WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

SUBURBAN PV IMPACT

CLOSEDOWN REPORT

LCN Fund
Low Carbon Networks

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Glossary

Abbreviation	Term
WPD	Western Power Distribution
FiT	Feed in Tariffs
DNO	Distribution Network Operator

Executive Summary

This report details the work undertaken and the findings from the Tier 1 project, PV Impact on Suburban Networks. The project had three phases which were achieved throughout the project:

- Selection of substation monitoring equipment,
- Installation in distribution substations,
- Recovery and Analysis of data to determine the impact of dense PV panels on suburban networks.

The project selected three split core current transformers, rogowski coils with transconductance amplifiers to measure current, modified fuse carrier handles and Nylon G clamps to measure voltage and EDMI and Subnet units as monitoring equipment. Devices were configured together to provide the most appropriate solutions for the networks requiring monitoring.

Substation monitoring was installed on seven LV feeders and one substation transformer measuring and recording a range of characteristics including minimum/average/maximum voltage and current, current Total Harmonic Distortion, voltage Total Harmonic Distortion, individual voltage harmonics up to 50th, power factor, real and reactive power flows.

The analysed data has shown the impact of densely connected on the LV distribution network operation. The limitations to further PV connections within the project area was voltage rise and how the analysis has updated WPD's policies allowing the connection of a further 20% solar PV for multiple LV connections due to the measured diversity.

The original project budget was £100k, the costs at project closure was £76k.

1 Project Background

The introduction of feed in tariffs within the UK has shown an increase in micro generation connected to the low voltage distribution network. This is becoming increasingly evident from the range of companies offering free PV installations in exchange for the revenue from the tariffs. If a high penetration of micro generation is installed in a compact suburban environment, the cumulative effect is expected to have a substantial impact on the existing distribution network.

Nottingham is one location where a significant number of PV panels have already been installed in dense locations; further dense areas are also due to be developed.

106 kW of PV Panels have been installed and up to 1235kW are scheduled to be installed in Aspley and the Meadows by the Meadows Partnership Trust, Nottingham City Council and Blueprint.

As the UK transitions to a lower carbon economy, it will see an evolution in our customers' behaviour. The installation of micro generation has seen the greatest uptake, especially solar PV due to government led initiatives. Micro generation can have a substantial impact on the distribution network, especially at the end of the low voltage network. WPD have planning guidelines to facilitate our customer's low carbon aspirations, allowing the multiple connections of micro generation whilst ensuring the networks operate safely within their design limits. Network monitoring projects, engagement with manufacturers and trade bodies, can lead to a better understanding in customers' use of new technologies and their cumulative effects on the network. Through LCNF projects, WPD are able to update the planning guidelines to maximise the capacity of the network before network reinforcement is triggered.

This project sought to comprehensively monitor sections of suburban network identified as having a dense PV penetration. The project aimed to better understand how multiple Solar PV installations impacts all aspects of the LV network operation, improving the future planning assumptions.

1.1 Nottingham as a trial location

Nottingham was one of the first areas within the Midlands to propose and install solar PV in focussed urban areas. These connections were carried out by the Meadows Partnership and Nottingham City Council in two phases across three locations within Nottingham.

The Meadows Partnership

The project utilised over 100kW of PV panels onto terraced properties constructed between 1900 and 1970's and PV installed on 38 new build eco homes constructed 2010-2012. In December 2009 the Meadows won £500,000 in a competition as part of the Low Carbon Communities Challenge to pay for the installation of solar panels on 55 houses 3 primary schools and a community garden. The properties include social housing, low income owner occupier houses and 10 privately owned homes. Construction was completed by March 2010.

Nottingham City Council

The project utilised PV installations amounting to 1200kW , these were installs undertaken in conjunction with Nottingham City Homes & E.ON. Aspley and Broxtowe were selected in 2011 to install PV panels on 1450 suitable properties. These were all social housing, terraced and semi-detached properties constructed in 1970's. Figure 1 shows the network trial locations and part of Broxtowe after PV was installed.

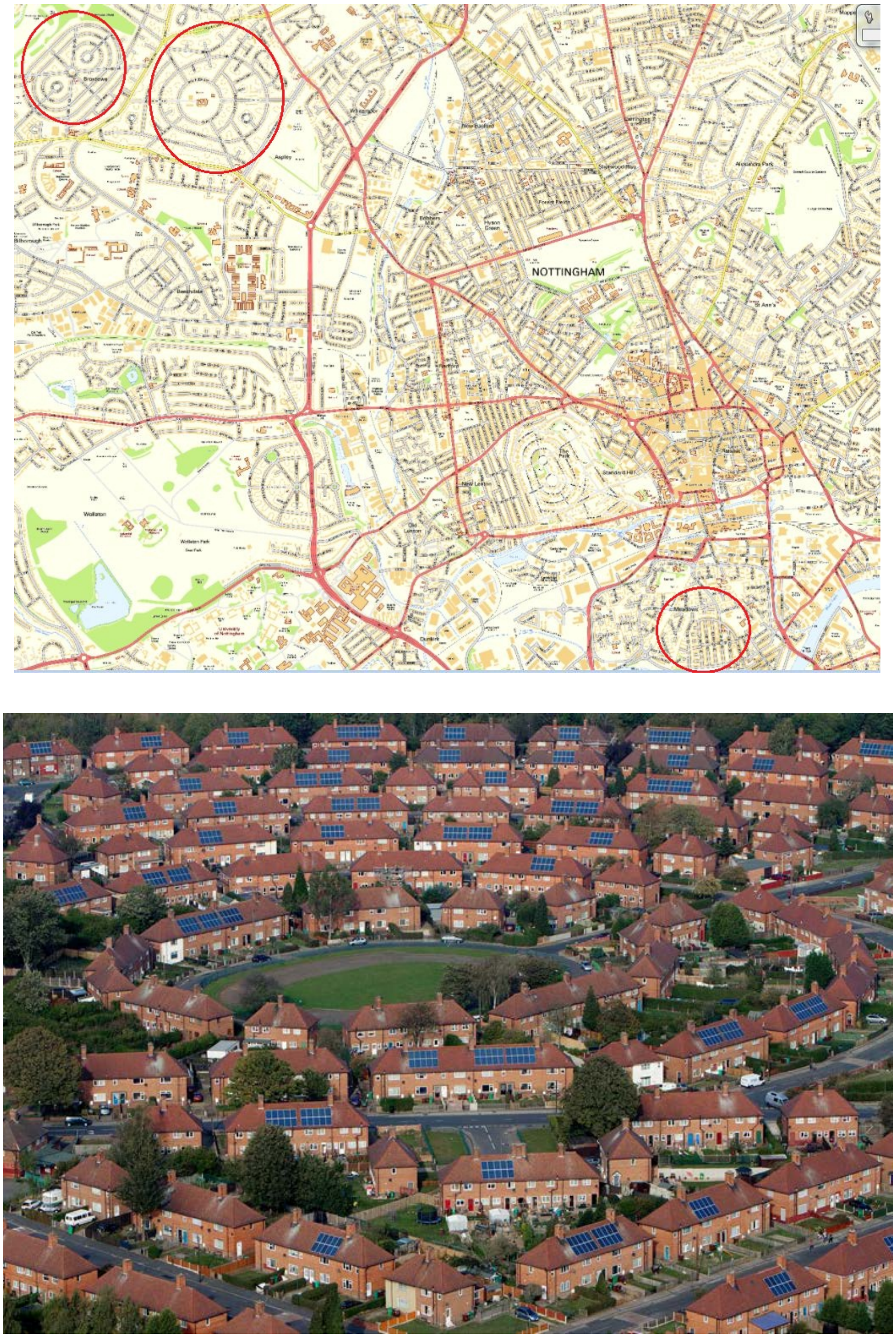


Figure1- Monitoring areas and aerial photography of Broxtowe, Nottingham

The distribution networks in the trial locations were all modelled and selected as they were deemed to be generic and representative sub-urban networks in many different areas.

1.2 Project Overview

This LCNF Tier 1 Project was split into several distinct phases, each with its own aims:

Phase 1 – Project Design

- Selection of substation monitoring technology,
- Selection of transducers,
- Selection of trial locations.

At the project inception, no suitable, cost effective off the shelf, semi-permanent distribution substation monitoring solution with appropriate transducers was available. A monitor capable of analysing all the network characteristics was sourced from a smart metering company, EDMI. The meter was configurable and designed for Transmission, Distribution and Industrial customers. A range of suitable transducers had to be combined together to provide a safe, easy way of monitoring distribution substations.

The trial locations were selected across the Meadows, Aspley and Broxtowe networks to monitor the feeders with the greatest modelled impact from the embedded generation. Appendix D and Appendix E identify the LV networks monitored.

Phase 2 – Installation in distribution substations

The project required installation of the most suitable monitoring equipment, transducers and remote communications in selected substations on either the substation or individual feeders.

Phase 3 – Recovery and Analysis of data

The data generated from the eight substation feeders required analysing to better understand the impact of Solar PV as observed at the distribution substation. The learning from this project has been used in conjunction with the WPD Projects, LV Network Templates and Early Learning, to update WPD's policies concerning the connection of LV connected solar PV generation.

The learning from these projects is complementary to other projects which have been monitoring PV under different circumstances.

- PV impact on suburban networks – Installation of PV on existing homes in large suburban estates with an existing electricity distribution network.
- LV Network Templates – Identifying the distribution network headroom for Low Carbon Technologies (LCTs) across a whole region.
- Early Learning – Installation of PV on a small estate of new properties, clustering of LCTs on every property, installed with a switchable distribution network configuration.

2 Scope and Objectives

The project will monitor the profile of eight selected substations or individual feeders in areas where PV panels have already been installed or are expected to be installed.

Through this project, WPD will explore the following aspects:

- How to measure and capture voltage, current, harmonic, real and reactive power data on a range of distribution assets in suburban areas.
- How to install equipment safely with minimal or no interruption of supply
- How often the network characteristics need to be monitored (for example 1min, 5min, 15min)
- How we can interrogate the large amounts of data generated to highlight significant network issues created by the installation of PV panels
- What the effect is of installing large numbers of PV panels on the LV network

The original aim was to share our learnings with DNOs in November 2012. The project encountered a number of delays; these resulted in a change request of the project being submitted to increase the project duration by 12 months. The WPD internal change mandates associated with this amendment are included in Appendix C.

Ofgem were notified on 10/2012 in line with the LCNF governance document how the project would still achieved its original scope and objectives.

3 Success Criteria

Success Criteria	Status
Select a range of sensors to be developed and tested by April 2011	✓
Install the substation monitoring equipment by May 2011	✓
Determine the frequency of monitoring each characteristic by July 2011	✓
Analysis 12 months data, highlighting the measured impact of PV on the distribution network by September 2012	✓
Write a close out report around the key objectives and the lessons learnt by November 2012.	✓

The success criteria detailed above were identified at the point of project registration. These success criteria will be used to determine the positive and negative learning throughout this report. All success criteria have been met through the project, however delays identified in the change request led to the delay in the installation of substation monitoring and all further milestones.

4 Details of the work carried out

4.1 Phase 1

4.1.1 Selection of substation monitors

WPD's existing network monitoring solutions have traditionally been used for two very different purposes.

LV feeder, Voltage and Current measurements - Temporary (typically 2 weeks).

These devices record current and voltage parameters, they do not have a full range of power quality analysis capability. Data from these devices is by a manual downloaded, i.e. it has no wireless backhaul of information.

HV and EHV, Power Quality, Voltage and Current measurements – Temporary (typically 1 month).

The devices and transducers are designed for HV networks and are not ideally set up for LV network monitoring and as such isn't a cost effective for roll out on the LV network. Often the data can only be downloaded manually from the device, i.e. it has no wireless backhaul of information.

This project required a monitoring solution suitable of recording and storing phase - neutral Voltage, single phase Current flows, voltage and current Harmonics, 2 – 50th, real and reactive power flows. It was deemed essential that the data could be recovered remotely as the monitors were required to record data for over 12 months.

The project selected two monitoring solutions after a review of the market, seven EDMI Mk6E and one EMS subnet as seen in figure 2.

EDMI Mk6E

Advanced Three Phase Electronic Revenue Meter the Mk6E is a high precision meter created for generation and transmission applications. It has GPRS Capability, Power Quality Indication, Advanced Tamper Detection & AMI ready.

EMS Subnet

This substation monitor carries out full analysis within each unit and can send auto prioritised graphical and numerical reports. The Monitor can be upgraded without removal or recalibration. Sub.net will report on voltage, current, power quality, voltage dips, frequency, harmonics and flicker.

Photo EDMI Mk6e

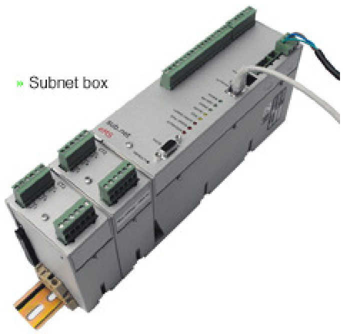


Photo EMS subnet

Figure 2- Monitoring Solutions

4.1.2 Selection of Voltage Connections

Most of the historic distribution substations do not have voltage monitoring points suitable for connecting a network monitor for over a 12 month period. The project required at least two different fused voltage connections which could be installed on a semi-permanent basis for typical LV distribution boards installed in Nottingham.

Two voltage connectors were selected to provide an effective fused measuring point between the LV busbars and neutral bar, as seen in figure 3.

Schneider voltage handle EE:200

The Schneider EE:200 has been developed to provide a fused voltage connection for an insulated connector and lead providing a voltage reference point on either the busbar or feeder.

- ✓ A minor modification to an existing WPD approved device
- ✓ Can be installed without any customer interruptions

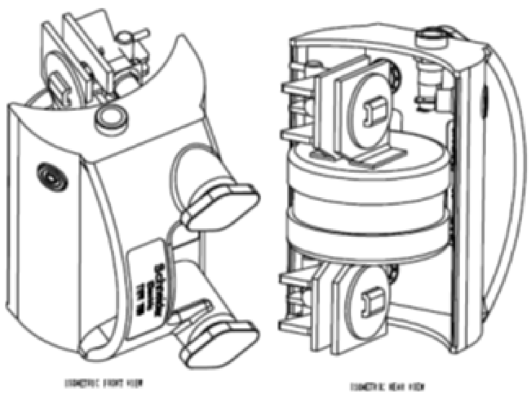
- ✓ Maintains the IP rating of the LV distribution board
- × Requires a separate neutral connection
- × Requires a circuit to be paralleled "back feed" from a neighbouring substation to install without an outage.

Nylon G Clamp

The Nylon G Clamp is an approved method of gaining a fused, doubly insulated connection for an open LV Distribution board. New nylon G clamps were manufactured to the existing specification providing a semi-permanent method of getting a voltage reference point on the LV busbar.

- ✓ Existing approval for use on the distribution network
- ✓ Transducers are safely installed without any customer interruptions
- × Only suitable on open LV distribution boards.

The use of both voltage connectors allowed for the network voltage to be effectively monitored without the requirement for a network outage.



Voltage Handle

Nylon G Clamp

Figure 3- Voltage connectors

4.1.3 Selection of Current Transducers

Most distribution substations have Current Transformers installed for Maximum Demand Indicators (MDI's) to provide a guide to the substation demand. Their function requires them to have a relatively low accuracy for 50Hz signals. This project required higher accuracy transducers for power quality analysis.

Four different current transducers were selected for use with the EDMI Mk6E meter.

Split core current transformers

This split core current transformer is a method of retrofitting accurate current transducers around LV feeders without requiring any outages.

- ✓ High accuracy
- ✓ They are robust solution for longer time monitoring.
- ✓ Don't require any calibration post manufacturing.
- × The design and construction must be matched to the application.
- × The design and construction must be match to the monitor
- × Most have a limited secondary wiring length.

The different network design characteristics required three different split core current transformers to be selected. CT's were selected to fit within the physical available space, operate safely with the maximum LV feeder current, connect to the monitor with the original or an extended lead and fit around the existing cable.

US1000A:1A

- ✓ The largest jaw aperture of the three split core CT's selected
- ✓ Designed for sustained monitoring up to 1000A
- ✓ 4mm safety plugs for users to supply and fit custom leads
- × Large CT not suitable for some distribution substations where LV feeders have a modest separation between cores.

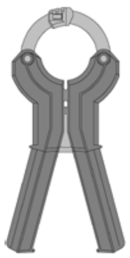


Figure 4 – US1000 Current transducer

Fluke i800 Current Clamp

- ✓ Designed for sustained monitoring upto 800A
- ✓ Highest accuracy CT including at low Currents
- × Large CT not suitable for some distribution substations where LV feeders have a modest separation between cores
- × Fixed length leads with safety plugs fitted

Figure 5 – Fluke i800 Current transducer

Fluke i400 Current Clamp

- ✓ Designed for sustained monitoring up to 400A
- ✓ The smallest overall size of the three split core CT's selected
- × Fixed length leads with safety plugs fitted
- × Not suitable for some high current feeders.

Figure 6 – Fluke i400 Current transducer

Rogowski Coils

- ✓ Designed to fit around any LV feeder
- ✓ No maximum current limitation
- × Requires a transconductance amplifier when used with some monitors
- × Requires calibration between the Rogowski coil and transconductance amplifier.
- × The transconductance amplifier requires additional space
- × Rogowski Coils with an interface box is a higher cost solution compared to split core current transformers.

Requirements for a Transconductance amplifier

The EDMI Mk6E energy monitors procured for this project, like most energy monitors, are designed to measure an alternating current between 0A and 1A from Current Transducers. The US1000, Fluke i800 and i400 Current transformers all have a 0-1A secondary output and could be easily integrated with the EDMI Mk6E meter.

Rogowski coils measure current like a current transformer, however the output is in mV rather than 0 – 1A current. To use a Rogowski coil with a traditional energy monitor requires a transconductance amplifier. The input voltage (mV) is converted into a variable current output. Haysys Ltd built a transconductance amplifier to allow Rogowski coils to be integrated with an EDMI Mk6E meter. This uses an off the shelf op amp and follows standard engineering designs, not generating any new IPR.

Figure 7 – Rogowski coil and transconductance amplifier Current transducer

4.1.4 Selection of trial locations

The project selected substations likely to have the greatest impact from the connected solar PV, though either the number of connections, the location of panels along the network or the network design. By selecting the substations likely to see the greatest impact, we selected the substations likely to produce the greatest amount of learning.

Meadows

Three substations were selected within the Meadows, South Nottingham.

- Wilford Crescent East - Transformer. Selected due to combination of new energy efficient housing with solar PV and the retrofitting of solar PV to existing 1920's housing stock.
- Ayton Close Meadows A – Feeder 1. Selected due to the dense connection of solar PV to existing 1940's housing stock.

- Ayton Close Meadows B – Feeder 4. Selected due to the dense connection of solar PV to existing 1940's housing stock.

Aspley

- Tunstall Crescent – Feeder 4. Selected due to the dense connection of solar PV to existing 1940's housing stock.
- Hilcot Drive Aspley – Feeder 4. Selected due to the dense connection of solar PV to existing 1940's housing stock.

Broxtowe

- Lindbridge Road – Feeder 5. Selected due to the dense connection of solar PV to existing 1940's housing stock.
- Frinton Road – Feeder 3. Selected due to the dense connection of solar PV to existing 1940's housing stock.
- Broxtowe Lane – Feeder 4. Selected due to the dense connection of solar PV to existing 1940's housing stock.

4.2 Phase 2 Installation

The site surveys and installation of all equipment was carried out by a team from the WPD Nottingham depot over a two week period with guidance from the Future Networks team. The installation of equipment took approximately half a day per substation and was completed without any interruption to supplies.

Each installation followed the same process:

- Installation of the Monitoring equipment in a suitable location
- Installation of cable ducting, maintaining the IP rating of the WPD package substations
- Installation of transducer cabling between the LV feeder pillar and monitoring equipment
- Installation of current transducers
- Installation of voltage transducers
- Commissioning monitors
- Commissioning the GPRS communications
- Affixing a notice in the substation, providing guidance for staff unfamiliar with the project.

Figure 8 - Example equipment installed in Meadows Crescent East and Lindbridge road distribution substations

4.3 Phase 3

The intention of the project was to maximise the learning, monitoring different characteristics at each site, changing the monitoring equipment characteristics. Each meter was configured to record a combination of Voltage, Current, Power Factor, Voltage Total Harmonic Distortion, Current Total Harmonic Distortion, and Individual Voltage Harmonics.

In addition to monitoring the individual characteristics, the waveform was analysed regularly to highlight any particular issues.

Over the duration of the project the monitoring equipment at each site has been configured for a period of time to recover data as detailed in the Figure 9.

	211377894 Frinton Road	211377895 Meadows Crescent	211377896 Ayton Close A	EMS Ayton Close B	211377897 Tunstall Crescent	211377898 Hilcot Drive	211377899 Broxtowe Lane	211377900 Lindbridge Road
Average Voltage	❍	❍	❍	❍	❍	❍	❍	❍
Max & Min Voltage				❍				
Average Current	❍	❍	❍	❍	❍	❍	❍	❍
Max & Min Current				❍				
Average Power Factor		❍			❍		❍	❍
Power (kW, kVA, kVAr)				❍				
Average Voltage THD	❍		❍		❍	❍		
Average Current THD						❍		
Individual Odd Voltage Harmonics	❍	❍	❍		❍	❍	❍	❍

Figure 9 – Configuration of network monitoring

5 The outcome of the Project

5.1 Measure and capture LV Performance on a range of distribution assets in suburban areas

The project developed and installed monitoring solutions to measure and capture the performance of the LV network on a range of distribution network assets in suburban areas. At the project inception a cost efficient LV monitoring solution did not exist. Off the shelf meters, current transducers and voltage connectors were selected where available. Nylon G clamps were manufactured as an additional voltage connector and a transconductance amplifier was designed and manufactured to facilitate the use of Rogowski coils as an additional current transducer.

The project measured and captured the LV performance including network Voltages, Current magnitudes, Power Factor, Voltage THD, Current THD and individual Voltage harmonics. Over the duration of the project, 2,192,750 data points was measured and recorded.

The EDMI Mk6E has a modest sized internal memory size meaning data had to be recovered manually for several months due to issues EDMI had configuring the monitors to recover data remotely.

Current Transducers, Voltage connectors and monitoring solutions.

- Both types of voltage connectors have proven to be very suitable for semi-permanent monitoring of LV busbar voltages and could be used for future rollouts. WPD's other projects are using these voltage connectors.
- The monitoring solutions and current transducers have shown to be adequate for the projects purpose, however it would not be appropriate to use both the monitors and current transducers as other better solutions now exist as detailed in Section 12.

5.2 How to install equipment safely with minimal or no interruption of supply

The project designed and installed all monitoring solutions safely with no interruptions of supplies to customers. This was feasible as the substations in suburban areas have suitable alternative points of supplies allowing new fuse carrier handles as a voltage connector as some substations.

The lessons learnt from this project when installing monitoring equipment into distribution substations have been included in WPD's current LV monitoring policy.

5.3 How often the network characteristics need to be monitored (for example 1min, 5min, 15min)

The project monitored a range of network characteristics over different time periods in order to find the most appropriate duration. Whilst the most granular recovery of data can provide additional information as to the operation of the distribution network at a relatively low cost, analysing very granular datasets can become disproportionately challenging.

An outcome of the project is to recommend the duration in minutes for each network characteristics that will providing significant granularity to identify issues, whilst allowing a manageable amount of data to be produced. Figure 10 lists each network characteristic monitored through this project and the recommended duration.

	Duration (minutes)		
Parameter	**Recommended**	**Shortest**	**Longest**
Voltage (Average)	10	1	30
Voltage (Maximum)	15	1	1440
Current (Average)	10	1	30
Current (Maximum)	15	1	1440
Power Factor	30	10	60
Voltage THD %	60	10	1440
Current THD %	60	10	1440
Individual Harmonics	60	10	1440

Figure 10 – Proposed network monitoring characteristics

The analysis of data from this project has shown that using the recommended settings, no significant learning would have been lost. A shorter duration settings resulted in additional data points, however no significant further learning.

5.4 Effect of installing a high density of PV panels on the LV Network

The installation of a high density of PV panels on a LV network can substantially change the characteristics of the distribution network. Figure 11 shows solar irradiance data provided by the met office plotted against monitored data. During high solar irradiance periods such as the 22nd May 2012 Figure 12 shows the feeder current as the distribution substation was only 20A due to the export from the installed micro generation. (a) During the 19th May the solar irradiance was considerably lower and the minimum feeder current was 79A. (b)

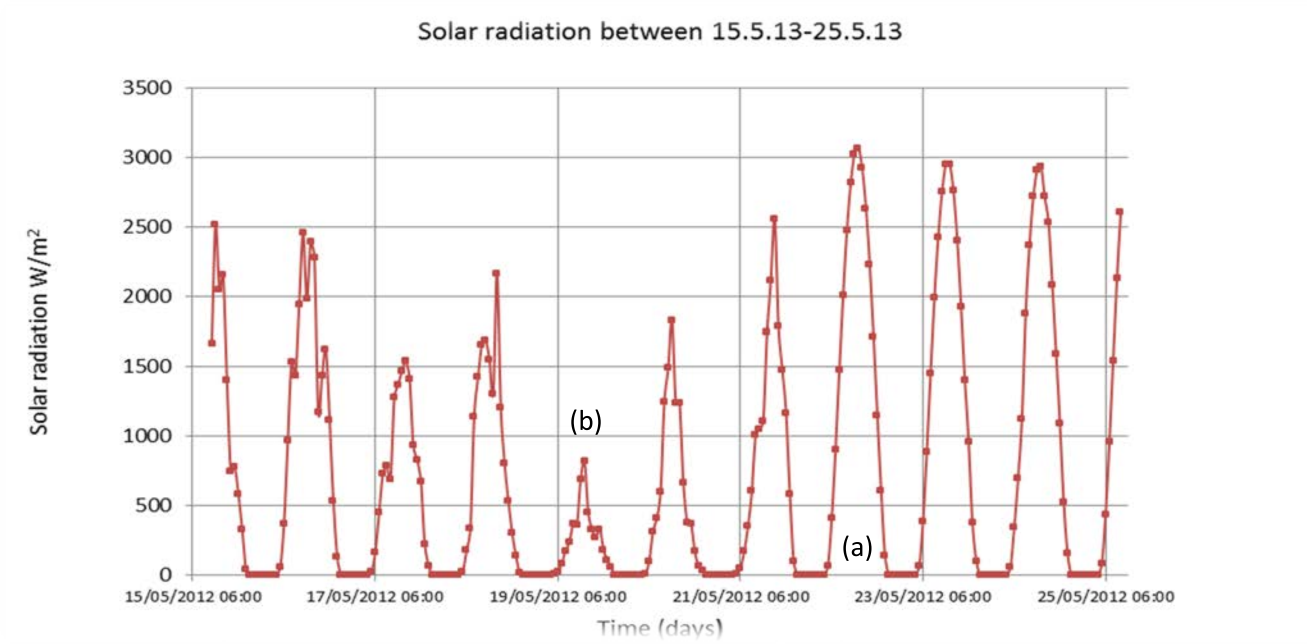


Figure – 11 Solar Radiation Measured

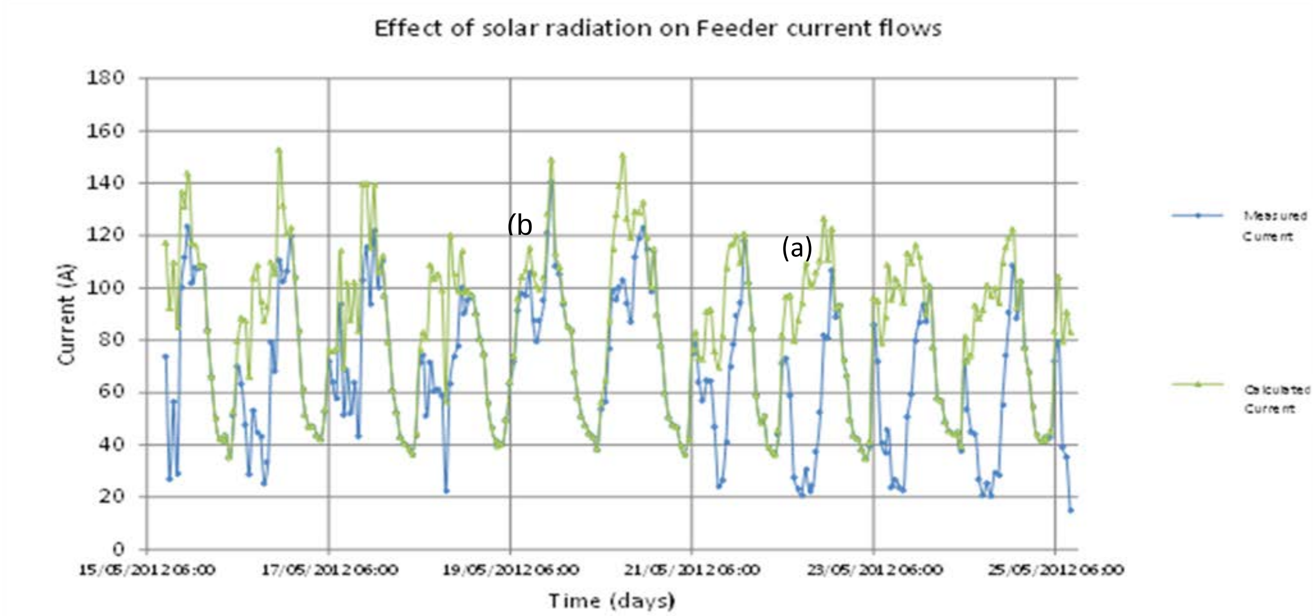


Figure – 12 Impact of solar PV on network current

The key constraint identified from the network monitoring was any voltage rise that would occur during periods of reverse power flows. The project did not record any reverse power flows across the eight monitored locations due to a level of diversity from the multiple small scale installed solar PV. The analysis shows the network would still operate within its design and statutory limits if customers installed a further 20% PV across all network locations.

The measured effects at the distribution substation of the specific network operating characteristics have been detailed below.

5.4.1 Power Flow Analysis

Current flows

The analysis of network data showed the effect of installing high density PV has a significant effect on the network power flows. The magnitude of power from the HV network, through the distribution transformer into the LV network is significantly reduced during periods of high solar irradiance. However, all sites showed throughout the trial period the flow of power was always from the HV network into the LV network. The installed solar PV never created conditions of reverse power flow with power flowing from the LV feeder through the LV bars or from the LV network into the HV network. The absence of reverse power flows is due to the higher than assumed daytime loads across the trial locations and diversity between the installed PV Panels.

The data shows that even during the longest summer days the installed solar PV had a relatively modest effect at reducing the traditional network peak demands at breakfast (7:00am – 8:30 am) and during the evening (6pm – 8pm). Figures 11 and 12 shows the impact of solar PV on the measured current flows.

The LV network is designed to operate as a balanced network across all three phases to reduce the current flow through the neutral conductor. The data analysis shows the network can operate with substantial levels of imbalance. Due to the random distribution of solar PV, during high irradiance periods this reduces the system imbalance on some feeders and increases the system imbalance at other feeders. Although the level of imbalance measured at the LV network currents is higher than the expected, it is not a network factor limiting the connection of dense PV. Figure 13 shows the level of current imbalance for a week in May 2012. The level of imbalance on the network will cause current to flow through the neutral conductor. This could have a greater impact on the networks thermal limit when incorporating other LCTs such as single phase heat pumps and electric vehicles. This analysis was outside of the scope of this project.

The impact of Solar PV changing power flows, impacting on network losses will complement other on-going research being conducted by Imperial University.

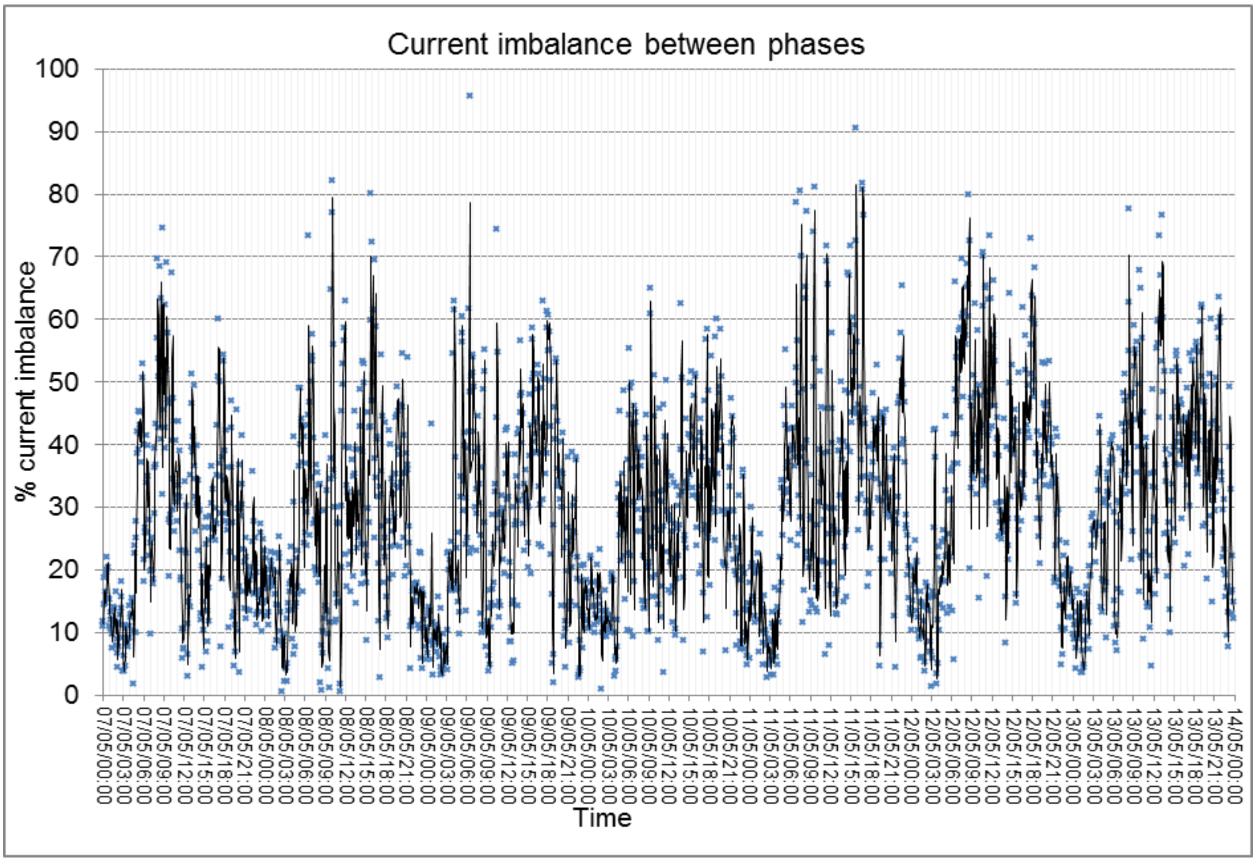


Figure 13 – LV current imbalance

The percentage of current imbalance between phases has been plotted; a trend line has been included to show how the level of imbalance varies over a week.

Voltage profile

The absence of reverse power flows for the duration of the trial means the voltage profile is still largely dominated by the tap changers on primary transformers as shown in figure 14 and not by voltage rise from the embedded solar PV.

The LV feeder voltage profile can be modelled from the measured substation data to show the voltage drop across the network is reduced during high irradiance periods however the peak voltage drops across the LV network still occur during periods of maximum demand with little or no contribution from solar PV.

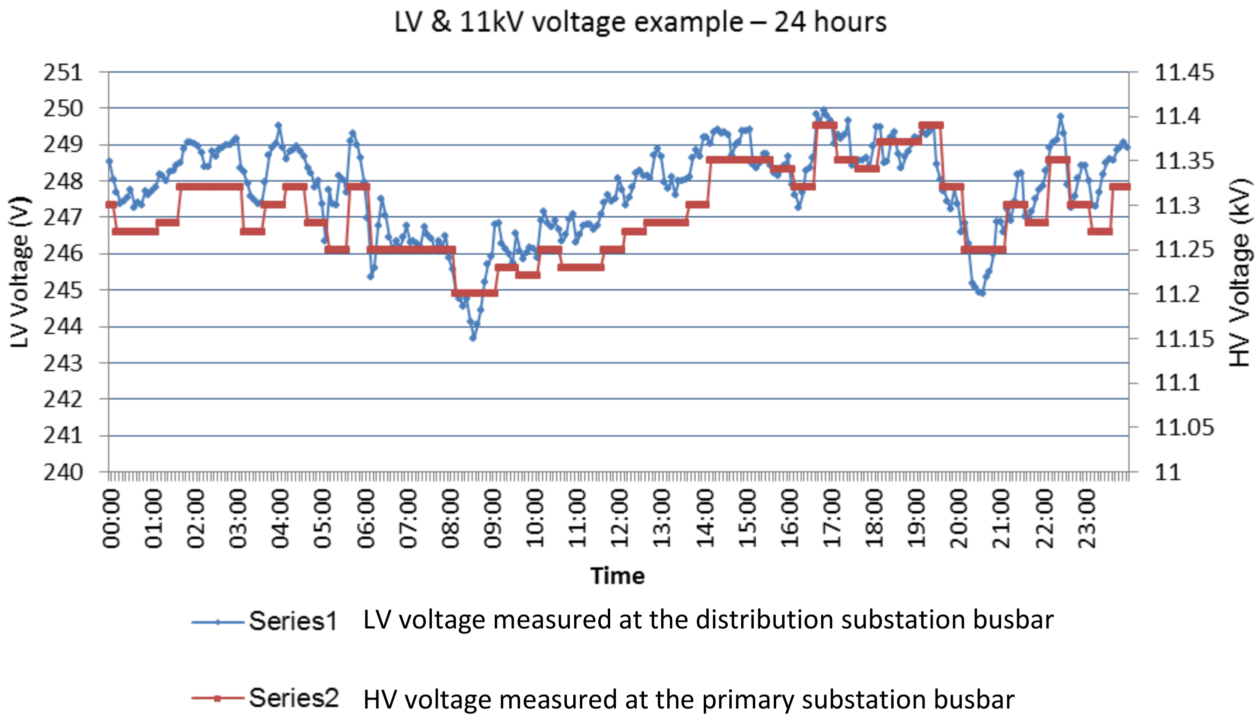


Figure 14 – LV and 11kV feeder voltage profile

Power Factor

One effect of installing significant amounts of PV generation operating at unity power factor onto a network where connected domestic loads operating at a lagging power factor is a worsening power factor at the substation during periods where the PV generation supports the majority of the network demand. The required reactive power demands are imported through the distribution network resulting in a poor power factor. Data analysed from other sites shows the issue is greatest when the measured demand is low.

The measured data shows the three phase power factor reducing to 0.2 during periods of high solar irradiance as shown in figure 15. The same substation had an average power factor of 0.98 for Q1 2013.

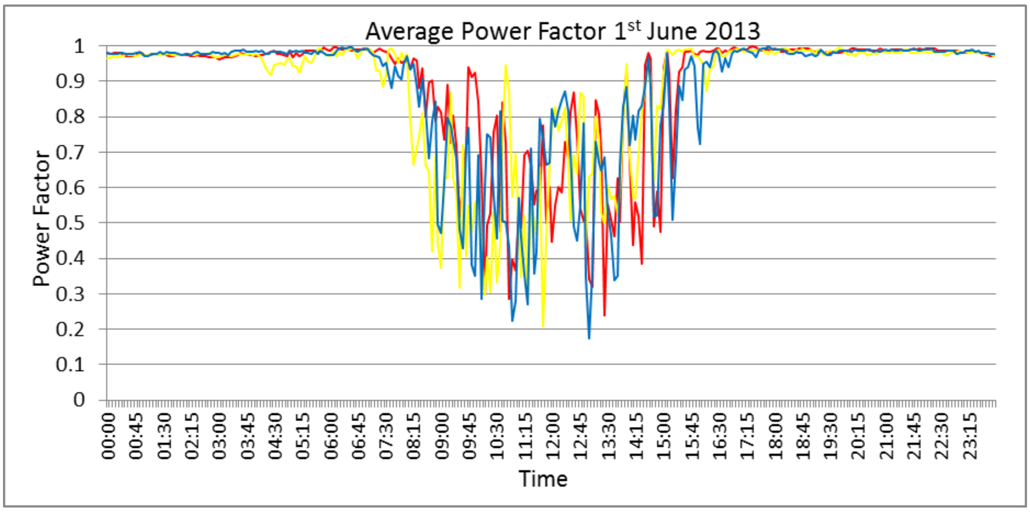


Figure 15 – LV power factor

5.4.2 Power Quality

Waveform Analysis

The analysis of current and voltage waveforms shows the voltage remains relatively sinusoidal at all times. The sinusoidal current waveform is distorted due to harmonics. The lower order odd harmonics are a significant % of the fundamental current at times of minimum demand. The effects of significant lower order odd harmonics are significant distortion to the current waveform resulting in a triangle waveform at the distribution substation. The results shown below were verified by two separate monitors using both split core current transformers and Rogowski coils to rule out any measurement errors.

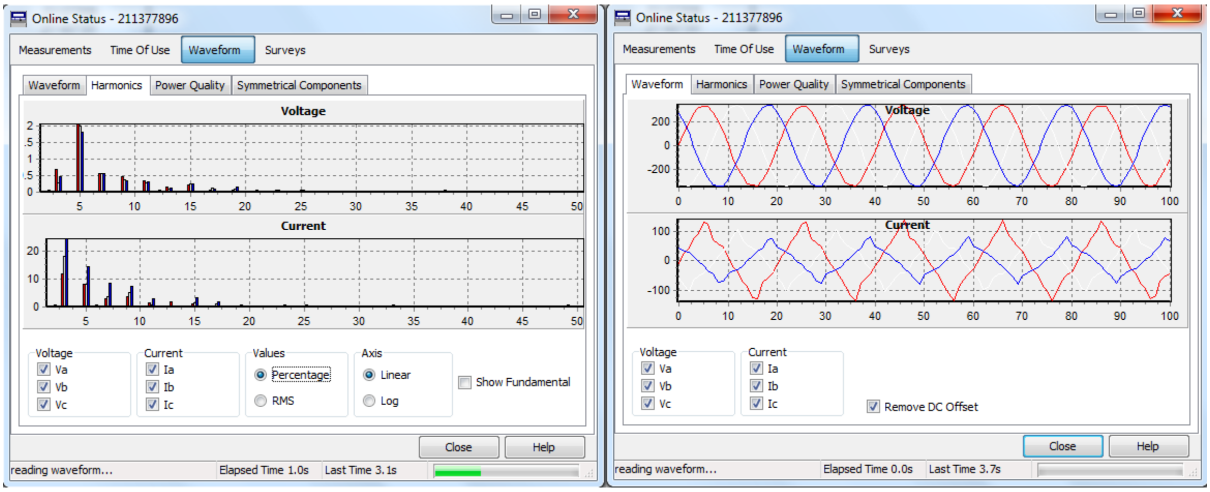


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Figure -16 Effect of harmonics on the LV current and voltage wave forms

Current THD

The measured current THD was higher during periods where the fundamental current imported from the HV network is reduced, i.e. when the installed solar PV is reducing the fundamental current being imported from the HV network. The results in Figure 16 are due a reduction in the fundamental current rather than excessively high current harmonics. Existing guidelines do not require the Distribution Network Operator to maintain levels of current harmonics at the distribution substation. Whilst PV has a substantial impact on the current waveform it is not a limiting factor to further PV installations. Distribution Network Operators do have an Engineering Recommendation G5/4-1 for planning and compatibility levels which is applied to Electricity Networks.

Voltage THD & individual harmonics

The voltage THD remained within the prescribed limits at all sites with little evidence from the network monitoring that the solar PV was have a detrimental effect on the voltage harmonics in this sub urban network environment. This was believed to be due to the fault levels associated with urban networks. The effect of dense PV on power quality may differ in very rural networks where the fault level is much lower.

The analysis of the measured data showed a greater presence of lower order odd voltage harmonics (5^{th}); however the embedded generation appears to have little impact on the power quality in these sub urban networks. Figure 17 shows a sample of measured voltage harmonics (plotted in Volts) during a high solar irradiance period.

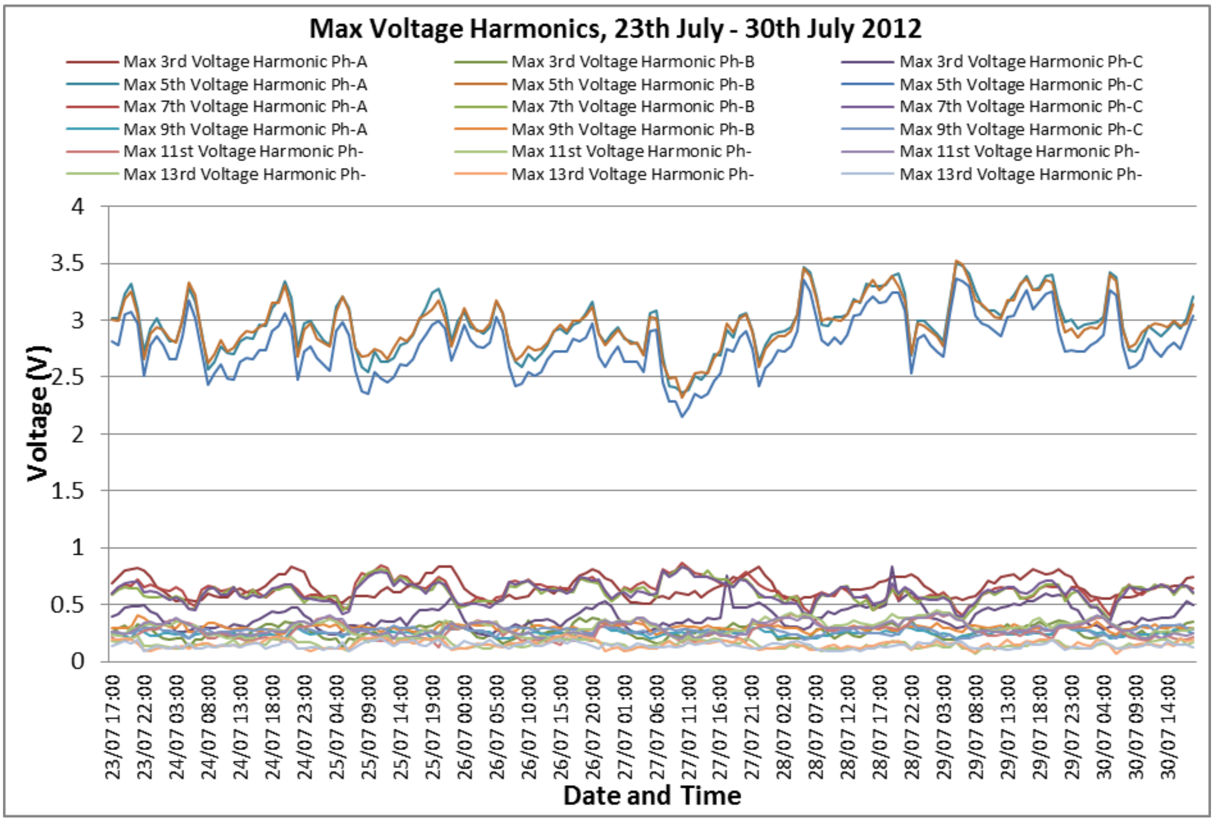

Figure 17 – 3rd- 13th maximum voltage harmonics

5.5 How we can interrogate the large amounts of data

The project recovered data as comma separated variables (.csv) files remotely from the installed meters, analysing and plotting the data within Microsoft Excel. All data has been displayed graphically and analysed manually to identify the network limiting factors.

This has been an adequate solution for a finite duration project with less than 10 distribution substations. The approach taken has highlighted that for anything greater than a small short term project there is a requirement for either purpose build data repositories and graphical displays or monitors reporting by exception. Neither of these was available at the inception of the project.

This is currently under evaluation for a further project study.

6 Performance compared to the original Project aims, objectives and success criteria

The project installed equipment to monitor the profile of eight selected substations across three areas where PV panels were installed. It reviewed and selected a range of sensors/transducers that were integrated with network monitors. The project measured and captured voltage, current, harmonic (Current THD, Voltage THD, Individual voltage harmonics), real and reactive power data on a range of distribution assets in Aspley, Broxtowe and Meadows areas. It installed all equipment safely, with no interruption of supply. The project varied the duration of monitoring network characteristics and has recommended the typical and range of durations for network measurements.

Interrogated large amounts of data generated over an 18 month period to highlight significant network issues created by the installation of PV panels and recommended possible alternatives for future investigation.

Summaries the key effect is of installing large numbers of PV panels on the LV network and the limiting factors.

Learning

Learning from this project has been shared with other DNOs at different stages throughout the project and the project was presented at both LCN Fund conferences,

This and other complementary projects was presented on during a LV network monitoring event hosted at Leicester space station, attended by over 100 people including all UK DNOs. The full close down report detailing the key knowledge generated. The data from this project is available to other UK DNOs for their own analysis and comparison.

The project change request was needed, allowing sufficient time to successfully complete all the original project aims, objectives and success criteria.

Activity	Target	Updated	Actual	Comments
Select and test a range of sensors	April 2011	-	April 2011	Conducted in line with the project plan
Install and configure substation monitoring equipment	May 2011	May 2012	Feb 2012	Completed in line with the amended project plan
Determine the frequency of monitoring each characteristic	July 2011	July 2012	July 2012	Completed in line with the amended project plan
Analysis 12 months data,	Sept 2012	Sept 2013	May 2013	16 months of data has been analysed
Write a close out report	Nov 2012	Nov 2013	Jan 2014	Published Jan 2014 as per the governance document

7 Required modifications to the planned approach during the course of the project

There were three main areas where the approach taken differed from the original plan. Whilst the project has completed all the intended aims and objectives, these modifications to the planned approach introduced significant delays.

7.1 Delays in equipment delivery (CR001)

The project selected and procured Mk6E meters from EDMI after a demonstration unit was tested within a laboratory environment. After ordering the meters, the delivery of the EDMI meters took significantly longer than forecasted.

- The quoted delivery time was 8 weeks & shipping,
- The meters took 23 weeks & shipping to be built, configured and tested.

The project intended to select a cost effective meter off the shelf as used in other applications to de risk the delivery. The meters selected for the PV impact on suburban networks project were selected due to their wide range of functionality making them suitable for a wide range of network monitoring applications capturing voltage, current, harmonic (Current THD, Voltage THD, Individual voltage harmonics), real and reactive power characteristics

7.2 Technical support & data recover (CR001)

The technical support including data recovery for the project was originally from E.ON Smart Metering. Following the WPD purchase of Central Networks, the E.ON Smart Metering business no longer wanted to support the project. Several companies were approached to recover data. The costs were significant due to the small number of meters and high start-up costs associated with calibration and testing. Western Power Distribution Smart Metering configured a system to recover data remotely from the meters, reducing the requirement for support from an external body.

7.3 Meter configuration (CR001)

The meters selected have turned to be very complex, with a limited processor power and memory. This caused issues setting them up and further problems recovering data. Within EDMI, there is no significant expertise within the UK for detailed configuring of the meters. Even at the point of receiving and installing the monitoring equipment, significant further configuration changes were required over the next 12 months with support from EDMI's manufacturing base in Singapore.

Manual downloads of data from May 2012 as a workaround to avoid the loss of data and further delays as remote recovery of data was not responding. The issue was due to a missing section of code, not included in the original factory set up. Due to the complexity of the meters, this took 4 months of debugging and a site visit from a technical specialist from Malaysia before remote recovery of data could be initiated.

8 Significant variance in expected costs and benefits

8.1 Project Costs

Description	Forecast	Actual	Variation (%)
WPD Project Management	£20,000	£ 20,588.65	+2.94%
WPD Labour	£46,000	£ 26,356.30	-42.7%
Equipment	£34,000	£ 30,253.55	-11.02%
TOTAL	**£100,000**	**£ 77,198.50**	

8.1.1 WPD Project Management

This element of work is associated with the running and managing of the project. Due to a slightly greater level of the work being completed internally the actual cost is 3% greater than the planned cost.

8.1.2 WPD Labour

This element of the work included pre installation site visits, installation of network monitoring, recovery and analysis of the data. The cost associated with the installation was substantially lower than forecasted due to the internal delivery by WPD Nottingham depot. The project was also completed without any network outages, reducing the amount of resource required at the installation phase. The project did not require any of the contingency funds.

8.1.3 Equipment

This element of the project included the purchasing of meters, Current Transducers, Voltage connections and all connectors. The contingency associated with the network monitoring equipment was not required, leading to a 10% variation in the final costs.

8.1.4 Expected Benefits

The project met all of the expected benefits as detailed throughout the report.

	Expected Benefits	Benefits Gained	
1	An assessment of the impact of PV panels on the LV network and which network factors could limit the further installation of more PV panels.	The project has assessed that a further 20% PV connections can be made in multiple small scale installations due to diversity	✓
2	An assessment of the effectiveness of the range of sensors selected	An assessment has been conducted, those deemed suitable have been used in further network monitoring projects.	✓
3	The feasibility of installing monitoring equipment	The project has concluded that better kit for LV network monitoring is now available, LV Sensors project	✓
4	An assessment of any incurred CML's or CI's and any safety concerns	No Customer Interruptions or Customer Minutes Lost were required. All network monitoring was installed with no safety concerns.	✓
5	An outline of the key constraints of installing high levels of PV panels in Suburban areas (Voltage, Current, Harmonics, 2 – 50th, real and reactive power flows)	The future network constraints were identified though this project, no major issues were recorded. – See section 8.	✓
6	A definition of an optimal interval of data capture and recovery	See Figure 10, section 8.	✓
7	An assessment of how many panels can be installed before network reinforcement is required.	A further 20% PV installations could now be made from the assessment of the diversity and the modifications to WPDs planning tools.	✓

9 Lessons learnt for future Projects

The project has produced significant learning, influencing many of our current innovation portfolio projects.

9.1 Developing network monitoring solutions using off the shelf components

At the time of project inception, an appropriate LV distribution substation monitoring solution for mass roll out didn't exist. The project aimed to use off the shelf components to demonstrate how LV networks could be monitored with more cost effective solutions. Whilst the project successfully installed and monitored network feeders, the solution was not user friendly and would not be ideally suited for a mass roll out. In the time since the problem was highlighted, the market has responded creating solutions which are easier, quicker to install and are more user friendly. Please see the LV Network Sensors project for further information.

Product Engineering

- When the original project was scoped, the LV monitoring supplier market was very immature and off-the-shelf solutions were not suitable for this application.
- A cost effective monitoring solution didn't exist within the market leading us to innovate and create one.
- The solution created was functional, however not ideal.
- When the market place caught up, they quickly overtook the solution installed.

Despite this learning, we recorded the data needed and were able to meet all of the expected project benefits.

9.2 Where to install monitoring in a LV substation

Different substation designs and equipment have varied over the last 60 years; however most substations don't have an ideal location for easily installing substation monitoring equipment.

The most appropriate option is to select substation monitoring equipment that is suitably sized so it can be installed inside the LV feeder pillar of distribution substation. This allows for a quick and safe installation within most substations, especially the most modern LV feeder pillars. The latest WPD specification for substation designs includes accessible voltage monitoring points and high accuracy current transducers for monitoring purpose.

9.3 Relying on GPRS

GPRS is a low capital cost communications solution, however even when installed in high signal strength areas, GPRS is unreliable and unpredictable causing regular issues when trying to recover data or change settings remotely.

9.4 Ensure companies have sufficient technical expertise within the UK

The EDMI monitoring solution provided was a particularly comprehensive meter suitable for a range of applications. However the meter was very complicated, and was not supplied with a detailed user guides to solve issues with the meter.

As the meter was specialist there was very little expertise when configuring and debugging this product, thereby increasing delays when recording and recovering information. In the future further emphasis should be placed on vendors being able to demonstrate they can provide UK support on site if needed.

9.5 Data analysis

The data analysis solution selected for this project allowed us to manipulate large amounts of data generated by the eight monitors for more than an 18 month period to determine impact of PV panels on suburban networks. However, the solution selected was labour intensive.

For permanent monitoring locations with a larger numbers of meters would benefit from custom software or meters capable of reporting by exception. Further research is to be carried out “Big Data”, this is beyond the scope of this project.

10 Planned implementation

10.1 Policies updated for the installation of multiple LV PV systems

This project has led to a better understanding in the operation of LV distribution networks after dense connection of PV panels into LV suburban distribution networks. The early learning from this project and the learning from LV Network templates and Early learning projects have been used to update WPD’s policies and design tools. WPD’s design tools have profiles for solar PV when modelling future PV connections. The LV design tool also applies a 20% diversity to the output of multiple PV installations, taking learning from lessons learnt from innovation projects.

10.2 Installations

LV monitoring will continue to be rolled out to substations which are deemed to be of strategic importance or have the potential to operate load patterns which fall outside of a template approach. LV monitoring technologies will be deployed using best practise from the LV Sensors report.

Voltage and current sensors avoiding Customer Interruptions and Customer Minutes Lost are not part of our Business As Usual for all new projects.

10.3 Further Research and Development work

If the installation of long term, large scale LV substation monitoring is required, then further development work will be required to find a software system that can handle large amounts of complex data with less manual intervention. A future “Big Data” project is being developed.

11 Facilitate Replication

11.1 Knowledge Required

The knowledge required to better understand the impact of solar PV on suburban distribution operation includes:

- The impact of solar PV on suburban networks.
- When combined with learning from other projects it will provide a more holistic overview to the impact of solar PV on all types of LV network.
- help network monitoring manufacturers to understand which network characteristics need to be monitored for in-depth projects analysis
- help network monitoring manufacturers to understand which network characteristics need to be monitored as part of the normal everyday operation.

Other DNOs are welcome to request copies of papers and policies, these will be sent to them from the WPD staff responsible for engaging with the buddy DNO.

11.2 Products/Services Required

As well as general project management and installation resources at the disposal of a distribution network operation, there are a number of other products and services that have been identified in this project as being prerequisites requirements before the network operation can be monitored.

11.3 Project IPR

This project integrated a number of existing products and services as outlined in section 7 to enable successful delivery against the project criteria. Whilst there was no foreground IPR generated, there have been a number of learning outcomes developed and disseminated across the wider business and other projects, as described in Sections 12 and 13.

The transconductance amplifier built for this project by Haysys Ltd has been designed using off the shelf components using good engineering knowledge, this has not generated any new IPR.

The nylon G clamps manufactured by Invirotech Ltd have been based on an existing WPD standard for nylon G Clamps; this has not generated any new IPR.

12 Points of Contact

Further details on replicating the project can be made available from the following point of contact:

Future Networks Team
Western Power Distribution
Pegasus Business Park
East Midlands Airport
Castle Donington
Derbyshire

DE74 2TU
wpdinnovation@westernpower.co.uk

Appendices

Project Proforma

https://www.westernpowerinnovation.co.uk/Document-library/2016/WEST2219_TIER1_PV-Close-out-Final.aspx

Project change

CNT1001- -Tier 1 Proforma - PV In Sub

Internal Change request

CNT1001 - Change Mandate PV In Suburl

Broxtowe and Aspley - LV feeders

D) Broxtowe and Aspley - LV feeders.jı

Meadows – LV feeders

E) Meadows LV Feeders.jpg