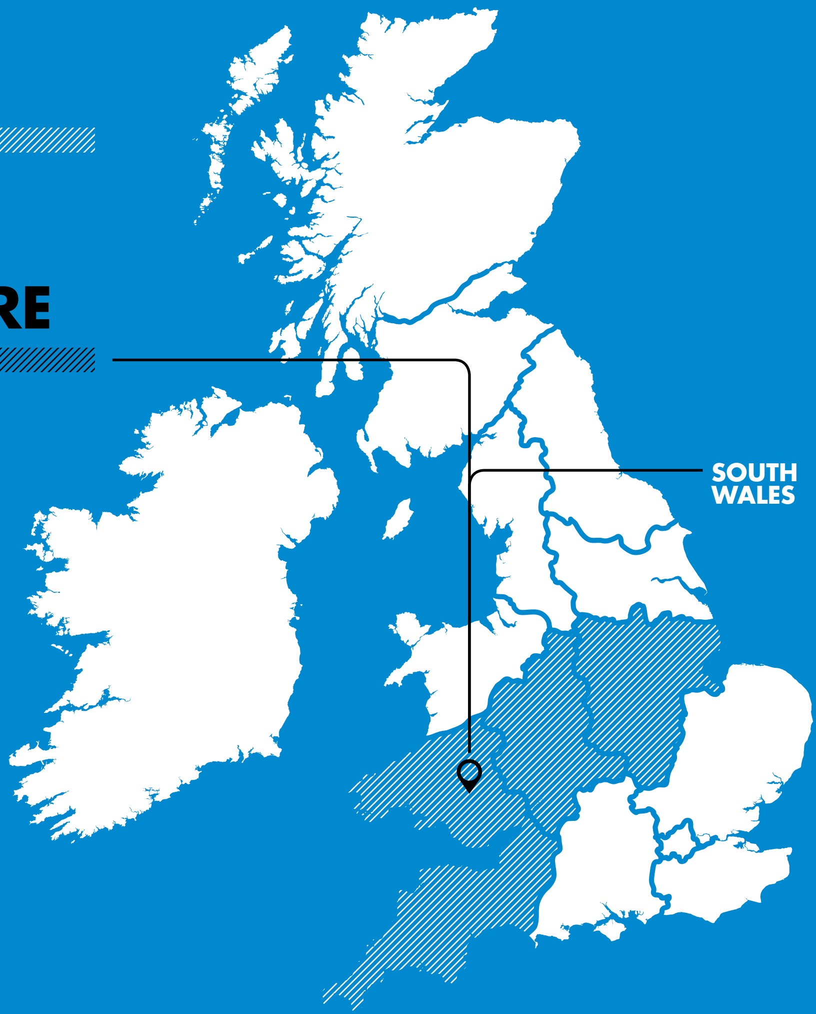
WESTERN POWER DISTRIBUTION

NETWORK TEMPLATES

LV NETWORK TEMPLATES FOR A LOW-CARBON FUTURE

PROJECT PROGRESS REPORT
REPORTING PERIOD: DECEMBER 2012 TO MAY 2013



LCN Fund Low Carbon Networks
Llywodraeth Cymru Welsh Government
npower
UNIVERSITY OF BATH
GE imagination at work
passivenergy

DOCUMENT CONTROL

Prepared by	Mark Dale	Title / role: Innovation & Low Carbon Engineer
Reviewed by	Roger Hey	Title / role: Future Networks Manager
Approved (WPD)	Nigel Turvey	Title / role: Design & Development Manager

REVISION HISTORY

Date	Issue	Status	Author
06 May 2013	1.0	Initial Draft prepared	Mark Dale
20 May 2013	1.1	Incorporating comments from internal review	Mark Dale
08 June 2013	1.2	Final version for release	Mark Dale

CONTENTS

1 EXECUTIVE SUMMARY

1.1 Project Background

The LV Network Templates LCNF Tier 2 project is designed to provide data on the low voltage (LV) distribution network.

Generally in the UK, the final stage of monitoring is on the outgoing 11kV feeders in a primary substation, where current and voltage are measured. The real-time loading of the distribution substations, located along the 11kV feeders, is currently not recorded or visible without being obtained by a site visit. Additionally during a site visit a read will be taken of the maximum demand indicator, which has variable and poor accuracy across the loading range.

This project provides remote monitoring of current and voltage at over 800 distribution substations. In addition, voltage monitors have been installed in approx. 3,500 premises, at the end of low voltage feeders, to allow voltage profiles to be developed. The original submission stated the monitoring of 1,036 substation and 7,000 voltage monitors, but a combination of telecommunication issues and low customer take up has resulted in the lower number of monitored sites. Ofgem and the wider DNO community have been informed of this following a number of dissemination events and a letter of support from The University of Bath accepting that the change would not adversely affect the accuracy of the findings or credibility of the Project.

The findings and derived templates of this Project are important due to the forecasted increase in load and low carbon technologies being connected to the LV network e.g. photo-voltaic generation, heat pumps and electric vehicles.

Having a better understanding of the time of day loading and voltage "headroom" currently available on different types of LV network with different types of customer behaviour is crucial in effectively planning the network of the future.

1.2 Project Progress Highlights

During this final reporting period (Dec 2012 to May 2013) both monitored substation and voltage data has continued to be transferred to the University of Bath for analysis. Some of the key project highlights during this period are identified below:

Network Templates: In the past 6 months the University of Bath has focused on the analysis of data to identify and further refine groupings of data (Clusters) in order to develop representative Network Templates

Classification Tool: Work has also continued on the creation of a classification tool so that other DNO's can utilise and input their existing network data to allocate their substations to an LV Network Template

Customer Engagement Workshop Ofgem: In April 2013, a report on the learning from customer engagement was presented to Ofgem, highlighting the lessons learnt. The report and its findings are included in appendix 3

Successful Delivery Reward Criteria (SDCR): The two SDCR reports have been submitted by The University of Bath, to Ofgem:

- The use of proxy PV feed in tariff (FiT) meters to reflect local area generation
- Stresses on the LV Network caused by Low carbon technologies

These two reports and their findings are included in appendix 1 and 2.

Dissemination Workshop: Both the initial templates and classification tool have been disseminated on 14th May 2013 to Ofgem and representatives from each DNO. The purpose of this workshop was to explain how the templates were developed, highlight how they can be applied in business as usual network planning and to provide the opportunity for us to validate the templates on other DNOs monitored networks. It is our intention to include each DNOs feedback of the classification tool as well the suitable application of templates on their network within the final Templates Report due on 1st July 2013. If the feedback and analysis cannot be incorporated in time before this deadline then this feedback will form part of the close-down report due on the 30th of October.

To date all project milestones have been achieved on time. A more detailed breakdown of some of the key activities undertaken in this period is provided below:

1.3 Learning Highlights

The capturing and sharing of learning is being managed and undertaken by leading power engineers, statisticians and psychologists from the University of Bath. Resulting in a number of both on-going and new activities having taken place within this period that targeted internal and external stakeholders. These activities have been summarised below alongside an overview of some of the key learning points during this reporting period:

Interviews (New): During this period, the University of Bath have continued to interview key personnel from within the project around topics such as “customer engagement”. The insight from this was fed into a report that was presented to Ofgem in April 2013

Monthly Project Meetings (On-going): Key personnel across WPD’s business continue to attend the monthly project meetings, to enable them to share what has been learnt with their colleagues. These meetings have provided a great forum for getting feedback from the wider WPD organisation; enabling the Project team to address specific questions that have been raised from our engineers to call centre employees

Initial embedding of learning into business as usual workshop (New): An initial workshop has been undertaken that looks to identify and embed the learning to-date into business as usual. As a result of this workshop the Technical Policy Manager has already identified and shared with the wider DNO community some initial ideas, at the DNO event on the 14th May 2013.

DNO LV Network Template Event (New): On the 14th May 2013, WPD and the University of Bath hosted a LV network template workshop. This workshop had both representatives from Ofgem and the other DNOs present. The purpose of this workshop was to share and incorporate the feedback from our industry peers by looking at the template development method (including the classification tool). This workshop has given other DNOs the opportunity of providing the University of Bath with data in order to help validate wider GB application. Feedback from this event is attached as Appendix 4.

1.4 Key learning points during this reporting period

- Proxy PV FiT meters can be used within a high level postcode area, to successfully predict the output of other domestic PV Installations
- The actual generation output, of a domestic PV installation, is significantly lower than the installed capacity
- Domestic PV installations appear to have no visible impact on the voltage profile of monitored substations
- Air Source Heat Pump connections appear to have an impact upon the voltage profile
- The majority of the voltage profiles are at the higher end of the statutory limit. This suggests it may be viable to reduce the network voltage levels. It may also be worth considering lowering the UK statutory limits to +/- 10%, (from +10% -6%) to align with the current EU standard. If adopted this could result in substantial benefits for both customers and Network Operators

A detailed learning and dissemination report will form part of the final close down report due on the 30th of October 2013.

2 PROJECT MANAGER’S REPORT

In the final six months of the project, the collection of data and its analysis has been the main delivery focus. For this reason as part of the Project Managers report, attention will be given to the communication infrastructure, data capture and its statistical analysis.

2.1 Communication Infrastructure

The project is currently monitoring and retrieving data from 800 substations and over 3,500 monitored feeder ends. WPD’s Surf Telecoms have continued to maintain the telecoms infrastructure. In the past 6 months two issues have arisen that are either resolved or in the process of being resolved:

One of the communication carriers being trialled is based on GE STIP power line carrier (PLC) technology. This carrier technology has recently caused some network flooding problems and as a result is currently not supplying any feeder end data. This issue is only affecting 1.25% of the total number of monitored sites. The University of Bath have re-assured us that this percentage will not have an adverse impact on the projects output. This issue is currently in the process of being resolved by Surf Telecoms and GE.

One of the antenna types [b3]within the project has been identified as having performance issue leading to poor device connectivity. GE provided on-going support and after further investigation, agreed to replace all antennas at no cost to the project or customers. Data is now successfully being transmitted from the re-fitted antennas

2.2 Data Capture
Substation, PV and voltage monitor data continue to be captured and transferred on a weekly basis throughout the period; supplemented with fixed Arbed data from the Welsh Assembly Government (WAG).

2.2.1 Substation Monitoring
All substation monitors were installed prior to this reporting period. As previously reported to Ofgem the number of substation monitors actually providing data is in excess of 800.

2.2.2 Feeder End Monitoring
As reported in the previous 6 monthly report, due to poor customer uptake, a plug in type voltage monitor was developed in an attempt to increase numbers. This proved very successful with all of 250 developed being installed. The only concern with this equipment is that the customer has control over whether or not it remains plugged in. The final number of phase ends being monitored is in excess of 3,600.

2.2.3 PV Monitoring
WPD partnered with energy supplier npower in this project to identify customers in the project area who have installed small scale embedded generation (SSEG) under the feed-in-tariff (FIT) arrangement (following confidentiality and data privacy protocols). WPD has worked with npower and received nearly 120 consents to install WPD FiT monitors, for customers with photo-voltaic (PV) generators in the project area (although only some of these are associated with substations monitored by the project). Of these consents 80 FiT monitors could be installed.

The data gathered from the FiT monitors was necessary to ensure that the findings of the Stresses and PV FiT Report were representative and credible. A minimum sample of 250 PV installations was required for the University of Bath to be 98% confident in the conclusions that could be drawn from it. With this in mind, enquiries were made with several PV suppliers to secure further data to supplement the npower customer FiT monitors. As a result, Passiv Systems were able to provide a full 12 months' worth of data covering 525 PV installations throughout the project area. This data included the bearing, inclination and installed capacity at domestic sites and proved invaluable in the analysis for the Proxy PV FiT meter report.

2.3 Statistical Analysis
Data analysis has been the focus during this period, resulting in the creation of preliminary templates, a working classification tool and the submission of the two reports. The delivered reports and the upcoming report will be discussed in further detail below:

- Template Creation Report (Report due on 1st July 2013)
- Stresses on the LV Network Report (Report submitted 1st May 2013, refer Appendix 1)
- PV Proxy FiT Report (Report submitted 1st May 2013, refer Appendix 2)

2.3.1 Template Creation
Clustering work has continued throughout the period which has identified 10 Templates. The report that discusses these in further detail is currently in progress and will be published on 1st July 2013.

2.3.2 Stresses on LV Network Report & PV FiT Report
The 10 Templates (clusters) mentioned above are listed below along with a description of the type of substation they represent. The analysis focused on the ability to cluster similar substations and then identify which clusters are able to absorb low carbon technology. A brief summary of each cluster is provided below. They are also included in the full report, attached as Appendix 1.

Cluster 1

Cluster 1 is largely commercial dominated with a relatively high flat demand during day time and lower demand overnight, its demand profiles for weekday and weekends are shown in figure 1.

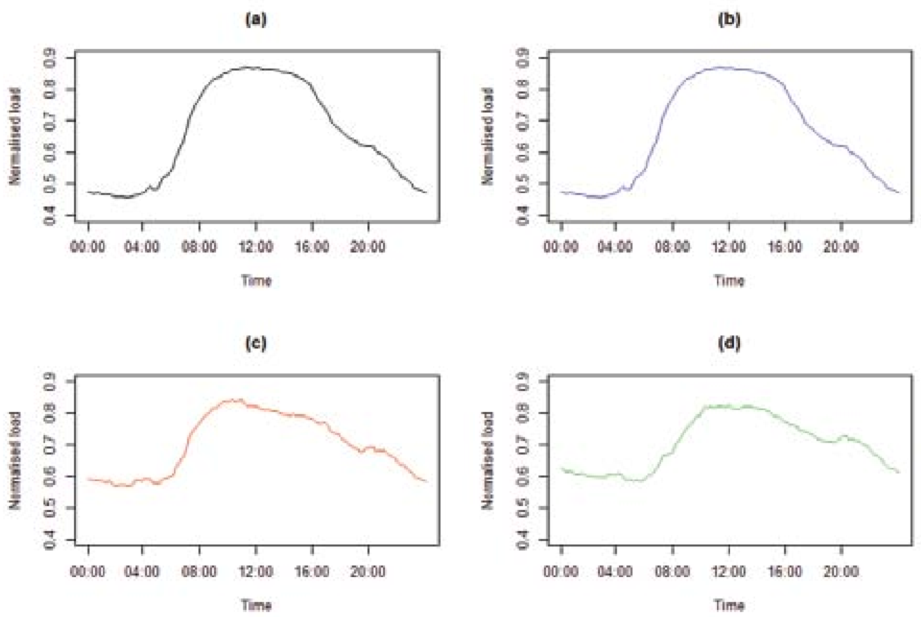


Figure 1: Substation demand profiles for cluster 1. Panels show results for (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

From the load and voltage profiles, the ability of cluster 1 substations to absorb low carbon stresses introduced by differing low carbon technologies is detailed in Table 1.

TYPE	COMMENT
Workplace / Retail EV charging	Unsuitable time of day pattern as need is coincident with prevailing peak
Overnight EV charging	Very suitable
Heat Pump	Only if linked with insulation or heat storage to permit off peak operation
PV	Suitable - complimentary to both power and voltage curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 1: Cluster 1: ability to absorb low carbon stress

Cluster 2

Cluster 2 comprises predominately of substations dominated by domestic customers, its demand profiles for weekday and weekends are shown in figure 3. The associated voltage profiles are depicted in figure 4[b4].

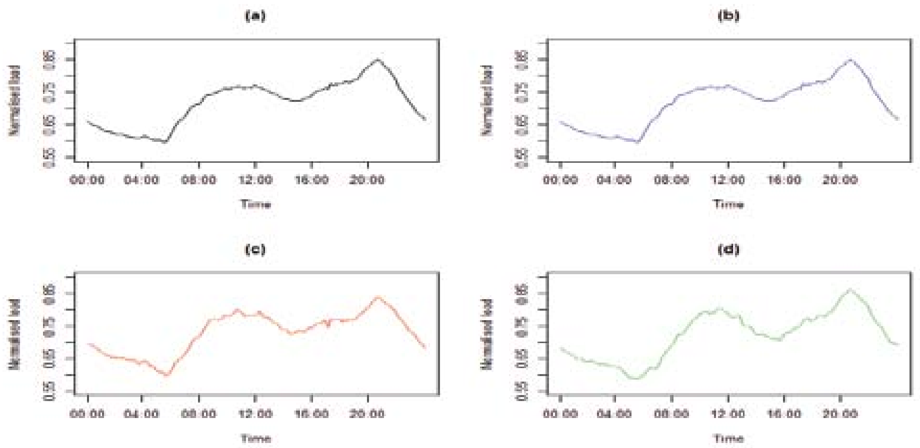


Figure 3: Substation demand profiles for cluster 2. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

From the load and voltage profiles, the ability of cluster 1 substations to absorb low carbon stresses is detailed in Table 2.

TYPE	COMMENT
Workplace / Retail EV charging	Suitable time of day pattern with limited need to curtail charge rate around 1730 peak - for workplace potentially not an issue if staff travelling then anyway, but possible minor constraint on commercial for shopping malls etc being visited at that time en-route from work.
Overnight EV charging	Suitable
Heat Pump	Suitable with insulation or heat storage with limited time of day constraint
PV	Suitable - complimentary to power and voltage curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 2: Cluster 2: ability to absorb low carbon stress

Cluster 3

The patterns observed for cluster 3 are similar to those observed in cluster 2 but here there are more commercial customers. The substation demand and voltage profiles are shown in figures 5 and 6 respectively.

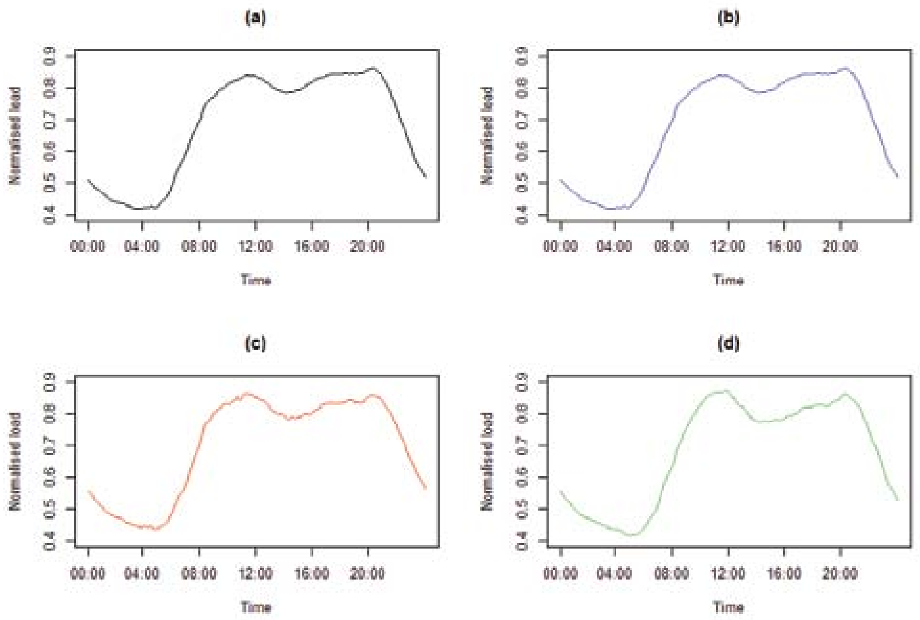


Figure 5: Substation demand profiles for cluster 3. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

From the load and voltage profiles, the ability of cluster 3 substations to absorb low carbon stresses is detailed in Table 3.

TYPE	COMMENT
Workplace / Retail EV charging	Less unsuitable time of day pattern as load curve shows limited drop off during working hours
Overnight EV charging	Suitable
Heat Pump	Suitable if linked with insulation or heat storage to permit off peak operation
PV	Suitable - complimentary to both power and voltage curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 3: Cluster 3: ability to absorb low carbon stress

Cluster 4

Cluster 4 comprises largely of domestically dominated substations. The substation demand and voltage profiles are shown in figures 7 and 8 respectively[b5].

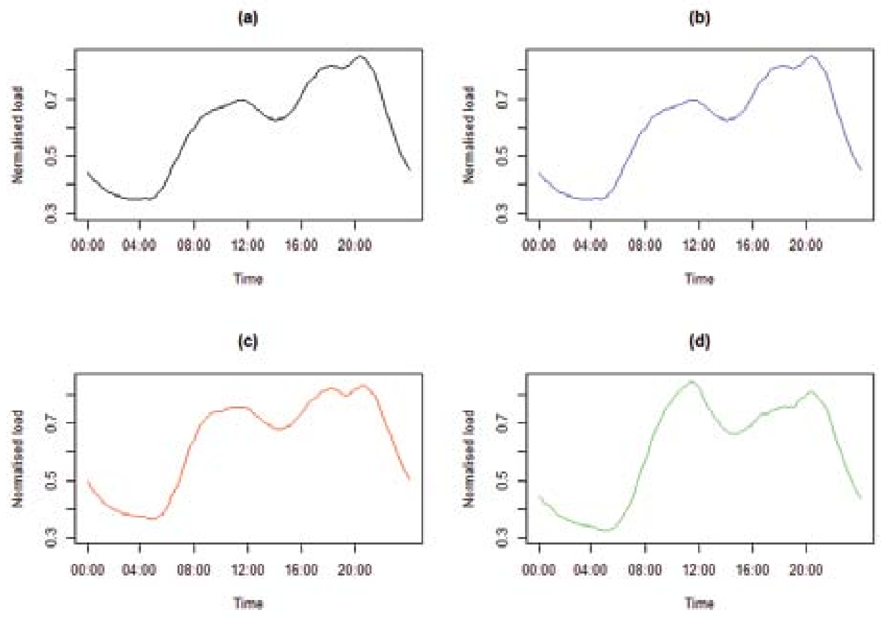


Figure 7: Substation demand profiles for cluster 4. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

From the load and voltage profiles, the ability of cluster 4 substations to absorb low carbon stresses is detailed in Table 4.

TYPE	COMMENT
Workplace / Retail EV charging	Unsuitable time of day pattern as need is coincident with prevailing peak
Overnight EV charging	Suitable
Heat Pump	Only if linked with insulation or heat storage to permit off peak operation
PV	Suitable - complimentary to both power and voltage curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 4: Cluster 4 - ability to absorb low carbon stress

Cluster 5

As with clusters 2 and 4, cluster 5 represents domestic dominated substations. The substation demand and voltage profiles are shown in figures 9 and 10 respectively[b6].

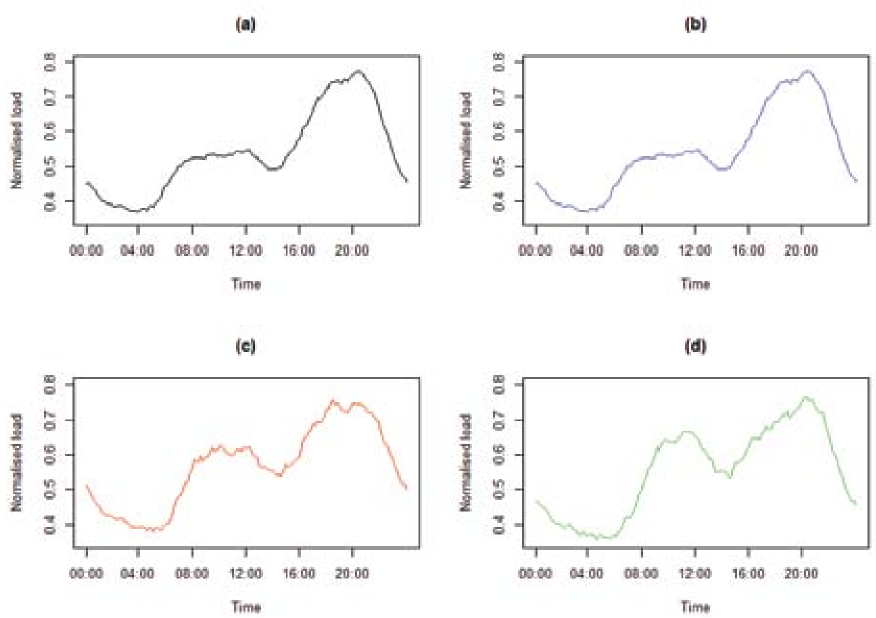


Figure 9: Substation demand profiles for cluster 5. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

From the load and voltage profiles, the ability of cluster 5 substations to absorb low carbon stresses is detailed in Table 5.

TYPE	COMMENT
Workplace / Retail EV charging	Suitable providing that work / sole operating hours are not coincident with peak
Overnight EV charging	Suitable
Heat Pump	Might require link with insulation or heat storage to permit off peak operation
PV	Less suitable - as not complimentary to power curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 5: Cluster 5: ability to absorb low carbon stress

Cluster 6

As with clusters 1 and 3, cluster 6 represents commercial dominated substations. The pattern observed for cluster 6 is very similar to cluster 1 but with a higher magnitude due to these substations serving mainly large-size industrial and commercial customers. The substation demand and voltage profiles are shown in figures 11 and 12 respectively[b7].

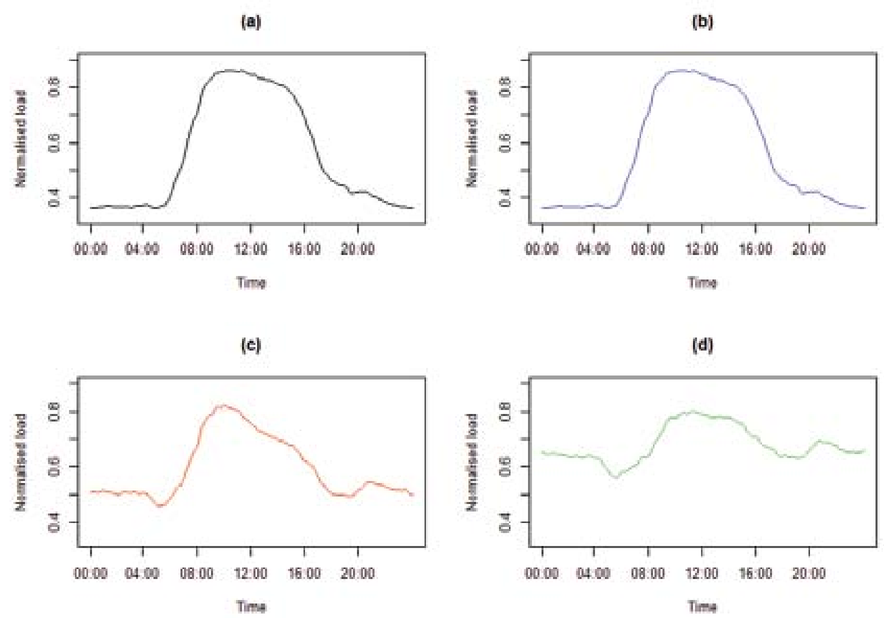


Figure 11: Substation demand profiles for cluster 6. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

From the load and voltage profiles, the ability of cluster 6 substations to absorb low carbon stresses is detailed in Table 6.

TYPE	COMMENT
Workplace / Retail EV charging	Unsuitable time of day pattern as need is coincident with prevailing peak
Overnight EV charging	Very suitable
Heat Pump	Only if linked with insulation or heat storage to permit off peak operation
PV	Suitable - complimentary to both power and voltage curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 6: Cluster 6: ability to absorb low carbon stress

Cluster 7

Cluster 7 largely contains substations of a mix of domestic customers and small commercial customers in rural areas with low demands. There are two obvious peaks, the first of which appear around 12:00 pm driven by commercial customers and the second of which happens at approximately 20:00 pm triggered by domestic customers. The substation demand and voltage profiles are shown in figures 13 and 14 respectively[b8].

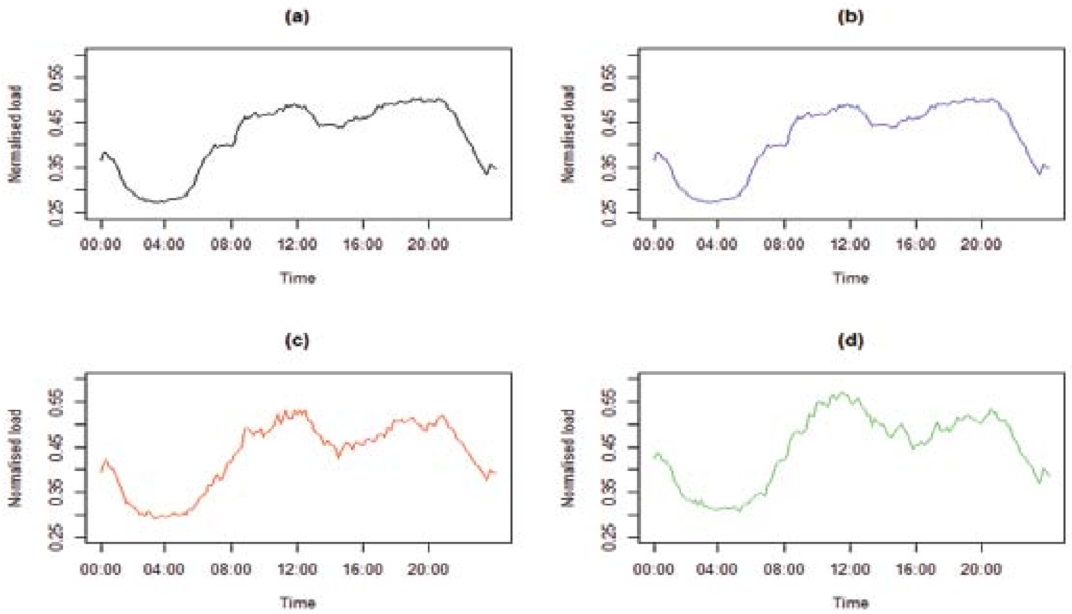


Figure 13: Substation demand profiles for cluster 7. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

From the load and voltage profiles, the ability of cluster 7 substations to absorb low carbon stresses is detailed in Table 7.

TYPE	COMMENT
Workplace / Retail EV charging	The wider variability within this cluster precludes firm conclusion though the tendency is a curve that is not complementary to workplace EV charging
Overnight EV charging	Suitable
Heat Pump	Only if linked with insulation or heat storage to permit off peak operation
PV	The wider variability within this cluster is less suitable for PV-
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 7: Cluster 7: ability to absorb low carbon stress

Cluster 8

Cluster 8 comprises of a mix of commercial and domestic customers. At the time of writing, there no remote feeder end voltage monitors were associated with this group of substations. The substation demand profiles are shown in figure 15.

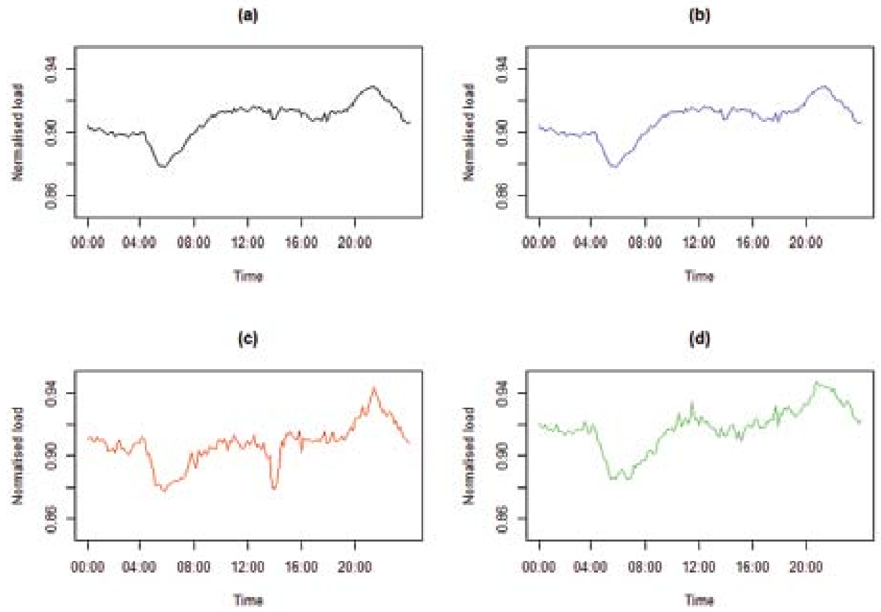


Figure 15: Substation demand profiles for cluster 8. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

From the load and voltage profiles, the ability of cluster 8 substations to absorb low carbon stresses is detailed in Table 8.

TYPE	COMMENT
Workplace / Retail EV charging	Unsuitable time of day pattern as need is coincident with prevailing peak
Overnight EV charging	Less suitable
Heat Pump	More limited capability due to lack of depth and duration of off peak demand
PV	Suitable - complimentary to power curves
CHP, AD, Hydro, Wind	More suitable than most given that generation is not naturally limited to time of day and demand curve has reduced depth and duration of off peak period

Table 8: Cluster 8: ability to absorb low carbon stress

Cluster 9

Cluster represents domestic dominated substations with significant Economy 7 customers. The substation demand and voltage profiles are shown in figures 16 and 17 respectively[b9].

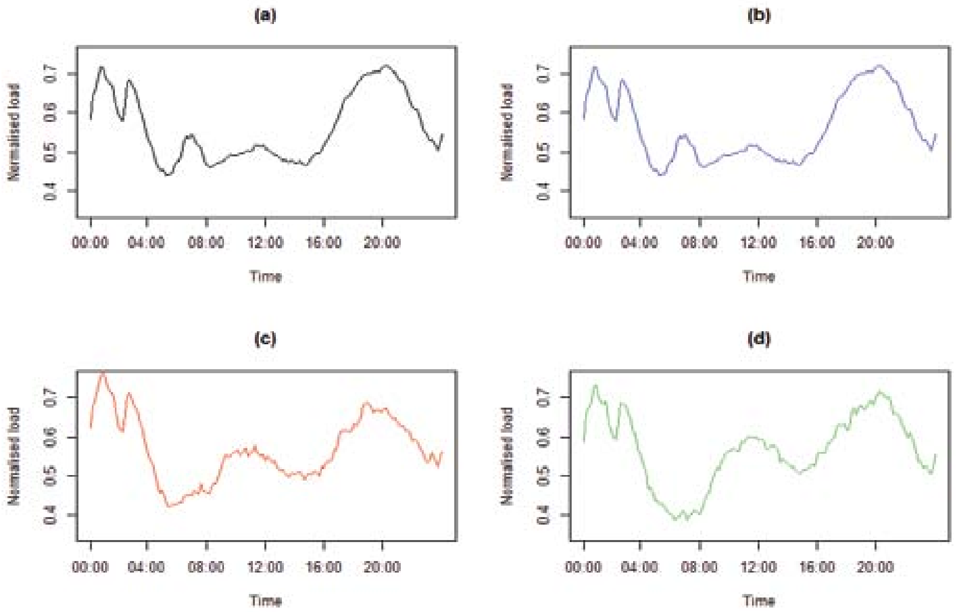


Figure 16: Substation demand profiles for cluster 9. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

From the load and voltage profiles, the ability of cluster 9 substations to absorb low carbon stresses is detailed in Table 9.

TYPE	COMMENT
Workplace / Retail EV charging	Suitable providing that work / sole operating hours are not coincident with peak
Overnight EV charging	Not suitable
Heat Pump	Requires further examination of nature of activity - might require link with insulation or heat storage to permit off peak operation
PV	Less suitable - as not complimentary to power curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 9: Cluster 9: ability to absorb low carbon stress

Cluster 10

Cluster 10 comprises exclusively of substation for motorway communication/ lighting pillars. There are no remote feeder voltage end monitors associated with these substations. The substation demand profiles are shown in figure 18.

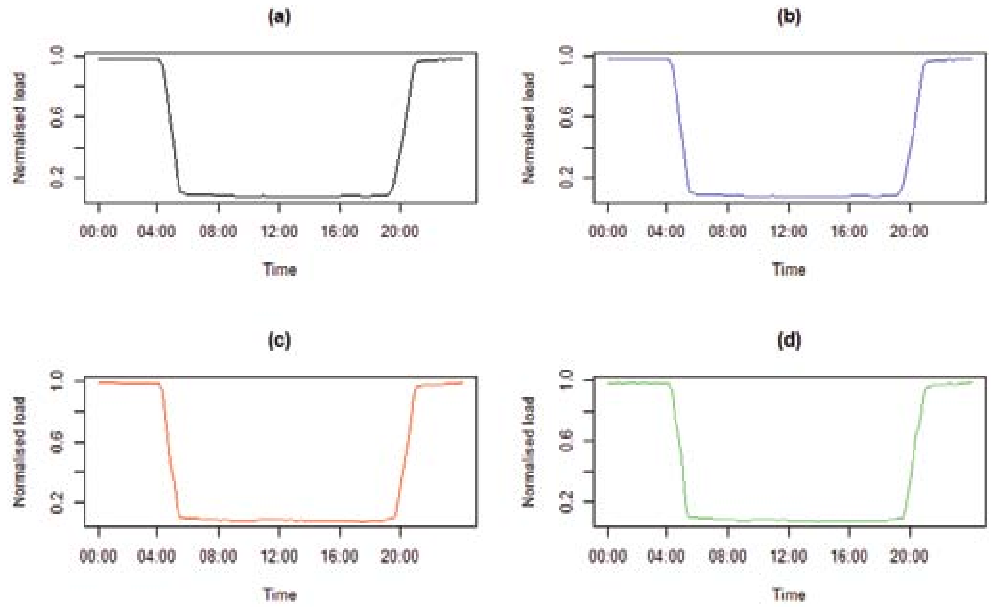


Figure 18: Substation demand profiles for cluster 10. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

Only from the load profiles, the ability of cluster 10 substations to absorb low carbon stresses is detailed in Table 10.

TYPE	COMMENT
Workplace / Retail EV charging	Suitable, complementary with power profiles
Overnight EV charging	Unsuitable time of day pattern as need is coincident with demand
Heat Pump	Suitable
PV	Unsuitable, demand is not there when PV radiation is at peak
CHP, AD, Hydro, Wind	Suitable

Table 10: Cluster 10 - ability to absorb low carbon stress

The clusters within the Stresses Report and its analysis looked at the effect of PV and Air Sourced Heat Pump installations on the LV network. Also, although not part of the initial project directive, analysis of the statutory voltages limits and the effect of expanding these limits to +/- 10% has also been investigated.

CONCLUSION ON COMPARISON BETWEEN GROUPS OF SUBSTATIONS WITH AND WITHOUT PV INSTALLATIONS

The groups with and without PV exhibited the same voltage and demand profiles. This was not as anticipated, as significant installations of PV would be expected to show an increase in voltage during daylight hours.

In seeking to understand this, the findings of the PV FiT report have demonstrated that the maximum aggregate output generated from multiple PV installations within a postcode was only 81% of the declared capacity. Consequently, since the associated voltage rise/drop is related to the square of the current, the voltage impact of the PVs is at least 36% lower than at full rated output.

The current analysis suggests that the level of PV installed at the monitored substations had little impact on the network. This may be due to a combination of system design, assuming 100% efficiency, and possible overstatement of maximum rated output by installers. It is proposed to undertake further analysis to compare individual and similar substations with or without PV and also compare individual substations on days of high and low solar radiation. These findings will be disseminated.

CONCLUSIONS ON COMPARISON BETWEEN GROUPS OF SUBSTATIONS WITH AND WITHOUT ASHP'S

In high summer there is little evidence of the effect of ASHPs. So clusters with and without adopt a very similar profile.

In winter there is a clear increase in demand from around 00.00hrs to 07.00hrs, which is believed to be the effect of ASHPs. This is clearly evident in cluster 5, but can also be seen in cluster 6, when domestic load is dominating.

It would appear that the ASHPs are operating in line with Economy 7 type time of use tariffs. If the increased demand from ASHPs shifted to coincide with the tea time peak (Cluster 5) or the daytime peak (Cluster 6) there could be network issues.

There is reduced capacity for EV overnight charging on Cluster 5 if ASHPs are connected to the network because charging would coincide with the peak overnight demand. They could be accommodated during the working day (08.00hrs to 16.00hrs).

When the headroom identified by this project has been exploited by the connection of greater densities of low carbon technologies, templates will need to be updated or new ones developed.

It is proposed that there will be further analysis to better understand the impact of ASHP on the LV network.

THE EFFECT OF EXPANDING THE STATUTORY VOLTAGE LIMITS

To date there have been approximately 98 million measurements from remote feeder ends, with spurious readings removed after sense checking. This resulted in approximately 96 million measurements being taken with 10 min intervals being analysed. Of these, 99.62% were within the UK limits 216.2V- 253V and 0.38% outside. The split between those outside these limits was 0.021% below the lower limit and 0.35% above the upper limit.

Had the analysis revealed a widespread problem with multiple locations at the limit or in breach of the current UK lower voltage limit, it would suggest that the additional "headroom" which would be afforded by the move to the lower EU limit was already being exploited (in breach of current UK ESQCRs). Since that has not been the case, there is an argument that a reduction of some 2.5%, which is a tap step on ground mounted transformers, could be applied without danger of a substantial numbers of LV connected customers experiencing voltages under lower EU limit. A similar level of voltage reduction could be applied by re-setting target voltages at primary substations.

The benefits to both customers and UK would arise from the demand reduction associated with lower supply voltage. For purely resistive load a 2.5% reduction in voltage amounts to a 2.5% reduction in instantaneous demand (kW). In practice some types of demand, e.g. heating, may still use the same amount of energy (kWh), but over a longer time period. A midline estimate would be that 2.5% voltage reduction would produce around 1.5% reduction in demand. This would benefit

- network capacity
- need for reinforcement
- headroom to deploy low carbon demand technologies
- reduction in network losses
- reduction in peak UK demand, supporting the displacement of least efficient generation
- reduction in UK CO_2 emissions

CONCLUSIONS

The above analysis leads to the following observations:

- The current system behaves extremely well with only 0.38% of some 96 million voltage measurements being outside the range 216.2-253V over the eleven month period (April 2012-February 2013)
- The data shows that in the few cases where the LV networks do have out of limit voltages the majority of incidents are over limit voltage problems rather than under limit problems; 0.35% of remote feeder ends were observed to be over-limit compared to 0.0187% 230V -6 to -10% and 0.0022% below -10%;
- There are very few measurement locations (feeder ends) that have a persistent over/under limit problems
- Most of the measurement locations have only limited time of over voltage problems, and only very small number of measurement locations have prolonged over voltage problems
- Of the small number of cases of under voltage, 90% fall within the EU voltage limits
- To put a scale of value to adoption of the EU voltage limits, a 1.5% fall in energy use through voltage reduction of 2.5% across only half of the 230,000 UK ground mounted distribution transformers, at an average of 150 domestic customers per transformer would save some 850,000 MWh each year. (Using Ofgem factsheet 96, 2011, average UK domestic electricity customer of 3,300kWhr). Using the cost per unit valuation from the same factsheet at 12.8p / unit), the value of that saving to domestic end customers is over £100M each year. If voltage reduction was more widespread and included pole mounted connected customers, through adjustment of primary substation target voltages, the savings would be higher
- Statistical analysis has identified 10 cluster types, having differing capabilities to absorb low carbon generation or demand technologies. A detailed report on these clusters is to be published, in line with the Ofgem Project Direction, in July. Use of these clusters will aid network design planning and loss reduction. Findings from the Proxy PV FiT meter report have identified significant capacity headroom for LV PV installations

3 BUSINESS CASE UPDATE

There has been no change to the business case in this reporting period.

Progress against budget

The table below is a budget overview for the reporting period: 01/12/11 to 31/05/12.

Budget identifier	Item	Total budget	Expected spend to date	Actual spend 20.05.13	Variance £	Variance %
	Box 6 (Employment costs)	£1,347,000	£1,323,969	£1,238,982	-£103,259	-7.8%
6.1	Substation monitor fitters	£414,000	£414,000	£434,030	£20,030	4.8%
6.2	Planning Manager	£187,000	£176,719	£110,856	-£76,144	-43.1%
6.3	B2B External Relation Manager	£112,000	£112,500	£141,590	£1,933	1.7%
6.4	B2B Manager	£112,000	£112,500	£109,052	-£2,948	-2.6%
6.5	Project Manager	£187,000	£173,250	£118,682	-£40,661	-23.5%
6.6	Project Management Team (3 staff)	£300,000	£300,000	£289,545	-£5,696	-1.9%
6.7	Call centre staff	£35,000	£35,000	£35,227	£227	0.6%
	Box 7 (Equipment costs)	£5,301,000	£5,301,050	£5,900,719	£483,911	9.1%
7.1	Data concentrator at substation	£200,000	£200,000	£222,627	£18,720	9.4%
7.2	ENMAC updates	£100,000	£100,000	£111,313	£9,360	9.4%
7.3	Message switching/hub software	£150,000	£150,000	£166,970	£14,040	9.4%
7.4	Enhanced FEP software	£95,000	£95,000	£105,748	£8,892	9.4%
7.5	Data concentrator/ substation monitoring	£1,190,000	£1,190,250	£1,324,629	£111,384	9.4%
7.6	Data comms hub	£150,000	£150,000	£166,970	£14,040	9.4%
7.7	Data comms using meshed radio type technology	£735,000	£735,000	£818,153	£65,153	8.9%
7.8	Data comms using PLC technology	£867,000	£866,550	£965,087	£81,151	9.4%
7.9	LV end voltage monitors	£1,765,000	£1,765,200	£1,964,680	£156,585	8.9%
7.11	LV FIT meter installs	£49,000	£49,050	£54,544	£4,586	9.4%
	Box 8 (Contractor costs)	£1,293,000	£1,221,911	£1,337,143	£21,621	1.8%
8.1	Monitor fitter contractors / appointment booking contractors	£727,000	£726,800	£752,045	£20,286	2.8%
8.2	Project management / consultancy	£160,000	£112,000	£136,167	-£23,833	-21.3%
8.3	Bath University analysis	£306,000	£283,111	£337,618	£15,809	5.6%
8.4	Radio site survey contractors	£80,000	£80,000	£89,051	£7,488	9.4%
8.5	System testing / analysis contractors (SCADA)	£20,000	£20,000	£22,263	£1,872	9.4%
	Box 10 (Other costs)	£1,074,000	£982,714	£845,747	-£94,681	-9.6%
10.1	IT costs	£106,000	£106,000	£109,582	£3,582	3.4%
10.2	Contingency	£820,000	£739,784	£572,872	-£97,747	-13.2%
10.3	Public engagement/ learning dissemination	£148,000	£136,930	£163,293	-£516	-0.4%
		£9,015,000	£8,829,644	£9,322,591		

It should be noted that £350,000 remains in the Project Bank Account. This is equivalent to the cost of the unused voltage monitors previously agreed.

The following items show a variance of more than 5%:

Item 6.2. The work of incorporating the learning of the project into the business is going to happen towards the end of the project in July 2013, to coincide with the development of the templates. The final figure is not expected to be more than 5% higher than the budget.

Item 6.5. The assistance of Accenture with the project management has reduced the project management requirement so far. The final figure is not expected to be more than 5% higher than the budget.

Item 6.6. The costs of the project management team are slightly lower than predicted.

Items 7.1 to 7.11, 8.4 and 8.5. As previously reported, these figures are higher than 5%, due to the compressed timescales for installing the communications system and procurement of radio frequencies from the JRC. As a result additional contractors were required to allow WPD to meet the necessary project deadlines. Within this reporting period, there have also been extra costs for the installation of plug in type voltage monitors to increase the numbers, and continuing work to maintain the radio comms stability. The final figure will not exceed 10%.

Item 8.2. This cost has been loaded earlier in the project, due to increased project management complexities in the period up to June 2012. The final figure is not expected to be more than 5% higher than the budget.

Item 8.3 and 10.3. A delay in sending the main load of data to Bath has caused the spend for Bath to be delayed. There was also the need to extend the contracts for two Research Assistants to undertake further data analysis activities. The final figure is not expected to be more than10% higher than the budget.

Item 10.2. The contingency money spent to date, has been used to support the phase checking activities and for installing additional monitoring in (street pillars) as a result of a lack of customer consents. Some of the contingency fund will be allocated to a hosted GPRS data collection service that still needs to be procured from GE.

The final project spend in each box will not exceed the 110% limit set in section 6 of the Project Direction.

4 BANK ACCOUNT

See Appendix 6

5 SUCCESSFUL DELIVERY REWARD CRITERIA (SDRC)

See the sub-sections below for a summary of progress made towards meeting the delivery criteria.

Provision of six-monthly report (target date 17/06/11)
Completed by issuing the first six-monthly report in June 2011

Communications path to sensors proven (target date 14/09/11)
Completed (as discussed in the second six monthly report)

Data transfer to Bath University (target date 25/10/11)
Completed (as discussed in the second six monthly report)

Provision of live generation data to National Grid (target date 19/12/11)
Although not on the critical path for template generation, it can be noted that most of the necessary work has been completed on a separate Tier 1 project. The system has been tested with dummy data; NG & WPD are working towards adopting this as business as usual.

Deployment of all data concentrators complete (target date 31/03/12)
Completed the installation of all CTs, communications enclosures and antennas by March 2012.

All voltage sensors deployed (target date 07/04/12)
Due to difficulty in obtaining consent from customers, this activity was completed at the end of Oct 2012. The reduced number of installed voltage sensors has been agreed with Ofgem.

Identification of the effects of low-carbon stresses (target date 01/05/13)
Completed, report submitted on time see Appendix 1

Report on the ability to use proxy FIT meters (target date 01/05/13)
Completed, Report submitted on time see Appendix 2

Report on network templates (target date 01/07/13)
In Progress, the University of Bath are finalising this report for submission on 01.07.13.

Share learning with partners and interested parties (target date 31/07/13)
In Progress, WPD was able present progress on this project at the national ENA organised LCNF Conference in Cardiff in Oct 2012. The raw data collected so far is available to third parties. The University of Bath will be undertaking this work in conjunction with WPD, including running the website www.lowcarbonuk.com for technical and academic audiences. WPD has also established a website, www.

westernpowerinnovation.co.uk for members of the general public and other stakeholders. In July 2012, WPD hosted a briefing session with the industry, including any interested DNOs, to share the current project findings and to obtain feedback to improve the development of the network templates. In September 2012 WPD presented the project, alongside other DNO's, at Brunel University as part of the 47th International Universities Power Engineering Conference. An interim report was published in September2012. A DNO Event was held on the 14th May in Bath, to disseminate learning and request data to validate the Templates in other areas. The 2 reports submitted on 1st May have been published on the websites.

WPD have held an initial meeting with the BRE (National Solar Centre) to discuss the proxy FIT meter work monitoring of 525 installations, and ability to share output monitoring data on some 80 of these at 10 min averages to assist other DNOs, academia and research bodies such as BRE (remainder can't be shared without agreement of Passiv Systems). This was welcomed by BRE as their newly opened National Solar Centre 's raison d'etre is to help the solar industry to grow " by researching and channelling evidence based information on design and installation techniques, performance, durability and costs to industry, government and other stakeholders" . " there is a need for a shift towards the integration of PV and construction products and BRE intends to take a pivotal role" (ref BRE document – National Solar Centre – Helping the solar industry to grow, mature and thrive – see BRE website www.bre.co.uk/nsc). This has opened further discussions on building/estate design, and is the first example of disseminating the project findings to the "right people" outside of the DNO/ academic sectors.

WPD have also had requests from Smart Cornwall, Reading University and CSE, to share the Templates data. We are currently working on a data share agreement, with the intention of providing data to all parties as soon as this is in place.

6 LEARNING OUTCOMES

Along with the learning's from the 2 reports submitted in May and included as Appendix 1 & 2. An interim report for Ofgem was produced in March and is included as Appendix 3

7 INTELLECTUAL PROPERTY RIGHTS (IPR)

There are no Intellectual Property Rights associated with this project.

8 RISK MANAGEMENT

Two key risks have been identified, from which a number of mitigating actions have derived. These are highlighted in the table below:

9 OTHER

The LV Current Sensor Technology Evaluation Tier 1 project was registered in January 2012, as a dependency of LV Templates. The project was established as a joint scheme with UK Power Networks and was designed to evaluate a range of off-the-shelf substation monitors that could be installed without needing to interrupt electricity supplies. Equipment has now been installed from 7 manufacturers at 14 indoor substations in Central London, and 14 outdoor sites in Market Harborough. A series of calibration tests have been completed testing a range of performance parameters on the equipment. A full close out report is due from the project in September 2013 detailing the outputs and learnings from the scheme.

10 CONSISTENCY WITH FULL SUBMISSION

The project continues to progress in accordance with the full submission and is on course to achieve all targets on time.

11 ACCURACY ASSURANCE STATEMENT

This report has been prepared by Mark Dale (Network Templates Project Manager), recommended by Roger Hey (Future Networks Manager for WPD), and approved by Nigel Turvey (Design and Development Manager for WPD).

All the information regarding Clusters/Templates and the stresses and effects of Low Carbon Technologies on the LV Network is taken from the analysis from The University of Bath and supported by the submitted reports attached as Appendices 1 & 2.

APPENDIX 1

RISK	HOW MITIGATED OR FEATURED IN CONTINGENCY
Technical Risk	
GE capacity to meet DNO demand, given all DNOs utilise GE products at some point	Risk now Closed
Monitor specification not supporting requirements	Risk now Closed
Integration with NG systems not been tried before	Systems Tested with dummy data Now a separate Tier 1 project..
Delivery risks	
Skills shortage of contractors to install the required number of monitors	Risk now Closed
Project learnings not conclusive or disseminated	Ensure robust project methodology (processes, data capture, data analysis) and embed learnings into Knowledge Bank
Network Template Validation: DNO data and its required analysis, does not arrive in time for it to be incorporated into the final templates report on the 1st of July.	Risk Open Mitigating actions Collaborating closely with all DNOs WPD are trialling templates on a wider part of their network for further validation (formerly Central Networks)
Financial risks	
Cost of CI/CML 'hits' prove prohibitive	Exemption with Ofgem agreed Risk now Closed
Cost of components increases over project lifetime	Risk now Closed
Funding from External Collaborators falls through	Risk now Closed
Political/external stakeholder risks	
Non-cooperation at microgeneration sites, perhaps due to contractual breakdown	Risk now Closed
Non-starting or non-availability of key WAG schemes, reducing data quantity	All relevant data supplied. Risk now Closed
Wide-scale customer refusal of FIT/voltage monitor install	Supplemental data acquired from Passiv Systems Risk now Closed
Bath University does not produce suitable modelling from data	Preliminary Templates produced confidence high that all modelling will be suitable
Non-availability of WAG/Arbed data on potential projects	Obtained in advance of project start Risk now Closed
Wider Adoption: The templates themselves are not representative and credible for wider adoption across the rest of the GB network.	Host a number of dissemination workshops with the wider industry stakeholders Host a number of one-to-one workshops with DNOs in capturing their feedback about the templates and the potential areas in refining them for wider adoption (Top-down and bottom-up engagement approach)
Internal stakeholder risks	
Two internal support teams (Records and Customer Contact teams) not ready for go-live	Risk now Closed
Management unsupportive of on-going project value	Final report due on 1st July management continue to support project

APPENDIX 2

LV Network Templates for a Low Carbon Future

Stresses on the LV Network caused by Low Carbon Technologies

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

LCN Fund
Low Carbon Networks

Llywodraeth Cymru
Welsh Government

UNIVERSITY OF BATH

imagination at work

npower
An RWE company

passivSYSTEMS

Western Power Distribution (South Wales) plc
Registered in Wales No. 2366985
Registered Office: Avonbank, Feeder Road, Bristol, BS2 0TB

Version: 1.0

Authored by: Prof. Furong Li and Dr Gavin Shaddick

Recommended by: Mark Dale

Approved by: Roger Hey

Stresses on the LV network from low carbon installations

Table of Contents

1 Executive summary

Distribution network operators face new network challenges facilitating the connection of increased demand from low carbon technologies and increased penetration of distributed generation. Each technology brings different constraints varying from time of day to seasonal. Economic connection of these technologies is hampered by a lack of real-time LV network visibility of actual stresses on the network.

This report is one of three major reports that investigate the aforementioned challenges as part of the work undertaken by WPD in the LCN funded "LV Network Template Project":

1. Stresses on the LV network from low carbon installations
2. Use of proxy PV FiT meters to reflect local area Generation
3. Demonstration of LV Network Templates through statistical analysis

The "Stresses on the LV network from low carbon installations report" will specifically focus on demand capacity and voltage headroom in DNO networks; highlighting the effects of local low-carbon technologies and micro-generation on the existing network.

In order to gain such fundamental understanding, WPD's LV Network Template Project undertook the largest monitoring of its LV network in the UK. This approach led to the successful monitoring of over 800 substations and 3609 remote feeder ends. The data that was extrapolated from the monitors allowed the University of Bath to undertake extensive statistical and power analysis identifying 10 representative substations groups with unique voltage and demand profiles. The clustered voltage and demand profiles for each of these groups have and can be used to identify the headroom available for the application of low carbon technologies by time of day, weekday/weekends and season.

In addition to WPD and the University of Bath being able to prove that it is possible to cluster substations successfully, the following findings have also been identified:

- The maximum aggregated generation from PV within a postcode was on average only 81% of the declared capacity, consequently leading to a the voltage impact on our network approximately 36% lower than anticipated. Our findings illustrate even in locations with high PV penetration the outputs and impact to the network are relatively low. In comparison in areas where there are few heat pumps installed, there was a noticeable difference. This finding is key as current DNO network planning is based in part upon the declared capacity of registered low carbon technologies. As such there is the potential for DNO planners to more accurately assess the impact of low carbon technologies avoiding unnecessary costly network reinforcement.
- A second key output that this report highlights is that over an 11 month period, 96 million voltage measurements at remote feeder ends were taken. From this WPD have been able to identify that for those monitored points, 99.62% of the voltage readings were within statutory voltage limits. The analysis shows that in

the minority of cases the proportion of excursions associated with a single site was extremely small. If the UK were to adopt EU voltage limits, 99.998% of voltage readings would be within limits.To put a scale of value to the adoption of the EU voltage limits, a 1.5% fall in energy use through voltage reduction of 2.5% across only half of the 230,000 UK ground mounted distribution transformers, at an average of 150 domestic customers per transformer would save some 850,000 MWh p.a. The value of that saving to DNO customers would be over £100M p.a. If voltage reduction were more widespread and included pole mounted connected customers, through adjustment of primary substation target voltages, the savings would be even higher

As identified above and throughout this report, the Clusters identified as part of this Project deliver real value, cost and potential carbon savings to DNOs, their customers and the wider industry.

Moving forward the insight gained can and has already begun to be applied within WPD in the form of policy changes and the ability to help make more informed decisions about the networks effective operation/design of its LV network. WPD have taken proactive steps in immediately addressing statutory voltage excursions and hope to use the Projects findings to deliver greater GB saving by with Ofgem the potential for the UK to adopt European standards. Finally, WPD will continue to collect, monitor, analyse and share our findings with the industry in order to continue understanding the impact low carbon installations have on the LV network.

2 Introduction

The UK government has committed to reducing the greenhouse gas emissions by at least 80% by 2050 relative to the 1990 emission levels. Supporting this commitment is the “UK Renewable Energy Roadmap” that applies targets for 30% of electricity, 12% of heat and 10% of the energy generated for transport to come from renewable sources [1]. In its December 2012 update, DECC confirmed that by 2020, 15% of UK energy demand is to be supplied by renewable distributed generation.

It also recognised that the uncertain nature of deployment across the portfolio of technologies as well as relative cost effectiveness means that generation may end up at the high end of one technologies deployment range therefore requiring less deployment of others. Solar PV is now included as a key technology.

As the UK transitions to a low carbon economy, the energy sector faces significant challenges, both in the generation mix, the patterns and type of consumption seen (Demand). As a consequence DNOs will be impacted in the way they need to design and operate the electricity distribution networks in order to maintain security and quality of supply [2-3].

4

A key question that a DNO therefore needs to be able to answer is ‘how and to what extent the LV network is impacted by the adoption of low carbon technologies and distributed generation’.

Some collaborative works involving DNOs and academia have sought to answer the aforementioned question. Such as the study by Centre for Sustainable Energy and Distributed Generation- Imperial College [4], concluding that the impact from electric vehicles, heat pumps has the greatest impact the LV network (specifically HV & LV transformers) Other studies have identified that the maintenance of voltages is further impacted by the introduction of LV connected intermittent renewable generation technologies such as Photovoltaic cells (PV).

This report aims to understand the actual demand and voltage headroom available on areas of the network with and without distributed generation and low carbon technologies connected to it. This will allow us to understand in detail the related time of day and seasonal performances of low carbon technologies versus the capacity and voltage headroom available. In addition, this report examines whether low carbon technologies are likely to cause issues with voltage levels being outside of statutory limits.

Finally the key findings of this Project will help DNOs to make more informed cost-effective investment, and operational decisions for the management of the low voltage distribution network; as the UK transitions to a low carbon economy.

2.1 The LV networks project

As identified in our LCNF submission the “LV Network Template Project” sought to explore;

- The degree of headroom available across differing types of LV system topology and customer mixes
- The effect of stresses on the network from low carbon installations
- The ability to identify low carbon stresses through templates and the associated voltage profiles

The major challenges facing the DNOs network development and operation are thus to timely accommodate the expected increase in intermittent low carbon generation and the heat and transport demand, and at the same time deliver value to customers. Work done by others, notably the DECC / Ofgem, ENSG and Imperial College has pointed to the role of demand side management and voltage optimization in partial mitigation of the network impacts. There are however, significant gaps in our understanding on the headroom or the margin of the current system, as there are marked differences in network topographies and customer mixes, and the degree of stress that might be imposed by the low carbon technologies

5

A second key challenge could as a result of voltages being above or below statutory limits potentially leading to adverse consequences on end customers' energy use, power quality, and equipment life. Whilst not initially the intention of this Project, the Expert Panel were also advised that in checking the actual voltages measured across wide parts of the LV system, valuable insight could be gained into the headroom that might, or might not exist, within the existing 230v+10%/-6% limits set out in the UK legislation.

Furthermore, if it were to be demonstrated that there was a valid case that compliance was maintained throughout daily and seasonal voltage changes, then there could be a strong case to argue for a change in legislation to move to the EU 230v +10/-10% voltage range. (White goods have, for many years, been manufactured to be compliant with the wider EU voltage limits). If the Project demonstrated very limited numbers of non-compliant voltage excursions against the -6% limit then a wholesale drop in network voltage by a 2.5% tap on distribution transformers, or by lowering target voltage at primary substations could achieve measurable drop in both UK peak power and to a lesser extent overall UK energy demand and the potential deferment of network reinforcement.

3 Monitoring

Two types of monitoring were undertaken as part of the LV Network Template Project, substation and at the remote feeder end usually within the customers premise. This was to understand substation demand and the voltages at both ends of the LV network.
In total circa 800 substations provided data for analysis, the exact number depending on the time period of study. Each substation monitor captured 13 channels of data including:

- L1, L2, L3 Voltage
- L1, L2, L3 Current
- Real Power import/export
- Reactive Power lag/lead
- Total Harmonic Distortion (3 phases)

Measurements of each comprised of the average values over 10 minute intervals providing us with the granularity and confidence of being able to clearly develop load and voltage profiles needed to understand the impact of the stresses to the network

3.1 Remote feeder end monitoring

In addition to the voltage monitored on each phase within the substation, there are 3609 individual phase monitors on remote feeder ends measuring voltage. Recorded

measurements are again the averages over ten minute intervals. The majority of these are in customer homes with some monitored on cable ends and LV poles.

4 Network headroom

Whilst DNOs will frequently have the facility to determine simultaneous annual maximum demand information on ground mounted HV/LV substations through use of so called Maximum Demand Indicators "MDIs", these will also capture increased demand imposed on a substation during occasional transfers of demand when responding to network faults or planned shutdowns. By the end of 2019 it is planned that "smart meters" will have been installed in all UK households, and this would enable the aggregation of their individual demands to arrive at an annual maximum. However such aggregation would not provide the full picture of HV/LV transformer loading as it would not include for the network losses on the LV system or so called "unmetered demand" from un-metered street lighting, street furniture such as traffic lights, bus shelters and bollards and advertising hoardings. Nor will it provide as standard phase related or real time voltage information.

The accommodation of low carbon technologies onto the LV network not only requires knowledge of the existing peak demand, but also the variation of the shape of the demand curve through the day and how that varies over the week and seasons. The identification of periods during the day when demand is significantly below its peak represents the unutilised demand "headroom" that can be occupied by low carbon technologies imposing network demand, such as electric vehicle (EV) charging or ground / air source heat pumps. Conversely demand profiles that peak coincident with the output of low carbon generation technologies afford opportunity for absorption of higher levels of such generation. Parallel considerations on the maintenance of voltage within statutory limits also apply, and periods of time when there is latitude for further voltage rise or drop within those limits represent the "voltage headroom".

The cluster analysis has identified ten distinct groups or clusters of substations. Statistically, the demand profiles of substations within a particular cluster are more similar than those in the other clusters. Voltage profiles for each cluster were obtained by linking measurements at remote feeder ends associated with substations in each of the different clusters and calculating average profiles for each cluster. In order to further illustrate the impact of system loading level, voltage profiles are calculated by phase and both load and voltage profiles for each cluster have been assessed for weekdays, Saturday and Sundays.

The detailed reporting of work on the clustering analysis will be set out in another report, to be published in July. However, here we use results from the clustering analysis in order to demonstrate the potential of effects of low carbon stresses on the network. Specifically, results from the analyses for high summer, which would be expected to most reflect the effects of the significant LV PV penetration imposed by the Arbed and FiT initiatives, are presented (see Section 5 for details).

It should be noted that a separate report on Proxy PV FiT meters, published coincident with this report, contains significant findings in relation to aggregate local PV power output versus aggregate declared installed rating.

4.1 Demand and voltage profiling

The following sections provide the following information for each of the ten clusters (based on real power delivered)

- Power profiles over time for weekdays and weekends (Saturday and Sunday separately)
- Voltage profiles using data measured at the remote feeder ends
- A summary of the ability to accommodate low carbon stress

The demand profiles are, as normal practice in establishing load and loss load factors normalised to the respective peak within the time period under consideration.

4.1.1 Cluster 1

Cluster 1 is largely commercial dominated with a relatively high flat demand during day time and lower demand overnight, its demand profiles for weekday and weekends are shown in figure 1.

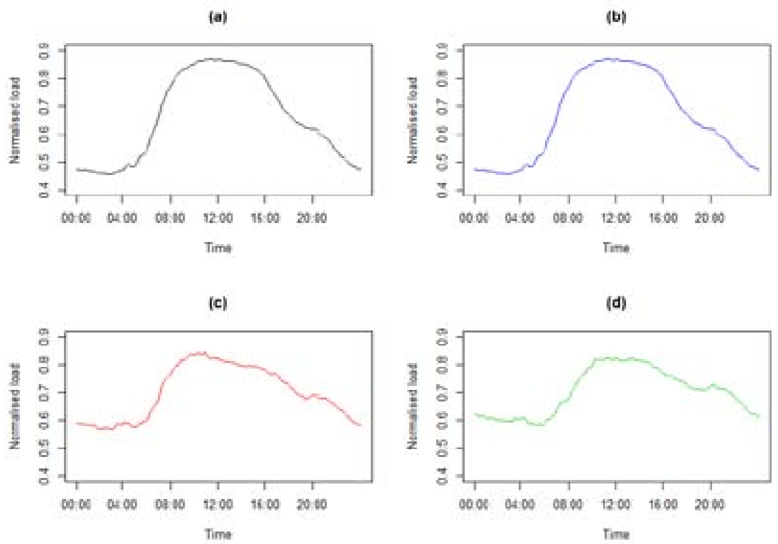


Figure 1: Substation demand profiles for cluster 1. Panels show results for (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

The voltage profiles (at remote feeder ends) are shown in figure 2. During weekdays, all three phases have similar patterns with higher voltages when demand is lower and vice-versa.

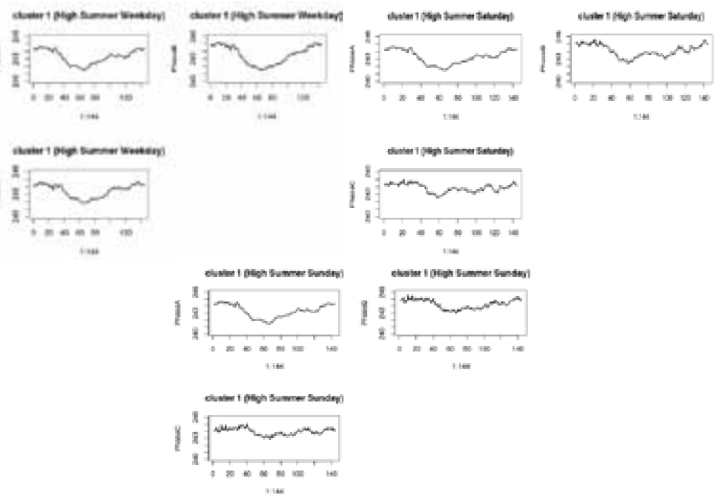


Figure 2: Voltage profiles at remote feeder ends for cluster 1. Clockwise, the figures represent the three-phase voltages in weekdays, Saturday and Sunday.

From the load and voltage profiles, the ability of cluster 1 substations to absorb low carbon stresses introduced by differing low carbon technologies is detailed in Table 1.

Type	Comment
Workplace / Retail EV charging	Unsuitable time of day pattern as need is coincident with prevailing peak
Overnight EV charging	Very suitable
Heat Pump	Only if linked with insulation or heat storage to permit off peak operation
PV	Suitable - complimentary to both power and voltage curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 1: Cluster 1: ability to absorb low carbon stress

4.1.2 Cluster 2

Cluster 2 comprises predominately of substations dominated by domestic customers, its demand profiles for weekday and weekends are shown in figure 3. The associated voltage profiles are depicted in figure 4.

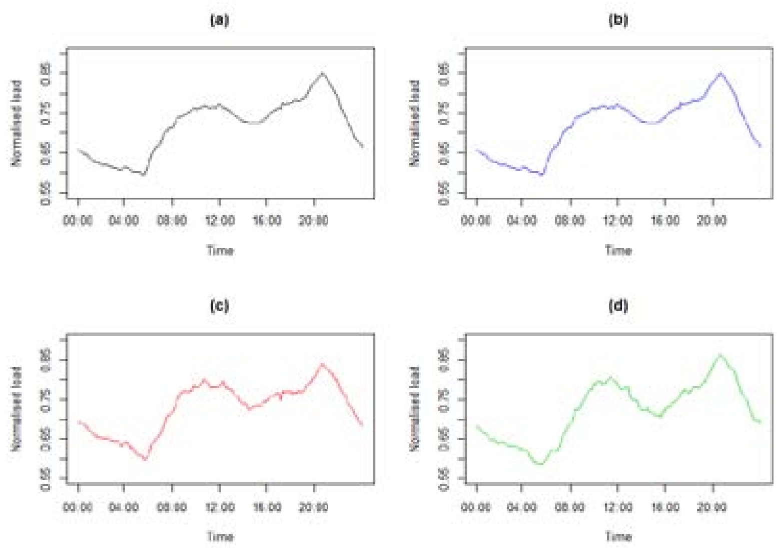
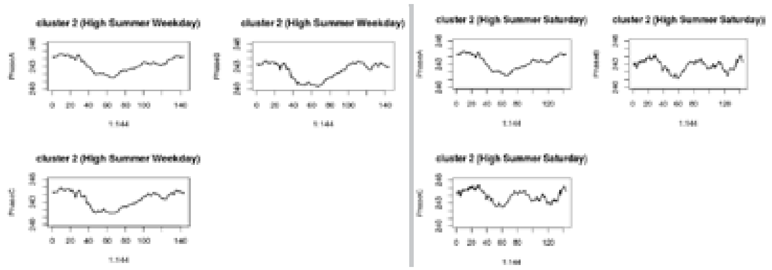


Figure 3: Substation demand profiles for cluster 2. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

The three-phase feeder end voltage profiles during weekdays differ slightly from each other, all showing a minimum demand around 10am where phase B has a lower minimum (240V at 10am) than phases A and C, suggesting that phase B is more heavily loaded at this time than the other two phases., Compared to weekdays, the voltages are higher for all three phases over weekends. In contrast, profiles and magnitudes of phase A do not change as much compared to weekdays, probably because of its demand is not greatly affect by day of the week.



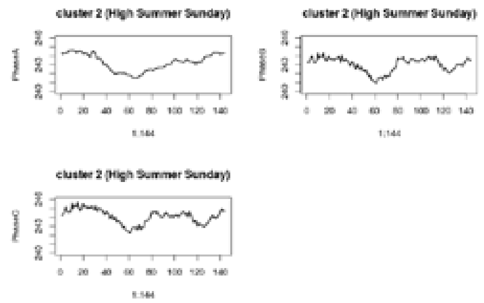


Figure 4: Voltage profiles at remote feeder ends for cluster 2. Clockwise, the figures represent the three-phase voltages in weekdays Saturday and Sunday.

From the load and voltage profiles, the ability of cluster 1 substations to absorb low carbon stresses is detailed in Table 2.

Type	Comment
Workplace / Retail EV charging	Suitable time of day pattern with limited need to curtail charge rate around 1730 peak - for workplace potentially not an issue if staff travelling then anyway, but possible minor constraint on commercial for shopping malls etc being visited at that time en-route from work.
Overnight EV charging	Suitable
Heat Pump	Suitable with insulation or heat storage with limited time of day constraint
PV	Suitable - complimentary to power and voltage curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 2: Cluster 2: ability to absorb low carbon stress

4.1.3 Cluster 3

The patterns observed for cluster 3 are similar to those observed in cluster 2 but here there are more commercial customers . The substation demand and voltage profiles are shown in figures 5 and 6 respectively.

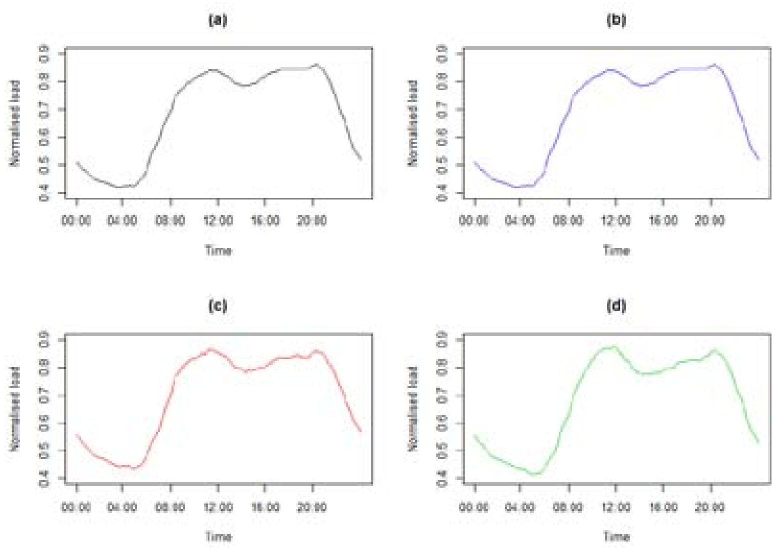


Figure 5: Substation demand profiles for cluster 3. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

The voltages at remote feeder ends conform well to the load cluster profile, with lower voltages when demand is high and vice versa.. During weekends, the three-phase voltage profiles follow similar patterns of weekdays, with higher magnitudes due to light loading.

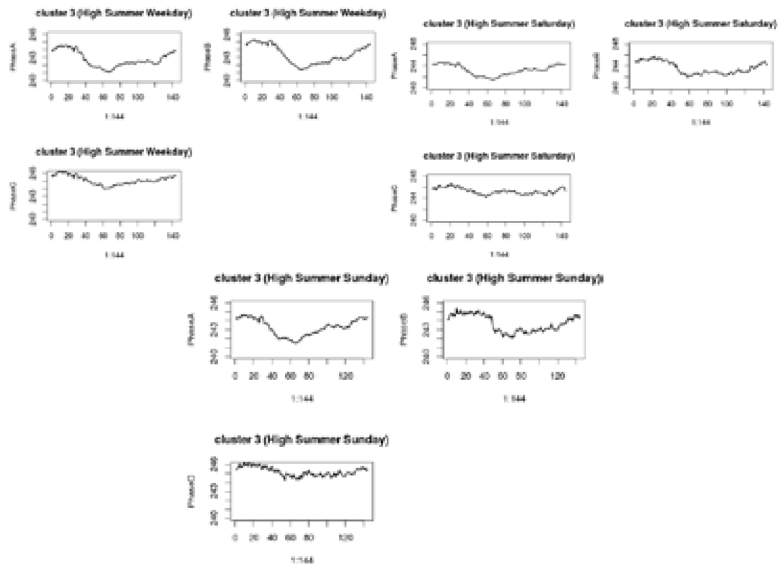


Figure 6: Voltage profiles at remote feeder ends for cluster 3. Clockwise, the figures represent the three-phase voltages in weekdays Saturday and Sunday.

From the load and voltage profiles, the ability of cluster 3 substations to absorb low carbon stresses is detailed in Table 3.

Type	Comment
Workplace / Retail EV charging	Less unsuitable time of day pattern as load curve shows limited drop off during working hours
Overnight EV charging	Suitable
Heat Pump	Suitable if linked with insulation or heat storage to permit off peak operation
PV	Suitable - complimentary to both power and voltage curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 3: Cluster 3: ability to absorb low carbon stress

4.1.4 Cluster 4

Cluster 4 comprises largely of domestically dominated substations. The substation demand and voltage profiles are shown in figures 7 and 8 respectively.

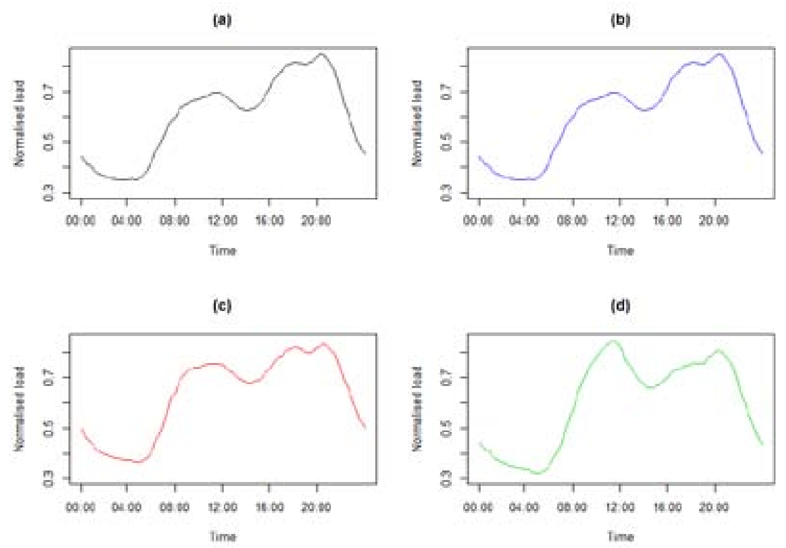


Figure 7: Substation demand profiles for cluster 4. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

The three-phase remote feeder end voltages linked to cluster 4 are very similar in terms of both magnitude and profiles.. The voltages are as high as 244-245V during the night, dropping to 241-242V during the day. The weekend three-phase voltage profiles are also similar, but the Sunday's profiles have more variation.

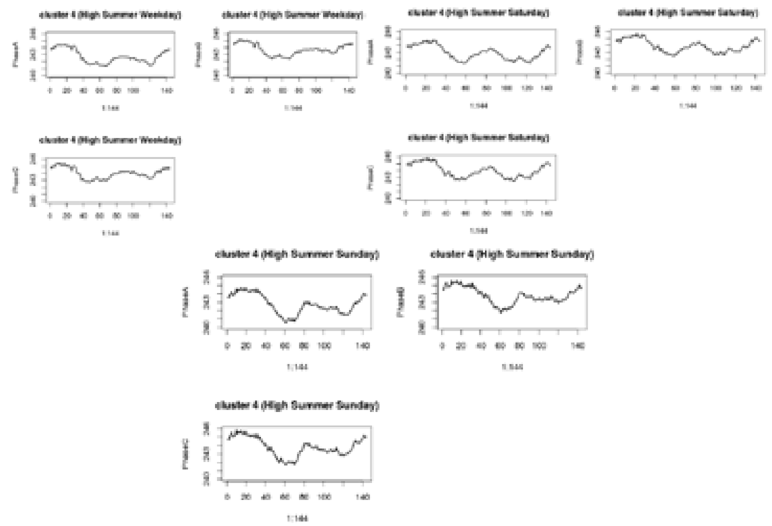


Figure 8: Voltage profiles at remote feeder ends for cluster 4. Clockwise, the figures represent the three-phase voltages in weekdays Saturday and Sunday.

From the load and voltage profiles, the ability of cluster 4 substations to absorb low carbon stresses is detailed in Table 4.

Type	Comment
Workplace / Retail EV charging	Unsuitable time of day pattern as need is coincident with prevailing peak
Overnight EV charging	Suitable
Heat Pump	Only if linked with insulation or heat storage to permit off peak operation
PV	Suitable - complimentary to both power and voltage curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 4: Cluster 4 - ability to absorb low carbon stress

4.1.5 Cluster 5

As with clusters 2 and 4, cluster 5 represents domestic dominated substations. The substation demand and voltage profiles are shown in figures 9 and 10 respectively.

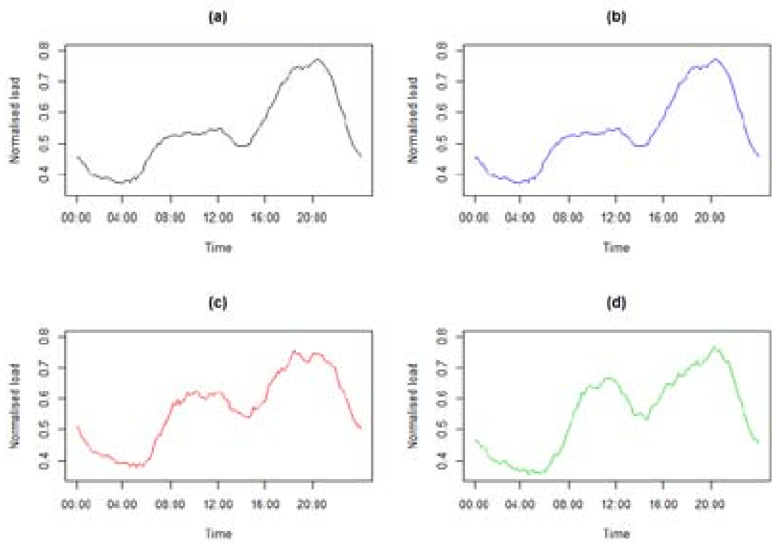


Figure 9: Substation demand profiles for cluster 5. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

This cluster consists entirely of substations that are single phase. The voltage profiles show the inverse pattern to demand with a minimum of 242V at 20:00pm. The profiles for weekends show an apparent rise during the middle of the day together with more variation than is seen for weekdays.

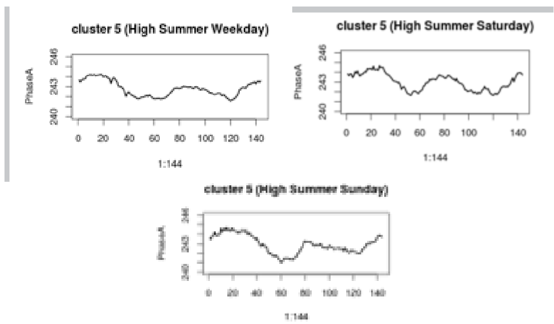


Figure 10: Voltage profiles at remote feeder ends for cluster 5. Clockwise, the figures represent the three-phase voltages in weekdays Saturday and Sunday.

From the load and voltage profiles, the ability of cluster 5 substations to absorb low carbon stresses is detailed in Table 5.

16

Type	Comment
Workplace / Retail EV charging	Suitable providing that work / sole operating hours are not coincident with peak
Overnight EV charging	Suitable
Heat Pump	Might require link with insulation or heat storage to permit off peak operation
PV	Less suitable - as not complimentary to power curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 5: Cluster 5: ability to absorb low carbon stress

4.1.6 Cluster 6

As with clusters 1 and 3, cluster 6 represents commercial dominated substations. The pattern observed for cluster 6 is very similar to cluster 1 but with a higher magnitude due to these substations serving mainly large-size industrial and commercial customers. The substation demand and voltage profiles are shown in figures 11 and 12 respectively.

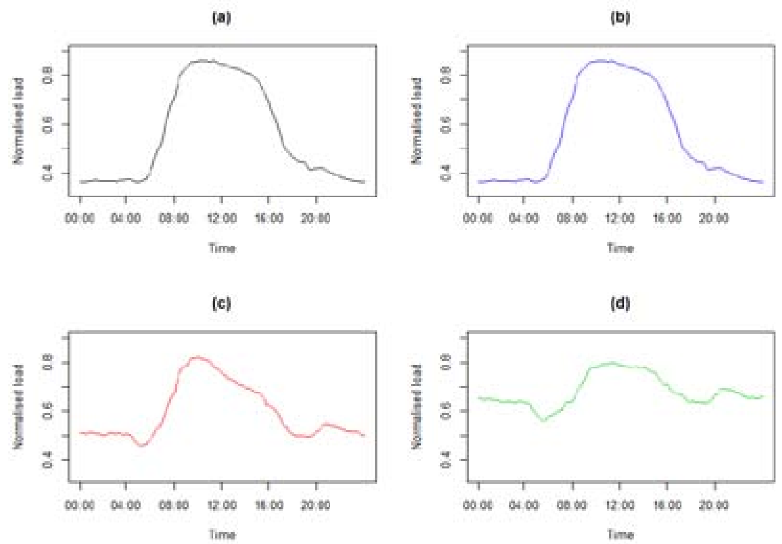


Figure 11: Substation demand profiles for cluster 6. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

17

The remote feeder end voltage profiles on the three phases are nearly identical and reflect the demand. At weekends, higher magnitudes are observed when compared to weekdays.

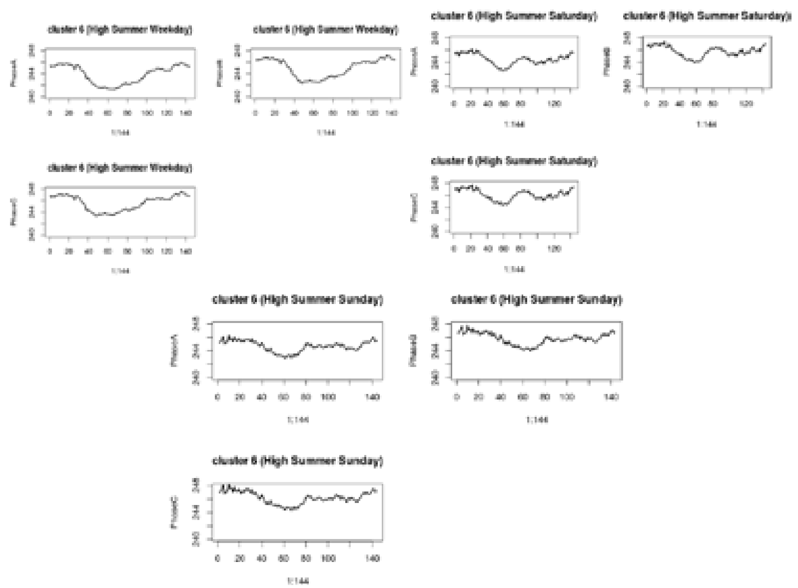


Figure 12: Voltage profiles at remote feeder ends for cluster 6. Clockwise, the figures represent the three-phase voltages in weekdays Saturday and Sunday.

From the load and voltage profiles, the ability of cluster 6 substations to absorb low carbon stresses is detailed in Table 6.

Type	Comment
Workplace / Retail EV charging	Unsuitable time of day pattern as need is coincident with prevailing peak
Overnight EV charging	Very suitable
Heat Pump	Only if linked with insulation or heat storage to permit off peak operation
PV	Suitable - complimentary to both power and voltage curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 6: Cluster 6: ability to absorb low carbon stress

4.1.7 Cluster 7

Cluster 7 largely contains substations of a mix of domestic customers and small commercial customers in rural areas with low demands. There are two obvious peaks, the first of which appear around 12:00 pm driven by commercial customers and the second of which happens at approximately 20:00 pm triggered by domestic customers. The substation demand and voltage profiles are shown in figures 13 and 14 respectively.

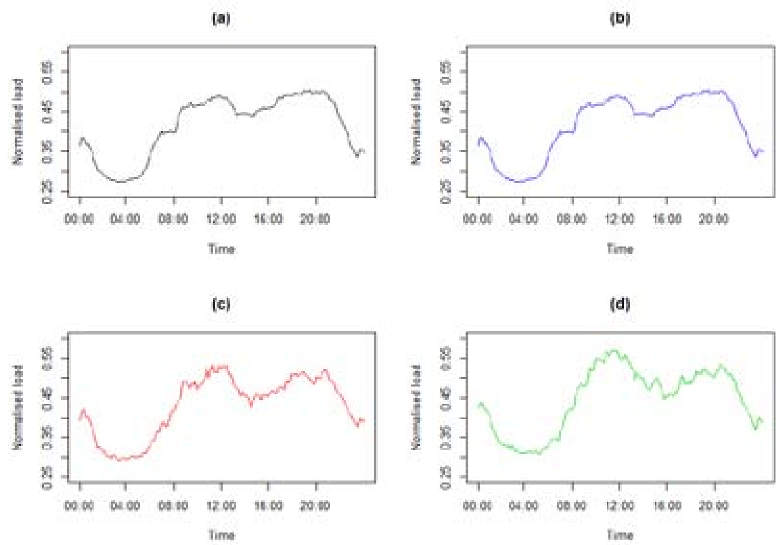
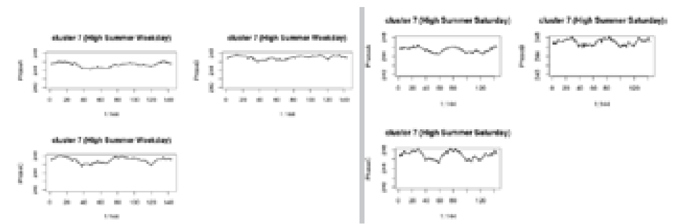


Figure 13: Substation demand profiles for cluster 7. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

The voltage profiles at remote feeder ends show that weekdays are relatively steady, fluctuating within a small range (245V-248V). The magnitude of phase A is smaller than those of phases B and C, indicating relatively higher loads. For the weekend profiles, phase A's are comparably steady, while phases B and C exhibit larger variation.



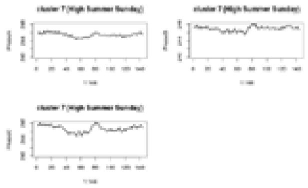


Figure 14: Voltage profiles at remote feeder ends for cluster 7. Clockwise, the figures represent the three-phase voltages in weekdays Saturday and Sunday.

From the load and voltage profiles, the ability of cluster 7 substations to absorb low carbon stresses is detailed in Table 7.

Type	Comment
Workplace / Retail EV charging	The wider variability within this cluster precludes firm conclusion though the tendency is a curve that is not complementary to workplace EV charging
Overnight EV charging	Suitable
Heat Pump	Only if linked with insulation or heat storage to permit off peak operation
PV	The wider variability within this cluster is less suitable for PV-
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 7: Cluster 7 : ability to absorb low carbon stress

4.1.8 Cluster 8

Cluster 8 comprises of a mix of commercial and domestic customers. At the time of writing, there no remote feeder end voltage monitors were associated with this group of substations. The substation demand profiles are shown in figure 15.

20

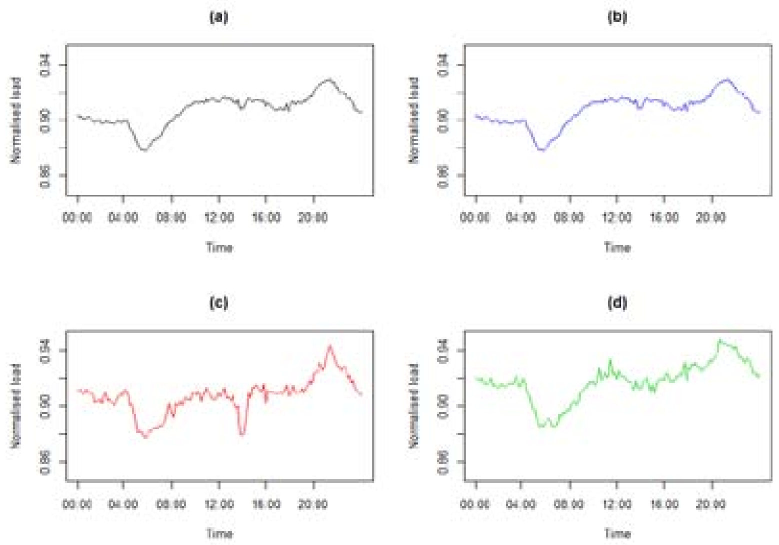


Figure 15: Substation demand profiles for cluster 8. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

From the load and voltage profiles, the ability of cluster 8 substations to absorb low carbon stresses is detailed in Table 8.

Type	Comment
Workplace / Retail EV charging	Unsuitable time of day pattern as need is coincident with prevailing peak
Overnight EV charging	less suitable
Heat Pump	More limited capability due to lack of depth and duration of off peak demand
PV	Suitable - complimentary to power curves
CHP, AD, Hydro, Wind	More suitable than most given that generation is not naturally limited to time of day and demand curve has reduced depth and duration of off peak period

Table 8: Cluster 8: ability to absorb low carbon stress

4.1.9 Cluster 9

Cluster represents domestic dominated substations with significant Economy 7 customers. The substation demand and voltage profiles are shown in figures 16 and 17 respectively.

21

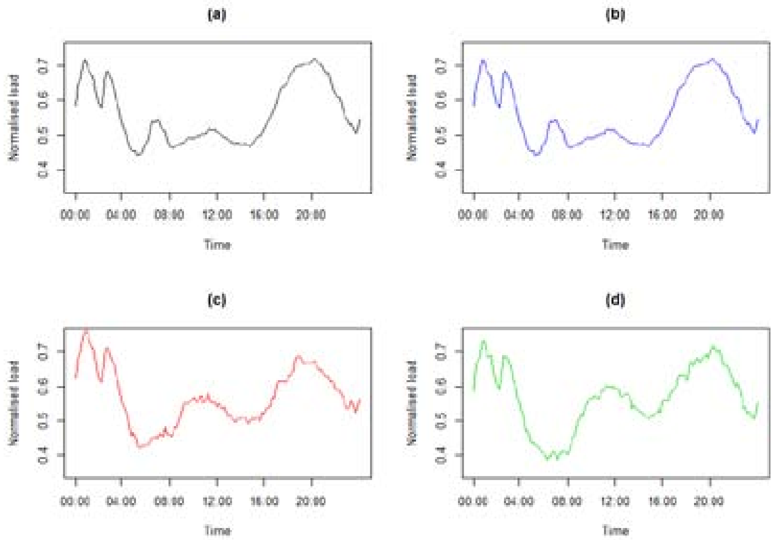


Figure 16: Substation demand profiles for cluster 9. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

The remote feeder end voltage profiles are relatively flat, without any apparent voltage dip, with more variation being observed in the weekend profiles.

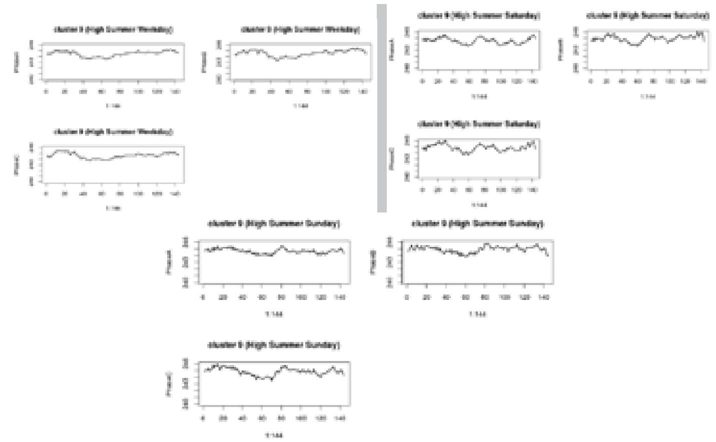


Figure 17: Voltage profiles at remote feeder ends for cluster 9. Clockwise, the figures represent the three-phase voltages in weekdays Saturday and Sunday.

From the load and voltage profiles, the ability of cluster 9 substations to absorb low carbon stresses is detailed in Table 9.

Type	Comment
Workplace / Retail EV charging	Suitable providing that work / sole operating hours are not coincident with peak
Overnight EV charging	Not suitable
Heat Pump	Requires further examination of nature of activity - might require link with insulation or heat storage to permit off peak operation
PV	Less suitable - as not complimentary to power curves
CHP, AD, Hydro, Wind	Since generation is not naturally limited to time of day, potential need for constraint for voltage reasons off peak

Table 9: Cluster 9: ability to absorb low carbon stress

4.1.10 Cluster 10

Cluster 10 comprises exclusively of substation for motorway communication/ lighting pillars. There are no remote feeder voltage end monitors associated with these substations. The substation demand profiles are shown in figure 19.

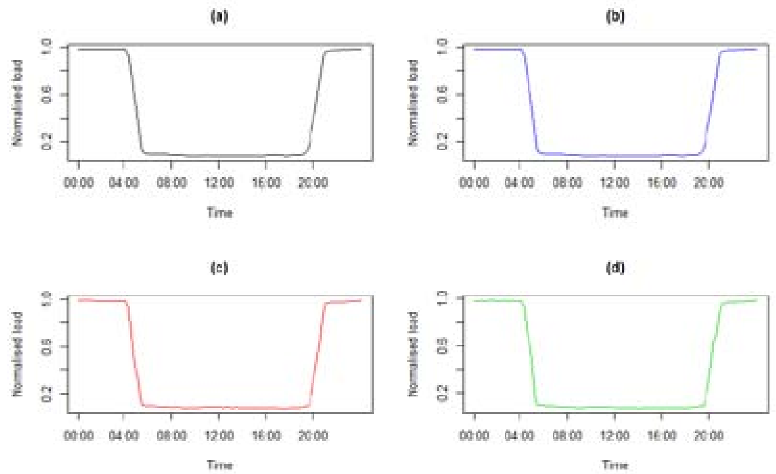


Figure 18: Substation demand profiles for cluster 10. Panels show results for; (a) all days, (b) weekdays, (c) Saturdays and (d) Sundays.

Only from the load profiles, the ability of cluster 10 substations to absorb low carbon stresses is detailed in Table 10.

Type	Comment
Workplace / Retail EV charging	Suitable, complementary with power profiles
Overnight EV charging	Unsuitable time of day pattern as need is coincident with demand
Heat Pump	Suitable
PV	Unsuitable, demand is not there when PV radiation is at peak
CHP, AD, Hydro, Wind	Suitable

Table 10: Cluster 10 - ability to absorb low carbon stress

5 The effect of local low carbon installations.

The low carbon stress analyses draw heavily from Wales Strategic Energy Performance Investment Programme – Arbed initiative, aiming for increasing 'domestic energy efficiency, community-scale renewables and alleviating fuel poverty'. The initiative is set out in "A Low Carbon Revolution –The Welsh Assembly Government Energy Policy Statement part of Welsh government", as part of the Welsh government's ambitious energy plan - 'making low carbon energy a reality' [5].

The total number of properties registered with Arbed at the time of analysis was 4036. At these properties 912 PVs, 616 SHWs (Solar Water Heaters), 2198 EWI (External Wall Insulation), 539 fuel switching, 213 boiler replacements and 62 ASHPs (Air Source Heat Pumps) were installed. These installations were associated with 115 substations of which ca. 100 were monitored as part of this study. We now compare profiles of power and voltage profiles between two groups of substations: (i) those with registered low carbon initiatives that might be expected to have an effect on the network and (ii) those without. The creation of these two groups and the numbers of substations available for analysis can be seen in Figure 19. In order to perform as direct a comparison of the possible effects of the installations as possible, demand and voltage (at remote feeder ends) were obtained for the substations in cluster 4. Cluster 4 is dominated by domestic customers and has the highest penetration of low carbon installations of any of the clusters.

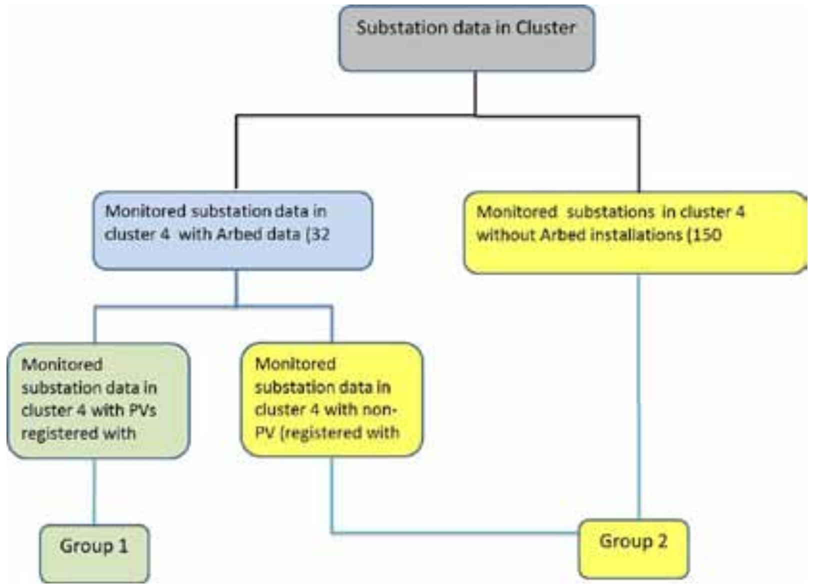


Figure 19: Schematic of the creation of two groups for analysis of the effects low carbon installations on demand and voltage profiles. Groups 1 and 2 contain substations in cluster 4 with and without Arbed registered PV installations respectively.

5.1 Assessing differences in demand and voltage profiles due to PV installations

5.1.1 Comparison of substation demand profiles

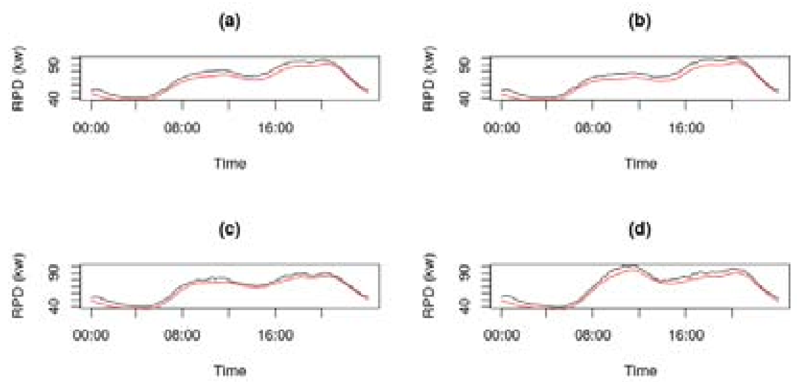


Figure 20: Substation load profiles (real power delivered) for Group 1 (black line) and Group 2 (red line). Panels show results for (a) all days; (b) Weekday; (c) Saturday; (d) Sunday.

5.1.2 Comparison of substation voltage profiles

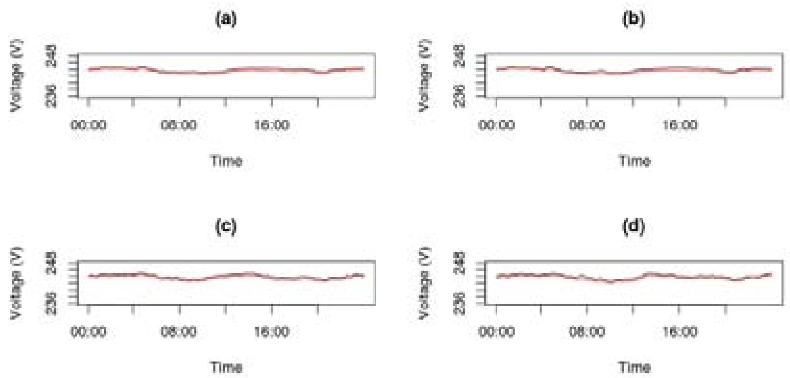


Figure 21: Substation voltage profiles (Phase A) for Group 1 (black line) and Group 2 (red line). Panels show results for (a) all days; (b) Weekday; (c) Saturday; (d) Sunday.

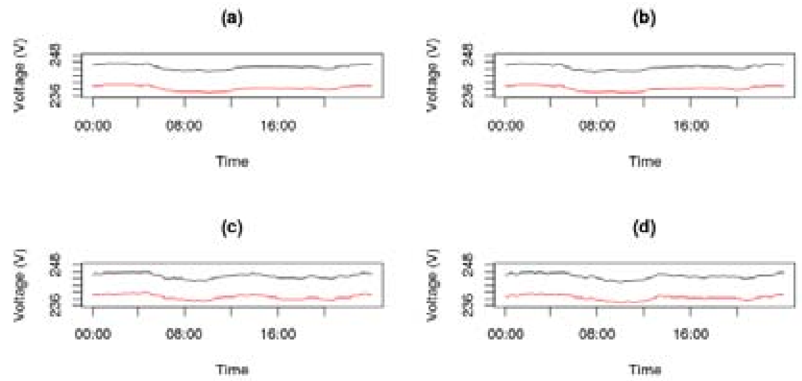


Figure 22: Substation voltage profiles (Phase B) for Group 1 (black line) and Group 2 (red line). Panels show results for (a) all days; (b) Weekday; (c) Saturday; (d) Sunday.

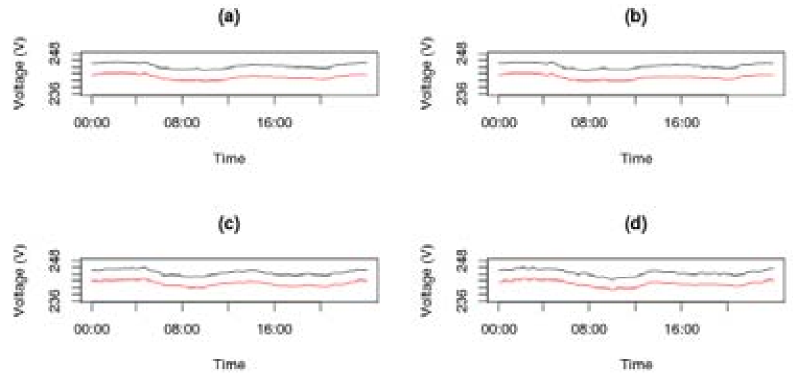


Figure 23: Substation voltage profiles (Phase C) for Group 1 (black line) and Group 2 (red line). Panels show results for (a) all days; (b) Weekday; (c) Saturday; (d) Sunday.

5.1.3 Conclusion on comparison between groups of substations with and without PV installations

- The above groups with and without PV clearly exhibit the same voltage and demand profiles. This is not as anticipated, as significant installations of PV would be expected to show a relative increase in voltage during daylight hours.
- In seeking to understand this, the findings of the PV FiT report have demonstrated that the maximum aggregate output generated from multiple PV installations within a postcode was only 81% of the declared capacity.

Consequently, since the associated voltage rise / drop is related to the square of the current, the voltage impact of the PVs is at least 36% lower than at full rated output.

- The current analysis suggests that the level of PV installed at the monitored substations had little impact on the network. This may be due to a combination of system design, assuming 100% efficiency, and possible overstatement of maximum rated output by installers. It is proposed to undertake further analysis to compare individual similar substations with or without PV and also compare individual substations on high and low solar radiation days. These findings will be disseminated.

5.2 Assessing differences in power profiles due to heat pumps

In assessing the potential effects of air source heat pumps, two substations had substantially more Arbed registered installations than all others. Two substations had 23 each (out of the total of 62 over all Arbed substations). These two substations were in clusters 5 and 6). In the following analysis, the demand profiles of the two substations in comparison to the others in their respective clusters are presented. Results are initially presented for the same period as that chosen to maximise the potential for observing difference due to PVs, i.e, high summer. As it might be expected that there might be little evidence of any effect of air source heat pumps during this period, results are also presented for winter.

5.3 Substation with 23 registered air source heat pumps compared to other substations in cluster 5.

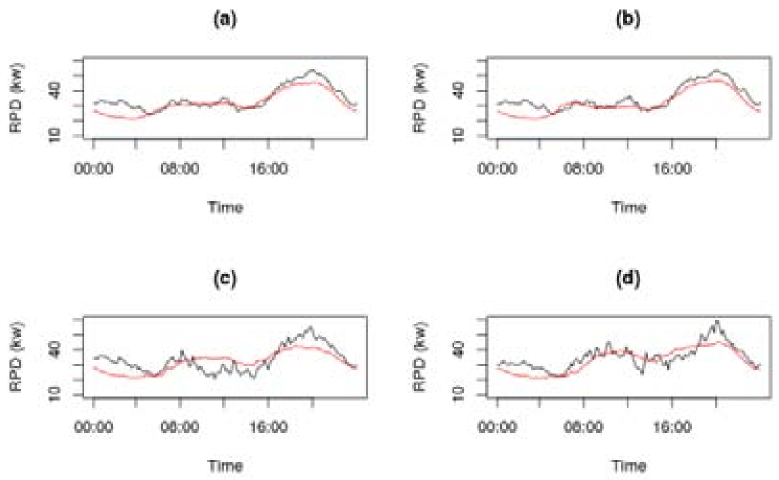


Figure 24: Substation load profiles (real power delivered) for substation in cluster 5 with 23 Arbed registered air source heat pumps (black line) and remaining substations in cluster 5, excluding substation with 23 Arbed registered air source heat pumps (red line). Results are for High summer. Panels show results for (a) all days; (b) Weekday; (c) Saturday; (d) Sunday.

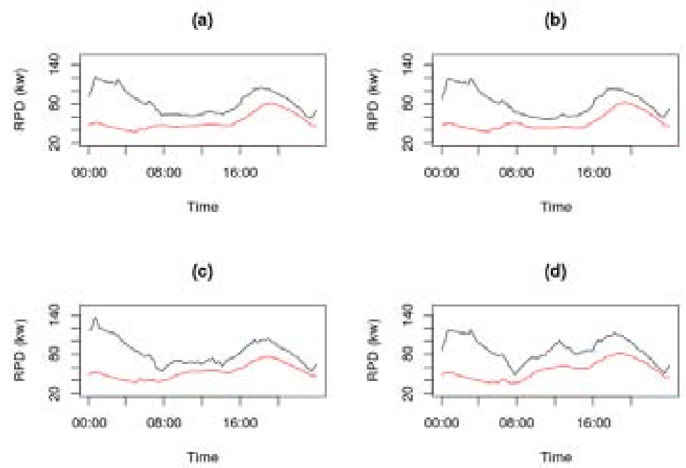


Figure 25: Substation load profiles (real power delivered) for substation in cluster 5 with 23 Arbed registered air source heat pumps (black line) and remaining substations in cluster 5, excluding substation with 23 Arbed registered air source heat pumps (red line). Results are for winter. Panels show results for (a) all days; (b) Weekday; (c) Saturday; (d) Sunday.

5.4 Substation with 23 registered air source heat pumps compared to other substations in cluster 6.

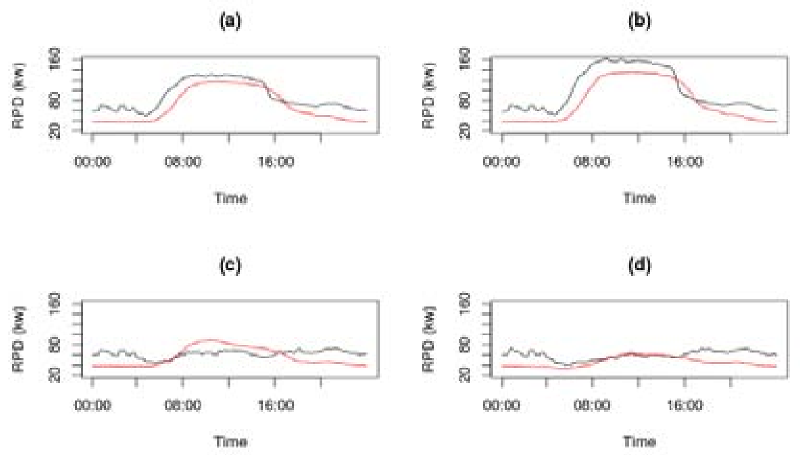


Figure 26: Substation load profiles (real power delivered) for substation in cluster 6 with 23 Arbed registered air source heat pumps (black line) and remaining substations in cluster 6, excluding substation with 23 Arbed registered air source heat pumps (red line). Panels show results for (a) all days; (b) Weekday; (c) Saturday; (d) Sunday. Results are for High Summer.

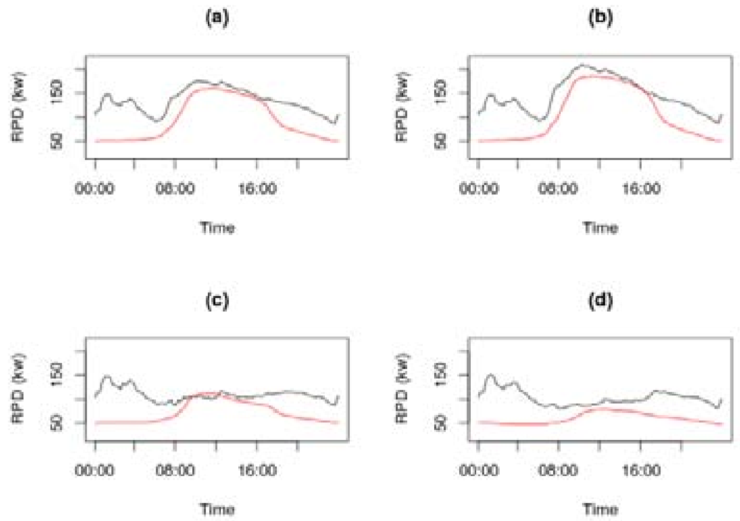


Figure 27: Substation load profiles (real power delivered) for substation in cluster 6 with 23 Arbed registered air source heat pumps (black line) and remaining substations in cluster 6, excluding substation with 23 Arbed registered air source heat pumps (red line). Panels show results for (a) all days; (b) Weekday; (c) Saturday; (d) Sunday. Results are for winter.

5.5 Conclusions

- Amongst other things, these figures show the ability of the clusters to discriminate between substations with differing customer mixes. Cluster 5 is dominated by domestic customers, the demand profile for which can clearly be seen in Figure 24 (excluding the substation with the 23 heat pumps) and the substation with the Arbed registered heat pumps in this cluster has 100% domestic customers. Cluster 6 comprises of substations that are commercially dominated as is demonstrated by the demand profiles shown in Figure 26 that shows the profiles averaged over substations excluding the one with the Arbed registered heat pumps. Relative to the majority of substations in cluster 6, this substation has a higher proportion of domestic customers, the effect of which can be seen in the different profiles observed at weekends during which the commercial load drops off, leaving the domestic load as dominant.
- In high summer there is little evidence of the effect of ASHP's within the profiles of substations, with and without ASHP's. With both Clusters 5 & 6 adopting a very similar pattern.
- In winter however there is a clear increase in demand from around 00.00hrs to 07.00hrs, which is believed to be the effect of ASHP's. This is clearly evident in cluster 5, but can also be seen in cluster 6, when the domestic load is dominating.
- It would appear that the ASHP's are operating coincidentally with Economy 7 type time of use tariff. What is evident is that, if the increased demand from ASHP's was shifted to coincide with the tea time peak (Cluster 5) or the daytime peak (Cluster 6) there could well be some network issues as a result.
- There is reduced capacity for EV overnight charging on Cluster 5 if ASHP's are connected their use would coincide with the peak overnight demand, but they could be accommodated during the working day (08.00hrs to 16.00hrs)
- When the headroom identified with this project has been exploited by the connection of greater densities of low carbon technologies there will clearly be a need to examine the case for updated or new templates

6 Adherence to voltage limits

Networks are designed to operate within UK statutory voltage limits set out over many years in the Electricity Supply Regulations and most recently in the Electricity Safety Quality and Continuity Regulations 2002(as amended). (ESQCRs) These require (Reg 27 (2)) for low voltages to be maintained between 230v +10%/-6%.

In the 2002 issued Guidance to the ESQCRs, UK Government also stated "in 1993 the UK government committed to harmonisation of low voltage tolerances across the

European Community in accordance with CENELEC document HD 472 S1. In July 2001 the CENELEC Technical Board decided to extend the existing tolerance for low voltage systems (see regulation 27(3)(b)) to 2008, at which time it is possible that further consolidation of voltage tolerances across Europe will take place".

Whilst there has not yet been a change to the wider EU LV tolerances of 230v +/- 10% - i.e an extension from -6% to -10%, it was clearly within UK Government consideration. In the event that this Project were to reveal that in practice there was widespread evidence that networks were consistently performing at or close to the lower limits, there would be a weaker case to argue for adoption of the EU limits as there would be less confidence that wholesale voltage reduction would not adversely affect larger numbers of outliers.

In this section, we present an analysis of over/under voltage problems at substations and remote feeder ends using the real-time monitored voltage data from April 2012 to end of February 2013. This project provided for long term and very widespread monitoring of voltages across ca. 800 substations, mostly with 3 phase outputs, and ca. 3600 ends of LV feeders, every 10 minutes. An individual measurement of a single phase and location is termed "an instance". This currently provides a database of ca. 180, 000, 000 measurements with monitoring still on-going. It is understood to be the largest ever check of LV network voltages in UK.

The purpose of making these measurements was threefold; to verify that the actual performance was consistently within UK statutory limits, to understand how voltage varied with daily load patterns and clusters, and to see what headroom was left relating to opportunities / constraints on installation of low carbon technologies

The monitored voltages are the averaged voltage values at 10-minitue intervals; a measurement recognised in EN 50160. Analysis has been undertaken to verify compliance with UK voltage limits and to understand the frequency, duration, magnitude, and distribution of voltages across the voltage monitors. Where instances have been identified that pass threshold criteria set near but within statutory limits, those have been subject to further detailed analysis as described below. Finally, there is discussion into the potential for adopting the EU voltage standards.

The analyses comprises of the following components:

1. Sense checking to filter out suspect data
2. Identifying patterns of lower / higher voltages; times, duration and magnitude both between substations and over time.
3. Further investigation of these patterns over seasons, days of week , hours and locations
4. Assessing the potential for adopting EU voltage standards; extending the lower boundary from -6% to -10% (with the upper boundary unchanged).

6.1 Sense checking

It is recognised that there is a potential for problems in data acquisition, transfer and storage and consequently the analysis undertaken has had sense checking inbuilt to the process. Given that voltages measured are 10 minute averages, as recognised by EN 50160, a fault or loss of supply impinging within that 10 minute period will be reflected as a lower average voltage; it is thus necessary to set some boundaries that are wide enough not to exclude genuine under or over voltage problems that would clearly generate a customer contact. Measurements above 276V and below 184V at both substations and remote feeder ends were deemed to fall into this category and were excluded from the following analyses. Figure 28 shows the limits used for this sense checking

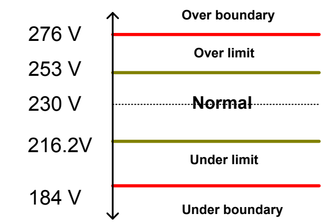


Figure 28. Criteria for sense-checking voltage measurements. Upper boundary for inclusion in analysis, 276V, lower limit 184V. The UK limits of 216.2-253V are shown together with EU lower limit of 207V.

6.2 Network pressures under the UK standards

6.2.1 Voltages measured at substations

Out of the 84,300,929 measurements of voltage made at 828 substations during this time period, 81,105,726 were within the range 184-276V and are used in the following analysis. Out of these, 99.31% (80546257 measurements) were within the UK limits of 216.2-253V and 0.69% outside. The split of those outside limits were 0.0078% below the lower limit and 0.69% above the upper limit

Table 11 shows the distribution of the magnitude of the measurements that were outside the limits. Figure 29 shows the distribution of measurements above the UK limit of 253V by substation that shows that the majority of substations have very few occurrences. Figure 30 shows the corresponding information for the small number of measurements that were under the limit of 216.2V.

Range: 230 V+/- given percentage	Percentage
>10% (>253V)	0.69%
8 to 10% (248.4V, 253V)	6.98%

6 to 8% (243.8V, 248.4V)	49.17%
-2 to -4 % (220.8V, 225.4V)	0.00076%
-4 to -6 % (220.8V, 216.2V)	0.00025%
-6 to -10% (216.2V, 207V)	0.00025%
<-10% (207V<)	0.00053%

Table 11: Distribution of the magnitude of voltage measurements measured at substations.

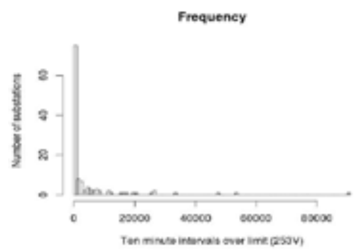


Figure 29: Distribution of measurements above the UK limit of 253V by substations

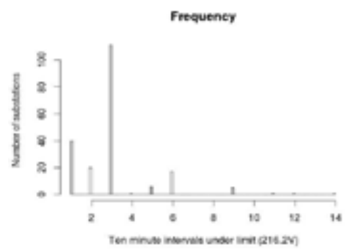


Figure 30: Distribution of measurements below the UK limit of 216.2V by substations

6.2.2 Voltages measured at remote feeder ends

There were 96,407,984 measurements from remote feeder ends which were inside the sense checking boundaries (97.7% of the total of 98,663,154 ten minute interval measurements). Of these, 99.62% were within the UK limits 216.2-253V and 0.38% outside. The split between those outside these limits was 0.021% below the lower limit and 0.35% above the upper limit.

Table 12 shows the distribution of the magnitude of the measurements respective to 230V. Figure 31 shows the distribution of measurements above the UK limit of 253V by remote feeder end monitor which shows that the majority of substations have very few occurrences. Figure 32 shows the corresponding information for the small number of measurements that were under the limit of 216.2V.

Range: 230 V+/-	Percentage
>10% (>253V)	0.35%
8 to 10% (248.4V, 253V)	5.22%
6 to 8% (243.8V, 248.4V)	32.30%
-2 to -4 % (220.8V, 225.4V)	0.1234%
-4 to -6 % (220.8V, 216.2V)	0.0437%
-6 to -10% (216.2V, 207V)	0.0187%
<-10% (<207V)	0.0022%

Table 12: Distribution of the magnitude of voltage measurements measured at remote feeder ends.

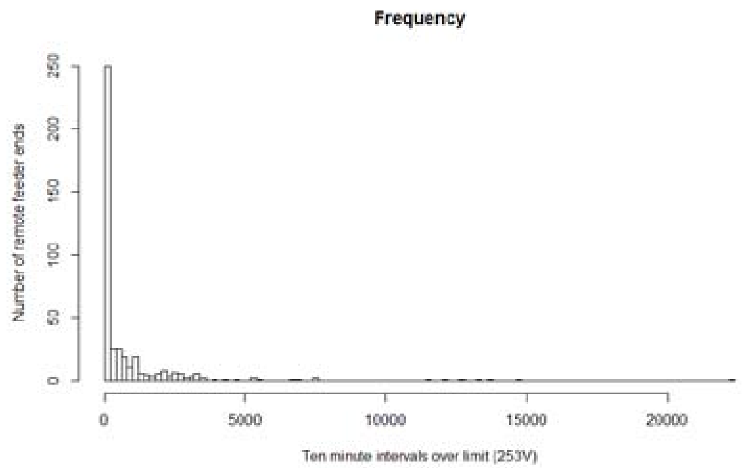


Figure 31: Distribution of measurements above the UK limit of 253V by remote feeder ends.

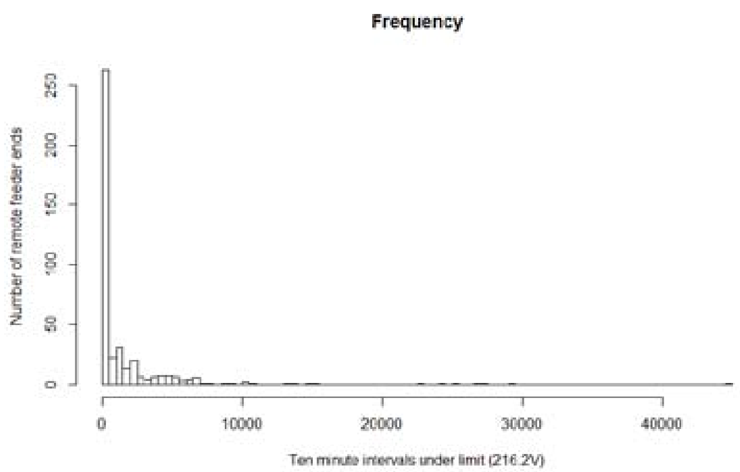


Figure 32: Distribution of measurements below the UK limit of 216.2V by remote feeder ends

6.3 Network Pressure Analysis under EU Standards

This section examines the difference that would be made by moving to the wider EU voltage standard, 230 +/-10%.

Had the preceding analysis revealed a widespread problem with multiple locations at the limit or in breach of the current UK lower voltage limit, it would suggest that the additional "headroom" which would be afforded by the move to the lower EU limit was already being exploited (in breach of current UK ESQCRs). Since that has not been the case, there is an argument that a reduction of some 2.5%, which is a tap step on ground mount transformers, could be applied without danger of substantial numbers of LV connected customers actually experiencing voltages under lower EU limit. A similar level of voltage reduction could be applied by re-setting target voltages at primary substations.

The benefits to UK and Customers would arise from the demand reduction associated with lower supply voltage. For purely resistive load a 2.5% reduction in voltage amounts to a 2.5% reduction in instantaneous demand (kW). In practice some types of demand, e.g. heating, may still use the same amount of energy (kWh), but over a longer time period. A midline estimate would be that 2.5% voltage reduction would produce around 1.5% reduction in demand. This would benefit

- network capacity,
- need for reinforcement,

- headroom to deploy low carbon demand technologies reduction in network losses
- reduction in peak UK demand, meaning displacement of low merit and least efficient generation
- reduction in UK CO2 emissions

The following paragraphs illustrate the different numbers of instances of out of limit voltage instances that would have applied in this Project had the EU lower limit been in place. The results for the upper limits remain as before given that UK and EU limits are the same.

In this scenario, the total number of measurement locations (remote feeder ends) that have under voltage drops from 152 to 32 and the total voltage instances reduce to 2019, accounting for 0.0022% of all voltage measurements, as can be seen in Figure 33.

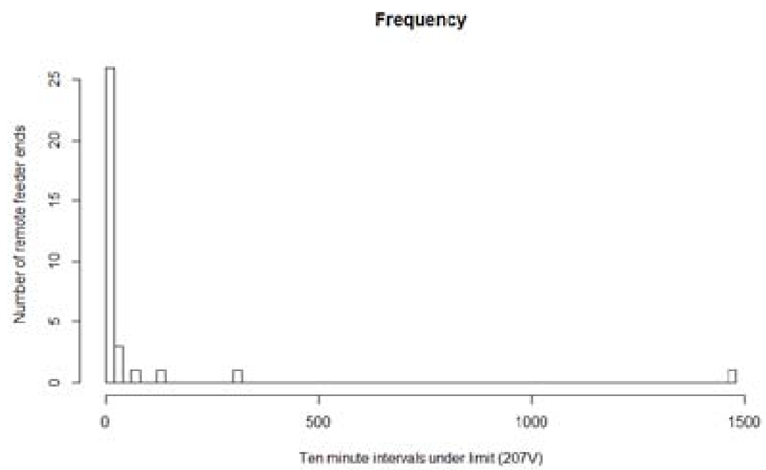


Figure 33: Distribution of measurements below the EU limit of 207V by remote feeder ends

6.4 Conclusions

The above analysis leads to the following observations

- The current system behaves extremely well with only 0.38% of some 96 million voltage measurements being outside the range 216.2-253V over the eleven month period considered here (April 2012-February 2013)
- The data shows that in the few cases where the LV networks do have out of limit voltages the majority of incidents are over limit voltage problems rather than under limit problems; 0.35% of remote feeder ends were

observed to be over-limit compared to 0.0187% 230V -6 to -10% and 0.0022%below -10%;

- There are very few measurement locations (feeder ends) that have a persistent over/under limit problems,
- Most of the Measurement locations have only limited time of over voltage problems, and only very small number of Measurement locations have prolonged over voltage problems
- Of the small number of cases of under voltage, 90% fall within the EU voltage limits.
- To put a scale of value to adoption of the EU voltage limits, a 1.5% fall in energy use through voltage reduction of 2.5% across only half of the 230,000 UK ground mounted distribution transformers, at an average of 150 domestic customers per transformer would save some 850,000 MWh p.a. (Using Ofgem factsheet 96, 2011, average UK domestic electricity customer of 3,300kWhr). Using the cost per unit valuation from the same factsheet, at 12.8p / unit), the value of that saving to domestic end customers is over £100M p.a If voltage reduction were more widespread and included pole mounted connected customers, through adjustment of primary substation target voltages, the savings would be higher.
- Statistical analysis has identified 10 cluster types, having differing capabilities to absorb low carbon generation or demand technologies. A detailed report on these clusters is to be published, in line with the Ofgem Project Direction, in July. Use of these clusters will aid network design planning and loss reduction. Findings from the Proxy PV FiT meter report have identified significant capacity headroom for LV PV installations.

8. References

1. "UK Renewable Energy Roadmap –Update 2012", DECC, Dec 2012,
2. Low Carbon Transition Plan, DECC, July 2009.
3. Carbon Plan Updates, DECC, Dec 2011.
4. Benefits of Advanced Smart Metering for Demand Response based Control of Distribution Networks, G. Strbac, *et al.*, April 2010.
5. A Low Carbon Revolution –The Welsh Assembly Government Energy Policy Statement, March 2010

38

APPENDIX 3

LV Network Templates for a Low Carbon Future

Report on the use of proxy PV FiT meters to reflect local area Generation

Version: 1.0
Authored by: Dr Gavin Shaddick
Recommended by: Mark Dale
Approved by: Roger Hey

Western Power Distribution (South Wales) plc
Registered in Wales No. 2366985
Registered Office: Avonbank, Feeder Road, Bristol, BS2 0TB

1

Using proxy PV FiT meters to reflect local area generation output

Table of Contents

1. Executive Summary

This report is one of three major reports that investigate the aforementioned challenges as part of the work undertaken by WPD in the LCN funded "LV Network Template Project":

1. Stresses on the LV network from low carbon installations
2. Use of proxy PV FiT meters to reflect local area Generation
3. Demonstration of LV Network Templates through statistical analysis

The ability to cost effectively obtain a real time view of the output of multiple small-scale local PV installations via a single "proxy" feed-in tariff (FiT) meter would aid in smart local network control, planning and generation forecasting. This report examines the feasibility of such proxy PV FiT metering.

In order to understand the capability of being able to undertake FiT proxy metering, an initial sample size study was undertaken by the University of Bath that identified that the monitoring of 250 PVs would be required in order to credibly assess the variability of PVs within the South Wales area. Therefore, in addition to half hourly data being collected from 80 FiT NPower customers another 525 PV outputs from Passiv System was collected for the period of January – December 2012. The Arbed, Passiv and Npower data sets have allowed us to credibly identify a number of key findings, such as:

- The use of proxy PV FiT metering can be adopted to accurately reflect the local distributed generation connected to the network, which can then be factored up

- The use of proxy PV FiT meters across multiple postcodes can be fed into DNO SCADA systems providing National Grid with real time PV generation information at Supergrid Point level. This provides National Grid with greater visibility of the hidden demand whilst improving their demand / spinning reserve forecasting capabilities

- The Installed capacity of PV installation does not represent the actual generation output seen on the LV Network. The orientation and bearing of each individual installation is critical to its output. This combined with the solar irradiance levels in the project area result in a maximum of only 81% of the installed capacity being visible on the LV network. As network planning and design is in part based upon the maximum distributed generation capacity, the effect of the above would be an overstatement of installed peak rating, even though the annual kWh calculation for PV FiT was accurate. Such a finding would mean that there is even more than 19% overstatement of peak rating in more northerly parts of the UK from South Wales, and slightly less to the South Due to the variation in solar irradiation. For additional analysis on the effect of stresses on the LV network please refer to the Stresses Report

As identified above and throughout this report, the ability of being able to adopt proxy PV FiT metering as well as the understanding of the true installed capacity versus actual output helps to provide a credible representation of the load, voltage and demand flows across the network. Potentially delivering cost savings to connection customers as network planning and the timely reinforcement of the network is improved.

Moving forwards, these findings will be adopted into WPD's Planning and Design policies and rolled out throughout the company. They will also be disseminated to the other DNO's through the publishing of this report and future event workshops.

It is important that this data continues to be collected and analysed to fully understand the impact on the LV network that advances in technology and numbers installed may have.

2. Introduction

The UK government has committed to reducing the greenhouse gas emission by at least 80% by 2050 relative to the 1990 level. The UK Renewable Energy Strategy lead scenario envisaged ambitious targets of 30% of electricity generated from renewables, 12% of heat generated from renewables and 10% of transport energy from renewables. In its December 2012 update to the UK renewable energy roadmap, DECC confirmed the commitment of meeting 15% of UK energy demand from renewables by 2020. It also recognised that the uncertain nature of deployment across the portfolio of technologies as well as relative cost effectiveness means that generation may end up at the high end of one technologies deployment range therefore requiring less deployment of others. Solar PV is now included as a key technology. Taken with the Governments Low Carbon Transition Plan the energy sector is facing significant changes, both in the mix of generation and the patterns and types of consumption, impacting on the design and operation of electricity distribution networks. The connection of low carbon technologies will have significant impact on the HV/LV transformers and on low voltage networks. The maintenance of voltages is further impacted by the introduction of LV connected renewable generation technologies such as PV having weather and time of day/ season variable output. It is thus important to DNOs to understand in detail the related time of day and seasonal performance of the HV/LV substations and LV networks to determine the times when there is capacity and voltage headroom available to accommodate these new low carbon stresses. By so doing the costs of connection of these technologies can be reduced by better utilising the network and understanding the opportunities for the deployment of smart demand / generation.

2.1. The LV networks project

As identified in our LCNF submission the "LV Network Template Project" sought to explore;

- explore the effect of stresses on the network from low carbon installations
- examine the statistical validity of so called templates characterising the daily and seasonal demand profiles, and associated voltage profiles to identify what headroom, if any, exists to accommodate new low carbon stresses.
- examine the ability to use a limited number of "proxy" Feed in Tariff (FiT) Meters to reflect the behavior of neighbouring low carbon generation and, in combination

4

with the templates above, understand what network headroom there might be to absorb further low carbon stresses

In setting up the Project and selecting the study areas, WPD had no control or investment in provision of low carbon generation, but sought to utilise the generation being installed under the Welsh Government's "ARBED" initiative. The dominating technology within the LV connections area that is the subject of this LCNF project has been PhotoVoltaic, PV installations. The ARBED scheme has provided a valuable opportunity to examine the network impacts of multiple installations e.g. on social housing estates, within small network areas; an issue of concern to DNOs. The Project has sought to explore through monitoring of PV outputs and examination of coincident network voltages whether additional headroom exists, allowing existing network planning criteria to permit further generation connections without the need for costly reinforcement.

A further important strand to the project is to assess the statistical case for using a limited number of the PV FiT meters to reflect the aggregate output of multiple others in the locality. If proven, it would provide a lower cost smart network control input to enable "smart" dynamic interaction of network demand and generation at local level, to further enable absorption of low carbon generation.

This will also provide National Grid with a real time view of actual PV generation down to the LV network, showing "backed off / hidden" demand at the Supergrid Point level when the Proxy PV FiT meters are in turn aggregated via DNOs existing SCADA systems. The DNO ENMAC SCADA / NG XA21 system linkage is the subject of another ongoing WPD LCNF (Tier 1) Project number WPDT1001.

In order to understand how PVs might impact on distribution networks, it is necessary to determine the output profiles of PVs and to be able to assess potential variations in outputs between locations and over time.

Monitoring the outputs of all PV installations in area would achieve the most accurate representation, however is very expensive and would need to overcome the difficulty of obtaining customer consent. Within small areas and time periods, sunlight and cloud cover and thus the underlying potential for PV generation likely to be similar with actual output being dependent on characteristics of a particular installation. These characteristics will include the maximum capacity, bearing, inclination and elevation. In this report, we assess the potential for using the measurements from a single meter within a small area to act as a proxy for other installations. This is achieved by isolating underlying output profiles and by applying correction factors dependent on the characteristics of the installations within the area.

5

3. Aims

The overall aim of this report is to assess the validity of using the outputs from a sample of photovoltaic installations (PVs) to represent those from a wider group.

Specifically we are interested in:

1) The relationship between the magnitude of outputs and characteristics of the PVs such as their capacity (size), inclination, direction and elevation
2) Patterns of outputs over time and space, specifically changes in outputs within days and proximity
3) The development of a statistical model to predict the outputs of all PVs within a small area based on the output of a sample within that area
4) Approaches for the practical implementation of the prediction model in small areas within the South Wales region
5) Measurement of the bias that may result from treating the output from a single PV within a small area as representative of others within that area
6) The relationship between actual output of PVs compared to their potential outputs

To facilitate wider dissemination and understanding to the academic community and industry, this report has been prepared by Bath University, aided by WPD

4. Photovoltaic outputs in South Wales in 2012

4.1. Data

The collaboration with nPower resulted in measurements from over 80 PV installations. Previous work on the size of the sample required in order to assess the variability of PVs within the South Wales area indicated that a sample of closer to 250 would be preferable (see Appendix for details). For this reason, this data was supplemented with measurements for a large number of PVs acquired from Passiv systems. The data consisted of PV outputs for 525 PV installations within the South Wales area for the period January – December 2012. The locations of the installations were known at the postcode district level and Figure 1 shows the locations of the installations within the study region. Additionally, the outputs from the installations, details of their maximum capacity, inclination, bearing and elevation were also obtained in order to calculate the potential outputs and relationships.

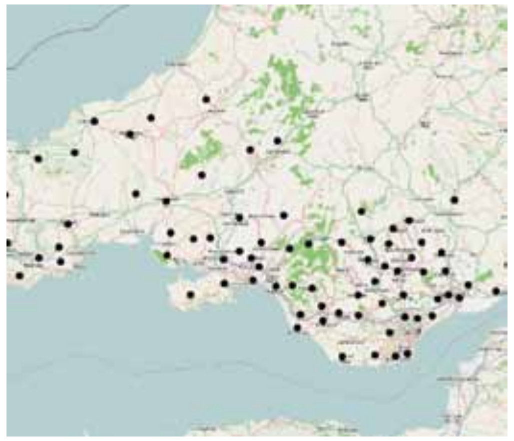


Figure 1: Locations of PV installations within the study region (centroids of the postcode district containing the installation).

The measured data took the form of half hourly measurements of generated energy (kWh). Data was not consistently available from all installations throughout the time period under consideration. Figure 2 shows a schematic of this in which each row relates to one of the 525 installations with blue lines indicating that data is available and yellow lines non-availability.

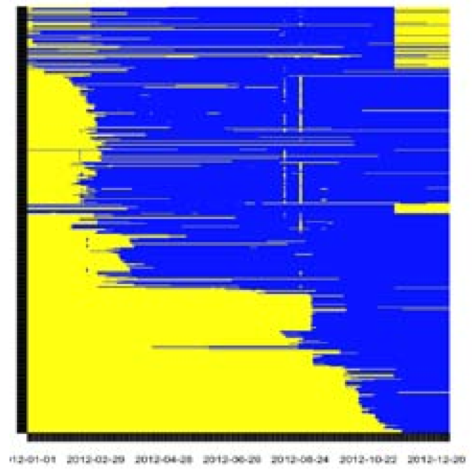


Figure 2: Schematic of data availability over time. Rows represent individual installation: blue lines indicate data available, yellow lines non-availability.

There was considerable variety in the number of installations within each 75 postcode districts that contributed to our overall data analysis. The largest, in terms of the number of installations, was CF45 that contained 51 PVs whilst Seventeen PC districts contained only a single PV per district. A more detailed overview of the distribution of PVs by postcode district can be seen in Table 1.

Postcode sector	Number of PVs	Postcode sector	Number of PVs
CF45	51	CF33	13
CF3	46	SA4	12
SA18	32	NP44	12
SA14	25	NP22	12
CF32	22	NP20	12
NP11	21	CF37	11
CF38	18	SA16	10
SA12	15	CF44	10
SA15	14	All others <10 PVs	

Table 1: Numbers of PV installations for postcode districts having more than 10 PV installations

There is considerable variation in the populations of the postcode districts in the study with the largest (in terms of population at the 2011 census) being CF14 with a population of 77,856 and the smallest SA41 (1,882). The mean population was 25, 174 (standard deviation 15528) with a median of 22, 273 and an inter-quartile range of 13-849-36,775. A full list of the populations for the postcode districts in the study can be found in the Appendix.

4.2. Variability in PV output profiles.

There is considerable variability in the outputs from different PV installations across South Wales within a single day. An example can be seen in Figure 3 that shows the output from the 525 PVs supplying data on August 17th 2012.

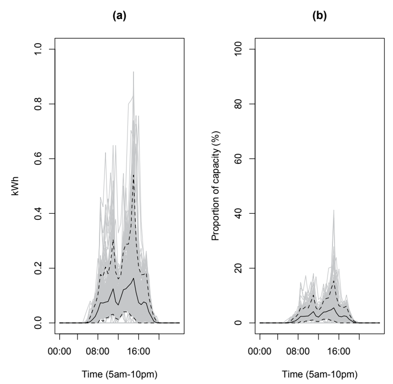


Figure 3: Outputs from 525 PV installations per half hour period for August 17th 2012. Grey lines show outputs from individual PVs, solid black line is the mean over all installations and dotted lines show the 5th and 95th percentiles. Panel (a) shows the actual measured data and (b) normalized values (proportion of actual capacity)

A substantial component of this variability is likely to be due to differences in cloud cover, together with the maximum capacity, inclination, bearing and elevation of the PV. The distributions of the latter factors for the 525 PVs can be seen in Figure 4.

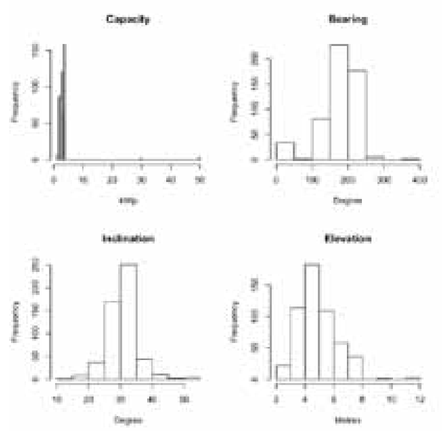


Figure 4: Histograms showing the distributions of capacity, inclination, bearing and elevation.

4.3. The effects of inclination and bearing

The latitude of the installation (i.e. the elevation of the sun for the time of year) and cloud cover dictate the available solar radiation at any location. The efficiency of a solar panel installation in capturing that radiation is then influenced by inverter efficiency, the inclination and bearing. The optimum inclination and bearing vary according to geographical area. In the UK, PVs should ideally face south with an inclination between 30-40 degrees. The received energy as a proportion of that which would be received by an optimal orientation (denoted henceforth as Received as a Proportion of Optimal, RPO) under different combination of inclinations and bearings are presented in Table 2 (source: http://www.eci.ox.ac.uk/research/energy/downloads/pv-inthe-uk.pdf).The inclination is the angle between PV panel and the horizon and a bearing of 180 represents South.

Inclination / Bearing	10-20	20-30	30-40	40-50	50-60
0-15	0.79	0.74	0.60	0.58	0.49
15-45	0.80	0.77	0.65	0.63	0.52
45-75	0.82	0.80	0.74	0.72	0.63
75-105	0.89	0.87	0.86	0.82	0.78
105-135	0.92	0.93	0.93	0.9	0.88
135-165	0.95	0.97	0.98	0.97	0.95

165-195	0.96	0.98	1.00	1.00	0.97
195-225	0.95	0.97	0.98	0.98	0.96
225-255	0.93	0.94	0.94	0.92	0.89
255-285	0.90	0.88	0.86	0.84	0.8
285-315	0.82	0.80	0.74	0.72	0.62
315-345	0.80	0.77	0.65	0.63	0.52
345-360	0.79	0.74	0.6	0.58	0.49

Table 2: The received energy as a proportion of that which would be received by an optimal orientation (RPO)

A statistical analysis of the effects of these factors found that size, inclination and bearing had a significant association with output but elevation did not. Defining 'orientation' to denote the combined effects (as described above) of the inclination and bearing also had a significant association with no significant reduction in the variation explained compared to using the two separate variables.

The distribution of the different proportions of received energy (RPO) due to the orientations of the PVs in this study can be seen in Figure 5.

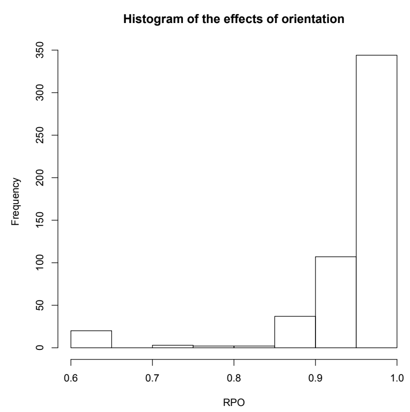


Figure 5: Distribution of RPOs: the received energy as a proportion of that which would be received by an optimal orientation (RPO) for the 525 PV installations in South Wales, 2012.

5. A statistical model for PV outputs

The aims of developing a statistical model for the PV outputs are to assess whether measurements from single meter can be used to represent the outputs from other meters within a small area (which, in terms of the resolution of the available data are postcode districts). The rationale is that the potential for PV generation will be dependent on sun elevation and cloud cover which might be expected to be the same over a small enough area. Within such areas, differences in output over time will still be observed due to differences in the capacity and orientation of individual installations. The aim of the

10

statistical model developed here is to estimate the effects of these differences on the outputs. Given these estimates, we can assess how accurately the output from a single PV installation can be used to predict those from installations in the surrounding area.

The aims of the statistical modelling are as follow:

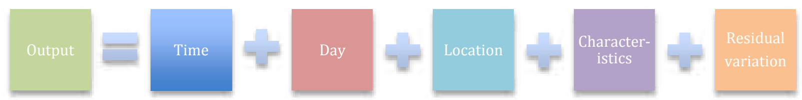
(i) to examine the contribution of variations over space (both between individual installations within postcode districts and between postcode districts) and time (within and between days)

(ii) to obtain underlying profiles of outputs

(iii) To obtain estimates of the effects of the capacity and orientation for use in predicting outputs from other installations and enable subsequent assessments of bias.

The statistical model acknowledges the contribution of these different components to the overall variation in PV output within the study region. Due to the constraints of non-negativity, skewness and the appropriateness of a multiplicative structure for combining the effects of different factors when predicting outputs, the log of the output is modeled as a function of time, space and characteristic factors.

The following shows the components of the model that define the output as functions of time, day, location, the combination of which will act as a proxy for sun elevation and cloud cover at any particular point in time and space, together with the characteristics of a particular PV installation.



(i) Output: log(kWh) per 30 minute interval measured at an individual installation

(ii) Time: Time interval within the day (from 5am to 10pm)

(iii) Day: Effect of time within day is permitted to vary across days

(iv) Location: The effects of time and day may vary between postcode districts

11

(v) Characteristics: Adjustment for the maximum capacity and orientation of the individual installation

(vi) Residual variation: The difference between the measured data for a 30 minute interval and what can be explained using the model.

Further details of the statistical model can be found in the Appendix.

6. Predicting PV profiles

This section presents an example of how the output from a single PV installation within a small area can be used to represent the measurements for other installations within close proximity. Examining the output profiles within a small area shows clear variation between the outputs from the individual PVs, much of which will be due to differences in the maximum capacity and orientation. The estimates of the effects of these characteristics gained from the statistical modelling can be used to 'correct' the output from a single installation to give an underlying (or average) profile. This underlying profile can then be used as a basis for prediction of the outputs for installations within that area, by adjusting the underlying profile to take into account differences in size and efficiency. This modelling is performed on the actual measurements from the PVs, in Section 9 we consider the outputs as a proportion of the maximum capacity.

6.1. Illustrative example: PV output in CF38, August 17th 2012

For the purposes of illustration, we use postcode district CF38 which contains 12 installations. Figure 7 shows the outputs for these 12 installations between 5am and 10pm on August 17th 2012.

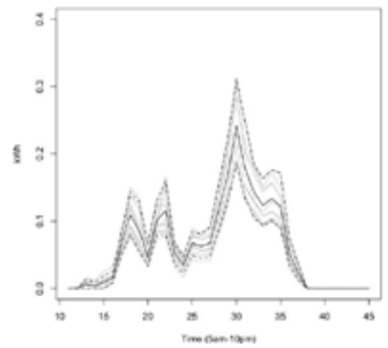


Figure 7: Output from 12 PV installations per half hour period for August 17th 2012 in postcode district CF38. Grey lines show outputs from individual PVs, solid black line is the mean over all installations and dotted lines show the 5th and 95th percentiles.

12

To illustrate the potential for using the output from a single PV to predict the outputs from other installations within a postcode district we consider the 12 PVs in the CF38 postcode district for a single day (August 17th 2012).

Each panel in Figure 8 shows the results of taking the output from a single PV (black line) and using this to predict the outputs for the remaining eleven PVs for that day (grey lines), adjusting for differences in size and the effects of orientation. It can be seen that set of predictions throughout the panels, i.e. using different installations as the basis, are very similar.

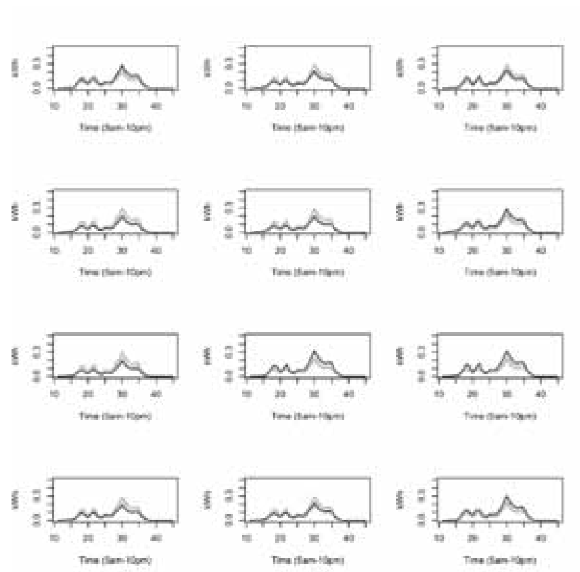


Figure 8. Predictions of PV outputs within a postcode district (CF38) for August 17th 2012. Each panel shows the predictions of outputs for PVs based on measurements from a single PV. Black lines show the data used for the predictions (from one PV) with grey lines the predictions for the other eleven within this postcode district.

7. Measuring bias in predicted outputs

Comparing the differences between the predicted outputs for each PV with its measured values allows us to estimate the bias that would be associated with using this approach.

In the example presented there are twelve choices of which installation could be used on which to base the predictions. Ideally this choice would not have a large effect on the accuracy of the predictions, although it might be expected that more stable predictions might be made from installations which are likely to represent the majority of other installations, i.e. do not represent unusual factors such as very large or small PVs or very inefficient ones.

13

7.1. Measures of bias

There are a number of ways of representing the bias that may occur using a predictive model in this way. The choice of methods used to assess the bias will be determined by the intended use of the predictions.

Here we present two methods for estimating bias; at individual time intervals (Method A) and cumulative over longer periods of time, e.g. days (Method B)

Assessing errors at individual time intervals, over single or aggregated over multiple areas, might be important for real-time operations or for periods of high stress on the network. Alternatively, for billing purposes interest may lie in the total difference over a day or longer period of time.

Method A

One approach is to compare the difference between the measured and predicted values at each time interval and calculate the root mean squared error (RMSE). This will result a set of n(n-1) RMSEs where each of the n installations is used to predict outputs for the other (n-1).

For the *kth* set of predictions at time interval *i* for installation *j*;

$$RMSE_{ij} = \sqrt{\frac{\sum_{i=1}^{35}(X_{ij}-Y_{ijk})^2}{35}} \quad for\ j \neq k$$

From this set of RMSEs, summaries can be calculated for example mean, minimum and maximum that can be used to indicate different aspects of the differences.

The mean difference (over the set of predictions from different installations) is defined as:

$$BiasA = \sum_{k=1}^{n}\sum_{j=1}^{n}\sqrt{\frac{\sum_{i=1}^{35}(X_{ij}-Y_{ijk})^2}{35}} \div n \div (n-1)\ for\ j \neq k$$

Method B

An alternative approach is to consider differences in the output (predicted and measured) over an entire day (or longer period). For one set of predictions, *k,* for a day within area, this is calculated as follows:

$$BiasB = \frac{\sum_{j=1}^{n}\sum_{i=1}^{35}X_{ij} - \sum_{j=1}^{n}\sum_{i=1}^{35}Y_{ijk}}{\sum_{j=1}^{n}\sum_{i=1}^{35}X_{ijk}} \times 100\%$$

14

Where n is the number of installations within the area.

Again, summaries can be calculated for example mean, minimum and maximum that can be used to indicate different aspects of the differences.

The mean value (over the set of predictions) of the summed bias is calculated as follows:

$$Bias.sum.mean = \sum_{k=1}^{n}\frac{\sum_{j=1}^{n}\sum_{i=1}^{35}X_{ij} - \sum_{j=1}^{n}\sum_{i=1}^{35}Y_{ijk}}{\sum_{j=1}^{n}\sum_{i=1}^{35}X_{ijk}} \times 100\% \div n$$

7.2. Illustrative example: Biases in PV output in CF38, August 17th 2012

For the twelve installations within the CF39 postcode district, each is taken in turn as the basis of predictions for the other eleven. Plots of the predicted versus measured outputs can be seen in Figure 9 in which each panel shows the results from choosing one of the twelve installations as the basis of the predictions. The coloured dots represent the predictions of the outputs from the other eleven installations.

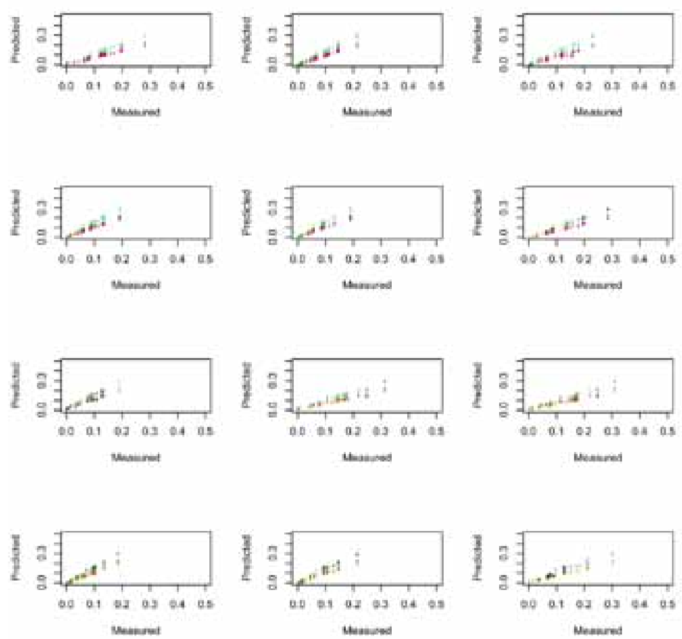


Figure 9: Comparison between predicted and measured PV outputs for twelve installations in CF39 postcode district on August 17th 2012. Panels show results from using different installations as the basis for predictions.

15

The root mean square error (RMSE) corresponding to each panel (Method A) in Figure 9 can be seen in Table 3.

Predicted	Based on installation 1	2	3	4	5	6	7	8	9	10	11	12
1	0.024	0.024	0.019	0.031	0.031	0.008	0.036	0.016	0.018	0.03	0.024	0.007
2	0.019	0.018	0.018	0.007	0.008	0.026	0.013	0.038	0.04	0.007	0.001	0.031
3	0.032	0.007	0.023	0.023	0.024	0.021	0.028	0.027	0.027	0.019	0.018	0.024
3	0.032	0.008	0.024	0.001	0.001	0.034	0.007	0.045	0.047	0.006	0.008	0.038
4	0.007	0.026	0.02	0.033	0.033	0.034	0.007	0.045	0.047	0.007	0.008	0.038
5	0.036	0.013	0.028	0.007	0.006	0.039	0.039	0.018	0.019	0.031	0.025	0.009
6	0.016	0.037	0.027	0.044	0.044	0.017	0.049	0.05	0.052	0.011	0.014	0.043
7	0.018	0.039	0.026	0.045	0.046	0.019	0.05	0.005	0.005	0.042	0.037	0.012
8	0.03	0.007	0.02	0.006	0.007	0.032	0.012	0.043	0.044	0.043	0.038	0.015
9	0.024	0.001	0.018	0.008	0.008	0.026	0.014	0.037	0.039	0.008	0.008	0.037
10	0.007	0.031	0.024	0.037	0.038	0.009	0.042	0.012	0.015	0.036	0.03	0.03

Table 3: Root mean squared errors for predictions of PV outputs at half hourly intervals on 17th August in CF38

In terms of the worst case scenario, i.e. the choice of which installation on which to base the predictions, the maximum value of the average of the biases is 0.032 and occurs when installation 9 is chosen on which to base the predictions of the other installations.

Table 4 shows the summed bias (using method B) between predicted output and real output for the PVs in CF38 on 17th Aug. Results are given for using each of the 12 PVs as basis for predicting the others. The maximum bias observed is ca. 30% and the minimum 1.2%. The mean is 18.2%. Here the minimum bias occurs when the PV chosen (which has a maximum capacity of 2.82) on which to base the predictions of the others in the area lies at the centre of the distribution of the values of maximum capacity of all the installations in the area (mean = 3.06, range = 2.3-4.0) and has high RPO (98%). This pattern is seen through the analysis.

Monitored PV	Summed Bias (%)	Monitored PV	Summed Bias (%)
1	13.1	7	29.6
2	11.7	8	25.3
3	1.7	9	28.1
4	20.5	10	16.1
5	21.1	11	11.4
6	19.6	12	20.1

Table 4: Summed Bias for 12 installations in CF38 on August 17th 2012.

8. Assessing bias over the entire study area and period

Choosing a single day in a single area is not likely to give an accurate representation of the magnitude of biases that might be expected to occur. Based on the premise that it is will more difficult to predict outputs for postcode districts where there are larger numbers of installations we have selected a number of the larger postcode districts and run the analysis for a set of days which were selected to represent times when there are differing amounts of variability in PV outputs.

Table 5 shows the selection of areas and times used in these analyses. Details of the results from the individual analyses can be found in the Appendix.

AREA (postcode district)	DAY(S)
ALL	17th February
CF**	17th April
NP**	17th August
SA**	21st December
CF38	11th – 17th August
SA14	
NP11	

Table 5: Selection of areas and times used to assess bias over the study area and period

The patterns of bias seen in the example (CF38, August 17th) are repeated over these periods and areas. The minimum of the summed biases (Method B) for the entire study area is 0.26% for the same period (1.7% for CF38). For the same day, the equivalent biases for the other two postcode districts are 2.02% (SA14) and 1.35% (NP11). For the larger areas the corresponding figures are 0.01% (all CF** postcode districts), 0.65% (NP**) and 0.05% (SA**). The largest of these biases for single days was 7.82% (SA14, February 17th) and the smallest 0.83% (SA14, December 21st). When considering a week (11th-17th August), the biases ranged from 0.15% (SA14) to 8.09% (CF38). In all cases, the corresponding figures for the larger areas were smaller (ranging from 0.1%, NP** to 0.39%, SA**)

This analysis of biases over aggregation of space (in terms of multiple areas) and time (in terms of days) shows that differences between the predicted and measured values tend to 'even out' over larger time periods.

9. Installed capacity against actual output

The distribution of maximum capacities of the 525 installations can be seen in Figure 4 and the distribution of the received energy as a proportion of that which would be received by an optimal orientation (RPO) in Figure 5. Figure 10 shows the distribution of maximum capacity multiplied by the RPO (henceforth referred to as 'actual capacity')

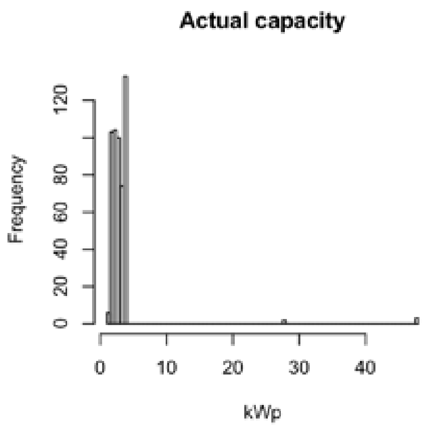


Figure 10: Histogram showing the actual capacities (maximum capacity * RPO) of the 525 PV installations in South Wales, 2012.

9.1. Illustrative example: PV output in CF38, August 17th 2012

Figure 11 shows the output from the 12 installations in CF38 for the 12th August as percentage of actual (green line) and maximum (red line) capacities. The maximum percentage of the actual capacity was 11.6% with a mean of 2.1% over the period 5am-10pm. The maximum in this case occurred at 1430.

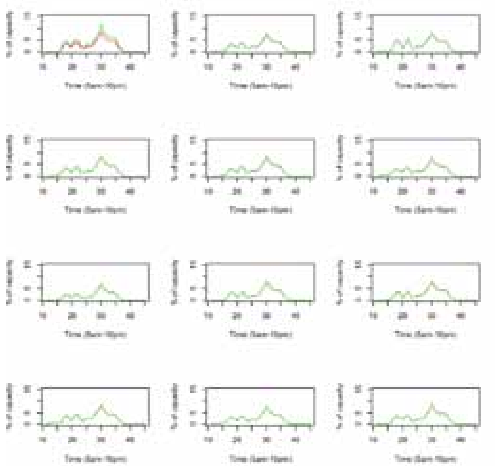


Figure 11: Output from the 12 installations in CF38 for the 12th August as percentage of actual (green line) and maximum (red line) capacities

18

9.2. Maximum proportions of actual capacity

Using readings from the entire time period (January 1st-December 31st; 5am-10pm) and all areas within the study, the mean proportion of output against actual capacity was 5.3% with a maximum of 81.1% (which occurred in NP11 at 1230 on the 19th April). The distribution of these proportions is highly skewed with a median of 0%, and interquartile range (IQR) 0.0-5.5%. The corresponding figures for proportions of maximum capacity are mean=5.0%, median=0.0%, IQR=0.0-5.3% and maximum=78.9%.The distribution of proportions of actual capacity for all 30 minute intervals can be seen in Figure 12.

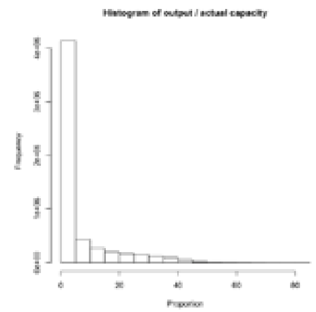


Figure 12: Distribution of outputs as a proportion of actual capacities.

The proportion of intervals for which output exceeded 50% of actual capacity exceeded was 0.2% (0.05% for maximum capacity). The corresponding proportions for exceeding 70% are less than 0.01%.

9.3. Maximum proportions of actual capacity - by day

In considering the maximum values of the proportion of actual capacity, the distribution of maximum values for each day (over the entire area) can be seen in Figure 13. The frequency of the times at which these maximums occur can be seen in Table 6 in which it can be seen that the maximums largely occur between 1030 and 1230.

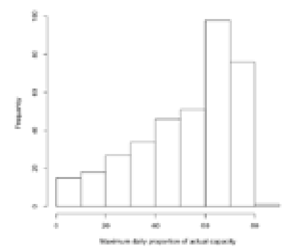


Figure 13: Distribution of maximum values of proportion of actual capacity for each day (over the entire area).

19

Time	Frequency	Time	Frequency
08:30	0.8	13:00	6.6
09:00	1.1	13:30	6.3
09:30	1.9	14:00	2.7
10:00	4.4	14:30	4.1
10:30	9.6	15:00	1.1
11:00	12.6	15:30	1.1
11:30	14.5	16:00	0.5
12:00	17.5	16:30	0.3
12:30	15		

Table 6: Frequency (percentages) of times at which daily maximum proportion of actual capacity occurs.

9.4. Maximum proportions of actual capacity - by postcode district

When considering the maximum proportions by postcode district, the mean is 53.3% (SD 10.9%) with a median of 50% and IQR 47.2-55.5%. The minimum is 22.4% (in SA67) and the maximum 81.1% (in NP11). The distribution of maximum values for each postcode district (over the entire year) can be seen in Figure 14.

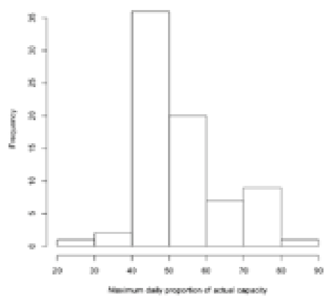


Figure 14: Distribution of maximum values proportion of actual capacity for each postcode district (over the entire year).

9.5. Maximum proportions of actual capacity - by installation

When considering the maximum proportions by individual installations, the mean is 44.0% (SD 10.3%) with a median of 45% and IQR 39.7-47.9%. The minimum is 0.0% and the maximum 81.1%. The distribution of maximum values for each installation (over the entire year) can be seen in Figure 15.

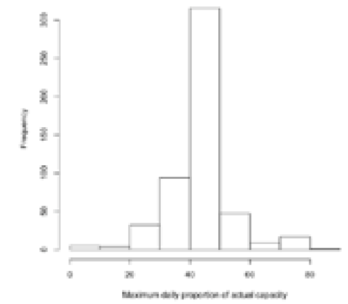


Figure 15: Distribution of maximum values proportion of actual capacity for each installation (over the entire year).

10. Summary

There is a statistically significant relationship between the maximum capacity and orientation of PV installations and their output and allowing for these factors, the underlying patterns of output within days are similar within the areas considered here (postcode districts). A statistical model was developed which allows the output from a single installation within an area to be used to accurately predict the outputs of other within the area. It was found that the vast majority of the PV installations under consideration are efficient in terms of their inclination and bearing and that the installation chosen on which to act as a proxy for others should represent an 'average' installation, having a non-extreme maximum capacity and high RPO (near optimal orientation).

For the majority of time intervals (10 minute periods) analysed here, the actual output compared to the potential output is low. It was found that the proportion of time for which the proportion of actual to potential output is greater than 50% is very low (<0.2%) and for greater than 70% extremely low (<0.01%). The maximum proportion observed at any installation over this time period was 81.1%. Over all installations the average (median) maximum proportion of actual output compared to potential output was 44% with an inter-quartile range of 39.7-47.9.

11. What learning has been achieved and what use is it?

- The finding that, at postcode level that the maximum percentage of aggregate installed rated capacity was 81% prompted further examination beyond the reductions caused by orientation and inclination. This has revealed issues over the ratings of solar panels that appear to be well recognized within the solar industry but less so elsewhere.

- Given the global nature of the solar panel market, manufacturers and Standards bodies rate solar panel outputs against a common level of applied solar radiation;

1000W/m2. The value of the solar radiation at any place is called "irradiation", and varies widely throughout the world and by latitude, time of day, season cloud cover etc. UK trade bodies for solar installers readily state that such a level would never be seen in UK. This irradiation figure is however very rarely mentioned as installers and customers are primarily interested in the energy produced over a year in kWh to determine Feed in Tariff payments and pay back periods for installations. Consequently most solar measurements relate to "insolation" values which are the kWh / m2 over a period of time, often annual.

- It thus suggests that when UK installers make application to DNOs for connection of small scale PV installations, the peak kW rating stated is possibly not scaled back to the relevant UK location irradiation figure, but is based on the manufacturers datasheets which are based on 1000W/m2. The effect of that would be an overstatement of installed peak rating, even though the annual kWh calculation for FiT was accurate. Such a finding would mean that there is even more than 20% overstatement of peak rating in more northerly parts of the UK from South Wales, and slightly less to the South.
- Further notes on the issue of solar panel ratings are provided in Appendix A, which comprises solely of extracts from the "free to use" book, Sustainable Energy – Without the Hot Air, by Prof David MacKay, who was appointed UK Government Chief Scientific Advisor to DECC in 2009.
- As only 81% of installed capacity is seen coincidentally (per 1/2 hr period). This has an impact on network planning criteria and in its simplest view identifies some 20% additional network headroom for accommodating LV connected domestic scale PVs.
- The work has demonstrated an accurate indication of aggregate PV output can be obtained if required by monitoring a single "proxy" installation within a postcode locality and factoring this up. This output can then be employed in active network management at local distribution and primary substation level.
- The use of proxy PV meters across multiple postcodes, fed into DNO SCADA systems can provide National Grid with real time PV generation information at Supergrid Point level, showing that level of hidden demand and aiding day ahead demand / spinning reserve forecasting. The linkage between DNO ENMAC and NGT XA21 SCADA systems is the subject of another ongoing WPD LCNF Tier 1 project

12. Appendix: Populations (2011 census) by postcode districts

postcode	2011	postcode	2011
CF14	77,856	NP22	22,024
CF5	66,024	CF63	21,924
CF83	55,242	CF47	21,886
NP19	51,623	SA62	21,332
NP20	50,789	CF34	20,612
NP44	47,175	SA73	20,354
SA1	47,081	CF82	20,233
CF23	47,027	NP13	19,827
NP4	45,537	SA13	19,663
CF31	44,883	CF45	19,553
SA4	44,356	NP18	17,277
CF3	42,223	SA31	16,923
CF62	41,446	CF81	16,431
CF44	39,211	CF35	16,152
SA2	38,386	CF36	16,005
CF37	38,323	SA9	15,179
NP11	37,796	SA7	15,118
SA15	36,736	CF33	14,464
SA11	36,588	CF46	14,280
CF64	36,574	SA8	12,556
SA5	36,460	SA43	12,535
SA6	34,182	SA33	12,346
SA14	33,963	SA44	11,490
NP12	33,524	SA72	10,581
NP23	33,505	SA71	10,272
SA12	32,658	CF61	9,983
CF32	29,905	SA70	9,731
SA10	29,827	SA17	9,407
SA18	29,687	SA19	9,394
CF39	28,926	SA48	8,951
CF48	27,283	SA16	8,547
SA3	26,235	SA32	7,758
NP7	26,071	SA67	6,930
CF72	25,557	SA38	4,761
NP16	23,955	SA65	4,379
CF38	23,277	SA68	4,305
NP10	23,201	SA20	3,574
NP26	22,521	SA41	1,882

13. Appendix: A statistical model for PV outputs

At its simplest level, for each day for each installation, the (log) output per half hourly interval, t, is modeled as

$$\log(\text{output}_t) = \text{overall level} + f(t) + \epsilon_t \ldots (1)$$

where f(t) represents a function of time, t =10,…,44 represents a ten minute interval in time and εt the residual variation at that period in time.

Combining information from several PVs, for example within a postcode district, allows the effects of capacity and orientation (through the RPO) to be assessed.

$$\log(\text{output}_{it}) = \text{overall level} + \text{level for installation}_i + f(t_i) + \beta_{cap}\text{capacity} + \beta_{RPO}\text{RPO} + \gamma_i + \epsilon_{it} \ldots (2)$$

where *i* represents different installations. Note that there are two distinct error terms now data is being used from more than one installation, the first (γi) represents the overall variability between the installations and the second (εt) the variability within the installations, i.e. between the measurements from a particular installation. This is known as a random effects model, in which variability can be attributed to different levels of hierarchy within the data.

Subsequent enhancements of the model include additional random effects terms representing variation between postcode districts and days. It also incorporates the possibility of relationships between the proximity of installations and similarities in their output and correlations between outputs over time. The complexity of the model means that traditional, likelihood, based estimation is not feasible and here we utilize fast computational methods using integrated nested Laplace approximations (INLA) together with stochastic partial differential equations (SPDE) to represent possible spatial relationships in the data.

24

14. Appendix: Biases for selection of areas and time periods

The following gives the biases associated with predictions as given in Table 3. Further results are available on request. Postcode district CF38, which is used for illustration purposes in the list, are highlighted (NB: only one PV data available on 17 Feb in NP 11).

PC	From	To	Bias A	Mean of Bias B	Min of Bias B
all	11-Aug	17-Aug	0.24	24.14%	0.16%
all	17-Feb	17-Feb	0.12	61.45%	0.71%
all	17-Apr	17-Apr	0.29	23.24%	0.06%
all	17-Aug	17-Aug	0.07	41.98%	0.26%
all	21-Dec	21-Dec	0.11	38.33%	0.12%
CF	11-Aug	17-Aug	0.22	21.91%	0.33%
CF	17-Feb	17-Feb	0.06	25.05%	0.78%
CF	17-Apr	17-Apr	0.25	22.47%	0.55%
CF	17-Aug	17-Aug	0.07	32.74%	0.01%
CF	21-Dec	21-Dec	0.1	42.16%	0.20%
NP	11-Aug	17-Aug	0.19	20.98%	0.10%
NP	17-Feb	17-Feb	0.1	50.93%	5.11%
NP	17-Apr	17-Apr	0.25	19.91%	0.11%
NP	17-Aug	17-Aug	0.08	32.11%	0.65%
NP	21-Dec	21-Dec	0.17	45.06%	0.79%
SA	11-Aug	17-Aug	0.24	24.87%	0.39%
SA	17-Feb	17-Feb	0.14	76.68%	3.15%
SA	17-Apr	17-Apr	0.3	24.62%	0.12%
SA	17-Aug	17-Aug	0.04	37.54%	0.05%
SA	21-Dec	21-Dec	0.07	22.85%	0.43%
CF38	11-Aug	17-Aug	0.11	18.82%	8.09%
CF38	17-Feb	17-Feb	0.02	11.44%	2.18%
CF38	17-Apr	17-Apr	0.13	15.92%	3.97%
CF38	17-Aug	17-Aug	0.02	18.23%	1.71%
CF38	21-Dec	21-Dec	0.05	18.10%	1.25%
SA14	11-Aug	17-Aug	0.22	28.67%	0.15%
SA14	17-Feb	17-Feb	0.11	69.38%	7.82%
SA14	17-Apr	17-Apr	0.35	36.45%	1.26%
SA14	17-Aug	17-Aug	0.02	30.89%	2.02%
SA14	21-Dec	21-Dec	0.05	11.87%	0.83%
NP11	11-Aug	17-Aug	0.2	43.63%	2.67%
NP11	17-Apr	17-Apr	0.24	32.18%	1.83%
NP11	17-Aug	17-Aug	0.06	46.80%	1.35%
NP11	21-Dec	21-Dec	0.11	41.21%	6.19%

25

15. Appendix: Extracts from "Sustainable Energy - Without the Hot Air"

Professor David Mackay - Appointed Chief Scientific Advisor to UK Department of Energy and Climate Change 2009

The power of raw sunshine at midday on a cloudless day is 1000W per square metre. That's 1000 W per m^2 of area oriented towards the sun, not per m^2 of land area. To get the power per m^2 of *land area* in Britain, we must make several corrections. We need to compensate for the tilt between the sun and the land, which reduces the intensity of midday sun to about 60% of its value at the equator (figure 6.1). We also lose out because it is not midday all the time. On a cloud-free day in March or September, the ratio of the *average* intensity to the midday intensity is about 32%. Finally, we lose power because of cloud cover. In a typical UK location the sun shines during just 34% of daylight hours.

The combined effect of these three factors and the additional complication of the wobble of the seasons is that the average raw power of sunshine per square metre of south-facing roof in Britain is roughly 110 W/m^2, and the average raw power of sunshine per square metre of flat ground is roughly 100 W/m^2.

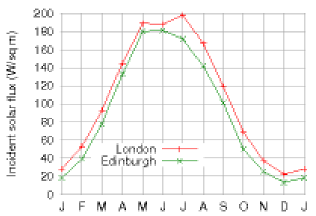


Figure 6.2. Average solar intensity in London and Edinburgh as a function of time of year. The average intensity, per unit land area, is 100 W/m^2

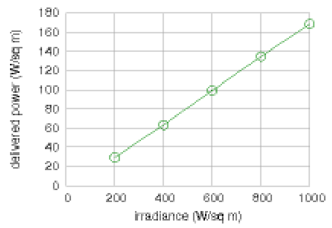


Figure 6.15. Power produced by the Sanyo HIP-210NKHE1 module as a function of light intensity (at 25°C, assuming an output voltage of 40 V). Source: datasheet, `www.sanyo-solar.eu`

In a typical UK location the sun shines during one third of daylight hours.
The Highlands get 1100 h sunshine per year – a sunniness of 25%. The best spots in Scotland get 1400 h per year – 32%. Cambridge: 1500 ± 130 h per year – 34%. South coast of England (the sunniest part of the UK): 1700 h per year – 39%. [2rqloc] Cambridge data from [2szckw

The average raw power of sunshine per square metre of south-facing roof in Britain is roughly 110 W/m², and of flat ground, roughly 100 W/m². Source: NASA "Surface meteorology and Solar Energy" [5hrxls]. Surprised that there's so little difference between a tilted roof facing south and a horizontal roof? I was. The difference really is just 10% [6z9epq]

The average power delivered by photovoltaic panels...
There's a myth going around that states that solar panels produce almost as much power in cloudy conditions as in sunshine. This is simply not true. On a bright but cloudy day, solar photovoltaic panels and plants do continue to convert some energy, but much less: photovoltaic production falls roughly ten-fold when the sun goes behind clouds (because the intensity of the incoming sunlight falls ten-fold). As figure 6.15 shows, the power delivered by photovoltaic panels is almost exactly proportional to the intensity of the sunlight – at least, if the panels are at 25°C. To complicate things, the power delivered depends on temperature too – hotter panels have reduced power (typically 0.38% loss in power per °C) – but if you check data from real panels, e.g. at `www.solarwarrior.com`, you can confirm the main point: output on a cloudy day is *far less* than on a sunny day. This issue is obfuscated by some solar-panel promoters who discuss how the "efficiency" varies with sunlight. "The panels are more efficient in cloudy conditions," they say; this

may be true, but efficiency should not be confused with delivered power

This is a free book

I didn't write this book to make money. I wrote it because sustainable energy is important. If you would like to have the book for free for your own use, please help yourself: it's on the internet at www.withouthotair.com.

This is a free book in a second sense: you are free to use *all* the material in this book, *except* for the cartoons and the photos with a named photographer, under the Creative Commons Attribution-Non-Commercial-Share-Alike 2.0 UK: England & Wales Licence. (The cartoons and photos are excepted because the authors have generally given me permission only to include their work, *not* to share it under a Creative Commons license.) You are especially welcome to use my materials for educational purposes. My website includes separate high-quality files for each of the figures in the book.

16. Appendix: Paper submitted to ISEE detailing methodology behind sample size assessment.

Assessing Regional Variability in Photovoltaic Outputs

Ran Li, *Student Member, IEEE*, Gavin Shaddick, Haojie Yan, Furong Li, *Senior Member, IEEE*

***Abstract*-- With the rapid development of low-carbon technologies in the UK, low-voltage (LV) distribution networks are facing substantial changes and challenges. In order to assess the effect potential impact of new low-carbon technologies, such as photovoltaic (PV) installations, electric vehicles (EV) and heat pumps (HP) on LV networks it is important to be able quantify the likely outputs from these technologies. The accuracy of the assessment of these effects will increase with larger numbers of monitored PV installations. However the installation of monitoring equipment is expensive and there may be technical considerations and issues with obtaining customer permission which mean that monitoring large numbers of PV installations may be difficult in practice. Therefore it is important to consider the minimum number of PV installations that could be monitored whilst still producing a representative sample of the likely outputs from PV installations throughout the study area.**

This paper proposes a novel statistical approach to determine the effect of sample size in producing an accurate representation of the output of PV installations within South Wales in UK. Probability distributions are used represent the variability in parameters that directly influence PV generation profiles, such as size and orientation, over the area of study. The basic idea is then to use Monte-Carlo simulation techniques to build up representations of the distribution of PV outputs by month within the study area. The potential biases associated with choosing different sample sizes and sampling procedures are then assessed.

***Index Terms*-- Photovoltaic Profile, Probability Distributions, Monte Carlo Simulation, Sample Size**

Introduction

THE UK government has committed to reducing the greenhouse gas emission by at least 80% by 2050 [1] and as a consequence there will be major challenges and changes in the energy sector, including significant changes to electricity networks. To meet the target for carbon reduction the electricity suppliers are seeking to utilise low-carbon generation such as using wind and solar sources

Ran Li and F. Li are with the Department of Electronic and Electrical Engineering, University of Bath, Bath BA2 7AY, UK (e-mail: rl272@bath.ac.uk; f.li@bath.ac.uk)

Gavin Shaddick and Haojie Yan are with the Department of Mathematical Sciences at the University of Bath, Bath BA2 7AY, UK (e-mail: G.Shaddick@bath.ac.uk, h.yan@bath.ac.uk)

in an effort to reduce the use of traditional fossil fuels [2, 3]. There is a corresponding interest in low-carbon technologies such as micro-PV, electric vehicles (EV) and heat pumps (HP) at the low voltage (415V) customer side [4-6]. The increased electrification of transport and heat sectors will substantially increase the load demand which may increase the requirement for distributed generation (DG). The increase in DG will assist in reducing the load but will change the network energy usage profiles dramatically. Low-voltage electricity networks are therefore facing substantial changes which are likely to have significant impacts on power quality, voltage and utilisation.

There is thus a need for greater understanding of the potential impact of such changes on the LV network and subsequent changes in LV planning in the UK [7]. In order to address this need, Western Power Distribution (WPD), the distribution network operator responsible for energy distribution for Southwest England, South Wales and the Midlands in the UK, has initiated a project which aims to identify and quantify the potential impact of new low-carbon technologies.

One component of this project involves the installation of monitors along selective LV distribution substations in South Wales. These monitors will collect real time voltages and currents which will be used to develop LV network template profiles that may prove to be applicable for the entire UK network. In order to understand how PVs influence distribution networks, it is important to determine the output profiles of PV systems. In an additional part of the project, monitoring devices need to be deployed for household PVs in order to assess the impact of these PV at the substation level.

There has been rapid development of PV generation systems in the UK with the numbers expected to rise in the future [8, 9]. There are currently over 3500 registered PV installations in South Wales, over 1000 of which are associated with substations in the study area.

Theoretically, monitoring devices could be installed for every PV installation within the study area, however there are difficulties associated with this including cost, technical issues and obtaining customers' permission. This paper focuses on determining the size of the sample of PV installations that would be required in order to obtain an accurate representation of the distribution of PV outputs over a region.

A number of studies have investigated the relationship between PV input factors and PV output (see Section II for details). The output is influenced by a variety of factors including irradiation, azimuth and tilt angle, temperature and system efficiency [10]. Traditionally, methods for assessing required sample sizes are based on assessing the difference between two values which are assumed to follow a given probability distribution, often the Normal [11-13]. However, in the case considered here this is unlikely to be tenable assumption. Additionally, it is also assumed that the parameters of the distributions are known which ignores the inherent uncertainty and thus underestimates the size of the sample that is required. In reality, the number of input factors and the uncertainty associated with them results in a level of complexity which means, in all but the simplest examples, it is impossible to find a simple distributional form for the PV output.

In this paper, we propose a more flexible approach to the calculation of sample sizes required to accurately represent PV output over an extended area using Monte Carlo analysis (or error propagation) to produce distributions of output [14]. A Monte Carlo simulation (MC) involves a large number of drawings (typically hundreds of thousands) from the distribution of the input parameters in the model that are combined to obtain values for the output parameters (which will be a function of the input parameters). As many values are available for the output parameters a probability distribution can be evaluated. It should be noted that Monte Carlo analysis does not require that probability distribution function are defined for all input parameters. Where there is no basis for assigning a probability distribution function to particular parameters in multiple-parameter models, it is acceptable to keep a fixed value for those parameters while assigning probability density functions to parameters where sufficient information is available.

30

Monte Carlo simulation has been applied in a number of studies including investigating the levelised cost of energy (LCOE) for PVs when the available data of PV output is limited [15]. However, in this example some of the factors influencing PV output including installed angles and PV sizes were not considered and the correlations between each factor were assumed to be independent which may not a reasonable assumption. Here, we adopt the form of relationship between PV input and output proposed by [16]. Owing to limitations in the information that is available for some of the required inputs, for example solar irradiation, installed angles and PV sizes, a set of carefully selected distributions are used to represent the variability for each input parameter. Within each iteration of the Monte-Carlo simulation, samples from each of these distributions are used to compile a distribution of PV output over the study region. This simulated distribution of PV outputs are then treated as 'real' in the second stage of the process in which the potential effects of different sampling strategies are investigated.

At this second stage, a selection of different 'samples' are drawn from the distribution of PV outputs obtained from the first stage and which are now treated as 'real'. The effects of choosing different sampling sizes in terms of obtaining a representative sample are assessed in terms of bias both of mean levels and variability.

The rest of the paper is organised as follows: Section II describes the deterministic relationship between a selection of important input factors and PV output. Section III describes the rationale for the probability distributions used to represent the variability in the input parameters and the choice of parameters for these distributions. In Section IV details of the Monte Carlo method used to simulate the distribution of PV outputs are presented. Section V contains a statistical analysis of the effects of different sample sizes and strategies on the estimation of both mean levels and variability. Finally, Section VI provides a discussion of the findings of this study together with suggestions for future research.

The Output Profile of Photovoltaic

The output of a PV is influenced by various factors, including irradiation, azimuth, tilt angle, temperature, system efficiency and PV material [10]. Mathematically, the power of a PV can be by expressed as follows

$$P = \frac{G}{G_0} \times A \times eff_{nom} \times eff_{rel}(G, T_m) \tag{1}$$

where G_0 =1000W/m^2. G is the solar irradiance on the PV module, A is the surface area of the PV modules, eff_{nom} is the module efficiency at Standard Test Condition (STC) (1000W/m^2 solar irradiance, a module temperature of 25°C and a solar spectrum corresponding to an air mass of 1.5) and eff_{rel} is the relative module efficiency which is a function of irradiance and module temperature, T_m.

The nominal peak power is the power output of the module(s) measured at Standard Test Conditions (STC). The module efficiency measured at Standard Test Conditions is referred to as eff_{nom}. The relationship between P_{STC} and eff_{nom} can be expressed as

$$P_{STC} = A \times eff_{nom} \tag{2}$$

where P_{STC} is the nominal peak power and A is the panel surface area of the PV modules.

By substituting (2) into (1), the power, P, can be expressed as

$$P = \frac{G}{G_0} \times eff_{rel}(G, T_m) \times P_{STC} \tag{3}$$

31

The nominal peak power can be written in the following form:

$$P_{STC} = V_{STC} \times I_{STC} \quad (4)$$

where V_{STC} and I_{STC} are the voltage and current of the PV, respectively under the electric load that produces the maximum power at Standard Test Conditions (STC). When the values of temperature and irradiance differ from STC, the maximum current and voltage become I_m and V_m. From (3) and (4), the relative efficiency eff_{rel} can be therefore expressed as [16]:

$$eff_{rel}(G,T_m) = \frac{P \times G_0}{P_{STC} \times G} = \frac{I_m V_m G_0}{I_{STC} V_{STC} G} = (1 + \alpha_I \times (T_m - T_0)) \times (1 + c_1 \times \ln(\frac{G}{G_0}) + c_2 \times (\ln(\frac{G}{G_0})^2 + \beta_V \times (T_m - T_0)) \quad (5)$$

where the coefficients, α_I, β_V, c_1 and c_2 are empirical constants [17]. The module temperature has a corresponding relationship with the ambient temperature of the form [18]:

$$T_m = (T_{NOCT} - 20) \times \frac{G}{800} + T_{amb} \quad (6)$$

where T_m is a PV module's temperature, T_{amb} is ambient temperature and T_{NOCT} is nominal operating cell temperature.

The choice of Probabilistic Distributions to Represent PV Input Factors

Predicting the power output of a PV using the formula given in Section II can be very challenging as some of the input factors may vary significantly under different conditions or in different regions. For example, in most previous studies the conversion efficiency and solar radiance are assumed to be known values adopted from historical data or experimental values under Standard Test Conditions [19]. However in practice they may vary substantially across different regions and vary depending upon installation angles and materials. [20]. The advantage of using fixed values is its simplicity and ease of computation but it takes no account of the uncertainty that may be present. One approach is to use probability distributions to represent the uncertainty in PV input factors and to draw samples from these distributions for use in the subsequent formulae. Normal distributions have been adopted for this purpose in a number of previous studies and [15] gave an example of using probability distributions in calculating PV cost. However the assumption of normality is unlikely to be realistic for all the PV input and in this paper we introduce an improved method to estimate the output of PVs based on a selection of probability for sample size assessments. The proposed approach offers a more realistic and ultimately more accurate method for simulating PV outputs. The proposed method aims to take into account as much of the variability in conditions as possible within the study area.

Temperature and Solar Irradiation

As can be seen from (3), G_0 is a constant as discussed above. Information on temperature T_m and solar irradiance was obtained from The Photovoltaic Geographic Information System (PVGIS) of European Communities [21]. As the study region, part of South Wales, is a relatively small geographically area, it may be assumed that temperature and solar irradiance are constant at any time point over the study area.

Previous studies have found that solar irradiation and temperature within a small area can be reasonably represented by normal distributions [15, 22]. Here, the irradiation and temperature for each month are assumed to be normally distributed with means and standard deviations based on historical data obtained from PVGIS [23]. Figure1 shows the distribution for average daily irradiation distribution in June.

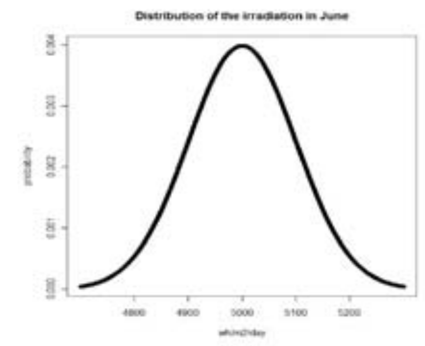


Fig.1. Normal distribution used to represent the solar irradiation in June in South Wales

Azimuth Angle

It is noted that the irradiance G absorbed by PV modules in (3) is not only influenced by the solar irradiation but also the tilt angle, azimuth and the material of the PV [24]. The optimum azimuth angle in the UK is south. For north-south facing houses, most customers will install their PVs on south roof in order to obtain the highest power output. Although for the optimum power output PV panels should be installed at this orientation and ,angle factors such as roof types and non-south facing properties, mean the range of orientation is extended from almost 360 degrees for azimuth angle (south=0, west=90, north=180=-180 and east=-90) and from 0 to 45 degrees for tilt.

Based on these factors, the distribution of the azimuth angle is assumed to be normally distributed with a mean angle of 0 degrees and standard deviation of 60 degree.

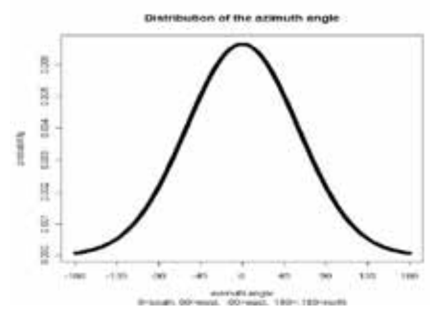


Fig.2. Normal distribution representing the azimuth angles of PVs in South Wales

Tilt Angle

The optimum tilt angle in the UK is 30-40 degrees [24] and the majority of the PVs are put within the range [25]. However in the case of flat roof, due to safety requirements, some PVs may be installed horizontally. In such cases, the solar radiation received may still be almost 90% of that at the optimum angle [25]. Previous research has shown that the received solar radiation starts to fall sharply when the angle is above 50 degree and is substantially reduced when above 70 degrees [25].

Angles below 30 degrees are more likely to appear than those above 40 degrees due to them being more efficient. Based on this information, the distribution for tilt angles of all PVs in the study region is assumed to be a truncated skewed normal [26] with a mean of 35 degrees, a standard deviation of 15, a skewness parameter of 0.7 and with truncation occurring at 0 degrees seen in Fig.3.

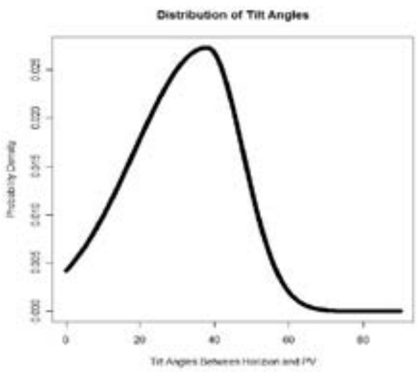


Fig.3. Distribution representing tilt angles of PVs in South Wales

PV Size

The size of a PV is often represented in terms of its total nominal peak power. For example, a 1 Kw-size PV indicates a nominal peak power of 1 Kw and a 10 Kw-size PV has nominal peak power of 10 Kw, therefore higher power is associated with larger PV size. As can be seen in (3) there is a linear relationship between, the size of PV and its output and as such it is essential to be able to determine the distribution of PV sizes in the study area.

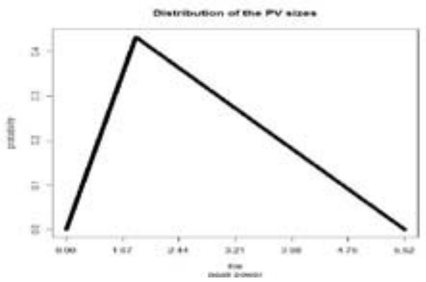


Fig.4. Triangular distribution representing sizes of the PVs in South Wales

Bases on information supplied from WPD relating to a sample of approximately 300 PVs in the study area, a suitable distribution for PV sizes is the triangular distribution. Within this sample PVs, the maximum size is 5.52Kw and minimum size is 0.9Kw with a mode of 1.85. Figure 4 shows the corresponding triangular distribution used to represent PV sizes of all PVs.

Other Factors

There are other factors that are less amenable to being assigned a probability distribution due to difficulties in obtaining enough information on which to basis a sensible choice. Examples include trees shading, PV material and inverter failure. In the absence of additional information, the effect of such factors is represented white noise [27, 28], in the form of the variance of a normal distribution.

Simulation of the PV Output profiles by Combining the Distributions of input Factors

Monthly Profiles of Photovoltaic outputs

In order to assess whether samples of a certain size are likely to be an accurate representation of the population of PVs in the study area we aim to simulate an output profile for each of the PVs and then to assess the effects of different sampling procedures. The profiles of PVs can be presented in two ways; (i) the daily profile is the power output on a half-hour basis over a day, and (ii) the monthly power output profile is the daily average power output of each month over a year. Although the daily profile is most suitable for electricity network analysis, for simplicity we demonstrate the approach on monthly profile due to constraints in the data required to determine the required distributions at the higher level of temporal resolution. .

The product Pi for average daily power output of a PV in month *i* with irradiation G_i, efficiency $eff_{rel}(G_i,T_m)_i$ and peak power P_{STCi} is represented by,

$$P_i = \frac{G_i}{G_0} \times eff_{rel}(G_i,T_{mi})_i \times P_{STCi} \quad (7)$$

where i=1, … , 12 represents months of the year.

In order to obtain the distribution of power outputs from PVs of the PVs can be calculated by drawing repeated samples from the distributions defined in Section III for factors that feed into the calculations leading to (7), resulting in distributions for power outputs.

Monte Carlo simulation and correlated inputs

Using Monte-Carlo simulation techniques samples are repeatedly taken from the distributions of the input factors used to build up distributions for the power. Here we aim to simulate the output profiles to represent approximately 1000 PVs within the study area.

If all the input variables can be assumed to be independent then the sampling can be made from univariate distributions but where is not the case multivariate distributions may have to be considered. This will be necessary in cases where, for example, increases in one input are associated with decreases in another. In this example, temperature and irradiance in particular are to a large extent dependent. Independently they are both represented by normal, distributions and the extension to using a multivariate normal for the combination of the two is intuitive. Although there is variation in the amount of correlation that might be expected between the ranging from 0.6 to 0.9, a value of 0.8 is generally accepted for the UK [29, 30]. Figure 5 shows the multivariate normal distribution that represents the combination of these two inputs.

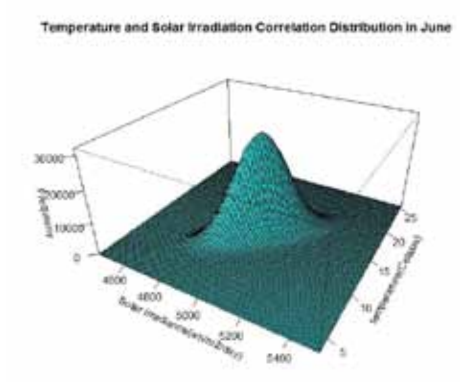


Fig.5. Multivariate normal distribution of the temperature and solar irradiation in June in South Wales

Simulation of the profile

Profiles were simulated for the outputs of 1000 PV installations based on the input parameters and their associated distributions.

However, there are a number of factors which may have major effects on PVs such as system losses, shading and inverter failure [27, 28]. Based on a study of these factors[27], a noise term representing 50 W is incorporated into the simulation models, via the standard to represent this additional variability. The value of the noise term will be used as the standard deviation in a normal distribution. Further, in order to investigate the uncertainty of the white noise, a series of different values of the white noise from 1 W to 100 W is tested.

Figure 6 shows the resulting estimated daily output profiles for the 1000 PVs over a year together with the mean over all the profiles.

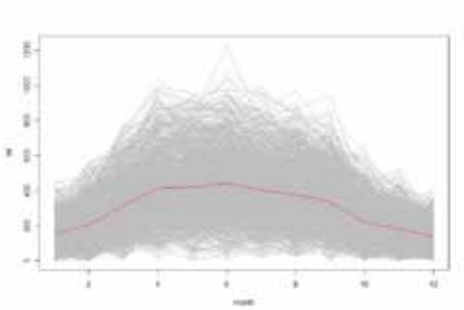


Fig.6. Daily output profiles of 1000 PVs over a year. The red line shows the mean output over all PVs

Obtaining a Representative Sample

Programming and simulation

After the profiles of the 1000 PVs have been simulated, this is considered the true population, or 'real data'. We now present a method to assess the efficacy of using samples to make inference about the entire population in a similar fashion as would be carried out in practice. The difference here is that we know the truth, i.e. the features of the entire population we are sampling from, and so can assess the bias associated with different samples. The performance of samples of varying sizes: 2, 10, 100, 250 and 500, is assessed in terms of biases of the sample mean and standard deviation.

To allow for sampling variability, samples of each size are repeated drawn and the bias calculated for each sample. This procedure is repeated 1000 times for each sample size. Fig.7 shows clearly that as the sample size increases, the sample mean approaches to the population mean and that the return in increasing sample size is greatest when increasing very small samples. There are fewer effects when increasing sample size above 100, after which the sample means are very close to the true population mean.

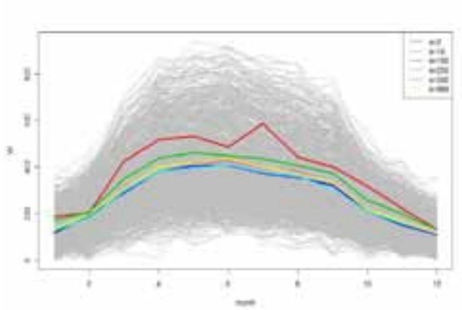


Fig.7. Mean profiles associated with different size samples with additional variation term (white noise) of 50W

The corresponding results when the term representing the additional variability associated with factors such as system losses, shading and inverter failure is increased to 100W can be seen in figure 8.

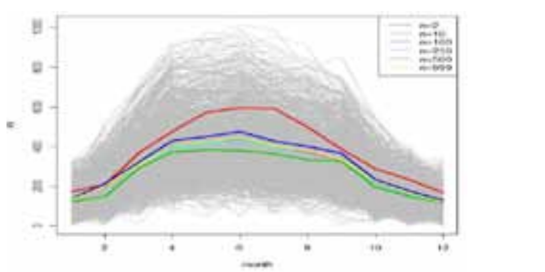


Fig.8. Mean profiles associated with different size samples with additional variation term (white noise) of 100W

Bias of sample mean and standard deviation

In order to assess the bias associated with samples of different sizes, the root mean square error (RMSE) is calculated for both means and standard deviations. For any given sample size, the RMSE is calculated using the mean of the repeated samples and the (known) mean of the population for each month. Formally, the bias is expressed in the following form:

$$Bias_{Smean} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_{spi} - P_{smi})^2} \quad (8)$$

where n=12 represents the 12 months, P_{spi} is the sample mean of PVs output in month i and P_{smi} is the 'true' mean

The mean values of bias, over the repeated samples, for different sample sizes can be seen in Figs 9. Using an additional variability term from 1W to 100W, it can be seen that the bias can be as high as 100W when using a sample size of 2, reducing to 50W with a sample size increase to 10 and decreasing markedly after that. With sample sizes of 250 or greater, the bias is lower than 8W.

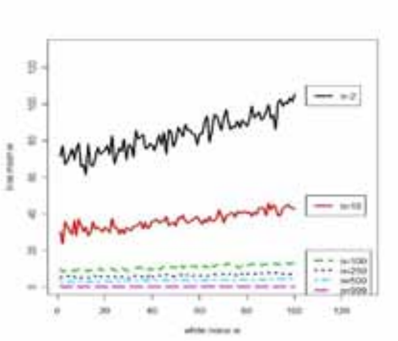


Fig.9. Bias (W) of means under different sample sizes with varying amounts of additional variability (white noise) terms

As observed in Fig 7 and 8, the effect of additional variation is more marked with smaller sample sizes and this is again seen in the estimation of biases in which biases increase markedly as the noise term increases but this effect is decreased with large sample sizes.

In addition to bias of the mean we also consider biases in estimating the variability of PV outputs by calculating the RMSE of the sample standard deviations, defined as:

$$Bias_{st} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(D_{spi} - D_{smi})^2} \quad (9)$$

Fig.10 shows the bias of the standard deviations for different sample sizes. Again large biases are seen for the very small sample sizes with the effects of increasing sample size reducing after n-100.

38

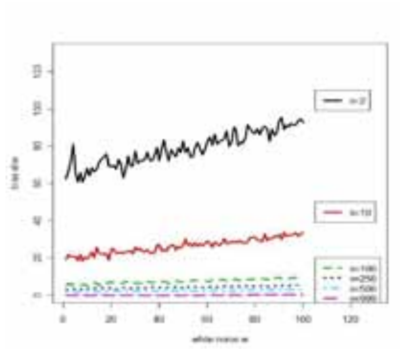


Fig.10. Bias (W) of standard deviations using different sample sizes and varying amounts of additional variability (white noise)

Investigating the Potential Effect of Clustering

In the analyses presented, it should be noted that the samples are all selected randomly in respect to the factors which govern PV output. When selecting a sample in practice, this might not be feasible due to costs, i.e. accessing remote areas, or by design, i.e. PVs within a small area might be likely to be installed with similar sizes. The latter can arise if, for example, installations are provided by local housing associations. Additional analyses were performed using sampling schemes which incorporated such clustering of input factors.

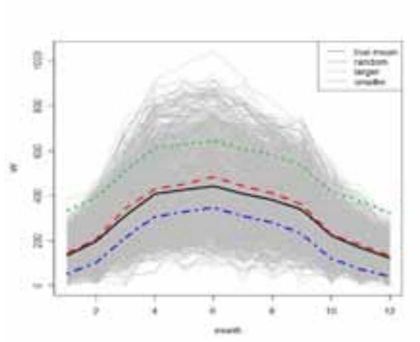


Fig.11. Mean profiles obtained when using three sampling schemes; (i) random, (ii) weighted towards larger and (iii) smaller PV sizes. Sample size is 250 for all schemes.

Using a sample size of 250, we compared the results of three sampling schemes: (i) random selection (as in the previous analyses); (ii) sampling probabilities weighted to give a sample biased towards larger sized PVs and (iii) mainly smaller sized PVs. Schemes (ii) and (iii) were designed as follows; two groups of PVs were defined (1) < 1.85 kW,) and (2) PV size > 1.85 kW and sampling probabilities were defined as 0.75 from (2) in scheme (ii) and 0.25 in scheme (iii). The values are chosen because the mean ratings of the PVs are around 1.85kW and the probability ratio between the two groups is 3:1.

39

The results of applying the three schemes can be seen in Fig 11. It can be seen that the mean profile obtained from the random sampling is very close to the real one while those chosen from the other two schemes deviate from the real one.

Conclusions

This paper proposes method for estimating the distribution of PV outputs over a region. Relationships between in out factors and PV outputs are expanded to incorporate both the inherent variability in values of the input factors but also additional levels of uncertainty. This is performed using Monte-Carlo techniques which enable representative distributions of PV outputs to be generated over the region of interest. We then used these representative distributions to perform a study to assess how accurately data from samples of PVs, rather than monitoring the entire population, would be in assessing output profiles.

Under the assumptions presented in the paper, it is observed that there is a marked relationship between accuracy and sample size when dealing with samples of less than 100 but that after 100 there is a diminishing return in terms of estimating mean and variability. In addition, we investigated the possible effects of non-random sampling schemes that might be used in practice where time, costs and other issues may necessitate targeting many installations within a small area which may for example be likely to be similar in terms of size.

Further development of this approach will focus on two main areas to enhance the applicability of the results for network analysis.

i. In the future, the increasing penetration of PVs may require a larger scale of sample size. The result will be updated according to the increase of PVs in the study area.
ii. Due to the availability of data and to aid presentation of the method, monthly profiles are used here. However, networks analysis is usually based on half-hourly daily profiles. In order to enhance the applicability of the results, future work will apply this approach into half-hourly daily profiles.
iii. At present, the distributions of input factors are based on a number of assumptions derived from previous studies and the literature. In the future, as data is collected from the monitors placed as part of the project, these assumption will be tested and updated based on real data

Acknowledgments

The authors gratefully acknowledge the contributions of Dr Chenghong Gu and Miss Yiwei Yu for their work on the original version of this document.

References

[1] "2050 Pathways Analysis," DECC, LondonJuly,2010 July,2010.

[2] G. Sinden, "wind power and the uk wind resource," Enviromental Change Institute University of Oxford2005 2005.

[3] U. Trade and Investment, UK photovoltaics sector: a guide to world-class products and services: UK Trade & Investment, 2008.

[4] "UK Renewable Energy Roadmap," DECC, LondonJuly 2011.

[5] J. H. Julian Prime, Steve Dagnall, "Renewable Energy production in 2010 " DECC, AEA28/07/2011 2011.

[6] D. Infield and F. Li, "Integrating micro-generation into distribution systems — a review of recent research," in Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE, 2008, pp. 1-4.

[7] M. G. Pollitt, Bialek, Janusz, "Electricity network investment and regulation for a low carbon future," Faculty of Economics, University of Cambridge, UKoct-2007.

[8] D. Infield, "A Draft Road Map for Photovoltaics Research in the UK," UKERC, Research Report REF: UKERC/RR/FSE/2007/001, August 2007 2007.

[9] J. L. F.Li, "Network Charges for Micro-Generation," presented at the General Meeting of the IEEE Power and Energy Society, Pittsburgh, PA., 2008.

[10] T. Huld, M. Šúri, and E. D. Dunlop, "Geographical variation of the conversion efficiency of crystalline silicon photovoltaic modules in Europe," Progress in Photovoltaics: Research and Applications, vol. 16, pp. 595-607, 2008.

[11] C. S. Chen, J. C. Hwang, and C. W. Huang, "Application of load survey systems to proper tariff design," Power Systems, IEEE Transactions on, vol. 12, pp. 1746-1751, 1997.

[12] C. S. Chen, J. C. Hwang, Y. M. Tzeng, C. W. Huang, and M. Y. Cho, "Determination of customer load characteristics by load survey system at Taipower," Power Delivery, IEEE Transactions on, vol. 11, pp. 1430-1436, 1996.

[13] D. Chih-Shun, W. Qing, H. Cheng-Ta, and M. Pedram, "Stratified random sampling for power estimation," Computer-Aided Design of Integrated Circuits and Systems, IEEE Transactions on, vol. 17, pp. 465-471, 1998.

[14] G. C. Christian P. Robert, Monte Carlo Statistical Methods, 2nd ed. New York, NY: Springer-Verlag, 2004.

[15] S. B. Darling, F. You, T. Veselka, and A. Velosa, "Assumptions and the levelized cost of energy for photovoltaics," Energy & Environmental Science, vol. 4, pp. 3133-3139, 2011.

[16] T. A. Huld, M. Suri, R. P. Kenny, and E. D. Dunlop, "Estimating PV performance over large geographical regions," in Photovoltaic Specialists Conference, 2005. Conference Record of the Thirty-first IEEE, 2005, pp. 1679-1682.

[17] F. G. Kenny RP, Chianese D, Bernasconi A, DunlopED, "Energy rating of PV modules: comparison ofmethods and approach," presented at the Proceedings of the 3rd WorldConference on Photovoltaic Energy Conversion, Osaka,Japan, 2003.

[18] D. E. Kenny R, Ossenbrink H, Mullejans H, "A practical method for the energy rating of c-Si photovoltaicmodules based on standard tests," presented at the Progress inPhotovoltaics: Research and Applications 2006, 2006.

[19] A. B. Barhdadi, Mouncef, "PVGIS approach for assessing the performances of the first PV grid-connected power plant in Morocco," Physics and Society vol. arXiv: 1208.4325, p. 11, 2012.

[20] S. R. Williams, T. R. Betts, P. Vorasayan, R. Gottschalg, and D. G. Infield, "Actual PV module performance including spectral losses in the UK," in Photovoltaic Specialists Conference, 2005. Conference Record of the Thirty-first IEEE, 2005, pp. 1607-1610.

[21] Š. M. Huld T.A., Dunlop E.D., Micale F, "Estimating average daytime and daily temperature profiles within Europe," Environmental Modelling & Software, vol. 21, 12, 1650-166,, 2006.

[22] R. D. Harmel, C. W. Richardson, C. L. Hanson, and G. L. Johnson, "Evaluating the Adequacy of Simulating Maximum and Minimum Daily Air Temperature with the Normal Distribution," Journal of Applied Meteorology, vol. 41, pp. 744-753, 2002/07/01 2002.

[23] M. Šúri, T. A. Huld, and E. D. Dunlop, "PV-GIS: a web-based solar radiation database for the calculation of PV potential in Europe," International Journal of Sustainable Energy, vol. 24, pp. 55-67, 2005/06/01 2005.

[24] K. L. Christian N Jardine, "Photovoltaics in the UK," Environmental Change Institute, University of Oxford.

[25] C. T. K. Tovey "Performance of two photovoltaic arrays in the UK," Proceedings of the ICE - Energy, vol. Volume 161, pp. pages 11 –21 01 February 2008 2008.

[26] D. A. a. P. N. Cedric Flecher, "Truncated skew-normal distributions: moments, estimation by weighted moments and application to climatic data," Metron - International Journal of Statistics, vol. vol. LXVIII, pp. 331-345, 2010.

[27] N. M. Pearsall, K. M. Hynes, C. Martin, and M. Munzinger, "Analysis of Performance Parameters for UK Domestic PV Systems," in Photovoltaic Energy Conversion, Conference Record of the 2006 IEEE 4th World Conference on, 2006, pp. 2300-2303.

[28] A. R. Rohatgi, Alan ; Yelundur, Vijay "Cost and Technology Roadmaps for Cost-Effective Silicon Photovoltaics," presented at the 12th International Workshop on the Physics of Semiconductor Devices, New Delhi, India, 2003.

[29] M. Rivington, G. Bellocchi, K. B. Matthews, and K. Buchan, "Evaluation of three model estimations of solar radiation at 24 UK stations," Agricultural and Forest Meteorology, vol. 132, pp. 228-243, 2005.

[30] R. Hodgkins, "Seasonal evolution of meltwater generation, storage and discharge at a non-temperate glacier in Svalbard," Hydrological Processes, vol. 15, pp. 441-460, 2001.

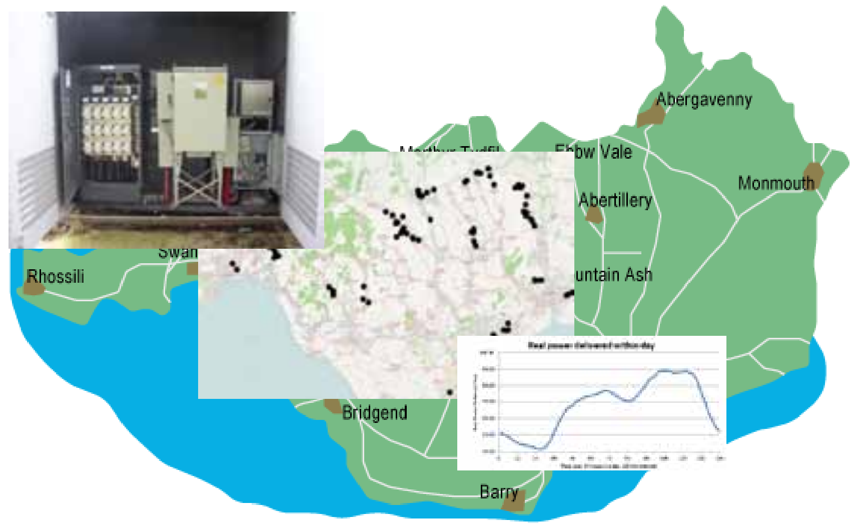
APPENDIX 4

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

UNIVERSITY OF BATH

Low Voltage Network Templates

Interim report on learning identified to March 2013



Executive Summary

This interim report summaries the learning generated to-date by Western Power Distribution's (WPD) Low Voltage Network Templates Project, funded by Ofgem through the Low Carbon Network Fund (LCNF) second tier mechanism.[1]

This Project is designed to provide data on the low voltage (LV) distribution network. Currently, the final stage of monitoring is on the outgoing 11kV feeders in a primary substation, where current and voltage is measured. The real-time loading of the distribution substations, located along the 11kV feeders, is not recorded or visible remotely, and can only be obtained by visiting site to read a maximum demand indicator, which has variable and poor accuracy across the loading range. This project has provided remote monitoring of current and voltage at c. 800 distribution substations, through the addition of monitors and communication infrastructure. In addition, voltage monitors were installed in c. 3,500 houses at the end of low voltage feeders, to allow voltage profiles to be developed.

Collecting this data now is important due to the forecast increases in loading and voltage stresses on the network arising from expansion in the numbers of low-carbon equipment to be connected into the low voltage network, including photo-voltaic (PV) generation, heat pumps and electric vehicles. Better understanding of the time of day loading and voltage 'headroom' currently available on different types of LV network and customer is crucial to planning the network of the future. This project will develop statistically sound network templates for different types of LV network, comparing traditional networks with those including low-carbon technologies.

Working with the University of Bath, capturing both the technical learning (*what* we did) as well as the process learning (*how* we did what we did) has been an integral feature of this Project. This interim report has been prepared to support the presentation to Ofgem on the 19th March 2013. The main focus is on process learning - particularly the learning that has arisen from interactions with customers, which happened during the early stages of the project. A fuller treatment of all learning identified from the technical aspects of the Project (i.e. the installation of substation monitoring, telecommunications) and the creation of the Templates themselves will follow in the final reports.

The capture has been via semi-structured interviews with individuals and teams, as well as documentary analysis of both formal and informal material generated during the project. The process of undertaking such significant and direct customer engagement has generated significant learning that is directly applicable to other LCNF projects in other DNOs, including:

- How to engage effectively with customers (including engaging via third parties) to ensure a good success rate.
- How to further increase success rates via raising project awareness in the community.
- Reducing potential disruption and maximising benefits for customers through design.

Much of this customer engagement learning has already been successfully integrated into other LCNF projects. As this Project draws to a close, we are now shifting our attention to issues such as how to integrate the more technical learning into both WPD's and other DNOs' Business as Usual (BaU) activities.

[1] http://www.ofgem.gov.uk/Networks/ElecDist/lcnf/stlcnp/Pages/stp.aspx

Contents

1. Introduction

The nature of electricity supply and consumption is changing: a combination of renewable generation and the increasing uptake of new low-carbon technologies (such as electric vehicles and heat pumps), combined with more efficient buildings means that overall the pattern of electricity use is becoming harder to predict.

Western Power Distribution's (WPD) Low Voltage Network Templates ('LV Templates') Project, sponsored by Ofgem via the Low Carbon Network Fund (LCNF) second tier mechanism[2], aims to generate a better understanding of how the LV network can best cope with such changes, to help facilitate a low-carbon future.

To generate this understanding data was gathered by installing c. 3,500 individual voltage monitors in customers' homes and c. 800 associated substations in an area of South Wales. The resulting data was analysed by the University of Bath using various statistical clustering techniques to produce 'templates' representing groupings of substations that exhibit similar demand profiles. Whilst the existing Elexon Load Profiles[3] give information on customers' energy consumption, the Templates created by this Project give knowledge of patterns of consumption at substation-level. This information is an important asset for Distribution Network Operators like Western Power Distribution, allowing improved planning and ultimately reducing the need for costly and sometimes disruptive network investment.

Capturing the learning generated during the Project has been a key objective, in terms of both:

- The installation of monitoring equipment and creation of the templates themselves **(the *technical* learning)**
- What WPD learned along the way and how WPD and other DNOs can best undertake projects of this nature in the future **(what we term the *process* learning).**

This report summarises learning to-date from the *process* perspective *(*with particular focus on the process learning around customer interaction) and is structured as follows: After a description of the methods used to capture the learning in section 2, a more in-depth treatment of learning from the process of customer engagement is undertaken in section 3. Construction issues and learning from the installation telecommunications equipment are then presented in section 4, before learning from the process of template creation is summarised in section 5. Examples of cross-project learning and how the learning may be integrated into Business as Usual activities is then discussed in sections 6 and 7 respectively, before conclusions are drawn in section 8.

[2] http://www.ofgem.gov.uk/Networks/ElecDist/lcnf/stlcnp/Pages/stp.aspx
[3] http://www.elexon.co.uk/reference/technical-operations/profiling/

4

2. Methods of capturing learning

For the purposes of this report, the University of Bath define knowledge and learning as follows:

- ***Knowledge*** is the internal belief state of a person or people (e.g. in an organisation) - Knowledge may be created by integrating information with one's existing knowledge. It is communicated in the form of information.
- ***Learnings*** are a type of information arising from endeavour, that (with sufficient context) can be used to create new knowledge.

WPD have worked with the University of Bath to undertake various knowledge capture and dissemination activities during the Project. The learnings contained in this report have been collected via a number of techniques, but predominantly through semi-structured interviews with individuals and groups. These interviews were conducted at various stages throughout the project, to ensure the potential learnings were still fresh in people's minds and - in the case of temporary staff - that those people were still available to be interviewed. These interviews were used individually to identify specific learning and also collectively to identify commonly occurring themes. Learning identified from interviews was also cross-checked by assessing related documentation, such as formal reports, presentations and other less formal sources produced during the course of the project.

3. Lessons learnt through customer engagement

This section details learning arising from the process of engaging with customers (predominantly householders) in the Project area in South Wales:

5

Customers were engaged through a range of activities and at various points in the project, as shown below:

This section will focus on the learning gained during phase checking, voltage monitor installation, engaging via third parties and engaging PV customers. Much of this learning has already proved to be of direct use to other WPD projects.

Phase checking – a missed opportunity?

Soon after the project start, it was discovered that before contacting customers to install monitoring equipment, an additional step was required to check which phase of the substation feed to which customers were connected. This was necessary to ensure a balanced number of monitors across the three phases. Although the check did not require any interruption to supply, it did involve entering customer premises to connect monitoring equipment to a standard electrical outlet for a short period. Consent was therefore required and to obtain this, customers at the end of feeders were sent letters inviting them to contact WPD. These letters were followed up by telephone calls (where this information was available) and visits by the project team. In total, around six months was spent performing c. 12,000 phase checks from a total population of c. 24,000 homes.

The letter sent to customers to request access for phase-checking is reproduced in Appendix A. It was felt by the project team that in future, focussing more on the overall benefits of the project may be a useful approach, rather than explaining the technical detail of how the benefits would be realised.

It was also felt by the project team that another key issue that may have reduced the response rate to letters was the lack of information available about the occupier of the property. Traditionally, WPD have dealt with the property rather than the occupier. Consequently letters

6

were often addressed to 'the occupier'. This may have reduced the likelihood of customers reading the letters.

In hindsight, it may also be considered that there was a missed opportunity during these phase checks to also install the monitor at the same time. However, this would have delayed the phase checking. Furthermore, the purpose of phase checking was to ensure a balanced number of monitors on each phase of the feeder. By installing at the same time as phase checking, there would have been a risk of the number of monitors not being balanced across the three phases of the feeder.

These issues notwithstanding, there was still an opportunity to talk to the customer about the best times to contact them, and also to check whether the property was suitable for installation of a monitor (e.g. checking for sufficient space around the meter). By improved planning of similar activities in future projects, it may be possible to sign-up more customers, more quickly for monitoring equipment installation, and also present multiple activities in a more joined-up manner.

L1: Ensure customer interaction across the whole project is viewed as one activity, and where there may be several steps involved, ensure opportunities to minimise disruption and visits to customer premises are exploited where possible.

Installation of monitoring equipment

Following the phase checking, customers in the target area were initially approached by letter. From this population of c. 12,000 phase-checked properties, 11,580 letters were sent and followed-up by 7,900 telephone calls to 5,500 different properties. These letters and telephone calls translated into 1,381 monitors installed, and 1,754 responses declining our request. Initially the success rate was low. However, as the Project progressed, the approach was adapted in various ways to significantly increase our success rate:

- Modifying the language and message of the letters
- Offering an incentive
- Ensuring working patterns suited the customers
- Raising awareness of the project through other routes
- Changing to a ‘plug-in’ type of monitor, rather than a ‘hard wired’ monitor
- Recruiting and maximising value from installers

Each of these changes, and the subsequent learning is discussed in turn below.

Written communications to householders

It was recognised that letters sent to homeowners needed to use an appropriate level and style of language. Therefore, the content of the letters was simplified and included more emphasis on the benefits of the project, incorporating messages such as ‘this project could help to enable a lower-carbon future’. The initial and modified letters are reproduced in Appendices B and C.

Another issue that had an unknown effect on response rates was trying to ensure the letters were opened and read by householders. As for the phase-checking letters, missing or out-of-date information on customers living in the properties meant many letters were addressed ‘to the occupier’. Whilst methods such as printing 'This is not a circular' on the envelopes to encourage customers to read the letters may have been helpful, if a similar project was to be run, general

7

awareness raising (such as advertising through local media and public information displays in e.g. libraries) might help to encourage customers to read letters and take part in the study.

L2: It is important to ensure the overall benefits of the project are emphasised, as customers respond well to this.

L3: Don't rely on letters in isolation – use a range of methods to increase the chances of the letter being read and acted upon.

The Importance of incentives and word-of-mouth

The modified letter (Appendix C) included a £10 incentive for a successful monitor install. However, during interview, installers did not feel that this incentive significantly influenced customers' behaviour (i.e. whether they allowed the monitor to be installed or not).

Interestingly, as mentioned above, the installers reported that the most effective message was the work being important for the future of the network, which was reflected in the contents of the modified letter. The figures also suggest that the modified letter resulted in a statistically significant increase in consents, from 12% to 18%:

Letter Type	Sent	Further Contact	Letter Consent	Letter Decline
Original wording, no incentive	4347	42%	12%	20%
Modified wording with incentive	7236	52%	18%	20%

However, despite the installers perception of the effect of the incentive, it was felt that word-of-mouth (particularly with respect to the incentive offered) meant that more people on the same street would be interested in taking part. Not only did such word-of-mouth introductions make communicating with customers easier, but it was more efficient, avoiding the need for representatives to make multiple visits to the same area.

Another word-of-mouth related benefit noted by the project team was having a community advocate. Whilst there was only one case of this during the LV Templates project, (A University Lecturer who helped explain the project to her neighbours), identifying and engaging with other people or groups who can potentially engage with their community could be a useful strategy to consider.

L4: Offering incentives may not dramatically improve sign-up rates – people seem to respond more to messages about work being important for the future of the network – this should be reflected in communications with customers.

L5: Incentives may, however, prove useful in encouraging sign-ups via word-of-mouth, because this prepares people for the visit and increases levels of trust.

L6: Word-of-Mouth is also an effective way of saving installers time by increasing their chances of being able to perform multiple installs in the same area at the same time, reducing the need to travel.

8

Increasing the chance of speaking to the customer

It was found that it was important to visit at a time when householders were more likely to be in, such as the early evening or at weekends. Another successful technique was to leave postcards to let the householder that WPD had visited, giving them a chance to rearrange the visit. This was particularly useful in cases where the WPD representative had only just missed the customer and was able to return to the house immediately.

L7: Understand your customers and be prepared to work to their schedules when visiting their homes.

Raising awareness of the Project in the community

As well as awareness raising to increase the chances of customers opening written correspondence, it was also found that greater project awareness in the community could have other positive effects. For example, brand awareness of WPD appeared low. Whilst every effort was made to reassure the customer through ensuring representatives used WPD vans, uniforms and credentials, there were a small number of instances where customers were unclear who WPD were and consequently felt concerned about the representative. A number of quick, low cost methods were developed to reduce this possibility. It is strongly recommended that future LCNF Projects involving customer interaction consider:

- Ensuring all customer-facing WPD teams know where and when representatives are likely to be visiting customers, to ensure consistent, high quality information is given in response to such queries (e.g. if a customer calls to verify a representative's ID card)
- Where and when representatives are likely to be in the customer's area, to ensure consistent, high quality information is given in response to such queries.
- Contacting the local council, police and trading standards to make them aware of the project and potential door knocking, including detailed information on the likely times and areas.
- Where the area involves student halls of residence, or a high concentration of privately let student housing, contacting the appropriate Student's Unions means the university could inform students, who, due to the temporary nature of their residence, may be harder to reach through other means such as 'to the occupier' letters or local media.

L8: As well as trying to ensure customers are aware of the Project in advance (through letters, telephone calls and general awareness raising through local media), ensure all relevant authorities (and customer-facing teams in your business) are aware of the project to provide consistent, high quality advice to avoid the possibility of complaints.

L9: Awareness raising via relevant authorities is often quick and cost-effective, especially if doing so avoids customer complaints.

9

PLUG-IN VS. BOARD-WIRED MONITORS

in September 2012, as an attempt to increase the number of installs, a plug in type monitor was designed. This required only a conventional plug socket and therefore no supply interruption.

'Hard-wired' monitor

'Plug-in' type monitor

Whilst the number of plug-in monitors installed represented a small proportion of the overall monitors installed, of the 250 plug-in monitors built, 249 were successfully installed. The plug-in monitors had numerous advantages over the hard-wired type:

- No supply interruption required for the installation
- Quicker and easier to install - No drilling/fixing
- Easier to explain and more consumer friendly – a tangible object that the customer can see before the installation
- Potential to use installers with less technical knowledge (and consequently to recruit installers with high levels of soft skills)

L10: Consider how the appeal to customers can be increased by design – how can technology be used to reduce disruption, or enable other benefits.

RECRUITING AND MAXIMISING VALUE FROM INSTALLERS

The success rates of the installers increased over time. For example, some installers were very organised, pre-wiring to reduce time. The installers were paid per job and were further incentivised by increasing the pay per job after they had installed 30 monitors. Whilst this had an incentivising effect, it may have meant that installers were more likely to focus on quick and easy jobs, not making multiple return visits to areas with low sign-up rates. Whilst this effect was not analysed in detail, it is not thought to have had any detrimental effect on the data collected.

10

L11: It is important to consider how installers are remunerated and what effect this may have on sign-up rates and installation speed.

L12: The most motivated installers may have valuable knowledge (like how to pre-wire components to reduce installation time) – ensure there are opportunities to capture this.

KNOWLEDGE OF INSTALLERS - ENGINEERING VS. SALES

As previously mentioned, using plug-in monitors meant that installers required less technical knowledge. This meant that installers with more previous experience in sales or customer facing roles could be recruited. Installers with sales experience were often better at changing a customer's mind, or persuading them to sign-up, especially faced with difficult questions such as *'do I have to have it?'*.

However, had the phase-checking stage also been used to either assess an installation, or actually carry out the installation, installers with a higher level of technical skill would have been essential.

L13: It is important to consider the level of technical knowledge required to undertake the installation – a simple installation requiring a low level of technical knowledge may mean installers with a sales background bring higher sign-up rates.

INSTALLATION OF PHOTOVOLTAIC MONITORS - NPOWER SUCCESS RATE

This part of the Project aimed to monitor the generated output of selected PV installations to assess the impact on the LV Network and to understand if a proxy meter could be used to predict the output of other installations.

WPD were able to work with NPower to identify customers in the project area who have installed small scale embedded generation (i.e. Solar PV) installations under the feed-in-tariff (FIT) arrangement.

As well as being able to take advantage of NPower having more complete customer names and contact details, it was found that customers with existing solar PV installations were also generally more interested in their electricity usage, and generally more amenable to adopting new technology. However, as a consequence, these customers asked a lot more questions about the monitor installation, meaning it was important to ensure installers were fully briefed on the wider aims and benefits of the project, as well as what the installation itself involved.

L14: It is important to ensure installers or other representatives are sufficiently well-briefed on the project aims to deal with queries from the most engaged customers.

Of 400 letters sent to these customers, 120 consents were received. Whilst this is a similar overall success rate to the main LV monitoring installation, the consents were obtained at a significantly faster rate.

L15: Where customer numbers allow, consider taking a more personal approach to the interaction through an organisation with an existing relationship with the customer.

11

Other learning arising from the customer interaction

This section records other relevant learnings arising from customer interaction.

Permission to install equipment in rented properties

When seeking consent to install equipment in customers' premises, it is important to note that in the case of rented properties, that the consent of both the tenant and the landlord must be obtained. Seeking such consent can add significant time, or reduce the overall success rate.

L16: It is important to recognise that having to seek permission from both the tenant and landlord for installation of equipment in rented properties will delay the process, or result in a lower success rate.

Additional benefits

Whilst the phase checking requirement was not anticipated at the bid stage, visibility of which customers are on which phase could help in fault management.

A further interesting additional learning that also constitutes an additional benefit arising from the customer interaction was the ability of the installers to identify potentially illegal or unsafe installations. Safety aspects checked as part of the monitor installation included looking for rotting meter-boards and inadequate cut outs (fuses that do not have a sufficient rating for the type of property, or that have become damaged).

As well as allowing immediate rectification of potential safety issues, the installers photographed customers' installations before and after the monitor was fitted. As well as protecting WPD from complaints about installations causing damage, the images also forms a useful repository of typical customer installations which could be useful to future projects to illustrate space constraints, typical condition etc.

L17: It is important to consider what other incidental benefits or learning could be obtained in the course of interactions with customers – safety checks and other data on typical customer installations are two examples.

4. Learning from the construction and installation of substation-monitoring and the telecommunications network

This section summarises the main learning points from the construction and installation of substation monitoring hardware and associated telecommunications equipment.

The installation of substation monitoring equipment and associated telecommunications involved a considerable amount of work. Every substation required the installation of CT's and the associated monitoring cabinet. In addition a telecoms solution via uhf radio link was required to every site.

Design and installation of substation monitoring equipment

Due to unforeseen delays to the design of the communications architecture at the beginning of the project, the design of the enclosure suffered an associated delay. Further shorter delays to the design and manufacture of the enclosures were caused by:

- Having to develop a slim-line enclosure in order to fit it into some very restricted substations.
- Needing to CE mark the entire enclosure.
- Space restrictions in the manufacturing facility in Bilbao, meaning the manufacture of the enclosures had to be undertaken in batches

L18: Where hardware is not available off-the-shelf, ensure the proposed design is explored thoroughly at bid stage, and ensure sufficient contingency is built-in to the design phase.

L19: Where there is a need for significant hardware, assess practical aspects such as the logistics of transportation and storage at the bid stage or early design phase.

Customer interaction learning during sub-station monitoring installation

The majority of the substation monitoring installation was carried out by teams of installers, with the following learning points recorded:

- The shutdowns for the installation of CTs caused unexpected issues around customer connectivity. This required every substation to be checked for connectivity prior to shutdown which warranted additional team support activity.
- During some shutdowns it was found that the CTs would not fit due to internal restrictions of the LV plant / cabinet. This reduced the substation availability for the Project, but still incurred CMLs and CIs.
- The management of customer enquiries and questions around the shutdowns took a great deal of time because of significant customer impact.
- All types of customer affected because of the nature of the project including domestic, commercial and industrial.
- Where appropriate, certain customer interruptions were catered for during 'out of normal office times' including evenings, weekends and early hours of the morning. Whilst this reduced the potential disruption to customers, it did impact on the following day's work availability.
- Undertaking work during the summer months (i.e. between March and October) would have been preferable, because taking customers off supply during winter is likely to cause more disruption, and land is usually wet during the winter.

- The land owner consents required for access to pole mounted substations caused some delays and led to some sites not being available. A copy of the letter sent to land owners may be found in Appendix D).
- Each substation had multiple visits for installation of: i) CTs and brackets, ii) the monitor enclosure, iii) aerial and communications. Where the installations required access to equipment not located on public land, combining visits would have minimised further potential disruption and may have made obtaining permission easier.

L20: Many installation issues (and consequently some of the disruption to customers) could have been avoided had a full substation survey been completed prior to the installations. For example, surveys could have ruled out installation in steel kiosks and on some very congested poles.

L21: If supply interruptions are not avoidable, planning to carry out installations over the summer months may reduce disruption to customers, as well as making the installation easier.

L22: For unavoidable supply interruptions, out-of-hours working further minimises disruption to customers, although the resource implications of significant out-of-hours work must be considered.

The importance of dedicated staff and early engagement

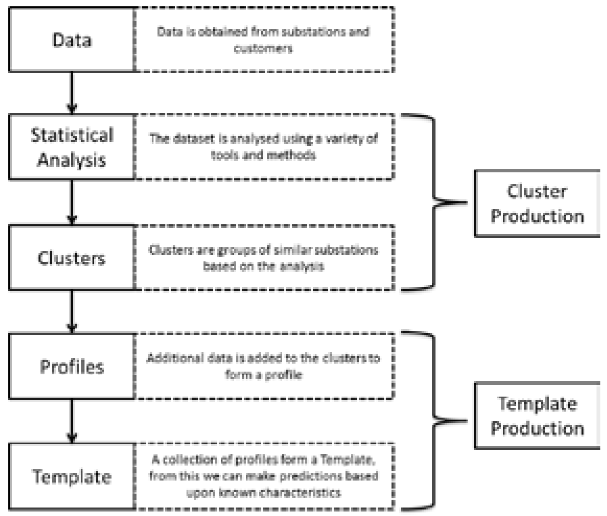
The appointment of a full-time Team Manager and Team Support for the installation works was essential to ensure smooth running of the installation process. This was further helped by consulting staff with pole installation experience, which proved beneficial in specifying materials and suppliers, and methods of installing connections.

However, with respect to the installation of the telecommunications network, it was felt that the Project would have benefitted from the earlier involvement of Surf Telecoms. Because of a high level of pre-existing commitments the earlier engagement with Surf Telecoms might not have allowed their earlier involvement, but it could have allowed for a greater degree of planning and other mitigations.

L23: Ensure sufficient dedicated resources are in place, and all other relevant parties within the business are engaged as early as possible – at bid stage if possible.

5. Learning from the process of creating templates

As this Project and the associated data analysis is on-going, the technical learning from template creation is outside the scope of this report, but will be reported on fully at the end of the Project. This section focusses on the learning arising from the process of creating templates, which may be roughly summarised as follows[4]:



The importance of data

A pre-requisite for the analysis and subsequent template creation is data. A number of learnings around the collection and use of data have been identified through the transformation of data gathered from the voltage monitors installed in this Project have been identified, including:

- The need to decide at an early stage the practical issue of collating, storing and transferring the data to be analysed. This is particularly important when an external organisation is involved (in this case, the University of Bath) meaning the data needs to be transferred securely across networks.
- The sometimes significant amount of time and work required to transform raw data into a form that can be used for statistical analysis. Early visibility of even small amounts of data can help.
- The importance of sense checking, reporting and feeding back information for updating and correction. For example, some unexpected data was the result of an incorrect voltage

[4] Note that the terminology used in this interim report is likely to change as the process of template creation is further refined.

monitor installation. Feeding back information on the location of such data meant the installations could be corrected.

- The importance of knowing exactly what the data contains, in terms of units of measurement and time periods. Having an agreed standard 'specification' for the data early in the project can be helpful in this regard.
- The role of non-measured characteristic information, i.e. the fixed data - both in understanding the clusters and in helping inform further analyses that will result in the development of templates. It is sometimes difficult to know at the outset of the project what fixed data would be useful. It is also important to understand whether such fixed data has limitations in terms of quality and whether it gets outdated.
- The potential difficulties in linking different datasets, for example the data from household voltage monitors, substations and PV installations.

L24: There are many potential issues to consider when undertaking projects involving the analysis of data, including practical issues of data transfer.

L25: Sense checking data prior to analysis is an important step and can be useful to help identify, for example, incorrect installations.

Integration of statistics and electrical expertise

Another area where learning has occurred has been the around the need to combine expertise on statistics with expertise in electrical engineering and network design. This is important to ensure that not only appropriate statistical techniques are used, but also to ensure the output is useful to its intended audience. There is a related need for experts in both domains to ensure they understand the language used by the different disciplines - particularly when it is very important to understand the precise definitions that might be used to express different things, and when this may be less important.

An example of this may be found in the difference between clusters and templates: The clusters produced from the statistical analysis of the data are not the same as templates. Here, 'clusters' are used to describe the output of statistical clustering techniques on measured data (real power delivered). The creation of templates involves the refinement of clusters using other data such as substation characteristic information to help better understand their nature. It is possible, for example, that some clusters may be normalised, whilst others will be split in light of this further analysis.

L26: It may necessary to combine different areas of expertise to solve a problem. It is important that this integration is effective, to ensure the outputs are both valid and useful.

L27: Domain expertise often brings with it a specialist vocabulary. It is important that discipline understands where the language used has a special meaning, to avoid confusion and potential errors.

Linked to this, there is also a need to re-purpose the project outputs to make them appropriate to a number of different audiences with varying levels of technical knowledge, from mathematicians, to various potential users within DNOs, and other interested parties such as Ofgem and the general public.

Additional learning arising from the process of template creation

Additional learnings relating to the process of template creation included, for example, the requirement for the project partners to learn new skills in, e.g. R and RStudio - a programming language and environment for statistical analysis. Using such tools and techniques in a new domain led to potentially useful technical learning, such as

- How to present maps in R
- Methods for converting postcodes so they are mappable
- Faster clustering methods for similar datasets generated by WPD or other DNOs in the future.

L28: The use of tools and techniques not commonly employed in the electricity industry may give rise to useful domain-specific leaning, such as the fastest clustering methods for data gathered from voltage monitoring.

6. Examples of learning transferred to other projects and beyond

Many of the learning points identified in the above sections have informed more recent LCNF projects, either indirectly, through discussions and general sharing of good practice between project managers, and also directly – i.e. both the technical and process learning feeding directly into other projects.

The SoLa Bristol project has benefitted directly from the experiences of the LV Templates project with respect to the approach taken to engaging with customers. For example, it was decided to use a community group (Knowle West Media Centre - KWMC) to mediate communication between customers and WPD. As well as WPD benefitting from KWMC's local knowledge to gain consents for installations more easily. KWMC have also supported WPD in producing marketing materials tailored specifically to the customers that were sought as part of the Project. More generally, wider communications about the project have benefitted from learning such as to what type of messages customers best respond.

The load estimation task of Project Falcon was able to make use of the LV Templates meter data, which assisted the process of generating and evaluating substation load profiles. Falcon also benefitted from learning from the installation of substation monitoring equipment that avoids the need for customer supply interruptions. This synergy between the two projects was identified late in the bid stage and gives an example of providing better value for money across WPD's LCNF projects.

Beyond WPD, much of the learning presented in this interim report was shared with other DNOs and the wider industry through a cross-LCNF knowledge sharing event held in July 2012. As well as presentations from LV Templates, SoLa Bristol and Project Falcon, a series of workshops allowed various members of the LV Templates project team to discuss in detail much of the learning discussed in this report, particularly around communicating with customers and the installation of monitoring equipment. A summary of this event may be found at WPDs LCNF Tier 2 portal for academic and specialist audiences: http://lowcarbonuk.com/lcuk/articles/45-lcnf-day-17-july-2012

7. What next? - how we propose to integrate learning into BaU

Throughout the Project, a number of ideas on how templates can integrated into Business as Usual (BaU) activities (and therefore provide benefit to WPD and other DNOs beyond project-end) have been recorded. Whilst the precise potential benefits (and therefore the approach to integrate them) will be somewhat dependent upon the final project outputs, many of these initial ideas have been developed by a WPD policy manager who has attended many project team meetings, highlighting the importance of early collaboration with potential end users.

L29: Identify and engage with the people who might find the output useful from the early stages of the project, both internally and from other DNOs.

This section therefore first summarises potential benefits using the Templates, before discussing possible strategies to embed them in our BaU activities, and also to engage with other DNOs.

Potential applications in BaU activities

Some potential applications identified include:

1. Using the data to feed into Crown – for example, by changing demand figures to reflect a greater degree of granularity, it may be possible to:
   a. Gain a better understanding of which substations may be overloaded.
   b. Carry out better investment planning – e.g. calculating capacity for connections, or deferring reinforcement
2. Improved LV network design by refinement of the data in Windebut, an LV network planning tool.
3. Utilising the voltage data to give visibility below primary substations, which could impact upon, for example, policies covering voltage drops on parts of a network. Better visibility of the LV network may add data to further evidence such policies, or change them.
4. Better visibility of the LV network may also allow fuller advantage to be taken of statutory limits for voltage, enabling more flexible connection of generation or load. For example, modifying Crown to model voltage effects could mean we are able to be less conservative about PV connection in some circumstances, which has the potential to reduce connection time and also the cost of analysing the connections.
5. Influencing statutory voltage limits – the data could be used to demonstrate benefits of dropping lower voltage limits – potentially allowing more generation and deferring reinforcement.
6. Active network management – using templates to predict load requirements on the network and plan events better.

It must be noted that whilst some of these potential applications (and how to embed them in practice) are relatively clear and well understood, some others would take more significant changes to systems or processes and thorough evaluation, and therefore could only be implemented over a longer time period. For example, one potential early and immediate change to current practices could be in the area of generator connection studies where at present, it is assumed that that mininimum is 20% of maximum demand. The templates may allow this assumption to be challenged, resulting in an immediate change to this design rule. It should also be noted that some of the potential applications may require the data or resulting templates to be updated, to ensure their continued utility.

18

Internal WPD workshops

As well as pursuing the above suggestions, a series of internal WPD workshop will be developed to introduce LV Templates to members of WPD who may be able to suggest other applications and methods for integrating the templates into BaU. As noted above, a number of potential applications have been suggested, which vary in terms of ease and timescales for implementation. It is likely that other members of WPD may have other ideas to how best to implement the learning in their own areas of expertise.

DNO workshop

We are also planning to hold a DNO workshop which will provide project background, information on the clustering and template creation process, and provide examples of how a planner could use this information. It is hoped that through sharing information with other DNOs, we might find areas where we can collaboratively develop the templates. For example, other DNOs may have monitoring data that could be used to test or validate the templates. Encouraging the sharing of not just the templates themselves, but also the data and suggested application areas has the potential not only to validate the templates, but improve their accuracy or utility.

L30: Whilst many potential application areas relevant to WPD and other DNOs can be identified, further engagement in the form of workshops is required to ensure the benefits are realised.

8. Conclusions

This interim report on learning generated during the course of the Low Voltage Network Templates project has been prepared to support the presentation to Ofgem on the 19th March 2013. The main focus has been on process learning (i.e. learning from the process of undertaking the Project), particularly with respect to learning arising from interactions with customers. A fuller treatment of all learning gained from the technical aspects of the Project (i.e. the installation of substation monitoring, telecommunications) and the creation of the Templates themselves will follow in the final reports.

However, significant process learnings have been identified in a number of areas. Some have already integrated into other WPD LCNF projects and many others disseminated to DNOs and the wider industry. As this Project draws to a close, we are focussing our attention on a number of potential opportunities to integrate the templates or the data itself into Business as Usual activities of WPD and other DNOs.

The table overleaf summarises the learnings presented in this document, classified against a number of themes:

19

Customer Engagement	L1: Ensure customer interaction across the whole project is viewed as one activity, and where there may be several steps involved, ensure opportunities to minimise disruption and visits to customer premises are exploited where possible.
	L2: It is important to ensure the overall benefits of the project are emphasised, as customers respond well to this.
	L3: Don't rely on letters in isolation – use a range of methods to increase the chances of the letter being read and acted upon.
	L4: Offering incentives may not dramatically improve sign-up rates – people seem to respond more to messages about work being important for the future of the network – this should be reflected in communications with customers.
	L5: Incentives may, however, prove useful in encouraging sign-ups via word-of-mouth, because this prepares people for the visit and increases levels of trust.
	L6: Word-of-Mouth is also an effective way of saving installers time by increasing their chances of being able to perform multiple installs in the same area at the same time, reducing the need to travel.
	L7: Understand your customers and be prepared to work to their schedules when visiting their homes.
	L8: As well as trying to ensure customers are aware of the Project in advance (through letters, telephone calls and general awareness raising through local media), ensure all relevant authorities (and customer-facing teams in your business) are aware of the project to provide consistent, high quality advice to avoid the possibility of complaints.
	L9: Awareness raising via relevant authorities is often quick and cost-effective, especially if doing so avoids customer complaints.
	L10: Consider how the appeal to customers can be increased by design – how can technology be used to reduce disruption, or enable other benefits.
People & Culture	L11: It is important to consider how installers are remunerated and what effect this may have on sign-up rates and installation speed.
	L12: The most motivated installers may have valuable knowledge (like how to pre-wire components to reduce installation time) – ensure there are opportunities to capture this.
	L13: It is important to consider the level of technical knowledge required to undertake the installation – a simple installation requiring a low level of technical knowledge may mean installers with a sales background bring higher sign-up rates
	L14: It is important to ensure installers or other representatives are sufficiently well-briefed on the project aims to deal with queries from the most engaged customers.
Customer Engagement	L15: Where customer numbers allow, consider taking a more personal approach to the interaction through an organisation with an existing relationship with the customer.
	L16: It is important to recognise that having to seek permission from both the tenant and landlord for installation of equipment in rented properties will delay the process, or result in a lower success rate.
	L17: It is important to consider what other incidental benefits or learning could be obtained in the course of interactions with customers – safety checks and other data on typical customer installations are two examples.
Technology & Equipment	L18: Where hardware is not available off-the-shelf, ensure the proposed design is explored thoroughly at bid stage, and ensure sufficient contingency is built-in to the design phase.

20

Construction process	L19: Where there is a need for significant hardware, assess practical aspects such as the logistics of transportation and storage at the bid stage or early design phase.
	L20: Many installation issues (and consequently some of the disruption to customers) could have been avoided had a full substation survey been completed prior to the installations. For example, surveys could have ruled out installation in steel kiosks and on some very congested poles.
	L21: If supply interruptions are not avoidable, planning to carry out installations over the summer months may reduce disruption to customers, as well as making the installation easier.
	L22: For unavoidable supply interruptions, out-of-hours working further minimises disruption to customers, although the resource implications of significant out-of-hours work must be considered.
People & Culture	L23: Ensure sufficient dedicated resources are in place, and all other relevant parties within the business are engaged as early as possible – at bid stage if possible.
IT & comms	L24: There are many potential issues to consider when undertaking projects involving the analysis of data, including practical issues of data transfer.
	L25: Sense checking data prior to analysis is an important step and can be useful to help identify, for example, incorrect installations.
Project Management	L26: It may necessary to combine different areas of expertise to solve a problem. It is important that this integration is effective, to ensure the outputs are both valid and useful.
	L27: Domain expertise often brings with it a specialist vocabulary. It is important that discipline understands where the language used has a special meaning, to avoid confusion and potential errors.
IT & comms	L28: The use of tools and techniques not commonly employed in the electricity industry may give rise to useful domain-specific leaning, such as the fastest clustering methods for data gathered from voltage monitoring.
Industry process & regulations	L29: Identify and engage with the people who might find the output useful from the early stages of the project, both internally and from other DNOs.
	L30: Whilst many potential application areas relevant to WPD and other DNOs can be identified, further engagement in the form of workshops is required to ensure the benefits are realised.

21

LIST OF APPENDICES

22

APPENDIX 5

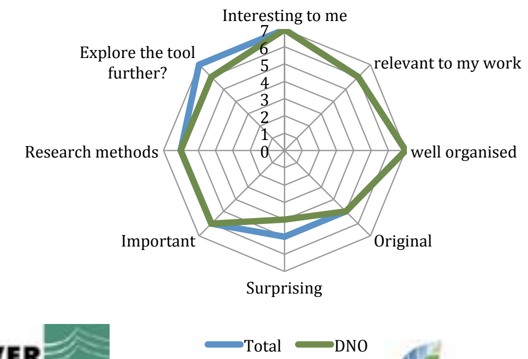
LV Network Templates Knowledge Sharing Event

- The majority of feedback was positive, with all of the DNOs indicating that they would be interested in exploring the tool further.

- Indeed only one participant indicated that they would not utilise this tool and they clarified that this was because it would be outside of their job role.

- The event was seen to be well organised and relevant to the participants. Generally participants reported the templates to be original and important for the industry.

- In the graph the most frequent response to each question are indicated, the closer to 7 the more positive the response. Line one shows responses from all attendees while line two focuses on the response from DNOs (excluding WPD). 16 responses were provided and all but 2 provided contact details.



WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales
LOWCARBONUK.COM
UNIVERSITY OF BATH

LV Network Templates Knowledge Sharing Event

Questions Asked:

- How sensitive is it to specific input; would making a tiny tweak have a disproportionate effect?
- What's going to happen if things change dramatically in terms of amount of LV technologies; will the historical data be no longer valid?
- Which parameters are used for classification? Are these the same as in clustering?
- Have you checked the tool in other WPD areas?

Suggested metrics for potential inclusion:

- Consider minimum demands, this might be useful for planning.
- Is this corrected for British summer time? Does it matter?

WESTERN POWER DISTRIBUTION
Serving the Midlands, South West and Wales

LOWCARBONUK.COM

UNIVERSITY OF BATH

APPENDIX 6

Bank statement – confidential

It should be noted that £350,000 remains in the Project Bank Account. This is equivalent to the cost of the unused voltage monitors as agreed previously.

HSBC

Acc name	WPD WALES LCNF PROJECT
Account number	401413-12550571
Bank name	HSBC Bank plc
Currency	GBP
Country	Great Britain
BIC	MIDLGB22
IBAN	GB41MIDL40141312550571
Closing ledger balance brought forward From 04/06/2013	349,853.68
Closing available balance brought forward From 04/06/2013	349,853.68
Current ledger balance as at 05/06/2013 10:45	349,853.68
Current available as at 05/06/2013 10:45	349,853.68
Specified date range	01/05/2013 to 31/05/2013

Bank reference	Customer reference	Value date (dd/mm/yyyy)	Credit amount	Debit amount	Post date
Balance brought forward 15/05/2013			349,816.30		
TO 14MAY2013 GROSS INTEREST TO 14MAY2013	NONREF	15/05/2013	37.38		15/05/2013
Balance as at close 15/05/2013			349,853.68		

Page 1 of 1

NOTES

WESTERN POWER DISTRIBUTION

NETWORK TEMPLATES

LCN Fund Low Carbon Networks

Llywodraeth Cymru Welsh Government

npower

UNIVERSITY OF BATH

imagination at work

passivenergy™