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Title: **Deliverable 4.3 “Comparison with outputs of the WPD Low Voltage Templates Project”**

Synopsis: This report highlights the main similarities and differences between the LCNF Tier 1 Project “Low Voltage Network Solutions” run by ENWL and the Tier 2 Project “Low Voltage Templates” run by WPD.

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Executive Summary

This report corresponds to Deliverable 4.3 "Comparison with outputs of the WPD Low Voltage Templates Project" part of the Low Carbon Network Fund Tier 1 project "LV Network Solutions" run by Electricity North West Limited (ENWL).

In particular, this report highlights the main similarities and differences between the project "LV Network Solutions" and the Tier 2 Project "Low Voltage Network Templates" run by Western Power Distribution (WPD). This comparison considers aspects such as monitoring, network modelling, load modelling, low carbon technologies, the corresponding impact assessment, and key results.

From the perspective of the "LV Network Solutions" project, the main differences are:

<u>Main Differences</u>

- *Monitoring*. The WPD project monitored the generation of individual PV systems and the aggregated effects of EHP. Although the ENWL project considered LV networks with PV systems, individual monitoring was not performed. In addition, EHP installations were not present in the analysed ENWL networks.
- *Monitoring data* analysis. The analysis of voltages carried out by the WPD project did not consider the performance of individual substations. Instead it was a simple quantification of all measurements across substations. A more thorough analysis was done by the ENWL project taken into account the BS EN50160 standard.
- *Network data*. The ENWL project modelled the LV networks in detail using demand and LCT profiles with 5-minute intervals. This allowed quantifying the LCT impacts on feeder congestion and voltages along the feeders.
- *Profiles of LCT*. The WPD project adopted PV and EHP profiles directly or indirectly based on measurements. The LCT profiles from the ENWL project, although realistic, were produced from data available from trials or weather stations.
- *LCT Impact Assessment Methodology (WPD)*. Although the WPD project determined the effects from PV and EHP by comparing the corresponding network with similar ones without these technologies, the general conclusions of the impact assessment for each of the templates was done qualitatively. In addition, due to the substation level nature of the WPD project, the impact assessment is essentially related to the usage of the LV transformer. Voltages were not considered given that this would require network models.
- *LCT Impact Assessment Methodology (ENWL)*. The detailed models adopted by the ENWL project allowed producing a quantitative assessment of the impacts per LCT. In addition, the Monte Carlo approach allowed presenting the likelihood of potential impacts rather than 'definite' numbers.
- *LCT Impact Assessment Findings*. The WPD project suggests that overnight EV charging would not affect (mainly domestic) LV transformers. This is contrary to the findings of the ENWL project. In addition, the latter captured many potential voltage and congestion issues at a feeder level that within the WPD project was not possible to quantify.

In addition, it is important to highlight that the "LV Network Solutions" did not attempt to create LV network clusters or to use or validate the LV clusters from the WPD "LV Network Templates" project.

Based on the busbar monitoring carried out by the ENWL project, most substations were found to have voltages above 240V, implying an opportunity for voltage reduction without affecting customers (assuming a 6% voltage drop from the busbar to the end of the feeder). Nonetheless, this 'opportunity' has to be considered carefully given that lowering voltages at the busbar might increase PV penetrations and reduce energy consumption but might also affect the ability of LV networks to host wide spread installations of EHP or EV. Further research is needed to find the optimal busbar voltages *for different types of LV networks* that allows coping –to some extent– with both voltage rise from PV but also voltage drops from EHP or EV.

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1 Introduction

As part of the transition towards a low carbon economy, Electricity North West Limited (ENWL), the Distribution Network Operator of the North West of England, is involved in different projects funded by the Low Carbon Network Fund. The University of Manchester is part of the Tier 1 project "LV Network Solutions".

The objective of this project is to provide ENWL with greater understanding of the characteristics, behaviour, and future needs of their LV networks. This is based on the analysis of data gathered by appropriate monitoring schemes deployed on hundreds of LV feeders and substations, and the assessment of the corresponding computer-based network models in current and future scenarios considering different low carbon technologies (LCT) such as photovoltaic systems (PV), electric vehicles (EV), electric heat pumps (EHP), and micro combined heat and power (μCHP).

The following report highlights the main similarities and differences between the project "LV Network Solutions" and the Tier 2 Project "Low Voltage Templates" run by Western Power Distribution (WPD). This comparison considers aspects such as monitoring, network modelling, load modelling, low carbon technologies, the corresponding impact assessment, and key results.

Three reports produced by the WPD project, the Close Down Report [1], the Stress Caused by LCT Report [2] and the Summary Report [3], were used to carry out the comparisons. In addition, teleconferences were held with representatives from WPD to ensure an accurate picture is provided throughout the assessment.

It is important to highlight that the objectives of the two projects, although aligned, are not the same. The WPD project was primarily aimed at characterising LV networks by measuring different parameters at the corresponding substations. By comparing similar networks (e.g., having mostly domestic customers) with and without actual low carbon technologies (specifically PV and EHP), the corresponding effects were inferred. No network models were used and most of the impact analysis was focused on the effects of LCT on the transformer capacity.

Finally, it should be noted that the comparisons presented in this report were made from the perspective of the "LV Network Solutions" project. This means that particular findings or tasks carried out by the "Low Voltage Templates" project that were not in the scope of the ENWL project, were not compared.

2 Comparison

This section discusses the similarities and differences considering aspects such as monitoring, network modelling, load modelling, low carbon technologies, and the corresponding impact assessment.

2.1 Monitoring

Similarities

- Both projects focused on the monitoring of phase voltages, phase currents, active/reactive power and THD at the substation (i.e., head of the feeder).
- In addition, both projects also considered phase voltages at the end of the feeders.
- Ten minute intervals were also adopted in both cases.

Differences

- ENWL considered actual phase active/reactive power rather than three-phase values differentiated by imports/exports (or leading/lagging). In addition, ENWL considered neutral currents at the substation (transformer and ambient temperature).
- As for the THD, ENWL considered currents (per feeder) whereas WPD calculated it using VAh measurements per phase.
- In terms of intervals, ENWL also explored the use of 1 and 5 minutes. It also considered the monitoring of mid-points in the feeders (phase voltages and phase/neutral currents).
- For the end-points, WPD mostly adopted voltages at customer premises, i.e., phase voltages, and considered a significant number of sites (3,600). ENWL, on the other hand, considered three-phase voltages and this was done on a much smaller scale.
- PV generation (kWh) was directly monitored by WPD for 30-minute intervals. This was not done by ENWL. Instead, synthetic profiles as well as profiles derived from actual irradiance data (from weather stations) were used in the ENWL project considering 5-minute intervals and directly using kW.

Analysis of Data

- In terms busbar voltages, the WPD project quantified the proportion of 10-minute measurements within 216.2 and 253V across all the substations. This resulted in only 0.69% of measurements outside the range. However, this analysis does not provide insights of how individual substations perform. A more thorough analysis was carried out by the ENWL project by which 6.6% substations were identified to have voltages outside the range for more than 5% of the time (following the BS EN50160 standard).
- According template 2 (i.e., cluster 2 [2]), identified by the WPD project as substations dominated by domestic customers, the summer weekday average voltage is around 243V (1.056pu). This is aligned with the findings from the ENWL project where daily average busbar voltages for all substations varied between 1.03pu and 1.10pu and most of the substations (69%) had averages between 1.05pu and 1.08pu.
- The THD behaviour of the LV networks was not analysed by the WPD project. This was done by the ENWL project (see updated Deliverable 3.3 [5]).
- The phase voltages at the end of the feeders were not analysed by the ENWL project.
- The clustering exercise carried out by the WPD project (done to characterise LV networks based on their net demand) was done also on half-hourly data resulting in the same set of clusters. Therefore, it was concluded by WPD that the time interval made no difference to the clusters. For the ENWL project, however, due to the nature of the impact assessment (where the BS EN50160 standard plays an important role), time intervals did make a significant difference (see Deliverable 3.6 [6]).

2.2 Network Modelling/Data

Similarities

- Both projects considered the transformer size, type, number of feeders as well as their lengths and capacities.

Differences

- The WPD project did not model the monitored networks as was not part of their objectives. Some aspects of network data were used as part of the clustering process. The modelling for the ENWL project was, however, significant and detailed as it required the GIS data to be translated into a distribution network analysis software package (see Deliverable 1.3-1.4 [4]).

2.3 Load Modelling

Similarities

- Both projects considered the customer classification made by Elexon (i.e., PC1, PC2, etc.) and the corresponding number of customers in each network.
- Although it is difficult to set a confidence level in terms of the accuracy of customer numbers per network (based on GIS or similar data), both ENWL and WPD were confident of figures being close to reality.

Differences

- The quantification of customers in the ENWL project was done per feeder given the analyses required. This brought further challenges as the accuracy was affected. WPD did not carry out any quantification per feeder as the focus was on the LV networks at substation level only.
- The ENWL project mostly used the tool produced by CREST (Loughborough University) to create individual household demand profiles with time intervals of 5 minutes. The WPD project, on the other hand, does not model loads but considers a range of aggregated mixed loads at the substation level (10-minute intervals).
- The tool produced by the WPD project considers the Elexon-based half-hourly profiles.

2.4 Profiles of Low Carbon Technologies

Similarities

- Both projects consider PV and EHP.

Differences

- As mentioned previously, WPD used monitoring data (kWh in 30-min interval) from individual PV systems to understand the effects on aggregated net demand for an LV network. This allowed creating realistic PV profiles that can either be aggregated or used individually. The ENWL project, on the other hand, produced detailed models of single PV systems considering 5-min intervals.
- In terms of EHP, the WPD project compared substations (in the same template/cluster) with and without EHP to determine the impact at substation level, i.e., the corresponding profiles were inferred by aggregated comparison (number of EHP were known). The ENWL project, on the other hand, produced detailed models of single EHP units considering 5-min intervals derived from a μCHP trial carried out in the UK.
- The WPD project did not consider electric vehicles or μCHP in the creation of profiles. This, however, was done by the ENWL project adopting electric vehicle and μCHP profiles with 5-min intervals derived from data produced trials carried out in Ireland and the UK, respectively.
- In general, the approach of the WPD project was to build the templates from observed readings rather than models. Hence, no models or profiles were used from other sources.

2.5 LCT Impact Assessment – Methodology

Similarities

- Both projects consider PV, EHP and EV.

Differences

- The monitoring data from individual PV systems as well as substations with EHP was used by the WPD project to determine whether the corresponding networks and customers were affected. This allowed to quantify the effects of PV and EHP on these networks relative to similar ones (same template) without PV or EHP.
- However, the general conclusions of the impact assessment (including other LCT such as EV) for each of the templates was done qualitatively, i.e., the potential ability of a template to host high penetrations of a given LCT is discussed based on the template's main characteristic (e.g., mostly domestic).
- In addition, due to the substation level nature of the WPD project, the impact assessment is essentially related to the usage of the LV transformer. Voltages were not considered given that this would require network models.
- The ENWL project, on the other hand, adopted detailed feeder and network models and analysed them for specific penetration levels of LCT. This allowed producing a quantitative assessment of the impacts per LCT.
- Furthermore, a Monte Carlo approach by which many simulations were carried out was used to cater for the uncertainties of customer behaviour, as well as LCT location, size and behaviour. This allowed presenting the likelihood of potential impacts rather than 'definite' numbers.

2.6 LCT Impact Assessment – Findings

The following comments consider template 2 (i.e., cluster 2 [2]) identified by the WPD project as substations dominated by domestic customers. This particular template matches the qualitative characteristics of the LV networks modelled and analysed by the ENWL project.

Similarities - PV

- The WPD project concludes that domestic LV networks are "suitable" for PV. Although the penetration level for which this statement is applicable is not mentioned, when considering the impacts on the transformer capacity, it can be said that is aligned with the findings of the ENWL project (only 5 out of 25 LV networks were likely to have issues but at 90% or 100% of penetration [6]).

Similarities - EHP

- The WPD project suggests that domestic LV networks can only be suitable for EHP if "linked with insulation or heat storage to permit off peak operation". Although the penetration level for which this statement is applicable is not mentioned, when considering the impacts on the transformer capacity, it can be said that is aligned with the findings of the ENWL project (17 out of 25 LV networks were likely to have issues at different penetration levels [6]).

Differences - PV

- The ENWL project highlights that more than 60% of LV feeders (> 25 customers) are likely to have voltage rise issues at some PV penetration level. In addition, around 15% of the feeders are likely to have congestion issues at some penetration level. These findings were not possible to capture within the WPD project.

Differences - EHP

- The ENWL project highlights that more than 55% of LV feeders (> 25 customers) are likely to have congestion issues at some EHP penetration level. In addition, more than 40% of the feeders are likely to have voltage drop issues at some penetration levels. These findings were not possible to capture within the WPD project.

Differences - EV

- The WPD project concludes that domestic LV networks are "very suitable" for overnight charging of EV. Although the penetration level for which this statement is applicable is not mentioned, when considering the impacts on the transformer capacity, the findings from the ENWL project differ to some extent. The latter highlighted that 5 out of 25 LV networks were likely to have issues at different penetration levels when EV charging happens mostly after peak hours (normal EV case in [6]).

- The ENWL project also highlights that more than 25% of LV feeders (> 25 customers) are likely to have voltage drop issues at some EV penetration level. In addition, more than 20% of the feeders are likely to have congestion issues at some penetration levels. These findings were not possible to capture within the WPD project.

3 Discussion of Key Results from "LV Network Templates"

The key results listed in the "Low Voltage Network Templates Summary Report" [3] are discussed below in the context of the "LV Network Solutions" project.

1. A set of ten templates were generated for planning use that covered different mixes of domestic and non-domestic customers. The algorithm used to determine which template was appropriate for a substation from basic data was seen to have high levels of accuracy and the confidence at which substations were selected was seen to be the same for other DNOs. The scaling algorithm was also seen to produce values for the peak load which were very representative of the actual peak loads. (updated description of templates provided by WPD on 13th June 2014).

The ENWL project did not aim to produce a similar clustering of LV network substations, or to validate the WPD templates. However, WPD considers the majority of ENWL substations would be well represented with the load profiles from LV Network templates.

Via ENWL's Load Allocation system, which uses the same data inputs as WPD's templates plus HV feeder loads, ENWL instead has an alternative approach for load estimates which allows a greater flexibility in load profile shape. The Load Allocation was reviewed against the monitoring data as part of the LV Network Solutions project, with improvements made subsequently.

2. Outputs from a single PV installation can be used to accurately predict the outputs of others located within the same postcode.

This was not assessed in the ENWL project.

3. 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.

The generation of individual PV installations were not monitored in the ENWL project. However, the Monte Carlo approach adopted (considering DECC statistics of PV installation across Britain) resulted in most simulations in an average generation of approximately 3kW. Given that the maximum PV installation possible was 4kW, this equates to around 80% of the 'worst case scenario'.

4. 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.

Although feeder-end voltages were monitored in the "LV Network Solutions" project, the corresponding analysis was not carried out thoroughly enough to adequately assess network performance. From the monitoring carried out in the ENWL project [5], 93% of the 136 substations do not have busbar voltages above 253V. The daily average busbar voltages for all substations varied between 237V and 253V. Finally, most substations (>60%) had a daily average busbar voltages between 241V and 248V. Although busbar voltages can only be considered as a proxy of potential issues to nearby or remote customers, the findings from the monitoring highlight that most substations meet the statutory limits (between 216 and 253V at the customer connection point).

5. 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.

Feeder-end voltages were not assessed in the “LV Network Solutions” project, however, based on the busbar monitoring, most substations were indeed found to have voltages above 240V, implying an opportunity for voltage reduction without affecting customers (assuming a 6% voltage drop from the busbar to the end of the feeder). Nonetheless, this ‘opportunity’ has to be considered carefully, given that lowering voltages at the busbar might increase PV penetrations and reduce energy consumption but might also affect the ability of LV networks to host wide spread installations of EHP or EV. Further research is needed to find the optimal busbar voltages *for different types of LV networks* that allows coping –to some extent– with both voltage rise from PV but also voltage drops from EHP or EV.

4 Conclusions

This report presented the main similarities and differences between the project “LV Network Solutions” and the Tier 2 Project “Low Voltage Network Templates” run by Western Power Distribution (WPD). This comparison considers aspects such as monitoring, network modelling, load modelling, low carbon technologies, the corresponding impact assessment, and key results.

It is important to highlight that the objectives of the two projects, although aligned, are not the same. The WPD project was primarily aimed at characterising LV networks by measuring different parameters at the corresponding substations. By comparing similar networks (e.g., having mostly domestic customers) with and without actual low carbon technologies (specifically PV and EHP), the corresponding effects were inferred. No network models were used and most of the impact analysis was focused on the effects of LCT on the transformer capacity.

The main similarities and differences found are:

Main Similarities

- *Monitoring*. Both projects considered key parameters such as phase voltages, phase currents, and active/reactive power at the substation. They also considered phase voltages at the end of the feeders. In addition, ten minute intervals were adopted in both cases.
- *LCT Impact Assessment Findings*. Both projects are aligned in that transformer capacities of (predominantly) domestic LV networks are in general suitable for high penetrations of PV but not for EHP.

Main Differences

- *Monitoring*. The WPD project monitored the generation of individual PV systems and the aggregated effects of EHP. Although the ENWL project considered LV networks with PV systems, individual monitoring was not performed. In addition, EHP installations were not present in the analysed ENWL networks.
- *Monitoring data* analysis. The analysis of voltages carried out by the WPD project did not consider the performance of individual substations. Instead it was a simple quantification of all measurements across substations. A more thorough analysis was done by the ENWL project taken into account the BS EN50160 standard.
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- *LCT Impact Assessment Findings*. The WPD project suggests that overnight EV charging would not affect (mainly domestic) LV transformers. This is contrary to the findings of the ENWL project. In addition, the latter captured many potential voltage and congestion issues at a feeder level that within the WPD project was not possible to quantify.

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5 References

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