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CLASS Capability Report for Trial Scenarios

15 September 2014

CLASS
Customer Load Active System Services

CONTENTS

VERSION HISTORY

Version	Date	Author	Status	Comments
1	29/09/2014	Electricity North West	Completed	

1 EXECUTIVE SUMMARY

By aligning demand to existing network capacity through voltage control, CLASS has the potential to minimise the need for costly asset-based interventions and make a positive contribution to a low carbon future. Network operators face a number of new challenges from current patterns and increases in demand. CLASS is seeking to provide innovative approaches for redressing the specific challenges detailed below. This paper proves the ability of CLASS to address these challenges. A detailed study will be carried out by The Manchester University to fully understand the impact of each function.

High peak demand reduction

CLASS is seeking to exploit the natural relationship between voltage and demand to manage demand at peak times. The ability to actively manage peak demand through voltage control, in a way that does not adversely affect customer perceptions of their electricity supply, could provide DNOs with a useful tool for accommodating increasing demand, and for avoiding or deferring costly network reinforcement.
The demand reduction manually activated half and full functions were found to reduce the demand on Middleton Primary by 4% and 6% respectively. The automatic demand reduction function trialed at Golborne Primary activated /de-activated at the correct levels and showed a demand reduction.

Frequency response to support system balancing

CLASS will demonstrate the application of a number of voltage control measures that will enable rapid and significant reductions in demand, thus providing the National Grid with a flexible and cost-effective tool for frequency response and achieving their balancing requirements.
The frequency response stage 1 function operated automatically within a second for a frequency of 49.7HZ providing a demand reduction until the function was de-activated after a 1/2 hr period of time. The stage 2 frequency response function has the same characteristic as the full demand reduction but automatically activates for a frequency setting of 49.8Hz.

High network voltages

A key challenge for network operators is managing the unacceptably high voltages that can occur on distribution and transmission networks during periods when high renewable generation output coincides with low local demand. The operation of primary transformers in a staggered tap configuration has the potential to provide a highly flexible and cost-effective means of absorbing reactive power within a network, thus controlling these dangerous over-voltages.
The reactive power absorption function has three stages and for each stage increased the tap stagger across the pair of primary transformers at Middleton Junction. For each stage this was found to have a varying effect on the reactive power according to the number of taps staggered.

Excess generation

As the volume of renewable generation increases there is an increasing probability that the available generation within a network may exceed the demand or network capacity leading to the need to constrain the generation output. This constraint acts to decrease the efficiency of the generation and hence drive up costs to customers.
The demand boost half and full function was found to increase the demand on Middleton Primary by 4% and 7% respectively.

All functions activated correctly and the capability was proved.

1 INTRODUCTION

1.1 Background and context

Current trends towards a significant increase in electricity demand driven by greater levels of low carbon technologies (LCTs), combined with an increased uptake of renewable and low carbon energy generation, will present new challenges to operators of electricity networks in Great Britain (GB). In particular, these trends have the potential to necessitate expensive capital investments. In addition to being costly, these capital investments would also be carbon-intensive and would cause considerable traffic disruptions etc.

To minimise financial costs – which will inevitably be passed to customers – as well as disruption and carbon emissions, innovative approaches to managing electricity networks are required.

1.2 The CLASS Project

Electricity North West is leading the Customer Load Active System Services (CLASS) project. It is seeking to demonstrate a low cost, rapidly deployable solution that applies innovative and active voltage management to provide a range of demand response capabilities and network voltage regulation services. By aligning demand to existing network capacity through voltage control, CLASS has the potential to minimise the need for costly asset-based interventions and make a positive contribution to a low carbon future.

CLASS is funded via Ofgem's Low Carbon Networks (LCN) second tier funding mechanism. The project is being undertaken by Electricity North West in partnership with key industrial and academic partners, namely General Electric (GE), Siemens, Parsons Brinkerhoff, Impact Research, Chiltern Power and the University of Manchester. Formal notification of selection for funding was received from Ofgem on 21 December 2012. The project is due for completion by 30 September 2015.

1.3 The challenges that CLASS is seeking to address

Network operators face a number of new challenges from current patterns and increases in demand. CLASS is seeking to provide innovative approaches for redressing the specific challenges below.

1.4 High peak demands

Demand for electricity is not constant. Demand tends to be greatest during specific seasons, such as winter; and during particular times of the day typically early evening.

Although these periods of 'high peak demand' are temporary and seasonal, networks must be built with enough capacity to accommodate these peaks. In some cases therefore, this could result in costly investments being made to increase capacity in order to accommodate high demand peaks that only occur a few times a year. This may be exacerbated by the expected doubling in electricity demand by 2050, possibly increasing peak demands and therefore necessitate significant investment in network capacity.

Cost-effective tools to accommodate short-term, high peak demand, without expensive asset-based interventions, would therefore provide significant benefits. Not only might such tools achieve cost-savings for customers, they could also give DNOs time to fully investigate any new patterns of peak demand and only invest where absolutely necessary.

CLASS is seeking to exploit the natural relationship between voltage and demand to manage demand at peak times. The ability to actively manage peak demand through voltage control, in a way that does not adversely affect customer perceptions of their electricity supply, could provide DNOs with a useful tool for accommodating increasing demand. Ultimately this would provide cost savings for customers.

1.5 Frequency response to support system balancing

In addition to owning the electricity transmission network, National Grid is also the national electricity transmission system operator (NETSO) for GB. In its role as NETSO, National Grid has a licence obligation to maintain frequency within the limits specified in the electricity supply regulations, ie ±1% of 50 Hz.

In the period to 2050, the generation mix in GB is expected to change significantly, with increased amounts of low inertia intermittent generation connected to the system along with large nuclear generating units. The increasing proportion of intermittent renewable energy sources in the GB generation mix will increase the need for so-called ‘frequency balancing services’ used by the NETSO to maintain system stability and to ensure that frequency remains within statutory limits.

The traditional approach for ensuring a ready source of frequency balancing has been by maintaining a number of power stations connected to the grid ready to produce power when required. These ‘spinning reserves’ are effective but expensive and very carbon intensive.

CLASS will demonstrate the application of a number of voltage control measures that will enable rapid and significant reductions in demand, thus providing the NETSO with a flexible and cost-effective tool for frequency response and achieving their balancing requirements. By providing the NETSO with a fast-acting and flexible demand management capability for frequency balancing, CLASS has the potential to contribute to both reductions in costs to customers as well as carbon emissions.

1.6 High network voltages

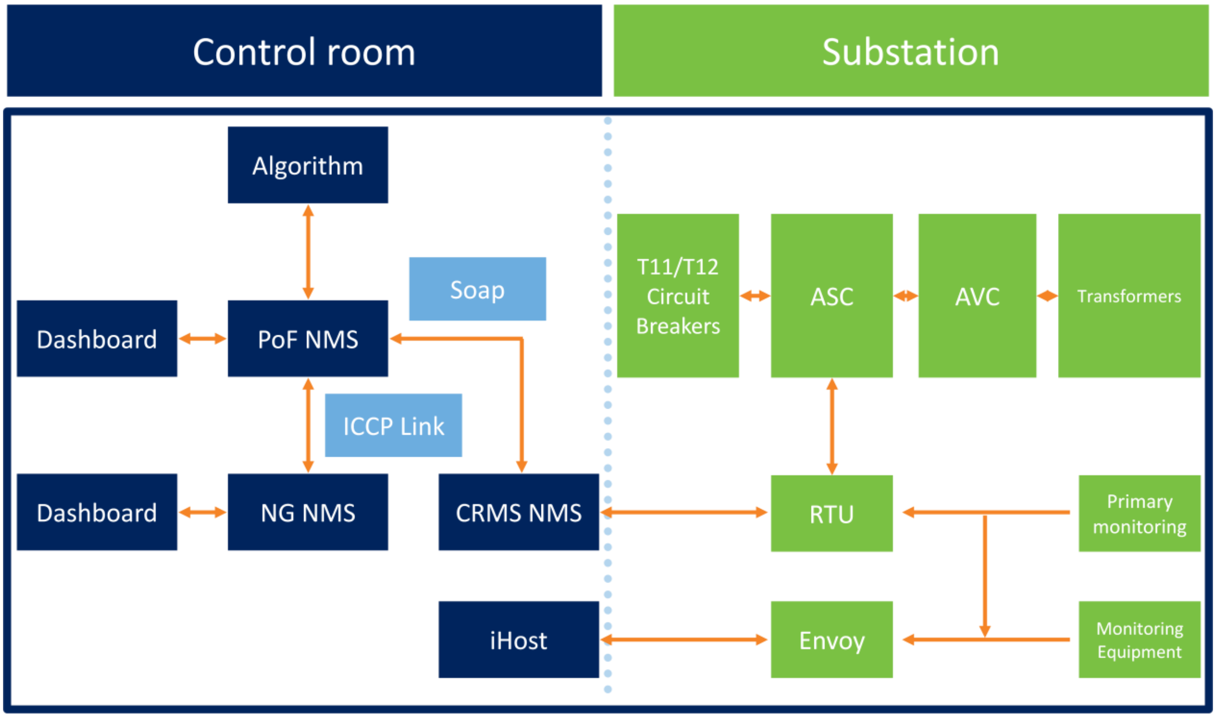
A key challenge for network operators is managing the high voltages that can occur on distribution and transmission networks during periods when high renewable generation output coincides with low local demand. The operation of primary transformers in a staggered tap configuration has the potential to provide a highly flexible and cost-effective means of absorbing reactive power within a network, thus controlling these over-voltages.

CLASS will demonstrate the viability of the tap staggering technique for provision of reactive power services (ie voltage regulation) to the NETSO and the DNO. The aim is to demonstrate that a reactive power absorption service can be provided, quantify the effect on the distribution network and the aggregate effect on the transmission network.

1.7 The CLASS Technologies

The CLASS solution is underpinned by a suite of interconnected technologies. These technologies are split between (i) Electricity North West's Control Room, (ii) Primary Substations and (iii) National Grid's Control room.

The suite of CLASS technologies are summarised in Figure 1 below.



Further details about the CLASS technologies and how they are integrated, can be found in the *CLASS Commissioning Report, CLASS Voltage Regulation Scheme Report*, the *CLASS ICCP Link Commissioning Report*, all of which can be found at the following link: http://www.enwl.co.uk/class/about-class/key-documents.

1.8 The CLASS Trials

To demonstrate the applicability of the CLASS approach and to assess customers' perceptions of the effects, the range of CLASS techniques will be trialled on 60 primary substations, representing 17% of the Electricity North West's network and serving around 350,000 customers (348,500 domestic and 1500 commercial customers).

The five CLASS trials that will be undertaken are summarised below.

Trial Ref.	Description	Objective	Technique	Trial Period
T1	Load Modelling	*Establish voltage-demand relationship*	*Raise and lower tap positions*	*Across entire annual cycle*
T2	*Peak demand reduction*	*Demand response for peak reduction*	*Lower tap position*	*Peak demand*
T3*a*	*Stage 1 frequency response*	*Response to reduce demand when system*	*Switch out transformer*	*Anytime*

T3*b*	*Stage 2 frequency response*	*frequency falls*	*Lower tap position*	*Anytime*
T4	*Reactive power absorption*	*Reduce high volts on transmission network*	*Stagger tap position*	*Minimum demand*

These are described in greater detail below.

- Trial 1: Voltage increment and decrement over one year – Trial 1 will use the normal increment and decrement of system voltage at primary substations across an annual period to assess the relationship between voltage and demand. The outcome from this trial will be a voltage /demand relationship matrix, to be developed by the University of Manchester. This matrix will describe mathematically the voltage/demand relationship for every half-hour in a year.
- Trial 2: Voltage decrement to achieve a demand response at times of system peak – Trial 2 will investigate the demand response that can be achieved through voltage reduction at times of high peak demand. The outcome of this trial will be confirmation that a demand response can be realised at times of peak demand (eg in winter), thus maximising existing network capacity and deferring costly network reinforcement.
- Trial 3a: Voltage decrement to provide very fast frequency response – This trial will investigate the use of a low frequency relay to switch out one transformer of a standard primary substation and will also quantify the demand reductions achieved. The outcome of this trial will be confirmation that a very fast demand response (ie <0.5 seconds) can be provided to meet the NETSO criteria for frequency response.
- Trial 3b: Voltage decrement to provide a fast frequency response to the NETSO – Trial 3b will investigate the use of demand response, initiated by lowering primary substation taps, as a means of providing fast frequency response to the NETSO. The outcome of this trial will be confirmation that a fast demand response (ie <30 seconds) can be provided to the NETSO.
- Trial 4: Reactive power absorption to redress high network voltages – Trial 4 will investigate the viability of tap staggering for the provision of reactive power services (ie voltage regulation) to the NETSO and the DNO. During the trial, the tap positions across the pair of primary transformers will be staggered, and the change in power factor (ie the reactive power absorbed) quantified at each primary substation. The outcome of this trial will be confirmation that a reactive power absorption service can be provided. The impact on the distribution network in terms of losses and network loading and the aggregate impact of this on the transmission network for voltage stabilisation will also be quantified.

Further information about the suite of CLASS trials can be found in the CLASS Trials Design document, available at the following link: http://www.enwl.co.uk/docs/default-source/class-documents/design-approach-to-class-trials-and-associated-test-schedules.pdf?sfvrsn=4

1.9 Purpose of this document

For the CLASS trials to be undertaken effectively, and for them to provide the range of data required to interrogate the project's hypotheses, it is important that the technologies are capable of providing the range of services and techniques outlined in the CLASS bid.

The purpose of this document is therefore to demonstrate that the CLASS technologies are capable of, and indeed do, undertake the array of CLASS techniques specified in the CLASS bid submission.

To do this, a number of tests were undertaken at selected sites to assess whether the various CLASS techniques could be implemented with the installed CLASS technologies.

This document outlines the results of those tests.

2 CAPABILITY OF CLASS TECHNOLOGIES FOR PEAK REDUCTION

2.1 Introduction and Expectations

This trial seeks to demonstrate that at peak load when voltage reductions of discrete levels 3% and 5% are applied across a range of Primary substations, the demand at that substation is reduced and customers do not observe any adverse effects on their electricity supply.

There are two methods of implementation of this technique, central dispatch using the CLASS dashboard and on site autonomous activation using the CLASS ASC.

The demand reduction functionality can be initiated at any point in time by a Control Engineer from the CLASS dashboard to manage an expected or emerging thermal constraint relating to primary transformer capacity. Use of the ‘half’ or ‘full’ demand reduction commands will be dependent upon the level of response required. Central dispatch of this command will result in near real time on site activation. Once the target voltage reduction has been achieved the ASC will aim to maintain this voltage level until a disable command is issued.

The alternative method of achieving peak demand reduction is to enable the ASC to autonomously control system voltage to ensure compliance with a capacity threshold. The ASC device can be pre-set with a maximum demand value for the site and if it detects load approaching this level it automatically initiates the tap changer to start reducing the HV voltage and maintain capacity limits.

The two alternative methods of implementation allow increased operational flexibility for the network operator but both will result in the same action of the primary transformer tap changer. The CLASS system architecture below illustrates the alternative activation methods.

Fundamentally the delivery of the CLASS peak reduction capability is achieved through a decrease in tap position which will subsequently reduce the downstream voltage. Successful activation of this functionality can be determined by observing a change in tap position both on site and the on dashboard. Confirmation of the level of voltage reduction achieved against target can be inferred from a pre and post activation comparison of onsite system voltage indicator, dashboard analogues and inspection of monitoring equipment data. For the purposes of the capability testing all available sources of data will be used to ensure correct actions have occurred.

The stage 2 frequency response function has the same effect as the demand reduction full function but it also can be activated on site by the frequency dropping to 49.8HZ. This on site activation is currently under test but a frequency event has yet to occur so in terms of the capability report the stage 2 frequency response is the same as a demand reduction full.

2.2 Testing Approach and Results

Testing of the CLASS technology at Middleton Junction Primary substation was conducted on 22nd September 2014 commencing at 11:14 hrs.

(a) Demand Reduction Half - Central dispatch from CLASS dashboard

Table 1 shows the pre-test conditions at Middleton Junction before the function was activated at 11:14.

	T11	T12
Pre- test tap position	6	6
Start Voltage (kV)	10.99	10.98
Power (MW)	5.8	5.7

Table 1 Pre-test conditions

Figure 1 & 2 show the resultant voltage and power reduction when the demand reduction half function was activated from the CLASS dashboard.

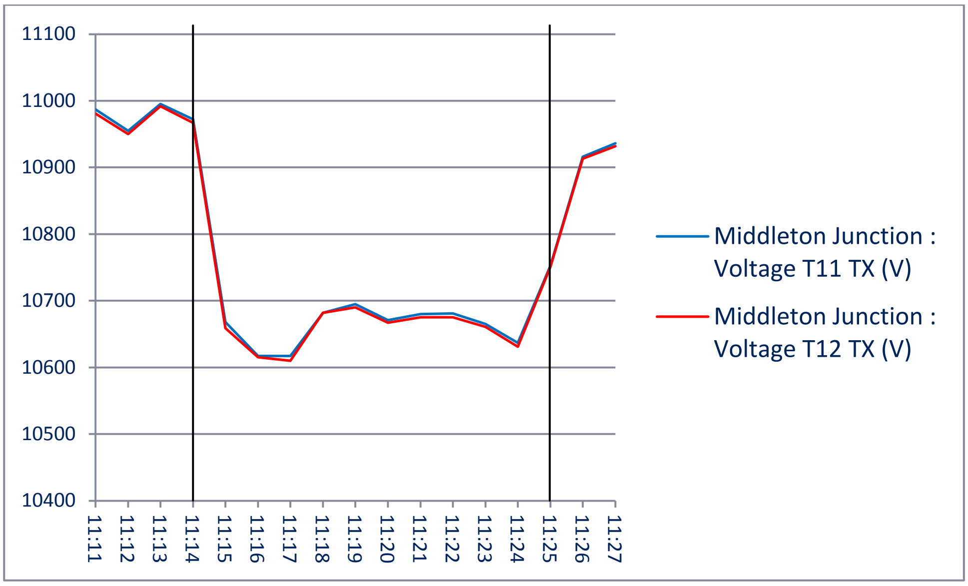


Figure 1 Middleton Junction demand reduction half voltage graph

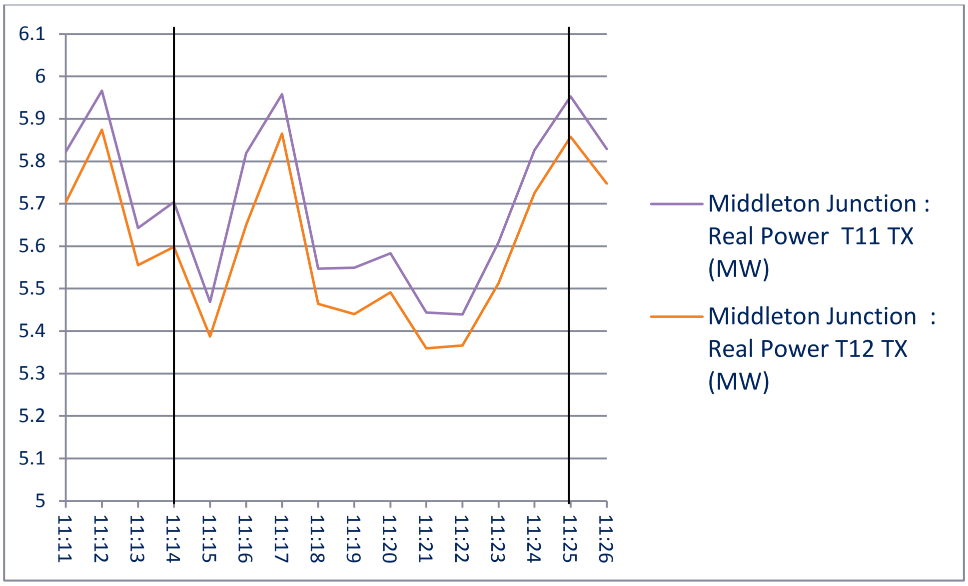


Figure 2 Middleton Junction demand reduction half real power effect

	T11	T12
Tap position during test	5	5
Voltage Reduction achieved	2.1%	2.1%
Demand reduction achieved	4.1%	3.68%

Table 2 Middleton Junction demand reduction half response.

It can be seen from tables 1 & 2 that the demand reduction half function caused a 2.1% voltage reduction by tapping both transformers down one tap. This voltage reduction was lower than the expected 3% level for this function but this difference can be explained by tap changer bandwidths. The voltage reduction produced a demand reduction of 3.5 – 4.1% which proves the capability of this function. It is expected that this demand reduction will vary at different points of time and for different customer types.

2.3 Demand Reduction Full (Stage 2 Frequency Response) – Central dispatched from CLASS dashboard

Table 3 shows the pre-test conditions before the function was activated at 11:28hrs.

	T11	T12
Pre- test tap position	6	6
Start Voltage (kV)	10.94	10.93
Start power (MW)	5.829	5.748

Table 3 Middleton Junction Pre-test conditions

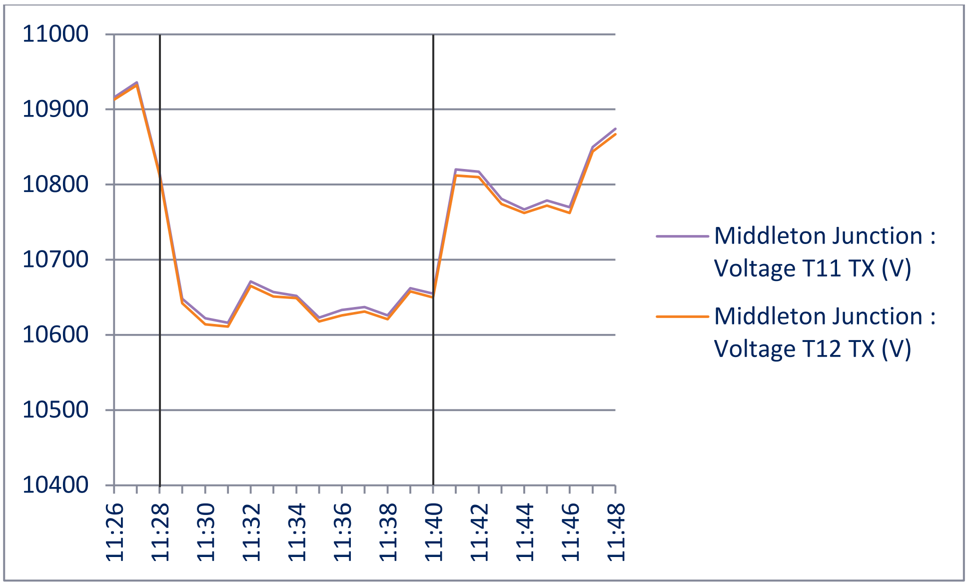


Figure 3 Middleton Junction demand reduction full voltage graph

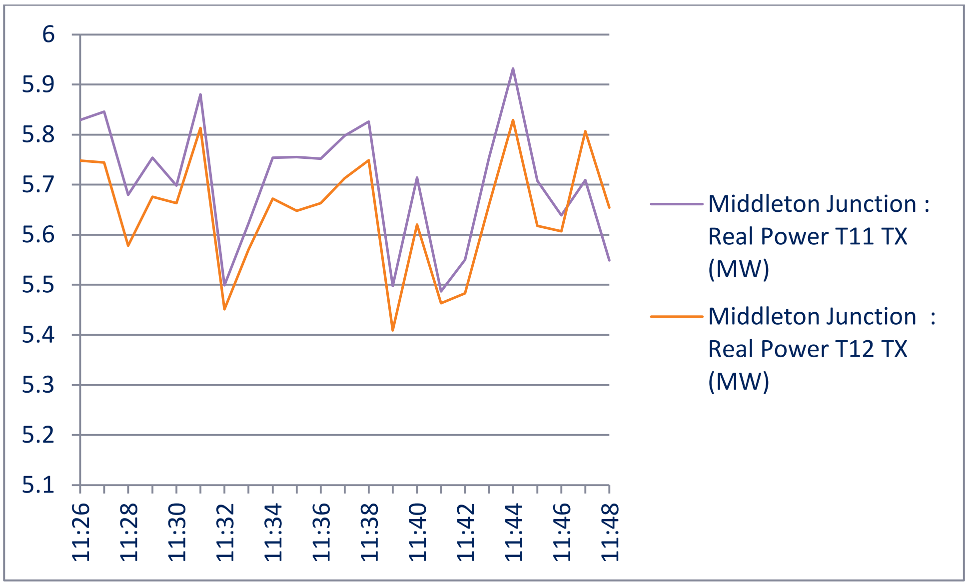


Figure 4 Middleton Junction demand reduction full real power effect

	T11	T12
Tap position during test	4	4
Voltage reduction achieved (%)	3.5	3.5
Demand reduction achieved	6.33	5.83

Table 4 Middleton Junction demand reduction full response

It can be seen from graphs and tables that the demand reduction full function caused a 3% voltage reduction by tapping both transformers down two taps. This voltage reduction was lower than the expected 5% level for this function but this difference can be explained by tap changer bandwidths. The voltage reduction produced a demand reduction of 5.83 – 6.33% which proves the capability of this function. It is expected that this demand reduction will vary at different points of time and for different customer types.

2.4 Peak demand reduction – ASC activated

Due to the ever changing nature of network demands, scheduling the testing of this function is difficult to achieve. However for the purposes of this testing the capacity threshold was set within the ASC to 19MVA which is at a level that is likely to be achieved during the testing time window. This function was enabled at Golborne Primary on the 25th September at 14:41hrs. Confirmation of the ASC activation to autonomously control demand to within the pre-set capacity threshold was recorded in SCADA events log. The on-site automatic activation took place at 16:08 which can be seen in figure 5. As part of the tests the function was switched off and then back on again which explain the voltage spike early on in the trial. The function was automatically switched off by the ASC at 22:34 when the load dropped to 85% of the firm capacity.

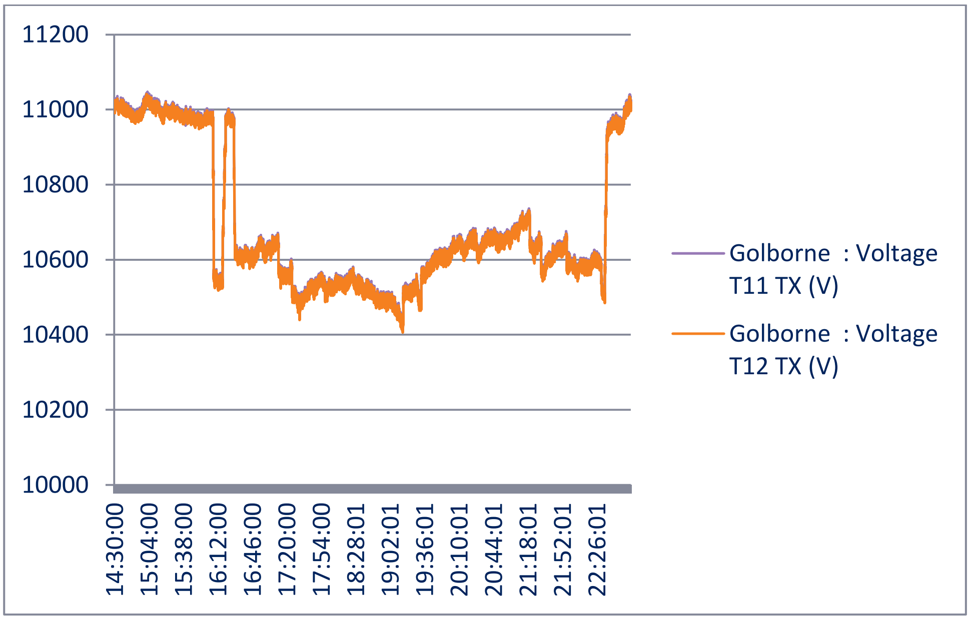


Figure 5 Golborne automatic peak demand reduction voltage effect

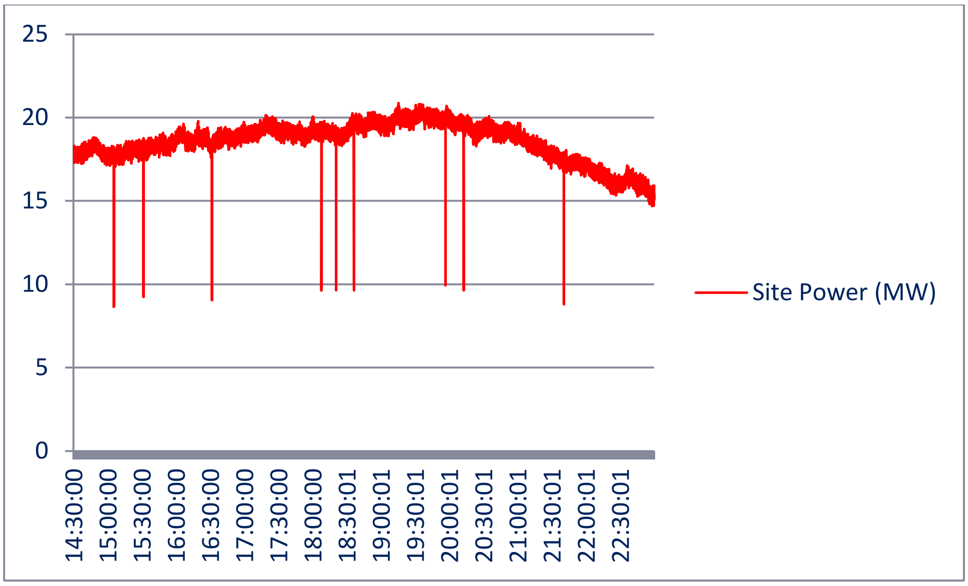


Figure 6 Golborne automatic peak demand reduction site power effect

Figure 6 shows that the load did exceed the 19MVA level but this was expected as the site capacity level was set low to make sure that the function was activated. The demand level recorded was lower than the pre and post trial days so the capability of this function has been proved.

3 CAPABILITY OF CLASS TECHNOLOGIES FOR PRIMARY FREQUENCY RESPONSE

3.1 Introduction and expectations

To test that the installed CLASS technology and existing network assets can deliver primary timescale static frequency response. The necessary demand response required to assist frequency balancing will be achieved through the disconnection of one of a paired arrangement of Primary transformers. The resultant instantaneous change in voltage will trigger a demand reduction in the connected load. The practical implementation of this functionality will be through automatic on site detection of a low frequency signal of 49.7Hz, and the disconnection of a primary transformer within 2 seconds. A sustained demand reduction will be required for the following 30 minutes.

3.2 Testing Approach and Results

The frequency response stage 1 function was enabled at Middleton Junction on the 1st April and did not activate until the 17th September at 20:44hrs which was the first time that National Grid had a frequency drop to 49.7Hz in that period of time (See figure 7). The activation tripped the Middleton Junction T11 11kV circuit breaker transferring all of the demand on to the T12 transformer. Figure 8 shows that the voltage dropped due to this transfer and stayed at this level until the T11 11kV CB was re-closed. The circuit breaker was re-closed by the Control Engineer on receipt of the close circuit breaker alarm that is generated after 1/2 hr period.

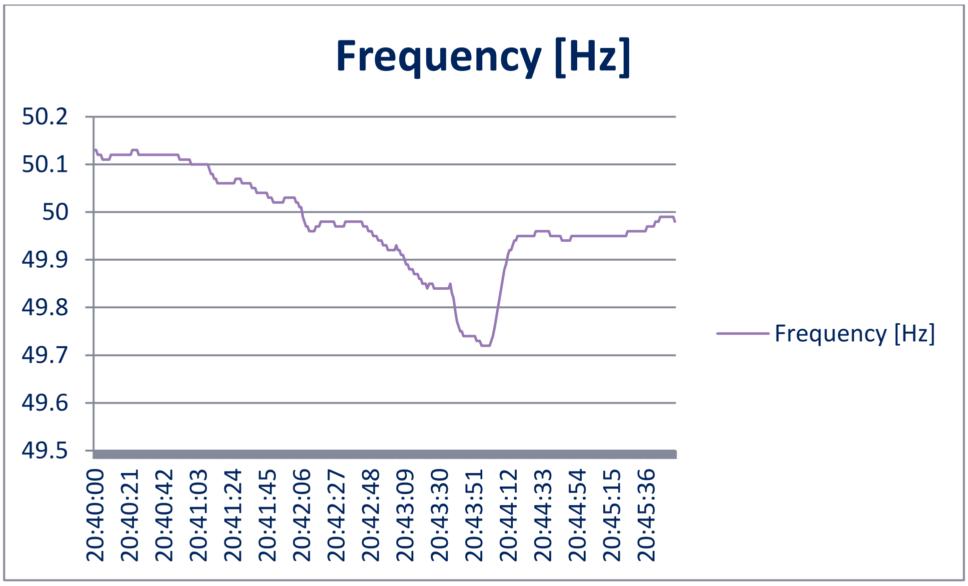


Figure 7 Network frequency on 17th September

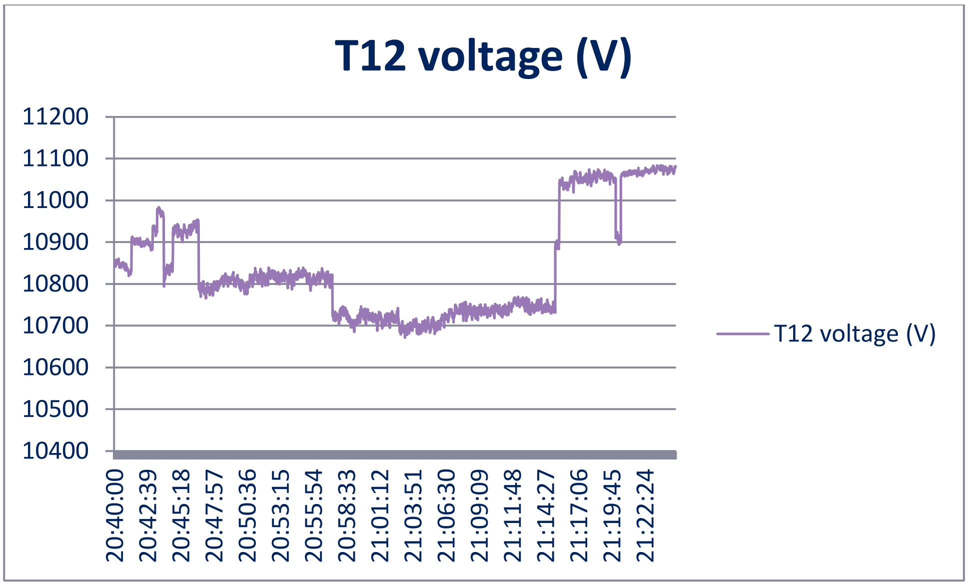


Figure 8 Middleton Junction T12 voltage during Stage 1 frequency response

Figure 9 shows that the site demand did reduce due to the function and did return to its normal level when the function was de-activated at 21:15hrs. The period of time that the frequency event took place in was a decreasing load but a step up can be seen.

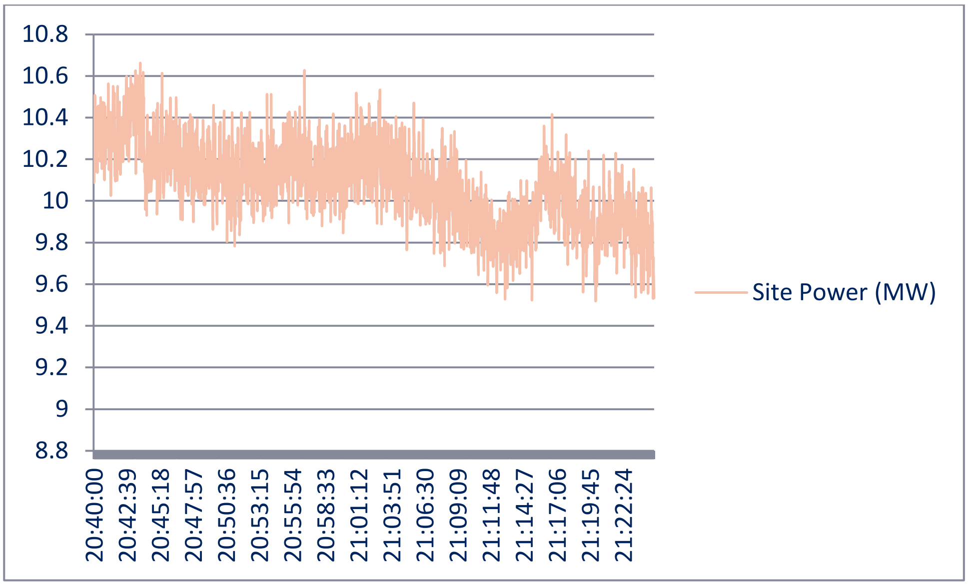


Figure 9 Middleton Junction demand during stage 1 frequency event

4 CAPABILITY OF CLASS TECHNOLOGIES FOR DEMAND BOOST

4.1 Introduction and Expectations

This trial seeks to demonstrate that at times of low load when voltage boosts of discrete levels 3% and 5% are applied across a range of Primary substations, the demand at that substation is increased allowing more generation on the network and customers do not observe any adverse effects on their electricity supply.

The demand boost functionality can be initiated at any point in time by a Control Engineer from the CLASS dashboard to manage an expected or emerging constraint to primary transformer capacity. Use of the 'half' or 'full' demand boost commands will be dependent upon the level of response required. Central dispatch of this command will result in near real time on site activation. Once the target voltage boost has been achieved the ASC will aim to maintain this voltage level until a disable command is issued.

4.2 Testing Approach and Results

When testing this function the opposite demand reduction function will always be activated afterwards to make sure that there is no detriment to the customers involved in these trials.

4.3 Demand Boost half centrally dispatched from CLASS dashboard

The demand boost half function was activated at Middleton Junction on the 22nd September 2014 at 10:53hrs. Table 4 shows the pre-test conditions at Middleton Junction.

	T11	T12
Pre- test tap position	6	5
Start Voltage (kV)	10.99	10.98
Power (MW)	5.8	5.7

Table 4 Pre-test conditions.

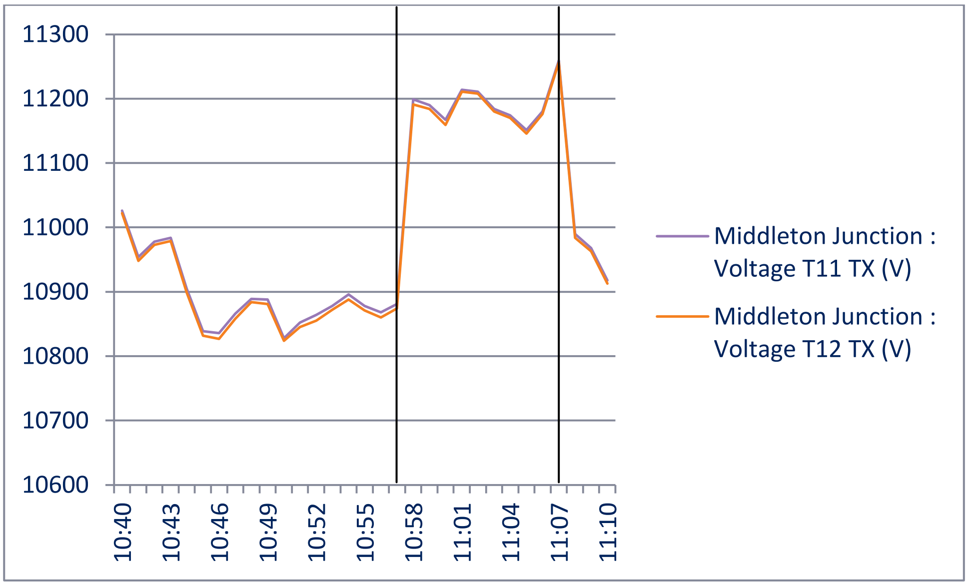


Figure 10 Middleton Junction demand boost half voltage effect

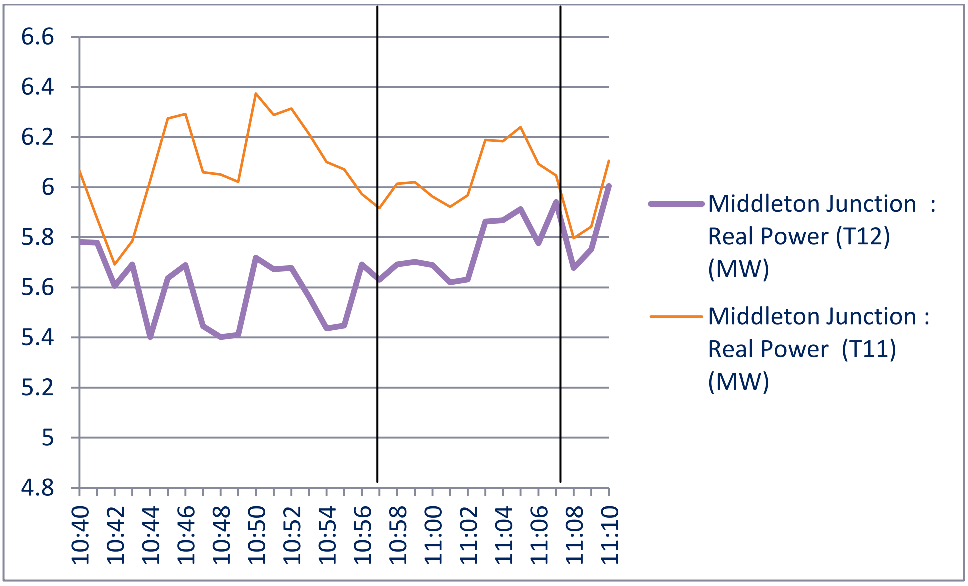


Figure 11 Middleton Junction demand boost half demand effect

It can be seen from graphs and tables that the demand boost half function caused a 3% voltage boost by tapping both transformers up one tap. The voltage boost produced a demand boost of 3.3 – 4.3% which proves the capability of this function. It is expected that this demand boost function will vary at different points of time and for different customer types.

	T11	T12
Tap position during test	7	6
Voltage boost achieved	3%	3%
Demand boost achieved	4.3%	3.3%

Table 5 Middleton Junction demand boost half response.

4.4 Demand Boost Full – Central dispatch from CLASS dashboard

The demand boost full function was activated at Middleton Junction on the 22nd September 2014 at 13:24hrs. Table 4 shows the pre-test conditions at Middleton Junction.

	T11	T12
Pre- test tap position	6	6
Start Voltage (kV)	10.94	10.93
Start power (MW)	5.829	5.748

Table 6 Middleton Junction Pre-test conditions

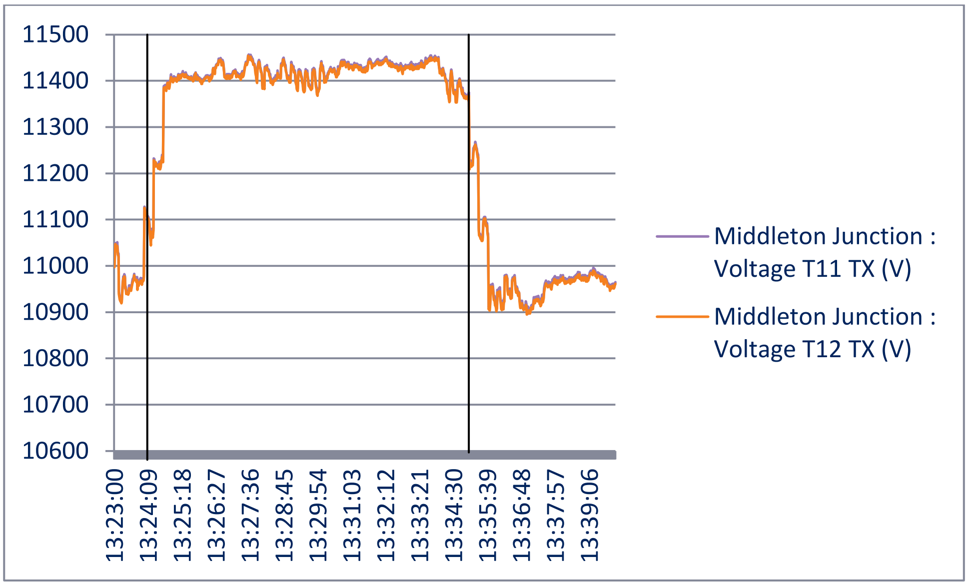


Figure 12 Middleton Junction demand boost full voltage effect

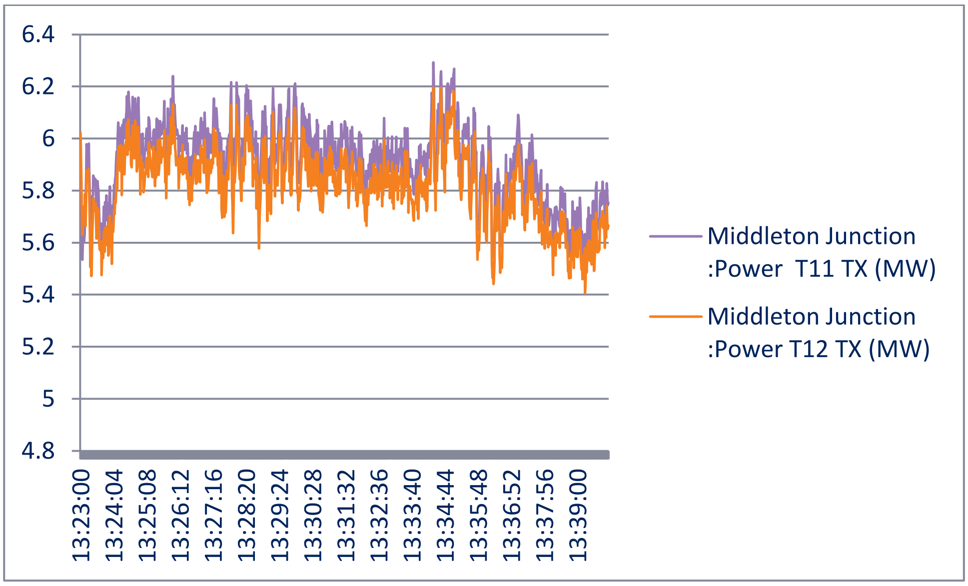


Figure 13 Middleton Junction demand boost full power effect

It can be seen from graphs and tables that the demand boost full function caused a 3.7% voltage boost by tapping both transformers up three taps. This voltage boost was lower than the expected 5% level for this function but this difference can be explained by tap changer bandwidths. The voltage boost produced a demand boost of 7 – 7.1% which proves the capability of this function. It is expected that this demand boost function will vary at different points of time and for different customer types.

	T11	T12
Tap position during test	9	9
Voltage boost achieved (%)	3.7	3.7
Demand boost achieved (%)	7	7.1

Table 7 Middleton Junction Demand boost full response

5 CAPABILITY OF CLASS TECHNOLOGIES FOR REACTIVE POWER ABSORPBTION FUNCTION

5.1 Introduction and Expectations

This trial seeks to demonstrate that at times of low load and high generation a tap stagger applied across a range of Primary substations will absorb reactive power.

The reactive power absorption function can be initiated at any point in time by a Control Engineer from the CLASS dashboard to manage an expected or emerging constraint to the network. Use of the Stage 1, 2 or 3 commands will be dependent upon the level of response required. Central dispatch of this command will result in near real time on site activation.

Once the target tap stagger has been achieved the ASC will still tap in line with demand changes keeping the stagger in place.

5.2 Testing Approach and Results

Testing of the CLASS technology at Middleton Junction Primary substation was conducted on 22nd September 2014 commencing at 10:00 hrs with each stage tested in turn.

5.3 Stage 1 Reactive power absorption

Stage 1 was activated at 10:00hrs and then de-activated at 10:19hrs. The function put a one tap stagger between T11 and T12 transformers (Table 8).

	T11	T12
Pre- test tap position	6	6
Trial tap position	6	5

Table 8 Stage 1

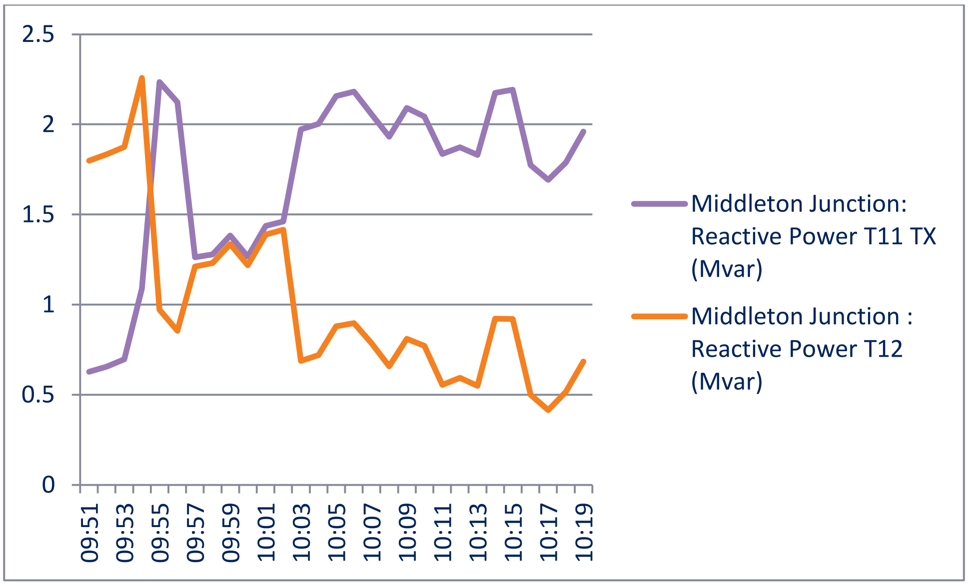


Figure 14 Middleton Junction Stage 1 reactive power absorption effect

5.4 Stage 2 Reactive power absorption

Stage 2 was activated at 10:24hrs and then de-activated at 10:39hrs. The function put a two tap stagger between T11 and T12 transformers (Table 9).

	T11	T12
Pre- test tap position	6	6
Trial tap position	7	5

Table 9 Stage 2 tap stagger

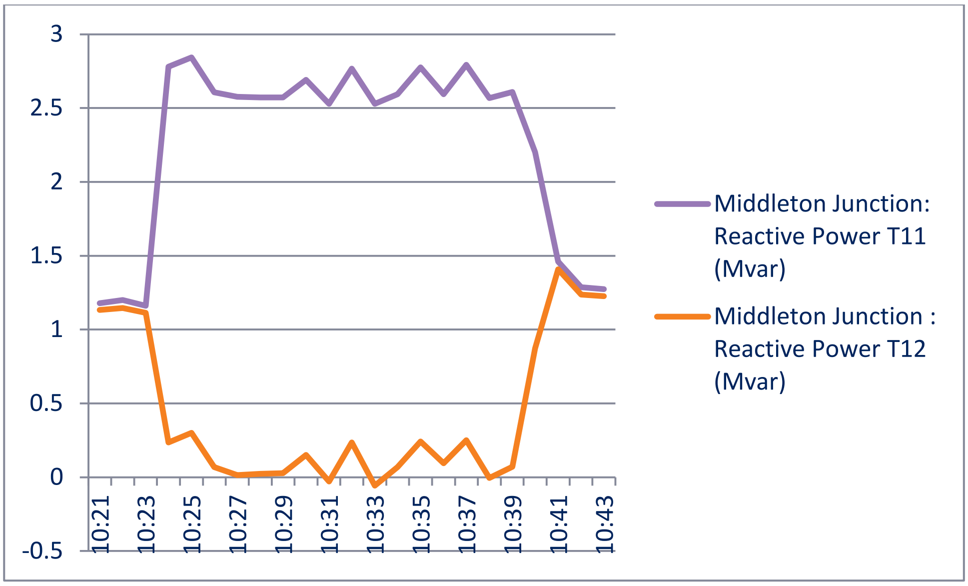


Figure 15 Middleton Junction Stage 2 reactive power absorption effect

5.5 Stage 3 Reactive power absorption

Stage 3 was activated at 10:43hrs and then de-activated at 10:53hrs. The function put a three tap stagger between T11 and T12 transformers (Table 10).

	T11	T12
Pre- test tap position	6	6
Trial tap position	7	4

Table 10 Stage 3 tap stagger

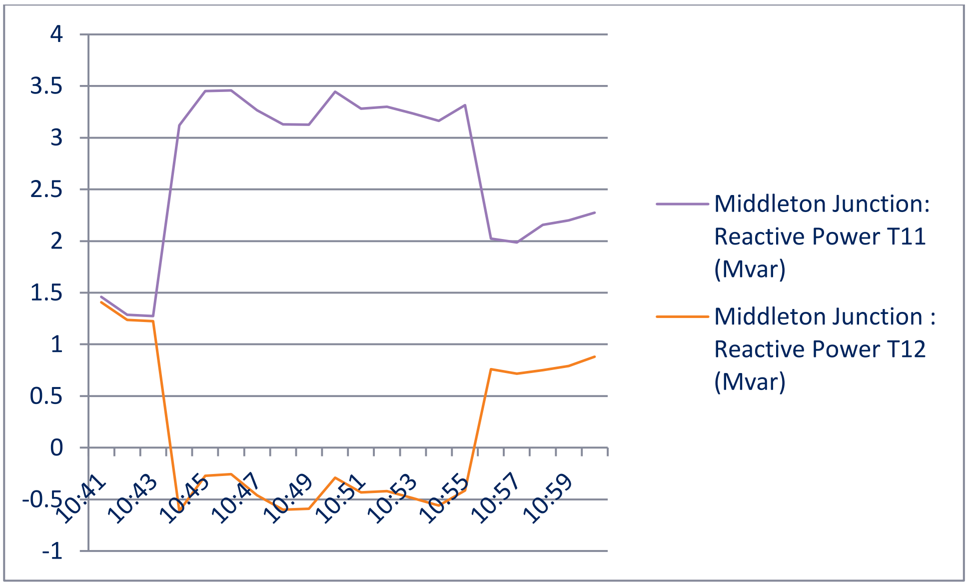


Figure 16 Stage 3 reactive power absorption effect

It can be seen from graphs and tables for the three stages for reactive power that the larger the tap stagger the greater the effect on the reactive power at Middleton junction. This proves that all 3 of the tap stagger functions have an effect on the network and so proves the capability.