WILSON POWER SOLUTIONS
Responsible Power Engineering

SUPER LOW LOSS AMORPHOUS

TRANSFORMER REPLACEMENT PROJECT

PROJECT SUMMARY

McCain was founded more than five decades ago on "good and responsible" business ethics. To this date McCain continue to live by these ethics and put sustainability at the center of everything they do, including improving the energy efficiency of their manufacturing plant and infrastructure.

The replacement of an existing nine year old 1.6MVA, 11kV:433V, CRGO transformer (manufactured in 2006) with a Wilson e2, 2MVA, 11kV;415V, 2021 Eco Design compliant, super low loss, amorphous core transformer (manufactured in 2015), combined with a reduction in supply voltage will deliver energy savings of ~273,00kWh and financial savings of over £22,000 per year.

£22,500
ANNUAL SAVINGS

KWH REDUCTION
272,949
ANNUALLY

Based on electricity costs of £0.08 /kWh

> This represents a fantastic case study and is the kind of application that generates a very attractive return on investment.
>
> INDEPENDENT POWER QUALITY CONSULTANT

INSTALLATION BENEFITS AT A GLANCE

1. ANNUAL SAVINGS OF ~£22,500 (BASED ON AN AVERAGE RATE OF 8P/KWH)
2. 272,949 KWH REDUCTION PA
3. CUT 12T OF CO2 PA (BASED ON 0.44548KG OF CO2/KWH)
4. CCL REDUCTION OF AROUND £670 PA (BASED ON 2015 RATE OF 0.554P/KG).

OUR FINDINGS

The measurements show that the installation of the Super Low loss Amorphous Transformer, combined with voltage reduction, has reduced the kWh used. A further 2.5% reduction of site voltage (Tap 3) will deliver significant additional energy savings.

The combined benefits (at Tab 3) are:

- 2.6% energy reduction (of T2 consumption).
- 272,949 kWh reduction pa
- £21,835 of energy saving pa
- 12t of CO2e avoided pa
- CCL reduction of around £673 pa
- Approximate total saving £22,500 pa

THE SCOPE

The purpose of the study was to determine the energy savings associated with replacing the existing CRGO transformer (Sub 1, T2) with a modern, super low loss, amorphous core transformer. The replacement was undertaken in between two, 14-day monitoring periods, which are featured within this report. The associated savings have been calculated and a detailed technical and commercial summary has been provided in this report.

The following activities have been undertaken:

- 14-day detailed load profiling of the 'Existing' supply via the 1.6MVA CRGO supply prior to replacement.
- 14-day detailed load profiling of the 'Replacement' Wilson e2, 2MVA Super Low Loss, 2021 Eco Design compliant, amorphous core transformer.
- Non-invasive inspection of existing loads and identification of voltage dependent loads.
- Non-invasive assessment of PFC and associated harmonic interaction.
- Power quality assessment based on key characteristics of G5/4-1, EN 50160 & ESQCR Regulations 2002.
- Calculation of voltage management related savings.
- Calculation of transformer loss reduction (NLL + LL).

GENERAL INFORMATION

VOLTAGE

The voltage supplied to many sites is higher than it needs to be. The network operator often keeps the Primary Voltage high to reduce transmission losses while keeping the voltage within statutory limits for all customers on the network.. In 2008 the final stage of the European Voltage Harmonisation came into place setting the voltage levels to 230V ± 10% (see Appendix A); the statutory limits for voltage are now from 207 to 253V phase-neutral.

Most sites have a L-N voltage of 240V or higher giving rise to equipment running at inappropriate levels resulting in additional costs. Reducing and maintaining the voltage at the most favourable level is an established way to significantly reduce energy consumption and costs whilst having the additional benefits of reduced maintenance and increased equipment life.

POWER EFFICIENCY

The efficiency of a supply is expressed as a 'power factor' (pf) where 1.0 (unity) is ideal and anything below 0.95 is highly likely to attract significant penalty charges. Power Factor Correction (PFC) equipment is installed to ensure that the pf is automatically maintained above the charging threshold of 0.95. The correct type and rating of this equipment is based upon the total power, the uncorrected pf, and levels of harmonic currents.

SITE SURVEY AND LOAD PROFILING DATA

The 'Existing' supplying transformer was located in a dedicated external pen adjacent to the LV switch room. The following information was taken from the nameplate and the associated recorded data. Information relating to the replacement transformer was obtained from the rating plate and technical product data supplied by the manufacturer.

Characteristic	'Existing'	'Replacement'
Primary supply voltage:	11kV	11kV
Secondary winding voltage:	433V	415V
Current tap setting:	2 (+2.5% HV)	4 (Normal)
Capacity:	1,600kVA	2,000kVA
Current (secondary) per phase:	2,133A	2,782.49A
Impedance:	5.08%	6.0%
Year of construction:	2006 (9 Y.O)	2015
Manufacturer/ Type:	Power & Distribution (standard CRGO)	Wilson Power Solutions e2 ECO Amorphous Core
Cooling:	ONAN	ONAN
Total Mass:	3,670kg	6,750kg
Vector Group:	DYN-11	DYN-11
Standard:	IEC 60076	EU Ecodesign (2021)
No Load Losses (core):	1,800W	850W
Full Load Losses (winding):	21,700W	15,000W
Average loading on existing TX (kVA/%):	1,257kVA/78.56%	*1,257kVA/62.85%
Peak load (kVA/%):	1,554kVA/97%	*1,554kVA/77.7%

*Identical load values have been used for the 'Replacement' transformer.

SITE SURVEY AND LOAD PROFILING DATA CONTINUED...

INCOMING LV SUPPLY

The main incoming LV cabling from T2 terminates at the LV switchboard in the adjacent LV switch room.

The main incoming LV overload protection is a Merlin Gerin Masterpact NW32H1, 3,200A ACB, on which the (In) long time trip is set to 0.7, which allows 2,240A of design current. The short term (Isd) is set to allow no more than 6,272A for 0.4 seconds and the instantaneous trip value is set to actuate if a current of around 13,440A is seen by the device.

The sub distribution circuits are supplied via integrated switch fuse isolators/MCCBs.harmonic currents.

POWER FACTOR CORRECTION

The existing PFC unit is an Electroflow 200kVAr detuned, multistaged system. It is connected to the main LV section board via a local overload protection. The power factor was maintained at an average of around 0.955 during the monitoring period, which is may need to be improved to meet the latest site-wide standard (TBC).

The power factor and reactive power trends for this supply can be seen in Sections 6.3.5 & 6.3.6 and also Sections 6.4.5 & 6.4.6 of this report.

The PFC was isolated over two separate periods over the 4-week total monitoring period to determine both reactive power contribution and any associated harmonic interaction. This temporary isolation of this system suggests that the 200kVAr unit is currently operating at around 80%, with approximately 160kVAr of reactive power compensation under peak periods and negligible harmonic interaction.

VOLTAGE DROP

During the site survey voltage readings were recorded at several known far points of utilisation in order to determine the absolute minimum voltage that is likely to be seen anywhere on the LV network.

A maximum value of 3V (Uo) or 5V (U) was recorded and has subsequently been used in the associated calculations featured in the following sections of this report.

SITE-SPECIFIC LOAD ANALYSIS – SUB 1, TRANSFORMER T2.

OVERVIEW

In order to determine the energy reduction that can be exhibited from a controlled reduction in the supply voltage, load-bearing equipment should be divided up into two main categories. Voltage Dependent Loads – Will exhibit a reduction in kWh when the voltage is reduced to the optimum level, subject to specific characteristics and load design.

Voltage Independent Loads – Will exhibit little or no reduction in kWh when the voltage is reduced.

Further generic information on voltage management has been provided in Section 3 of this report.

SUMMARY LOAD ANALYSIS

The following table has been populated to show the approximate consumption for the various types of site-specific loads. Access to the entire area was limited during the survey process and therefore, the following information has been based upon the cross section that was accessible.

Load Category (Green shading denotes voltage dependent loads)	% of Total Load Energy Consumed*	VD Factor
Lighting none-HF or non-constant wattage	12	1 (12)
Electronic lighting	3	0
Resistive thermostatic heating	3	0
Resistive non-thermostatic heating (no stat)	0	1
Motors/Pumps VSD	24	Neg
Motors/Pumps non-VSD	56	0.3 (17)
IT/Electronic Equipment	2	Neg
Miscellaneous Small Power	Negligible (MIXED)	Neg
TOTAL	100%	27%EVD

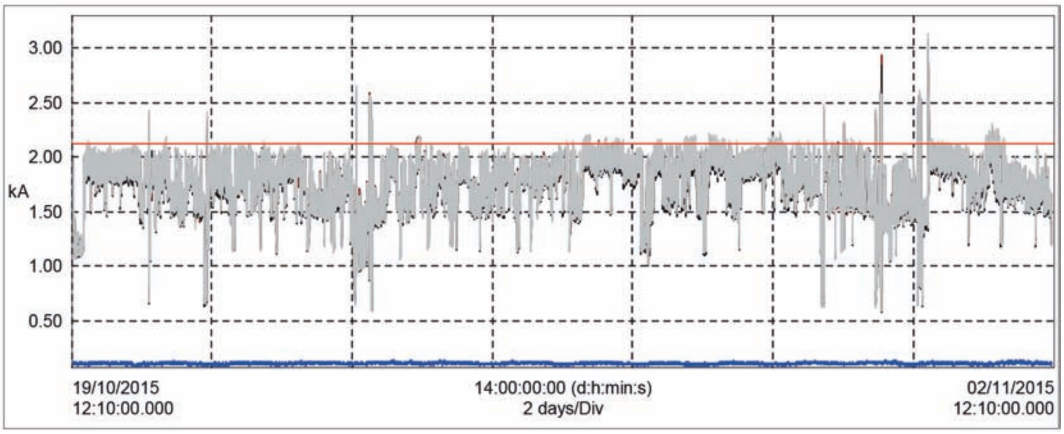
*Having determined the approximate amount of energy that is consumed by the voltage dependent loads, the 'Effective Voltage Dependency' of the specific load type is applied to calculate the overall savings achievable from a controlled reduction in voltage. These factors have been considered along with site-specific voltage profiles, all of which are summarised in Section 7 of this report. The voltage dependent motor loads (non-VSD) at this installation are mostly 230V/400V rated. This information has been considered alongside associated criteria to determine the optimum voltage for the load bearing equipment, as detailed in Section 7. The 'Optimum Voltage' for the installation is determined from the design rating of the majority of load bearing equipment, with an allowance for site-specific volt drop. The optimum for this installation has therefore been calculated at 233V, as detailed in the chart in Section 6.3.2.

14-DAY LOAD PROFILING – 'EXISTING' – T2.

6.3.1 - Phase Currents				
Name	Units	MIN	AVG	MAX
A1 rms	kA	0.599	1.757	3.088
A2 rms	kA	0.578	1.751	3.066
A3 rms	kA	0.587	1.771	3.136
AN rms	A	73.100	106.840	131.800

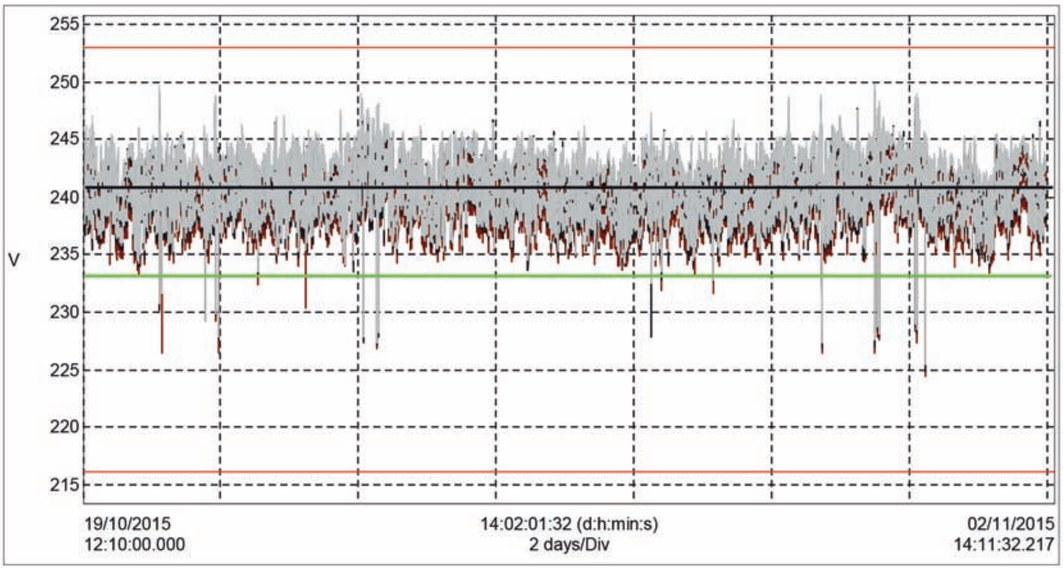
The maximum recorded current through the monitoring period was 3,136A on L3 (grey). The red line indicates the LV current rating of the existing transformer, details of which have been provided in Section 6.1.1 of this report.

The maximum inrush event indicated by the red arrow lasted 3.23s and occurred at 16.50hrs (GMT adjusted).



6.3.2 - RMS Phase Voltage (Uo)				
Name	Units	MIN	AVG	MAX
V1 rms	V	224.400	239.743	248.000
V2 rms	V	224.800	240.509	249.300
V3 rms	V	225.400	240.858	249.800

This chart illustrates the rms voltage recorded throughout the 7-day monitoring period including half cycle dips. The maximum (Uo) voltage was 249.8V and the average value was around 240.3V. The rms voltage dipped to 224.4V (Uo) during the maximum inrush event captured in 6.3.1 above.

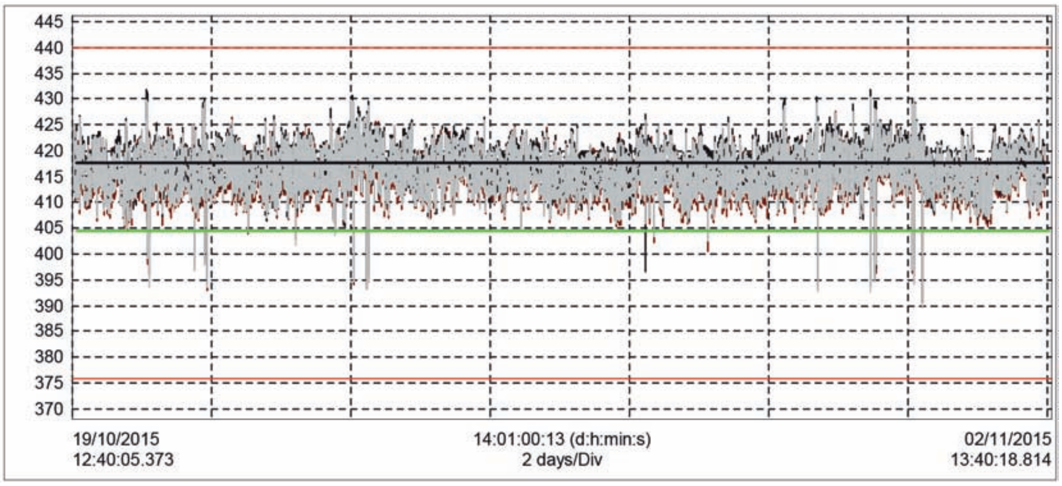


The red lines show the upper and lower tolerances of the ESQCR regulations, as amended.

The green line indicates the optimum average output voltage (233V Uo) at the incoming LV terminals, which is considerate of site specific loads and volt drop and the black line indicates the existing average level (240.3V Uo). Please refer to Section 7 for further detail.

6.3.3 - Three Phase Voltage (U)				
Name	Units	MIN	AVG	MAX
U12 rms	V	390.600	416.033	431.400
U23 rms	V	390.400	416.845	431.900
U31 rms	V	389.700	416.213	430.300

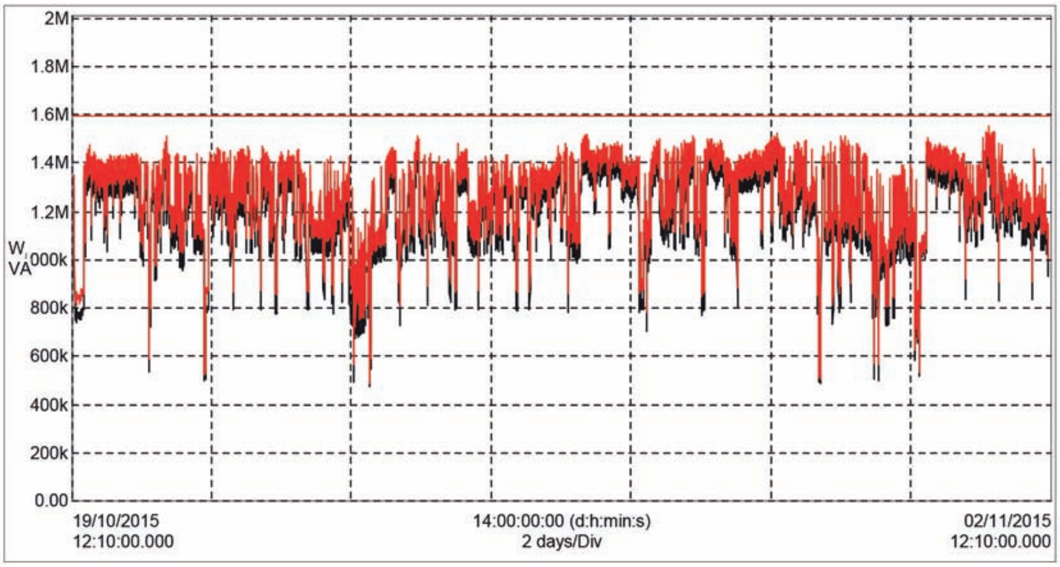
The following chart illustrates the 3-phase voltage levels at the incoming LV terminals, including 10ms events. The black line indicates the average voltage being delivered to the load bearing equipment during the monitoring period.



As in 6.3.2, the red lines indicate the upper and lower tolerances of the ESQCR Regulations 2002 and the green line indicates the approximate voltage required at the main LV terminals to deliver the optimum level to the site-specific load bearing equipment.

6.3.4 - kVA (Apparent power) & kW (True Power) Demand				
Name	Units	MIN	AVG	MAX
ST (VA)	MVA	0.490	1.257	1.200
PT (W)	MW	0.475	1.200	1.500

The following chart illustrates the kVA (red) & kW (black) profile throughout the monitoring period.

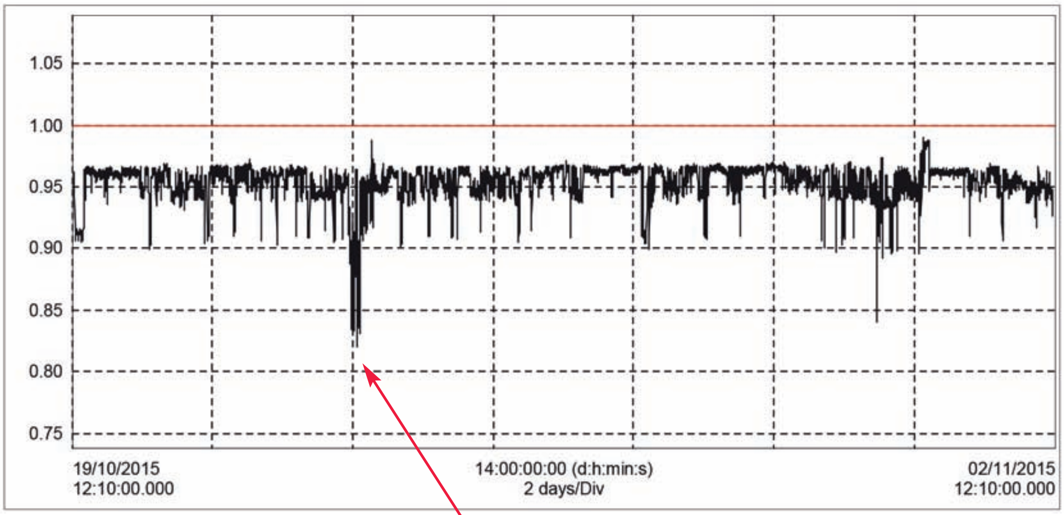


The red line represents the capacity of the 1,600kVA supplying transformer.

The differential between these values can also be seen in the power factor and reactive power charts 6.3.5 & 6.3.6 on the following page.

6.3.5 - Power Factor			
Name	MIN	AVG	MAX
PFT	0.820	0.953	0.990

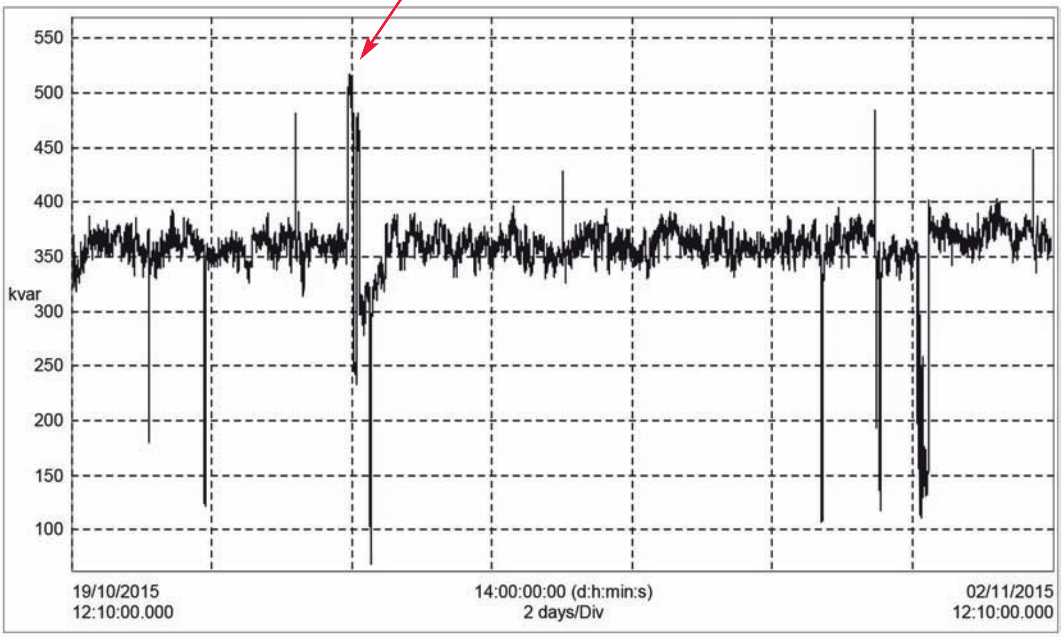
The following chart illustrates the power factor level recorded through the 7-day period. The red line represents a 'unity' power factor. This chart must be read in conjunction with the reactive power chart in 6.3.6 below.



The power factor correction equipment was isolated at 10.30hrs on 23rd October and was re-energised 4 hours later. This change can be seen in the power factor chart and also in the corresponding reactive power chart below, as indicated by the red arrows

6.3.6 - Reactive Power (kVAr)				
Name	Units	MIN	AVG	MAX
QT (var)	kvar	68.671	357.924	517.076

The isolation of the existing 200kVAr PFC equipment revealed that the unit was contributing around 160kVAr of reactive power.

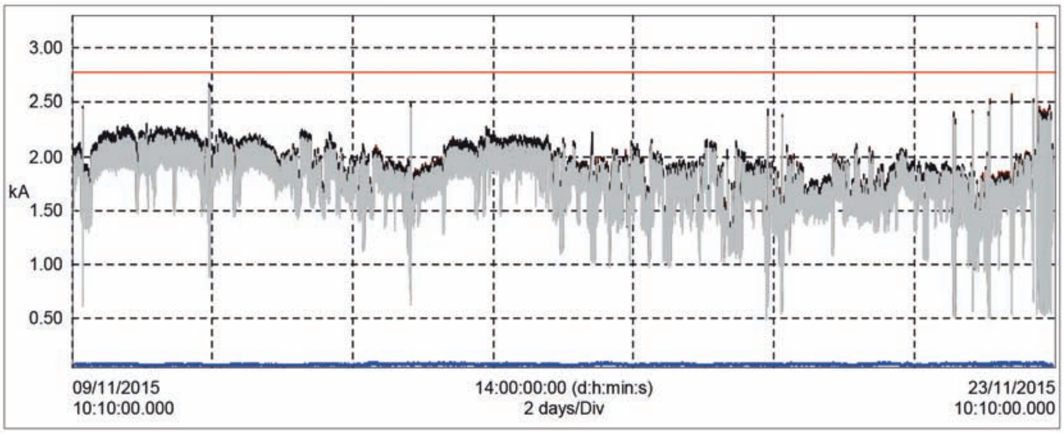


This should be read in conjunction with the harmonic current distortion charts in Section 6.3.7 of this report.

14-DAY LOAD PROFILING – 'REPLACEMENT' – T2.

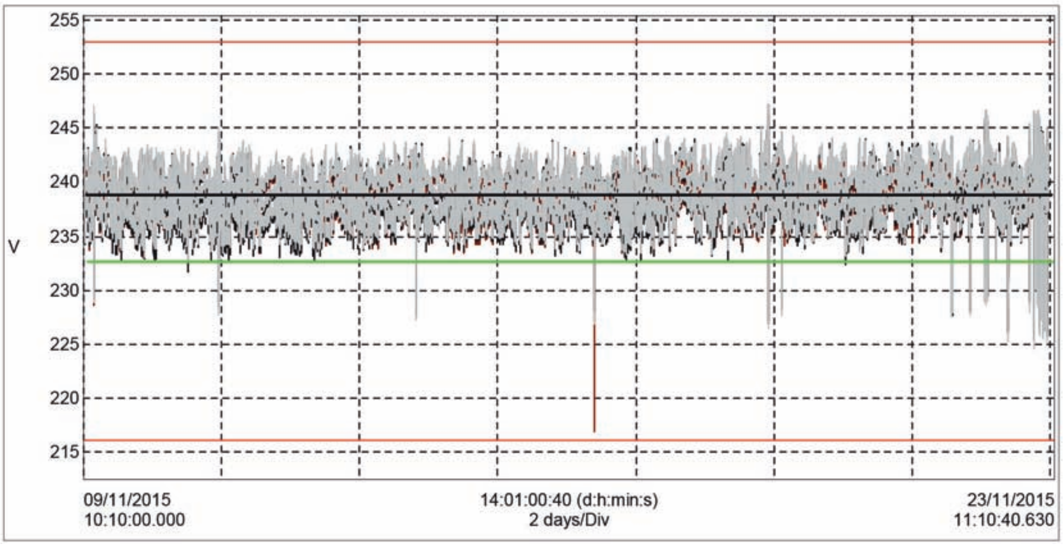
6.4.1 - Phase Currents				
Name	Units	MIN	AVG	MAX
A1 rms	kA	0.540	1.774	3.227
A2 rms	kA	0.511	1.781	3.196
A3 rms	kA	0.494	1.728	3.174
AN rms	A	49.600	74.001	104.100

The maximun recorded recorded current through the monitoring period was 3,227A on L1 (brown). The red line indicates the LV current rating of the existing transformer, details of which have been provided in Section 6.1.1 of this report.



6.4.2 - RMS Phase Voltage (Uo)				
Name	Units	MIN	AVG	MAX
V1 rms	V	216.900	238.600	246.300
V2 rms	V	225.500	238.711	247.200
V3 rms	V	224.600	239.031	247.200

This chart illustrates the rms voltage recorded throughout th e7-day monitoring period including half cycle dips. The maximum (Uo) voltage was 247.2V and the average value was 238.7V. (c1.5V less than previous 'existing' period). The rms voltage dipped to 224.6V (Uo) during normal utilisation of the supply and the 216.9V dip on L1 was a very short duration dip created by an upstream event.

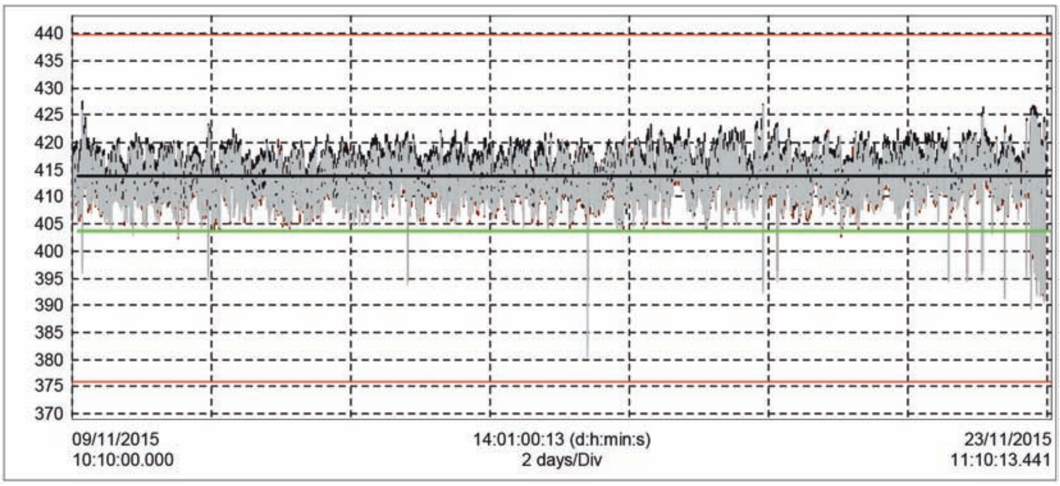


The red lines show the upper and lower tolerances of the ESQCR regulations, as amended.

The green line indicates the optimum average output voltage (233V Uo) at the incoming LV terminals, which is considerate of site specific loads and volt drop and the black line indicates the 'Replacement' average level (238.78V Uo). Please refer to Section 7 for further detail.

6.3.3 - Three Phase Voltage (U)				
Name	Units	MIN	AVG	MAX
U12 rms	V	382.300	413.303	426.900
U23 rms	V	390.900	414.359	427.500
U31 rms	V	380.500	413.175	426.600

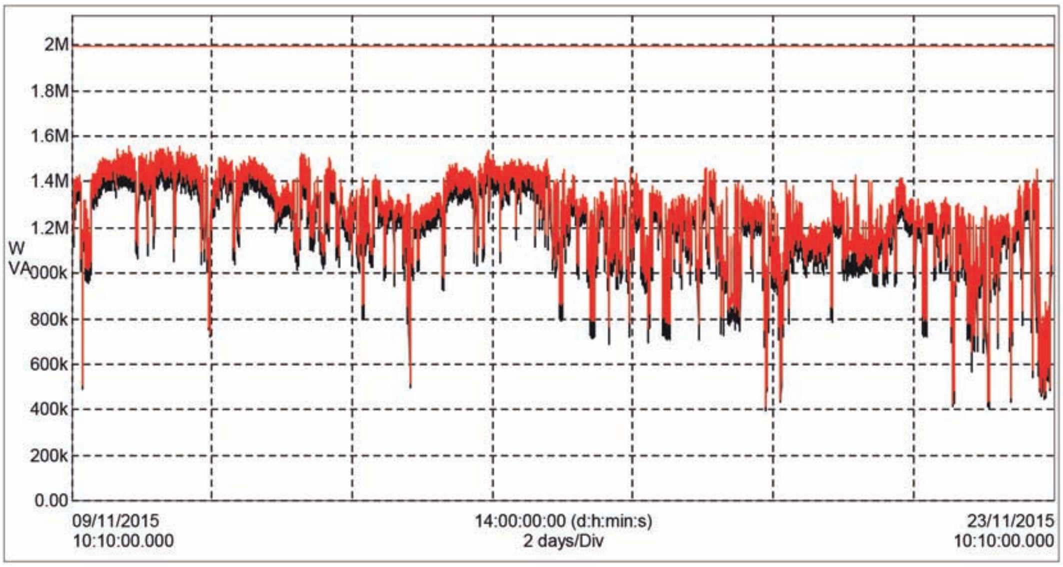
The following chart illustrates the 3-phase voltage levels at the incoming LV terminals, including 10ms events. The black line indicates the average voltage being delivered to the load bearing equipment during the monitoring period.



As in 6.4.2, the red lines indicate the upper and lower tolerances of the ESQCR Regulations 2002 and the green line indicates the approximate voltage required at the main LV terminals to deliver the optimum level to the site-specific load bearing equipment.

6.4.4 - kVA (Apparent power) & kW (True Power) Demand				
Name	Units	MIN	AVG	MAX
ST (VA)	MVA	0.415	1.247	1.559
PT (W)	MW	0.398	1.197	1.510

The following chart illustrates the kVA (red) & kW (black) profile throughout the monitoring period.

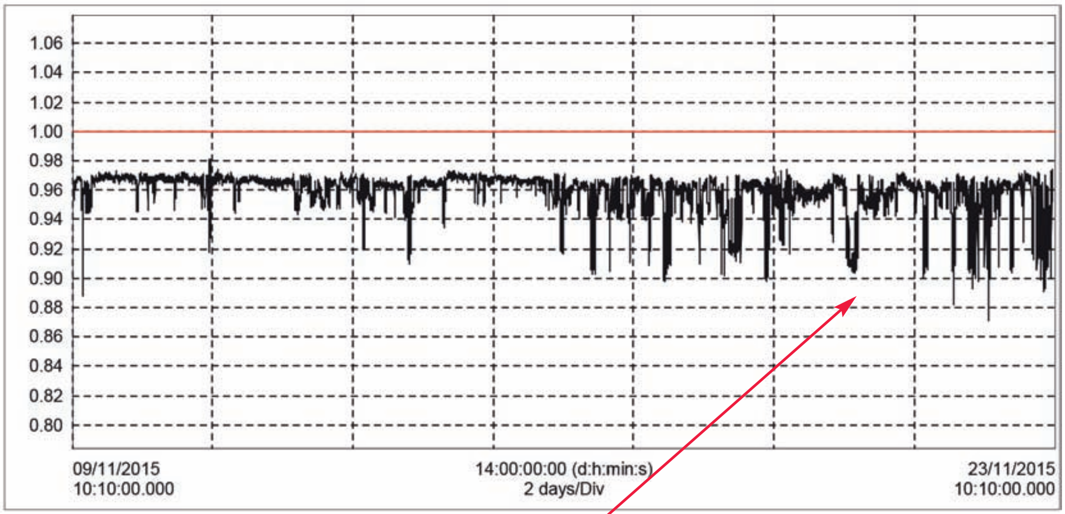


The red line represents the capacity of the 'Replacement' 2,000kVA supplying transformer.

The differential between these values can also be seen in the power factor and reactive power charts 6.4.5 & 6.4.6 on the following page.

6.4.5 - Power Factor			
Name	MIN	AVG	MAX
PFT	0.871	0.958	0.981

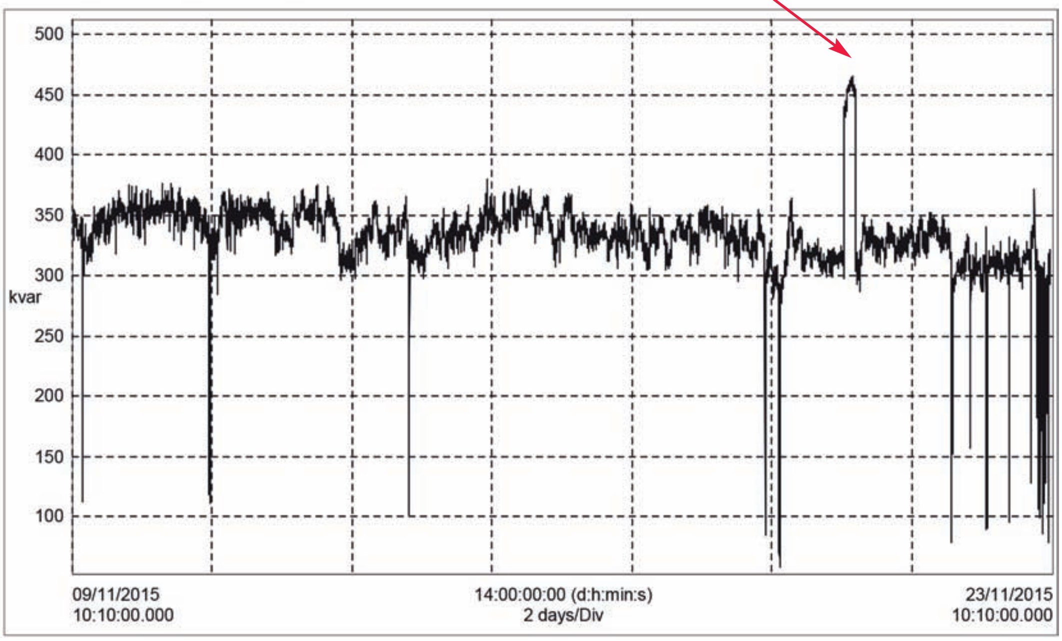
The following chart illustrates the power factor level recorded through the 7-day period. The red line represents a 'unity' power factor. This chart must be read in conjunction with the reactive power chart in 6.4.6 below.



The power factor correction equipment was isolated at 11.15hrs on 20rd November and was re-energised 4 hours later. This change can be seen in the power factor chart and also in the corresponding reactive power chart below, as indicated by the red arrows.

6.3.6 - Reactive Power (kVAr)				
Name	Units	MIN	AVG	MAX
QT (var)	kvar	58.129	333.511	465.524

The isolation of the existing 200kVAr PFC equipment revealed that the unit was contributing around 160kVAr of reactive power.



This should be read in conjunction with the harmonic current distortion charts in Section 6.3.7 of this report.

TECHNICAL & COMMERCIAL SUMMARY

VOLTAGE

This section provides further information and key characteristics relating to the replacement of the 'Existing' 11kV:433V, 1.6MVA,CRGO transformer. Please also refer to the 'Executive Summary' in section one of this report.

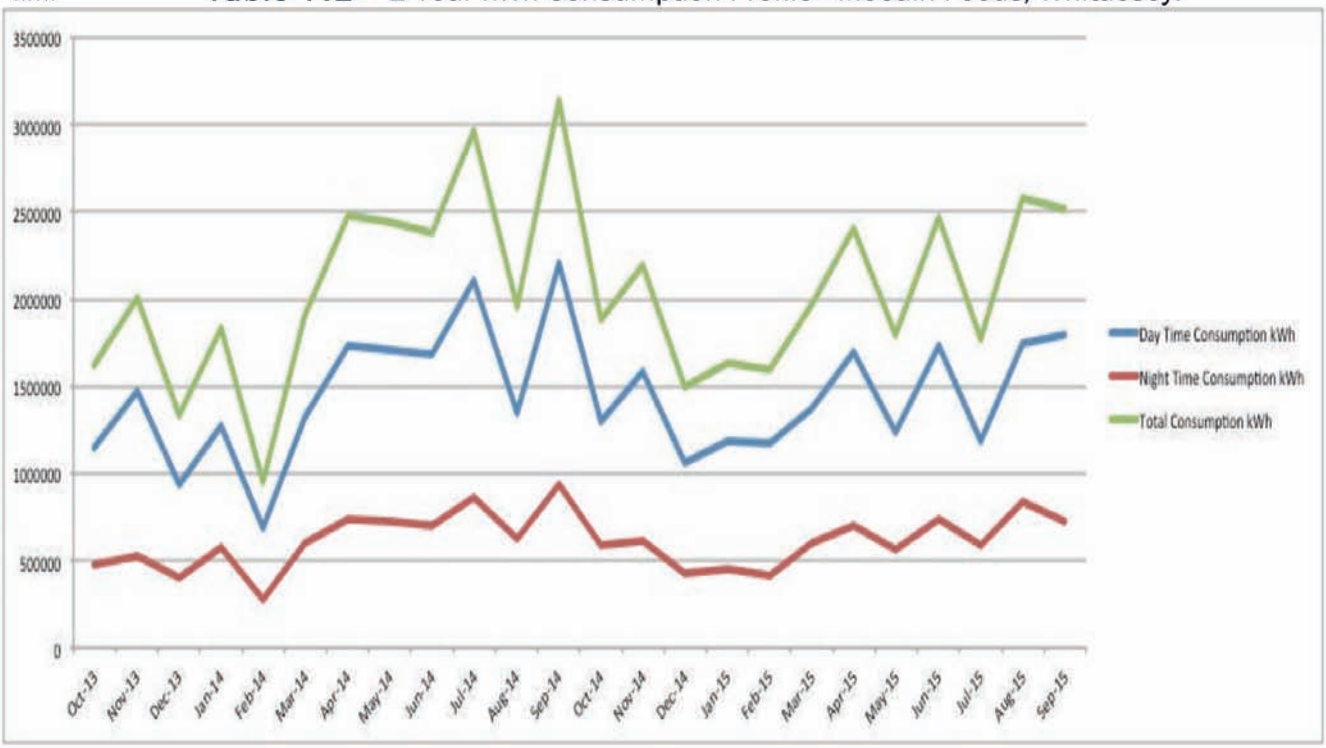
The 'Existing' transformer was monitored between Monday 19th October and Monday 2nd November 2015. This transformer was subsequently decommissioned and replaced with a Wilson Power Solutions e2, 2021 Eco Design Compliant, 11kV:415V, 2MVA Super Low Loss, Amorphous Core 'Replacement' transformer, which was set to work week ending Friday 6th November.

VERIFICATION & CALCULATION OF SAVINGS

Due to the inherent difficulties in verifying relatively small percentage energy savings in a typical industrial application, good engineering principles and manufacturer's equipment data should be utilised to determine the associated gains.

Table 7.1 below illustrates the variations in consumption over the past 24 months at this site.

Table 7.1 – 2-Year kWh Consumption Profile - McCain Foods, Whittlesey.



Even when applying production output and degree-day variations, the ability to verify savings, typically in the region of 1-4%, may be considered as unreliable at best. The following sections have therefore been provided to exhibit the associated energy savings and the method of calculation, where appropraite.

VOLTAGE MANAGEMENT – KEY INDICATORS & CONSIDERATIONS

Generic information on voltage management has been provided in Section 3 of this report. The recorded profiles and various load types have been analysed and considered with the following key principles in mind.

- The average rms voltage under typical load conditions should be as close as possible to the design rating of the majority of the load bearing equipment.
- Exceeding this value may result in excess power being drawn by certain loads and untimely failure or increased maintenance of equipment due to overheating.

Due consideration has been given to short duration voltage dips that may cause problems at voltage sensitive equipment. The power quality analyser was deployed to determine the absolute minimum rms voltage, including 10ms events on the network. These events have been captured within Table 7.2 below. The table provides a summary of the values recorded during the logging periods and the resultant values following the setting to work of the 'Replacement' transformer. We have also provided calculated resultant voltages following the recommended 2.5% tap change*.

Table 7.2 - Voltage Values – *Measured & Proposed

Supply	Min Voltage Measured(Uo)	Max Voltage Measured(Uo)	Av Voltage Measured(Uo)	Av Under Load (Uo)	Optimum (Uo) Under Load
'Existing' 1.6MVA 11kV:433V Tap 2 (+2.5% HV)	*224.4V	*249.8V	*240.37V	*239.75V	233V
'Replacement' 2MVA 11kV:415V Tap 4 (Normal)	*224.6V (excludes 216.9V up-stream event)	*247.2V	*238.78V (only -1.6V Uo reduced)	*238.25V	
*'Replacement' 2MVA 11kV:415V Tap 3 (+2.5% HV)	219V	241V	232.81V	232.25V	

NOTE:
• The tabulated values relate to the voltage at the main incoming terminals. • The blue highlighting shows the resultant & optimum voltages.

By design, the voltage supplied to the installations should remain within the tolerances of the ESQCR regulations, as amended (230V +10/-6% at the incomer).

Table 7.2 illustrates that the optimum average voltage will be achieved within <1% with the 'Replacement' transformer off-load tap at setting – '3' (+2.5% HV). Having considered all of the relevant data, the following section details the approximate energy savings that the nominated voltage reduction is likely to exhibit.

CALCULATED SAVINGS FROM VOLTAGE REDUCTION

The voltage managed energy gains at these installations would emanate mainly from the voltage dependent equipment tabulated within Section 6.2.2 of this report. The calculated energy gains are therefore based mainly upon the following three factors.

1. The degree of voltage reduction.
2. The amount of energy that is consumed by the voltage dependent loads.
3. The energy reduction that each voltage dependent load will exhibit. This influences the 'Effective Voltage Dependency'.

Table 7.2.1 - Voltage Management Savings

Supply	Approx Energy kWh PA	Effective (%) Voltage Dependency	V.D Load Effective kWh PA	Approximate kWh PA Energy Gains @ (- 7.56V Uo)	Annual Saving @ 8p/kWh (avg rate over 5 years)
Sub 1 T2	10,512,000	Approx 29%	3,048,480	188,700kWh P.A (1.8% of total)	£15,096

In summary, a 7.56V reduction in the supply voltage will exhibit an energy reduction of around 1.8% at this installation, reduce the average light output at magnetic ballast luminaires by approximately 4% and decrease earth fault loop impedance values by around 1.5%.

The latter factor and the slight increase in current drawn by switch mode power supplies are unlikely to be significant and will be accommodated through design headroom. It should also be noted that this voltage reduction may slightly increase the life expectancy of certain load bearing equipment.

TRANSFORMER LOSS REDUCTION

By replacing the standard CRGO transformer with a Wilson e2, 2021 EcoDesign, super low loss, amorphous core unit, further energy gains an be exhibited, as detailed below.

These savings can be calculated using manufacturers design data in conjunction with site-specific profiling information. Ultimately, these energy savings are made up of two main characteristics, as detailed below.

1. No Load Losses (NLL) – Fixed core losses, regardless of load.
2. Load Losses (LL) – Winding losses, subject to transformer loading.

The following table has been provided to exhibit the benefits of these characteristics in this sitespecific application.

Table 7.3 - NLL & LL Annual Savings Summary

Transformer	No Load Losses P.A (Core Losses)	Load Losses P.A (Winding Losses)	Combined Losses P.A (LL + NLL)
'Existing' (78.56% average load)	15,768kWh P.A	127,831kWh P.A	143,599kWh
'Replacement' (62.85% average load)	7,446kWh P.A	51,904kWh P.A	59,350kWh
SAVING/ENERGY DIFFERENTIAL	8,322kWh P.A	75,927kWh P.A	84,249kWh/ £6,739.92 (0.80% of total P.A)

COMBINED VOLTAGE REDUCTION & TRANSFORMER LOSS SAVINGS

The following table details the combined energy and fiscal savings based upon an average rate of 8p/kWh.

Table 7.4 - Combined Annual Energy Gains

Supply	V.M Savings	Combined TX Loss Reduction	Combined Annual kWh Reduction	Approximate % Energy Saving	Approximate Cost Saving @8p/kWh
T2	188,700kWh	84,249kWh	272,949kWh	2.6% of total	£21,835 P.A

It should also be noted that the replacement transformer would have the facility to manually adjust the output voltage (off-load) by a further 5% reduction or up to 7.5% increase, subject to future load or network changes.

POWER QUALITY

The power quality at this site was benchmarked against G5/4-1, the ESQCR regulations 2002 and some characteristics of EN50160.

In summary, the installation was compliant with all standards, as assessed, although the 5th harmonic current & voltage distortion should be considered if any additional drives are added to this LV network.

POWER FACTOR CORRECTION

The existing 200kVAr PFC bank appears to be operating at around 80% of the design output and annual cyclic maintenance will be required to avoid natural deterioration of the caps.

The average power factor at this supply was around 0.955 during the monitoring periods. This should be considered in conjunction with the site wide target power factor in order that due consideration may be given to upgrading systems, as required.

SUMMARY OF RECOMMENDED FINAL 'TAP CHANGE'

If the new 'Replacement' transformer is left on tap 4:

- Voltage management savings 40,240kWh P.A
- No Load Loss reduction 8,322kWh P.A
- Load Loss reduction 75,927kWh P.A
- Total energy saving of 124,489kWh P.A
- Fiscal saving on energy @ 8p/unit £9,959 P.A
- 1.18% of total energy at T2
- CO2 reduction of 55,457kg P.A
- CCL reduction £307 P.A
- Total fiscal saving £10,266 at present If/when adjusted to tap 3
- ADDITIONAL Voltage management savings of £148,460kWh P.A (188,700kWh total)
- No Load Loss reduction 8,322kWh P.A
- Load Loss reduction 75,927kWh P.A
- Total energy saving of 272,949kWh P.A
- Fiscal saving on energy @ 8p/unit £21,835 P.A
- 2.6% of total energy at T2
- CO2 reduction of 121,593kg P.A
- CCL reduction £673 P.A
- Total fiscal saving £22,508 if changed to tap 3

Please also refer to the Executive Summary in Section 1.

SUMMARY OF MEASURED CHARACTERISTICS, TRANSFORMER T2.

'EXISTING' (1.6MVA TRANSFORMER)

A1 MAX	Maximum current 3,088A inrush.
A2 MAX	Maximum current 3,066A inrush.
A3 MAX	Maximum current 3,136A inrush.
AN Max	Maximum neutral current 131.8A.
V1RMS.	Average 239.7V, min 224.4V, max 248.0V.
V2RMS.	Average 240.5V, min 224.8V, max 249.3V.
V3RMS.	Average 240.8V, min 225.4V, max 249.8V.
URMS	(Av) Average 416.36V.
kW.	Max 1,500kW, average 1,200kW.
kVA.	Max 1,554kVA, average 1,257kVA.
Power Factor	Average 0.953, min 0.820, max 0.990.
kVAr	Average import 357kVAr, max on isolation of PFC was 517kVAr.
ATHD.	Average harmonic current distortion per phase 6.47%, 6.57%, 6.38% respectively.
Ah	5th harmonic current max 126A. All other harmonic currents were G5/4-1 compliant.
V THD.	Total voltage harmonic distortion peaked at 3.1%, against max allowable of 4% at 11kV PCC.
Flicker	Pst & Plt were both compliant with EN 50160 for >95% of period, as required.
Crest Factor	The crest factor level recorded ranged between 1.46 and 1.51 against a pure sine wave value of 1.414.
Frequency	Ranged between 49.83 and 50.19.
Balance	The voltage imbalance peaked at 0.3% and the current imbalance peaked at 3.9% during the monitoring period.

'REPLACEMENT' (2MVA TRANSFORMER)

A1 MAX	Maximum current 3,227A inrush.
A2 MAX	Maximum current 3,196A inrush.
A3 MAX	Maximum current 3,174A inrush.
AN Max	Maximum neutral current 104A.
V1RMS.	Average 238.6V, min 216.9V (upstream event), max 246.3V.
V2RMS.	Average 238.7V, min 225.5V, max 247.2V.
V3RMS.	Average 239.0V, min 224.6V, max 247.2V.
URMS	(Av) Average 413.7V.
kW.	Max 1,510kW, average 1,197kW. (0.8% energy reduction).
kVA.	Max 1,559kVA, average 1,247kVA.
Power Factor	Average 0.958, min 0.871, max 0.981.
kVAr	Average import 333kVAr.
ATHD.	Average harmonic current distortion per phase 6.6%, 6,7%, 6.8% respectively.
Ah	Ah 5th harmonic current max 141A. All other harmonic currents G5/4-1 compliant.
V THD.	Total voltage harmonic distortion peaked at 2.7%, against max allowable of 4% at 11kV PCC.
Flicker	Pst & Plt were both compliant with EN 50160 for >95% of period, as required.
Crest Factor	The crest factor level recorded ranged between 1.46 and 1.50 against a pure sine wave value of 1.414.
Frequency	Ranged between 49.83 and 50.25.
Balance	The voltage imbalance peaked at 0.40% and the current imbalance peaked at 6.9% during the monitoring period.

APPENDIX A – EUROPEAN VOLTAGE HARMONISATION

Up until January 1995 the nominal supply voltage in the UK was 240/415V +/- 6%. In Europe the nominal standard was 220/380V +/- 6%.

Following European harmonisation standards coordinated by The European Committee for Electro-technical Standardisation (CENELEC) , all electricity supplies within the EU are now nominally 230V +/-10% . The statutory band that electricity network operators have to supply within is therefore between 216.2 and 253V for single phase and 380V to 440V for three phase. Customers can expect to remain within these limits except in abnormal circumstances, which are described in the Grid Code.

These limits enable countries such as the UK who previously supplied at 240V nominal to continue, thus reducing the need for considerable investment in distribution infrastructure to accommodate the new nominal voltage. The continued deviation in the UK from harmonised European voltage has been criticised in particular by light bulb manufacturers. The higher voltage reduces significantly the lifetime of their product.

The next stage in the European harmonisation process took place in 2008, when the voltage supply range in the UK broadened to 207 and 253V (+/-10%) . Most equipment manufactured for use in Europe is typically rated at 230V (or even 220V) meaning that it could be running as much as 33V above the supplied voltage.

APPENDIX B: VOLTAGE MANAGEMENT

As voltage management is one of the key considerations at this installation, we have provided a generic overview of this energy saving technique for information and clarity.

Terminology such as optimisation, reduction, regulation and stabilisation are often used to describe the hardware that can be commissioned to manage the amount of voltage that an installation is supplied with. The term voltage management is therefore accepted as a common reference.

Subject to a number of variable factors, this technology can assist consumers in making significant financial savings by reducing and in some cases regulating the mains voltage used to power electrical equipment.

There are two main families of engineering solution, both of which can deliver a reasonable return on investment with minimal on-going maintenance requirements. Namely, these are fixed ratio/step down transformers and voltage regulators/stabilisers. Generally, before any additional hardware is invested in, a study should be carried out to determine if the existing site transformer could be tapped down to increase the stability of the load bearing equipment whilst reducing the kWh consumption.

During the site survey, load-bearing equipment should be categorised into 'voltage dependent' & 'voltage independent' equipment.

Voltage dependent equipment such as luminaires with magnetic ballasts and certain induction motors without any optimisation, are likely to exhibit an energy saving when the supply voltage is managed at the optimum level.

However, 'voltage independent' loads such as high frequency lighting, IT equipment, thermostatic resistive heating and motors fitted with variable speed drives, will not benefit in the same way.

However, it should be noted that reducing the voltage to within the design parameters of load bearing equipment would generally increase the lifespan and stability of the equipment. More information on the general effects that a voltage reduction may have on various load types has been provided below.

GENERAL EFFECTS OF VOLTAGE REDUCTION (GENERIC)

Estimating the amount of power that load bearing equipment will exhibit when a voltage is reduced is dependent upon many variable factors. The type of load, specific power rating, optimum design voltage and the duty cycle are some of the factors that should be considered in order to be able to provide an estimate of the resultant power reduction. External influences add a further variable dimension in systems with heating pumps and chiller units.

The benefits of an energy reduction through voltage management are well documented and include the following statement published by the IEE:

- A 230V linear appliance used on a 240V supply will take 4.3% more current and consume almost 9% more energy.

It should be noted that ratio relates most accurately to voltage dependent lighting loads, rather than motor loads, as detailed further on the following pages.

THREEE PHASE AC MOTORS (GENERIC)

Three phase AC induction motors are probably the most common type of load and are used in a variety of equipment including refrigeration, pumps, air conditioning and conveyor drives. The derating effects of overvoltage and three-phase imbalance on AC motors are well known. Excessive overvoltage can result in the saturation of the iron core, wasting energy through eddy currents and increased hysteresis losses. In drawing excessive current, excess heat is created due to copper losses.

The additional stress of overvoltage on motors will decrease the design lifetime of the motor. Avoiding overvoltage high enough to cause saturation does not reduce efficiency and therefore substantial energy savings can be made from reducing iron and copper losses.

However, motors designed for the nominal voltage (e.g. 400V) should be able to cope with normal variations in voltage within the supply limits (+/-10%) without saturation, so this is unlikely to be a significant problem.

Reducing voltage to an induction motor may affect the motor speed as slip will increase, however, speed is mainly a function of the supply frequency and number of poles. Motor efficiency is typically optimum when loaded at 75% and when supplied at the design voltage.

Lightly loaded motors (<50%) and small motors will benefit most from the voltage reduction. Motors driven by a variable speed drive will generally use the same power as before but may draw more current and with reduced stored energy in the DC bus capacitors, may be slightly more vulnerable to power dips.

Lighting (Generic) When lighting loads are used for a high portion of the time, energy savings on lighting equipment can be extremely valuable. When the voltage is reduced, incandescent lighting will see a large decrease in power drawn, a decrease in light output and an increase in lifetime.

Other types of lighting that utilise inductive ballasts such as discharge lighting can also benefit from voltage reduction. Fluorescent lighting with conventional magnetic ballasts will see a reduction in power consumption, but also a reduced lumen output.

Fluorescent lamps on modern electronic ballasts will use approximately the same power and give the same light. A common concern is that some lighting will fail to strike at lower voltages, however this can usually be avoided as the aim of voltage management is not to simply reduce the voltage as far as possible, but to maintain the voltage at the optimum level or range. Heating (Generic) Heaters will consume less power but will give out less heat. Thermostatically controlled space or water heaters will consume less power while running but will have to run for longer to produce the required output, resulting in no saving and in some cases,increased consumption due to additional standing losses.

Switched mode power supplies (Generic) Switched mode power supplies will typically consume the same amount of energy with voltage reduction but will draw slightly greater current to achieve this. In some cases this may increase the risk of MCB's tripping out on over load.

Losses (Generic) We should also note that when adding another series transformer, consideration should be given to the losses associated with any system. These losses can be calculated if the No Load Losses (NLL) and Load Losses (LL) are known.

A site-specific assessment was carried out at Transformer T2 and the associated downstream installation and the results can be found within this report.

APPENDIX C: GLOSSARY

AC: Alternating Current

ACB: Air Circuit Breaker

AF: Air Forced (transformer cooling)

AHF: Active Harmonic Filter

AN: Air Natural (transformer cooling)

CCL: Climate Change Levy

CRGO: Copper Rolled Grain Orientated

CFL: Compact Fluorescent Lamp

CT: Current Transformer

DNO: Distribution Network Operator

EFLI: Earth Fault Loop Impedance

EN50160: European standard for 'Voltage Characteristics of Electricity Supplied by Public Distribution'

ENAG5/4-1: Electricity Networks Association Power Quality Standards

ESQCR: Electricity, Safety, Quality & Continuity Regulations 2002

HF: High Frequency

HV: High Voltage (exceeding low voltage)

IEE/IET: The Institute of Engineering & Technology

IT: Information Technology

kVA: Kilovolt-Ampere (apparent power)

kVAr: Kilovolt-Ampere Reactive

kW: Kilowatt (real power).

kWh: Kilowatt hour.

KNAN: Midel(K) Natural Air Natural (transformer cooling).

LL: Transformer winding Load Losses.

LV: Low Voltage (<1,000V AC).

MCB: Miniature Circuit Breaker.

MCCB: Moulded Case Circuit Breaker.

NLL: Transformer core No Load Losses.

ONAN: Oil Natural Air Natural (transformer cooling).

PCC: Point of Common Coupling to the DNO.

PFC: Power Factor Correction.

PF: Power Factor.

PQ: Power Quality.

RMS: Root Mean Squared.

ROI: Return on Investment.

THDA: Total Harmonic Distortion Amps (current).

THDV: Total Harmonic Distortion Voltage.

U: Voltage between phase conductors.

Uo: Voltage between phase and earth conductor.

VSD: Variable Speed Drive.

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