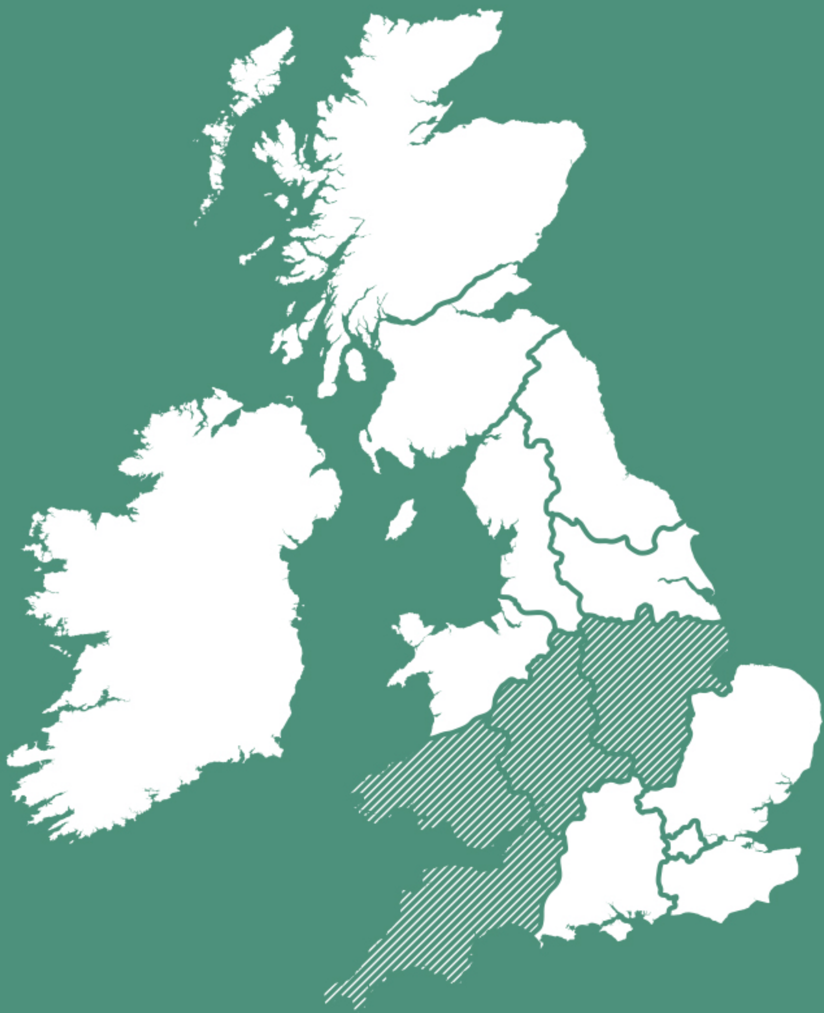
WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

EARLY LEARNING OF LV NETWORK IMPACTS FROM ESTATE PV CLUSTER

CLOSEDOWN REPORT



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Prepared by:	Steve Gough	01.12.2016
Reviewed by:	Roger Hey	01.12.2016
Approved (WPD):	Nigel Turvey	01.12.2016

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01.12.2016	v2.0	Rebrand and updated

Contents

Executive Summary

The hypothesis that this project was attempting to address was the suspicion that a high density of solar panels may impact on the voltage on the local network. If the rate of installation of PV continues this could be an expensive and wide ranging problem to solve. However, identifying an area of network with the sufficient density of customers in order to carry out the project needed to be identified.

The project was registered in July 2011 with an intended lifecycle of 18 months, and during this time it collected data from a small housing estate in Crickhowel, South Wales, where all the houses had photovoltaic (PV) panels.

The key objective was to establish what effect this high density of PV had on the low voltage (LV) network, in particular looking at the voltages for different sizes of LV main. Monitoring was installed mid feeder and the feeder end for each phase which was also complemented with additional data on PV output, tap change and solar irradiance.

In collecting the data we then undertook a data analysis phase in order to understand more fully the impact with the intention of then sharing our results and recommendations with our stakeholders.

Our findings in summary were:

- the voltage seemed to be unaffected by the choice of cable.
- The original LV design prior to the PV was installed indicated that 95mm^2 cable would be sufficient. The peak voltages were seen while PV output was minimal, suggesting that the approach to modelling embedded domestic generation ought to be reviewed

The PV had very little direct influence on the voltage at the feeder level although there was some increase in the average voltage at the feeder ends. The key learning from the project was that the voltage was not significantly affected by the LV main impedance or by the PV panels, leading us to recommend revisiting the LV planning assumptions.

In undertaking this project it also allowed us the opportunity to then consider it's learnings in conjunction with the more wide ranging follow on project call PV Suburbia. This would look at a more widespread footprint of PV to see the implications of that on the network, but based heavily on the findings of this project with the intention of further refining our planning assumptions.

1. Project Overview

Early learning of LV network impacts from estate PV cluster project was registered in July 2011. A new low carbon housing development of some 20 houses has been developed by Melin Homes in Crickhowell, South Wales. The estate features high efficiency houses each equipped with PV. Traditional network studies indicate that voltage limits would be exceeded without an overlay of existing 95 sq. mm LV cable. The scheme provided a low cost opportunity for early learning of PV voltage impacts and validation of existing design assumptions. Installation of two different size LV cables in parallel to the existing cable, with linking facilities at each end, provided a real life, on load, capability to change the impedance of the feeding LV cable and measured the resulting changes in voltage performance.

2. Scope and objectives

As detailed above this project sought to understand more about the impacts of high densities of PV on the network, the opportunity afforded to us early in the stages of the development of this type of Low Carbon Technology and so therefore we took the opportunity to test the accuracy of present modelling through real life voltage and load measurements on one feeder of an LV system.

The objectives were to seek early data on the behaviour of multiple densely populated PV units on a single estate and to test the validity of the traditional network modelling that indicated that no more than 12 units could be accommodated.

Such data could benefit modelling with the consequential impact on seeking to reduce reinforcement cost for future connection of multiple LV PV installations

Objectives	Status
Obtain early data on the behaviour of multiple densely populated PV units on a single estate	✓
To test the validity of the traditional network modelling	✓
To see if the data could benefit DNO modelling and determine whether there would be a consequential impact on reinforcement costs	✓

3. Success criteria

All of the objectives have been achieved and in some cases expanded on from the original scope of the project, and this is detailed in Section 6.

Success Criteria	Status
The estate having all PV units installed	✓
WPD installing the cabling, pillars and monitoring	✓
Data being captured and analysed	✓

WPD writing report and sharing with other DNOs	✓

4. Details of the work carried out

4.1 Project Background

Western Power Distribution (WPD) has seen and continues to see a significant increase in the level of domestic PV solar panels across its four license areas which has led to concerns about their impact on and the potential future implications on LV networks.

The design assumptions on the LV network tend to be cautious to ensure a reliable network infrastructure and this is a crucial aspect of a DNO's modelling and business operations. As there is less visibility of the LV network in general, the design assumptions need to take into account the possibility of issues that may have not been originally envisaged at the time of design. In this project we wanted to understand the potential implications of a high concentration of domestic PV installations on the local feeder. This new housing development provided the perfect platform for us to achieve this.

In particular we wanted to explore what effect the LV main impedance would have on the voltage rise caused by the PV panels. By gathering the data for various scenarios from the different LV mains in service for this particular estate, we were able to challenge the assumptions currently in use for LV design. We believe that this will be an extremely valuable outcome for the industry as a whole.

4.2 Project Works

Melin homes had built a housing estate in Crickhowel where they wanted to install PV panels shortly after building the homes. The LV designer calculated, using his standard tools, that the voltage rise would be above statutory limits and therefore a 300mm^2 cable would need to be installed to replace the existing 95mm^2 cable. We decided to explore what effect replacing the cable would have, and compare this with a scenario where reinforcement was not applied.

To allow us to understand these effects we installed two pillars for the LV main which allows us to select either 95mm^2, 185mm^2 or 300mm^2 cable.

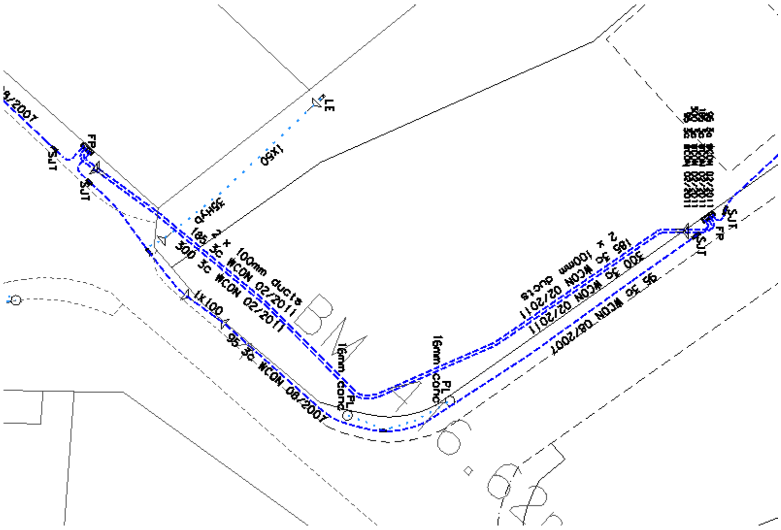

Figure 1 – Cable and cabinet install

The cabinets were standard pavement mounted 3 phase, three feeder cabinets. The cables were selected by inserting or removing links into the cabinets. To avoid any interruptions to the customers supply each cable was put in parallel briefly while carrying out the changeover. The entire feeder length is 223m and we overlaid 60m of this with the other two cable types.

Initially we installed two PM3000 power quality meters at each of the cabinets, however the values obtained at each were very similar. So we removed one unit just leaving one PM3000 at the cabinet closest to the domestic homes.

The PM3000 was selected as it is widely used by the staff in the local office for data collection purposes. The PM3000 is a ruggedized 3 phase power quality meter which can measure voltage, current, real and reactive power, harmonics and flicker. The units were readily available from the local depots and local staff had the relevant software on their laptops. They are Class 1 devices and can record down to appropriate intervals, adapting to any rate of change of the signal using an algorithm. The disadvantage is that they have no communications module so the data needed to be downloaded every two weeks by the local planner when the local memory became full.

Several months after the project had been running we decided to install single phase PM1000s at 3 customer's meter boxes which were at the end of the feeder on each of the three phases. This allowed us to see the feeder end voltage and compare this to the cabinet, but also provided a proxy for the PV export. The data which came back from the feeder ends was very informative and so further PV meters were installed on three houses with varying PV panel orientations.

The data was collected initially from February 2012 with the main body of data being collected from May 2012 onwards at the pillar and feeder ends. This meant we had data through the summer months at the four main locations. The PV meters were more difficult to install and set up so data only started being collected from November 2012. To allow us to approximate the PV output of the site we used post code specific irradiance data for the summer months. Additional data was collected at the time of the tap changes at the local Primary Substation. The Distribution Substation at the site was the first on the 11kV feeder, so the voltage was highly affected by taps at the Primary Substation. The data allowed us to attribute any large voltage step changes to the tap changer rather than local effects.

The data we collected was the three phase voltage and the real and reactive power from the PM1000s and PM3000. The PV data was kWh data of output from the PV. All of this data was used in the analysis however it was the voltage with relation to PV export where the key conclusions were drawn. The vast majority of this data was recorded from April 2012 through to February 2013. The only data which was used prior to this was background data measured at the pillars.

We were naturally very cautious when changing the cables from 300mm^2 down to the other sizes. We ensured that we had plenty of background 300mm^2 data before deciding to reduce the size of the cable. We analysed the absolute peak, the statutory 10 minute average peak and the time of day the peaks were occurring. The LV planner had designed the network for the homes without the PV so we knew that the thermal capabilities and voltage drop of the load were well within limits. It was only the voltage rise from the PV which was the unknown factor. From the initial data (please see Appendix A) it was easy to see that the voltages were not remotely close to the statutory limits. Although the occasional instantaneous peak was over the 253V limit, these were invariably late at night when load was low, rather than when the PV output was high. We did the same analysis for the change between 185mm^2 and 95mm^2 too. The new smaller cable was in service for a few days before changing back to the higher size again to analyse the voltages and only utilised if voltages were well below the statutory limits.

Cable	Impedance (ohm/km)	Impedance for 60m (ohm)	Summer cyclic rating (A)	Spring/autumn cyclic rating (A)	Winter cyclic rating (A)
95 SAC EPR	0.427011647	0.025621	273	242	308
185 SAC EPR	0.236080166	0.01416481	399	426	452
300 SAC EPR	0.162989488	0.009779369	526	561	598

5. The outcomes of the Project

This trial allowed us to explore what impact cable impedance had on voltage rise due to domestic PV. We collected a large amount of high resolution data and this has led us to conclude that in this case the impedance of the cable had negligible effect on the voltage. The other data collected has given us a clearer understanding of how voltage at the feeder ends relates to the LV main during different times of day and the scenarios included properties net export from the PV. Also we saw how installed capacity can be affected by the orientation of the PV panel and its efficiency meaning that the tangible effect on the distribution network is less than initially expected.

All data from the project was collated in E.ON New Build & Technology's report Experiences with Building-Mounted Photovoltaics which explored and concluded the findings in a statically robust way, this is provided within Appendix A.

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

The original registration proforma outlined the following core objectives for the project.

- The estate having all PV units installed.
- WPD installing the cabling, pillars and monitoring.

- Data being captured and analysed.
- WPD writing report and sharing with other DNOs

The first two criteria were completed very early on in the project. To allow the PV units to be installed the larger 300mm2 cable needed to be laid under our current design policy. This was carried out as connection works to allow Melin homes to install its PV panels. However rather than install the least cost scheme WPD installed the additional pillars with the selectable alternative cables: both 185mm2 and 300mm2 in addition to the existing 95mm2 cable. The additional cost of these works was covered by the project.

Monitoring, in the form of PM3000s, was added shortly after the PV panels were installed by the developer and eventually included the feeder end monitors. In addition to this, PV meters were installed to compliment the data later on in the project. Tap change indication and solar irradiance data were also collected to help with the data analysis.

The data was collected consistently throughout the key times although a few two week blocks were missed during the less critical times. This data was briefly analysed when it was uploaded to ensure that the voltages were within limits and to check if there were any unusual patterns. Then at the end of the project all of the data was collated and analysed to produce the project report in Appendix A.

This report, along with the findings from the data in the data analysis study, were submitted to Ofgem and made available through both the Ofgem and WPD Innovation websites. In addition the learning from this project will feed into the LV Templates Tier 2 project and will be shared alongside its findings as part of its wider dissemination.

In summary all of the objectives have been achieved and in some cases expanded on from the original scope of the project.

7. Required modifications to the planned approach during the course of the Project

The scope remained broadly unchanged with the exception of more data being collected from more locations than was originally planned. With this data we were able to do more in depth analysis and therefore draw more useful conclusions in comparison from the original set up of the project. This allowed us to reap more benefits from the analysis without increasing the costs above what was originally budgeted for by using existing monitoring kit from the local depots.

8. Significant variance in expected costs and benefits

The project has been delivered on budget with more than the planned objectives met. The key benefits from the project are twofold.

Firstly, the high resolution data can be used to inform specific instances of high propagation of domestic solar and feed directly into the LV templates project.

Secondly, the learning from the analysis will be able to inform changes to the LV design assumption to reduce the installation of oversized cables for embedded domestic generation. Also the monitoring equipment, which is capable to high accuracy voltage, current, power and power quality measurements, is portable and can be used for other projects going forward.

Spending Category	Cost (£k)
Equipment: Monitoring kit, cables and cabinets	7.7
Labour: Installation of cabinets	3.5
Contractors: Laying the cables	5
Future Networks Team Project Management	2
Total	**18**
Total to be claimed through LCNF	16.2
DNO Contribution	£1.8k

9. Lessons learnt for future Projects

The key lessons learnt, and how they were derived, are documented in the report in Appendix A.

The report concludes that, the voltage seems to be unaffected by the choice of cable. The differences in impedance seem not to be large enough to cause concern. The fact that the original LV design prior to the PV was installed indicated that 95mm^2 cable would be sufficient and the peak highest voltages were seen while PV output was minimal suggests the approach for modelling embedded domestic generation ought to be reviewed. The current methodology predicted significantly higher voltages which did not materialise. This is probably influenced by the relatively small changes in impedance of the circuit, just over 25% of the cable was overlaid with the alternative cable choices while the overall feeder impedance is dominated by the transformer.

When the PV units were installed a maximum PV output of 37.8kW was calculated, with 10% of peak demand assumed, for the net export used in voltage rise calculations. This assumption seems sensible as the efficiency of the PV panels was not known and their maximum export was likely to coincide with days of minimum demand. However from the recorded data it is clear that PV outputs did not reach this level, the maximum export actually only reached 29.8kW suggesting that a PV efficiency or diversity factor could be implemented. If, for instance, a value of 30kW was used for the voltage rise calculation rather than 37.8kW then a similar cable size to the existing one would have been selected.

Also, as noted from the project report, the PV had little direct influence to the voltage at the feeder level although there was some increase of the average voltage at the feeder ends. That being said, it was still a long way short of the statutory limits so it was not a concern. The voltage looked to be driven from the primary substation's voltage which at its extremes was dominated by low demand. This particular substation was the first distribution substation along the 11kV feeder from the primary substation so this effect was even more noticeable. This also explains the generally high voltages which were noted. In this area of Wales, the 11kV feeders are typically long, therefore the voltage at the primary substations are kept high to ensure that the customers at the feeder ends are within the statutory lower limit at peak demand.

The solar PV data gives a good picture on how variable the output from the PV panels is. This is particularly highlighted by the significant difference between Houses C and D which are adjacent but have large differences in output. It is worth investigating this further across a wider sample of houses and this could be implemented as a DNO applied PV efficiency factor to be applied to all domestic PV from its installed capacity. This would allow LV planners to take a more realistic view of the PV output in a similar way to how diversity factors are applied to a load. A factor like this would also take into account the morning or evening bias which is observable from the data caused by the panel's orientation.

Other than the learning directly from the data there were a few other parts to the learning from the implementation of this project. From a customer engagement perspective, face to face discussion with customers proved successful when arranging the installation of PM1000 at customer's houses. Conversely when we tried to remotely arrange appointments to install the PV meters, it was a lot more difficult to arrange a time and it took several attempts to actually install the meter. The local contact and immediacy of getting the monitoring kit in was a far better approach.

Another noteworthy aspect is the advantages and disadvantages of manually downloaded data. The disadvantage is clear, it is easy to miss slots and required a more proactive approach and therefore was more of a burden on the project. However the fact that we took a more proactive approach meant the data was analysed at high level as it was downloaded making it easier to keep abreast of the key learning in real time.

Finally, once we got to the end of the data recording phase we needed to collate the data from several different sources which were not consistent due to differing recording systems and inconsistent time stamps. Bringing together all this data meant some of the data was disregarded if there were not corresponding parts but this was a time consuming process. It is therefore very important to have as much corresponding data being recorded at the monitoring stage to try avoiding this issue at the analysis stage.

10. Planned implementation

The learning from this project will feed directly into the learning objectives for the Tier 2 LV Network Templates on the area specifically looking at the effects on the LV of a high propagation of PV. Equally from these findings we can reassess the assumptions being used in LV design for embedded generators and how voltage rise calculations are being carried out.

This data was incorporated into LV Network Templates to give a much sharper focus on domestic generation. The data will also allow the key settings in WinDebut, that influence the PV assumptions and the load factors, to be adjusted in light of the data collected in this project. Facilitate Replication

The key learning and output from this project is contained in this Closedown Report and its Appendices.

11. Point of Contact

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

Future Networks Team
Western Power Distribution
Pegasus Business Park,
Castle Donington,
Derbyshire
DE74 2TU
Email: wpdinnovation@westernpower.co.uk

12. Appendices

E.ON New Build and Technology Report

TEP-EN-624.pdf

Proforma

Tier 1 Proforma WPDT1004 (2).pdf