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Low Carbon Network Fund Project ENWT1001 - The Smart Fuse

Closedown Report
May 2014

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Durham University | electricity north west — Bringing energy to your door | KELVATEK

FIGURES

TABLES

1 EXECUTIVE SUMMARY

1.1 Aims

The aim of the project was to both monitor and record a number of low voltage network performance metrics and reduce the impact of transient faults on our customers.

1.2 Methodology

Methodologies used for the introduction of the Smart Fuse were similar to those used for the introduction of any new technology into a DNO business. Specific training programmes including regular refresher courses were developed with Kelvatek and rolled out across out field staff as the Smart Fuse was deployed. Data analysis was carried out by Durham University.

1.3 Outcomes

The outcome of the project is a demonstration of the benefits of the Smart Fuse. The development of the device funded through the Innovation Funding Incentive was based on a cost/benefit analysis that contained a number of financial and network performance projections. Whilst these projections were based on the best available information at the time, they were still only estimated figures and the outcome of this project has allowed those projections to be improved based on real data.

1.4 Key Learning

There were a number of key learning points regarding the management of low voltage networks and the use of technology to improve this performance.

1.5 Conclusions

The Smart Fuse has been a demonstration of the positive impact of the innovation incentives available to DNOs. What began as a simple concept for a low voltage auto-reclosing device to meet a perceived has now grown into a significant business activity across a number of DNOs. The Smart Fuse is generating measurable financial benefits to DNOs and improved service to our customers and not least has created long term employment opportunities within Kelvatek.

2 PROJECT TITLE

ENWT001 The 'Bidoyng' Smart Fuse

3 PROJECT BACKGROUND

In recognition of the number of transient faults being experienced on low voltage (LV) distribution networks and the constant drive to improve customer service, Electricity North West initiated the IFI funded Fuse Restorer Project in 2006 with Kelvatek. The aim of the project was to develop a device capable of carrying two low voltage fuses in a standard size fuse carrier. The device would be designed to automatically insert a secondary fuse into a circuit following a transient fault to restore supplies to our customers and could then send an alarm to a nominated contact. Kelvatek delivered the final device in November 2010, subsequently known as the 'Bidoyng Smart Fuse' and three were installed on Electricity North West's network in Wigan, Lancashire. They successfully operated to restore supplies to over 100 customers following a transient fault at 11.30pm on 12th November 2010. Following the success of the IFI project this project funded under Tier 1 of the Low Carbon Network Fund was launched in December 2010 and was aimed at facilitating the deployment of Smart Fuses across a number of feeders to both gather a range of network performance data and to attempt to make a positive impact on customer restoration performance.

As part of the original IFI funded project, financial projections were made describing the potential benefits of implementing the Smart Fuse across Electricity North West's entire business. The ultimate aim of ENWT1001 was to move the Smart Fuse through the design, development, deployment to business as usual process and provide real data to further develop the original financial cost and benefit projections.

3.1 Development of the Smart Fuse

The Smart Fuse was developed between 2006 and 2010 by Kelvatek in response to a specification developed by Electricity North West. The original specification contained the following performance parameters;

- The unit will contain two off JP type fuses
- The unit will have a panel engagement footprint of approximately 60 mm x 160 mm
- The packaging volume will be made up of two parts
    - Part 1 : 60 mm x 160 mm x 120 mm high
    - Part 2 : 85 mm x 160 mm x 30 mm high
    - Part 2 will sit on top of part 1 to give an overall height of 150 mm
- The unit will incorporate a handle to facilitate handling and installation, the handle must not impeded any part of the low voltage fuse pillar
- The overall height of the unit will be determined by the fundamental requirement to package the components into a compact integral unit, incorporating any additional features necessary to provide an easy to use product
- The unit will incorporate tang clamping arrangements generally as per existing products
- The unit will incorporate a switch to transfer electrical load to the secondary fuse in the event of failure of the primary fuse. Switch configurations to be investigated. Options to be considered include linear or rotary motion incorporating plates or pins
- It is desirable that the actuation of the switch should be as fast as possible. Actuation speed cannot be determined until the switch is manufactured and tested
- A delay of typically 10 seconds is acceptable between operation of the primary fuse and triggering of the switch
- The unit will incorporate a spring(s) as the motive force to operate the switch
- The unit will incorporate a latching arrangement to prime the spring. The unit will be designed to facilitate spring latching before or after installation into the electrical panel
- It is envisaged that a special latching tool will be required. The design of the latching tool is within the scope of this proposal
- The unit will be designed to incorporate visual indication as to the state of the spring mechanism i.e. latched or unlatched. It is also desirable to have an indication that the secondary fuse has failed
- The unit will incorporate a triggering mechanism to automatically unlatch the spring on detection of failure of the primary fuse
- The triggering mechanism will be designed around an electrically operated solenoid device
- The electrical triggering signal will be generated from an electronic system within the unit. The system will also verify if it is safe to trigger the switch
- The unit will be of a robust construction capable of withstanding the loads experienced during handing, installation, clamping and latching
- The unit will incorporate a cover to prevent access to live components when installed into a panel
- The circuit diagram must be as shown in Figure 3-1

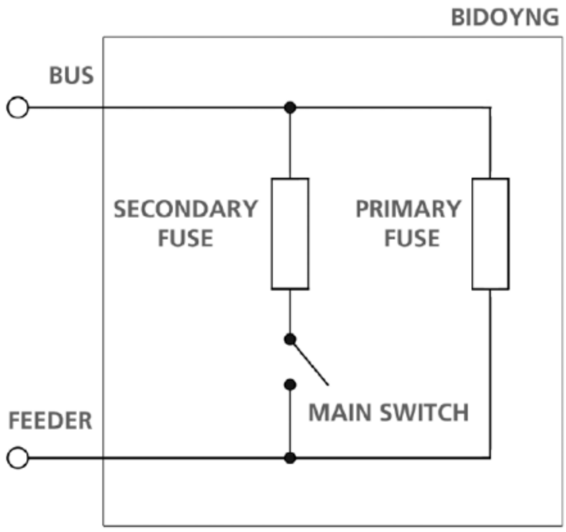
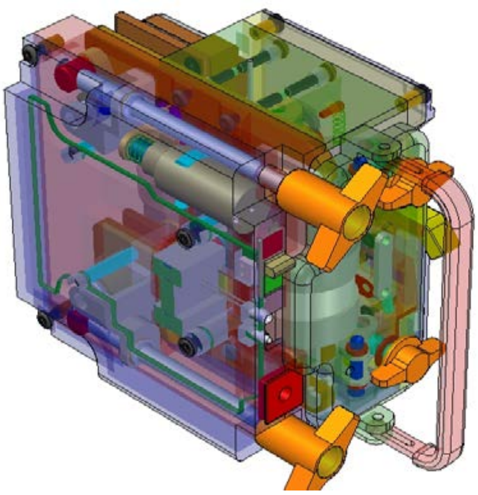
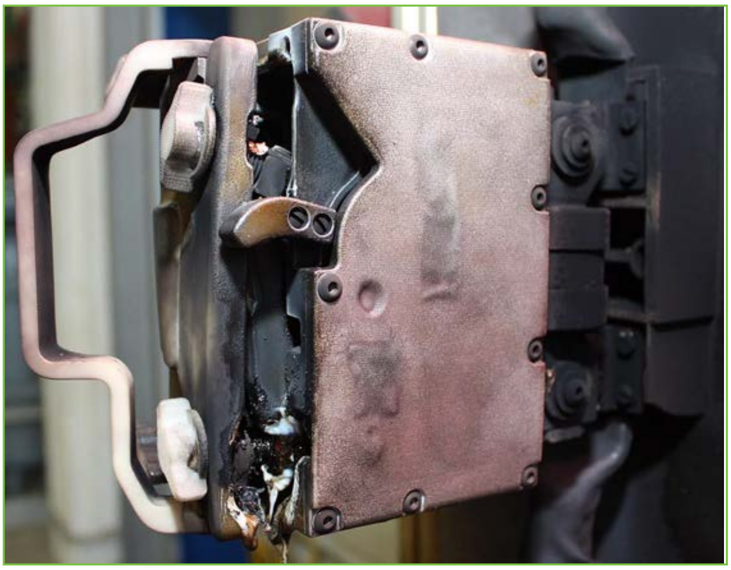


Figure 3-1 - Circuit diagram of a Bidoyng



Initial Design

Prototype to Production



Testing to Destruction

First Installation

Figure 3-2 - Smart Fuse Development

Following installation of the first three units on 11th November 2010 they successfully operated following a fault on the low voltage network on 12th November 2010 to restore supplies to over 100 customers and the IFI project was considered to be successfully completed.

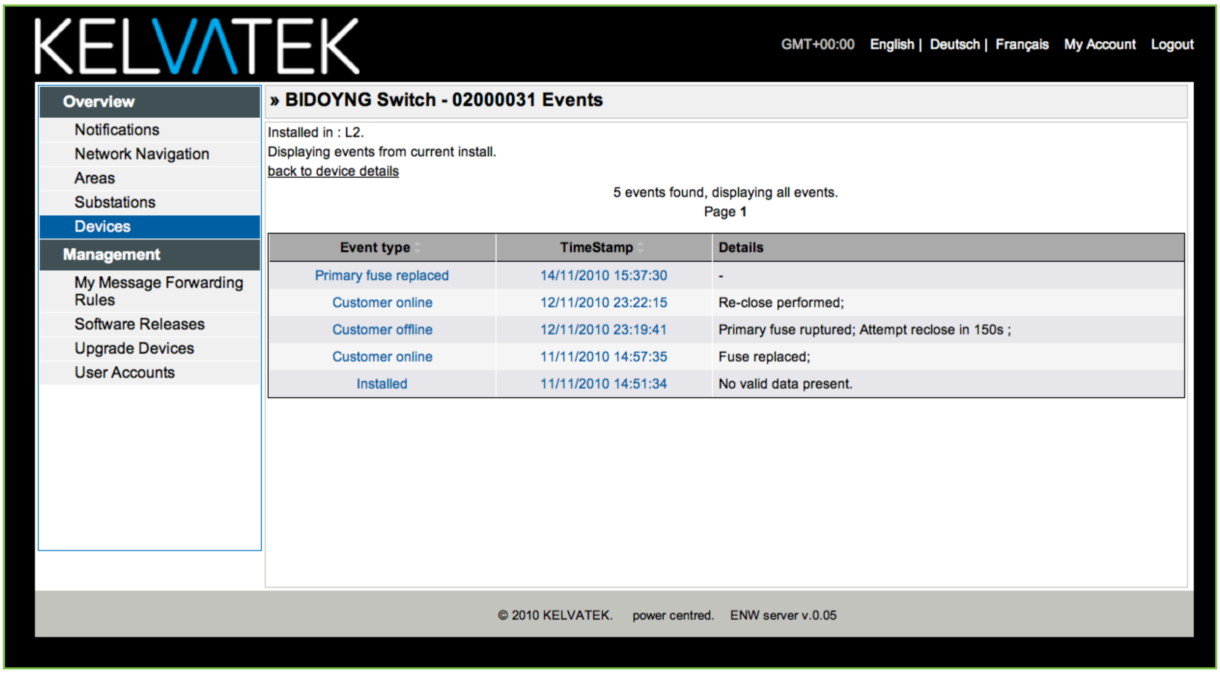


Figure 3-3 - First Successful Re-close of the Smart Fuses on a UK Network

4 ENWT1001 - SCOPE AND OBJECTIVES

The scope and objectives section of the original low carbon networks fund registration pro forma is contained in Appendix A. The four specific objectives of the project were to;

1 Purchase and install 200 Smart Fuses, 100 for Electricity North West's fault restoration teams to be used in response to faults and moved around the low voltage network as required and 100 to be installed in a fixed location to monitor loads.

2 To gather data regarding the performance of low voltage networks, particularly in light of the significant amount of distributed generation in the form of domestic solar photo voltaic (PV) panels that were installed in 2009 and 2010 in response to Feed-in-Tariffs. During the development of the Smart Fuse the debate on smart grids developed significantly. There was recognition that the low voltage network will become ever more important as domestic scale renewable energy generation is expected to play an ever greater part in the transition to a low carbon economy. The Smart Fuse has been designed to provide a high specification voltage and load profiling platform with full communications capability and a range of fault analysis applications and this project was intended to provide the data needed to develop the network load modelling and profiling algorithms to support the optimisation of our low voltage network.

3 To improve customer service by reducing the time to restore supplies following a fault. When a fault occurs on an underground low voltage circuit a fuse within the distribution substation operates and disconnects the faulty circuit with its connected customers from the network. The first response is to simply replace the fuse protecting the individual circuit with a new fuse and for approximately 80% of faults, supplies are restored with no further fault activity. These types of faults are known as 'Transient' faults. The aim of the Smart Fuse is to automatically perform this fuse restoration action within the first few minutes of the fault occurring so restoring supplies to (80% of) customers.

4 To provide enough data to develop policies and procedures regarding the use of the Smart Fuse on low voltage networks. The management of faults on electricity networks or indeed any contact with energised conductors presents a number of significant risks to operators. The project provided the opportunity to develop a set of procedures to describe the correct use of the Smart Fuse.

5 ENWT1001 - SCALE OF PROJECT

The Smart Fuse design was rigorously tested in laboratories and on live test networks during the IFI funded project[1] and was shown to operate as designed. The rationale for this project was to scale up the deployment of Smart Fuses to gather data that could be used for a meaningful statistical analysis to assess the performance of the device and the potential for deployment across Electricity North West. The rationale for the size of the trial was to ensure a significant number of locations could be covered to guarantee enough faults could be recorded to prove the reliability and robustness of the Smart Fuse.

6 ENWT1001 - SUCCESS CRITERIA

Following procurement and installation of the Smart Fuses, the project was to be considered a success by achieving four milestones: installation of the devices, recording and analysis of low voltage network performance metrics, demonstration of the advantages of the technology (auto-reclosing, load profiling) in restoring customers supplies following a fault and internal policy and installation procedure development.

7 ENWT1001 - DETAILS OF THE WORK CARRIED OUT

7.1 Installation of the Smart Fuses

7.1.1 Load Monitoring

The first units were installed in collaboration with Stockport Homes in Stockport, Cheshire in an area identified for a significant installation of solar PV on domestic properties. A great deal has been learnt about the effects of wide scale PV adoption on urban underground networks through a range of other low carbon network fund sponsored projects since 2010 but at the time the project was initiated there was a lack of monitored data to complement the various models that had been developed. In total 94 units were installed across 6 distribution substations in Stockport described in Table 7-1.

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[1] Type testing carried out at IPH in Berlin during Nov 2009, Test Report No 3147.2091118.0847 available on request

Substation Name	Number of Installed Smart Fuses
Brinnington Mount	6
Cornwall Crescent	23
Dunton Green	13
Keston Crescent	20
Lapwing Lane	16
Middlesex Rd	16
Total	**94**

Table 7-1 - Details of Substations where the Smart Fuses were installed

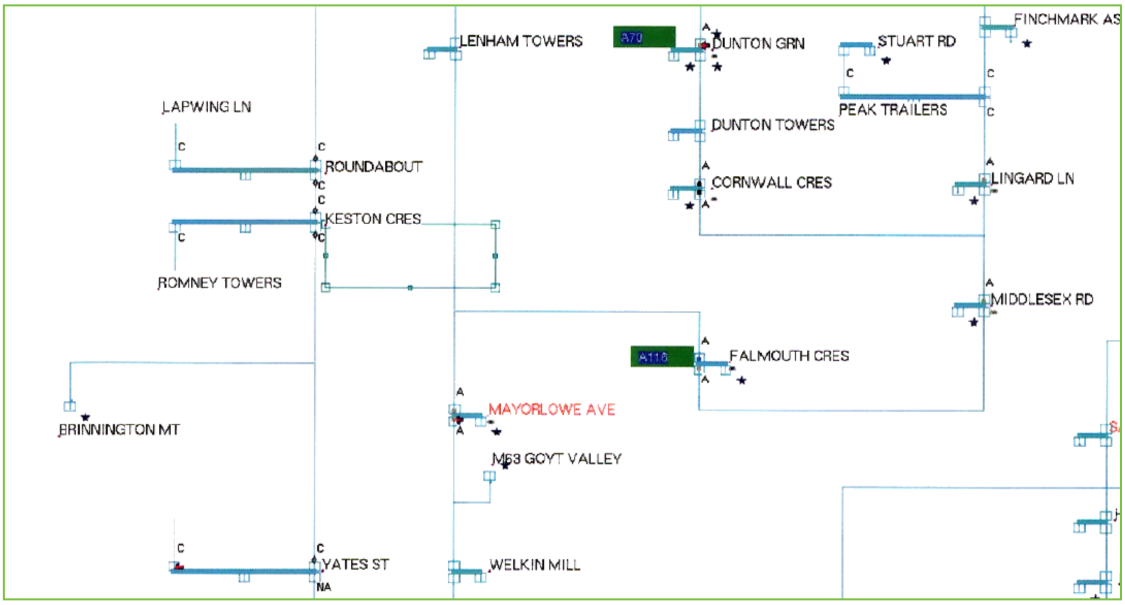


Figure 7-1 - Single Line Diagram of the LV Network where the Smart Fuses were installed

The Smart Fuse is installed with a ‘Gateway’ which can communicate via low power radio with up to 15 individual units; the Gateway communicates with a central server via the GSM Network.

Figure 7-2 - Smart Fuse Gateway

As would be expected, a number of issues were encountered during the installation due to the variations in the design of the various indoor and outdoor low voltage distribution boards and valuable learning was generated regarding the types of solutions that were required to facilitate installation. Issues included some designs of low voltage feeder positions requiring stalk extensions to ensure clearances could be met, pre-work for low voltage supplies for the Gateway unit, the development of installation instructions and guidance and the creation of laminated short-form cards that were left on site with the installed units to ensure anyone attending site was fully informed with technical and contact details.

Figure 7-3 - Various Installation showing the types and variations of indoor and outdoor LV Feeder Pillars

Following physical installation the Smart Fuses were commissioned via the Gateway that can confirm the 'health' of the units and that communications to the main server are present.

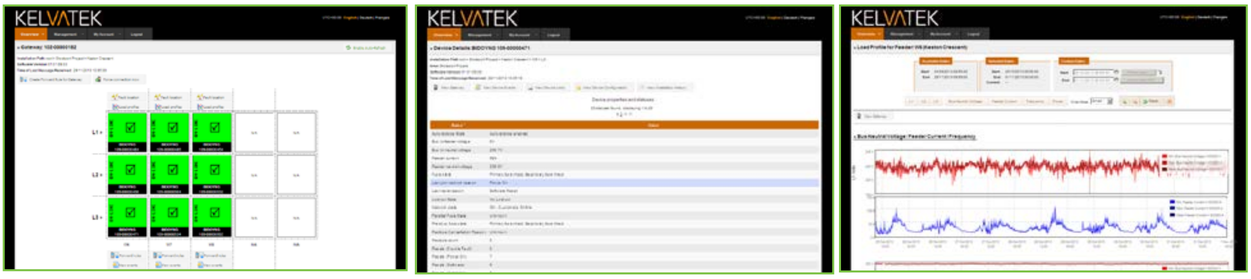


Figure 7-4 - Screen Shots from the Web Server

Load data from the units is remotely retrieved through the Kelvatek Web Server (Figure 7-4 - Screen Shots from the Web Server) and a range of analysis algorithms are available to display all parameters relating to singe phase power flow on low voltage feeders. Load readings are taken on each phase on a 1 minute interval providing a significant amount of data for analysis.

7.1.2 Fault Management

The remaining 106 Smart Fuse Units were issued across Electricity North West's fault restoration teams for trailing in response to transient fault management. The Smart Fuses were issued to a number of fault teams across Electricity North West's region and training was provided by Kelvatek.

7.1.3 Defects

Of the 200 units purchased three were found to be defective during the installation period. The defects were only apparent when the units were 'shaken' and a loose part could be heard inside the case, these units were returned to Kelvatek and replaced under the terms of the commercial agreement. No 'operational' defects were found with any of the units.

7.2 Data Gathering to Support Analysis of Low Voltage Networks Performance

The second project objective, analysis of load data, was performed by the Durham Energy Institute at Durham University by PhD students under the guidance of Dr Neal Wade and Professor Phil Taylor. The results and analysis in the following section is illustrated with examples from a very large data set gathered during the project, the full data is available on request from Electricity North West.

7.2.1 Network Data

The data analysed in the following sections was sourced from a number of locations including GIS drawings of the low voltage network, known locations of PV systems and monitoring data downloaded from the Smart Fuse. It was not possible to monitor loads on every low voltage feeder (due to a limited number of Smart Fuses) so a criteria was developed to monitor those feeders with the greatest number of PV installations and a sample of feeders with no PV. The aim was to highlight the differences between 'normal' feeders (no PV) and those with a high penetration of installed PV. Table 7-2 shows a summary of the monitored feeders.

Substation Name	No. Of Outgoing Circuit (usually 1 to 5)	Loads	PV systems installed	Ratio of PV to loads
Brinnington Mount	4	44	6	14%
	5	54	4	7%
Cornwall Crescent	1	41	9	22%
	2	56	14	25%
	3	20	8	40%
	4	45	6	13%
Dunton Green	2	73	40	55%
	3	29	8	28%
	4	32	6	19%

	5	67	45	67%
Keston Crescent	2	61	8	13%
	4	42	5	12%
	5	53	24	45%
Lapwing Lane	1	16	0	0%
	2	31	0	0%
	3	55	2	4%
	4	58	4	7%
	5	48	0	0%
Middlesex Road	1	50	5	10%
	2	60	9	15%
	3	55	9	16%
	4	83	31	37%
	5	77	11	19%

Table 7-2 - Monitored Feeders

7.2.2 Measured Parameters

The measured data included the following parameters on each phase:

- Mean, minimum and maximum bus-neutral voltage [V]
- Mean, minimum and maximum feeder current [A]
- Mean apparent power [VA]
- Mean power factor
- Mean reactive power [VAr]
- Mean real power [W]
- THD [%]
- Frequency [Hz]

7.2.3 Baseline Results (No PV)

7.2.3.1 Real Power

All of the monitored feeders exhibited a typical daily load cycle and annual overall trend of higher winter than summer demand as would be expected from a densely populated suburban location. As an example, the energy delivered through each of the Keston Crescent feeders is given in Figure 7-5.

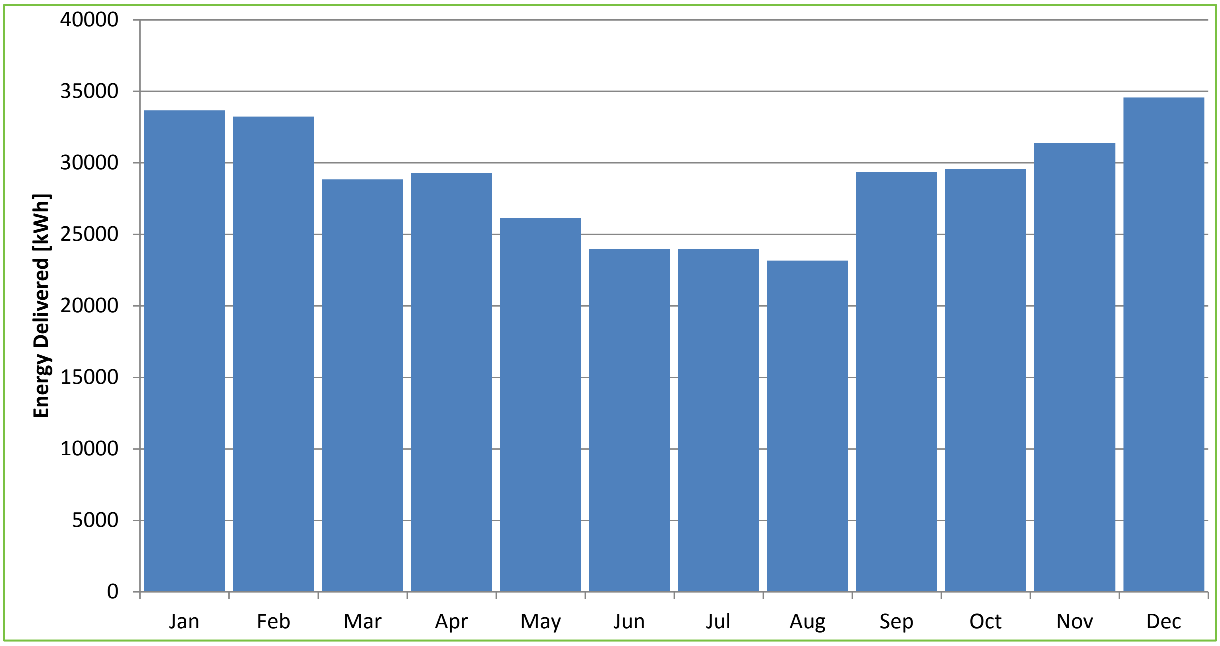


Figure 7-5 - Energy delivered through Keston Crescent transformer in 2012

As shown in Figure - B-1 (in appendix), all feeders exhibited a typical daily load cycle with morning and evening peaks with some variability between maximum loading. This is almost certainly related to the types of demand or number of occupants on each feeder and is further illustrated by the peak power seen in the week 10th-16th February 2012 (Table 7-3).

Substation Name	Transformer Size (kVA)	Peak Power [kW]
Lapwing Lane	**315**	**39.9**
Keston Crescent	**500**	**43.4**
Brinnington Mount	**500**	**51.9**
Dunton Green	**750**	**54.9**
Middlesex Road	**1000**	**83.8**

Table 7-3 - Peak power through transformers in study for week 10th-16th February 2012

7.2.3.2 After Diversity Maximum Demand (ADMD)

By comparing the number of customers connected to each way and the maximum power flows seen in the data, the ADMD has been calculated as shown in Table 7-4. The ADMD is varied across the feeders which has important planning considerations.

Substation Name	Way	Number of loads	After diversity maximum demand per customer [kW]
Brinnington Mount	**4**	**44**	**1.53**
	5	**54**	**1.83**
Cornwall Crescent	**1**	**41**	**1.65**
	2	**56**	**1.38**
	3	**20**	**3**
	4	**45**	**1.55**
Dunton Green	**2**	**73**	**1.53**
	3	**29**	**2.11**
	4	**32**	**1.73**
	5	**67**	**1.17**
Keston Crescent	**2**	**61**	**1.28**
	4	**42**	**1.37**
	5	**53**	**1.29**
Middlesex Road	**1**	**50**	**1.66**
	2	**60**	**1.89**
	3	**55**	**2**
	4	**83**	**1.96**
	5	**77**	**1.6**

Table 7-4 - ADMD Figures

7.2.3.3 Reactive Power

For feeders with no installed PV, the reactive power generally follows the real power (Figure 7-6) and reactive power demand is generally very low, leading to a high power factor. Statistical analysis shows the reactive power demand, although low, is more dynamic than real power demand.

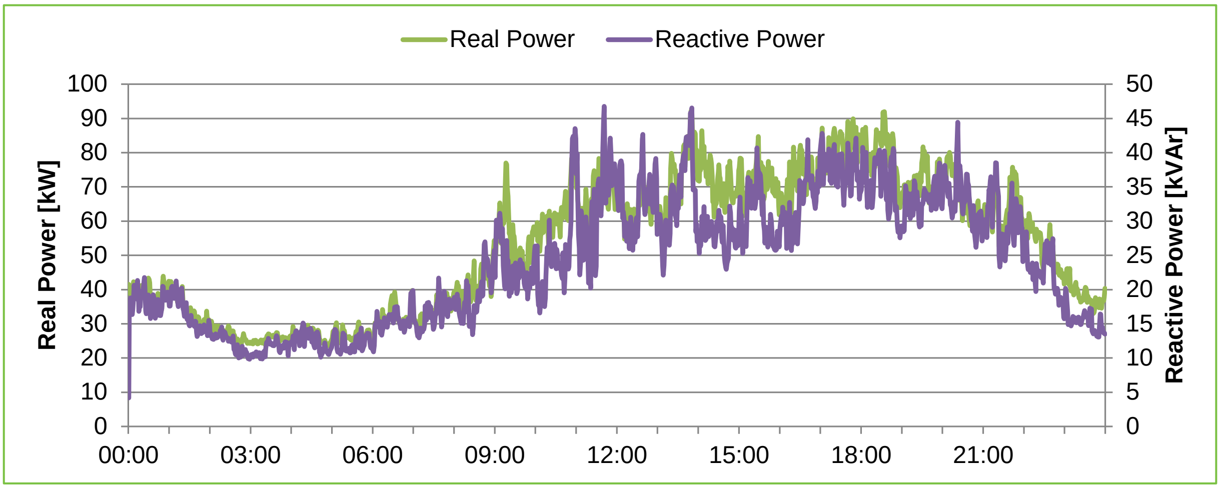


Figure 7-6 - Real and reactive power through Brinnington Mount on 12th February 2012

7.2.3.4 Voltage

Under baseline conditions operation, voltage measured at the low voltage side of the transformer is largely unaffected by the load on the network. As shown in Figure 7-7 there is little or no evidence of voltage drop at the secondary side of the transformer as the load increases. This indicates that the primary voltage management is working effectively. Further, by considering the distribution of voltages (Figure 7-7) it can be seen that the voltage is maintained within a 6V band for more than 98% of the time.

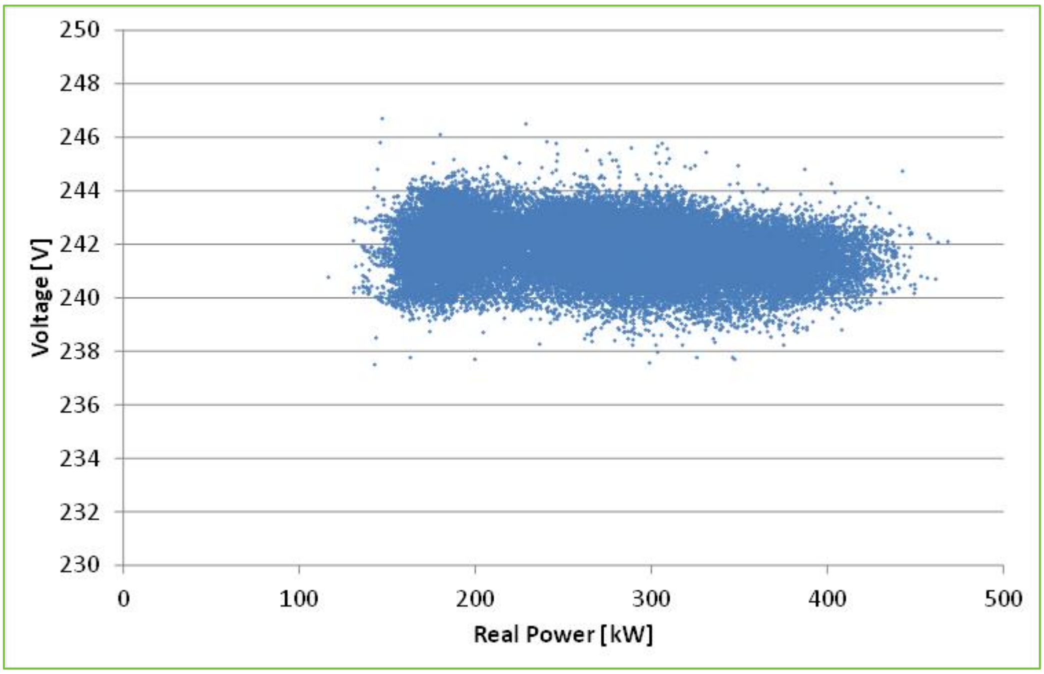


Figure 7-7 - Voltage and real power for Middlesex Road, 12th December 2011 – 9th January 2012

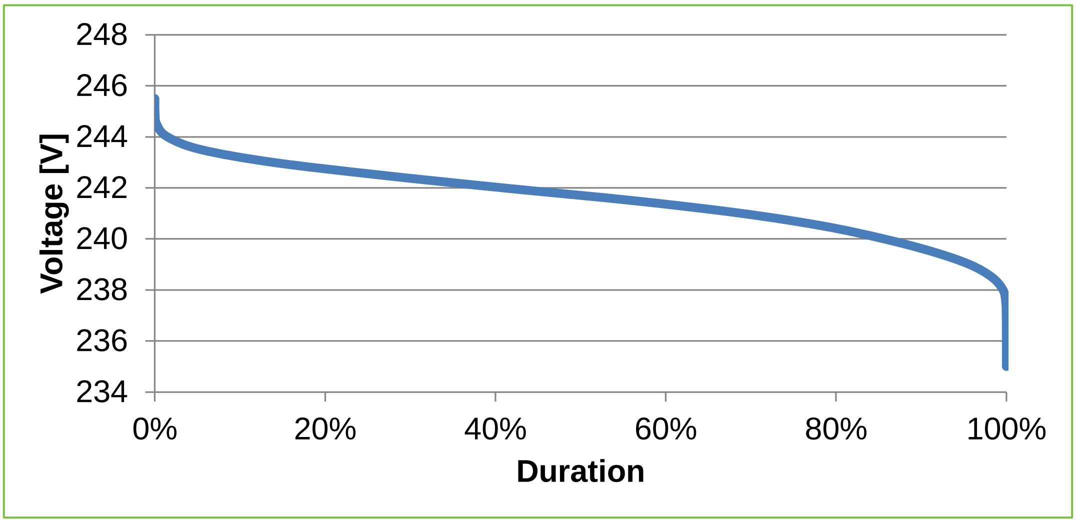


Figure 7-8 - Distribution of voltages for Middlesex Road for 10/02/2012 to 21/12/2012

7.2.3.5 Voltage Unbalance

Key points:

- Voltage unbalance is low (normally under 1%) across all monitored networks
- There are recorded events which cause the voltage unbalance factor to exceed limits (>2%)

For all of the transformers, the average voltage unbalance factor (VUF) is low (normally under 1%), but with a relatively large standard deviation (Table 7-5 – Average and Standard Deviation of Voltage Unbalance for all data available for all substations). As shown in Figure 7-9 the average voltage unbalance factor does correlate with the observed load pattern with slightly higher VUF in the morning and evening peak than during the night and the middle of the day. Probability distributions of the VUF for Middlesex Road and Dunton Green are shown in Figure 7-9. It can be seen that for the majority of the time, the VUF is less than 1%. However, there are some extreme events where the VUF limit of 2% is exceeded. Table 7-5 summarises the biggest voltage unbalance seen on each secondary transformer. It is seen than a VUF greater than 2% is seen on all feeders and these last between one and four minutes. Figure 7-11 shows the VUF over one day for one of the feeders which is typical of the pattern seen in the data. Generally, VUF excursions occur during periods of low demand during the night. There is no correlation between voltage unbalance between the secondary transformers. Further, there is no evidence that the VUF excursions are caused by sudden increases in demand on a single phase of a feeder. However, these commonly occur when demand is low. No evidence has been seen to indicate that the levels of PV in the low voltage network are affecting the voltage unbalance at the transformer.

Transformer Name	Average voltage unbalance factor [%]	Standard Deviation of voltage unbalance factor [%]
Brinnington Mount	**0.374%**	**0.212%**
Cornwall Crescent	**0.504%**	**0.265%**
Dunton Green	**0.378%**	**0.212%**
Keston Crescent	**0.479%**	**0.192%**
Lapwing Lane	**0.267%**	**0.155%**
Middlesex Road	**0.381%**	**0.211%**

Table 7-5 – Average and Standard Deviation of Voltage Unbalance for all data available for all substations

Transformer Name	Peak VUF	Longest excursion (>2%) [mins]
Brinnington Mount	**2.99%**	**3**
Cornwall Crescent	**3.20%**	**4**
Dunton Green	**2.70%**	**2**
Keston Crescent	**2.81%**	**3**
Lapwing Lane	**2.57%**	**1**
Middlesex Road	**2.43%**	**2**

Table 7-6 - Largest voltage unbalance seen in data, and length of excursion above 2% limit

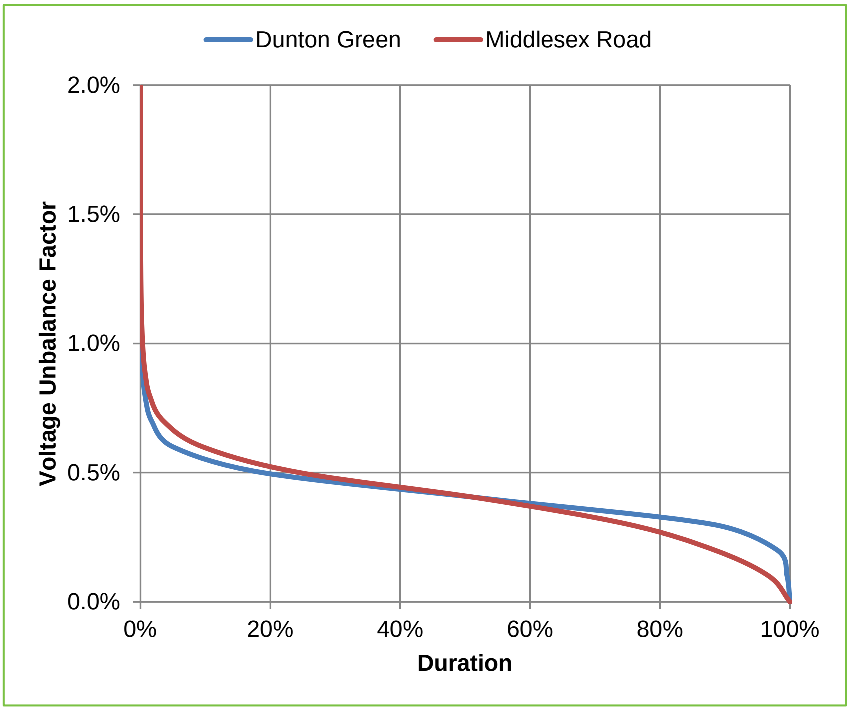


Figure 7-9 - Duration of VUF for Middlesex Road (low PV) and Dunton Green (high PV)

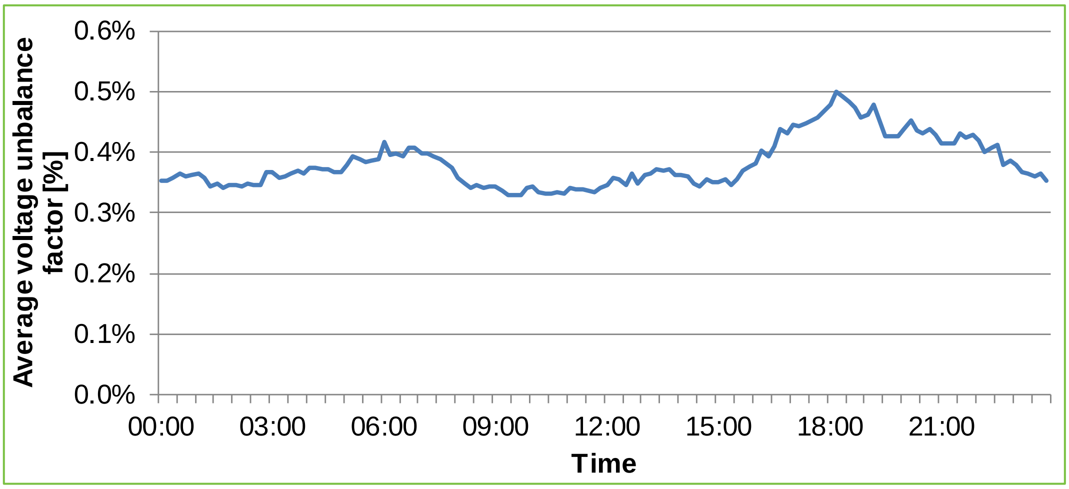


Figure 7-10 - Average VUF each minute over a 24-hour period for Middlesex Road

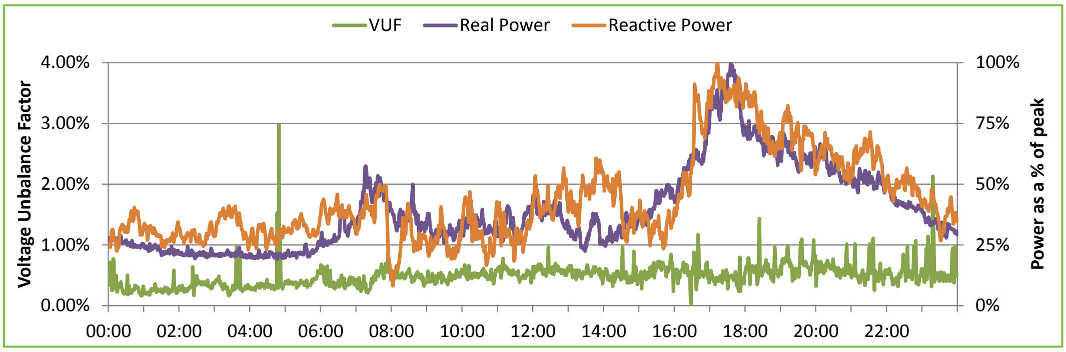


Figure 7-11 - Voltage unbalance factor for single way of Cornwall Crescent, 17th January 2012

7.2.4 Effects of PV on the Transformer

7.2.4.1 Measured Effects of PV on Power Flow

The obvious effect of PV on the transformer is in creating reverse power flow. As shown in Figure 7-12, there are varying degrees of reverse power flow seen in the data. On the feeders with the highest penetration of PV (Dunton Green way 2 and way 5), the reverse power flow exceeded 33kW and 55kW respectively during the study period.

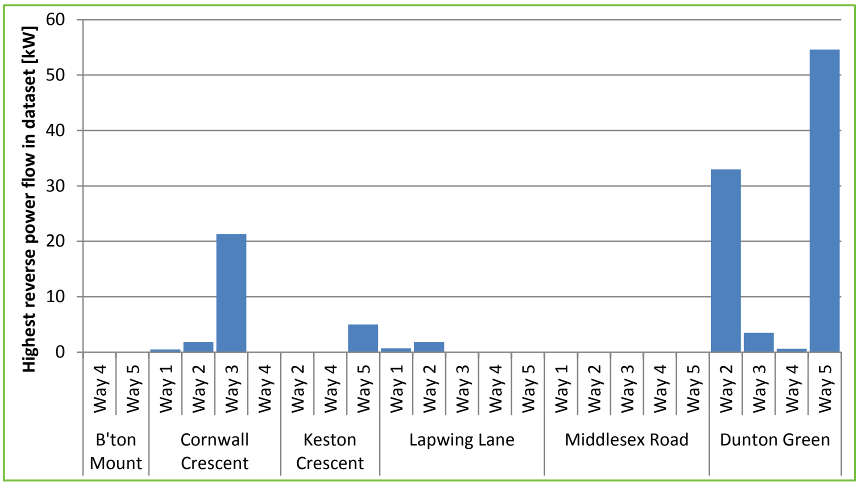


Figure 7-12 - Highest reverse power flow seen on all feeders in the Kelvatek data

Reverse power flow is seen on individual ways and one of the transformers (Dunton Green). Reverse power flow is most problematic in the summer when the irradiance is highest (Figure 7-13). A load duration curve is shown in Figure 7-14 for the transformer “Dunton Green” during winter and spring. There is a noticeable change in the shape of the load duration curve as the reverse power flow takes an effect. Reverse power flow occurs for approximately 2% of the time on the transformer with the highest PV penetration (Figure 7-13 - Reverse Power Flow for Keston Crescent

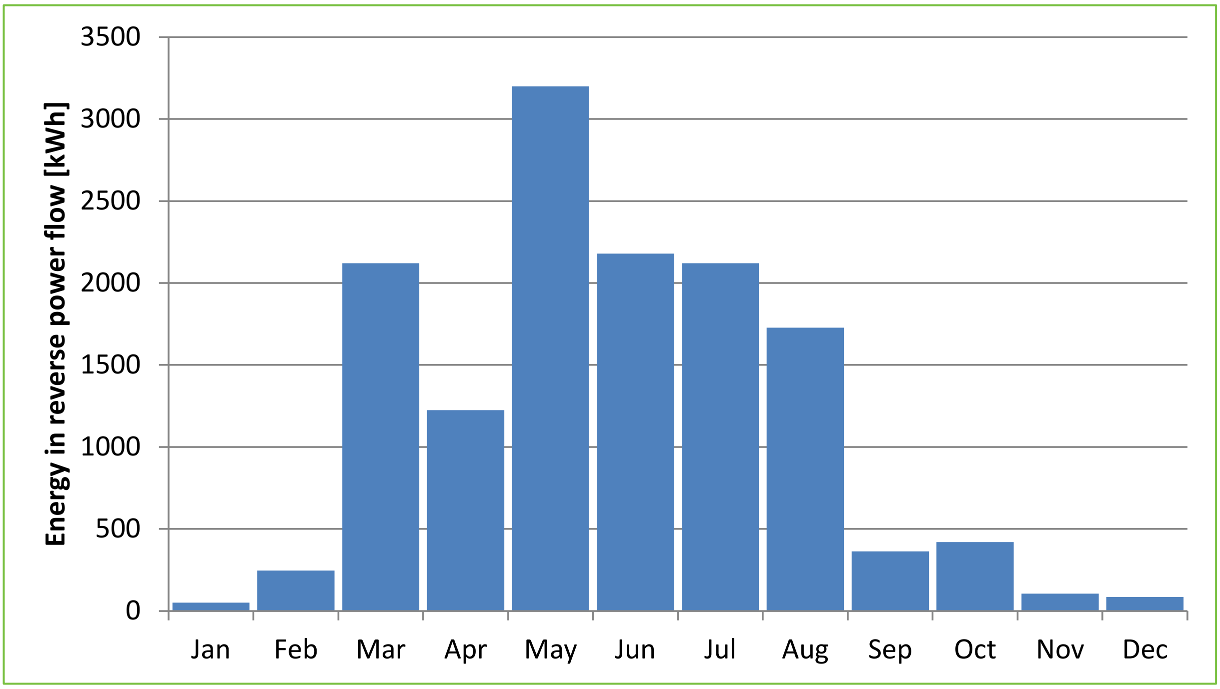


Figure 7-13 - Reverse Power Flow for Keston Crescent

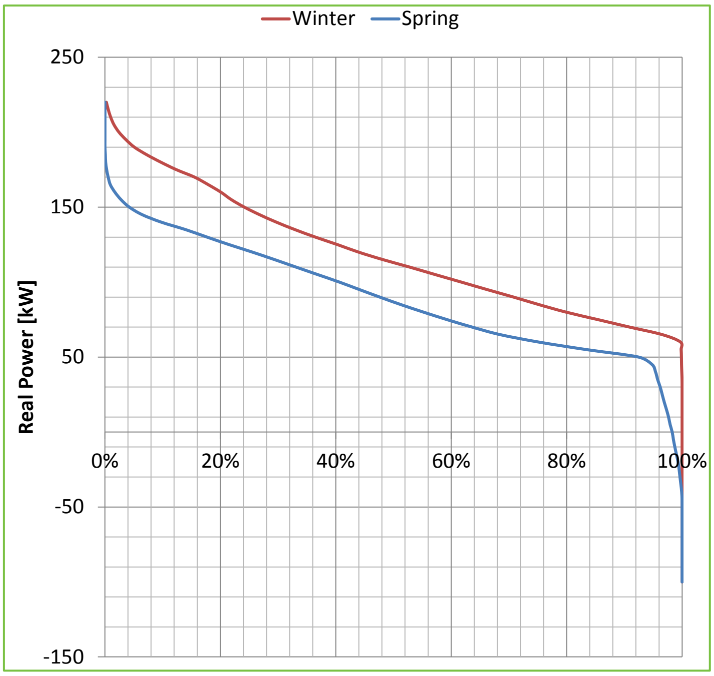


Figure 7-14 - Load duration curve for Dunton Green (all feeders) for winter and spring

7.2.4.2 Measured Effects of PV on Power Factor

The most noticeable effect of PV is on the power factor. During normal operation, with no generation, the power factor remains in a very tight band close to unity. Mostly, there is an export of reactive power. The effect of PV generation in the network is to reduce the power factor. This is due to the PV having a mostly real power component, so it is able to provide or exceed the real power demand but with no effect on the reactive power. As shown in Figure 7-15, the power factor is an effective proxy measure to understand when there is PV generation in the network. It can be seen in Figure 7-15 that there are quick changes in the PV output, likely caused by passing clouds.

This affects any control algorithms that might be developed to manage voltage rise as a result of PV.

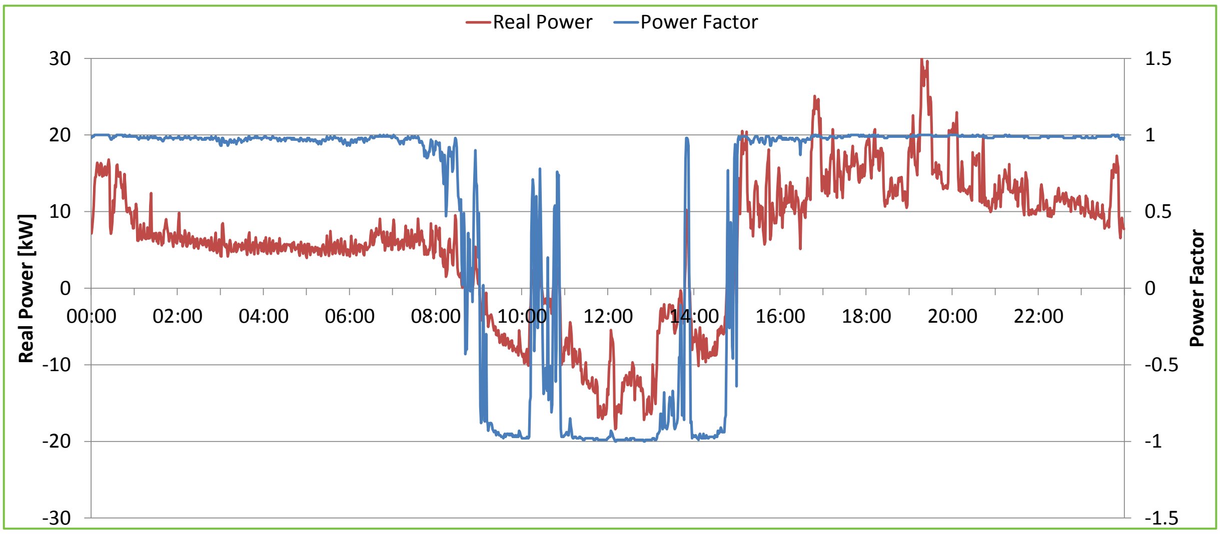


Figure 7-15 - Dunton Green, W5, Phase 1, 19/02/2012

7.2.4.3 Measured Effects of PV on Voltage

Key points:

- There is no evidence to suggest that the penetration of PV on the monitored feeders is affecting transformer voltage, although this may occur if the penetration of PV rises
- Voltage on the low voltage side of the transformer is largely governed by the voltage on the 11kV network

A scatter plot of voltage against real power flow (on the low voltage side of the transformer) for one feeder on Dunton Green is shown in Figure 7-16. It can be seen that there is no discernible link between reverse power flow and voltage under the current configuration. It may be deduced that the voltage during reverse power flow is even tighter than under normal power flow. However, there is insufficient evidence to draw a robust conclusion at the present time due to the limited amount of data for reverse power flow relative to that for forward power flow.

When considering the correlation of voltages it can be seen in Figure - B-2 (Appendix B) that there is a general correlation between all of the voltages in the network (apart from Middlesex Road W2 where the data is spurious). This supports the conclusion that the low voltage network voltage is most strongly regulated by that on the 11kV network. Further, by considering the correlation of the network voltage of Dunton Green during a high reverse power flow event to that on the other feeders, it can be seen that the PV currently has minimal effect on the voltage at the distribution transformer secondary.

However, Figure 7-17 shows the duration curve of voltages for two transformers (Middlesex Road and Dunton Green) which have low and relatively high penetrations of PV. It can be seen that, over the same time period, the voltage at Middlesex Road is much more variable than that at Dunton Green. The other difference between the two substations is that Middlesex Road has more load (1000kVA transformer vs. a 750kVA transformer). This shows that although there is a strong link between the voltage levels in terms of the capacity of the transformers, there may be some voltage rise or fall as a result of demand influencing the voltage along the 11kV network.

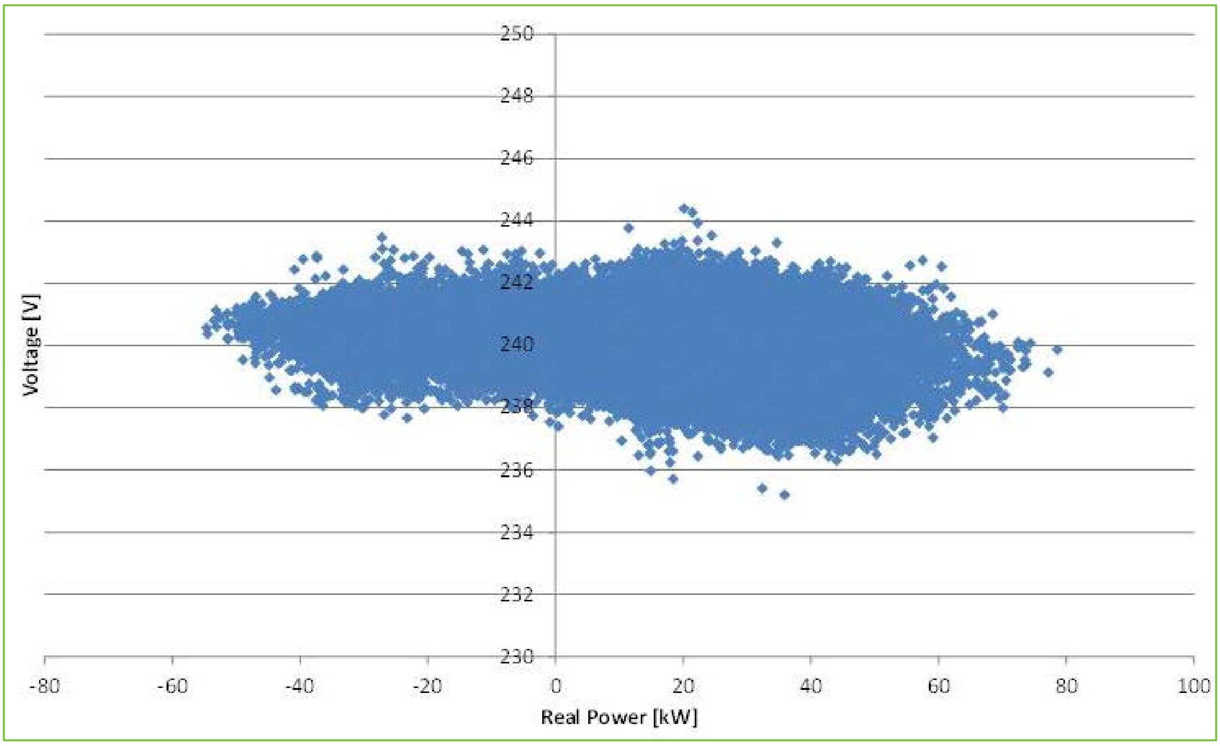


Figure 7-16 - Network voltage and real power flow for Dunton Green, Way 5 which has a high penetration of PV (9th February to 26th June 2012)

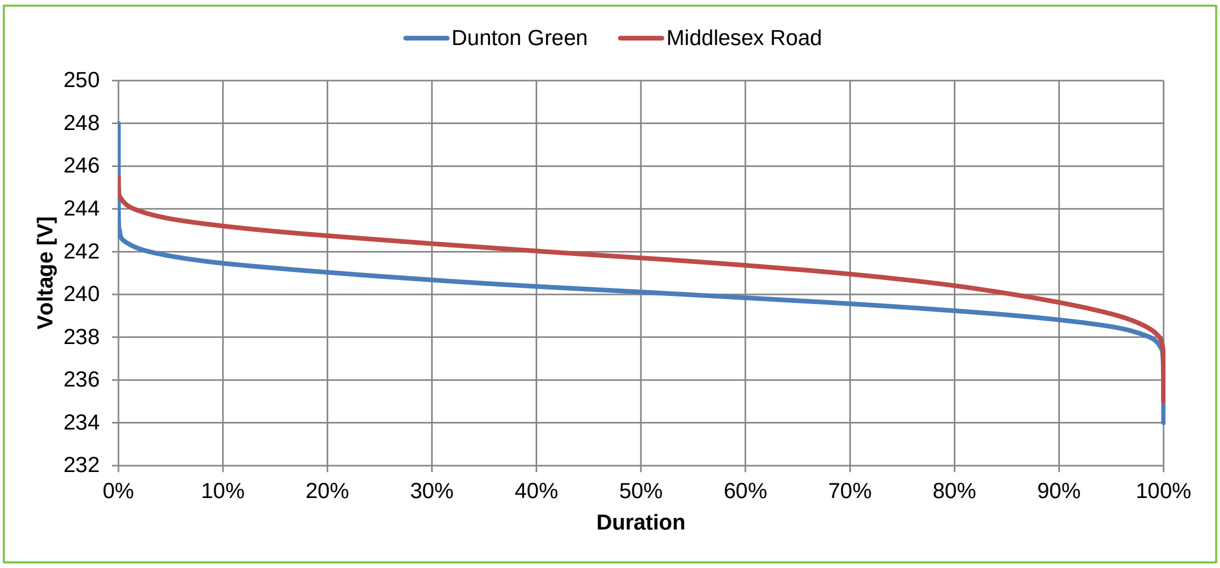


Figure 7-17 - Distribution of voltages for Dunton Green (high PV) vs. Middlesex Road (low PV) for 10/02/2012 to 21/12/2012

7.2.5 General comments and recommendations

7.2.5.1 Data Management

The data set is of high resolution and therefore contains a large number of data points resulting in very large file sizes (more than 2 GB of compressed data files representing the study period). These files are difficult to handle, especially in Excel where they can contain over a million rows of data. For further results from this and other data sets, there is a need to develop specific tools to analyse the data and present relevant findings. This should provide the following functionality as a minimum in order for more relevant results to be obtained:

- The ability to sort data into a number of time horizons to include:
    - Data over a given day
    - Data for a selected time period
    - Monthly data
- The ability to plot any of the measured variables against each other on an xy scatter plot over any of the time horizons specified above
- The ability to plot duration (cumulative probability curves) for any of the variables over the specified time horizons
- The ability to cross-correlate data between individual ways
- The ability to download any of the above data sets as csv files for import into Excel or similar

7.2.5.2 Planning tools

During analysis of the full data set models were developed that supported the creation of a new tool to assess the highest amount of PV that can be accepted into any given low voltage network. As shown in Figure 7-18, the exact number of PV systems that can be permitted depends on the rating of each installed PV system resulting in a region where PV is acceptable, a region where PV might be acceptable and a region where PV is definitely not acceptable.

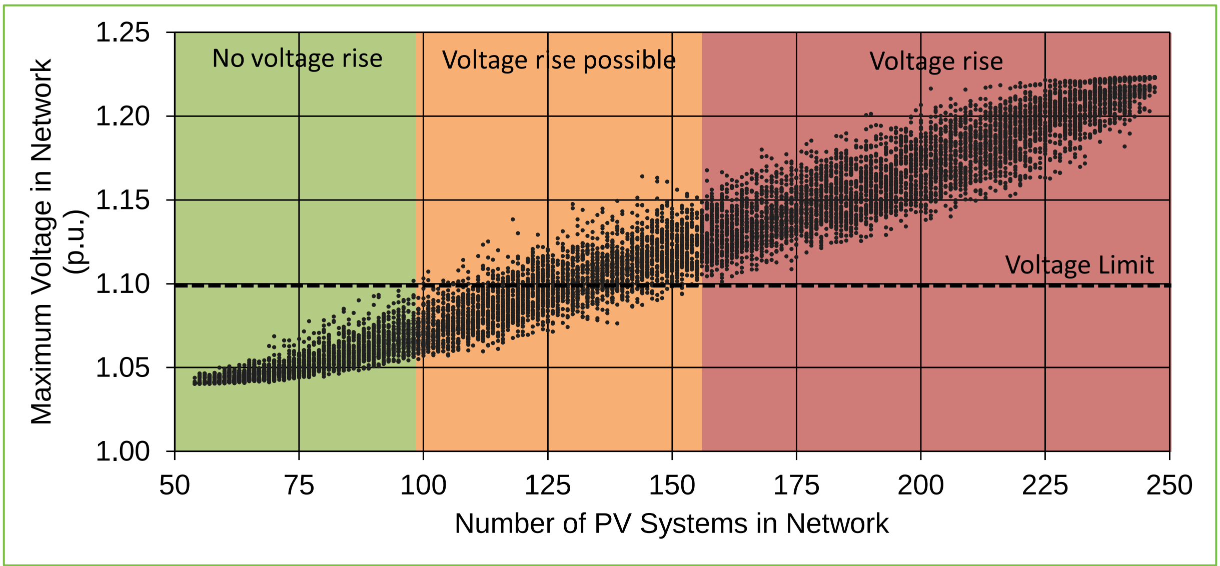


Figure 7-18 - Permissible penetration of PV in an LV network (for illustrative purposes). Here 50,000 load flows are performed with PV at random and feasible locations within the network

7.2.6 Results Summary

- Under normal operating conditions without the effects of PV:
    - Seasonal trends in energy are visible between summer and winter months
    - There is a daily cycling of energy, but there are noticeable differences in power flows between individual transformers
    - The reactive power closely follows the real power, but is much more variable and in smaller quantities
    - The voltage remains within a tight band on the low voltage side of the transformer and appears to be regulated by the voltage on the 11kV network
    - The voltage unbalance factor is generally low (less than 0.7%) but there are excursions in the data of more two minutes where it is greater than 2%

- Under operating conditions with PV within the low voltage network
  - There is reverse power flow over feeders and over one transformer in the study
  - The amount of reverse power flow follows a seasonal pattern with more seen in the summer when there is more irradiance and lower demand
  - The PV also influences the power factor, causing it to reduce due to the real power component of the PV output
  - There is no noticeable effect of PV on the low voltage side of the transformer further supporting the finding that low voltage is governed by the 11kV voltage. However, further analysis is needed on networks with higher PV penetrations to show this

7.3 Improving Customer Service by Reducing the Impact of Transient Faults

7.3.1 Background

The third project objective was to improve Electricity North West's Quality of Supply performance. The original IFI project was driven by an analysis of performance during 2006 which highlighted the need to address the number of transient faults that were affecting low voltage networks. As automation is rolled out across higher voltage levels the impact of faults (particularly transient faults) on low voltage networks becomes more apparent and in 2006 it was understood that eventually new technology would be needed to complement better organised workforces.

7.3.2 Analysis of Faults Types

Low voltage transient faults are characterised as faults that may occur causing the substation fuse protecting the feeder to operate and so disconnecting customers but when replaced, the new 'healthy' fuse does not operate and supplies are restored to customers. Transient faults can occur for a number of reasons, for example after periods of heavy rain moisture can ingress into directly buried cable joints to cause a short circuit leading to fault currents that will operate the substation fuse. However the resulting arc from the release of fault energy at the short circuit location can dry the cable joint removing the moisture that caused the short circuit.

Transient faults have four stages of development;

- Transitory (irregular voltage dips which don't cause fuse operation)
- Intermittent (irregular fuse operations)
- Persistent (repetitive fuse operations)
- Permanent (open circuit or short circuit weld)

A fault could potentially develop on any part of the underground low voltage network and the fault may miss stages of development. For example, a fault towards the end of a low voltage feeder with a small cross-sectional cable would have the transitory phase but jump to the permanent stage. Whereas, if the fault is closer to the substation on a larger cross-section cable then it could have all four stages. Networks with bottle ends and larger cross-section cables further away from the substation would have different phases of development. Furthermore faults very rarely 'regress' i.e. they do not move from 'Persistent' to 'Transitory', once a cable has experienced some fault activity it is only a matter of time before the fault becomes 'Permanent'.

7.3.3 LV Fault Performance Prior to the Introduction of the Smart Fuse

In developing the justification for the project, low voltage transient fault data was analysed from 2006-07, this data only includes transient faults and not those when a fuse operates and a fault is identified and repaired. Table 7-7 shows the number of repeated fuse operations and the impact on customer minutes lost and customer interruptions. Intermittent faults (irregular fuse operations) are shown in the table as a single fuse operation in 12 months. Persistent faults are 2 or more fuse operations within a 12 month period. Persistent faults will, after an indeterminate number of fuse operations, move to the permanent stage and hence the reason why the numbers of transients reduces as the number of operations increase.

No Fuse Operations	No. of Transient Faults	CML	CI
1	1665	6,196,584	40,574
2	635	2,553,842	17,400
3	329	1,117,709	8,666
4	204	871,631	6,243
5	131	549,895	3,978
6	96	293,337	2,847
7	67	318,429	2,575
8	53	175,713	1,754
9	43	181,939	1,512
10	33	155,451	1,100
11	22	109,074	690
12	15	55,997	575
13	13	89,151	694
14	9	20,409	288
15	8	74,456	333
16	5	66,056	228
17	1	6,875	50
18	1	2,832	24

Table 7-7 – Impact of Transient Faults 2006/7

Figure 7-19 shows the results of subdividing these faults into locations.

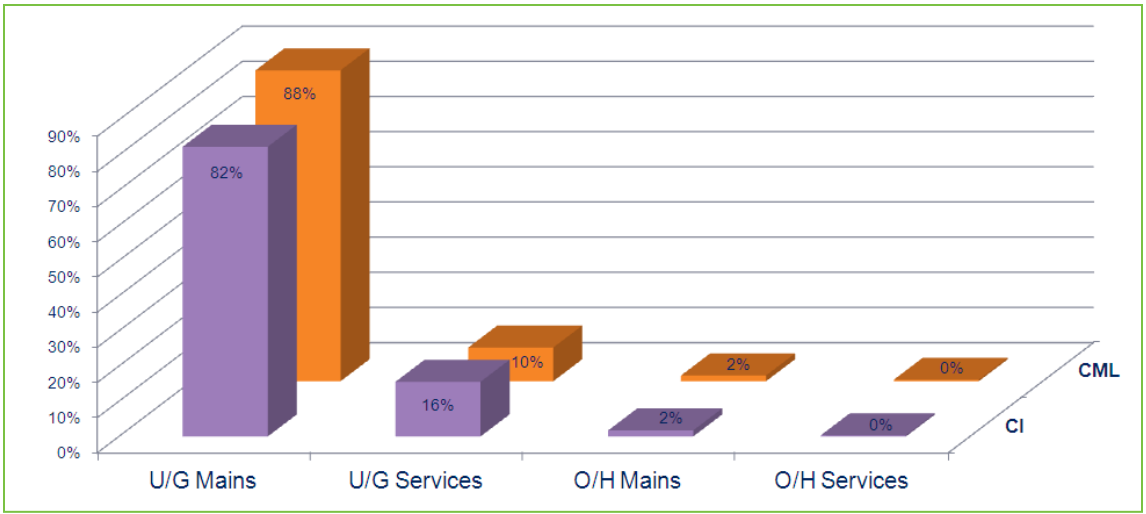


Figure 7-19 – Locations of Transient Faults

An important point discovered from the data analysis is that as a fault progresses, the time between fuse operations reduces (Table 7-8). For example, 50% of second fuse operations occur with 14 days of the first fuse operation and after the sixth operation 50% are operating within a day of the fifth operation.

No of Fuse Ops	CML	CI	No of Days 50% Op
2+	**4088954**	**31557**	**14**
3+	**2971245**	**22891**	**7**
4+	**2099614**	**16648**	**3**
5+	**1549719**	**12670**	**2**
6+	**1256382**	**9823**	**1**
7+	**937953**	**7248**	**1**

Table 7-8 – Time Between Transient Faults

Furthermore, of the transients that operate 3 times or more, 195 will never operate again within 12 months and it is assumed that these become permanent faults.

7.3.4 Improvements in IIS Performance

Due to the dynamic nature of the use of the Smart Fuse it was never the intention to directly map the financial benefit of each device. The aim was to use it to support the implementation of new strategy aimed at improving low voltage transient fault management as described in Section 7.4 in recognition of the increasing importance of low voltage networks as described elsewhere. When developing the financial justification for the project the financial benefits were calculated from an 'average' number of customers on each low voltage feeder and an 'average' time for restoration (without the use of the Smart Fuse). Electricity North West's current average short duration interruption is approximately 60 minutes therefore when a Smart Fuse restores supplies in under the IIS target of 3 minutes it effectively eliminates 'Customer Interruptions' (based on an average number of customers connected to low voltage feeders) and 60 minutes of 'Customer Minutes Lost' penalties, it is estimated that an average penalty of £500 is avoided with every Smart Fuse low voltage feeder supply restoration. In addition to the financial benefits from an enhanced performance under the IIS incentive, the benefits of being able to better manage transient faults whilst keeping customers connected cannot be underestimated.

*incomplete year

Table 7-9 shows the number of operation of the 106 Smart Fuses issues to our fault restoration teams between August 2011 and April 2014. The bulk of the devices were delivered by Kelvatek during July 2011 and issued to fault teams starting in Aug 2011. Each Smart Fuse could operate a number of times through the year as, for example, they are moved around the network in response to known transient faults where a Smart Fuse was installed going quiet, new transient faults developing and transient faults going permanent and repairs being carried out to cables. The increasing number of Smart Fuse operations reflects both the roll out of the training courses and the units being issued to increasing number of fault teams and fault engineers developing experience with the devices and being better able to target appropriate locations.

Primary Fuse Rupture Incidents	Type of fault	Aug 11 to July 12		Aug 12 to July 13		Aug 13 to Apr 14*	
		No. of faults	%	No. of faults	%	No. of faults	%
Successful Customer Restorations (< 3 minutes)	**Transient - supplies restored under 3 mins then planned fuse replacement**	**66**	**69%**	**85**	**70%**	**75**	**72%**
Secondary Rupture within 60 minutes of restoration	**Transient - supplies restored under 3 mins then a further fuse operation, engineer dispatched for fuse replacement**	**10**	**11%**	**7**	**6%**	**6**	**6%**
Secondary Rupture within 3 minutes of restoration	**Permanent fault - supplies off - engineer dispatched for fault finding according to COP617**	**19**	**20%**	**30**	**25%**	**23**	**22%**

*incomplete year

Table 7-9 – Smart Fuse Performance

Table 7-10 and Table 7-11 show Nafirs[2] information for low voltage underground transient faults recorded for the two complete years available at the time of writing, 2012 and 2013. They show a correlation between a reducing number of low voltage transients (because the Smart Fuse restores supplies so the transient is not recorded) and an increasing use of the Smart Fuse. Two years is not enough time to draw any firm conclusion between the increasing use of the Smart Fuse and a reduction in the number of transient faults but the results are certainly encouraging.

[2] National Fault and Interruption Reporting Scheme - http://www.energynetworks.org/electricity/engineering/nafirs.html;

	Number of incidents	Sum of number of customers interrupted	Sum of customer minutes lost
LV non-damage	**3,904**	**104,855**	**8,610,800**
LV Underground Mains - damage	**3,465**	**130,668**	**32,281,207**
LV All Other Switchgear, Plant & Equipment - damage	**131**	**6,681**	**1,230,616**
LV Services overhead (excl cut-outs) - damage & non-damage	**449**	**885**	**139,514**
LV Services underground (excl cut-outs) - damage & non-damage	**2,548**	**29,957**	**2,602,450**

Table 7-10 – Nafirs Data for LV Transients for 2012

	Number of incidents	Sum of number of customers interrupted	Sum of customer minutes lost
LV non-damage	**2,633**	**67,058**	**5,316,865**
LV Underground Mains - damage	**3,009**	**107,700**	**24,468,731**
LV All Other Switchgear, Plant & Equipment - damage	**301**	**9,584**	**1,607,917**
LV Services overhead (excl cut-outs) - damage & non-damage	**537**	**1,181**	**408,015**
LV Services underground (excl cut-outs) - damage & non-damage	**2,530**	**27,832**	**2,334,367**

Table 7-11 – Nafirs Data for LV Transients for 2013

7.4 LV Fault Management Policy Implementation

The use of the Smart Fuse in Electricity North West is now written into Code of Practice 617 - Fault Location Techniques for the LV Underground Network. The code of practice describes the various stages of fault development and the mitigation and makes use of several technologies developed under the Innovation Funding Incentive. COP 617 is a fully developed and approved internal procedure that describes types of faults and their implications. Sections covered include;

- Introduction
- Scope
- Definitions
- Faults
- Restoration and Pre-location Summary
- Restoration Equipment
- Pre-location Equipment
- Pre-location Notes
- Pinpointing Equipment and Techniques

COP 617 describes basic fault types including;

Arcing Faults - characterised by arcing which is very unstable and non-linear. There is a voltage drop across the fault. Burning occurs which rapidly heats the point of fault and produces hot conducting gases, through which the high fault current flows

Welded faults - Welded faults do not exhibit any of the Arcing Faults characteristics. They occur when insulation has broken down between two conducting metals and sufficient heat has been generated to weld the two conductors together, therefore completing a short circuit. A welded fault can be between any two or more phases or between any one or more phases and neutral. A characteristic of this type of fault is that the voltage gradient which is present on the supply side of the fault stops at the fault position (i.e. no voltage gradient beyond that point)

COP 617 also describes the various equipment used for fault management and its safe operation;

FuseMate – Comprises a miniature vacuum switch in series with a fuse. It is designed to re-energise a circuit temporarily after a fuse has operated and is inserted in place of the fuse. Once in place, the breaker can be operated remotely, thus re-energising the circuit from a safe distance

Rezap Fault Master and Modular Rezap – These units are auto-reclosers with a programmable number of trips-to-lockout and built in fault-finding capability. The reclose operation is performed by a vacuum recloser. Rezap units are the basic platforms used for supply restoration and pre-location of persistent faults on low voltage underground networks

Retrace – The Retrace can aid fault pre-location where there is uncertainty or apparent discrepancy in the low voltage network records. This is particularly useful for ensuring that fault finding equipment is connected to the correct phase

Delta V – This device uses the voltage gradient technique to locate faults on underground low voltage cables. It is especially effective when used with the Rezap Fault Master on both intermittent and persistent faults and for locating faults on complex cable networks

T-P22 – This is essentially a fault disturbance recorder. It displays, records and processes the waveforms of all three phases. It is particularly effective when used in conjunction with a Rezap and it can be left to record the waveforms and wait for a fault to occur

Cable Sniffer – This is used to pinpoint the location of underground faults by analysing the content of gas produced by burning insulation. The gasses produced during the fault remain for several hours and by analysing and quantifying the level of gas along the cable route it is possible to define a very accurate fault location prior to excavation

In addition to the Smart Fuse, COP 617 also prescribes the timescales to be adopted for the deployment of other low voltage fault management technologies as illustrated in Figure 7-20.

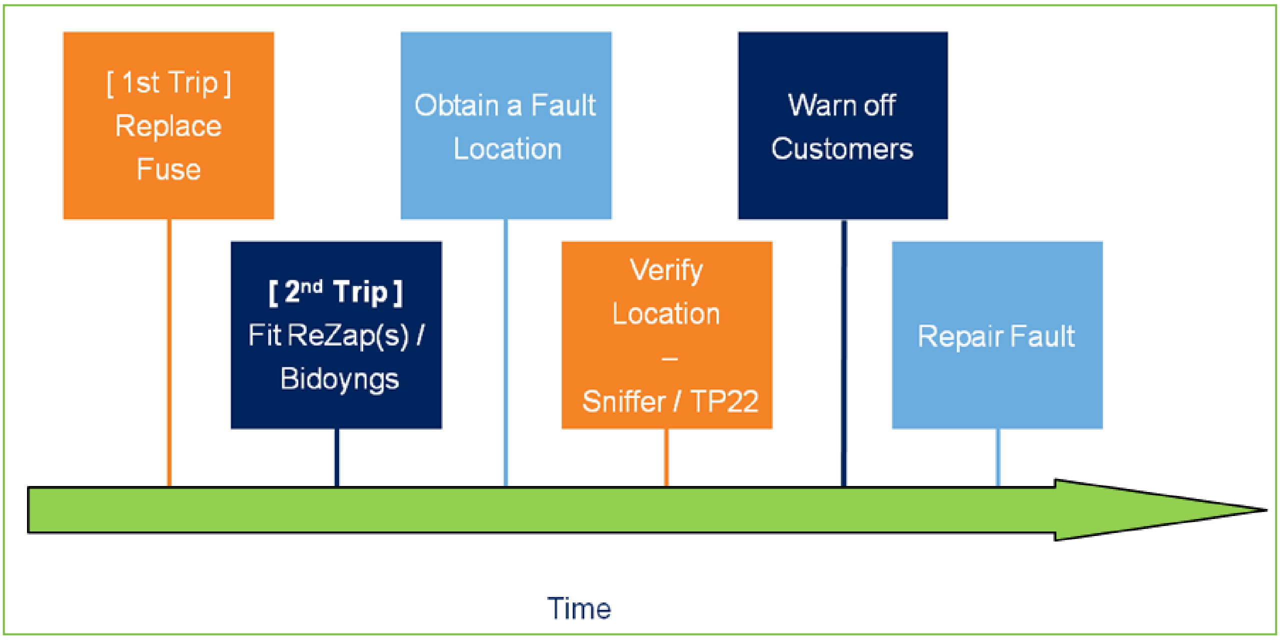


Figure 7-20 – Fault Mitigation

COP 617 is used in conjunction with Kelvatek's Smart Fuse Operation and Instruction manual (Appendix C and D) to provide all the information required for the Smart Fuse to be used by our LV Authorised fault technicians.

8 THE OUTCOMES OF THE PROJECT

8.1 Performance Compared To the Original Project Aims, Objectives and Success Criteria

The project met all its original objectives and in fact outperformed against the original aims;

Original Objective/Success Criteria	Section of Report	Outcome
To install 200 Smart Fuses	**7.1**	**200 installed, 94 for load profiling and 106 for fault management**
To gather data regarding the performance of low voltage networks, particularly in light of the significant amount of domestic solar PV that has been installed in recent years	**7.2**	**The Smart Fuse has provided over 2GB of high resolution data that has been used to analyse the performance of selected low voltage underground feeders. The analysis has determined that solar PV generation has not had any detrimental effect on voltage levels on the low voltage side of the transformer as described further in 7.2.6 Results Summary.** **The full set of data is not reproduced as part of this report due to the size of the files, the data is available on request from Electricity North West for academic research purposes**
To improve customer service by reducing the time to restore supplies following a fault	**7.3**	**The Smart Fuse now provides a means to manage low voltage transient faults by eliminating 80% of fuse operations once faulty feeders are identified**

To provide enough data to develop policies and procedures regarding the use of the Smart Fuse on low voltage networks	**7.4**	**The Smart Fuse has operated safely both due to design of the device and the development of robust operating procedures. The basis of ENWLs internal policy and code of practice documentation is contained in Section 7.4 7.4and installation instructions and procedures are contained in the Appendix to the report**

Table 8-1 – Performance Compared To the Original Project Aims, Objectives and Success Criteria

8.2 Required Modifications to the Planned Approach during the Course of the Project

There were no modifications to the scope or delivery of the project from the information provided at time of registration.

8.3 Significant Variance in Expected Costs and Benefits

There were no significant variations in the expected costs of the project. The original forecast at the time of Project Registration was £442,666, the final cost was £387,336.

Original Objective	Forecasted Cost	Actual Cost	Provider	Comments
Purchase 200 Smart Fuses, Gateways and associated Technical Support	**£357,666**	**£354,700**	**Kelvatek**	**Minor variation in original forecasted costings**
Project Management	**£35,000**	**£20,265**	**Electricity North West**	**Contingency not used, installation and project management costs less than forecasted**
Smart Fuse Installation	**£15,000**	**£4,871**		
Contingency	**£30,000**	**£0**		
Internal Policy Creation	**£5,000**	**£7,500**		
Network Fault Restoration Analysis	**£0**	**£0**	**Kelvatek**	**Provided as part of the technical support element of the contract**
Network Performance Analysis	**£0**	**£0**	**Durham University**	**Provided as part of an IFI Funded Project in Storage for Distribution Networks**
Total	**£442,666**	**£387,336**		

Table 8-2 – Forecasted and Actual Costs

Financial benefits resulting in restoring customers supplies in under 3 minutes were achieved on a device by device basis although no claims were made for the overall benefits of deploying the entire fleet of devices at the outset. Financial benefits from the data analysis are harder to quantify and will be delivered through the development of optimal design of low voltage networks. The EA Technology Ltd Transform model has been used to assess the projected volume of PV installations and the models developed by this project were used to assess the likely load flows from these volumes.

8.4 Lessons Learnt For Future Projects

During the course of the project no significant issues were discovered that prevented the use of the Smart Fuse and based on the on-going results, Electricity North West has already purchased further Smart Fuses for use by our fault restoration teams.

Transfer of new technology into DNO businesses is a standard activity as, for example, manufacturers develop new circuit breakers. This project followed a very similar path with the only real difference being that the new technology was developed at the behest of Electricity North West rather than relying on manufacturers to develop new technology, one of the many advantages of funding from the low carbon networks fund.

8.5 Facilitate Replication

The Smart Fuse is a fully developed device and has the full technical and commercial support structure in place that would be expected of any commercially available technology. Electricity North West can advise any DNO on adoption of the Smart Fuse and discussions have already taken place at the time of writing with a number of DNOs who are assessing the potential costs and benefits of the Smart Fuse. Whilst the benefits of the Smart Fuse would be related to the specific Quality of Supply Strategy of a DNO, there are no barriers in place regarding the technology or its use by any electricity network operator. There is no further development of the physical technology required although the fault analysis software that is employed within the device is under constant review and development. One feature built into the Smart Fuse at the request of Electricity North West is 'over the air' software and firmware upgrades managed by Kelvatek, the devices do not need to be returned to have their operating software upgraded to the latest versions, it is all done automatically as is GPS enabled tracking so the locations of the devices are known at all times.

8.6 IPR Ownership

IPR developed during the project is listed below;

Owner	Nature	Availability
Kelvatek	**Manuals, Operating procedures and technical training courses**	**Available**
Electricity North West	**Code of Practice and internal procedures**	**Available in a format to be agreed, procedures developed are specific to ENWL therefore consideration needs to be made to their suitability for use by another company**
Durham University	**Analysis of data**	**Available as part of PhD studies when the final theses are available**

Table 8-3 – IPR Ownership

9 PLANNED IMPLEMENTATION

The Smart Fuse has been fully adopted at Electricity North West and is use as a business as usual approach to the management and mitigation of faults on our low voltage underground network.

10 ACADEMIC PAPERS

Crossland, A., Jones, D., & Wade, N. (2013). Energy Storage/Demand Side Response in LV Networks: Design of Cost Based Planning Tools for Network Operators. *22nd International Conference on Electricity Distribution*. Stockholm.

Wang, L., Liang, D., Crossland, A., Wade, N., & Jones, D. (2013). Using a Smart Grid Laboratory to Investigate Battery Energy Storage to Mitigate the Effect of PV in Distribution Networks. *22nd International Conference on Electricity Distribution*. Stockholm.

11 CO-AUTHORS

Thanks to Dave Talbot at Electricity North West, Neal Wade and Andrew Crossland at Durham University and to Jonathan Rogers and Nigel Russell at Kelvatek.

APPENDIX A - ORIGINAL PROJECT SCOPE AND OBJECTIVES

As logged on Ofgem's LCNF pages (https://www.ofgem.gov.uk/publications-and-updates/first-tier-low-carbon-network-fund-project-bidoyng-smart-fuse-submitted-electricity-north-west-limited-enwlt1001)

Project title	**The 'Bidoyng' Smart Fuse**
Project background	In recognition of the number of Transient Faults being experienced on Low Voltage (LV) Distribution Networks and the constant drive to improve customer service, Electricity North West initiated the IFI funded Fuse Restorer Project in 2006 with Kelvatek. The aim of the project was to develop a device capable of carrying two LV fuses in a standard size fuse carrier that could automatically insert a secondary fuse into a circuit following a Transient Fault to restore supplies to our customers and could then send an alarm to a nominated contact. Kelvatek delivered the final device, now known as the 'Bidoyng Smart Fuse' and three were installed on Electricity North West's network in Wigan, Lancs, they successfully operated to restore supplies to over 100 connected customers following a transient fault at 11.30pm on 14th November. The Smart Fuse has been fully type tested (up to 50kA) and now provides a potential means to eliminate a significant proportion of Transient Faults based on developing a targeted installation strategy.
Scope and objectives	The primary aim of this project is to test the feasibility of installing a sufficient number of Smart Fuses to reduce the impact of Transient Faults on our network, if the Smart Fuse proves a reliable solution the project will provide enough data to develop a business case for the installation of a substantial number of units. During the development of The Smart Fuse the debate on smart grids has developed significantly with the recognition that the Low Voltage Network will become ever more important as domestic scale renewable energy generation is expected to play an ever greater part in the transition to a low carbon economy. The Smart Fuse has been designed to provide a high specification voltage and load profiling platform with full communications capability and a range of fault analysis applications under development and this project will provide the data needed to develop the network load modelling and profiling algorithms to support the optimisation of our low voltage network. The scope of the project is to install 200 Smart Fuse units and Gateways in identified LV circuits. The Smart Fuse units are retrofitted to the LV Fuse position in the LV Fuse pillar with 3 Smart Fuse units installed per feeder (one on each phase). 200 units will provide coverage for 66 feeders and one gateway is needed in each substation that Smart Fuses are installed. The objective is to demonstrate the advantages of being able to automatically restore supplies to LV connected customers and to gather data about the performance such a device will deliver to the network. It is envisaged that other smart grid opportunities will arise once data has been gathered and evaluated.
Success Criteria	The project will be considered a success by achieving three milestones: Installation of 200 Smart Fuse units, demonstration of the advantages of the technology (Auto-reclosing, Load profiling) and Smart Grid support. Fault restoration and load profiling data will be gathered from the time of installation which will then be will then be collated and analysed and recommendations published from the data analysis.

APPENDIX B - TOTAL REAL POWER THROUGH ALL TRANSFORMERS

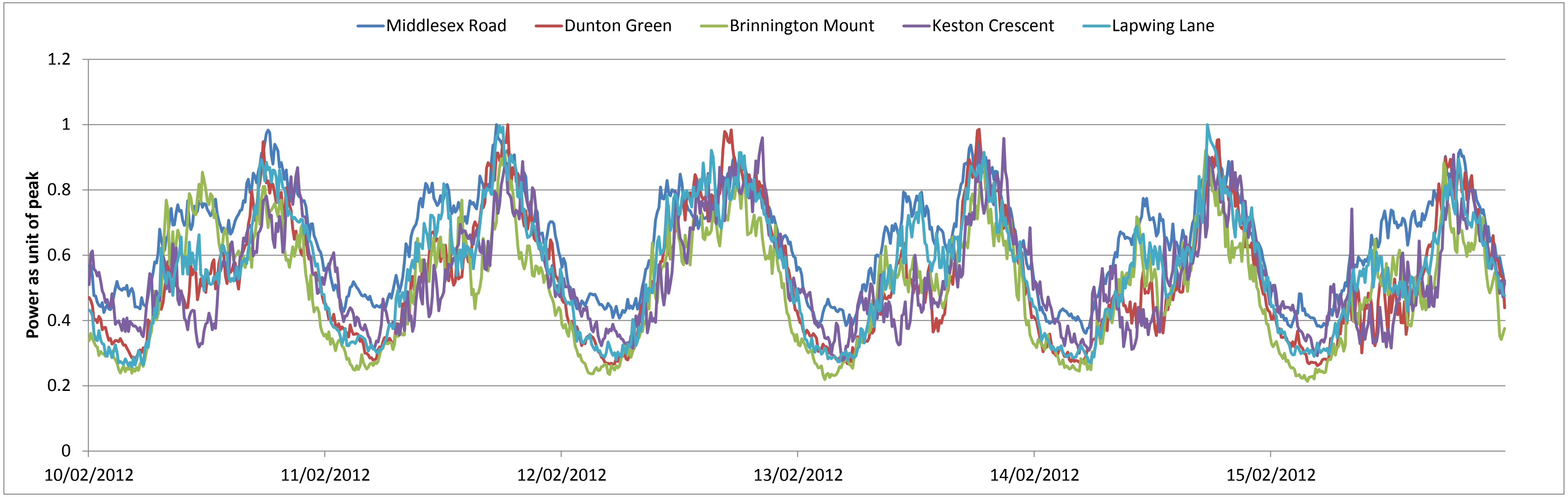


Figure - B-1: Power through all transformers for 10th-16th February 2012 as unit of peak power

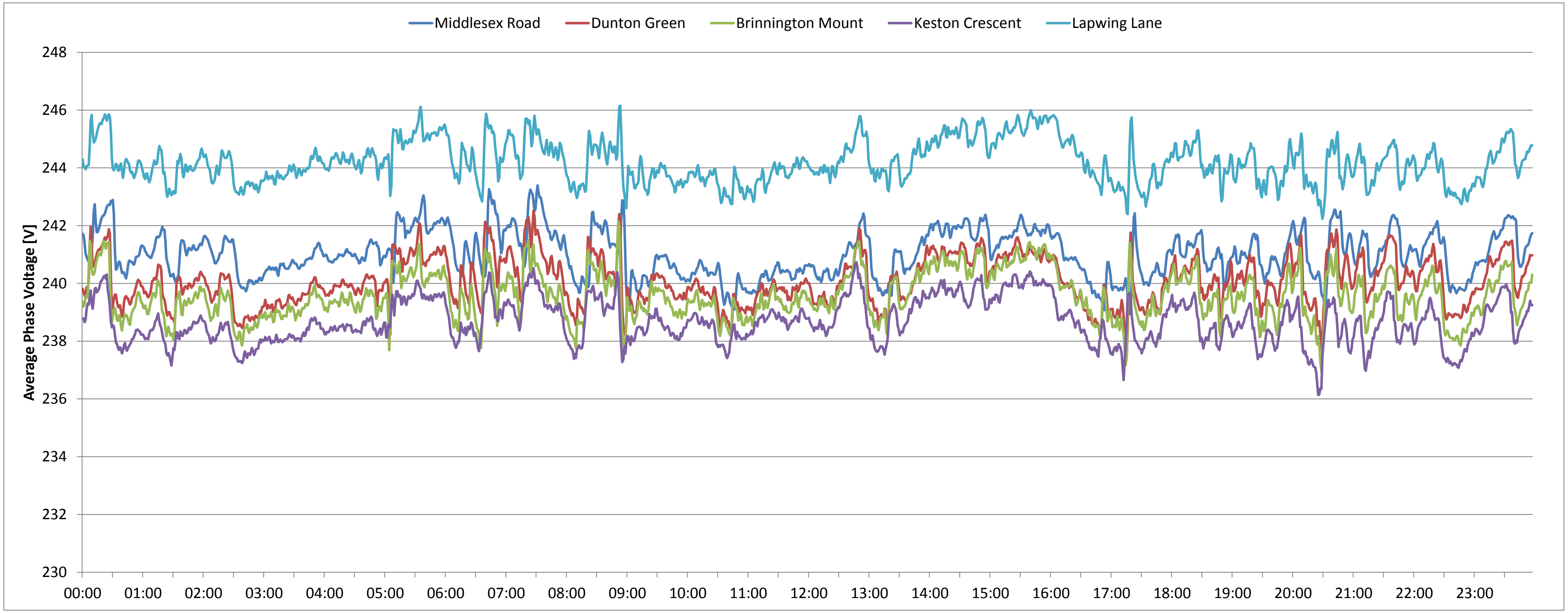
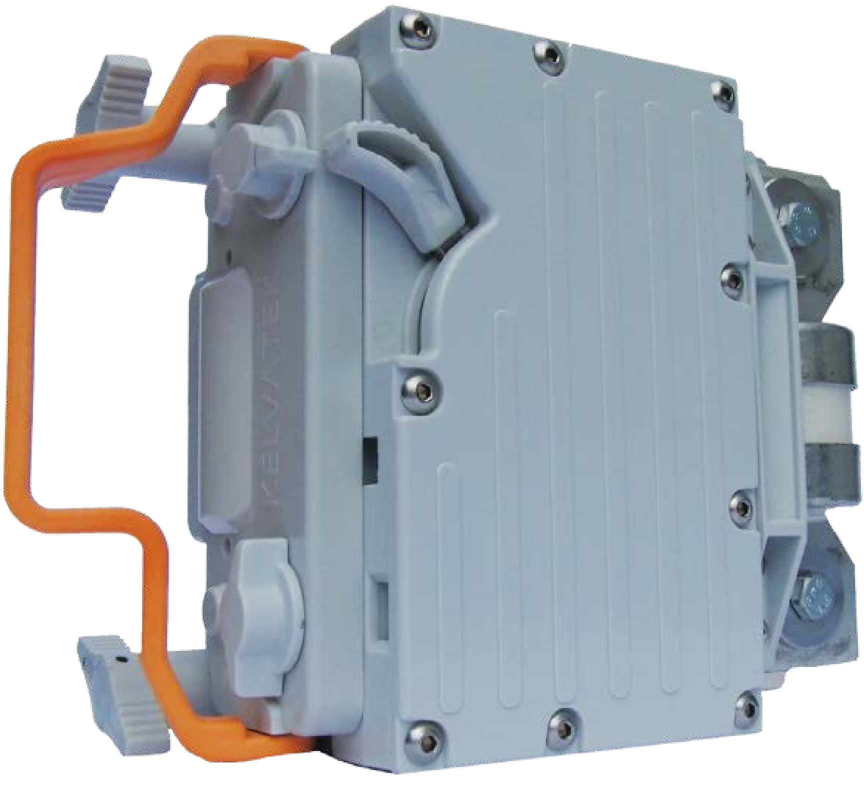


Figure - B-2: Average voltage across phases on 10/02/2012 for all transformers

APPENDIX C – INSTALLATION MANUAL

BIDOYNG

OPEATIONAL MANUAL



July 2011

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BIDOYNG

Operational Manual

www.kelvatek.com

Please register your details at our website to access product support and software updates.

IMPORTANT!

Please read this manual carefully to familiarise yourself with the safe and effective use of **BIDOYNG** before operation.

Please retain this manual for future reference.

Specifications are subject to change without notice. Look for the following items when reading this guide:

Important Information

This exclamation point means there is a note of interest that you should pay special attention to while using **BIDOYNG**.

Warning

Where the warning symbol is displayed means that user should exercise caution. Failure to follow proper procedure could damage property or the **BIDOYNG**.

Conventions

Throughout this manual, the following conventions shall be used:

- When a key term is mentioned, the definition will appear like this:
  definition

- **BIDOYNG** parts are referenced to Figure 2 like this:
  Part name (#)

Parts of the BIDOYNG

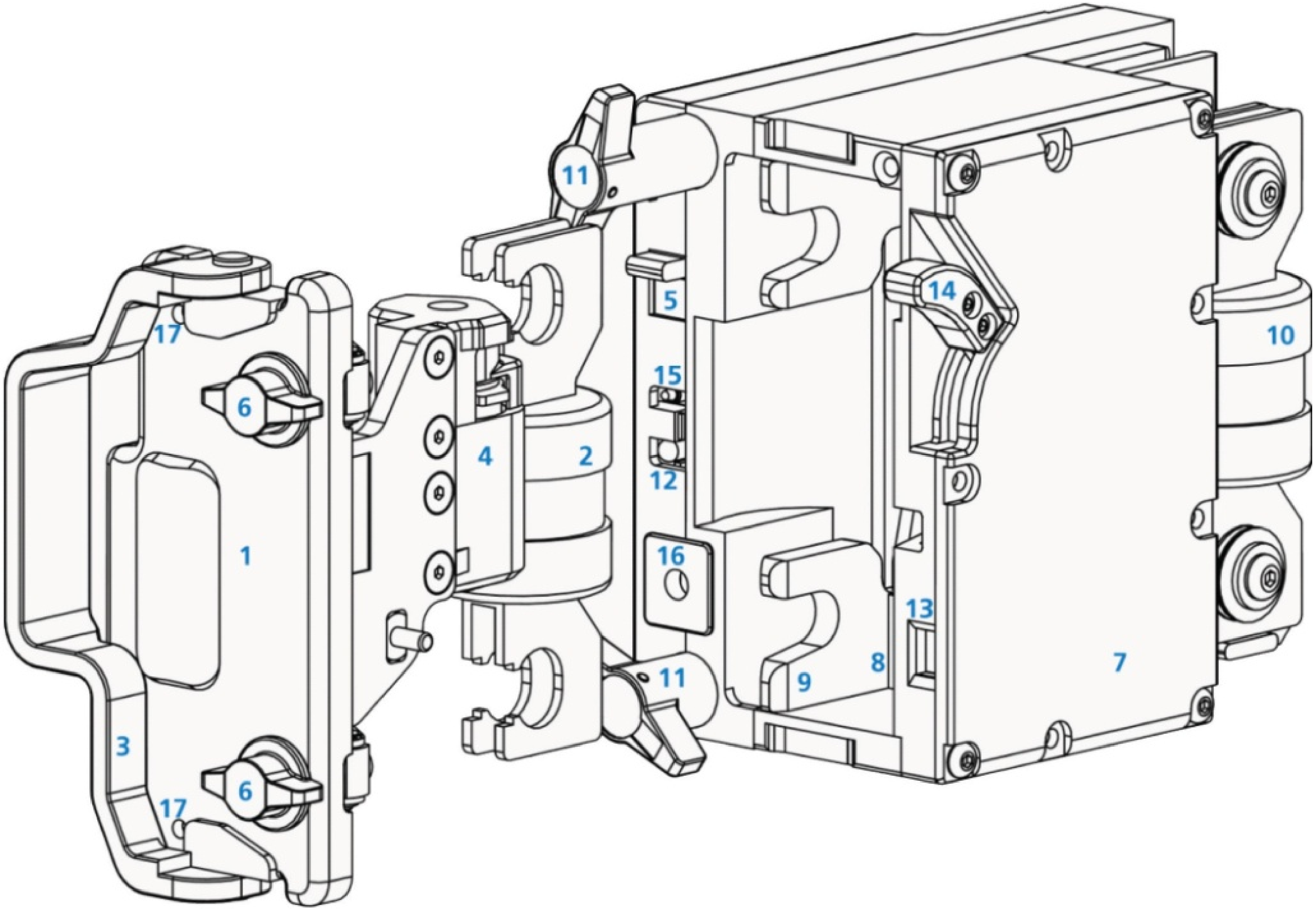


Figure 1: The BIDOYNG components

Key

1. *Primary Fuse Carrier*
2. *Primary Fuse*
3. *Fold-Away Handle*
4. *Spring Actuator*
5. *Auto Reclose Disable Switch*
6. *Primary Fuse Carrier Thumb- screws*
7. *Main Body*
8. *Switch*
9. *Primary Fuse Stocks*
10. *Secondary Fuse*
11. *Main Body Clamp Thumbscrews*
12. *Status Indicator LED*
13. *Warning Flag*
14. *Lever*
15. *Neon Indicator*
16. *Neutral Cable Connector*
17. *Test Lamp Connection Holes*

1. INTRODUCTION

BIDOYNG reduces Customer Interruptions (CI's) and Customer Minutes lost (CML's) on Low Voltage (LV) Networks. It is a cost-effective auto-recloser designed for wide-scale deployment on the LV network. The **BIDOYNG** is designed to replace a standard low voltage fuse holder and fuse, and uses a standard JS 400A fuse to interrupt the fault current. It contains 2 such fuses, (*Primary (2) &* Secondary *(10)*). When the Primary *(2) operates*, it can switch in the *Secondary Fuse (10)* after a pre-determined delay, restoring customers supplies. Communications back to the office ensures you are aware of what is going on in the network. This allows planning of fuse replacements, rather than having to react quickly to every fuse operation. The device can be used on L.V. networks with prospective fault currents of up to 50kA, and can carry load currents of 400 Amperes. **BIDOYNG** dimensions allow it to be installed on 80% of L.V. fuse pillars.

1.1 Basic Principles

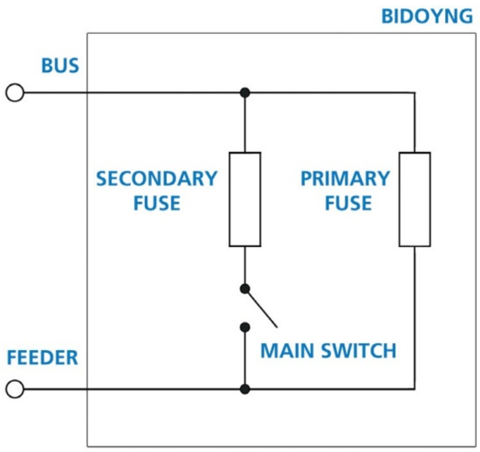


Figure 2: The **BIDOYNG** concept.

The *Primary Fuse (2)* carries the load current under normal conditions, the *Secondary Fuse (10)* is not in circuit because the *Switch (8)* is open. When a fault occurs the *Primary Fuse (2)* clears it by operating. This leaves the feeder cable without power.

After a reclose delay (default 2mins 30 secs), the *Switch (8)* is closed. If the fault is permanent, then the *Secondary Fuse (10)* will operate. If the fault is intermittent, the *Secondary Fuse (10)* can now carry normal load current, and supplies are restored.

The unit will also send information via a GATEWAY to utility staff to indicate activity.

When supplies have been restored by switching in of the *Secondary Fuse (10)*, the utility can plan to replace the *Primary Fuse (2)* before the next fault incident.

In this manner, the **BIDOYNG** can restore supplies to customers within the 3 minute regulatory outage period and dramatically reduce CML and CI figures.

2. BIDOYNG INSTALLATION

This section describes the installation of a **BIDOYNG** unit onto a fuse way. It assumes that a GATEWAY has been set up correctly in the substation.

2.1 BIDOYNG Pre-installation checks

The *Main Body (7)* of the **BIDOYNG** is designed to be inserted onto the fuse stalks using a non-pivoting action. In order to ensure that the **BIDOYNG** does not pick up fault current during installation, it is essential that the following checks are carried out:

1. Fit the *Secondary Fuse (10)*.
2. Ensure *Primary Fuse (2)* is removed.
3. Charge Spring *Actuator (4)*.
4. Re-Insert *Primary Fuse Holder (1)*.
5. Set *Lever (14)* to Secondary out.
6. ~~Set~~ to Auto.
7. Ensure open circuit between test points A & B.

If number 7 indicates closed circuit **DO NOT USE THE BIDOYNG** and check the above procedure was followed correctly.

2.2 Installation procedure

Ensure that the pre-installation checks (section 2.1) have been carried out before going ahead with the installation procedure.

Approved PPE must be used when installing the **BIDOYNG** onto the fuse way.

1. Put GATEWAY into install mode.
2. ~~Set~~ to Auto
3. Insert the assembled **BIDOYNG** onto the fuse way stalks and secure into position using the two *Main Body Clamp Thumbscrews (11)* on the left.
4. Connect the umbilical cable to the **BIDOYNG** and to the Neutral Bar
5. On the **BIDOYNG** set to AUTO mode by moving the auto-reclose switch to the ON position. Wait until the **BIDOYNG** switches the *Secondary Fuse (10)* into circuit (approximately 15 seconds). Check *Lever* is up
6. Ensure that the *Secondary Fuse (10)* holes, (*Neon Indicator (15)*) re mains off

When **BIDOYNG** is about to close it will give a warning beep. The last 10 seconds before close will be a fast beep.

7. Install the next **BIDOYNG**.
8. Follow GATEWAY on-screen instructions to choose **BIDOYNG** positions. Save and exit to complete the install on the GATEWAY.
9. Replace the *Primary Fuse (2)* using the procedure described in section 5.

3. RECLOSING

3.1 Auto reclosing

Auto reclosing can be disabled or enabled using the *Auto Reclose Disable Switch (5)* on the *Main Body (7)*.

After a fault event causes the *Primary Fuse (2)* to operate, the **BIDOYNG** will pause for a reclose delay (typical 2 minutes 30 seconds). During the reclose delay a slow warning beep will be sounded from the **BIDOYNG**. After this time, a fast warning beep is given for 10 seconds, after which the *Main Switch (8)* will close and the *Secondary Fuse (10)* will be switched into circuit.

3.2 Phase-phase fault

BIDOYNG will not reclose onto a phase-phase fault condition.

4. PERFORMING TESTS WITH BIDOYNG FITTED

4.1 Checking the state of the bus and feeder

The **BIDOYNG** has two *Test Lamp Connection Holes (17)* on the front of the *Primary Fuse Carrier (1)*. These holes give access to the BUS and FEEDER fuse stalks, and are designed to allow connection of a test lamp.

4.2 BIDOYNG Neon Indicator

The neon indicator on the front panel of the **BIDOYNG** indicates voltage across the BUS and FEEDER stalks.

When the *Lever (14)* is in SECONDARY IN position, and the *Neon Indicator* **(15)** is illuminated the entire **BIDOYNG** must be removed from the fuse pillar and pre-installation checks carried out.

5. PRIMARY FUSE REPLACEMENT

The *Primary Fuse (2)* on the **BIDOYNG** can be replaced without disconnecting customer supplies.

Only attempt *Primary Fuse (2)* replacement when the *Lever (14)* is in the SECONDARY IN position and the *Neon Indicator (15)* is NOT illuminated! Assume the fault can strike at any time.

Approved PPE must be used. Follow your utility's procedures for replacing LV fuses

5.1 To replace the Primary Fuse:

1. Ensure the load is carried by the *Secondary Fuse (10)*. (*Lever (14)* in SECONDARY IN position, *Neon Indicator (15)*, not illuminated).
2. Loosen the *Primary Fuse Carrier Thumbscrews (6)* and remove the Primary Fuse Carrier (1).
3. Replace the *Primary Fuse (2)* with a fresh fuse.
4. Charge the *Spring Actuator (4)* by pressing on the plunger until it locks in the retracted position.
5. Check again that the *Neon Indicator (15)* is out.
6. Place the bottom of the *Primary Fuse Carrier (1)* onto the lower *Primary Fuse Stalk (9)*. Use a pivoting action to insert the *Primary Fuse Carrier (1)*.

7. Hold the *Primary Fuse Carrier (1)* in place while tightening the *Primary Fuse Carrier Thumbscrews (6)*.

8. The *Primary Fuse (2)* is now in parallel with the *Secondary Fuse (10)* and the *Warning Flag (15)* indicator is RED.

9. Switch *Lever (14)* to SECONDARY OUT. This switches the load onto the *Primary Fuse (2)*.

5.2 Notes:

No attempt should be made to remove the *Main Body (7)*, or to open the contact when the *Primary Fuse Carrier (1)* is removed. If removing the entire **BIDOYNG** becomes necessary then insert the *Primary Fuse Carrier (1)* with NO fuse first.

The *Main Switch (7)* and *Lever (14)* is locked in position by means of an interlock when the *Primary Fuse Carrier (1)* is removed. This feature is to ensure the user's safety.

A red flag shows in the *Warning Flag (15)* window when the *Primary Fuse (2)* is removed. It will continue to show until the *Primary Fuse Carrier (1)* is re-inserted and the Secondary is out. Note that if the *Secondary Fuse (10)* is left in circuit, this flag will show RED. In this condition the *Primary (2)* and *Secondary (10)* fuses are running in parallel. A **BIDOYNG** should NEVER be left in this condition.

6. SECONDARY FUSE REPLACEMENT

If both the *Primary (2)* and *Secondary (10)* fuses have operated, then the entire **BIDOYNG** must be removed from the fuse pillar.

When the **BIDOYNG** *Switch (8)* is closed (*Lever (14)* in the up position), and the *Neon indicator (15)* is illuminated the entire **BIDOYNG** must be removed from the fuse pillar and pre-installation checks carried out.

- Loosen the *Main Body Clamp Thumbscrews (11)* and remove the entire **BIDOYNG** unit from the fuse pillar in a quick fluid movement.
- Follow the **BIDOYNG** installation instructions to install the **BIDOYNG** back onto the fuse pillar.

7. GATEWAY

The GATEWAY is designed to relay information about the status and operation of **BIDOYNG** units back to the office or forward the information directly to staff via e-mail and SMS.

8. ALARMS, WEB INTERFACE & MESSAGE FORWARDING

8.1 Alarms

Customer Supply Related Alarms

- *Secondary Fuse (10)* operated - Customers off supply.
- Awaiting reclose instruction - (Manual mode selected) Customers off supply.
- Customer supply restored via *Secondary Fuse (10)*

8.2 Operations Messages

- *Primary Fuse (2)* operated
- Reclose Timer started (Auto mode selected)
- **BIDOYNG** installed successfully
- Manual mode - awaiting reclose instruction - Customers off supply

8.3 Warnings

- **BIDOYNG** in parallel mode for >1 min
- **BIDOYNG** high temperature warning
- **BIDOYNG** critical high temperature warning - Attend site!
-

9. SPECIFICATION

SPECIFICATION	VALUES
Rated Voltage:	90 to 500 V rms
Rated load current:	400 A rms
Reclose Delay Range:	30 seconds to 10 minutes
Maximum fault making capacity:	50,000 A rms
Maximum fault current breaking capacity:	Determined by fuse (80kA typical)
Fault making life @ 10kA:	TBC
Maximum rating of fuses:	400 A Class J
Primary fuse insertion method:	Pivoting action
Nominal gateway radio range:	15 m
Communications:	via Kelvatek Gateway (GPRS)
Dimensions:	90.4 x 141 x 161 mm
Weight:	3 kg
Temperature range:	-20 to +50 °C

APPENDIX D – GATEWAY SET UP INSTRUCTIONS

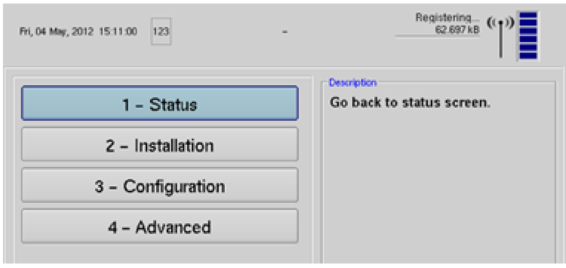
Gateway Quick Setup Guide

This guide explains how to setup a gateway at a substation – picking an area, and adding details like the substation name, address etc.

1 Connect Antenna and Power to Gateway. Gateway is not touch screen, press buttons on the keypad.

2 This is the status screen, it is split into 3 rows: L1, L2 and L3 for each of the 3 phases, and 5 columns, W1-W5 for 5 feeder cables. Press the button below Menu to see the main menu screen.

3 This is the main menu. We want to install the Gateway, so we choose option by pressing button 2 on the keypad.

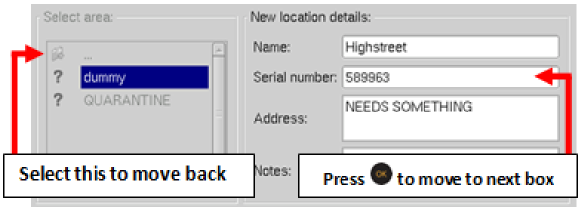


4 If this is the first time the Gateway has been used the get the areas and substations from the server by pressing 1 for [1 – Update Locations] otherwise move on to step 5.

5 Select [2 – Install Gateway] (by pressing 2 on the keypad.)

6 Choose [Create new location]

7 Select an Area: press [OK] to open Entire Network, then use the [up] and [down] keys to navigate. Choose [Accept area] to select an area.

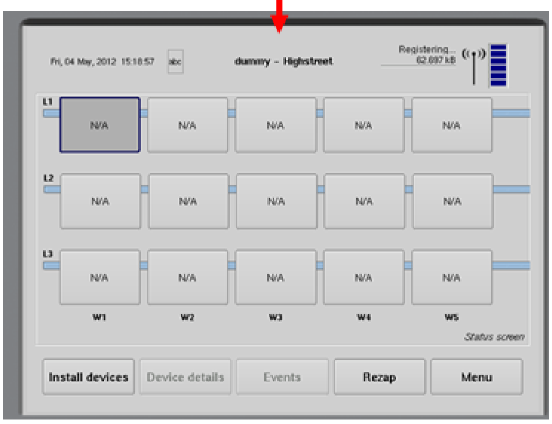


8 Enter location details. Enter text like basic mobile phone text entry. Press [a/A?] to change between text entry modes [123] (text, numbers, capitals etc.) Press [OK] to move to between text entry boxes. Name, Serial Number (unique Identifier, e.g. NRN or Substation Code) and Address all require information. When finished choose [Apply]

9 Check details are correct and [Confirm]

10 At the installation menu choose [Back] and to goto the status menu (Option 1).

The Area and Substation Name are now shown at the top of the screen:



The Gateway is now set up. Turn over for BIDOYNG installation instructions.

BIDOYNG Installation Guide

Read this procedure in conjunction with the manufacturers manual 40-0142-02 (supplied with a set of 3 BIDOYNG units).

Wear the appropriate PPE.

1. Carry out the pre-installation procedure printed on the side of BIDOYNG.
2. Where reasonably practicable, energise the faulty circuit using a fault re-energising device, to ensure that that fault is not active.
3. Select "Install Devices" on the Gateway, then select 1-BIDOYNG.
4. Ensure BIDOYNG is set to "NON-AUTO".
5. Align and Insert BIDOYNG main body onto the fuse way stalks and fully tighten the 2 main body thumbscrews(11) on the left of the device.
6. Connect the umbilical cable to the neutral Busbar and then to the BIDOYNG Neutral Socket(16), then push in and park the thumbscrews so that the primary fuse handle can be folded away.
7. Each BIDOYNG should emit a three tone sound to indicate it has been detected and the Gateway should show how many devices have been detected.
8. On BIDOYNG move the Auto Reclose Switch to the "AUTO" position. Move a safe distance from the LV board, wait until the BIDOYNG switches the Secondary Fuse into circuit (approx 15 seconds) and restores supply. Check that lever(14) is in the up (Secondary In) position.
9. Test with test lamps to ensure that the secondary fuse has energized the feeder stalk and confirm that the neon indicator remains off.
10. Carry out pre-install procedure and install next BIDOYNG – step (5).
11. On Gateway the should be X devices detected where X is the number of BIDOYNG units you have installed. Press NEXT on the Gateway, then NEXT. The Gateway will say auto-reclose, but this has already been performed, so press NEXT again.
12. The position devices screen will be shown with a mimic of the LV board.
13. Press the button below "Next Device"
14. A BIDOYNG will start to beep and the Status LED on the BIDOYNG will go RED to identify it.
15. Use the arrow keys to position the device on the screen to the corresponding position of the BIDOYNG on the LV board.
16. Press Select (4th button) to select the position.
17. Complete steps 13-16 for each remaining BIDOYNG.
18. Press the 5th Button – "Save and Exit" from the position devices screen.
19. Goto the Status screen to view the status of the installed BIDOYNG units.
20. Now insert the primary fuse into each BIDOYNG using the next instructions:

Insertion or replacement of the primary fuse

1. Set BIDOYNG to 'NON-AUTO'
2. Ensure the load is carried by the secondary fuse(10) – (Lever (14) in upper "SEC IN" position, neon indicator(15) not illuminated.
3. Loosen the primary fuse carrier thumbscrews(6) and remove the primary fuse carrier (1).
4. Fit a fuse(2) into the primary fuse carrier(1). Tighten the clamp screws finger tight.
5. Charge the spring actuator(4) by pressing on the plunger until it locks in the retracted position.
6. Check again that the neon indicator is(15) is *not* illuminated. Confirm both primary fuse contacts are live and zero volts across the primary fuse contacts with test lamps.
7. Place the bottom of the primary fuse carrier (1) onto the lower primary fuse stalk (9). Use a pivoting action to insert the primary fuse carrier(1). Note – this operation puts the primary fuse in parallel with the secondary.
8. Hold the primary fuse carrier(1) in place while tightening the primary fuse thumbscrews (6).
9. The primary fuse(2) is now in parallel with the secondary fuse(10) and the warning flag(15) indicator is RED.
10. Switch Lever(14) to 'SEC OUT'. This switches the load onto the primary fuse (2). Confirm that the feeder stalk is live using test lamps.
11. Move the Auto reclose switch to the 'AUTO' position.

QUICK BIDOYNG REMOVAL

BIDOYNG EMERGENCY REMOVAL INSTRUCTIONS

Follow these instructions if you need to carry out LV switching operations on a distributor with a BIDOYNG installed and you have not been specifically trained on the installation of the device.

1. Set the BIDOYNG to "NON-AUTO"
2. Open the folding handle(3).
3. Turn both thumbscrews(11) until the peg lines up with the slot and pull the thumbscrew out until it fully engages and the square section of the thumbscrew is visible.
4. Remove the neutral cable from the BIDOYNG
5. Support the BIDOYNG and turn the thumbscrews fully anticlockwise (as you would with a standard fuse) until they stop.
6. Remove the BIDOYNG in a smooth continuous motion.