

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#### Carbon embodied in 23MVA transformer installation





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Asset Carbon Impact

# 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<sub>2</sub>e

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

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

#### Peak Demand Reduction: asset carbon deferral



Celectricity

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# Operations carbon approach: PDR

# Load growth scenarios





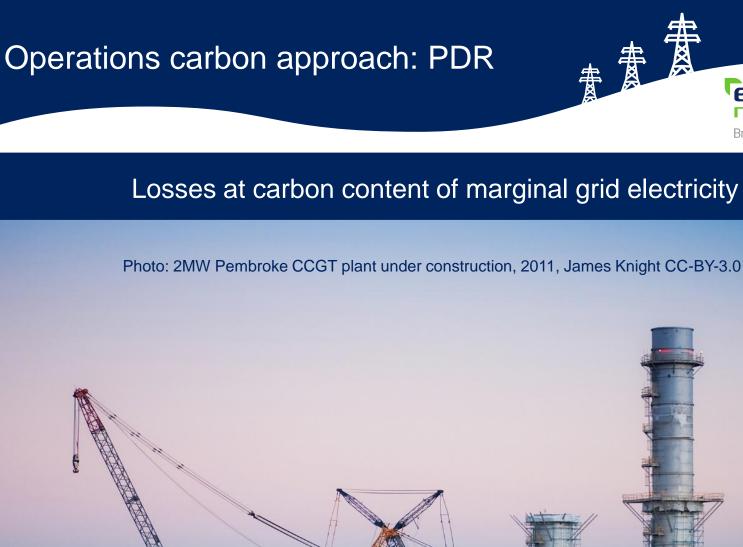
# Operations carbon approach: PDR

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**Celectricity** 

### Reinforcement modelling – Years deferred by CLASS

			Conditional Formal In Sightinght of MB 5 rating	4.4	Conditional Formal In highlight of HE 2 rating	Conditional Formal in highlight of HP 5 values		Conditional Formal In highlight of HD 2 values
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OATSNORTH 35	11.11 11.22 1.73 1.17 1 21.74 21.01 5.35 1.37 1 11.31 11.51 1.31	12.11 21.21 21.15	22.81 22.35 22.85 22.85 23.91 23.52 23.75 24.84 28.38 28.52 24.85 24.85 24.91 23.52 25.75 24.84		24.35 24.65 24.33 25.41 25.44 25.65 25.37 26.21 22.45 22.55 24.54 25.21 25.44 25.55 25.37 26.21	1 10.003 10.007 10.007 10.016 10.017 10.007 10.007 10.017 10.0050 10.0		22.0054 25.4023 25.4544 25.6746 25.0055 24.4244 24.4055 24.
VICK 35	3         13.33         11.33         3.31         1.31           5         3.16         3.12         1.31         1.43           5         3.16         3.12         1.31         1.43           3         11.44         3.31         3.24         1.35           3         4.31         4.21         1.44         1.35	16.01 10.26 10.31 17.51 10.74 10.33	18.41 18.58 18.81 18.81 18.55 11.85 11.24 11.57 11.82 11.15 11.44 11.45 11.55 11.57 11.85 12.85		11.52 11.67 11.73 11.51 12.82 12.14 12.23 12.45 12.13 12.34 12.48 12.58 12.72 12.84 13.88 13.15	1 5.78738 5.34242 10.465 10.4685 10.2735 10.5787 10.5664 10.6591155 1 10.3545 10.5175 10.7534 10.7406 10.8682 10.5785 11.478 11.5808788	2	18.8275 18.5582 11.8555 11.1354 11.5511 11.4155 11.5487 11
SIDE 33 TOH OH MERSEY 35			4.51 4.51 4.71 4.71 4.83 4.81 4.87 5.83 14.53 14.85 15.13 15.11 15.35 15.51 15.73 15.37		5.85 5.46 5.22 5.27 5.52 5.87 5.45 5.51 16.18 16.55 16.57 16.74 16.85 17.86 17.26 17.46	II 4.32346 4.35734 4.45532 4.4353 4.54332 4.51688 4.67345 4.72846468 II 45.7486 45.3651 44.2782 44.2748 44.4587 44.5674 44.842 45.8457446		4.78834 4.85446 4.58344 4.55344 4.5384 5.84848 5.48732 5.4 15.2887 15.4864 15.5744 15.7342 15.874 16.8324 16.2218 16
OH UNDER LYNE 55 OH-Gallarer 55 TOOD DALE 55	1 27.49 26.34 6.62 8.37 1 47.24 42.26 12.00 8.71	57,81         28,22         28,45           22,85         17,37         18,45           19,72         16,62         17,47	28.55 28.37 23.52 23.54 23.54 38.34 38.22 38.23 34.45 18.28 18.43 18.38 18.38 15.14 13.23 13.55 13.88 17.22 18.44 17.18 17.18 17.17 18.24 18.53 18.18		31.55 31.37 32.31 32.54 32.34 33.25 33.55 34.85 28.14 28.48 28.52 28.83 21.52 21.23 21.43 21.73 15.84 15.23 15.58 15.78 15.88 28.88 28.58 28.51 28.55	8 26.844 27.2565 27.0465 27.0394 28.4468 28.4468 28.4468 28.255457 8 47.4184 47.2738 47.2574 47.2545 47.2532 48.423 48.4244 48.6823684 4 46.4855 46.6385 16.8685 46.2535 45.3685 47.4456 47.4785 47.25364		23.6547 38.4472 38.353 38.6887 38.3532 34.2575 34.575 3 18.3275 35.4795 35.3788 35.2777 35.7554 35.3522 28.1883 20 47.3821 48.4548 48.323 48.5472 48.6852 48.1474 45.4884 4
TRIA 33	17.24         17.25         17.24         17.26         17.24         17.27         17.24         17.24         17.24         17.24         17.24         17.24         17.24         17.24         17.24         17.24         17.25         18.37 <th< td=""><td>13.72 10.32 17.37 15.00 5.40 5.54 51.00 24.34 25.24</td><td>7.66 17.49 16.00 16.07 16.07 16.07 16.20 16.23 16.00 9.66 5.14 16.13 16.14 16.24 16.43 16.53 25.31 25.71 26.21 26.27 26.56 26.14 27.52 27.64</td><td></td><td>10.00 10.23 10.24 10.20 10.00 00.01 00.01 00.01 00.00</td><td>16.1033     16.4013     16.0160     16.2033     16.3062     16.3063     16.3063     16.3063     16.3063     16.3063     16.3063     16.3063     16.3063     16.306     16.306     16.306     16.30     16</td><td></td><td>17.3021 10.7310 10.323 10.3172 10.4032 10.473 13.0397 12 10.0465 10.177 10.286 10.3316 10.4053 10.5304 10.7157 10 26.3115 26.6533 26.5335 27.2150 27.4753 27.4756 27.2166 20.066</td></th<>	13.72 10.32 17.37 15.00 5.40 5.54 51.00 24.34 25.24	7.66 17.49 16.00 16.07 16.07 16.07 16.20 16.23 16.00 9.66 5.14 16.13 16.14 16.24 16.43 16.53 25.31 25.71 26.21 26.27 26.56 26.14 27.52 27.64		10.00 10.23 10.24 10.20 10.00 00.01 00.01 00.01 00.00	16.1033     16.4013     16.0160     16.2033     16.3062     16.3063     16.3063     16.3063     16.3063     16.3063     16.3063     16.3063     16.3063     16.306     16.306     16.306     16.30     16		17.3021 10.7310 10.323 10.3172 10.4032 10.473 13.0397 12 10.0465 10.177 10.286 10.3316 10.4053 10.5304 10.7157 10 26.3115 26.6533 26.5335 27.2150 27.4753 27.4756 27.2166 20.066
HeH 33	1 23.31 23.75 2.72 1.33 1 11.46 11.36 1.43 1.33 1 12.76 12.51 2.53 1.31		18.35 11.45 11.37 11.37 11.58 11.68 11.82 11.36 15.58 15.58 15.58 16.21 16.21 16.21 16.35 16.35 16.27 16.35		12.12 12.27 12.48 12.53 12.65 12.77 12.32 13.88 15.14 15.33 15.58 15.64 15.88 15.58 16.45 16.54	1 41.2355 41.4577 41.6324 41.6123 41.0163 41.3005 41.4143 41.244652 1 42.0632 49.0650 49.3507 49.3527 49.5049 49.623 49.062 44.0407025		11.3003 11.537 11.6605 11.7002 11.0071 12.0055 12.1476 12 14.2233 14.4142 14.5606 14.7101 14.0547 14.3336 15.1772 12
ER PRIDGE 33	1         1 <th1< th=""> <th1< th=""> <th1< th=""> <th1< th=""></th1<></th1<></th1<></th1<>	22.06 20.07 21.05 22.06 15.50 15.74 15.50 12.01 12.31	21.83 21.42 21.38 21.83 22.13 22.54 22.76 23.83 15.73 16.83 16.33 16.53 16.57 16.73 17.84 17.24		23.53 23.63 25.88 24.13 24.35 24.53 24.88 25.18 17.46 17.63 17.88 18.86 18.23 18.41 18.63 18.85	I 19.022 20.1942 20.5055 20.5769 20.0059 21.002 21.090 21.6409245 I 14.0505 15.0721 15.41 15.4091 15.5746 15.7210 16.0106 16.20600177	1	21.5271 22.2121 22.4455 22.5884 22.8862 23.4462 23.5877 23 16.4145 16.6277 16.8857 16.5782 17.1925 17.5823 17.5877 15
ARA ST 53	3 12.23 12.82 2.55 8.38 3 18.66 18.64 8.58 1.88	15.58 12.81 12.31 17.58 11.25 11.23	12.35 19.15 19.45 19.44 19.53 19.72 19.38 14.14 11.32 11.58 11.76 11.75 11.88 11.39 12.22 12.36		14.32 14.51 14.55 14.81 14.35 15.18 15.28 15.46 12.52 12.53 12.82 12.35 13.87 13.28 13.36 13.52	I 12.1787 12.3623 12.6335 12.6351 12.7744 12.8552 13.1586 13.2323873 I 18.6415 18.8831 11.8514 11.8465 11.1634 11.275 11.4878 11.6223218		15.4632 15.6382 15.7842 15.3257 14.8521 14.152 14.36 1 11.7746 11.5247 12.8525 12.1761 12.2866 12.4885 12.5558 1
OH DOCK RD 55 ORD 55	1 11.11 11.43 2.61 1.37 1 11.13 17.24 2.71 1.31	21.31 11.17 12.13	11.35 11.53 11.73 11.73 11.32 12.83 12.26 12.48 15.14 15.44 15.88 15.87 22.85 28.28 28.58 28.51 18.82 18.19 18.19 18.19 18.27 18.28 18.28 18.39	<b>7</b> 2	12.55 12.72 12.85 12.33 13.11 13.24 13.48 13.55 21.57 21.45 25.68 21.38 22.48 22.58 22.58 22.45 41.81 41.21 41.21 41.55 41.42 41.52 41.25 41.21 41.31 41.47	I         10.6713         10.04         11.005         11.072         11.2072         11.5207         11.6555170           I         17.532         10.2754         10.6155         10.6757         10.0046         15.0121         13.4223         13.6223         13.6235177           I         17.532         10.2754         10.6155         10.6727         10.0046         15.0121         13.4223         13.6233177           I         1.6244         3.55141         3.24172         10.0027         13.0221         14.7027         14.7027         14.20194		11.053 11.3587 12.060 12.210 12.3217 12.4444 12.5517 12 15.3128 21.1415 22.577 22.5867 22.5868 22.7234 22.5813 22.62218 2 10.422 11.525 11.5775 11.72181 11.1775 11.3152 11.1152 1
AVE 35 AM 35 COUL 55	1 2.51 2.51 1.71 1.31 1 11.43 11.45 2.57 1.35 3 15.18 15.55 2.17 1.35	22.16 11.41 15.11 22.16 16.35 16.61	15.47 15.47 15.48 15.58 28.42 28.51 28.53 28.53 15.55 15.55 15.54 17.25 15.55		21.28 21.48 21.21 21.25 12.41 22.35 22.41 22.35 12.42 12.41 12.41 14.55 14.15 12.41 15.5 14.15 1	1 11.0142 10.2001 1.7445 1.7727 1.000 1.7162 1.717 10.001 1 11.0142 10.2001 10.7402 10.7410 10.000 10.000 10.441 10.676526 1 15.6474 15.6500 10.2501 10.2420 10.4236 10.5710 10.601 17.005544		15.3235 28.4005 28.4047 28.6142 28.0043 24.005 24.2524 2 47.3054 47.5244 47.2245 14.3051 48.0653 48.2662 48.4622 4
DURN 55 DURN RD CLAYTON 55			16.22 16.40 16.05 16.04 17.03 17.13 17.51 17.72 18.03 18.15 18.41 18.41 18.53 18.53 18.63 18.03 18.55		17.54 18.18 18.37 18.55 18.73 18.52 15.14 15.37 11.83 11.24 11.35 11.47 11.58 11.63 11.83 11.83	1 45.2403 45.403 45.0351 45.0232 45.0353 45.4557 45.4546 46.654020 1 3.42676 3.57524 3.71517 3.71543 3.0344 3.31735 40.4765 40.2355357		45,8585 47,8876 47,2785 47,4478 47,5852 47,7845 47,592 4 48,4275 48,5534 48,5755 18,7854 48,884 48,5924 44,4225
7RIARS 33 LEY 55 POOL 55	1         12.37         13.44         3.43         1.37           3         3.46         5.44         2.46         1.37           3         472.37         11.31         2.11         1.33           3         472.47         11.31         2.11         1.33           3         472.47         12.61         1.53         1.53           3         412.41         42.61         4.55         1.53           3         412.41         43.52         4.05         1.54           3         411.23         5.64         5.65         1.16           44.45         4.45         4.45         4.45         4.45	17.88 12.82 12.85 22.86 13.31 13.44	12.85 19.87 19.95 19.95 19.58 19.59 19.89 14.85 19.40 19.40 19.40 19.40 19.40 14.45 14.45 14.55 14.72		14.23 14.41 14.57 14.72 14.85 15.88 15.18 15.58 14.31 15.18 15.27 15.42 15.56 15.72 15.38 16.83	1 42,0307 42,2044 42,5565 42,5580 42,5385 42,0465 43,0529 43,205400 1 42,6784 42,07 43,1585 43,1525 43,239 43,4247 43,6784 43,0392472		15.5748 15.5486 15.5557 15.8545 15.5558 14.8585 14.2557 1 14.846 14.1582 14.3585 14.4576 14.5252 14.7745 14.5457 1
IGTON 35	1 14.00 19.22 4.05 0.34 1 11.20 9.64 5.65 0.05	25.25 14.54 14.21 15.11 11.23 11.12	14.82 15.85 15.85 15.88 15.55 15.78 16.88 16.18 11.88 12.88 12.85 12.85 12.48 12.61 12.85 <b>15.88</b>	<b>7</b> 1	15.55 15.58 15.78 15.55 17.11 17.28 17.48 17.55 13.47 15.56 15.48 13.52 15.76 15.88 16.84 14.21	8 45.5287 44.448 44.4552 44.4587 44.6455 44.7573 45.8564 45.2424455 8 41.485 44.5552 41.62 41.6448 41.7444 41.8554 42.8785 42.2282785		15.4879 15.5884 15.7753 15.3972 16.8849 16.242 16.4942 1 12.3775 12.5382 12.6724 12.8825 12.5187 13.8424 13.2848 1
HLESAHDS 33 HE 33	4 42 44 46 54 2 52 1 44	22 85 48 48 48 48 42	12,85 12,25 12,52 12,52 12,52 12,55 12,77 13,82 13,47 18,37 18,55 13,88 13,87 13,28 13,47 13,83 28,87 16,13 16,38 16,55 16,74 16,55 17,83 17,84 17,84		19.34 19.51 19.65 19.18 19.32 14.86 14.29 14.48 28.52 28.53 28.84 24.82 24.24 24.42 24.58 24.34 17.14 14.17 14.27 14.45 14.62 18.81 19.13 19.35	I         41.3337         41.5422         41.7285         41.755         41.836         42.0354         42.37530           I         47.2788         17.5421         47.3254         42.3254         42.82530         48.862530           I         47.6144         45.3352         15.3264         47.3254         16.6463         48.862530		12.5373 12.7883 12.8585 12.3581 13.858 13.2451 13.858 13.1843 13.3533 13.5585 13.2613 13.3487 28.1335 28.5775 15.7785 15.3883 13.7213 13.3465 13.2441 13.2784 13.2878 13.2875
0RD 55 HAWGATE 55	1         15.22         15.13         1.34         1.01           3         15.22         15.13         1.34         1.01           3         15.23         15.13         1.35         1.33           3         15.24         1.05         1.33           1         12.32         11.05         2.31         1.37	22.86 12.63 12.37 11.75 12.54 12.62	12.81 13.21 13.51 13.58 13.85 13.78 14.84 14.28 12.66 12.86 13.15 13.14 13.23 13.41 13.67 15.83		14.53 14.57 14.73 14.81 14.52 14.71 15.55 15.53 14.81 14.13 14.34 14.48 14.52 14.75 14.54 15.12	1 42.2257 42.4482 42.6366 42.6383 42.4383 43.4353 43.4481 43.4524665 1 41.6355 42.4882 42.5374 42.5523 42.4883 42.6873 42.6875		13.524 13.6338 13.8465 13.3886 14.1156 14.2562 14.4243 13.4632 13.5343 13.4771 13.6154 13.733 13.8758 14.84 1
ALL 33	1 16.21 16.21 1.00 1.00 1 16.37 16.07 2.31 1.30	17.51 14.84 15.83	15.87 15.31 15.65 15.65 15.82 15.37 16.27 16.46 14.33 15.16 15.58 15.43 15.67 15.82 16.11 16.38		16.57 16.83 17.87 17.24 17.40 <u>17.57 17.24 17.61</u> 16.51 16.73 16.31 17.88 17.23 17.41 17.51 17.82	3 14.1673 14.3384 14.713 14.7864 14.8784 15.8187 15.234 15.4738457 8 14.8312 14.2521 14.5716 14.5651 14.7272 14.8665 15.1471 15.5243877		15.5748 15.8756 16.8456 16.2483 16.3574 16.5283 16.7158 1 15.5243 15.723 15.8314 16.8545 16.2882 16.3646 16.5552 1
WAY 33 NEATH 33	1 3.53 3.37 1.74 1.30 1 26.63 26.53 2.03 1.35 3 11.32 11.00 1.62 1.35	22.86 9.81 9.55 41.88 27.85 28.25	18.81 18.47 18.48 18.33 18.51 18.61 18.84 18.54 28.51 28.75 25.48 25.58 25.71 25.53 58.55 58.52		11.88 11.22 11.34 11.46 11.55 11.58 11.82 11.35 51.51 31.72 32.85 32.33 32.68 33.81 33.48 33.88	8 3.41233 3.56423 3.77557 3.7742 3.87335 3.37356 18.1616 18.2885586 8 26.6878 27.8268 27.6527 27.6283 27.5277 28.1518 28.7235 23.8681578	1	18.4126 18.548 18.5683 18.7784 18.8684 18.3764 11.1863 1 23.4335 23.8161 38.1354 38.4447 38.721 31.827 31.3342
WAY 33 HAW 33 EY CENTRE 33	1         11.32         11.00         1.62         0.33           1         6.60         6.50         0.56         1.00           3         12.05         12.16         4.17         0.35	41.0         27.05         20.25           22.06         11.30         11.55           22.06         5.30         5.37	11.58 11.76 12.82 12.82 12.45 12.27 12.58 12.64 6.33 7.18 7.26 7.25 7.33 7.48 7.54 7.53 13.47 13.53 13.53 14.41 14.28 14.55 14.72		12.11 12.37 13.11 13.25 13.37 13.31 13.45 13.42 7.73 7.43 7.31 1.41 1.47 1.45 1.45 1.44 14.31 13.14 13.14 1.47 1.45 1.45 1.44	I         10.0025         11.0131         11.2101         11.2010         11.2		12.0382 12.0347 12.0252 12.4518 12.5548 12.035 12.041 1 7.25624 7.25858 7.45551 7.51588 7.5841 12.6555 7.75828 14.0416 14.0357 14.3557 14.655 14.2525 14.2728 14.355 1
			13.47 13.43 13.33 13.33 14.14 14.28 14.25 14.72 14.77 14.35 12.22 12.24 12.35 14.247 12.78 12.15 17.41 17.41 14.17 14.17 14.27 14.44 14.23 13.14		14.31 45.41 45.26 45.42 45.55 45.74 45.33 45.43 13.82 45.43 13.33 45.45 15.55 45.72 45.84 44.85 13.25 45.51 45.54 45.34 28.83 28.23 28.23	I 16.4665 16.1623 13.1544 13.1465 13.2548 13.4665 13.1738 13.1738 13.1538063 I 41.6655 11.2347 11.4865 11.4814 11.6832 11.7485 11.3484 12.1738 I 46.5583 46.4645 46.3854 46.3844 17.4785 17.5328 17.5533 17.1666768		12,2354 12,3344 12,5268 12,5554 12,7785 12,8375 19,364 1 12,2354 12,3344 12,5268 12,5554 12,7785 12,8375 19,1584 1 18,1352 18,3345 18,5277 18,2473 18,8078 13,0753 13,3187 1
W DECK 33 OUGH DRIDGE 33 TOWH CTR 33	1         11.23         11.13         1.21         1.33           3         16.44         16.33         1.33         1.01           3         14.74         14.46         2.54         1.31           3         14.74         14.46         2.54         1.31           3         15.52         14.33         5.11         1.31           3         42.23         12.41         1.41         1.31           3         42.23         12.41         1.41         1.31           3         42.23         12.41         1.42         1.32	17.50 12.24 12.30 22.05 15.15 15.20	12.42 12.61 12.83 12.83 13.85 15.15 13.48 15.56 16.52 16.58 16.35 16.54 17.15 17.25 17.62 17.85		15,75 15,51 14,86 14,21 14,34 14,41 14,65 14,65 14,85 14,85 14,85 14,25 14,25 14,45 14,54 14,54 15,85 15,25 15,45	11.6785 11.8547 12.1285 12.115 12.2455 12.3657 12.5551 12.7465782 15.3422 15.5858 15.5858 15.3552 15.3251 16.4855 16.5526 16.5524 16.7552752		12.3183 13.8782 13.2182 13.3533 13.4751 13.6833 13.7784 14.63716 17.1322 17.5765 17.5546 17.714 17.8384 18.4821 1
PELLST 33 HIST 35	1 12.20 12.20 1.43 1.00 1 20.40 27.05 1.32 0.35	17.58 12.42 12.75 36.88 23.86 38.48	12.73 12.33 13.28 13.27 13.42 13.55 13.88 13.37 38.18 38.66 51.34 51.33 51.68 51.38 52.58 52.58		14.15 14.33 14.48 14.63 14.76 14.51 15.83 15.27 33.53 33.82 34.18 34.53 34.85 35.13 35.61 <b>36.84</b>	8 12.8281 12.2834 12.4831 12.4775 12.5154 12.7355 12.375 13.4273283 1 28.3535 28.8155 23.4522 23.4655 23.2772 38.8588 38.5251 38.3845313		13.2355 13.4534 13.5137 13.7534 13.8782 14.8154 14.1823 1 31.3827 31.7387 32.1311 32.4583 32.7555 33.8817 33.4733
T 15	1         7.11         7.73         1.35         4.11           1         12.43         11.51         6.53         1.15           1         12.41         11.77         5.13         1.37	22.45 7.55 E.47 22.45 12.55 12.32 22.45 12.54 12.42	8.45 8.52 8.51 8.58 8.68 8.68 8.84 8.55 12.35 49.46 45.46 45.45 45.68 45.73 45.39 44.45 12.85 45.86 45.55 45.54 45.54 45.24 45.8 45.73		5.85 5.48 5.28 5.57 5.46 5.55 5.67 5.78 14.55 14.52 14.67 14.85 14.56 15.11 15.23 15.47 14.22 14.81 14.55 14.51 14.51 15.13	I 7.20415 7.02240 7.35704 7.35426 0.00524 0.45566 0.54567 0.44055470 I 42.4785 12.5745 12.6407 12.645 12.7057 12.5046 13.406 15.3020673		8.51985 8.62978 8.7222 8.81174 8.89171 8.58827 5.88655 5 19.478 19.6481 19.7942 19.8558 14.8628 14.2824 14.3785 1
ETOH 33 ST 55 SAL MAHCHESTER 35	1 12.11 11.27 1.15 1.27 1 12.15 11.36 1.74 1.35 1 13.61 13.64 2.17 1.35	22.85 12.58 12.82 22.85 12.58 12.78 22.84 14.81 14.82	12.85 13.86 13.55 13.34 13.45 13.62 13.88 14.84 12.73 12.33 13.22 13.21 13.56 13.43 13.74 13.8 14.56 14.58 14.51 14.31 15.81 15.58 15.58 15.58		14.22 14.48 14.55 14.71 14.84 14.35 15.17 15.35 14.88 14.25 14.42 14.57 14.78 14.84 15.82 15.28 15.88 14.83 14.25 14.57 14.78 16.74 15.74 15.74	1 42.002 42.2735 42.5405 42.545 42.6025 42.0025 45.0444 45.4950502 1 44.3564 42.4545 42.427 42.4245 42.5337 42.7415 42.5477 49.00360505 1 45.455 45.2125 44.2140 44.0055 44.2145 44.2514 44.5512 44.21036		15.5654 15.5484 15.6854 15.8255 15.8544 14.85 14.2558 1 15.2355 15.4485 15.5525 15.6515 15.4155 15.5535 14.4185 14.5285 15.4225 15.2844 15.644 15.5812 15.7535 15.5225 1
ERTON 55	1 16.36 15.21 6.82 8.33 1 28.64 28.85 4.25 8.92	21.11 17.21 17.22 21.15 24.45 24.54	17.27 17.54 17.34 17.35 18.48 18.58		13.11 13.35 13.55 13.75 13.34 28.14 28.38 28.14 23.57 24.28 24.55 25.15 25.12 25.12 25.12 25.12	1 46.2347 46.4384 46.86 46.8525 47.8484 47.2842 47.5258 47.7383322 24.3666 28.6834 24.4532 24.4488 24.3234 24.5142 24.3686 22.2453658		17.3588 18.1922 18.387 18.5758 18.7444 18.3941 19.1551 22.5548 22.8247 23.8551 23.9855 23.5474 23.7548 24.8527 2
ELWHARF 33 EHRD 33	1         3.51         3.45         1.32         1.01           1         14.45         14.34         1.73         1.33           1         15.37         15.24         2.02         1.33	22.85 5.72 5.72 16.68 14.37 15.28	3.73 3.73 3.88 3.88 3.82 3.32 3.36 4.83 4.81 15.24 15.43 15.83 15.83 16.88 16.15 16.46 16.55	<b>7</b> 1	4.13         4.18         4.23         4.37         4.31         4.35         4.41         4.46           16.85         17.88         17.28         17.44         17.58         17.28         17.35         18.28	8 5.51855 5.55555 5.64555 5.64555 5.64555 5.68445 5.71552 5.78552 5.85588573 8 14.5585 14.5555 14.8825 14.8756 15.8412 15.1854 15.47 15.6518523		3.00314 3.33362 3.37574 4.04655 4.05301 4.05337 4.14101 4 15.0521 16.0502 16.2301 16.3360 16.5456 16.7103 16.3001 1
	1 15.57 15.24 2.82 8.55 3 11.51 18.88 5.88 8.58	28.18 16.29 16.28 17.58 11.63 11.83	16.32 16.58 16.35 16.35 17.13 17.38 17.62 17.83 11.87 12.85 12.32 12.32 12.45 12.57 12.81 12.58		18.86 18.23 18.43 18.68 18.85 13.84 13.26 13.43 13.13 13.38 13.44 13.58 13.78 13.84 14.88 14.17	I 15.3447 15.5864 15.3358 15.3287 16.486 16.2582 16.5651 16.75381446 I 11.1533 11.323 11.5823 11.5778 11.7866 11.8173 12.8485 12.1842348		16.3743 17.435 17.3731 17.5575 17.7463 17.8333 18.1851 1 12.3378 12.4582 12.632 12.7617 12.8775 13.8858 13.1557 1
NE HULHE 55 THAM HILL 55	1         11.31         11.11         3.11         1.36           3         17.62         17.53         2.24         1.35           5         15.47         15.13         2.35         1.31	22.16 10.10 10.51 17.51 16.12 16.25 11.51 12.51 12.75	18.55 18.14 13.26 13.23 13.47 13.65 28.42 28.26 16.31 16.55 16.33 16.32 17.11 17.27 <b>37.38 17.8</b> 12.76 13.56 13.55 13.55 13.48 13.52 13.78 13.78	<b>7</b> 2	28.52 28.78 24.84 24.22 24.42 24.65 24.88 22.45 36.64 36.22 46.47 46.85 46.24 35.84 35.24 45.47 44.42 46.31 44.5 46.65 14.74 46.18 15.16 15.16	1         47.4354         47.27         10.107         10.303         10.304         10.4734         10.3224         13.0423539           1         45.3256         15.3663         15.3153         15.3004         16.0237         16.3644         16.73351           1         45.3256         15.3663         15.3153         15.3004         16.0237         16.3644         16.7304           1         41.3350         17.4353         17.4353         17.4353         17.4314         17.4184         17.4314		19.287 19.5978 19.747 19.3497 28.1987 28.5918 28.5718 2 16.5551 17.1755 17.5574 17.5558 17.6347 17.1785 18.1824 19.2718 19.4493 19.5172 19.7257 19.1519 19.3133 14.1514
ER RD 33 EY SOUTH 35 HDOH RD 35	3 12.14 11.23 1.13 1.00 3 13.14 13.03 1.17 1.00 4 12.54 12.07 12.04	31.51 12.51 12.75 17.51 15.71 15.51 22.45 12.45 15.47	12.76 12.36 13.25 13.25 13.48 13.52 13.78 13.94 13.33 14.15 14.47 14.46 14.62 14.76 13.54 15.24 13.18 13.51 15.51 13.51 14.57 13.88 14.75 14.31		16.10 16.30 16.40 16.31 16.44 16.43 16.25 16.44 16.64 15.41 15.61 15.78 15.34 16.83 16.25 16.44 16.64 14.43 16.58 16.58	11.3360 16.107 16.4363 16.4353 16.3313 16.710 16.350 14.105 13.8374 13.3837 13.6813 13.5358 13.7472 13.8771 14.135 14.384560 14.31451 14.31451 14.31457 14.2787 14.381 13.581 13.4524553		13.42741 13.4433 13.5474 13.7427 13.4333 13.3133 14.354 1 14.4883 14.6767 14.8338 14.3861 15.4221 15.2727 15.4535 15.625 15.8821 15.54535 14.8551 14.221 44.3526
LEYS 33 HJUNCTION 33	1         12.12         12.12         12.12         12.12         12.12         12.12         12.12         12.12         12.12         12.12         13.13         13.11         13.	17.51 15.54 14.83 17.51 18.37 14.27	14.15 14.55 14.57 14.57 14.15 14.37 15.25 15.45 11.51 11.41 11.75 11.75 11.16 11.57 12.21 12.34		15.65 15.05 16.00 16.17 16.91 16.40 16.67 16.07 12.50 12.66 12.00 12.33 15.04 15.17 13.33 15.43	I 45.2024 45.4546 45.7544 45.7075 45.3444 44.0732 44.3500 44.5066363 I 40.6456 40.7060 44.0206 44.0237 44.4464 44.2540 44.4641 44.5505374		14.633 14.004 15.0434 15.1378 15.3357 15.4005 15.6740 1 11.7473 11.3001 12.0275 12.1503 12.2612 12.3033 12.5233 1
R HILL 33 HE 55 RD 33	1 11.47 11.21 2.36 1.37 2 21.11 21.25 5.53 1.36 3 17.12 17.41 3.47 1.31	21.54 11.32 11.83 27.11 22.11 22.21	11.86 11.23 11.48 11.48 11.61 11.72 11.34 12.88 22.26 22.61 23.12 23.14 23.57 23.53 24.83 24.52		12.23 12.33 12.52 12.65 12.77 12.83 13.85 13.28 24.63 24.35 25.22 25.47 25.71 25.36 25.27 25.58	1 10.334 10.5577 10.7344 10.7035 10.3036 11.0120 11.2206 11.3513005 20.3204 21.250 21.7345 21.7240 21.3656 22.1743 22.5320 22.0573017		11.4378 11.6473 11.772 11.8323 12.8888 12.4283 12.2538 23.451 23.4513 23.783 23.3463 24.4637 24.4843 24.6332 2
221 33	1 17.12 17.41 5.47 1.31 1 11.11 11.71 2.11 1.35 1 11.32 15.76 2.11 1.35	22.16 11.19 11.71 16.71 12.31 12.47	18.75 19.84 19.47 19.46 19.68 19.86 28.24 28.48 12.58 12.78 12.78 12.38 19.12 19.25 19.58 15.65		21.74 24.84 24.23 24.45 24.65 24.65 22.42 22.33 15.83 44.84 44.56 14.31 14.44 14.51 44.53 44.53 44.55 45 58 45 25 45 14 45 25 45 24 24 45 45 45 45 45	II 17.6232 17.5087 18.582 18.2353 18.4375 18.6724 19.8248 15.2474556 II 11.7523 11.5374 12.285 12.1555 12.3553 12.452 12.687 12.8554528		15.4548 15.7482 15.5556 28.1645 28.5476 28.5582 28.7354 15.8884 15.1654 15.5184 15.447 15.5651 15.7842 15.8664 1
S ROW - DUSHELL S' 35 Gate 55 H East 55	1 11.32 11.76 2.00 1.33 1 15.56 15.27 1.33 1.31	22.06 14.05 14.00 20.47 15.07 16.21 17.50 14.20 14.04	14.32 15.45 15.43 15.43 15.66 15.81 16.11 16.23 16.25 16.51 16.88 16.87 17.86 17.22 17.55 17.25 14.38 15.22 15.25 15.55 15.73 15.87 16.17 16.38		16.51 16.72 16.31 17.87 17.23 17.41 17.61 17.61 17.31 18.21 18.41 18.61 18.77 18.35 13.18 13.41 16.57 16.53 15.71 17.44 17.51 17.47 18.55 13.18 13.41	14.8246     14.2455     14.5548     14.5583     14.7289     14.8555     15.44     15.347488      15.2776     15.5482     15.885     15.885     16.8855     16.4874     16.4825     16.281     16.28     16.28     16.281     16.28		15.514 15.7157 15.0033 16.847 16.1126 16.8535 16.5474 1 16.3 17.1137 17.303 17.407 17.6335 17.015 18.0258 1 15.5739 15.7010 15.550 16.1146 16.2020 16.0220 16.0271 1
NWEST 55 SONST 55	1         15.64         15.27         3.53         1.51           3         14.17         13.61         3.71         1.37           3         15.16         14.84         3.83         1.31           3         22.51         22.35         3.14         1.35	17.58 19.78 19.39 22.86 15.81 15.55 51.58 25.84 25.58	10.31         15.22         15.35         15.73         15.17         16.17         16.31           46.85         46.23         46.85         46.83         46.33         47.34         47.54           23.44         25.44         26.35         24.68         24.35         25.68         25.68         25.68		16.37 16.27 16.37 17.39 17.38 17.47 17.38 17.47 17.74 17.37 18.16 18.35 18.51 18.78 18.32 19.14 25.59 26.27 26.55 26.82 27.86 27.39 27.66 27.39	2 10.0027 10.004 10.001 10.001 10.002 10.0027 10.007 10.007 1 45.0745 45.000 45.052 45.045 45.0454 45.007 46.2704 46.40540 1 22.022 22.023 22.0753 22.004 22.0744 23.4255 23.0446 23.7152 24.005640		16.373 15.7711 15.3511 16.714 16.2641 16.4221 16.4771 16.572 16.007 17.8555 17.2440 17.013 17.5746 17.7826 24.3721 24.605 24.555 25.2401 25.455 25.552 25.5564
RY 55 OHRD 55	1 22.51 22.35 5.14 8.35 1 15.37 14.31 3.74 8.37 1 8.74 8.32 1.35 8.37	22.85 15.32 15.33 22.85 3.48 3.35	16.84 16.23 16.65 16.65 16.83 16.83 17.31 17.51 3.53 5.54 3.75 3.75 3.85 3.35 18.13 18.25		17.74 17.37 18.15 18.35 18.52 18.78 18.32 19.15 18.53 18.52 18.53 18.74 18.84 18.55 11.81 11.21	I 15.874 15.9144 15.6547 15.6477 15.8248 15.9744 16.2729 16.4699597 I 8.8248 8.95977 3.16472 3.46862 3.26258 3.95845 3.52663 5.69845295		46.6743 46.8346 47.8725 47.2478 47.4843 47.5776 47.7857 - 5.76458 5.88887 5.35476 48.8574 18.483 48.2585 48.4425 -
AS ST 55 SDEH EAST 55	1         1.74         1.52         1.35         1.37           3         16.34         16.10         2.15         1.33           3         17.51         17.47         3.31         1.31	22.63 17.53 17.73 19.62 10.25 10.45	17.84 18.72 18.52 18.51 18.72 18.58 19.25 19.48 18.58 18.73 19.21 19.28 19.42 19.68 19.87 28.28	2	13.73 15.33 28.28 28.41 28.53 28.88 24.84 24.58 28.46 28.75 28.35 24.47 24.36 24.57 24.89 22.85	I 46,7652 47,8232 47,4183 47,4834 47,5368 47,7632 48,8385 48,5485474 I 47,5885 47,6624 48,8583 48,8582 48,2544 48,2537 48,7744 48,354882	1	18.5455 18.7867 18.5878 19.4828 19.5553 19.5435 19.784 2 19.2552 19.4852 19.6555 19.855 28.8766 28.2765 28.5165 2
SLAHE 55	1 11.23 5.65 5.74 1.86 1 14.27 14.83 2.28 1.55	22.85 11.65 11.78	11.82 12.88 12.27 12.27 12.48 12.52 12.76 12.31 14.87 13.24 13.55 15.54 15.71 13.86 14.14 14.35 28.68 24.32 24.35 24.13 24.14 24.13 24.24 22.38		13.17 13.24 13.31 13.52 13.54 13.71 13.34 14.11 14.55 14.71 14.35 17.13 17.21 17.46 17.55 17.41 22.73 23.18 23.19 23.53 23.57 23.71 24.12 24.51 24.51	<ul> <li>41.4876</li> <li>41.2825</li> <li>41.5355</li> <li>41.5385</li> <li>41.6586</li> <li>41.768</li> <li>41.334</li> <li>42.4745</li> <li>41.2535</li> <li>44.6174</li> <li>44.775</li> <li>44.2535</li> <li>44.6174</li> <li>44.275</li> <li>44.2754</li> <li>44.2754<td></td><td>12.2872 12.4463 12.5882 12.7834 12.8247 12.3524 13.1857 15.5663 15.7687 15.3375 16.1811 16.2472 16.4831 16.6833 12.44137 24.6382 24.5386 23.1556 22.3754 22.4466 2</td></li></ul>		12.2872 12.4463 12.5882 12.7834 12.8247 12.3524 13.1857 15.5663 15.7687 15.3375 16.1811 16.2472 16.4831 16.6833 12.44137 24.6382 24.5386 23.1556 22.3754 22.4466 2
INGTON 55 ANDS 55 10NT 55	13.64         13.15         4.36         1.31           3         11.31         11.01         2.13         1.31           3         12.65         14.35         1.31	22.16 10.60 10.15	28.68 28.32 24.33 24.38 24.62 24.62 24.63 22.24 22.38 18.86 44.85 44.28 44.27 44.64 44.54 44.57 44.27 13.43 45.24 44.14 44.14 14.46 44.38 44.37 44.27		22.75 23.88 23.55 23.57 23.78 24.82 24.58 24.58 12.82 12.47 12.58 12.45 12.54 12.54 12.57 12.82 12.57	I 15.554 15.655 28.1052 28.1082 28.255 28.5161 28.5151 21.408228 I 18.2558 18.5765 18.6851 18.5384 18.7465 18.876 11.8721 11.15184 7 42.6443 42.0841 13.4723 13.477 13.4355 13.6355 13.6351 43.53544		21.4197 21.6982 21.9985 22.4558 22.3567 22.3794 22.0468 2 11.2341 11.4485 11.5654 11.6821 11.7882 11.3856 12.8465 14.8394 14.2439 14.5651 14.5155 14.6452 14.731 14.3654
HONT 33 ETON 35 Angest 35 Vorth 35	1         12.33         14.33         1.43         1.33           3         11.74         11.43         2.31         1.31           5         12.52         12.13         2.31         1.31           5         12.52         12.13         2.16         1.37           1         15.32         15.65         2.32         1.31	15.88 13.48 13.46 15.24 11.88 11.28 17.58 13.82 13.11	11.31 11.40 11.74 11.74 11.87 11.30 12.21 12.35 13.14 13.55 13.65 13.64 13.00 13.53 14.13 14.36		14.33 15.12 15.43 15.44 15.51 15.74 15.32 16.11 12.51 12.67 12.81 12.34 15.85 15.18 15.34 15.51 14.54 14.73 14.83 15.84 15.81 15.53 15.51 15.63	I 18.6284 18.7358 11.8378 11.8323 11.1557 11.2612 11.4737 11.6888278 I 12.3555 12.55 12.8314 12.8256 12.3684 13.831 13.3381 13.434217		11.7572 11.31 12.8375 12.1611 12.2715 12.3337 12.5484 1 15.6676 13.8452 13.3335 14.1372 14.2655 14.4875 14.578
VORTH 35	1 15.32 15.65 2.32 1.31 1 15.23 15.11 2.35 1.31	22.16 16.75 16.79 22.16 16.11 16.21	16.34 17.18 17.45 17.48 17.57 17.84 18.18 18.35 16.75 16.51 16.88 16.88 17.85 17.85 17.55 17.75		10.65 10.07 15.07 15.27 15.44 15.64 15.07 20.11 17.50 10.22 10.41 10.60 10.77 10.55 15.40 15.41	I 45.8287 46.878 46.4984 46.4944 46.6944 46.774 47.8876 47.2876244 I 45.2825 45.5292 45.8742 45.864 46.8486 46.4925 46.4973 46.6948288		17.5837 17.7373 17.3273 18.4143 18.2757 18.4577 18.6764 1 16.3855 17.1252 17.3886 17.4863 17.645 17.8287 18.8346
VORTH 33 COWLES 35	1         15.32         15.43         2.32         1.31           3         15.23         15.41         2.35         1.31           3         15.23         15.41         2.35         1.31           3         14.51         14.23         3.65         1.37           3         4.42         4.13         1.43         1.33           3         14.41         1.32         1.33         1.31           3         15.44         1.42         1.31         1.33           3         15.44         1.42         1.31         1.33           3         15.44         15.42         2.31         1.33           3         15.44         15.42         2.31         1.33           3         15.44         15.42         2.31         1.33           3         15.72         15.47         2.51         1.31	22.06 16.01 16.21 21.72 14.05 15.25 17.51 4.21 4.31	15.23 15.53 15.88 15.87 16.85 16.28 16.51 16.78		16.31 17.13 17.32 17.43 17.65 17.83 18.84 18.26 4.78 4.84 4.88 4.85 4.89 5.84 5.48 5.46	I 14.5715 14.5585 14.5285 14.5188 15.8845 15.2275 15.5145 15.5585578 I 4.85357 4.12737 4.22851 4.24852 4.25557 4.5855 4.58747 4.4585858		15.8382 16.1843 16.2773 16.4444 16.5337 16.7583 16.3573 1 4.43556 4.55333 4.68276 4.65881 4.69221 4.73834 4.73883 4
DO 55 ERICK RD 55	1 19.41 19.21 2.31 8.33 1 19.72 19.47 2.68 8.31	21.15 15.54 15.56 28.12 14.57 14.58	14.88 14.22 14.54 14.53 14.63 14.83 15.41 15.23 14.82 14.85 15.43 15.48 15.35 15.43 15.73 15.37		15.43 15.53 15.85 16.82 16.16 16.93 16.52 16.72 16.18 16.33 16.55 16.73 16.88 17.85 17.45 17.45	8 13.4685 13.3675 13.6672 13.6671 13.6131 13.3437 14.2863 14.3732484 8 13.746 13.3625 14.2735 14.2831 14.428 14.5644 14.8335 15.8123854		14.5575 14.7474 14.585 15.858 15.1547 15.346 15.5276 15.2859 15.4895 15.5685 15.7289 15.874 16.8291 16.2488 1
•	PDR Assets AE6-ENW		PDR Assets BV6-ENW PDR A	Assets	s GA6-T 🛛 PDR Ass 🛄 🕂	4		





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#### 142



# Operations carbon approach: PDR

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Celectricity



Operations Carbon Impact

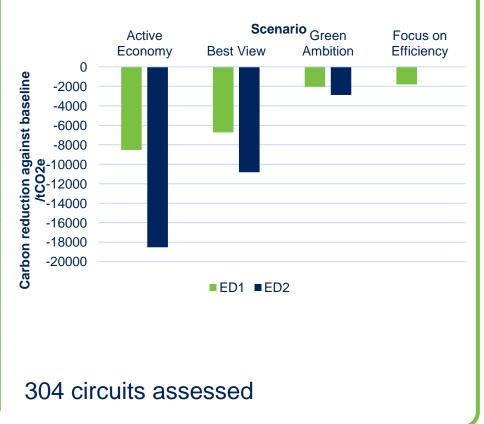
# Operations carbon findings: PDR



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#### Carbon penalty from CLASS across the ENW Network

ENW Network				
ED1	Substation reinforceme nt deferred >=3 yrs	Years deferred for >=3 yrs	Additiona I Losses /MWh	Operatio ns 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



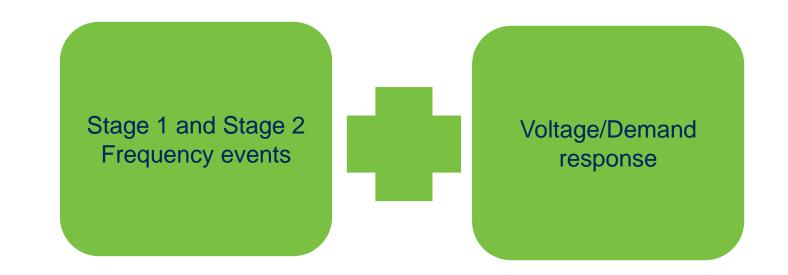


Celectricity

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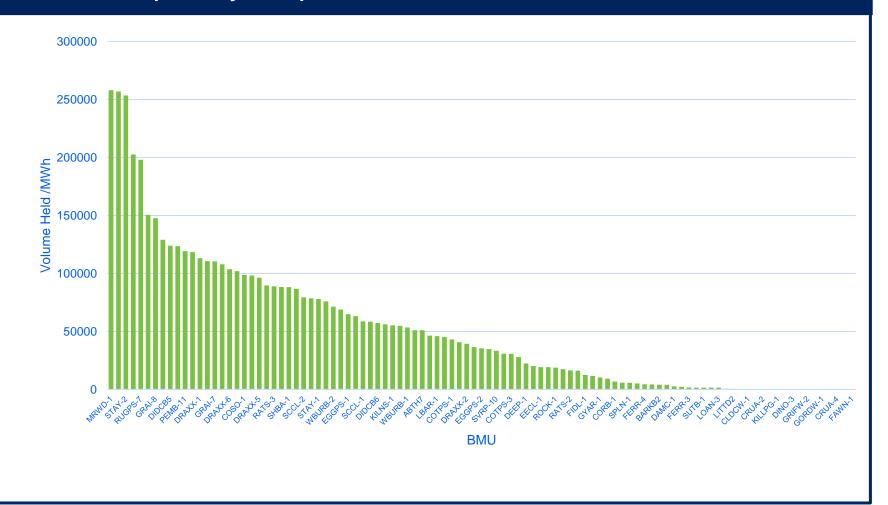
#### Operations carbon approach: DR

#### CLASS monitoring data





#### Frequency response utilisation data 2014/15



**Celectricity** 

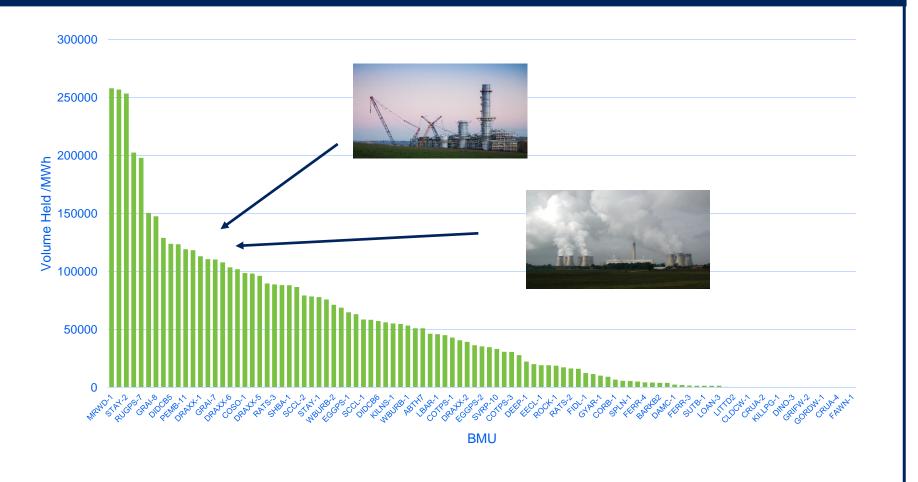
#### Operations carbon approach: DR





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#### Composite emissions factor







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Operations Carbon Impact

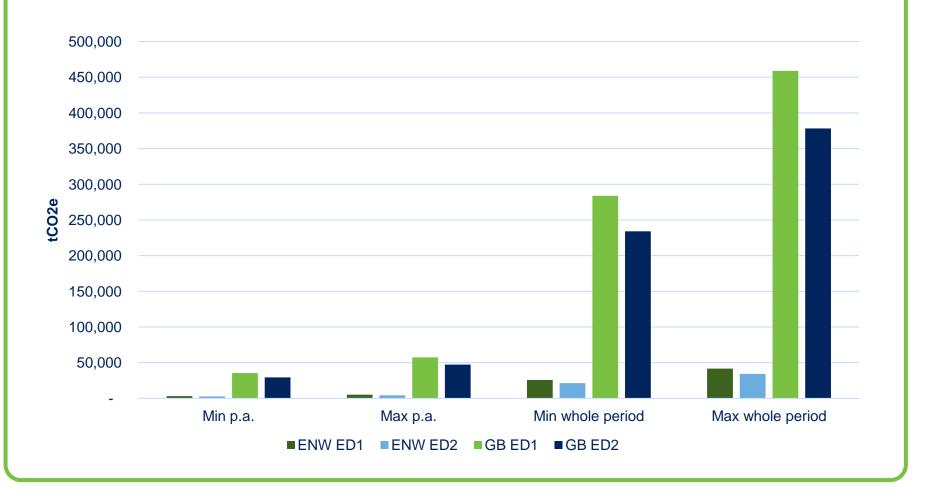
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#### Operations carbon findings: DR



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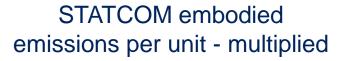
#### Demand response carbon savings - ENW and GB scale



#### Asset carbon approach: RP



#### Service estimate cf BAU equivalent





#### Asset carbon approach: RP



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Asset Carbon Impact

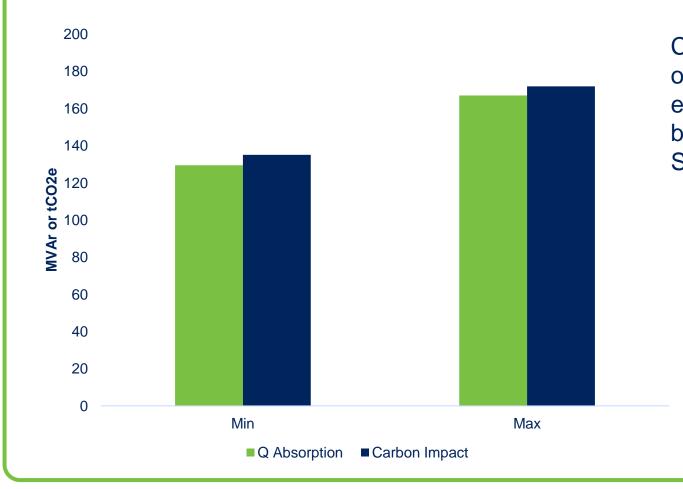
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#### Asset carbon findings: RP



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#### 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



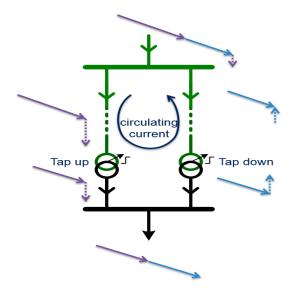
Losses in network under new powe<u>rflow</u> Operations carbon approach: RP

### Celectricity

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#### Usage profiles

### Transformer losses increase when tap staggered



### STATCOMs continuous "hot standby" consumption



PCS 6000 STATCOM: +/- 12.5 MVAr unit

#### Operations carbon approach: RP







Felectricity





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Operations Carbon Impact

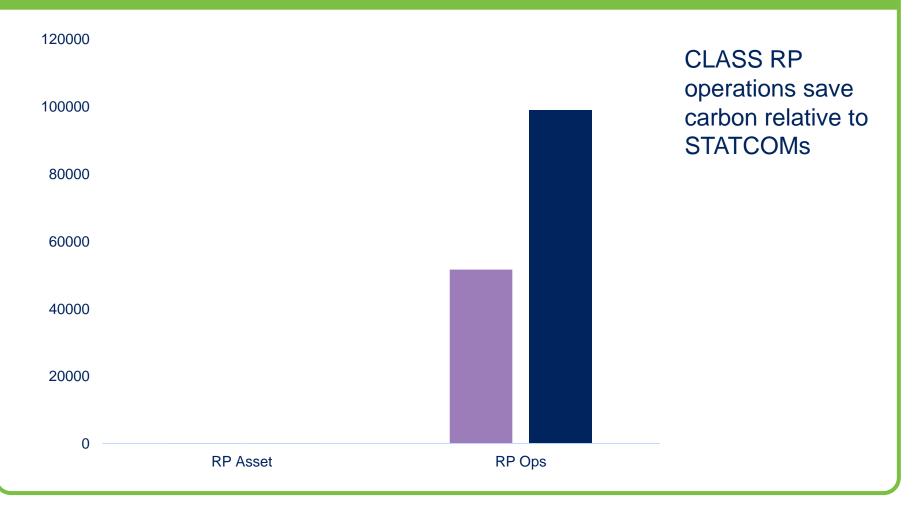
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#### Operations carbon findings: RP



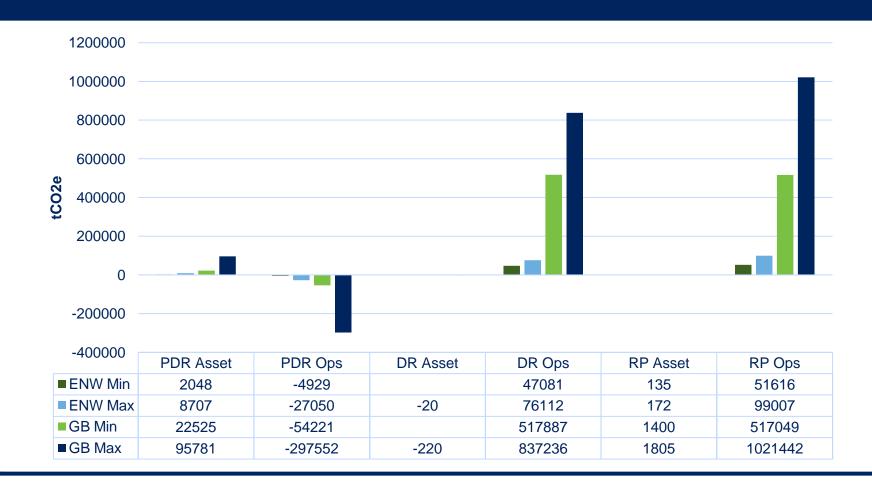
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#### Reactive power carbon savings ENW network ED1+ED2





#### CLASS carbon impacts over RIIO ED1+ED2



#### Conclusions



Bringing energy to your door

#### 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<sub>2e</sub> 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

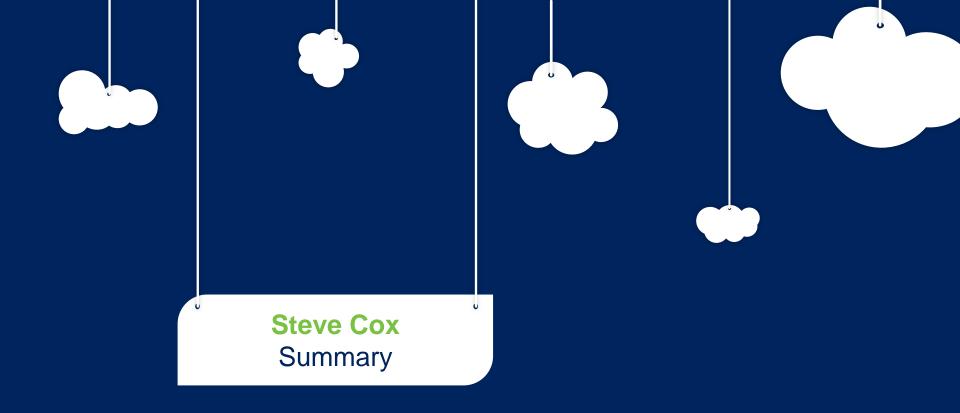


Facilitated carbon impact across the trial was found to be very small and highly uncertain.

## QUESTIONS

# ANSWERS



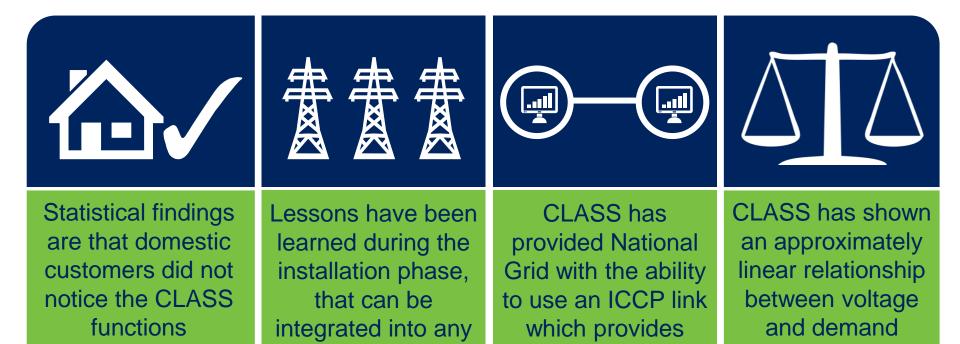




#### Summary



Bringing energy to your door



them with a

demand response

during a system

frequency event

future 'rollout'

162

#### High level benefits







Low cost high speed frequency support



3GW demand reduction or boost



2GVAr National Grid voltage control



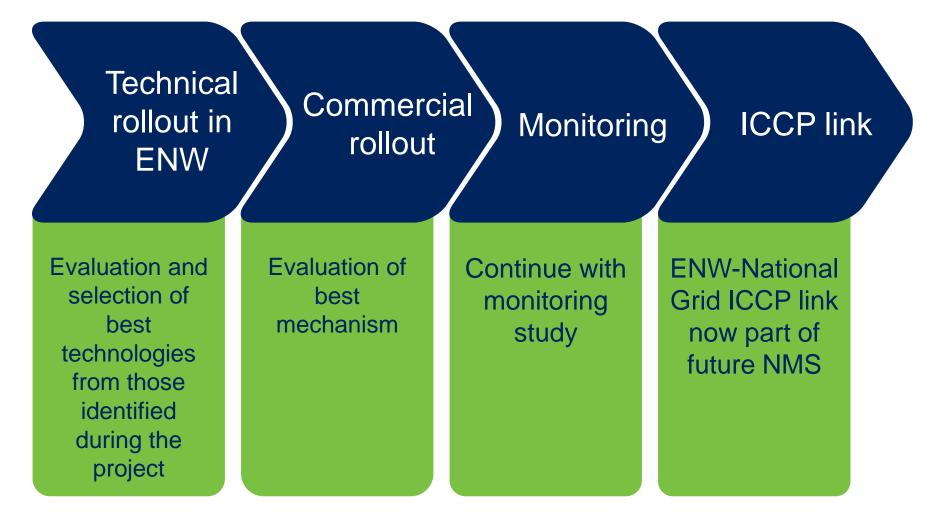
**Reinforcement deferral** 



24/7 voltage/demand relationship matrix

#### Next steps





## QUESTIONS

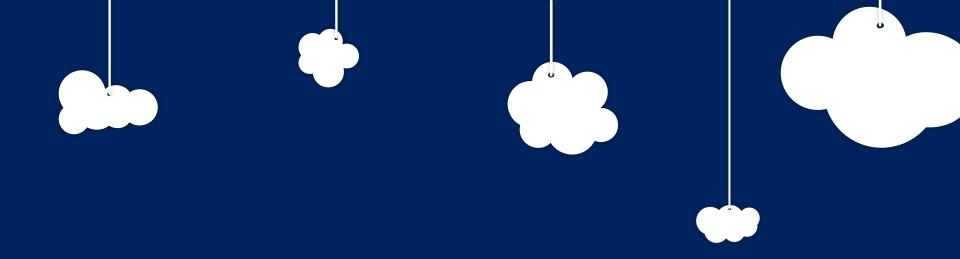
# ANSWERS



#### Want to know more?







### **CLASS closedown event**

### Wednesday 9 September 2015

