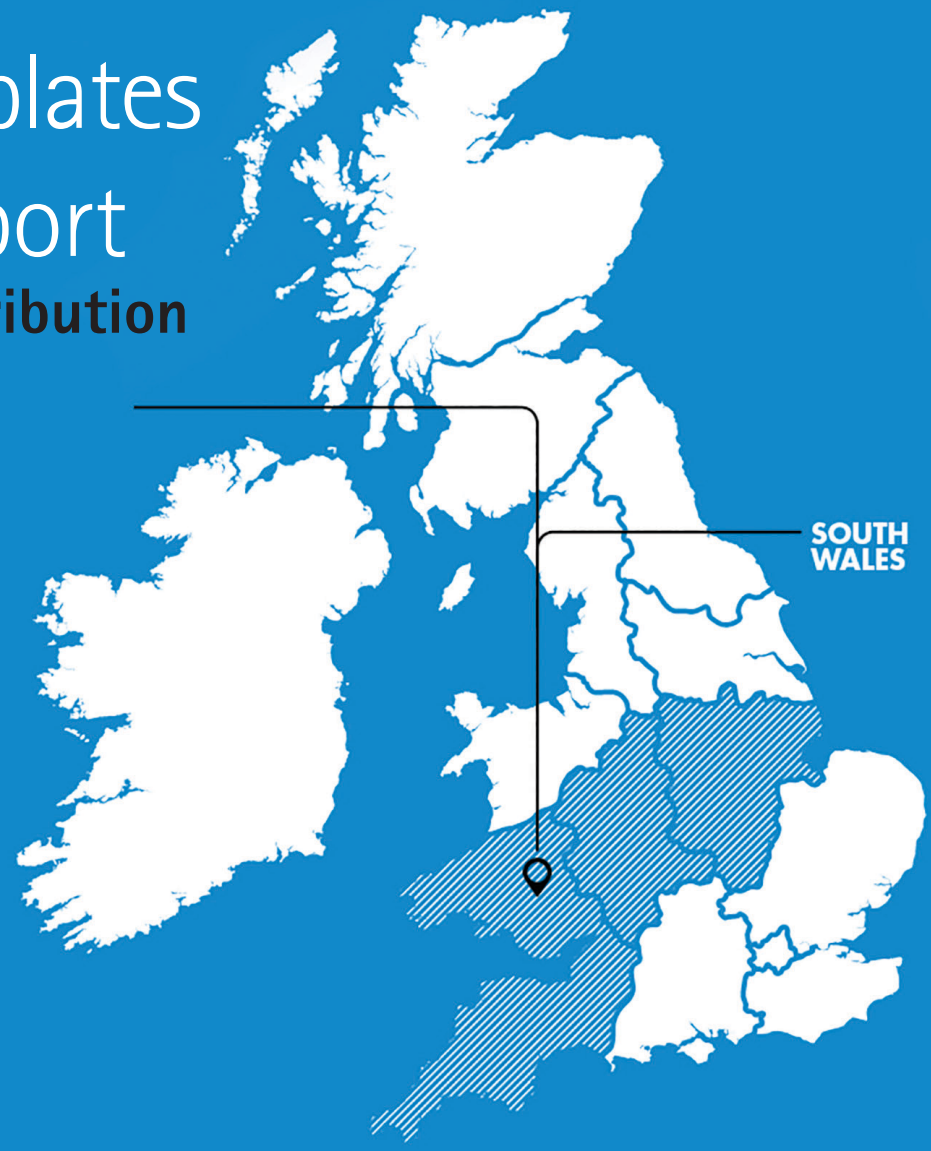
Low Voltage Network Templates Summary Report

Western Power Distribution and Accenture



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Foreword

Low Voltage Templates was the first Tier 2 Low Carbon Networks Fund project to start and successfully finish. The project was the biggest of its kind within the EU, and it has provided valuable lessons that will help us and our peers to integrate low carbon technologies into our low voltage network.

WPD has delivered what we promised and has already begun to embed the project's findings into our business, in order to pass on the benefits to our customers. A clear example of this can be found through the project's study of domestic PV installations which concluded that the maximum output generated was only around 80% of the installed capacity, and the expected voltage rise from such installations did not cause any significant issues to the LV network. As a direct result of this, WPD has already incorporated the 20% additional headroom into our domestic PV planning policy.

We are now also planning a voltage reduction trial in the South Wales area. This will reduce voltage on our higher voltage networks and is working towards delivering anticipated savings of 15.7MW in maximum demand, which will also reduce customers' bills and reduce carbon emissions.

WPD recognises the challenges associated with providing affordable energy, operating a sustainable infrastructure and meeting the Government's Carbon Plan. We have a vital role to play in shaping this future and adapting our existing assets to provide reliable power to our customers. This report highlights WPD's continual drive to deliver value-adding work in a focused and cost-effective way and to make sure that we communicate our work as clearly as possible to all those who could benefit from it.

WPD would like to thank all of the Project Partners—the University of Bath, GE, npower, PassivSystems, the Welsh Assembly Government and Accenture—for their hard work.

Finally, WPD would also like to thank all of the DNOs for sharing both fixed and variable data from their respective networks, enabling the project to validate the templates and classification tool even further. The information has been invaluable to underpin our results and show the possibilities of adopting these changes on a GB-wide scale. We will continue working with interested parties, to help the wider industry incorporate the outputs from this project into their business as usual activities.

Robert Symons
C.E.O. Western Power Distribution

Accenture is delighted to have supported Western Power Distribution and its partners in the delivery of the LV Network Templates project. Accenture is involved with smart grid projects across the globe. LV Network Templates is a globally leading project. The findings derived from this work are relevant and timely for both the UK industry and utilities and regulators internationally.

Accenture worked with WPD to secure funding for this project in the first year of the Low Carbon Networks Fund Tier 2. At that point, it was clear that the project would help to inform approaches as to how we can best address challenges that are fundamental to the UK's low carbon transition. Since being awarded funding, we have worked with WPD and its partners to deliver a successful project; assess the implications and understand how WPD and others can maximise the benefits from the project outputs; work with other DNOs to extend the analysis and disseminate what has been learned. This process has reconfirmed the importance of the Low Carbon Networks Fund to enable a cost-effective and secure move to a low carbon energy system.

It has also demonstrated the importance of understanding and engaging the customer. It is, after all, the customer who chooses to install solar panels, buy an electric vehicle and replace their oil heating system with a ground source heat pump. By taking these actions, customers are playing a key role in minimising their personal carbon footprint and the carbon footprint of the UK energy system. DNOs need to be able to support these choices while simultaneously keeping costs down and maintaining quality and security of supply.

This report has been written by Accenture working with WPD and its partners in order to further disseminate the learning from this project. We hope that the document helps contribute to a debate about our future energy system and the decisions and actions that need to be taken to balance cost, decarbonisation and security of supply.

Suleman Alli
Accenture, Managing Director

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Executive Summary

As the UK decarbonises its energy system, it also needs to minimise the cost of energy and maintain a secure supply of power to customers. Distribution Network Operators (DNOs)—the companies that own and operate the assets that send power from the high voltage transmission network to homes and businesses—have a key role to play in balancing these three imperatives.

One challenge for DNOs is managing the impact of customers connecting low carbon technologies such as heat pumps and solar PV to the low voltage distribution network—the part closest to the end customer. This is already happening today. Policy goals such as the plan to decarbonise and electrify heating and transportation will make these challenges more common and acute.

Low carbon technologies can place pressure on the secure and reliable operation of the low voltage distribution network. With only limited monitoring installed to date, it is hard to know what is happening within the LV network. Specifically, it is hard for DNOs to understand current and future spare network capacity, which changes during the day and across seasons. Limited understanding hampers effective planning and the optimisation of investment in response to new technologies.

WPD identified an approach that could help DNOs address this challenge. It would involve splitting the low voltage network into a number of clusters with common characteristics. These clusters would become LV Templates—a tool that helps those designing and operating the network to predict network behaviour.

These templates would be developed using statistical and power engineering principles supported by extensive network monitoring and the use of available fixed data from the Welsh Assembly Government's Arbed initiative. This approach was entered as a proposal for a Tier 2 project under the Low Carbon Networks Fund. The project won approval in December 2010.

Over 800 substation monitors and 3,600 voltage monitors were installed together with the associated communication and data-handling infrastructure. The University of Bath analysed over 500 million measurements, leading to valuable findings that have been shared with the rest of the industry, the regulator, universities and other interested parties. This is what was found, validated and disseminated:

- Ten distinct LV Templates can be defined and used to understand how the LV network is operating and the implications of connecting low carbon technologies. Further validation work was undertaken by analysing an additional 200+ substations, chosen by other DNOs from their networks. This demonstrated that the templates could apply to more than the 50% of British LV networks
- A ready-to-use classification tool was developed to help deliver a visual dashboard of load and voltage levels at a given clustered substation. This enables the industry to adopt the techniques developed by this project within their planning processes
- Analysis of actual LV connected PV installations identified 20% of additional headroom on the existing network for future connections
- The PV analysis also demonstrated the ability to use a single proxy LV PV FiT meter to accurately reflect the aggregate outputs of all other LV connected PV installations in the local high-level postcode area. This data can be used by National Grid to aid generation scheduling, forecasting and the effective management of spinning reserves. The aim is to progress this relationship further, with the adoption of an ongoing link between WPD and National Grid's systems to use on a day-by-day basis
- Voltage tolerance was shown to be within current limits, with greater numbers above the nominal level than below, thus affording the ability to reduce target voltages at HV, providing demand and CO2 reduction, savings in customer bills and additional voltage headroom for LV connected generation. As a result, WPD is planning to reduce the voltage levels in South Wales. This will achieve savings of approximately 15.7MW in maximum demand, over £9,421,000 and 41,000 tonnes of C02. This saving alone equals the total LCNF funding for the project
- If reduced voltage levels were rolled out nationally, in conjunction with the adoption of EU network voltage tolerances (+/- 10%), the savings from applying the approaches assessed by this project could be 618MW in maximum demand, and, £315,000,000 and 1.98 million tonnes of CO2 (annually). There are pros and cons to applying this approach across the country, which require further exploration

This report provides a high-level summary of the project, its findings and what it actually means to WPD and the wider GB industry. For a more detailed report of the end-to-end activities, please refer to "Close-Down Report" [1], submitted 31st October 2013.

Why WPD did this project

Introduction to the Low Carbon Networks Fund (LCNF)

This project was funded by WPD and the customer via the Low Carbon Networks Fund. The fund allows DNOs to invest in projects that, owing to the risks and uncertainties involved, they would not undertake as part of normal business activities. The maximum available funding across all the DNOs from 2010 to 2015 is £500m. To receive funding, projects must demonstrate support for the transition to a low carbon energy system and deliver good value to the customer.

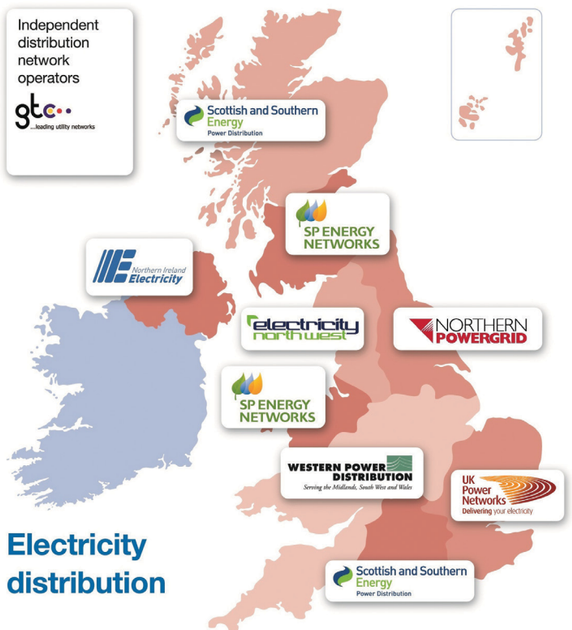
The creation of LCNF reflects Ofgem's recognition that using existing technologies and approaches could slow down the low carbon transition and make it more expensive. A variety of projects have been awarded LCNF funding, including LV Network Templates. They include lower cost approaches to connect wind farms to the distribution network; moving customer demand to off-peak periods to avoid spending money reinforcing the distribution network; and seeing how large batteries can help cost-effectively manage the impact of low carbon technologies by storing power. Lessons from all these are disseminated across the industry and will form the foundations to change the design and operation of the UK's distribution network.

For further information about LCNF, please refer to the Ofgem website [2].

The role of an electricity distribution network operator

DNOs are regulated by Ofgem to ensure they deliver value to the end customer. Six companies run electricity distribution networks in Britain. In addition, a number of smaller networks are owned and operated by Independent Network Operators (IDNOs) and located within the areas covered by the DNOs. An overview of where the six companies operate is provided below.

The DNOs are regulated to maintain safety, quality and security of supply, and keep bills down. They maintain and expand the network to meet customer demands, fix the network when it breaks and make sure that the power delivered to customers is of sufficient quality to allow lighting, devices and appliances to work as designed. This entails planning which assets need to be replaced when; reinforcing the network to handle new demand; enabling customers to connect to the network as needed—from a new flat to a large wind farm; maintain existing assets and going out in all weathers to resolve faults and get the lights back on.



Key challenges as we move to a low carbon energy system

The UK Government is committed to an 80% reduction in greenhouse gas emissions, relative to 1990 emission levels, by 2050. Supporting this commitment is the UK Renewable Energy Roadmap with targets for 30% of electricity, 12% of heat and 10% of transport to come from renewable sources [3]. In its December 2012 update, DECC confirmed that by 2020, 15% of UK energy demand will be supplied by renewable generation. Both Scotland and Wales have more ambitious targets of 42% and 40% [4] by 2020.

The increased connection of low carbon technologies (LCT) and generation to the distribution network will put pressure on existing assets. Responding to this effectively is hindered by uncertainty. LCT rates of adoption will be driven by policy, technological development and customer behaviour—all hard to predict. DNOs do not know when and/or where new challenges will emerge on their network.

These changes will impact the low voltage network, where there is currently limited visibility of real-time asset loading and voltage variations, which makes it hard for DNOs to optimise network planning and operation. National Grid also faces challenges, as it does not currently have full visibility of the output and voltage impact of generation connected to the distribution network. This restricts the System Operator's ability to balance the system efficiently.

*Source: Electricity Network Association (ENA) (http://www.energynetworks.org)

DNOs design the network to operate within statutory limits and remain resilient in a worst-case scenario, e.g., evening peak during the coldest part of winter. LV planners also size network assets on the assumption that load growth for existing customers will be relatively small, widespread and predictable. Large-scale LCT adoption could change the worst case scenario and undermine current load growth assumptions. Without LV visibility it will be difficult to identify the potential headroom available and hence enable the connection of more LCT.

The question this project sought to answer

All these challenges pose a key question: "Is there a simple method, other than costly widespread monitoring, that can help provide the visibility needed to effectively design, plan and operate the LV distribution network as more low carbon technologies and distributed generation is connected?"

This project addressed this question by developing a new planning tool: LV Network Templates. The LV Network Templates allow network planners to accurately estimate the load and voltage at any given substation without the need for costly monitoring. This will allow planners to estimate the capacity and voltage headroom available with greater accuracy and give them more confidence to determine whether the installation of a low carbon technology will lead to a breach of voltage or thermal limits.

The key findings of this project and the templates themselves will help DNOs 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.

The project scope and objectives

The primary objective was to establish the templates. In developing these, four important secondary objectives were also identified:

1. The ability to identify low carbon stresses through templates and the associated voltage profiles. With greater visibility of temporal variations, UK LV network planners would be able to more effectively identify headroom constraints and opportunities against each template for the absorption of future low carbon stresses.
2. A greater understanding of the actual difference between stressed and non-stressed parts of the network, due to either the connection, or not, of low carbon technologies (e.g., heat pumps, PV, electric vehicles). Having such an understanding would allow network planners to identify parts of the network better suited to accommodate certain types of low carbon technologies, at particular points in time, be it at weekdays/weekends and/or seasons.
3. The statistical case for using a limited number of PV feed-in-tariff meters (meter readings to reflect the aggregate output of others). If proven, it would provide a lower cost solution in understanding network demand and generation at a local level. This insight would be of value to both the distribution network operators and to National Grid in its short/long term forecasting and management of the wider GB network (e.g., spinning reserve capacity).
4. The degree of headroom and actual voltage levels measured across wide parts of the LV system (topology and customer mixes). The Low Carbon Networks Fund Expert Panel were advised at the time of the original submission that it might be possible to gain valuable insight into the headroom that might, or might not exist, within the existing 230v+10%/-6% limits set out in UK legislation. If a valid case could be made that compliance was maintained throughout daily and seasonal voltage changes, then there could be an argument in favour of 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 highlighted that a large number of feeder-end points operated at the upper limits of statutory voltage limits then a business case would present itself, in which the network voltage for that given feeder-point could be dropped by 2.5% via a 'tap down' of the primary substation transformer. This would result in a number of benefits, with one being the ability to allow for the accommodation of additional DG.

Further activities have since been added to the scope and objectives of this project. This additional work has taken two forms: **DNO Template Validation** and the development of a business-as-usual **Classification Tool.**

- **DNO Template Validation:** To demonstrate the project's findings validity outside the South Wales area, further work was carried out to analyse both fixed and variable data from all the other DNOs. This work considered the effectiveness of the classification process to confirm its validity for other DNOs. It also compared estimates to actual values as recorded by the other DNO's monitoring equipment to check that the templates themselves were not limited to local use. This work would be necessary for other DNOs to adopt the Network Templates and was carried out at no additional cost to the project. This further validation was regarded as a unique opportunity to share and validate the template's suitability in its application to at least 50% of the GB wider network
- **Classification Tool:** A classification tool was developed, at no additional cost to the project, within which the templates and models would sit. Alongside traditional planning tools, this would allow the templates to be immediately embedded into business as usual

What the team did

WPD undertook one of the largest and most complex low voltage monitoring trials to date in Europe. Over 14,000 customer properties had phase checking activities undertaken between January 2011 and December 2011. This was followed by the installation of monitoring equipment in over 800 distribution substations, 3,600 feeder-ends and 80 PV FiT sites, supplemented by an additional 525 PV data points obtained from PassivSystems. This took place between November 2011 and December 2012 in the South Wales area. The project team then analysed the data collected, developed the templates and produced and disseminated the project outcomes.

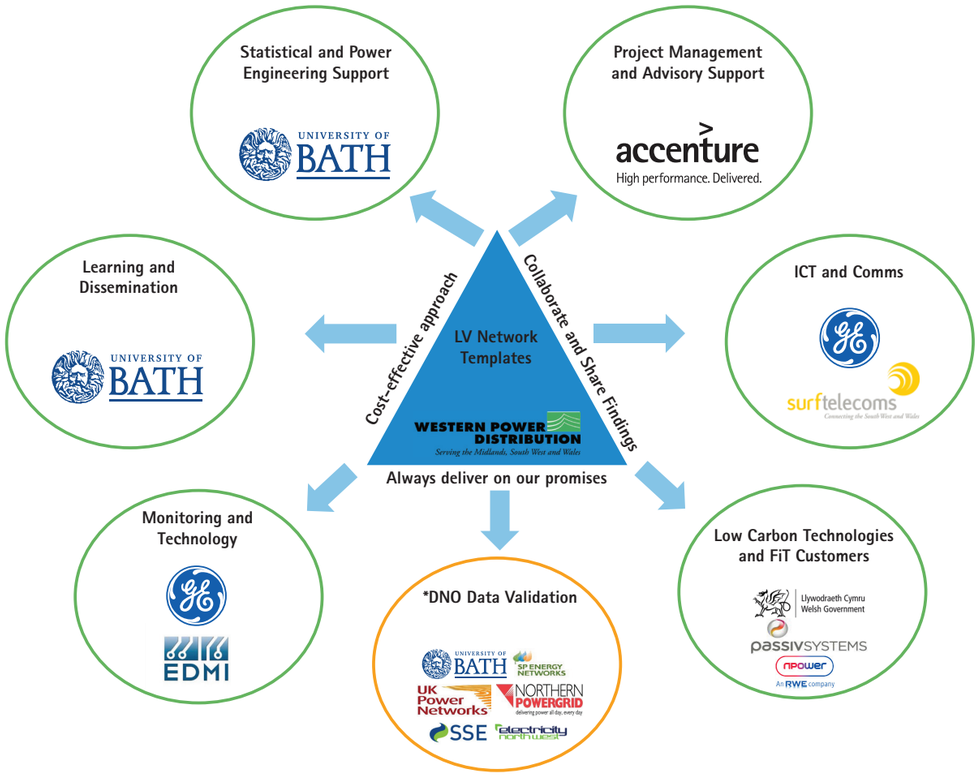
WPD's partners

Selecting the right partners to deliver LV Network Templates was central to ensuring success. Partners were shortlisted and selected on the basis of possessing the core strengths and leading expertise to successfully deliver this project. The partners and what they did is shown in the figure below.

The role played by customers

The project would not have been possible without the gratefully received support of WPD's customers. The team worked hard to ensure that customers' privacy was protected and that at all times they were kept engaged and informed of what was taking place. This involved sending letters, working with local authorities and communities and providing vouchers and a competition to win an iPad to encourage participation. As a result, customers kindly gave access for phase checking and participated in PV and feeder-end monitoring.

WPD engaged with the customer and provided the means for the customer to communicate back to the project team. This allowed the team to receive direct customer feedback and adapt the approach to meet customer's expectations and needs. This approach follows WPD's core belief of designing the network from the 'first mile' onwards, rather than the commonly stated 'last mile'. For further information about the methods applied and the role customers played, please refer to the close-down report.



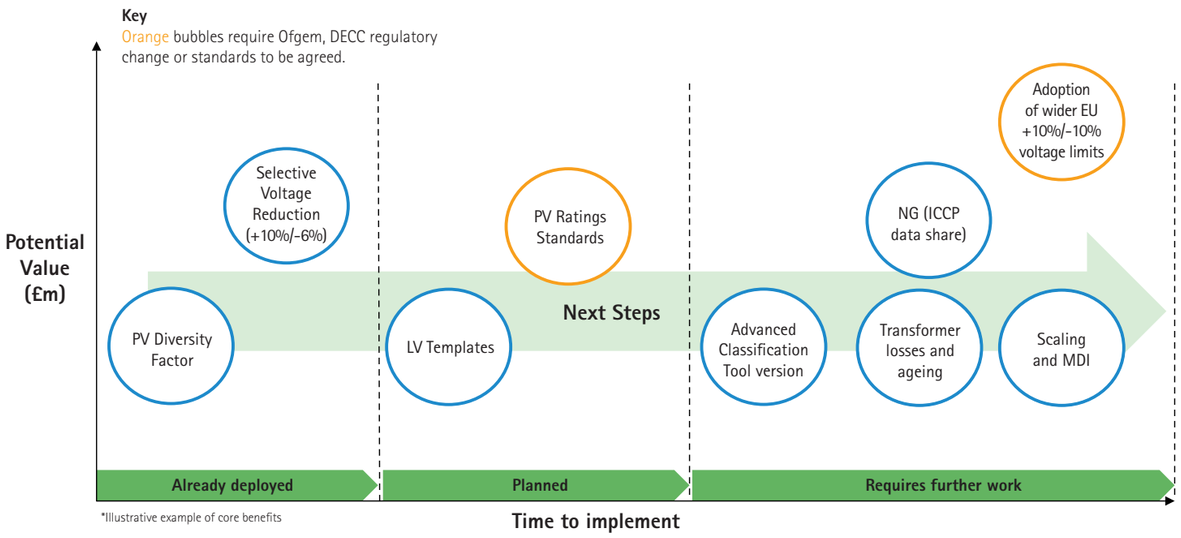
*Not initially in scope of work

The results and their implications

The project's results will allow WPD and other DNOs to change the way they plan and operate their networks. This has clear benefits for the end customer.

Results	Implications
The templates work. They can, with an 82.2% level of accuracy estimate the load and voltage flows at a given LV substation. This has been validated by other DNOs using their own networks and data—accuracy levels of between 80 to +90%. The templates are representative of 50% of the wider GB network.	DNOs can improve their planning without the need to install monitoring equipment. For example, using the templates, DNOs could improve the accuracy of load factors. This would help identify which distribution transformers were suitable candidates for early replacement in order to reduce network losses. The templates can also help optimise the planning for the integration of low carbon technologies such as solar PV and heat pumps by providing better insight into what is going on in the LV network and the amount of capacity that is available.
Outputs from a single PV installation can be used to accurately predict the outputs of others located within the same postcode.	Proxy FiT monitoring—installing one monitoring device for all the solar PV in a localrea rather than many monitoring devices—has the potential to avoid spending on monitoring equipment. The same approach could be used by National Grid. They are responsible for continuously balancing supply and demand. As solar PV becomes more prevalent, it will have a bigger impact upon the balancing process. Better data about solar PV output from proxy FiT monitoring will help them balance the system as cost-effectively as possible.
In the majority of solar PV installations, the output of actual PV generation was far below that of the potential generation output. The maximum aggregated generation from PV within a postcode was on average only 81% of the declared capacity.	Current network planning approaches use the declared maximum stated installed generation capacity. The effect of the above finding would be an overstatement of installed peak rating, even if the annual kWh calculation for PV FiT was accurate. By changing the assumptions about solar PV, the planning process will be able to reflect the actual headroom that is available. This will allow customers to connect more generation and demand to the network without paying for reinforcement.
For the points that were monitored, 99.62% of the voltage readings were within statutory voltage limits. And of the small number outside, the majority were overvoltage and just 0.015% were below the lower limits.	This indicates that historic network planning has been successful in meeting statutory limits (those feeder-end points that were outside of statutory voltage limits were immediately addressed).
Current feeder-end voltages suggest that there is an opportunity for voltage reduction. Given that only 0.015% of points were below the UK's -6% limit, there is a potential 4% opportunity through a move to the EU's -10% lower limit.	There is the potential to reduce the voltage on parts of the network within current UK statutory limits. And if the UK moves to the EU limits, the benefits are bigger. The benefits under the EU limit scenario are shown below based upon a widespread reduction of 2.5% in HV and LV supply voltage reduction. It would provide some leeway and still maintain 1.5% of the National Grid / GCRP OC6 voltage control demand response. 1. Reduction in customers' bills by reducing the power they consume. Impact of £315m per annum based on DECC's current valuation of marginal domestic and I&C rates. 2. Reduction in system demand. This could help manage the UK's potentially falling reserve margin. During the period of the trial, a 618MW fall in demand would represent an increase of 2.5% in current capacity margin. 3. Reduction in carbon emissions. Taking the voltage reduction applied at primary substation level would also apply to HV connected customers. This would deliver an annual saving of 1.98 million tonnes of CO2 with the current generation mix. For further details as to the impact, outcomes and calculations, please refer to the "Discussion paper on adoption of EU Low Voltage Tolerances" as part of the LV Network Templates Close-Down Report [1]. Persistent voltage reduction has potential. But there are pros and cons that need to be discussed at an industry level.

How this project will change the way WPD runs its business



This section outlines changes currently being implemented, those that are planned and the areas that require further work. The summary of these opportunities and their value potential is shown in the diagram below. Some cases (highlighted orange) will require regulatory change to support action. These opportunities are applicable to WPD and the other DNOs.

Changes that are being implemented today

WPD has moved quickly from learning to taking action. Faster application of what we have learned speeds up benefit realisation. WPD has identified and implemented two opportunities:

1. South Wales selective voltage reduction deployment (voltage reduction +10%/-6%)

Analysis of the data collected during the project has allowed WPD to identify a list of 147 primary substations in South Wales where the target voltage can be reduced from 11.4kV to 11.3kV. This means the overall voltage can be dropped without the customer experiencing a fall below the statutory limit. WPD is using the monitoring already installed (to make sure the voltages remain within the limits) to deliver a voltage reduction programme that will be fully implemented within the next three years. The benefits of doing this are shown below.

2. PV factors

The sizing of low voltage networks is based upon the declared maximum stated installed capacity of generation connected to the network. The project has shown that the stated installed capacity is generally greater than actual capacity. To reflect this insight, WPD has changed the assumptions with its low voltage planning tool. This will give customers wishing to connect localised distributed generation—e.g., solar PV, buy an electric car—more headroom to do so.

Benefits	Impact
Reduction in demand on the network	The reduction in HV in target voltage will reduce maximum demand by 15.7MW per annum. This has the potential to allow WPD to reduce reinforcement in the network.
Reduction in customers' energy bills	The reduction in HV and LV system voltage will reduce customer bills by a calculated £9.4M each year, based on DECC's current valuation of domestic and industrial and commercial tariffs. • Domestic customers amounts to circa £4.2M per annum • I&C customers circa £5.2M per annum
Reduction in CO2 emissions	As a result of the voltage reduction, it is anticipated that a reduction of 93,143MWh will be realised, resulting in a reduction of CO2 emissions. It is estimated that this would save some 41,000 tonnes a year of CO2. DECC's provisional 2012 data would give a figure 10% higher than this.

Changes that are planned

WPD has identified another two opportunities that require some further work before they are implemented into WPD's day-to-day approach to running the business.

1. LV Templates

WPD's planning engineers will make the move to using LV templates over time so that they are confident in their accuracy and comfortable with changing the way in which they do their job.

2. PV Rating

The project has shown that PV installers adopt varying approaches to determining the peak ratings included in their (retrospective) connection notice. This means that PV capacity is often overstated. WPD plans to explore this finding with the solar industry to identify opportunities for improvement and has organised relevant discussions with Ofgem, DECC, National Grid, DNOs and the solar industry.

Further work required

WPD has identified five opportunities that require further work. Realising the benefits is likely to take longer because the change is complex and/or there are dependencies with other parties.

1. Voltage Reduction (+10%/-10%)

The findings in the project highlight the opportunity of changing the statutory voltage limits from the current UK +10%/-6% to the current EU +10%/-10%, whilst still being able to respond to Grid Codes such as OC6 albeit whilst at a lower voltage level. Adoption of the EU levels, coupled with lowering target HV system voltages, would provide significant benefits.

These benefits include increased capacity margin; lower CO2 emissions; reduced customer bills; deferred network reinforcement and increased network capacity. In order to make the change, DNOs will have to change how their network is set up. This can be done relatively quickly. However, it requires further debate and statutory consultation by DECC before the DNOs can take action.

WPD outlined the potential for adopting EU voltage limits in their presentation to the Ofgem Expert Panel in October 2010. There has also recently been wider recognition of the potential for temporary voltage reduction (e.g., Electricity North West Tier 2 LCNF CLASS Project). There is now a case for initiating wider debate to test benefits and constraints with a view to DECC issuing a public consultation. Given the range of stakeholders potentially involved, initial discussions could be facilitated by the Energy Networks Association or by Ofgem.

2. Scaling and MD modelling

LV Network Templates could be used to enhance modelling of maximum demand values and load factors. Better modelling could allow DNOs to avoid manually checking the value at a substation. It could also allow earlier identification of maximum demand issues.

3. Transformer Losses and Ageing

The templates could also increase understanding of load, ageing and losses at a particular substation to enhance transformer replacement, reduce losses and increase reliability. Some initial analysis has already been undertaken and published.

4. Classification Tool (Version 2)

The project has already delivered a classification tool which can be used today. The tool provides network planners with a visual view of a substation's load and voltage flow by weekday, weekend and/or season by using commonly available fixed data. Identified potential improvements to the tool include the ability to automatically pull the data and present it on a single dashboard. This could make the tool easier to use and increase the insight it can display.

5. National Grid ICCP (operation status information around boundaries)

The project has demonstrated the statistical accuracy of the use of local 'proxy' PV FiT meters to reflect the real-time output of others in the locality. This, coupled with WPDs/National Grid's Tier 1 LCNF project, has the potential to provide National Grid with real-time visibility of 'hidden' LV connected PV generation. This would assist National Grid in their short- and long-term demand forecasting and management of generation scheduling and spinning reserves. Initial discussions have been held with National Grid. Further work will be required to develop and implement an enduring solution. There are also potential opportunities for further discussions with other DNOs to establish a standard industry design for the sharing of distributed generation and proxy PV data in order to make it easier for this approach to be applied across Britain.

References

[1] LV Network Templates Close-Down Report (http://www.westernpowerinnovation.co.uk/Documents-%281%29.aspx)

[2] Ofgem LCNF website (https://www.ofgem.gov.uk/electricity/distribution-networks/network-innovation/low-carbon-networks-fund)

[3] Ofgem "The Carbon Plan: Delivering our low carbon future" Dec 2011 (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47613/3702-the-carbon-plan-delivering-our-low-carbon-future.pdf)

[4] Scottish Power RIIO-ED1 Business Plan

About Accenture

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