Title:

Deliverable 4.1 “Assessment of Potential LV network solutions”

Synopsis:

This report presents the analysis of two potential solutions to increase the hosting capacity of low carbon technologies in low voltage distribution networks. The solutions proposed, implemented and analysed are the loop connection in LV feeder and the utilisation of on-load tap changer in HV/LV transformers.

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Executive Summary

This document corresponds to Deliverable 4.1 “LV Network Solutions”. This report is part of the Low Carbon Network Fund Tier 1 project “LV Network Solutions” run by Electricity North West Limited (ENWL), the Distribution Network Operator of the North West of England, and The University of Manchester.

Penetrations of low carbon technologies (LCT) such as photovoltaic panels (PV), electric vehicles (EV), micro combined heat and power (μCHP) and electric heat pumps (EHP), are likely to increase in the future, particularly at low voltage (LV) networks. By modelling and analysing real LV networks, this project assesses the impacts of LCT and the technical viability of innovative solutions to manage future networks.

This report analyses in detail from the technical and economic perspectives two potential alternatives to increase the penetration of LCT in the LV networks. These are: 1) the loop connection between radial LV feeders; and, 2) the implementation of OLTC (on load tap changer) in HV/LV transformers. To study these cases, the Probabilistic Impact Assessment Methodology presented in Deliverable 3.6 “What-if Scenario Impact Studies based on real LV networks”. This technique proved valuable in quantifying the benefits of the proposed solutions. The main aspects and findings are listed below.

Loop Operation of Feeders: PV Case

- Two cases are examined: loop connection between two feeders and meshed operation. In the former, connections between sets of two feeders are explored one by one to determine the increase in the hosting capacity. In the latter, every feeder is connected to its neighbours and therefore the network is completely meshed.
- This approach improves the utilisation of the network and its ability to host larger volumes of PV generation. Most of the problems are ‘delayed’ to higher penetration levels; for the examined networks, the occurrence of the first problems are moved from 40% of PV penetration level in the radial cases to 70% in the meshed operation (all feeders). Also, the results indicate that connecting different feeders lead to different degrees of benefits given their particular characteristics.

OLTC-Fitted Transformers: PV and EV Cases

- Two cases are explored: business as usual (without OLTC) and with OLTC control. For the latter, two types of control are implemented: local and remote. The local control use the information at the busbar level and the remote control uses the information coming from a distant point in the network (e.g., furthest customer in the feeder).
- The use of this device can improve the hosting capacity of the network when penetrations are ‘even’ among the feeders. For the studied network, voltage problems were delayed from 40% of PV penetration level without OLTC to 60% in the case with OLTC and busbar control. This figure increased to 80% in the case with remote control (furthest point in the network). This means it is possible to make staged investments (local control then remote control) in networks with progressive PV penetration. For the EV case, all the voltage problems were solved with the OLTC (local control) in the network analysed.

Comparison with Traditional Reinforcements Cost

- Considering the current cost of deploying devices for loop operation and OLTC-fitted transformers, the traditional cable-based reinforcement is a cost-effective option to tackle medium penetration levels of LCT (up to 50%). Nonetheless, it is likely that the cost of the alternatives examined (nowadays in trial stage) will be reduced in the future and therefore they might become more attractive for wide-scale implementation.

Contents

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 several of those projects. In particular, this report is part of the Tier 1 project called “LV Networks Solutions”.

Penetrations of low carbon technologies (LCT) such as photovoltaic panels (PV), electric vehicles (EV), micro combined heat and power (μCHP) and electric heat pumps (EHP), are likely to increase in the future, particularly at low voltage (LV) networks. By modelling and analysing real LV networks, this project assesses the impacts of LCT and the technical viability of innovative solutions to manage future networks. Thus, the main objective is to provide greater understanding of the characteristics, behaviour, and future needs of LV networks.

In particular, this report analyses from the technical and economic point of view two potential alternatives to increase the LCT in LV networks. These are:

1. the loop operation of LV feeders; and,
2. the implementation of OLTC (on load tap changer) in HV/LV transformers.

To study these cases, the Probabilistic Impact Assessment Methodology presented in Deliverable 3.6 “What-if Scenario Impact Studies based on real LV networks”. This methodology embeds the uncertainties related to LCT such as, location, size, behaviour, etc., and considers different penetration levels (percentage of houses with the new technology). Penetration levels ranging from 0% to 100% with increments of 10% are developed. This analysis takes into account 5-minute resolution time-series profiles and adopts a realistic representation of the unbalanced nature of LV networks. Thus, for each penetration level, a random siting of loads and LCT profiles (following a realistic probability distribution) is carried out to then run a power flow in order to capture the main results. This process is repeated one hundred times for each penetration level and is developed for the cases before and after the implementation of the solutions proposed (loop connection and OLTC implementation, independently). Two real LV networks are analysed, one for each of the solutions implemented.

Loop Operation of Feeders: PV Case

Traditionally, most LV networks have been operated adopting a radial configuration. The main advantages of this are: lower network cost (since the conductor size can be reduced downstream the feeders, a procedure called *tapering*, and a simpler, efficient protection scheme - generally overcurrent protection). Nonetheless, this configuration was not designed taking into account the presence of low carbon technologies. Thus, the loop operation of LV feeders is investigated as one of the possible alternatives to increase the penetration of these technologies. Two cases are examined in the loop operation alternative: loop connection between two feeders and meshed operation. In the first one, potential connections between sets of two feeders are explored one by one in order to determine the increase (if there is any) in the capacity of certain network to cope with PV panels (hosting capacity). In the second one, every feeder is connected to the neighbour feeders and therefore the network became completely meshed.

OLTC-Fitted Transformers: PV and EV Cases

The second alternative studied in this report is an extension of a common practice in higher voltage levels, where the voltages are usually managed by using On Load Tap Changers (OLTC) in the transformers. Low voltage networks, however, have no voltage regulation means as they simply use off-load tap changing transformers. In this report, the applicability of OLTC technology to HV/LV distribution transformers is analysed. Here, also two cases are explored: business as usual (without OLTC) and with OLTC control. For the latter, two types of control are implemented: local and remote. The local control use the information at the busbar level and the remote control uses the information coming from a distant point in the network (e.g., furthest customer in the feeder). The previous cases are examined in two different scenarios: only PV panels connected and only EVs.

Comparison with Traditional Reinforcements Cost

Finally, to assess the cost relates with the alternatives proposed, a simplified network reinforcement algorithm was implemented. The idea behind the elaboration of this methodology was to compare the business as usual approach taken by DNOs to solve problems in their networks (reinforcement) with the two solutions proposed in this report. Cost estimations are used to quantify the value for the loop connections and for the OLTC implementation. Since these alternatives are not yet common practices at LV level, they are still expensive. Nonetheless, it is expected that a future reduction in the cost of these technologies will create a business case for their implementation.

1.1 Report Structure

The rest of this report is divided into six chapters. Chapter 2 presents a brief summary about the individual profiles created in this project for this particular report, namely, loads, photovoltaic panels, and electric vehicles. A summary of the methodology to create them is presented in this chapter. Also, the Probabilistic Impact Assessment methodology is explained in this chapter in order to set the framework where the solution proposed will be examined.

Chapter 3 describes and analyses the two solutions implemented to increase the hosting capacity in LV networks. The cases studies before and after the solution implementation are explored for the loop connection and for the utilisation of OLTC in HV/LV networks. The economic assessment of these alternatives is studied in Chapter 5. This chapter also presents as a benchmark cost the implementation and calculation of the network reinforcement cost for the networks under analysis. The conclusions are drawn in Chapter 5. Finally, the main references are presented in Chapter 6.

2 Background for the LV Network Solutions

In order to compare the quality of the solutions proposed in this report a common framework need to be in place. This consists in the application of the Probabilistic Impact Assessment Methodology for the base case (fit and forget approach) and for the proposed solution case. Thus, both cases, with and without one particular proposed solution are analysed in the same probabilistic approach. The Probabilistic Impact Assessment Methodology was fully explained in Deliverable 3.6 [1], nonetheless, in this chapter a brief summary about the methodology inputs (profiles and networks) and about the methodology itself are presented.

2.1 Input Data

2.1.1 Time-Series Profiles

To understand the impacts of LCT on LV distribution networks, the creation of realistic time-series profiles is fundamental. In this section, a summary of the main characteristic of the profiles used/created is presented. Further details are included in the Deliverable 3.5 "Creation of aggregated profiles with and without new loads and DER based on monitored data" [2]. In particular, these profiles correspond to un-restricted residential loads, photovoltaic panels (PV) and electric vehicles (EV). All the profiles produced for the studies presented in this report consider 5-minute resolution data.

2.1.1.1 Load Profiles

The load profiles are obtained from the computational model developed by CREST (Centre for Renewable Energy Systems Technology) at Loughborough University. This model creates time-series profiles for residential loads based on the domestic behaviour of British costumers [3]; it takes into account the number of people at home, the type of day, the month, and the uses of the appliances. The profiles are randomly created based on a pre-defined set of characteristics. As an example, Figure 1 shows three different profiles created with the mentioned tool. In this project, the proportion of profiles with certain number of people is based on UK statistics [4].

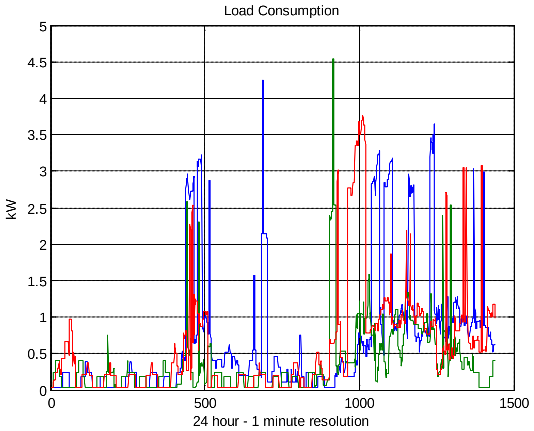

Figure 1: Individual load profiles – 1 minute resolution

2.1.1.2 Photovoltaic Profiles

The sun irradiance data used for the PV profiles was monitored by the Whitworth Meteorological Observatory located at The University of Manchester. As an example, the daily profiles for the period from July 2012 to December 2012 are presented in Figure 2. The efficiency for the PV inverter used in this work is 94.5% and for the energy conversion is 15%. The size of the PV systems in each house is randomly allocated based on UK statistics for residential PV generation [5].

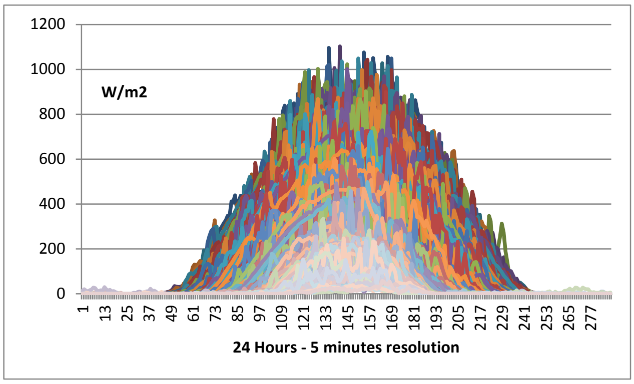

Figure 2: Daily sun radiation profiles

2.1.1.3 Electric Vehicles Profiles

In this work, the statistical analysis presented in [6], as the result of a one-year field trial of EV in Dublin, is used to create the electric vehicles profiles. The main information used for the creation of profiles is: the distribution of connection times and the distribution of energy requirement for each vehicle during each connection period. The EV used in these simulations is the Nissan Leaf, with a battery of 3kW and 24 kWh. Two examples are presented in Figure 3.

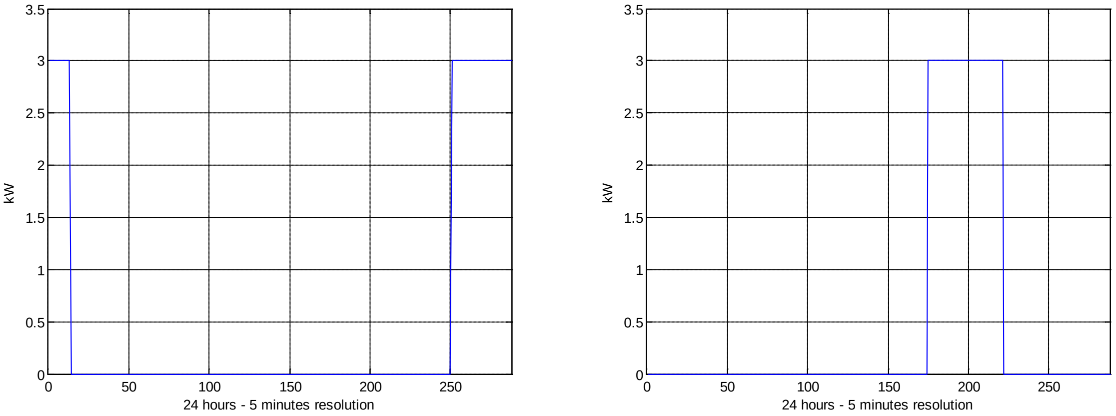

Figure 3: Example of individual EV profiles

2.1.2 Real UK LV Feeders

After the creation of the profiles of household loads and low carbon technologies, it is crucial to have realistic low voltage feeders to analyse the corresponding impacts. The information to create such networks was facilitated by ENWL through GIS files containing the network topology and the cable characteristics (type of cable, phase connection, etc.). The main stages of this modelling process are the topology reconnection and the OpenDSS representation. Both of them are fully explained in Deliverable 1.2: “Tool for Translating Network Data from ENWL to OpenDSS” [7]. With this methodology (additional details in [7]), 26 LV networks have been fully modelled in OpenDSS; this corresponds to 128 feeders, 7539 customers and about 200 kilometres of cables (including service cables) and 19 MVA of installed transformer capacity. All the networks modelled are underground networks.

The power flow studies were carried out using OpenDSS, an open source software package to solve power flows, harmonics analysis and fault current calculation in electrical distribution systems. One of the main characteristics of OpenDSS is the ability to represent the time dimension (daily and yearly simulations with different time step) in networks with distributed generation.

2.2 Probabilistic Impact Assessment Methodology

This methodology combines: Monte Carlo analysis, time-series simulation, unbalance power flows, and real-life networks (European style) [8], [9]. The main steps are described below and also summarised in Figure 4.

1. Firstly, different load profiles are allocated to each load in the feeder. These load profiles are randomly selected from the pool created in section 2.1.1.1 in order to represent properly the diversity among the residential customers.
2. Secondly, for a given penetration level (from 0 to 100% in steps of 10%), the houses to have the analysed low carbon technology (LCT) are randomly selected. In this work, the penetration level is defined as the percentage of houses with the LCT under analysis. Thus, if the penetration level is 20%, then 20% of the houses are selected to install a given technology. For example, the size of each PV panel is randomly selected according to the distribution of residential PV panels in the UK (as presented in section 2.1.1.2). It is important to remark that the sun profile used for all the houses in the feeder is the same (assumption: there are not big changes in a small geographical region). Specifically, for the simulations presented in this report, only the sunniest days are considered. In fact, the random sun profile is chosen among the thirty sunniest days of the year. The idea behind this assumption is to assess the worst case scenario, avoiding the analysis of very cloudy days. This random selection is also applied for EV. This probabilistic process is carried out to cater for the uncertainties related to the location, size and behaviour of these technologies.
3. Next, with the load profiles and LCT profiles allocated in the feeder, a time-series power flow with 5 minute resolution data is executed by using OpenDSS.

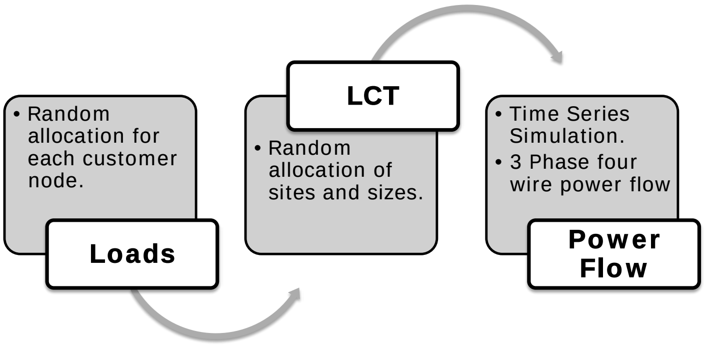

Figure 4: Methodology Flow Chart

The power flow results (voltage, current, losses, power, etc.) will be different according to the load profiles, the location and size of the low carbon technologies. To capture this stochastic nature a Monte Carlo analysis is considered in this work. Thus, the process presented here (Figure 4) is run a hundred of times for each penetration level (steps 1 to 3). The corresponding impacts are then stored for every single simulation (one penetration level, one case, 5 min) to develop a probabilistic impact assessment. Therefore, after a complete process the results for 1100 simulations are analysed. The main metrics to carry out this assessment are presented in the next section.

2.2.1 Assessment Metrics

To assess the probabilistic impacts, several metrics are implemented. In particular, for analysing the benefits of the LV network solutions, three metrics will be compared before and after the solution implementations. These are:

1. Percentage of customers with voltage problems: This metric takes the voltage profile calculated for each customer connection point from the power flow simulation, checking that the European Standard EN 50160 [10] is satisfied. If the customer’s voltage does not comply with the standard, then this costumer is considered to have a problem. All the customers with problems are added up, and this number is divided by the total number of customers in the

feeder. In this way, the percentage of customers with problems is calculated. Since the time-series profiles have a resolution of 5 minutes, the daily voltage profiles for each customer in the feeder are averaged in 10 minutes to make the calculation according to EN 50160. Once, the percentage of customers with voltage problems is calculated for each simulation, the average and standard deviation is determined for each penetration level.

2. Utilisation level at the head of the feeder: This metric assesses the utilisation level in the main segment of the feeder. This index is calculated as the hourly maximum current divided by the ampacity (cable rating) of the main segment of the feeder. To calculate the hourly maximum current, the current in the main feeder calculated from the power simulation (five minutes resolution) is averaged in one hour. The idea of this index is to show how the utilisation of the network behaves with different penetration levels of low carbon technologies. The average value +/- one standard deviation per penetration level for each technology is also determined.

It is important to clarify that the compliance of customer connection points with the EN 50160 standard is used here for quantification purposes. Furthermore, the standard considers a week-long analysis instead of a single day. Consequently, the quantification of non-compliant customers as adopted in this work is a good metric but does not necessarily mean that the corresponding customers’ appliances would face technical problems.

3 LV Network Solutions

The Impact Assessment Methodology implemented in the previous chapter is useful for understanding the behaviour of different feeders under different penetration levels of low carbon technologies. By using that methodology the technical impacts of LCT, specifically PV and EV, can be measured and therefore the impact mitigation of any possible solution can be quantified.

In particular, in this report two possible solutions are explored, these are the loop connection between typically radial LV feeders and the utilisation of OLTC (on-load tap changer) in distribution transformers (HV/LV). Two real LV networks are analysed, one for each of the solutions implemented.

3.1 Loop Operation

Traditionally, most LV networks have been operated adopting a radial configuration. The main advantages of this are: lower network cost (since the conductor size can be reduced downstream the feeders, a procedure known as tapering, and a simpler, efficient protection scheme - generally overcurrent protection) [11]. Nonetheless, this configuration was not designed taking into account the presence of low carbon technologies.

In this section, the loop operation of LV feeders is investigated as one of the possible alternatives to increase the penetration of these technologies. This potential benefit has been recently explored in high voltage (HV) distribution networks (also known as medium voltage internationally) with distributed generation (DG) [11]. Although the analysis considered losses, voltages, loading and short circuit levels, only snapshot scenarios (i.e., combinations of load and generation levels) were simulated instead of a time-series analysis. Also at HV level, three networks were studied in [12] looking at losses. In that case, the increase in the hosting capacity was investigated for only two DG locations (end and middle of a feeder). From a device perspective, the utilisation of soft open points for looping HV networks was introduced in [13], and included the potential control of reactive and active flow between the connection points. The same control capabilities are observed and tested in the intelligence nodes presented in [14].

To analyse the corresponding effects under the presence of generation and new loads, different penetration levels of PV panels are considered in this section by using the Probabilistic Impact Assessment Methodology [15].

3.1.1 Network under analysis

The real network implemented is presented in Figure 5, where each colour represents a different feeder and the red triangle represents the substation. It has four feeders, 180 costumers and 5.4 km of total length. The characteristics of each feeder are presented in Table 1.

It is important to remark that the substation is modeled as a whole and not feeder by feeder, this means that the power flow circulation among the feeder is fully considered, in this way the OpenDSS simulation solves all the LV network representation (substation plus feeders) at once. In practical terms, this makes possible that if one of the feeders has extra generation (more than the own feeder consumption), this generation can supply the load of the rest of the feeders when they need it. Furthermore, this representation allows the study of all the feasible loop connections among the feeders and the analysis of more than one connection.

LV Network	Feeder	Distance (m)	No. of Customers
1	1	1289	53
	2	920	26
	3	868	31
	4	2291	70

Table 1: Feeder characteristics

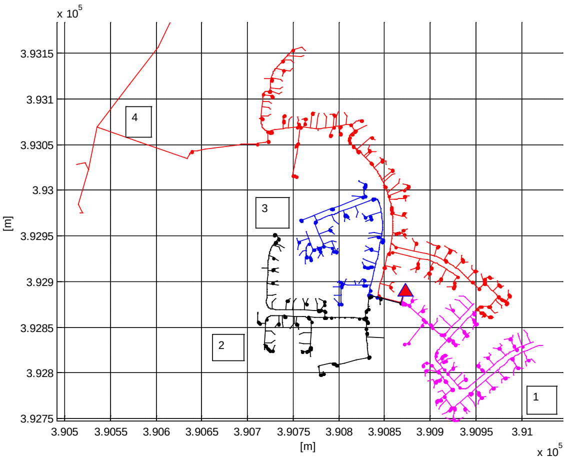

Figure 5: Network under analysis

3.1.2 Identification of feeder connection

Before the application of the assessment methodology, the identification of the feasible links among the feeder is needed. These connections must be done between three-phase buses in order to have equal power transfer capabilities. In the simulations presented in this section, the loop connection is done between buses that could not have necessarily the possibility to do an easy connection (maybe extra cable would be required). In spite of that, the results here help to understand the benefits of doing loop connections in LV networks. It is important to remark that in future works, the possibility of just closing link boxes will be explored. Figure 6 presents the link connections analysed in this section. In fact, the green lines represent the feasible loop connections.

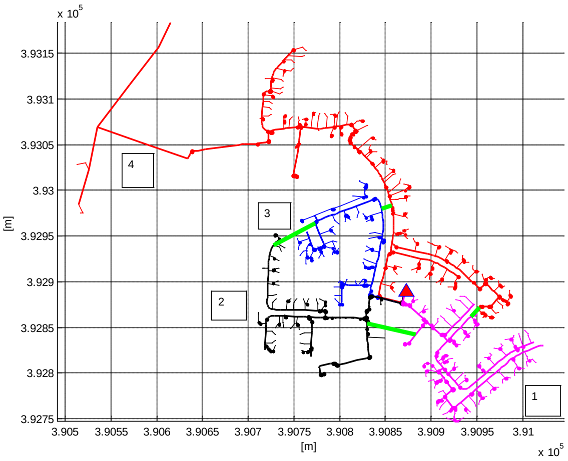

Figure 6: Feasible connections (green lines)

3.1.3 Connection Analysis

The voltage at the secondary of the transformer was set at 240 V; this value provides enough headroom for both voltage rise (due to PV) and voltage drop (due to peak demand). The connection between each pair of feeders is explored and also the meshed connection (all the links connected at the same time) is analysed.

3.1.3.1 Connection between feeder 1 and 4

The utilisation factor before and after the loop connection for feeder 4 and 1 are shown in Figure 7 and Figure 8, respectively. From the figures, it is possible to observe that feeder 4 (the longest and more loaded) decreases its utilisation after the loop connection and feeder 1 increases the utilisation level.

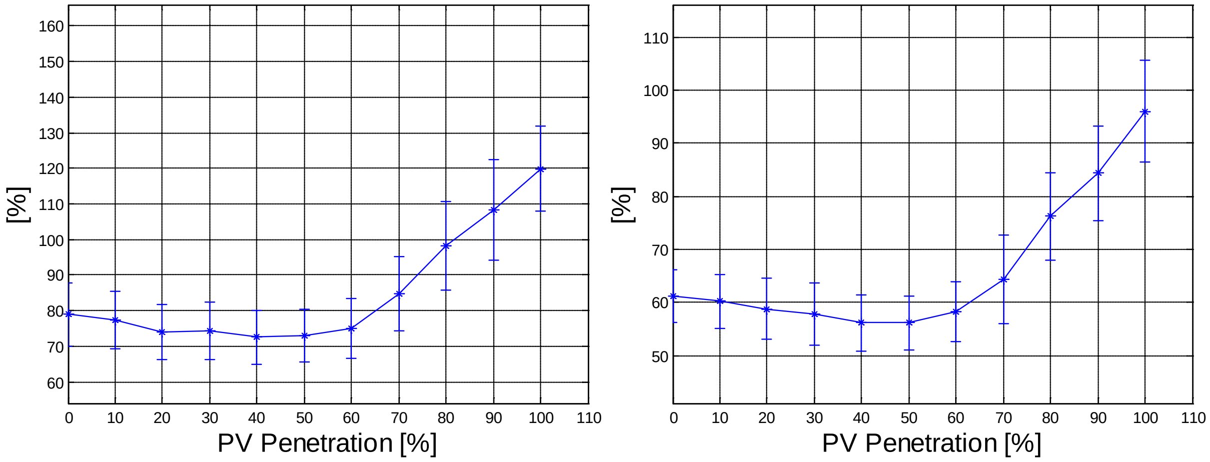

Figure 7: Utilisation level in feeder 4 before (left) and after (right) the loop connection 1- 4

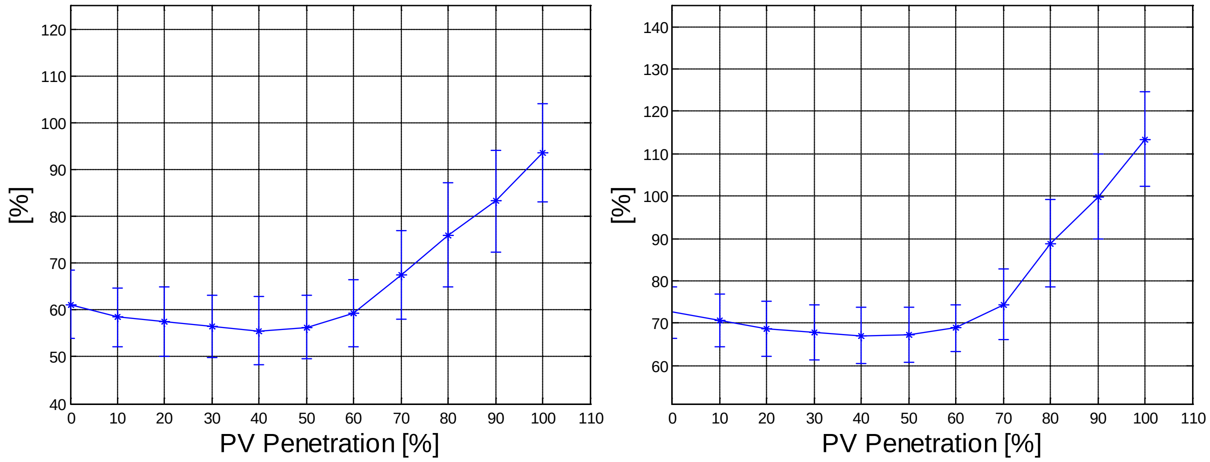

Figure 8: Utilisation level in feeder 1 before (left) and after (right) the loop connection 1 - 4

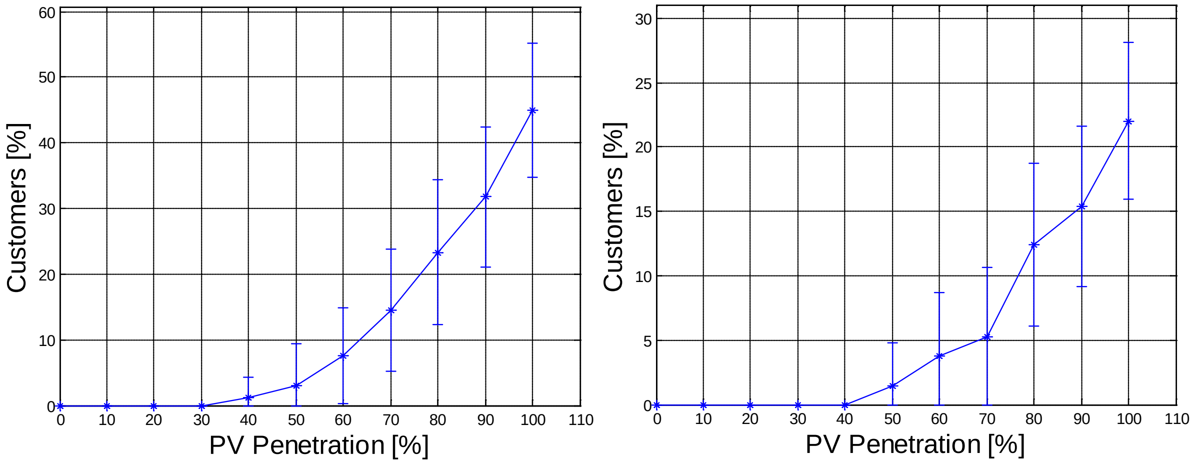

Figure 9: Voltage problems in feeder 4 before (left) and after (right) the loop connection 1 – 4

The % of customers with voltage problems before and after the loop connection for feeder 4 and 1 are shown in Figure 9 and Figure 10, respectively. From the figures, it is possible to observe that the magnitude of problems is lower in feeder 4 after the loop connection and it is bigger in feeder 1. For example, at 100% of penetration level, an average of 45% of the customers have voltage problems in feeder four before the connection, this number decreased to 22% after the loop connection.

In contrast, in feeder one for 100% of penetration level, in average 2% of the customers has voltage problems before the connection. This number increase to 4% after the loop connection.

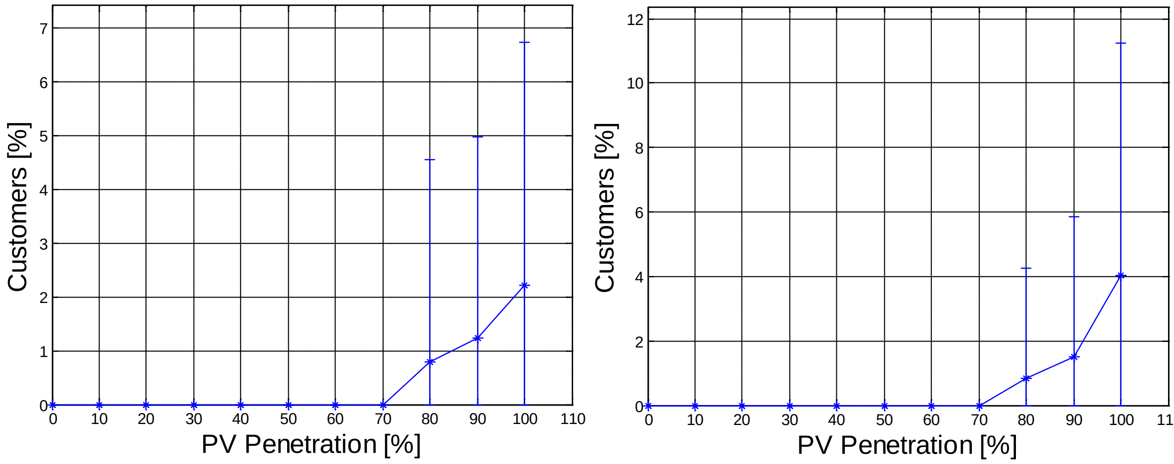

Figure 10: Voltage problems in feeder 1 before (left) and after (right) the loop connection 1 – 4

It is important to highlight that the first problems in these two feeders appear at first in feeder 4 at 40% of penetration level (voltage problems before than the thermal issues) and after the connection, the first problems occur at 50% of penetration level. Therefore, the loop connection delays the occurrence of the first problems in these feeders, increasing the hosting capacity on them.

3.1.3.2 Connection between feeder 4 and 3

Figure 11 indicates the decreasing in the utilisation level for feeder 4 after the loop connection and Figure 12 shows that the utilisation level rises in feeder 3. Nevertheless, after the loop connection none of the feeder reaches, in average, the maximum capacity. Thus, this connection is positive in terms of utilisation level.

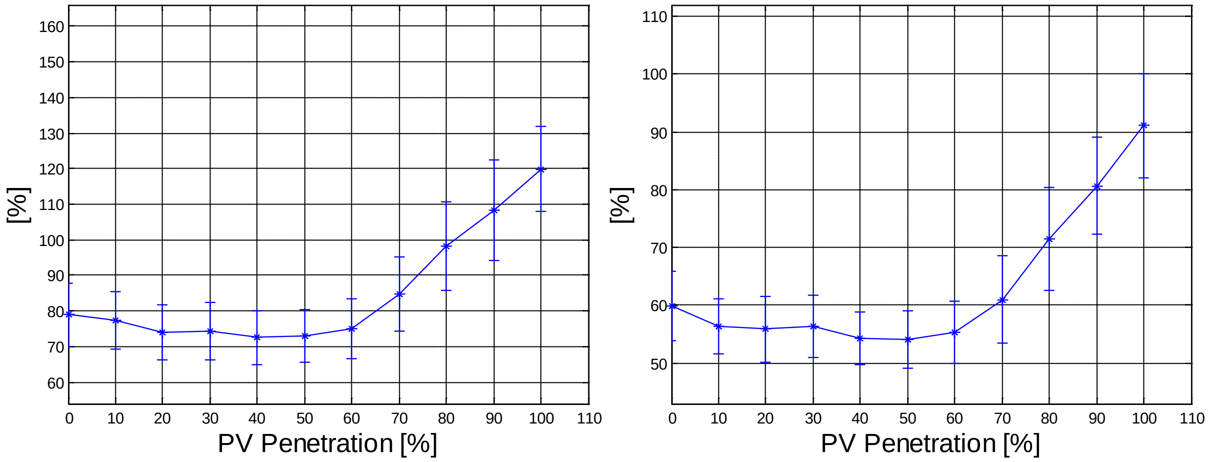

Figure 11: Utilisation level in feeder 4 before (left) and after (right) the loop connection 3 – 4

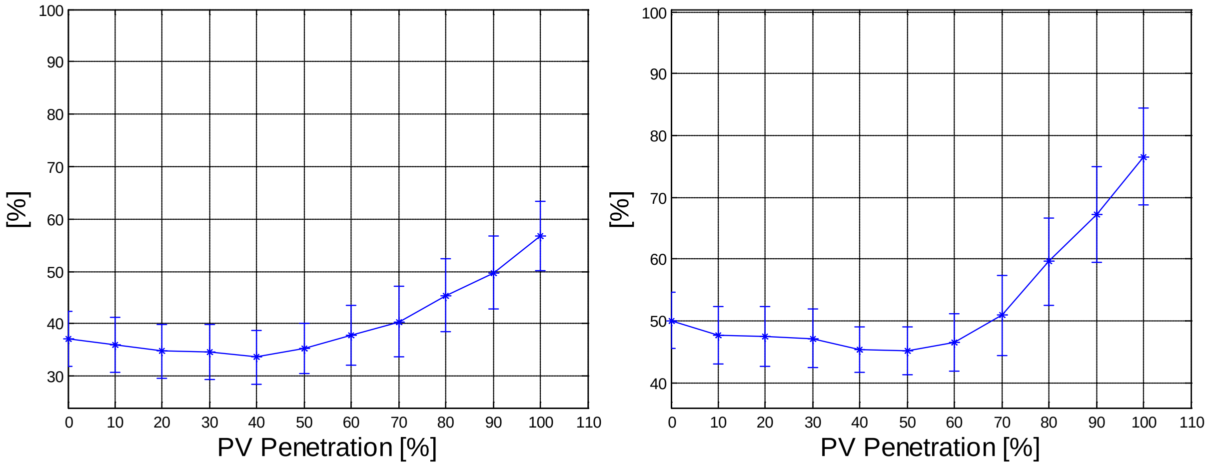

Figure 12: Utilisation level in feeder 3 before (left) and after (right) the loop connection 3 – 4

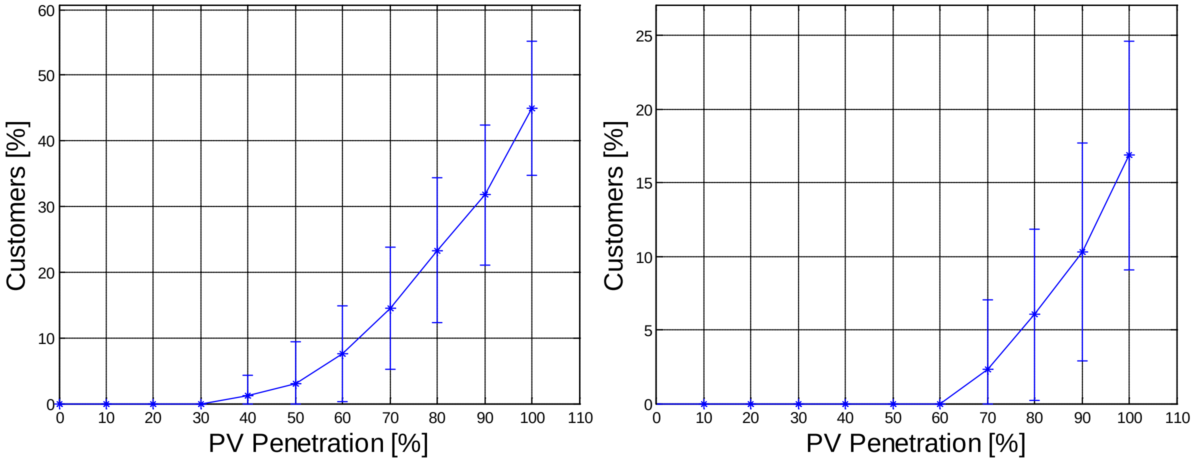

Figure 13: Voltage problems in feeder 4 before (left) and after (right) the loop connection 3 - 4

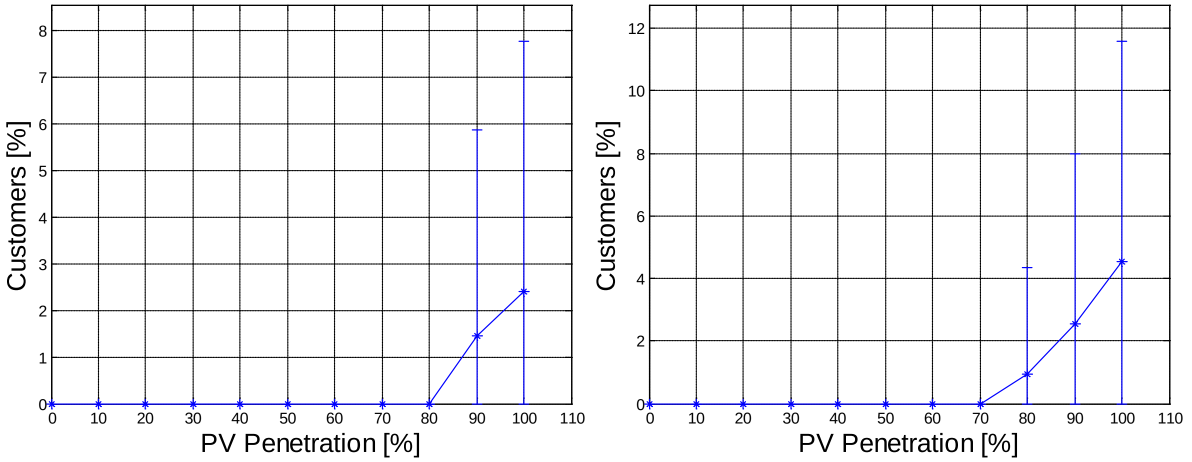

Figure 14: Voltage problems in feeder 3 before (left) and after (right) the loop connection 3 – 4

The number of customers with voltage problems decreases in feeder 4 after the loop connection, but it increases in feeder 3 as can be observed in Figure 13 and Figure 14, respectively. For example, in average at 90% of penetration level, feeder 4 has around 30% and 10% of customers with voltage problems before and after the loop connection, respectively. On the other hand, feeder 3 increases the percentage of customers from 0% before the loop connection to 1% after the loop connection at 80% of penetration level.

The first problems in these two feeders appear in feeder 4 at 40% of penetration level (voltage problems before the thermal issues) and after the connection, the first problems occur at 70% of penetration level for feeder 4 and 80% for feeder 3. Thus, in this case, the loop connection delays significantly the occurrence of the first problems in these feeders from 40% to 70%.

3.1.3.3 *Connection between feeder 3 and 2*

The third link connection is done between the feeder 3 and the feeder 2. The main results are presented from Figure 15 to Figure 17. In terms of utilisation level, there are not big changes. Both feeders (with similar lengths and number of customers) share almost equally the load consumption and the utilisation level slightly decreases in feeder 3 (Figure 15).

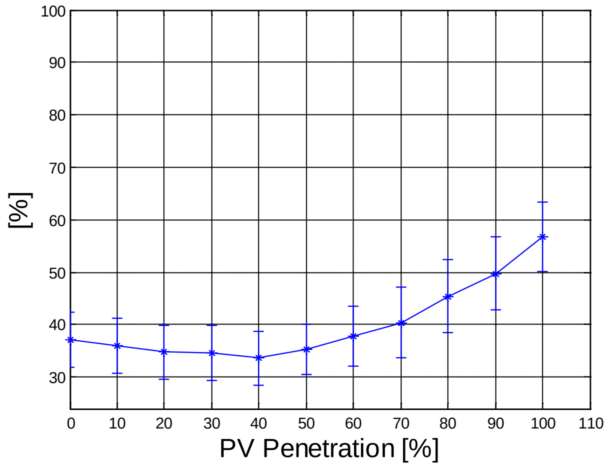

Figure 15: Utilisation level in feeder 3 before (left) and after (right) the loop connection 3 - 2

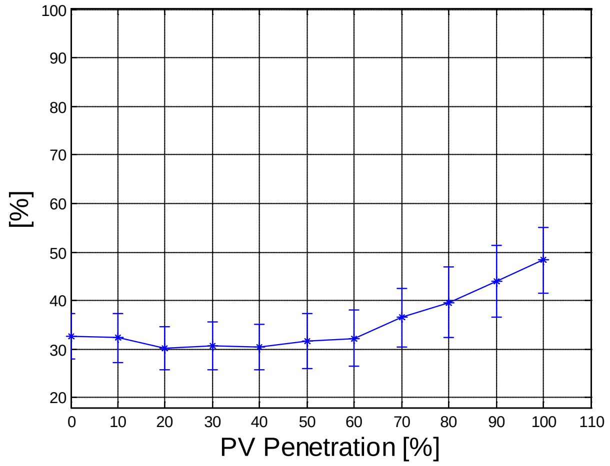

Figure 16: Utilisation level in feeder 2 before (left) and after (right) the loop connection 3 – 2

Before the loop connection of these two feeders only feeder 3 presents voltage problems as can be observed in Figure 17, those problems start at 90% of penetration level. After the loop connection, these voltage problems disappear completely.

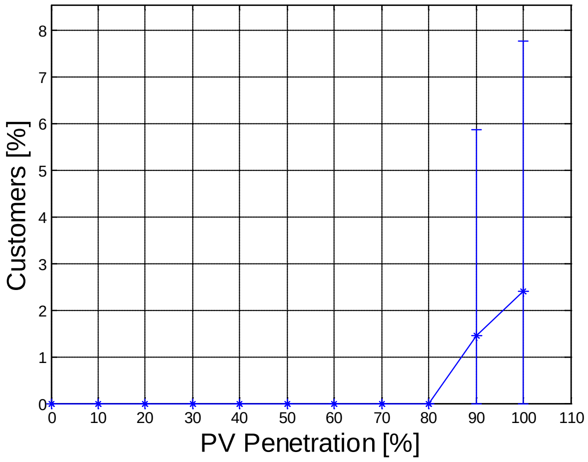

Figure 17: Voltage problems in feeder 3 before the loop connection 3 – 2

3.1.3.4 *Connection between feeder 2 and 1*

The utilisation factor before and after the loop connection for feeder 2 and 1 are shown in Figure 18 and Figure 19, respectively. From these figures, it is possible to observe that feeder 1 decreases slightly its utilisation level after the loop connection and feeder 2 stays without significant variation. Moreover, none of them reach the maximum cable capacity.

The percentage of customers with voltage problems before and after the loop connection for feeder 1 is shown in Figure 20. Feeder 2 does not present voltage problems either before or after the loop connection. Again, the loop connection produces a delay in the occurrence of the first voltage problems in feeder 1, moving the problems from 80% to 100% of penetration level.

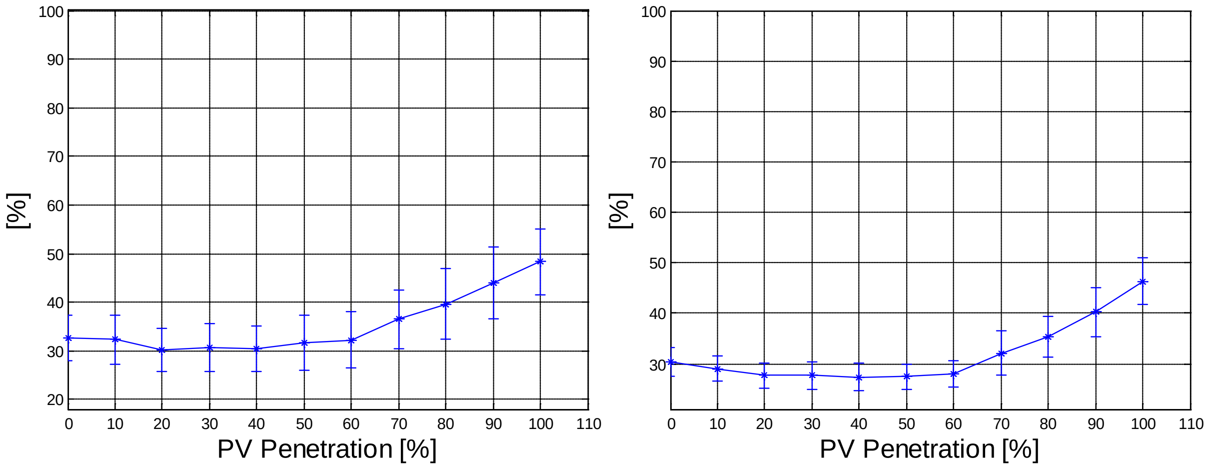

Figure 18: Utilisation level in feeder 2 before (left) and after (right) the loop connection 2 – 1

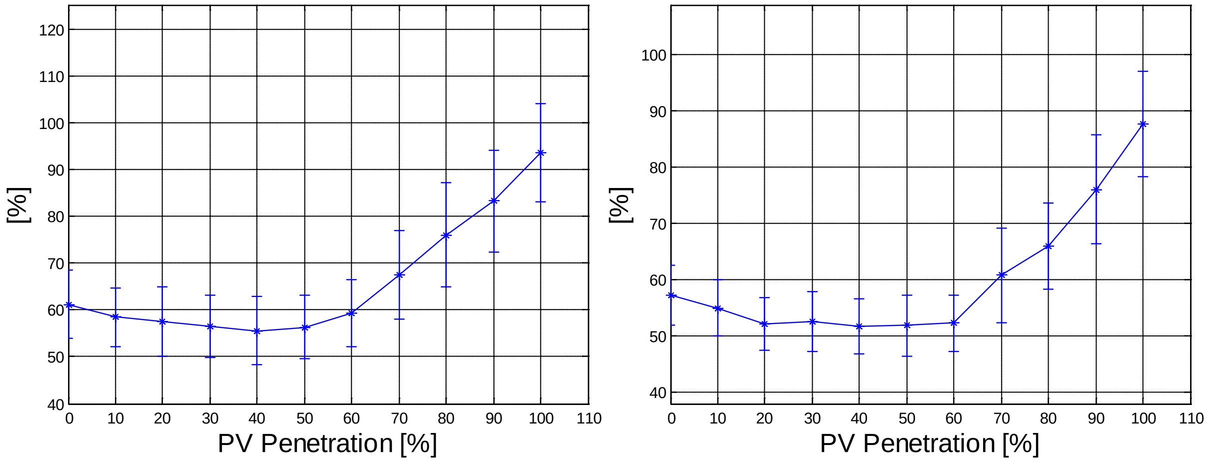

Figure 19: Utilisation level in feeder 1 before (left) and after (right) the loop connection 2 – 1

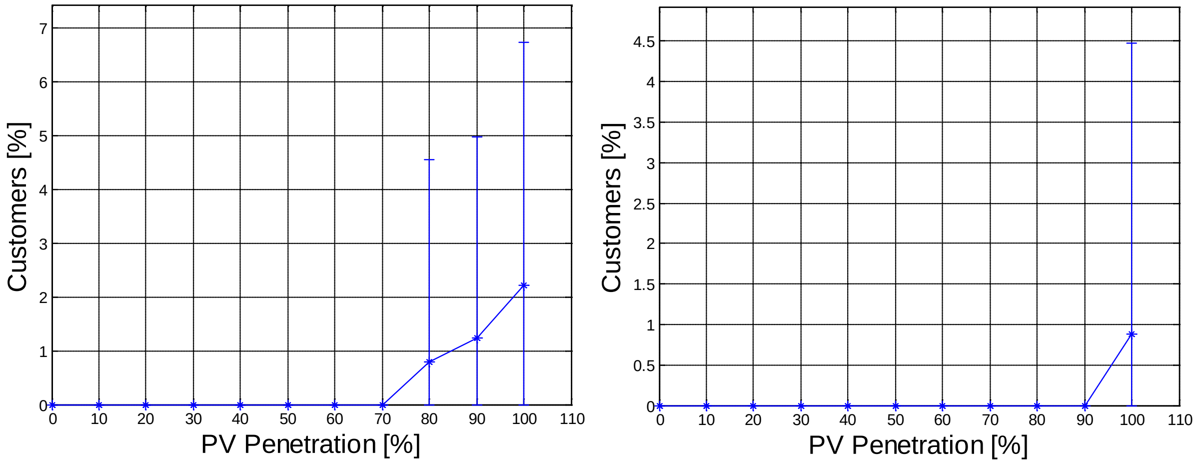

Figure 20: Voltage problems in feeder 1 before (left) and after (right) the loop connection 2 - 1

The previous results show potential benefits after the loop connection for all of the links analysed. A better utilisation of the cables was demonstrated and most important a delay in the occurrence of the first voltage problem was found.

Because of the inherent difference among the feeders (i.e., topology, impedance, length, and number of customers) the impacts of loop connection differ for different couple of feeders. A deeper research need to be carried out to determine the best connection points in each particular LV network. In fact, the University of Manchester and ENWL are starting a complete research and real implementation of loop operation of LV feeders through the project “Smart Street” (more information in www.enwl.co.uk/about-us/the-future/smart-street).

3.1.3.5 Meshed Operation of LV Networks

This case simulates the real LV network with all the links showed in Figure 6 connected. The analysis of the utilisation level indicates that after the meshed operation, feeder 4 for every penetration level decreases the percentage of utilisation at the head of the feeder (Figure 21) and feeder 3 and 1 increase that utilisation level (Figure 22 and Figure 24, respectively). Nonetheless, this increase is not enough to reach the maximum capacity of the cable in feeder 3 and just reach the maximum at 100% of penetration level for feeder 1. Finally, the utilisation level in feeder 2 increases slightly (Figure 23) without reaching the rating limit.

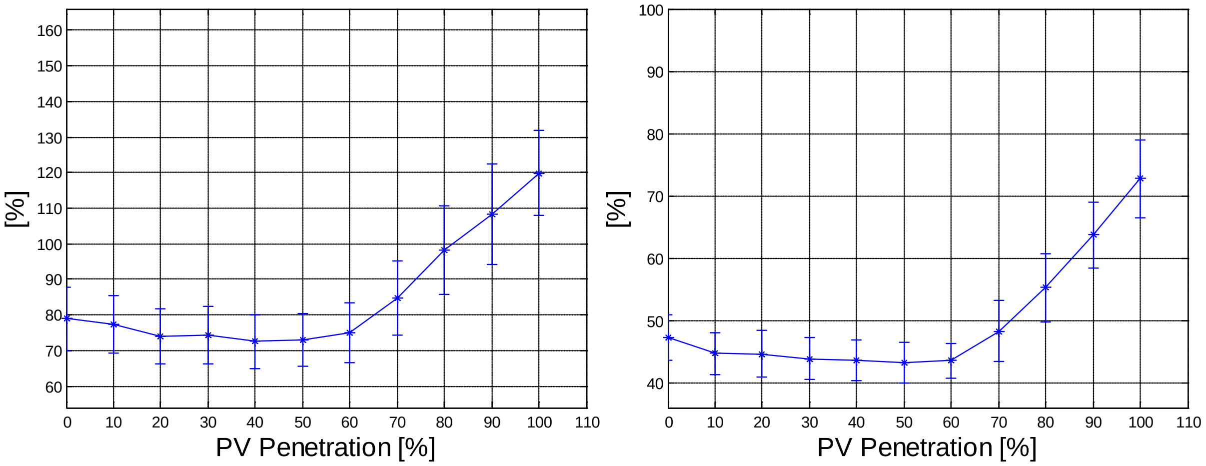

Figure 21: Utilisation level in feeder 4 before (left) and after (right) the meshed operation

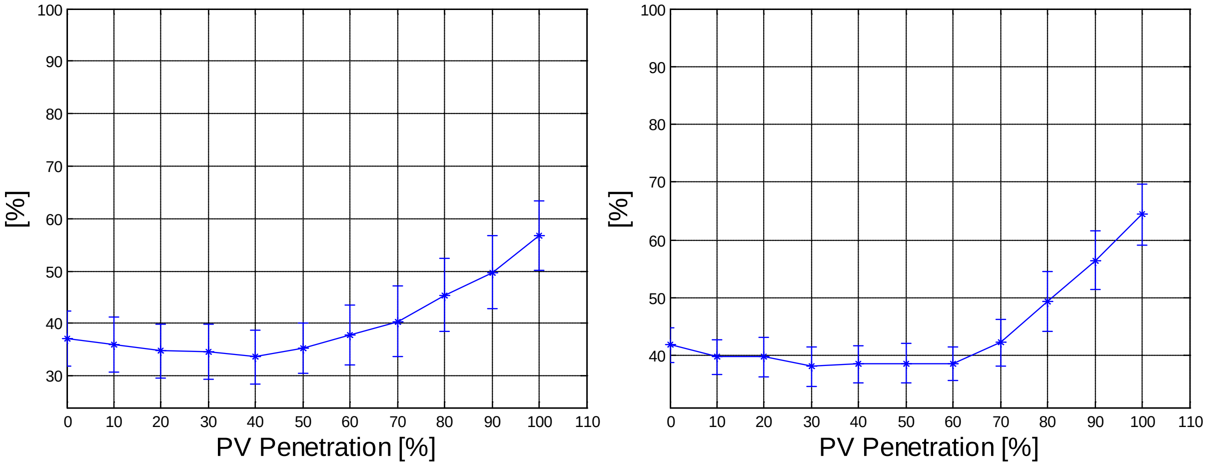

Figure 22: Utilisation level in feeder 3 before (left) and after (right) the meshed operation

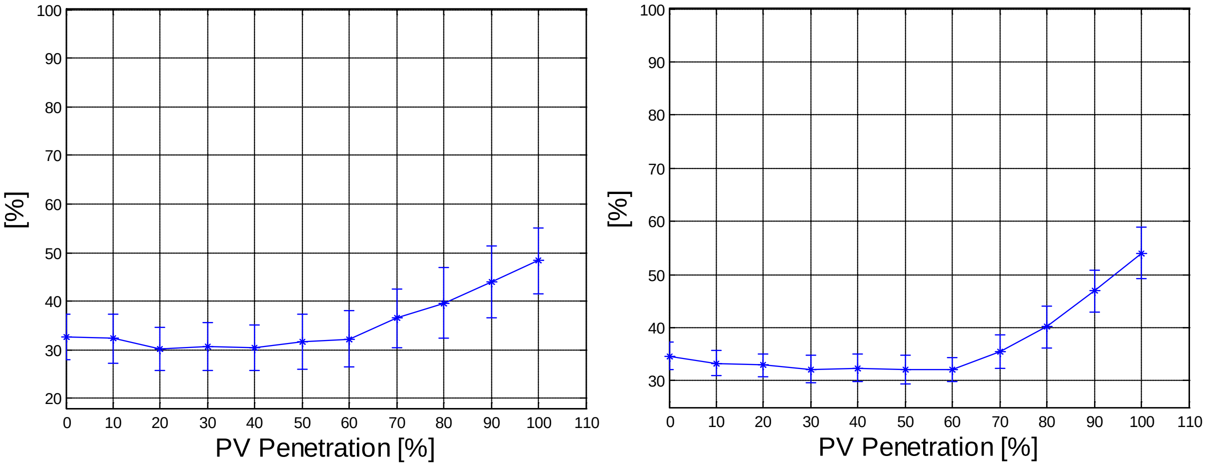

Figure 23: Utilisation level in feeder 2 before (left) and after (right) the meshed operation

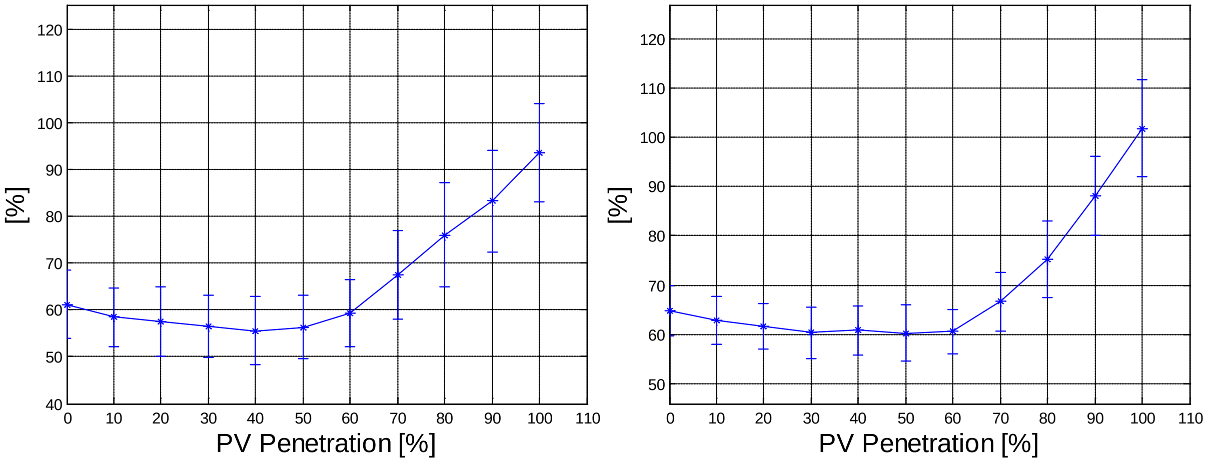

Figure 24: Utilisation level in feeder 1 before (left) and after (right) the meshed operation

The maximum capacity is reached in average for the first time at feeder 4 around 80% of penetration level in the radial operation, but after the meshed operation, the maximum capacity is just reached in average at first at 100% of penetration level in feeder 1 (note that feeder 4 does not reach the maximum rating after the meshed operation).

In respect of the customers with voltage problems, the voltage profiles improve considerably after the meshed operation. In fact, the percentage of customers with voltage problems decreases in feeder 4, feeder 3 and feeder 1 after the meshed operation (Figure 25, Figure 26 and Figure 27).

Before the meshed operation, the first voltage problems occur at 40% of penetration level in the network (feeder 4) and after the meshed operation, the customers with voltage problems just occur at 70% of penetration level (feeder 4), which means a 75% of improvement in the network hosting capacity. The magnitude of the problems are also reduced, for instance, the average percentage of customers with voltage problems at 100% penetration level is 45% before the meshed operation and then is below 8% after the meshed operation.

As a result, the meshed operation has the potential to improve not only the utilisation level but also the voltage regulation in the network.

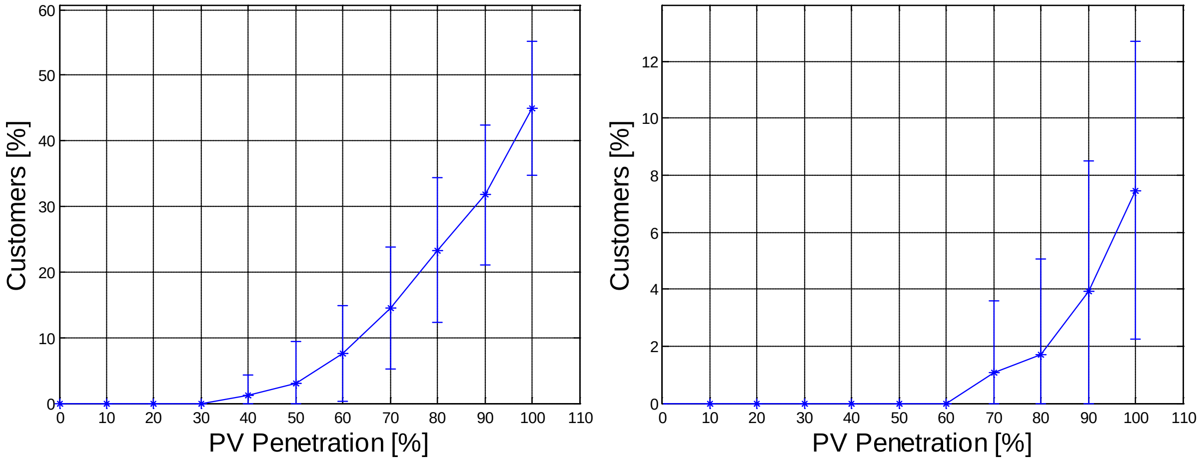

Figure 25: Voltage problems in feeder 4 before (left) and after (right) the meshed operation

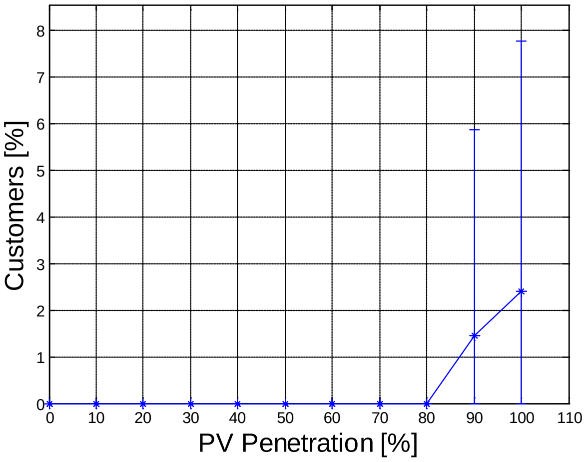

Figure 26: Voltage problems in feeder 3 before the meshed operation

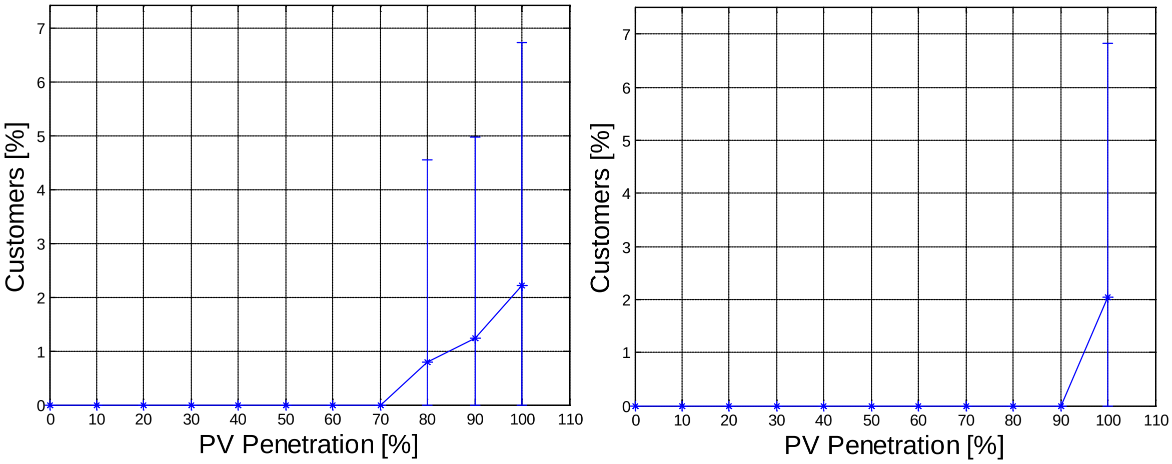

Figure 27: Voltage problems in feeder 1 before (left) and after (right) the meshed operation

Summarising, the voltage problems appear before than the thermal problems in the network under analysis for the cases before and after any loop connection (including the meshed operation). In particular, the occurrence of the first technical problems in the radial operation (without any loop) happens at 40% of penetration level (voltage issues – feeder 4), this value represent the bottleneck for the hosting capacity in this network.

To increase this hosting capacity, the loop connection proved to be an effective alternative. The connection between feeders 4 and 1 increases this penetration level from 40% to 50%. Alternatively, the connection between feeder 4 and 3 moves this value even further, reaching the first problems at 70% of penetration level (feeder 3 decreases this number from 90% to 80%; nonetheless the previous bottleneck is improved). Finally, the meshed operation reaches a bottleneck at 70% of penetration level without decreasing the performance (in terms of voltage) of the rest of the feeders. However, in this last case, 4 connections are needed, and therefore the cost of meshing could be higher than the simple connection between two feeders (i.e., connection between feeders 4 and 3). The economic assessment of these alternatives will be explored in Section 4.2.

3.2 OLTC Operation

In high voltage (HV) distribution networks, the voltages are usually managed by using On-Load Tap Changers (OLTC) in the transformers. Low voltage networks, however, have no voltage regulation means as they simply use off-load tap changing transformers. In this section, the applicability of OLTC technology to HV/LV distribution transformers is analysed.

Although a number of studies consider the potential coordinated control use of OLTC-fitted transformers, these are mainly focused on HV networks. In [16] the optimal coordination of reactive power from PV panels and the OLTC is presented to minimise OLTC operations (changes in the tap position). This approach was further developed in [17] using a heuristic process and also incorporating voltage regulators, shunt capacitors, shunt reactors and static VAR compensators. A similar problem is also solved in [18] but using nonlinear programming tools. All these works, however, rather than adequately modelling the time-series operational aspects of the network elements involved, adopt a day-ahead schedule based on the perfect forecast of loads and generation.

References [19] and [20] investigate the OLTC operation in LV networks. In both cases, the OLTC is studied adopting a remote control strategy and also in coordination with the decentralised reactive power control of PV panels. Additionally, [20] shows the economic evaluation of the alternatives presented. Nonetheless, in these two cases, only one low carbon technology is examined. Moreover, the networks implemented consider residential three-phase connections (mainly for loads and always for generation) as it is in the German case. Hence, the results presented cannot be extrapolated to networks with single-phase connections (such as in the UK) where the imbalance level can be significant.

This solution assesses the incorporation of OLTC-fitted transformers in LV networks to increase the penetration of low carbon technologies. Two technologies, photovoltaic panels (PV) and electric vehicles (EV) are analysed on one real LV network. Two OLTC control strategies are considered: busbar control and remote control. The Probabilistic Impact Assessment Methodology is used for all the cases analysed and the profiles for loads, PV and EV are the ones shown in Section 2.1.1 and explained in full detail in [2].

3.2.1 Network under analysis

The real network implemented in this OLTC analysis is presented in Figure 28, where each colour represents a different feeder and the red triangle represents the substation. It has 6 feeders, 351costumers and 9.2 km of total length (including the services cables). The real topology, conductor characteristics, customer locations and phase connection are considered. The characteristics of each feeder are presented in Table 2.

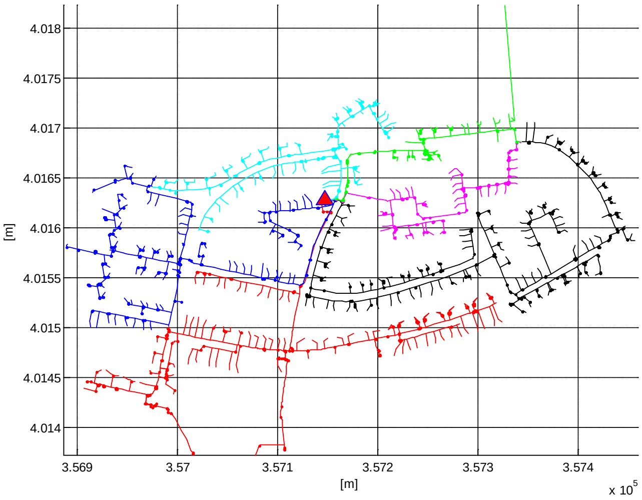

Figure 28: Network under analysis

Feeder	Length (m)	No. of Customers
1	2479	83
2	1823	68
3	2312	100
4	779	30
5	670	21
6	1220	49

Table 2: Feeder characteristics

3.2.2 Business as usual (no OLTC)

The probabilistic impact assessment methodology is applied on the network under analysis by running one hundred simulations for each penetration level and for each technology (PV and EV). The OLTC operation is not modelled in this case.

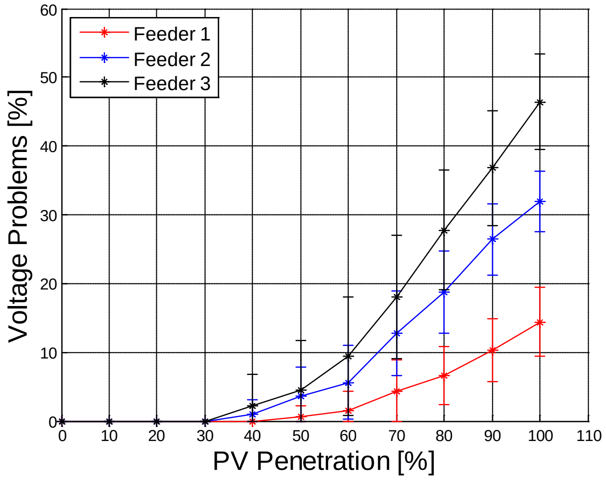

Figure 29: Percentage of customers with voltage problems – PV scenario

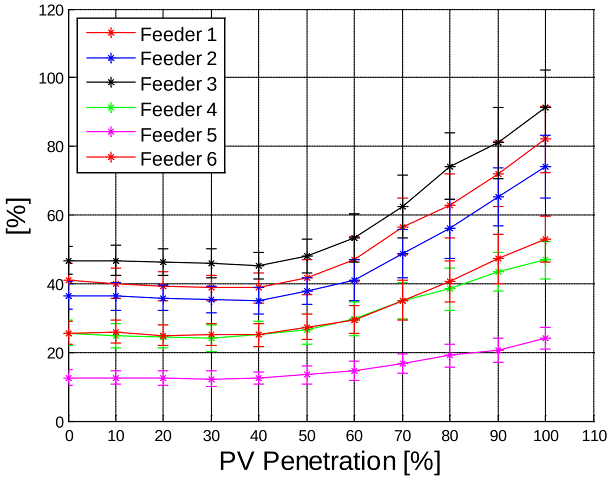

Figure 30: Utilisation Level at the head of the feeder – PV scenario

For the PV scenario, Figure 29 presents the percentage of customers with voltage problems per penetration level. It can be seen that in average the problems start at 40% of penetration level. Feeders 4, 5 and 6 are not presented in this figure because they do not face any voltage problem for any penetration level. Figure 30 presents the utilisation level at the head of the feeders. In this case, the utilisation level for the six feeders is shown. Only feeder 3 presents some simulations with results above the thermal rating at 100% of penetration level. Therefore, the penetration of PV panels in this particular network is limited by voltage issues. Hence, the use of an OLTC-fitted transformer could bring benefits.

On the other hand for the EV scenario, Figure 31 presents the percentage of customers with voltage problems. Only feeder 2 and 3 exhibit voltage problems, starting at 60% and 80% of penetration level, respectively. As for the thermal issues at the head of the feeder, only feeder 3 presents problems at 90% and 100% of penetration level (Figure 32). It is interesting to note that in all of the feeders with voltage problems in this network, the problems in the PV scenario are larger than in the EV scenario.

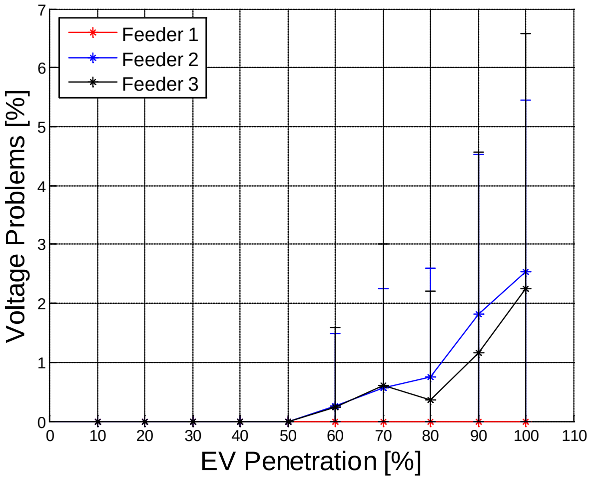

Figure 31: Percentage of customers with voltage problems – EV scenario

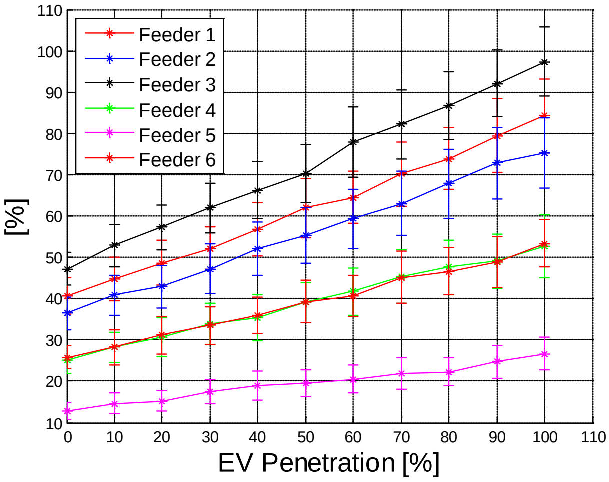

Figure 32: Utilisation Level at the head of the feeder – EV scenario

3.2.3 OLTC Analysis

The utilisation of transformers with On-Load Tap Changer (OLTC) enables varying the ratio between the corresponding primary and the secondary voltages for voltage regulation purposes. Traditionally, the HV/LV transformer cannot change the transformation ratio during operation. Nonetheless, the OLTC-fitted transformers are often used in networks with higher voltages. Thus, the application of this type of technology must be also explored in LV networks in order to increase the penetration of low carbon technologies [19].

Depending on the location whose voltage is to be controlled, the control strategy is classified into local (busbar voltage) and remote control (one node downstream in a given the feeder). Both cases will be analysed. The control cycle used in this report for voltage regulation (i.e., the OLTC) is five minutes. To have a fair comparison with the business as usual case, the same probabilistic impact assessment is carried out for the OLTC operation. One hundred simulations per penetration level are made, simulating in each of them the OLTC operation and calculating the percentage of customers with problems to check any potential improvement.

The OLTC implemented at the primary side of the transformer (lower current winding) has a regulation capability of +/-8% with nine tap positions; this means a tap step of 2%.

3.2.3.1 OLTC – Local Control

In this control strategy, a busbar voltage target is set. For the PV scenario, the voltage target is the minimum voltage that does not produce any voltage drop problem in any of the feeders without PV (i.e., 0% of penetration level). For the network under study, this value is 235V (phase to neutral) at the secondary of the transformer.

The percentage of customers with voltage problems for the OLTC case is presented in Figure 33. It can be observed that the voltage problems are delayed from 40% of penetration level in the business as usual case (Figure 29) to 60% of penetration level (Figure 33). Also, the magnitude of the problems decreases significantly. For example, at 100% of penetration level in the business as usual case, the average number of customers with voltage problems in feeder 1, feeder 2 and feeder 3 are 14%, 32% and 46%, respectively. In contrast, for the same feeders in the OLTC case, the percentages of customers with problems at 100% of penetration level are 4%, 11% and 18%.

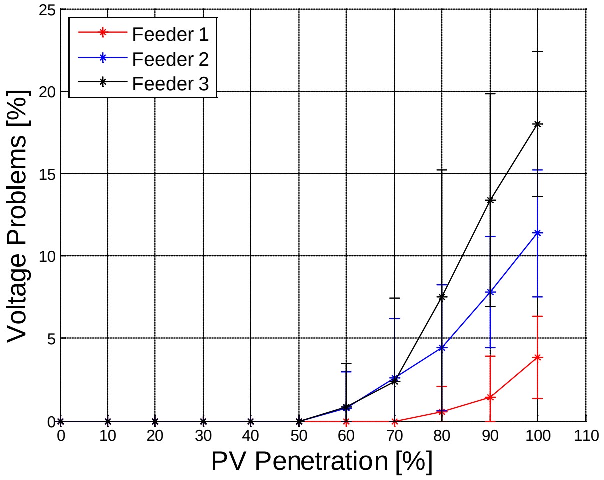

Figure 33: Percentage of customers with voltage problems for the OLTC case (local control) - PV scenario

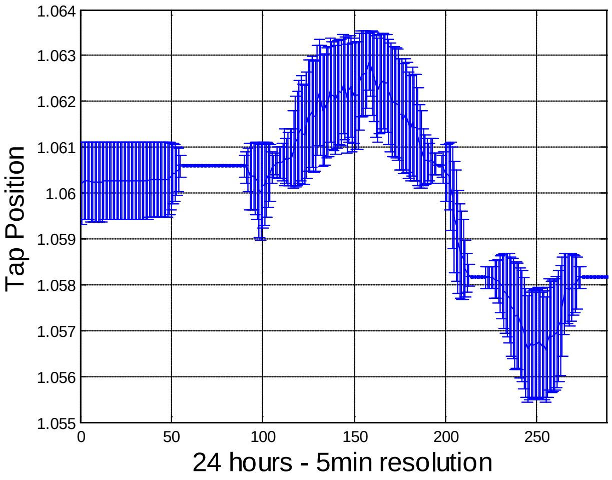

Figure 34: Average +/- one standard deviation for the OLTC operation – PV scenario

Additionally, to visualise the OLTC operation, Figure 34 shows the average position +/- one standard deviation during the day for all the simulations at 50% of penetration level. Here, the increase in the tap position is clear during the midday in order to reduce the voltage at the secondary of the transformer. It is important to recall that the OLTC is located at primary side of the transformer and therefore an increase in the tap position means a reduction in the ratio between the secondary and primary windings, producing as a result a decrease in the secondary voltage. This is totally consistent with the average OLTC operation (+/- one standard deviation) observed in Figure 34.

In the EV scenario, the voltage target is 245V (phase to neutral) at the secondary of the transformer. It is important to remark that still there is headroom above this target. However, it was not necessary to increase it because all the voltage problems were solved in the EV case with the OLTC operation at 245V. Therefore, the OLTC enables 100% of EV penetration in all of the feeders under analysis from the voltage point of view. Nonetheless, it must be highlighted that in the EV scenario, there are some simulations that present thermal issues at 90% and 100% of penetration level that cannot be fixed with the OLTC. For comparison purposes, Fig. 9 indicates the average OLTC daily operation in the EV scenario for 50% of penetration level, showing that the busbar is increased during the peak time.

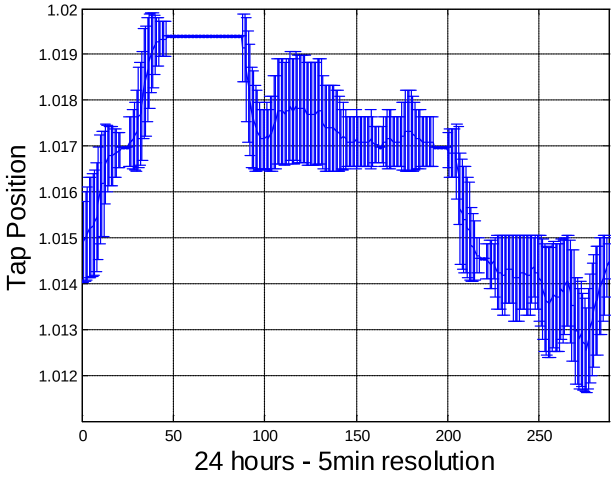

Figure 35: Average +/- one standard deviation for the OLTC operation – EV scenario

3.2.3.2 OLTC – Remote Control

The remote control approach requires a communication system between the OLTC and the node or nodes to be controlled. Basically, the main idea is to keep the voltages in the network within the EN50160 standard by using the measurements received from monitors located along the network to control the OLTC operation.

In [20], the control strategy for the OLTC is based on the measurements received from two locations in the network where maximum and minimum voltage deviation were expected. In contrast, the utilisation of two points per feeder (head of the feeder and remote end) and not per network is presented in [19]. These two works analyse only PV panels for different scenarios in a deterministic way (location of PV and size is known). In comparison, the approach proposed in this project is probabilistic. Therefore, to be able to run one hundred simulations per penetration level and to incorporate the OLTC remote control strategy, a simplified algorithm is adopted. Here, only the voltage in the furthest customer in the longest feeder of the network is monitored and used for controlling the OLTC operation. This approach could not take full advantage of the OLTC capabilities but it represents the natural midterm step after the implementation of the OLTC with busbar control (more communication systems imply more investment for the system). Thus, the potential benefits of this control strategy are analysed in this section.

Figure 36 presents the percentage of customers with voltage problems after the OLTC operation with remote control in the PV scenario. This figure indicates that the voltage problems start only at 80% of penetration level in comparison with 40% for the business as usual case. Again, reduction of the magnitude of the problems is observed. In fact, customers with voltage problems completely disappeared in feeder 1. In addition, these problems are in average below 6% of the customers at 100% of penetration level in feeders 2 and 3.

As in the busbar control case, with the OLTC remote control the voltage problems for the EV scenario are also overcome. Indeed, for the network under analysis, the basic OLTC configuration (without communication infrastructure) is good enough to enable a larger penetration level of EV.

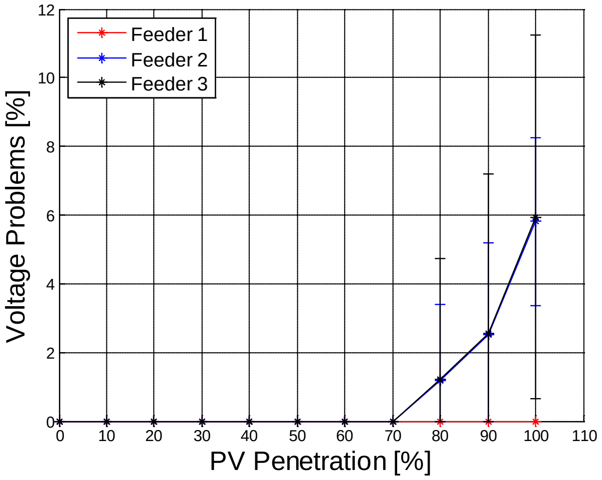

Figure 36: Percentage of customers with voltage problems for the OLTC case (remote control) PV scenario

3.2.3.3 *Comparison: Local and Remote control*

With the proposed methodology it was possible to technically quantify the benefits associated to the use of an OLTC transformer in a real LV distribution network. In particular, the OLTC with busbar control was enough to solve the voltage problems in every single feeder due to electric vehicles.

With photovoltaic panels, the voltage problems were delayed from 40% of penetration level in the base case to 60% in the case with OLTC and busbar control, and to 80% with remote control. Additionally, the percentage of customers with problems in each penetration level was smaller in the OLTC with remote control.

It is important to highlight that the results also show that staged investments can be done in networks with progressive penetration of PV panels. Indeed, in an earlier stage, only the investment in the OLTC with local control is enough to increase the PV penetration level. Further installations of PV panels can then trigger at some point the need for the remote control strategy and, hence, the corresponding communications infrastructure.

4 Economic Assessment

From the technical perspective, the two solutions proposed in this report: loop operation of LV feeders and utilisation of OLTC-fitted transformers, can indeed increase the penetration of low carbon technologies in LV networks. To understand when these alternatives are cost-effective, this chapter presents an economic comparison between the proposed solutions versus the network reinforcement cost for all of the penetration levels analysed.

4.1 Reinforcement Cost

The network reinforcement is the traditional approach used by DNOs to face the load growing. Basically, this consists in the replacement of conductors for bigger ones in order to supply the load without violating the thermal rating of the cables. This solution can also be implemented to solve voltage problems, in the sense that a bigger cable will have lower resistance and therefore will produce smaller voltage drop/rise. For that reason, this could be understood as the business as usual approach to tackle the impacts of low carbon technologies (either generation or load) in LV distribution networks.

With the purpose of assessing the cost of this alternative, a simplified network reinforcement tool is implemented in this report. This methodology calculates the investment cost (investment plus installation) required to enable certain penetration level of one particular low carbon technology. Hence, it is possible to determine the reinforcement cost for each of the simulations implemented in the Probabilistic Impact Assessment Methodology presented in Chapter 2.2.

The main steps in the reinforcement cost algorithm for each simulation per feeder are:

1. Determination of all the customers with voltage problems (e.g., red circles in Figure 37) according to BS EN 50160 [10].
2. Identification of the worst location, defined as the customer with higher voltage deviation (either voltage rise or voltage drop).
3. Identification of the main path, this is the route between the transformer and the worst location (e.g., green line in Figure 37). The main path is divided in segments of 100 metres.
4. The first segment (100m) is replaced by the next (larger) conductor size available (e.g., red line in Figure 37).
5. A new power flow is run and the voltages are checked.
    a. If there are still voltage problems and:
        i. If there are more feasible cables, go to step 4.
        ii. If there are not more feasible cables, go to step 4 but for the next segment (next 100m).
    b. If there are no more problems or the main path was entirely replaced go to step 6.
6. The thermal problems are checked for each cable. Those with thermal problems are replaced by a conductor with the minimum size for the rating required.

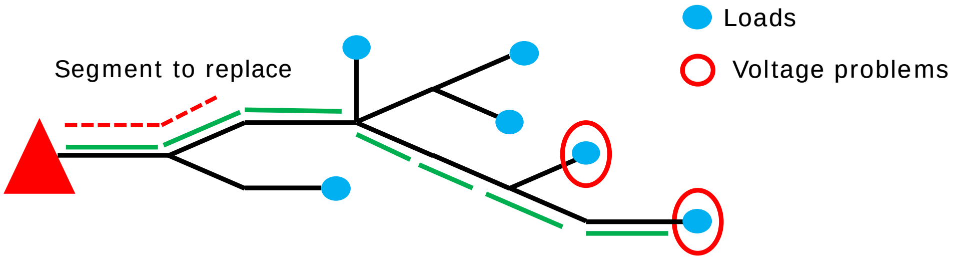

Figure 37: Visualisation of the main components in the reinforcement algorithm

This simplified reinforcement tool only analyses the replacement of conductors along the main path. Because of this in some of the simulations the voltage problems might not be completely solved. To quantify this phenomenon, the percentage of customers with voltage problems after the reinforcement is also calculated. The remaining customers with voltage problems are presented for the loop connection and OLTC alternatives in the next subsection; in both cases these problems can be neglected.

The installation plus investment cost used in this analysis corresponds to the average value presented in [21] for the UK DNO Electricity North West Limited. This value is equal to £140/m for the main cables and £80/m for the service cables, both for urban areas.

In order to get representative results, the reinforcement tool is applied for each simulation at each penetration level for the two solutions proposed in this report. Consequently, the total average reinforcement cost (aggregation of reinforcement feeder costs) +/- one standard deviation for each penetration level is determined in each of them.

4.2 Loop Operation: Economic Assessment

The results after the application of the reinforcement algorithm in the network with the loop operation strategy (Figure 5) are presented in this section. It is important to remark that the reinforcement algorithm was applied to the radial configuration (business as usual) for the network under analysis.

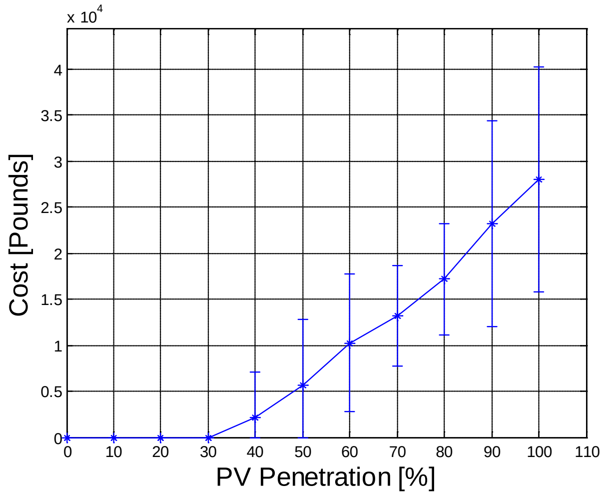

Figure 38: Reinforcement Cost – Base Case for Loop Operation

Figure 38 presents the total network reinforcement cost (adding up individual feeder costs) to ensure the different PV penetration levels. Thus, the average reinforcement cost is about £10,000 at 60% of penetration level and about £29,000 at 100% of penetration level. In this case, it is also important to note that there are cases with a required cost higher than £40,000. It is worth mentioning that in the analysis, the PV penetration was assumed the same among feeders. This means that 20% of penetration level implies that each feeder has 20% of penetration level (same percentage of houses with PV units, although the size and generation could be different since the Monte Carlo approach implemented).

To put these numbers in context, one should consider that ENWL own about 35,000 LV networks. Therefore, for an average reinforcement cost of £29,000 per substation for 100% of penetration level, ENWL would need to invest about £1 billion on cables if PV is to be adopted by all customers (this number could be even higher as will be observer in the next section). Technically feasible alternatives to avoid this massive cost, include those presented in the previous section of this report.

To compare the reinforcement cost with the loop operation strategy, the following costs have been provided by ENWL:

Equipment Type	Voltage Level	Assumptions	Unit Costs	Installation Costs	Total
Link Box	LV	Replacement or new link boxes to create mesh points from Network Studies	£ 650	£ 1,298	**£ 1,948**
Link box Switch	LV	3 for every link box or mesh point (assume 1 link box for every 2 LV feeders)	£ 2,000	£ 135	**£ 2,135**
Gateway		1 per every 3 link box switches plus 1 per distribution substation	£ 1,250	£ 135	**£ 1,385**
Circuits breakers (Weezap)	LV	3 for every LV feeder	£ 4,500	£ 135	**£ 4,635**
Joints	LV	2 Joints required for each new link box	£ 100		**£ 100**
Cable	LV	Assume 10m per new link box + extra for interconnection points from Mark's work	£ 17		**£ 17**
Monitoring	LV	1 every five LV feeders. Measuring the most electrically remote point from each distribution substation	£ 2,205	£ 2,100	**£ 4,305**

Table 3: Cost of Meshing (Smart Street Project)

From Table 3, it is possible to quantify the elements needed to implement the connection between only two feeders and also the meshed connection of the entire network. It is important to highlight that the equipment from this table is related to the project Smart Street that envisages the remote reconfiguration of networks. These are innovative devices and hence expensive at this stage.

For the connection of two feeders, the elements considered are:

- Link box : 1
- Link box switch : 1
- Gateway : 1/3
- Circuits breakers : 2
- Joints : 1
- Cable : 1

Since the gateway is shared between three link box switches, one third of the cost is allocated in this case. The monitoring cost is not considered because this was not included in the reinforcement cost, in this way a fairer comparison is possible. Consequently, the total cost for the connection between two feeders is £13,931. On the other hand, in the case of meshed operation, the following elements are considered:

- Link box : 4
- Link box switch : 4
- Gateway : 1
- Circuits breakers : 4
- Joints : 4
- Cable : 4

For comparison purposes, the monitoring was not considered in this case. Thus, the total cost for the meshed network operation is £36,724. It is worth mentioning that the costs of meshing presented here are based on new technologies in terms of its applicability to LV networks, and therefore is expected that these costs would be reduced in the future once they become part of the business as usual practice inside the DNO.

These meshing costs can be compared with the reinforcement cost presented in Figure 38 for the network under analysis (Figure 5). From there, it is possible to observe that the entire meshed operation is more expensive than the average reinforcement cost for any penetration level. Only at 100% of penetration level, there are some scenarios where the cost of meshing is cheaper than the network reinforcement. In the case of two-feeder connection, the cost of meshing is more competitive, presenting some advantage over the reinforcement. In fact, the average reinforcement cost is more expensive than the two-feeder connection from 70% to 100% of penetration level.

In order to set the comparison framework, these numbers should take into account the results from the Probabilistic Impact Assessment presented in Section 3.1. That analysis established that the occurrence of the first technical problems in the radial operation (without any loop) happens at 40% of penetration level for the network studied. By doing the connection between feeder 4 and 3, this limit value is delayed to 70% of penetration level. Therefore, the two-feeder connection solves the problems for 40%, 50% and 60% of penetration level. Nonetheless, it is precisely in these cases where the average reinforcement cost is cheaper than the two-feeder connection alternative. For that reason, to ensure a cost-effective implementation of the meshing for this network, a cost reduction should be expected. This does not imply that in other networks, the cost of reinforcement will be higher than the two-feeder connection. For instance, in the network used for the OLTC analysis, the reinforcement cost is more expensive than the two-feeder connection for almost every penetration level with problems (Figure 39).

One way to reduce the cost of meshing is by avoiding the use of a circuit breaker in the loop connection. In fact, the circuit breakers are the most expensive part in the cost structure presented in Table 3, so if these devices are replaced by fuses, then the two-feeder connection cost decreases to £4,661. Thus, the loop connection will be cheaper than the average reinforcement cost for almost every penetration level with problems (from 50% to 100% of penetration level) and even at 40% of penetration level there are several cases with the same cost relationship. Nonetheless, the implementation of fuses instead of circuit breakers can decrease some reliability indexes at low voltage level and therefore a quantification of these effects is needed. This point will be explored by the authors of this report in the future.

4.3 OLTC-Fitted Transformer: Economic Assessment

The results after the application of the reinforcement algorithm in the network with the OLTC control (Figure 28) are presented in this section. Figure 39 and Figure 40 show the cost for the PV and EV scenarios, respectively. From these figures, it is possible to observe that the reinforcement cost needed for ensuring a given penetration level in the PV scenario is much higher than in the EV scenario. For example, the average network reinforcement cost (investment plus installation cost) at 100% penetration level is around £7,000 in the EV scenario and above £90,000 in the PV scenario.

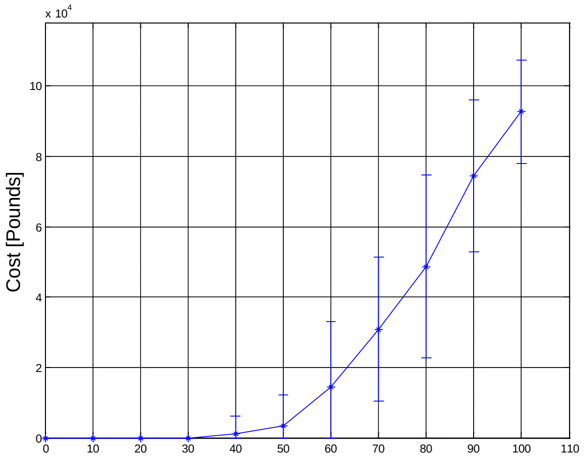

Figure 39: Reinforcement Cost – PV Scenario (Base case for OLTC)

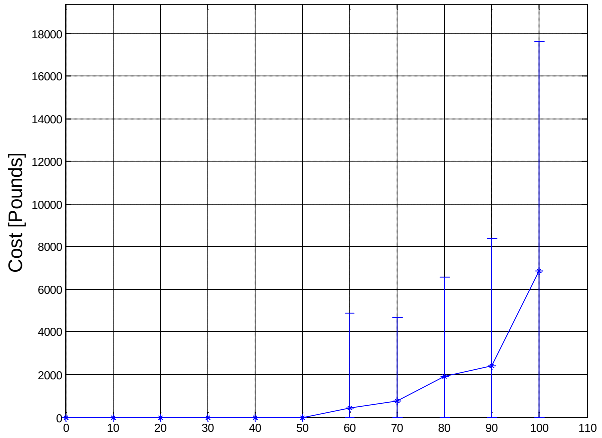

Figure 40: Reinforcement Cost – EV Scenario (Base case for OLTC)

After the application of the reinforcement algorithm, the remaining nodes with voltage or thermal problems are identified. In almost every simulation at each penetration level the network problems were completely solved with the proposed methodology. Only in feeder 3 for the PV scenario, after the reinforcement algorithm, 4 customers remained with voltage problems in one of the simulations at 90% of penetration level.

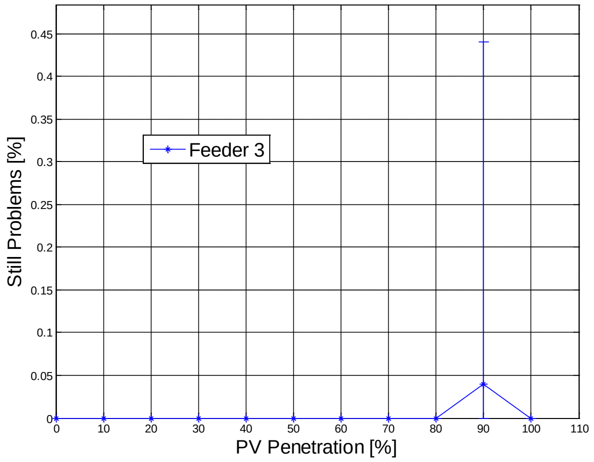

Figure 41: Remaining problems – PV Scenario

The current investment cost (equipment plus installation) for a HV/LV OLTC is approximately £36,000 [22]. This represents 3 to 4 times the cost of a traditional HV/LV transformer (typically between £8,000 and £10,000). For simplicity, the cost (capital and operational) associated with the monitoring of the remote point (i.e., OLTC with remote control) is not considered in the following analysis.

The cost of an OLTC transformer can be compared with the network reinforcement cost calculated and presented in this section. It is important to remark that no financial or load/generation growth considerations were taking into account in the simplified reinforcement algorithm developed; only the equipment plus installation cost required for one specific penetration level was calculated. Thus, the reinforcement cost presented is the cost required to assure a given penetration level without considering future installations of load and/or generation.

In Figure 39, there are several PV penetration levels where the reinforcement cost is lower than the OLTC cost. Indeed, from 10% to 70% of PV penetration level the average reinforcement cost is lower than the OLTC. Furthermore, from 10% to 60% the average reinforcement cost plus one standard deviation is lower than the OLTC cost.

By comparing this reinforcement cost with the business as usual case (Figure 29) and with the OLTC local control and the OLTC remote control cases (Figure 33 and Figure 36, respectively) for the PV scenario, it is possible to get some interesting results for the network under analysis. First of all, if the penetration level is up to 50%, the network reinforcement is the cheapest option. Secondly, if the penetration level is 60% or 70%, then in most of the cases the reinforcement cost is cheaper than the OLTC with local control. Only in some cases (2% and 15% of the cases for the 60% and 70%, respectively) the OLTC is cheaper than the reinforcement. Nonetheless, for these penetration levels, the busbar control is not enough for solving all of the problems and therefore a remote control is needed. Thirdly, above 70% of penetration level, the reinforcement cost is more expensive than the OLTC approach (even if some communication costs are incorporated) and, therefore, the proposed intelligence in the OLTC control should be improved in order to cope with the highest penetration levels. This could be achieved through additional communication systems and/or incorporating state estimation in the LV network. Related approaches are investigated in the project “Low Voltage Integrated Automation (LoVIA)” also run by ENWL.

These results indicate that if the DNO expects a lower penetration level in one particular network (e.g., physical constraints such as house orientation, available roof surface for the installation of PV panels or socioeconomic limitations), the reinforcement of the network is cheaper than the OLTC option. In contrast, if the DNO expects a higher PV penetration level (larger than 60% in the network under analysis) or if the DNO wants to be prepared for the 100% of penetration level, then the OLTC is cheaper than the network reinforcement cost. Furthermore, if the DNO wants to be prepared for the 100% penetration level and this level is expected to be reached gradually, then the investment in communication system and the incorporation of more sophisticated control algorithms for the OLTC can be done progressively with the penetration level. Finally, the OLTC cost is more expensive than the network reinforcement cost for each penetration level in the EV scenario (Figure 40) for the network studied.

5 Conclusions

In this report, two alternatives to increase the penetration of low carbon technologies (LCT) in low voltage distribution networks have been explored. This work has demonstrated the value and applicability of the Probabilistic Impact Assessment Methodology introduced in Deliverable 3.6 "What-if Scenario Impact Studies based on real LV networks". Indeed, this approach is not only useful to assess the impacts of LCT but also to investigate the benefits of potential solutions. The main findings from this report are presented below.

Loop Operation of Feeders: PV Case

- Regarding to the solutions implemented in this report, two cases were examined in the loop connection alternative: loop connection between two feeders and meshed operation (i.e., multiple loops at the same time). In the first one, potential connections between sets of two feeders were explored one by one. It was found that looped feeders 'share' the utilisation of the cables, helping decongest the more impacted one. In some cases, utilisation was reduced as much as 20-30% of the corresponding total capacity. More importantly, in all cases, the occurrence of voltage problems was also 'delayed', i.e., appeared only at higher PV penetration levels. In some cases, voltage problems were delayed as much as 30-40% of total PV penetration. However, it was also clear that due to the differences among the feeders (i.e., topology, impedance, length, and customers) the extent of the benefits differ. In the meshed operation, with every link between feeders connected simultaneously, the network's ability to host PV was also improved, but reaching the same level as one of the loop connections.
- These results show that the loop connection improves the utilisation of the network and its ability to host larger volumes of PV generation (most of the problems are 'delayed' to higher penetration levels). The degree of the benefits, however, depends on their particular characteristics. Consequently, more detailed studies are needed to determine the best connection points in each particular LV network. Further aspects, such as reliability and losses might also be important to understand in future studies.

OLTC-Fitted Transformers: PV and EV Cases

- The results indicate that the OLTC operation can improve the hosting capacity of the network. Indeed, the voltage problems are delayed from 40% of PV penetration level without OLTC to 60% in the case with OLTC and busbar control for the examined network. This figure increases to 80% in the case with remote control. These findings also highlight the possibility to make staged investments (OLTC with local control, then remote control) in networks with progressive PV penetration. For the EV case, all the voltage problems were solved with the OLTC (local control) in the network analysed.

Comparison with Traditional Reinforcements Cost

- With the purpose of studying the economic viability of the solutions proposed, a simplified network reinforcement algorithm was implemented. The idea behind the elaboration of this methodology was to compare the business as usual approach taken by DNOs to solve problems in their networks (reinforcement) with the two solutions proposed in this report. The investment analysis suggests that for smaller penetration levels the reinforcement cost is cheaper than the OLTC and loop connection approaches. This is driven mainly because the novelty of the solutions implemented and therefore the corresponding (high) cost. It is expected that a future reduction in cost will create a business case for their implementation.

The above studies considered even penetrations of LCT among the feeders. While this potentially neglects scenarios in which the OLTC-fitted transformer cannot provide benefits, it also may have underestimated the benefits from the loop operation of LV feeders.

Finally, it is important to highlight that although the alternatives analysed in this report are important examples, they are not the only LV network solutions available to DNOs. Solutions to LV network problems are still being developed. Indeed, the analysis in this project has and is leading into further work in other projects with Electricity North West, .e.g., "Low Voltage Integrated Automation (LoVIA)", "Smart Street".

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