MANCHESTER 1824

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Title:

Deliverable 4.2 “Recommendations on the deployment of monitoring devices in LV networks”

Synopsis:

This document summarises recommendations on the deployment of monitoring devices in LV networks mainly based on the findings from Deliverable 3.3 and Deliverable 3.6.

Document ID: UoM-ENWL_LVNS_Deliverable4.2v03

Date: 11th June 2014

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Executive Summary

This report corresponds to the "Recommendations on the deployment of monitoring devices in LV networks" part of the Low Carbon Network Fund Tier 1 project "LV Network Solutions" run by Electricity North West Limited (ENWL).

The aim of the LV Network Solutions project is to provide ENWL with greater understanding of the characteristics, behaviour, and future needs of their low voltage 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).

In particular, recommendations in terms of the deployment of monitoring devices in LV are presented. These recommendations are mainly based on the findings from Deliverable 3.3 and Deliverable 3.6.

In the context of monitoring to identify network issues caused by LCT, the main recommendations are:

- **Parameters to monitor**. Both line-to-neutral voltages and phase currents (or active and reactive power) at the head of the feeders should be monitored. Voltages are of particular importance for photovoltaic systems given that most LV networks are likely to experience voltage issues rather than congestion. For electric vehicles and electric heat pumps, phase currents also need to be monitored as many feeders are likely to experience congestion before voltage issues.

- **Sampling intervals**. For performance evaluation of the network, the mean value of 10 minute sampling intervals (or close to this, e.g., 15 minutes) should be adopted to avoid underestimating, in particular, voltage impacts. There is no significant benefit in adopting shorter sampling intervals (e.g., 1 or 5 minutes). For the monitoring of currents (or active and reactive power), hourly values are adequate.

- **Locations to monitor**. For voltage purposes, the end points of the corresponding feeders are monitored given that the busbar would only work as a proxy if some knowledge of the feeders exist. Mid points do not necessarily bring more critical information although they increase certainty and observability. However, for congestion purposes, currents at the head of the feeders should be monitored.

- **Timing**. The correlation metrics proposed in Deliverable 3.6 (or similar) should be adopted to find the most suitable penetration level of a given LCT for a feeder or LV network for which monitoring is required.

- **Other aspects**. The monitoring devices to be deployed, particularly at the substation, should ideally also monitor total harmonic distortions of voltage and neutral currents.

Finally, it is important to highlight that in the context of voltage management and depending on the control strategy (such in the case of the LoVIA project, also run by ENWL), sampling intervals can be higher than 10 minute (e.g., 30 minutes) and still guarantee a good performance of the LV network. Consequently, while the above recommendations are for prevention purposes, once an operational solution is adopted (e.g., LV OLTC-fitted transformer, use of capacitor banks, dynamic meshing, etc.) sampling intervals can be adapted accordingly.

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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 contains recommendations in terms of the deployment of monitoring devices in LV networks in the North West of England. These recommendations are mainly based on the findings from Deliverable 3.3 and Deliverable 3.6. Deliverable 3.3 describes the monitored performance evaluation of the network as it is now, and Deliverable 3.6 describes the modelled performance evaluation of the network with what-if scenarios for LCT uptake, including analysis of the percentage uptake levels at which LCTs start to cause voltage or thermal issues.

It is important to highlight that aspects related to cost were only considered in the context of minimising monitoring costs by defining the minimum technically useful specification for monitoring. No analysis was done on the economic value of monitoring data to identify network issues, or to assist or delay other network interventions.

2 Considerations for Monitoring

This section presents the recommendations and corresponding reasoning (based on Deliverables 3.3, 3.5 and 3.6) on the deployment of monitoring devices for LV networks. These four key aspects are: parameters to monitor, sampling intervals, locations to monitor, and timing. A final subsection also discusses other aspects that might be relevant.

2.1 Parameters to Monitor

Section 4.3 of Deliverable 3.6 "What-if Scenario Impact Studies based on real LV networks" presented that key metrics adopted throughout the impact assessment for all LV networks.

Two of these key metrics are related to voltages and thermal issues. Potential voltage issues were considered as the percentage of customers with voltage problems considering the BS EN 50160 standard, i.e., analysing how often line-to-neutral voltages at the connection points were outside the statutory limits. Potential thermal issues were considered by calculating the utilization factor at the head of the feeder considering the hourly maximum current divided by the corresponding ampacity.

To determine which potential technical problem would be more significant, section 5.1.1 of Deliverable 3.6 presented a quantification of the percentage of feeders likely to first experience one of them. This was done per LCT and per penetration level. Figure 1 displays the percentage of feeders (among the 90 feeders) that experience one technical problem (voltage or thermal) before the other.

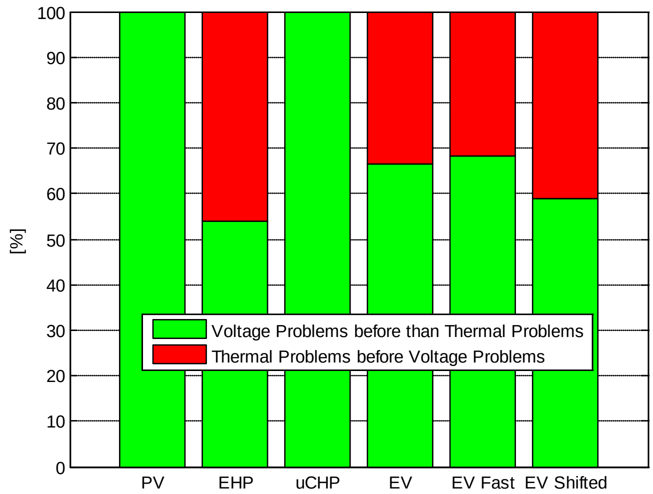

Figure 1: First technical issue among the feeders with problems (Deliverable 3.6)

The "bottleneck" for all the feeders in the case of PV is voltage. This also happens for the µCHP case but it is important to recall that only 4% of the feeders have problems. In the EHP case, the problems are triggered by voltage and thermal issues almost in half and half (54% for voltage and 46% for thermal issues). For the EV base case and EV Fast case, the occurrence of the first problems are divided around 35% and 65% between thermal and voltage issues. Finally, the EV Shifted Charging case presents a higher proportion of thermal issues as the first problem in comparison with the other EV cases (about 40% of the feeders).

Consequently, if the only LCT to be seen in the next few years is PV, then line-to-neutral voltage is a critical parameter to monitor the evolution of impacts. Nonetheless, once EHP or EV are considered, then not only voltages but also currents are required given that around 40% of the feeders might experience congestion. Therefore, it is recommended that:

In the context of a mix of LCT, both line-to-neutral voltages and phase currents (or active and reactive power) at the head of the feeders should be monitored.

2.2 Sampling Intervals

Section 4.4.2 of Deliverable 3.6 “What-if Scenario Impact Studies based on real LV networks” analysed the effects of different sampling intervals (or data granularity) in the impact assessment. It considered the mean values of 1, 5, 10, 15, 30 and 60 minute intervals for the load and PV generation profiles. For illustration purposes, this analysis was implemented only in a single feeder.

The daily energy losses and the percentage of customers with voltage problems from the Impact Assessment Methodology are presented in Figure 2 and Figure 3, respectively. It is important to remark that the sampling interval effect is not relevant in the utilization level mainly because this index integrates the results in one hour. In contrast, the effect on the calculation of voltage issues is significant due to the EN50160 requirement of 10 min averages. Indeed, the consideration of one hour daily profiles underestimates considerably the impacts from PV. For example, around 15% of customers would have a voltage problem at 70% PV penetration when considering 5 min intervals (base case). This figure goes down to about 4% when 60 min intervals are considered (Figure 3). A similar effect, although not so significant, can be observed for the daily energy losses.

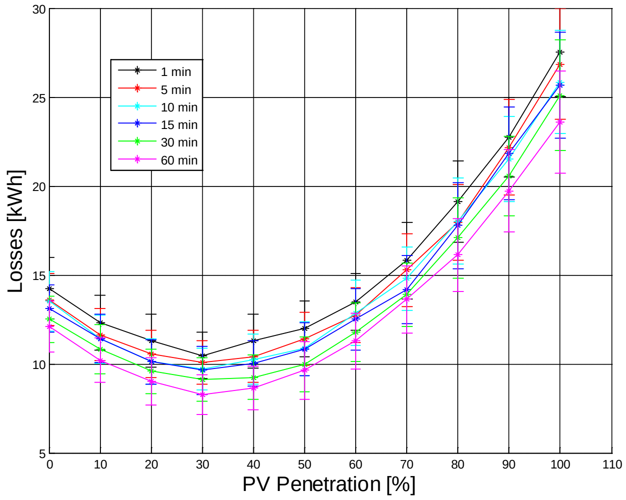

Figure 2: Daily energy losses – Data granularity (Deliverable 3.6)

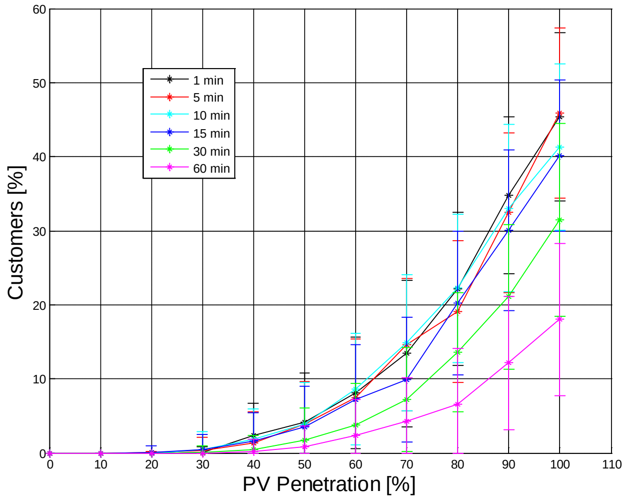

Figure 3: Voltage problems - Data granularity (Deliverable 3.6)

This particular analysis highlights the need of adequate sampling intervals if monitoring is to be deployed in networks with LCT to observe the evolution of potential impacts, in particular, voltages.

The utilisation of longer intervals (e.g., 15 min, 30 min and 60 min) for loads and generation profiles underestimates the impacts of LCT in LV networks. On the other hand, due to the nature of the quantification of voltage issues (i.e., following the BS EN 50160 which considers 10 minute averages), the benefits from shorter intervals, such as 1 or 5 minutes are not significant compared to 10 minute intervals. Therefore, it is recommended that:

For performance evaluation of the network, the mean values of 10 minute sampling intervals (or close to this, e.g., 15 minutes) should be adopted to avoid underestimating, in particular, voltage impacts.

It is important to highlight that although the adoption of mean values have proved to be adequate given its alignment with the BS EN 50160, no studies were carried out to assess the benefits from considering maximum or minimum values of the intervals.

2.3 Locations to Monitor

The busbar is the most practical and effective location for the monitoring of currents (or active and reactive power) for each of the corresponding feeders. This is mainly due to the aggregated effect of load or generation at the head of the feeders which can be used to determine potential issues on the corresponding segments or, if added up, the transformer.

In terms of voltages, however, it would only work as a proxy if some knowledge of the corresponding feeders exist (i.e., length, number of customer, installed capacity of photovoltaic systems). Figure 4, extracted from Deliverable 3.3 "Performance evaluation of the monitored LV networks" section 2.3, presents daily voltage metrics such as maximum, minimum, and average based on monitoring data (10 minute intervals) at the substation. Despite the fact that for some substations the busbar voltages are above the upper limit of 253V it does not necessarily mean that customers are negatively affected. Similarly, although relatively low voltages at the busbar, e.g., close to 230V, are indicative of potential issues for the corresponding customers, it is not possible to be certain.

Therefore, for voltages, the ideal positions are the end points of the feeders. Mid points do not necessarily bring more critical information although they increase certainty and observability.

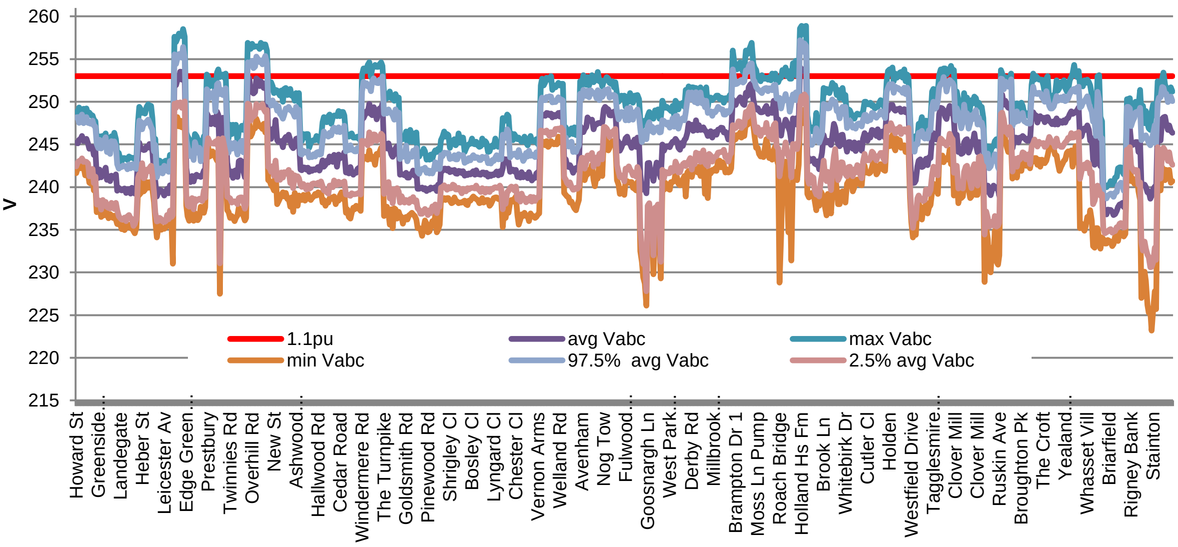

Figure 4: Voltage profiles (Deliverable 3.3)

Consequently, it is recommended that:

For voltage purposes, the end points of the corresponding feeders are monitored given that the busbar would only work as a proxy if some knowledge of the feeders exist. However, for congestion purposes, currents at the head of the feeders should be monitored.

2.4 Timing

Monitors should be placed when a potential problem is likely to happen in the near future. However, voltage or congestion issues depend on penetration levels of LCT and the characteristics of the corresponding feeders.

Figure 5, extracted from Deliverable 3.6 section 5.12, illustrates the histograms for voltage and thermal problems (left and right side, respectively) for the PV case. In particular, the histogram of thermal problems points out that only one feeder reaches the thermal limit at the head of the feeder at 10% of penetration level (a feeder already slightly overloaded without any LCT), whilst the rest of them reach the same limit for higher penetration levels (80% and above). On the other hand, the histogram of voltage problems shows that the distribution of the first penetration level with problems is observed in almost every single penetration level, having most of the cases between 30% and 50% of penetration level.

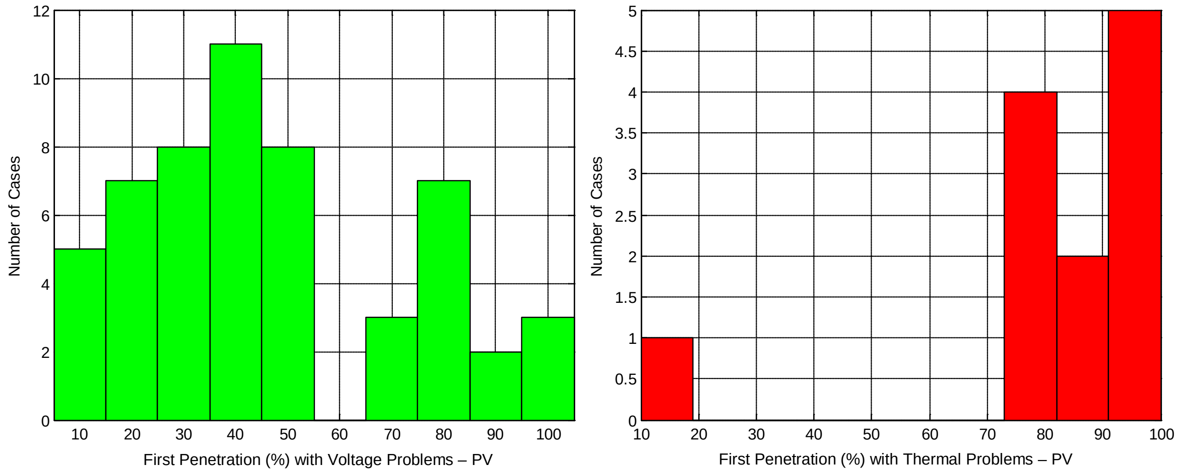

Figure 5: First Penetration Level with Technical Problems – PV Case (Deliverable 3.6)

For completeness, the following findings have to be also considered:

- For feeders with 25 or fewer customers (a total of 38 feeders), the analysis showed no voltage or thermal issues even at high levels of LCT uptakes.
- For feeders with greater than 25 customers (a total of 90 feeders), for 14% of cases, the analysis showed no voltage or thermal issues even at high levels of LCT uptake.

The spread of values in the graph above suggests that voltage issues can start to occur over a wide range of PV percentage uptakes. There is no typical penetration figure at which voltage issues begin. A similar spread of penetrations, in terms of the penetration level that results in voltage or congestion issues, was found when analysing other LCT. This is because different feeders have different hosting capacities. However DNOs ideally want some way to understand how much LCT a feeder can accommodate without voltage or thermal issues.

Deliverable 3.6 tested a range of feeder metrics for how well they would indicate the LCT penetration level that could potentially result in voltage or congestion issues. These metrics were based on known characteristics of a feeder. For instance, for the results for the feeder length and customer number are presented in Figure 6. Each point in the graph represents the penetration level at which a feeder has its first voltage or thermal problem (defined as when either the average percentage of customers with voltage problems is greater than or equal to 1%, or when the average utilization level at the head of the feeder is higher than 100%). The best performing metric was a combination of total path impedance and the initial utilisation level of the feeder.

An alternative easier to implement metric (in terms of access to input data) would be a combination of feeder length and number of customers. The corresponding results are shown in Figure 7.

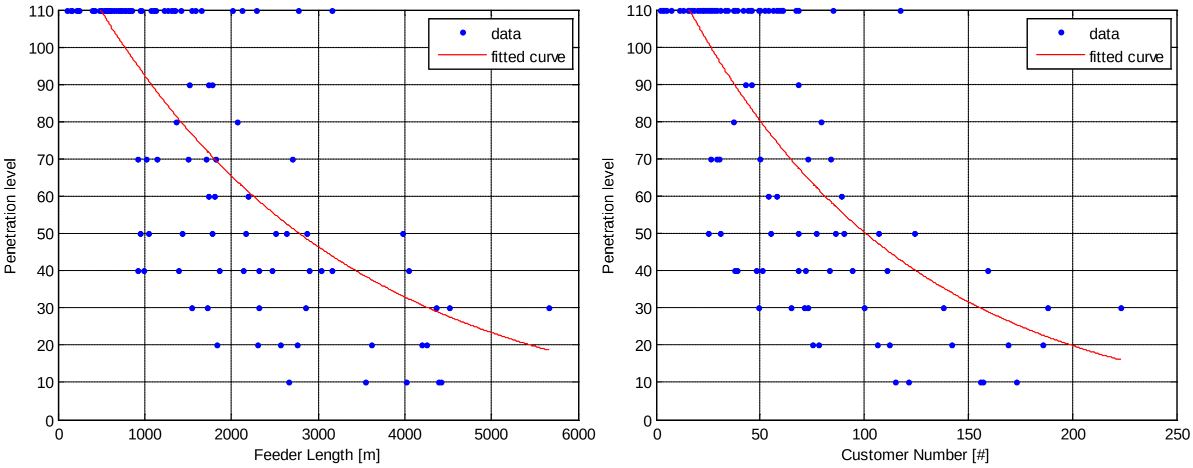

Figure 6: Feeder Length (left), R^2:0.57 and Customer No. (right), R^2:0.57 – PV (Deliverable 3.6)

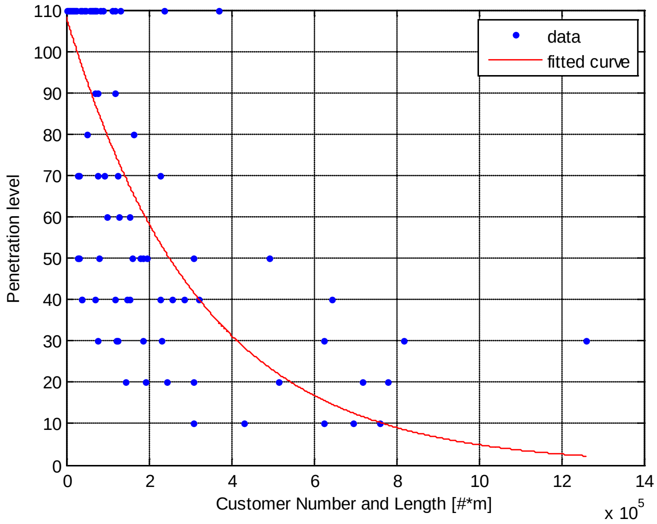

Figure 7: Customer Number and Feeder Length for the PV Case, R^2:0.61

For a given feeder and LCT type being considered by a DNO, the engineer could estimate the feeder length and customer numbers, multiply these together, and Figure 7 (for PV or the alternative graph for a different technology) would suggest the LCT penetration level at which a network issue would be expected to first occur, and therefore monitoring would be justified.

Consequently, it is recommended that:

The correlation metrics proposed in Deliverable 3.6 (or similar) should be adopted to find the most suitable penetration level of a given LCT for a feeder or LV network for which monitoring is required.

It is important to highlight that the analysis in Deliverable 3.6 was based on detailed network models and Monte Carlo analysis of 128 underground feeders with a range of lengths, loads and customer numbers. So the results are indicative of the voltage and thermal issues which would arise on Electricity North West’s underground feeders, but are not necessarily statistically representative of the underground networks. In addition, it is not possible to state that they are representative of the overhead networks.

2.5 Other Aspects

Although not formally reported via deliverables, analysis of the monitoring data has shown that total harmonic distortions (THD) of currents (only considered as a proxy of THD of voltage) and currents through the neutral are significant in many LV networks even without LCT. Given that high penetrations of LCT are likely to exacerbate these issues, it is advisable to monitor these parameters.

Consequently, it is recommended that:

The monitoring devices to be deployed, particularly at the substation, should ideally also monitor total harmonic distortions of voltage and neutral currents.

3 Conclusions

This report presented a discussion and recommendations in terms of the deployment of monitoring devices in LV networks in the North West of England. These recommendations were mainly based on the findings from Deliverable 3.3 and Deliverable 3.6. It is important to highlight that aspects related to cost were only considered in the context of minimising monitoring costs by defining the minimum technically useful specification for monitoring. No analysis was done on the economic value of monitoring data to identify network issues, or to assist or delay other network interventions.

In the context of monitoring to identify network issues caused by LCT:

- **Parameters to monitor**. Line-to-neutral voltage has been found to be a critical parameter to assess the impacts of most LCT. Indeed, it is of particular importance for photovoltaic systems (which are a reality and its penetration will continue to grow) given that most LV networks are likely to experience voltage issues rather than congestion at the head of the feeders or the distribution transformer. For electric vehicles and electric heat pumps, phase currents (or active and reactive power) also need to be monitored as many feeders are likely to experience congestion before voltage issues.

- **Sampling intervals**. Given that voltage issues are quantified following the BS EN 50160 standard, 10 minute sampling intervals (or close to this, e.g., 15 minutes) are ideal to avoid underestimating any potential problem. There is no significant benefit in adopting shorter sampling intervals (e.g., 1 or 5 minutes). For the monitoring of currents (or active and reactive power), hourly values are adequate.

- **Locations to monitor**. The busbar is the most practical and effective location for the monitoring of currents (or active and reactive power). In terms of voltages, however, it would only work as a proxy if some knowledge of the corresponding feeders exist (i.e., length, number of customer, LCT installations). Consequently, for voltages, the ideal positions are the end points of the feeders. Mid points do not necessarily bring more critical information although they increase certainty and observability.

- **Timing**. Monitors should be placed when a potential problem is likely to happen in the near future. However, voltage or congestion issues depend on penetration levels of LCT and the characteristics of the corresponding feeders. Hence, it is recommended that the correlation metrics proposed in Deliverable 3.6 are adopted to find the most suitable penetration level for a given feeder or LV network for which monitoring is required.

- **Other aspects**. Total harmonic distortions and currents through the neutral have been found to be significant in many LV networks even without LCT. High penetrations of LCT are likely to exacerbate these issues hence monitoring these parameters is advisable.

Finally, it is important to highlight that in the context of voltage management and depending on the control strategy (such in the case of the LoVIA project, also run by ENWL), sampling intervals can be higher than 10 minutes (e.g., 30 minutes) and still guarantee a good performance of the LV network. Consequently, while the above recommendations are for prevention purposes, once an operational solution is adopted (e.g., LV OLTC-fitted transformer, use of capacitor banks, dynamic meshing, etc.) sampling intervals can be adapted accordingly.