**Title:** Work Activity 2 “Low Voltage Networks” - Report for Deliverables 2.1, 2.2, and 2.3

**Synopsis:** This document describes the methodology used to process, correct, and translate GIS-based data corresponding to Northern Powergrid and Scottish and Southern Energy LV networks into OpenDSS. The methodology to analyse these LV network models is also presented, including basic time-series simulations. A literature review on EV modelling and charging management is also provided. Finally, an updated EV impact assessment on some of the LV networks is carried out.

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Executive Summary

This report corresponds to Deliverables 2.1, 2.2 and 2.3 “Low Voltage Networks” part of the GB Ofgem’s Low Carbon Network Fund Tier 2 project “My Electric Avenue” (MEA) run by EA Technology Ltd.

The aim of the MEA project is to implement and evaluate the performance of an innovative, cost-effective operational approach to control the charging points at which electric vehicles (EVs) are connected to: the low voltage (LV) distribution networks. This will allow more EVs to be connected to LV networks without the need of traditional reinforcement, thus deferring investment.

This operational approach is to be implemented in nine LV residential feeders, which are to be modelled in the open source distribution network analysis software package OpenDSS.

The following points are discussed within this report:

- Translation of network data from Northern Powergrid (NP) and Scottish and Southern Energy (SSE) into OpenDSS;
- Creation of non-validated computer-based models of monitored LV networks ready to be used for planning studies; and,
- Review of available data and techniques to model EV loads including an initial assessment for load shifting.

All of the above points have been thoroughly examined in this report. From this study, the following points can be highlighted:

Translation into OpenDSS

- The CSV files corresponding to the four NP LV feeders that are involved in the MEA project have been successfully translated into OpenDSS. The remaining feeders connected to each of the four substations have also been translated into OpenDSS.
- The GIS files corresponding to the five SSE LV feeders that are involved in the MEA project have been processed. Although some issues with the network data have been found, initial LV feeder models have been successfully created in OpenDSS. Feedback from SSE will be used to adopt adequate assumptions to improve the network data.

Computer-Based LV Network Models

- Computer-based models have been created for the LV networks that belong to NP. These models can now be used for planning studies.
- Computer-based models, considering the available data, have also been created for the LV feeders that belong to SSE. These models will be improved with feedback from SSE.

Literature Review on EV Modelling and Charging Management

- A thorough review has been carried out to examine the approaches that have been investigated in the literature for EV modelling. This review also shows the different EV projects that have taken place worldwide. It was found that complex optimization techniques have been used but primarily in medium voltage networks. In addition, none of them have actually studied the effects that the proposed control strategies have in customers.

EV Impact Analysis

- Time-series simulations of non-validated LV networks presented in Work Activity 1 have been updated to consider more accurate load modelling and more effective impact metrics. These simulations do confirm that technical problems (i.e., congestion and voltage drops) might occur for high EV penetration levels. In addition, in some cases, significant voltage drops could occur before congestion problems.
# Table of Contents

## Executive Summary ........................................................................................................... 2

1  Introduction .......................................................................................................................... 4

2  NP and SSE Network Data ..................................................................................................... 5
   2.1  Northern Powergrid (NP) Networks ............................................................................... 5
   2.1.1  Network and Feeder Identification ............................................................................. 8
   2.1.2  Creation of Line Segments ........................................................................................ 8
   2.1.3  Connectivity Issues and Network Reconnection ....................................................... 8
   2.1.4  Other Issues Identified in the CSV Files ..................................................................... 9
   2.2  Scottish and Southern Energy (SSE) Feeders ............................................................... 9
   2.2.1  Network and Feeder Identification ............................................................................ 10
   2.2.2  Important Issues within the GIS files from SSE ....................................................... 11
   2.2.3  Creation of Line Segments ....................................................................................... 15
   2.2.4  Connectivity Issues and Feeder Reconnection ......................................................... 16
   2.2.5  Other Issues Identified in the GIS Files ..................................................................... 17

3  Translation of Network Data into OpenDSS ......................................................................... 18
   3.1  OpenDSS Characteristics ............................................................................................. 18
   3.2  OpenDSS Representation .............................................................................................. 19

4  Creation of Computer-Based Models .................................................................................. 22
   4.1  Network Data and Assumptions .................................................................................... 22
   4.2  Residential Load Profiles ............................................................................................. 22
   4.3  OpenDSS Files ............................................................................................................. 22
   4.4  Simulation Results – Time-Series Power Flow Analyses ............................................ 23
   4.4.1  Cleadon Manor Feeder .............................................................................................. 23
   4.4.2  Gosforth Audley Feeder .......................................................................................... 24
   4.4.3  Valley Lane East Feeder ........................................................................................... 24
   4.4.4  Wylam Dene Feeder ............................................................................................... 24

5  Review of EV Modelling and Charging Management ............................................................ 27
   5.1  Background ................................................................................................................... 27
   5.2  EV Modelling ............................................................................................................... 27
   5.3  EV Charging Management ........................................................................................... 28
   5.4  Comparison of EV Trials .............................................................................................. 28

6  Updated EV Impact Analysis on LV Feeders ......................................................................... 31
   6.1  Introduction ................................................................................................................... 31
   6.1.1  Load Profiles .......................................................................................................... 31
   6.1.2  Electric Vehicle Profiles .......................................................................................... 31
   6.2  Impact Assessment on an LV Feeder – Cleadon Manor LV Feeder ............................... 32
   6.3  Multi-Feeder Analysis .................................................................................................. 32
   6.4  Transformer Analysis ..................................................................................................... 33

7  Conclusions ........................................................................................................................... 36

8  References .............................................................................................................................. 37
1 Introduction

In order to reduce greenhouse gas emissions by 2020 and beyond, the UK requires the decarbonisation of the entire energy system. Critical to this goal is the electrification of transport, particularly in the form of domestic-scale electric vehicles (EVs). The uncontrolled charging of EVs, however, might lead to technical impacts (low voltages and asset congestion) on the very infrastructure they will be connected to: the residential low voltage (LV) networks.

In order to cope with these challenges, EA Technology, Scottish and Southern Energy Power Distribution (SSEP), and other Partners are involved in the “My Electric Avenue” (MEA) project (submitted and reported to Ofgem as “Innovation-Squared: Managing Unconstrained EV Connections”), which is funded through Ofgem’s Low Carbon Networks Fund Tier 2. The University of Manchester is also part of this project providing independent network modelling and analysis of the trial data.

The MEA project aims to implement and evaluate the performance of an innovative, cost-effective operational approach (i.e., the ESPRIT Technology) to control the EV charging points in the LV distribution networks. This will allow more EVs to be connected to LV networks without the need of traditional reinforcements, thus deferring investment.

This report focuses on the following Deliverables:

- Deliverable 2.1 “Translation of network data from Northern Powergrid (NP) and Scottish and Southern Energy (SSE) into OpenDSS”
- Deliverable 2.2 “Creation of non-validated computer-based models of monitored LV networks ready to be used for planning studies”
- Deliverable 2.3 “Review of available data and techniques to model EV loads including an initial assessment for load shifting”

For Deliverable 2.1, this report presents a meticulous analysis of the data received about the LV feeders that are monitored as part of the MEA project. Moreover, it details the methodology to translate the CSV and GIS files corresponding to NP and SSE, respectively, into the open source distribution network analysis software package OpenDSS.

For Deliverable 2.2, this report details the deterministic methodology to create computer-based models using OpenDSS and MATLAB, as well as demand and EV profiles based on the literature. These realistic models are used to evaluate the potential impacts of different EV penetration levels.

For Deliverable 2.3, this report provides a thorough review on EV load modelling as well as EV charging management schemes available in the literature, including academic papers and industrial reports.

This report also presents updated time-series EV impact analyses of non-validated LV networks (initially provided in Work Activity 1). These analyses consider more accurate load modelling and more effective impact metrics.
2  NP and SSE Network Data

The MEA project involves 9 LV residential feeders and 2 LV business feeders. Due to the difficulties in monitoring the latter, it has been agreed to focus on the residential ones. From the 9 LV residential feeders, 4 belong to NP and 5 to SSE.

Prior to the translation of network data into OpenDSS, and the creation of computer-based models of the LV feeders, it is important to analyse the available information. This is needed to ensure that the necessary data is provided. Thus, this section presents an analysis of the network data that The University of Manchester has received corresponding to the LV feeders involved in the MEA project.

2.1  Northern Powergrid (NP) Networks

The data of the 4 LV residential feeders that belong to NP have been facilitated to The University of Manchester via EA Technology in the form of comma separated value (CSV) files. It is considered that these CSV files are the result of a pre-analysis performed by EA Technology from GIS files.

It is important to mention that the CSV files contained, for each monitored feeder, the information of all the other feeders connected to the same substation, i.e., the data of each substation (not only the monitored feeder) can be translated into OpenDSS. The CSV files included information of the following 4 substations: Cleadon Manor, Gosforth Audley, Valley Lane East and Wylam Dene. The nominal capacity of these substations is 1000, 750, 500, and 500 kVA, respectively.

Figure 1 and Figure 2 respectively show the network and customer attributes that are included within these CSV files. Among all the features, the following ones are particularly important for the LV modelling, i.e., to create the computer-based models: substation ID, feeder ID, cable section ID, cable section usage, point order, XY coordinates of each node, cable type, conductor, No. of cores, and type of customer, i.e., Profile Class 1 or 2 (PC1 or PC2, according to Elexon’s classification [1]).

![Graphical representation of the network attributes](image)

**Figure 1. Example of the network attributes**

Since the data received contained the XY coordinates of each node, as well as the point order, it was possible to plot using MATLAB the topology of each network. It was also possible to identify the number of customers per feeder and their geographical position, as their XY coordinates were given.

A graphical representation of these LV networks also eases the identification of connectivity issues. Figure 3-Figure 6 show the topology of these LV networks. Additionally, Table 1-Table 4 present the number of customers connected per feeder and the length of the corresponding feeder (without service cable/with service cable). It should be mentioned that some of these LV networks contain photovoltaic panels, which are also considered when creating the computer-based models.

Even though the data received was very detailed, a few issues (connectivity issues and lack of data), which are detailed in the following section, were identified. The final assumptions are detailed in the next section based on feedback received from EA Technology.
Figure 2. Example of the customer attributes

Figure 3. Topology of the Cleadon Manor LV network

Table 1. Total length and number of customers per feeder in the Cleadon Manor LV network

<table>
<thead>
<tr>
<th>Feeder</th>
<th>1 (blue)</th>
<th>2 (black)</th>
<th>3 (red)</th>
<th>4 (green)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Customers</td>
<td>54</td>
<td>9</td>
<td>36</td>
<td>64</td>
</tr>
<tr>
<td>Total Length (m)</td>
<td>418 / 1099</td>
<td>140 / 264</td>
<td>244 / 825</td>
<td>406 / 1237</td>
</tr>
</tbody>
</table>

Figure 4. Topology of the Gosforth Audley LV network
Table 2. Total length and number of customers per feeder in the Gosforth Audley LV network

<table>
<thead>
<tr>
<th>Feeder</th>
<th>1 (blue)</th>
<th>2 (black)</th>
<th>3 (red)</th>
<th>4 (green)</th>
<th>5 (Cyan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Customers</td>
<td>136</td>
<td>57</td>
<td>81</td>
<td>62</td>
<td>92</td>
</tr>
<tr>
<td>Total Length (m) (without and with service cable)</td>
<td>706 / 2737</td>
<td>670 / 1449</td>
<td>987 / 1910</td>
<td>966 / 1766</td>
<td>476 / 1645</td>
</tr>
</tbody>
</table>

Figure 5. Topology of the Valley Lane East LV network

Table 3. Total length and number of customers per feeder in the Valley Lane East LV network

<table>
<thead>
<tr>
<th>Feeder</th>
<th>1 (blue)</th>
<th>2 (black)</th>
<th>3 (red)</th>
<th>4 (green)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Customers</td>
<td>91</td>
<td>61</td>
<td>114</td>
<td>49</td>
</tr>
<tr>
<td>Total Length (m) (without and with service cable)</td>
<td>1275 / 2834</td>
<td>556 / 1371</td>
<td>755 / 2546</td>
<td>537 / 1377</td>
</tr>
</tbody>
</table>

Figure 6. Topology of the Wylam Dene LV network

Table 4. Total length and number of customers per feeder in the Wylam Dene LV network

<table>
<thead>
<tr>
<th>Feeder</th>
<th>1 (blue)</th>
<th>2 (black)</th>
<th>3 (red)</th>
<th>4 (green)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Customers</td>
<td>44</td>
<td>72</td>
<td>56</td>
<td>50</td>
</tr>
<tr>
<td>Total Length (m) (without and with service cable)</td>
<td>266 / 943</td>
<td>813 / 1988</td>
<td>371 / 1055</td>
<td>306 / 1089</td>
</tr>
</tbody>
</table>
2.1.1 Network and Feeder Identification

The CSV files include the substation ID, feeder ID and cable section ID. This information is important to identify not only the feeders connected to the same substation, but also the customers connected to each feeder. Indeed, Figure 3-Figure 6 show in different colours the feeders connected to the corresponding substation. Additionally, Table 1-Table 4 show the number of customers per feeder.

2.1.2 Creation of Line Segments

Given the XY coordinates of the nodes, and having identified the feeders connected to each substation, it was possible to create line segments that will represent the information of the cable to be modelled for each feeder. For example, the main section of the cable for the first feeder connected to Cleadon Manor substation contains 99 line segments that vary from 0.2 m to 13 m.

2.1.3 Connectivity Issues and Network Reconnection

Every line segment in the feeder has to be connected if power flow studies are to be carried out. To check the connectivity of the feeders, the connected components of each feeder needed to be found. A connected component of a graph is a subgraph in which vertices are connected to each other by paths (by definition one connected component is not connected to another connected component).

In only three cases (Cleadon Manor, Gosforth Audley and Valley Lane East), one of the main feeders was split into two (e.g., feeder 4 in Figure 3). During a discussion held with EA Technology, it was agreed to consider that both ends of the main cable are connected by a segment of cable whose type corresponds to the same cable from the conductor immediately upstream. Thus, the topology of the “modified” Cleadon Manor LV network is shown in Figure 7.

![Figure 7. Topology of the “modified” Cleadon Manor LV network](image)

**Connectivity issues between service cable and main cable:** Connection problems in the scale of millimetres between many service cables and the main section of the cable were also found. For example, one point of the service cable and the main cable seemed to be connected but in reality they were separated by less than 1 mm. This case is illustrated in Figure 8(a).

Basic analytical geometry was implemented to solve these connectivity issues. Thus, the intersection between the given service cable and the nearest main cable was determined. This intersection was defined as a new vertex, which corresponds to the connection point of the service cable on the main cable. Figure 8(b) shows the result of this solution applied to the example given in Figure 8(a). As it can be noted, the service cable is now connected to the main cable, and this will allow the creation of computer-based models to analyse these 4 LV networks.

It is important to mention that the connectivity issues described above were successfully solved for the 4 LV networks that belong to NP. Indeed, Figure 7 shows for the Cleadon Manor network that all the service cables are now connected (little black squares) to the corresponding main cable.
2.1.4 Other Issues Identified in the CSV Files

The data received about the LV networks that belong to NP presented other minor issues that were also discussed with EA Technology. These issues and the agreed solutions are detailed below.

- **Service cable type**: The cable type of the service cables was not given. Hence, it was filled by using the most common service cables for single-phase customers, i.e., 25 mm² XLPE.
- **Phase connection**: The phase connection was not specified in the CSV files. Thus, loads are randomly allocated to phases; each phase has the same probability to be selected.
- **Three-phase cables**: In few cases, the main cable type was unknown. The line will take always the information from the conductor immediately upstream. If the line upstream does not have one, the process follows with the next line upstream.

2.2 Scottish and Southern Energy (SSE) Feeders

The data of the 5 LV residential feeders that belong to SSE have been provided to The University of Manchester by SSE in the form of GIS (shape) files (extensions: .SHP, .SHX, .DBF). The data have been provided in 5 different ‘folders’. Each one contains multiple shape files representing the features of many LV distribution feeders that are geographically close to the one involved in the MEA project. This information is read using ARCGIS 10, which is available at The University of Manchester.

The GIS files within each folder mainly provided information of the following substations: Clydesdale Road, Corney Road, Cufaude Village, Forest Edge and Ryans Mount. The nominal capacity of these substations was not given. Figure 9 shows the visualisation of these GIS files.

The data received have been processed and the following information has been found: substation name, cable section usage, cable type, conductor, and No. of cores. Figure 10 shows an extract of the network attributes table of the LV feeders that are within the Clydesdale Road folder. As it can be noticed, some information about the cables (e.g., cable type) can be obtained from these files.

Nonetheless, other necessary information for modelling the LV feeders, such as feeder ID, service cables, and number of customer and their class profile (e.g., PC1 or PC2), has not been given within these files. These and other issues found within the GIS files are detailed in sections 2.2.2 and 2.2.5.

It is important to mention that SSE has separately provided the customer class profiles in an Excel file. An extract of this is shown in Figure 11. This Excel file contains the number of customers connected to all the feeders per substation. Since SSE later provided the feeder number that is being monitored, the number of customers and their corresponding class profile could be extracted for each feeder. Table 5 details this information. As it can be observed, most of the monitored feeders are residential and mainly with PC1 customers. These data will be used to create computer-based models.
2.2.1 Network and Feeder Identification

Due to the lack of feeder ID, the identification of the LV feeders that are monitored as part of the MEA project and belong to SSE was carried out by visually cross checking GIS data and PDF maps provided by EA Technology. Feedback from SSE was also used for this. For example, Figure 12(a) shows the PDF received from EA technology, and Figure 12(b) highlights the monitored feeder connected to the Clydesdale Road substation that was identified from the GIS data. A similar approach was used for all the other folders. The topologies of the 5 LV feeders that are involved in the MEA project and belong to SSE are shown in Figure 13.
2.2.2 Important Issues within the GIS files from SSE

After identifying the monitored feeders, their topology and the available information were analysed. There was a number of issues within the original data (GIS files) that needed to be solved prior to the translation of the network data into OpenDSS. These issues (basically the extracted data did not represent the actual LV feeder) are detailed below for those LV feeders with problems.

- **Clydesdale Road feeder**: The topology of this LV feeder is shown in Figure 13(a). This topology (extracted from the initially provided GIS files) was then compared to the actual (expected) topology shown in the PDF file received from EA Technology (see Figure 14).

Since the topology of this LV feeder (Figure 13(a)) was found to be different to its actual topology (Figure 14), SSE provided new GIS files about this feeder. When these new GIS files were received, it was then possible to obtain the topology shown in Figure 15. The new GIS files were found to contain the basic information to create a computer-based model of this LV feeder. Nonetheless, another issue (difference between the number of service cables and the number of customers) was later found. This issue is further detailed at the end of this section.
Figure 12: Clydesdale Road feeder

Figure 13: Topology of the 5 LV feeders involved in the MEA project that belong to SSE
- **Corney Road Feeder:** The topology of this LV feeder is shown in Figure 13(b). The topology of this feeder (extracted from the provided GIS files) was then compared to the actual (expected) topology shown in the PDF file received from EA Technology (see Figure 16).

As it can be noticed, the extracted topology (Figure 13(b)) indicates that the main cable is split into two cables near to the transformer (the black triangle), supplying thus a set of customers that are not shown in the corresponding PDF file (Figure 16). Feedback from both SSE and EA Technology suggested that this LV feeder had been reconfigured for the purposes of the MEA project. Thus, the final topology of this LV feeder is shown in Figure 17.

![Figure 14: Topology of Clydesdale Road feeder provided by EA Technology](image)

- **Forest Edge:** The topology of this LV feeder is shown in Figure 13(d). As it can be noticed, the information provided within the first GIS files about this LV feeder is very limited. Therefore, SSE provided new GIS files for this LV feeder. When the new GIS files were received, it was then possible to obtain the topology shown in Figure 18. The new data also allow the identification of overhead line segments (black colour), the cables (blue colour) and service cables (red colour). The new GIS files were found to contain the basic information to create a computer-based model of this LV feeder. Nonetheless, differences between the number of service cables and number of customers were also found. This is also detailed at the end of this section.
Figure 16: Topology of Corney Road feeder provided by EA Technology

Figure 17: Main topology of the monitored LV feeder connected to Corney Road substation

Figure 18: Main topology of the monitored LV feeder connected to Forest Edge substation
**Service cables and number of customers:** The number of the service cables (at the end of which customers will be connected) per feeder was extracted from the GIS files. This value was then compared to the number of customers per feeder shown in Table 5. Table 6 summarises the results for the 5 monitored LV feeders that belong to SSE.

### Table 6. Number of service cables and customer for the SSE LV networks

<table>
<thead>
<tr>
<th>Feeder name</th>
<th>Number of service cables</th>
<th>Number of customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clydesdale Road</td>
<td>34</td>
<td>59</td>
</tr>
<tr>
<td>Corney Road</td>
<td>81</td>
<td>239</td>
</tr>
<tr>
<td>Cufuade Village</td>
<td>56</td>
<td>125</td>
</tr>
<tr>
<td>Forest Edge</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>Ryans Mount</td>
<td>54</td>
<td>54</td>
</tr>
</tbody>
</table>

As it can be observed, most of the LV feeders contain more customers than service cables. This indicates that there are many services cables that were not given within the GIS files (SSE informed that a large number of service cables are not mapped within their GIS system). This could also happen if multiple customers live in the same address (block of flats).

Since the XY coordinates of the customers connected to each monitored LV feeder were not given (feedback from SSE suggested that they are unknown), SSE provided on August 7, the address of the customers (street name and postcode along with their MPANs) to identify their geographical position. An extract of these data is not shown due to confidentiality reasons.

This file was then used to identify the location of the customers that were not provided within the GIS files (using mapping tools such as Google Maps), define their XY coordinates, and trace a service cable from the defined location to the nearest point across the main cable.

However, in multiple cases the GIS files showed that a customer was connected to the monitored LV feeder, but the address of this was not included within the Excel file. In other cases, the data provided in the Excel file indicated that a house was connected to the monitored feeder, but the GIS files showed that this house was connected to a different one.

To exemplify these issues, the Clydesdale LV feeder shown in Figure 19 is used. The blue square shown in Figure 19 highlights a house that, based on the GIS files, is connected to this feeder. Nonetheless, the address of this house (12 Hanoverian Way) is not included within the Excel file. Similarly, the house highlighted in green in Figure 19 (12 Burmese Close) is included within the Excel file, but this house appears to be connected to another feeder (not shown in the GIS files).

These issues (found in the 5 LV networks that belong to SSE) were reported to SSE. Feedback received from SSE on August 19 suggested that both files (the GIS files and the Excel file) must be used to overcome the anomalous information that can be found within the files, as both files are indeed prone to errors/lack of information. Since this feedback was recently received, the creation of the final computer-based models is still work in progress.

### 2.2.3 Creation of Line Segments

Having identified the monitored feeder and solved most of the issues with the GIS files, another problem associated with the data structure within ARCGIS was found: the polyline representation of lines.

To create line segments for the data corresponding to the SSE LV feeders, the polyline representation of the lines in ARCGIS needs to be changed. The GIS files deal with a large amount of information by using the concept of polyline to store the data. A polyline is a continuous line comprised by one or more line segments. This is treated as a single object within the GIS file and, therefore, there is no direct visualisation of the coordinates associated with a polyline. For example, the polyline in Figure 20 is represented by just one row in the attributes table (Figure 10), and this row has just the coordinates for the source point and end point of the polyline, which is not enough to build the electrical model.
To have access to all the segments of the polyline it is necessary to implement a procedure in ARCGIS 10, which uses functions available in ARCGIS and is detailed below:

1. Split polyline to segments: The polyline is divided into segments. Each of them contains the whole information of the polyline, which means if the polyline has a “feature A”, each segment has the same “feature A”.

2. Split segments to vertices: This function indicates the vertices of each segment previously determined.

3. Add XY coordinates to each vertex: This function includes the coordinates of each vertex for each segment of the polyline.

Figure 21 shows the application of the previous procedure over one LV feeder (Cleadon Manor feeder). The points indicate the position of the vertices of each segment. As it can be seen, the amount of data to be managed increases significantly (the polyline is divided into segments).

2.2.4 Connectivity Issues and Feeder Reconnection

It must be mentioned that connectivity issues were not found for the LV feeders that belong to SSE. Nonetheless, other issues (lack of data) found within the GIS files are explained in section 2.2.5.
The network identification and the creation of line segments were implemented for the other 4 LV feeders that belong to SSE. Hence, it was possible to identify the 5 LV feeders that are involved in the MEA project and belong to SSE. The topology of these feeders was shown in Figure 13. The main cable is shown in blue colour and the service cables in red colour.

2.2.5 Other Issues Identified in the GIS Files

- **Service cable type**: The characteristics of the service cable, when provided in the GIS files (see Figure 10 for an example), could be extracted. Nonetheless, in a few cases the cable type information was not given. For these cases, the cable type of the service cables was filled by using the most common service cables for single-phase customers, i.e., 25 mm² XLPE.

- **Phase connection**: The available information about the phase connection in the GIS files is indicated by R (red), Y (yellow) and B (blue) for the single-phase cables (see Figure 10 for an example). However, there are a few cases where the codes are not specified. For these cases, the phase connection is randomly allocated to one phase; each phase has the same probability to be selected.

- **Three-phase cables**: In few cases, the main cable type was unknown (see Figure 10 for an example). The line will take always the information from the conductor immediately upstream. If the line upstream does not have one, the process follows with the next line upstream.
3 Translation of Network Data into OpenDSS

Once the feeders are identified and the network topology is totally connected, the next step to be able to run power flow simulations is to translate the processed information into the OpenDSS format. The proposed methodology builds on previous work carried out at The University of Manchester (“LV Network Solutions Project” [2]).

3.1 OpenDSS Characteristics

OpenDSS [3] is an open source software package to solve power flows, harmonics analysis and fault current calculations in electrical distribution systems. This computational tool was developed by the EPRI (USA) to help the analysis associated with distributed generation. This software is able to solve unbalanced network and it can be driven from other software, such as VBA or MATLAB.

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. This is important to quantify the impacts of intermittent sources (PV, micro-CHP, micron-wind turbines, etc.) and loads (EV, EHP etc.) on distribution networks. A visualisation of the software can be observed in Figure 22.

Figure 22: OpenDSS Visualisation

OpenDSS does not have a graphic interface. Instead, it uses its own programming language and each element must be incorporated by following certain instructions and codes. For example, Figure 24 summaries the OpenDSS codes for the small network presented in Figure 23.

Figure 23: OpenDSS Visualisation [2]
Consequently, to effectively use OpenDSS in this project it is necessary to translate the database files (after the application of the reconnection methodology) to OpenDSS format.

3.2 OpenDSS Representation

The typical structure for OpenDSS models is one master file that commands the reading and the executing of the rest of the files. These files are:

- **Transformers**: this file has the technical information about the transformer.
- **Linecode**: this file has the technical information for each conductor.
- **Lines**: this file contains the information about the sending and receiving node, as well as the length and type of conductor for each line.
- **Monitors**: this file allows monitoring and storing electrical parameters over time.
- **Loadshapes**: this file has the variation of load profile for different type of customer.
- **Loads**: this file specifies the load (and load profile) associated with each customer.

Therefore, the files presented above need to be built for each LV network/feeder. This process needs to be automatic to quickly carry out the analyses. The flow chart of the corresponding automatic process is shown in Figure 25.

---

**Figure 24: OpenDSS Visualisation [2]**

**Figure 25: Automatic translation into OpenDSS [2]**

From Figure 25 it is possible to note that the information to build the OpenDSS files comes from different sources. The technical information comes from the CSV and GIS files received from EA Technology and SSE, respectively. The topology information (connection between lines and vertices) comes from the database after the application of the reconnection methodology, if this is necessary.
The load information will be created using the CREST tool or similar tools. As detailed in section 4.1, this tool is used to generate a realistic pool of profiles that are allocated at customer nodes to model their demand.

These profiles will be allocated to the different MPANs (Meter Point Administration Number) that are part of a given LV network. It must be mentioned here that MPANs have been given for all the customers connected to the monitored feeders.

With the topology information, the technical data, the profiles information and the relationship between the MPAN and the adopted load profiles, it is now possible to create an automatic process to translate all the data into OpenDSS code. The files created in an automatic fashion for each feeder are:

- **Lines.txt**: After the application of the reconnection methodology, the precise connection between vertices is known. The type of cable and the distance between two nodes is known from the database. With this information the line file is created in MATLAB and the result is saved as a TXT file (OpenDSS can read files from this format). Figure 26 illustrates the line files in OpenDSS format.

  ![Figure 26: Example of line file](image)

- **Loads.txt**: This file indicates to which bus the loads are connected, the type of load (single-phase or three-phase), the nominal voltage and the power factor. Additionally, this file incorporates an important part to execute time-series analyses: the load shape (load profile) associated with each load. Here, only the load shape names are provided, their characteristics are indicated in a different file (Loadshapes.txt). All these properties are from the original files received from EA Technology and SSE and from the relationship between MPANs and load profiles. They are automatically written in OpenDSS format.

- **LoadShapes.txt**: This file provides the electrical behaviour of one load along a given period. In this report, that period corresponds to one day with 1-minute resolution. Each profile is located in one TXT file. Figure 27 illustrates the load shape file in OpenDSS format.

- **LineCode.txt**: This file includes the network parameters. The name of these conductors is the same name used in the Lines.txt file. Figure 28 shows the line code file in OpenDSS format.

- **Monitors.txt**: This file indicates the position where the monitors are located. The technical information from the network (i.e., voltages, currents, active power, etc.) can be obtained just in the locations with monitors. Therefore, the automatic process allocates monitors at least in each costumer to check the voltage profiles and in the main lines to check thermal limits.
Figure 27: Example of load shape file

Figure 28: Example of line code file
4 Creation of Computer-Based Models

Computer-based models have been created for the 4 LV networks that belong to NP and for the 5 LV feeders that belong to SSE. This section details the creation of these models. The computer-based models for the 5 LV feeders that belong to SSE are preliminary models that will be improved when all the aforementioned issues (section 2.2.5) are solved.

4.1 Network Data and Assumptions

The network data come from CSV and GIS files. The data within these CSV and GIS files have been described and analysed in detail in section 2. The network data have been processed and segments have been reconnected to translate the CSV and GIS files into OpenDSS (see section 3). The network used as an example is the Cleadon Manor network that belongs to NP. The topology of this network was shown in Figure 7. It has four feeders, about 473 line segments, a total length of 3.43 km and 163 customers. The characteristics for each particular feeder were presented in Table 1.

Due to the big amount of information associated with LV networks and the challenge that is to have a perfect GIS management system for LV networks, some information is missing in the files received by The University of Manchester. Therefore, with the purpose of completing that information the assumptions described in section 2 were considered. These are summarised below:

- **Phase connection**: When the phase connection of the service cable was provided, this was allocated to the applicable phase. Nonetheless, the phase connection of a service cable was randomly allocated (each phase with the same probability to be selected) when no information about the phase connection was indicated.

- **Service cable type**: In multiple cases, information about the cable type was not given for service cables. The conductor information was filled by using the most common service cable for single-phase customers, i.e., 25 mm² XLPE.

- **Three-phase cables**: For the three phase cables without conductor information, the line will always take the information from the conductor immediately upstream. If the line upstream does not have one, the process follows with the next line upstream.

- **Impedance**: To allocate the impedance values for each conductor, the characteristics of each cable are obtained from manufacture’s manuals. However, it is not always possible to identify which conductor in the CSV and GIS files corresponds to which conductor in the manuals. To overcome this issue, the size of the cable is used, and the most common cable for the same size is chosen.

- **Monitor placement**: ‘Measurements’ for the simulations will be taken from the transformer, the head of each feeder, and the customer nodes.

4.2 Residential Load Profiles

The load behaviour of customers in the circuit was not available. Therefore, the time-series behaviour of the domestic loads are created using the CREST tool [4]. This tool creates computational profiles for residential loads based on the domestic behaviour of British costumers; it takes into account the number of people at home, the type of day, the month, and the use of the appliances. In this way, it is possible to have one minute resolution profiles, indicating which appliance is on and how much power it is using. This tool is used to generate a pool of profiles that are randomly allocated at customer nodes to model their demand at each simulation. Figure 29 and Figure 30 show examples of individual load profiles and the diversified demand from 1000 load profiles, respectively.

4.3 OpenDSS Files

As it was detailed in section 3, the translation of the network data into OpenDSS was successfully achieved for the NP networks. The OpenDSS files for the SSE LV feeders were also translated, but this translation will be undertaken again as a few issues were found in the data.
The created OpenDSS files are used to produce the corresponding computer-based models. As previously explained, the main stages of this process are: feeder identification, creation of the line segments, topology reconnection and the representation in OpenDSS. The feeder/network identification, the creation of the line segments and the topology reconnection was described above. In addition, the representation of the network data in OpenDSS was given in section 3.2.

4.4 Simulation Results – Time-Series Power Flow Analyses

This section presents time-series power flow simulations using the created computer-based models for the 4 NP LV networks. It is important to mention that these results only show the time-series power flow results, in the base case (without EVs), for the monitored feeders. Section 6.3 summarises the potential impacts (for penetration levels from 0% to 100%) for all the feeders (a total of 17) that belong to NP. The analyses are done for only those feeders that belong to NP, as the models for the SSE feeders need to be improved. In each simulation a domestic profile from a predefined pool is allocated to each customer to model its demand. The granularity used is one minute, so the number of periods during a single day is 1440. The results presented below consider a line-to-line voltage of 416 V at the secondary of the distribution transformer (which is aligned with UK practice).

4.4.1 Cleadon Manor Feeder

The feeder topology and the transformer location (black triangle) are shown in Figure 31. The aggregated demand in this feeder is shown in Figure 32, the peak demand is 72.6 kVA and the minimum demand during the night time period is around 8 kVA. The number of customers in this feeder is 54, so the diversified peak demand is approximately 1.34 kVA and occurs around 7pm.
important to observe that the diversified peak demand is smaller than the real peak demand observed in the most remote load, which is above 12 kVA and occurs at a different time.

4.4.2 Gosforth Audley Feeder

The feeder topology and the transformer location (black triangle) for the Gosforth Audley feeder are shown in Figure 33. The aggregated demand in this feeder is shown in Figure 34, the peak demand is 70.3 kVA and the minimum demand during the night time period is around 8 kVA. The number of customers in this feeder is 57, so the diversified peak demand is approximately 1.23 kVA and occurs around 8am. It is important to observe that the diversified peak demand is smaller than the real peak demand observed in the most remote load, which is above 14 kVA and occurs at a different time.

4.4.3 Valley Lane East Feeder

The feeder topology and the transformer location (black triangle) for the Valley Lane East feeder are shown in Figure 35. The aggregated demand in this feeder is shown in Figure 36, the peak demand is 83 kVA and the minimum demand during the night time period is around 9 kVA. The number of customers in this feeder is 61, so the diversified peak demand is approximately 1.36 kVA and occurs around 7:30pm. It is important to note that the diversified peak demand is smaller than the real peak demand observed in the most remote load, which is above 3.5 kVA and occurs at a different time.

4.4.4 Wylam Dene Feeder

The feeder topology and the transformer location (black triangle) for the Wylam Dene feeder are shown in Figure 37. The load aggregated in this feeder is shown in Figure 38, the peak demand is 77
kVA and the minimum demand during the night time period is around 9 kVA. The number of customers in this feeder is 72, so the diversified peak demand is approximately 1.07 kVA and occurs around 5:30pm. It is important to note that the diversified peak demand is smaller than the real peak demand observed in the most remote load, which is above 2.5 kVA and occurs at a different time.

![Figure 33: Visualisation of the Gosforth Audley LV feeder](image)

![Figure 34: Load Profile at the head of the feeder (left) and most remote load (right)](image)

![Figure 35: Visualisation of the Valley Lane East LV feeder](image)
Figure 36: Load Profile at the head of the feeder (left) and most remote load (right)

Figure 37: Visualisation of the Wylam Dene LV feeder

Figure 38: Load Profile at the head of the feeder (left) and most remote load (right)
5 Review of EV Modelling and Charging Management

5.1 Background

According to the Climate Change Act 2008 [5], the UK must reduce its greenhouse gas emissions by at least 80% by 2050 compared to 1990 levels. Total UK emissions must be decreased by 34% by 2020 to help EU-wide target of 20% reduction in emissions. This target could rise to 42%, if the EU-wide 2020 target increases to 30%, after suggestions made by the UK Committee on Climate Change.

To help achieve these 2020 and 2050 targets, the adoption of domestic electric vehicles (EVs) in the UK is expected to increase in the near future [5]. Even though the estimate number of EVs in the UK is uncertain yet, international reports estimate that, under a moderate evolution, the proportion of EVs will be 35% of total vehicles by 2020. This increases up to 51% between 2030 and 2040, and to 62% of total vehicles by 2050 [6, 7].

However, the uncontrolled charging of these EVs might lead to technical impacts on the very infrastructure they will be connected to: the residential low voltage (LV) networks. Indeed, part of the electricity demand from high penetrations of EVs is likely to be coincident with the peak demand of households, resulting thus in significant stress on the LV networks [8-11]. Although this depends on the penetration level of EVs and the characteristics of the corresponding LV network (topology, size, etc.), significant asset congestion (transformers and cables) and voltage drops might occur.

5.2 EV Modelling

Before any analysis is carried out, the EV charging demand needs to be adequately modelled. This demand depends on the initial battery state of charge (SOC), the charging characteristics (slow or fast), and the start charging time. Since the adoption of EVs is still evolving, reliable data to adequately model their demand is limited.

Many researchers have extrapolated the results from travel surveys, which consider customers’ driving patterns on traditional cars (Internal Combustions Engine, i.e., ICE), to study the potential demand from EVs [10, 12-16]. These studies determine from the travel surveys the home arrival time to define the start charging time, and the travel distance to estimate the SOC at the start charging time. The initial SOC is related to the energy that will be required to fully charge the EV.

The main assumption made by the works that use these travel surveys is that customers will behave similarly when they will be using an EV. Most of these studies have also assumed that a significant number of customers will tend to connect their EV once they arrive at home – potential incentives to shift the start charging time are mentioned as well in these works. Finally, all these studies have assumed that customers will remain at home after returning from work, i.e., they do not consider that users could need their EV in a few minutes or hours after work to start a new journey.

Although the statistics from the use of ICE cars provide a good insight of how customers could use their EV, it is known that the driving patterns due to the new technology may dramatically change. In this context, the data from these surveys may underestimate or overestimate the demand from EVs.

Other studies have used the information collected during trials to derived statistical distributions for the start charging time, the initial SOC or the energy demanded during a reconnection [17]. This approach could significantly help to understand customers' behaviour with the new technology. Nonetheless, a large number of samples (EVs and reports from customers’ travels) are needed to ensure a minimum degree of confidence in the data.

Based on the above, the use of information from EV trials will result in the most accurate EV modelling since this will realistically represent the behaviour of EV users.
5.3 EV Charging Management

To cope with the potential negative impacts of EVs on distribution networks, different ways to manage EV charging demands (also called smart charging [18]) have been investigated in recent years [8-11, 15, 19-23]. In general, these and similar studies propose the use of complex optimization approaches (e.g., dynamic programming [11], linear programming [19, 21], mix-integer linear programming [22], receding-horizon optimization techniques [23, 24], sequential quadratic programming [15], etc.) that require extensive information/visibility of the network (e.g., voltages and currents), the EVs (e.g., state of charge), and, in many cases, the electricity market (e.g., real-time pricing).

The aforementioned requirements make such approaches difficult to be implemented by Distribution Network Operators (DNOs) given that in practice real-time data is limited and many interoperability challenges still need to be addressed [25].

A large number of the studies available in the literature aim to minimise network losses [19, 21]. However, this particular objective fails to address the actual challenge faced by DNOs which is to facilitate EV adoption without affecting customer satisfaction (in terms of charging times).

Other important number of studies are focused on resolving the aggregated impact of a large population of EVs on Medium Voltage (MV) distribution networks [22, 26] without quantifying the effects on LV networks – which are likely to be the first bottleneck as customers will connect their vehicles at home [27].

A few studies considering LV networks have been carried out adopting benchmark networks [11, 20] that may not reveal the particularities that can be found in real LV networks [28]. Some of the few studies that have been undertaken considering real networks, indeed they are trials, are summarised in Table 7.

Finally, and very important for the MEA project, the charging strategies available in the literature do not assess the effect that the control algorithm might have on customers. For instance, charging EVs at slower rates (i.e., applying a power cap) or frequently disconnecting EVs can result in charging times much longer than those expected by the customers. This impact assessment, critical to the performance of a charging management scheme, has not been studied in the past and can help accelerating the adoption of EVs.

Table 7. Summary of some studies that considered real networks

<table>
<thead>
<tr>
<th>Ref. No.</th>
<th>Main Topic</th>
<th>Real Network</th>
<th>Demand Response</th>
<th>Direct Load Control</th>
<th>Charging Status</th>
<th>Time Period</th>
<th>Time Interval</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>[21]</td>
<td>Maximising the total EV charging energy</td>
<td>Dublin, Ireland</td>
<td>No</td>
<td>Yes</td>
<td>Charging at a lower rate</td>
<td>22pm-7am</td>
<td>15 min</td>
<td>Voltage, Overloading</td>
</tr>
<tr>
<td>[29]</td>
<td>Demonstrating EV charging management capability</td>
<td>Victoria’s Smart Grid</td>
<td>Yes</td>
<td>Yes</td>
<td>None-charging for Emergency Scenario; Half-charging for Peak Charge Scenario</td>
<td>Monday – Thursday 7pm-10pm</td>
<td>1 min</td>
<td>Overloading</td>
</tr>
<tr>
<td>[30]</td>
<td>Coordinating with DNO and electrical retailers to optimise the EV charging</td>
<td>Danish Island of Bornholm</td>
<td>Yes (limited)</td>
<td>Yes</td>
<td>Deferring charging</td>
<td>Daily</td>
<td>15 min</td>
<td>Voltage, Power</td>
</tr>
</tbody>
</table>

5.4 Comparison of EV Trials

Multiple EV trials have already been undertaken, and there are many others that are under way. This section summarises those projects. The comparison of these trials is illustrated in Table 8.

The trial that took place in Dublin [17, 21] involved three stages: (i) investigation of the potential impacts, (ii) examination of basic control charging techniques, and (iii) investigation of the effects of

1 “Smart charging refers to a controlled charging process that optimises the use of the grid and the available electrical energy to minimise additional investments in the grid and facilitate the integration of RES”
network reconfiguration. During the trial, electric vehicles were driven and charged by typical residential electricity customers. The data recorded during the trial details the charging patterns of the vehicles and the associated effects on the network.

Table 8. Comparison of Current Electric Vehicle Trials

<table>
<thead>
<tr>
<th>Ref. No.</th>
<th>Trial Name</th>
<th>Size</th>
<th>Main Objective</th>
<th>Term Time</th>
<th>EV Type</th>
<th>Demand Response</th>
<th>Direct Load Control</th>
<th>Main Collaboration Parties</th>
</tr>
</thead>
<tbody>
<tr>
<td>[21]</td>
<td>The Great Electric Drive</td>
<td>19 people and two companies</td>
<td>To gain better insight in the driving patterns, charging requirements and the drivers’ needs</td>
<td>2012-2013</td>
<td>Nissan LEAF IMiev Kangoo</td>
<td>No</td>
<td>Yes</td>
<td>ESB ecars</td>
</tr>
<tr>
<td>[29]</td>
<td>Victorian EV Trial</td>
<td>$5 m 120 households</td>
<td>To understand the process, timelines and barriers for transitioning to EV technologies</td>
<td>Oct. 2010 – Mid 2014</td>
<td>IMiev, Nissan LEAF</td>
<td>Yes</td>
<td>Yes</td>
<td>Victorian Government RACV DIUS Computing Mitsubishi Nissan Toyota</td>
</tr>
<tr>
<td>[31]</td>
<td>EDISON</td>
<td>350 EVs</td>
<td>To manage, balance and predict the impact of EVs to the electric grid</td>
<td>2009-2012</td>
<td>Battery models (Limited)</td>
<td>Yes</td>
<td></td>
<td>Danish Ministry for Climate and Energy IBM Denmark DONG Energy University of Denmark</td>
</tr>
<tr>
<td>[32]</td>
<td>Low Carbon London</td>
<td>£30 m 50 EVs</td>
<td>To understanding how and when people use electricity to charge EVs</td>
<td>2012-2014</td>
<td>Nissan LEAF</td>
<td>Yes</td>
<td>No</td>
<td>Transport for London SIEMENS Imperial College London</td>
</tr>
<tr>
<td>[33]</td>
<td>CABLED</td>
<td>£25 m 110 EVs</td>
<td>To understand how EVs are used and assist in the planning of the further expansion of the supporting infrastructure</td>
<td>Jul. 2009-Jun. 2012</td>
<td>IMiev, Benz/smart, Tata etc.</td>
<td>No</td>
<td>No</td>
<td>Technology Strategy Board West Midlands Coventry University University of Birmingham Aston University</td>
</tr>
<tr>
<td>[34]</td>
<td>Switch EV</td>
<td>44 EVs</td>
<td>To assess the EV battery performance; To establish people’s existing and changing perceptions of EVs</td>
<td>Sep. 2010 – May 2013</td>
<td>Nissan LEAF</td>
<td>No</td>
<td>No</td>
<td>Technology Strategy Board Nissan Newcastle University</td>
</tr>
<tr>
<td>[35]</td>
<td>Smart Move EV Trial</td>
<td>264 drivers involved</td>
<td>To quantify the effect of range anxiety on vehicle usage patterns</td>
<td>Sep. 2009-Apr. 2011</td>
<td>Smart, IMiev</td>
<td>No</td>
<td>No</td>
<td>Genex Millbrook Proving Ground Cranfield University Newcastle University</td>
</tr>
</tbody>
</table>

The “Electric vehicles in a Distributed and Integrated market using Sustainable energy and Open Networks” (EDISON) trial [31] aimed to balance the supply of electricity generated from wind farms through the use of EVs. This trial introduced a fleet operator to aggregate the consumption of a number of EVs and handle their interactions with the electricity market, i.e., the EVs were under centralised/direct control. The control philosophy also considered the participation of EV users by taking the users’ trip information into account, i.e., by forecasting the use of EVs.

The “Low Carbon London” trial [32] monitored EV customers’ charging behaviour to determine how the electricity network can be developed to support the increasing numbers of EVs. This trial offered financial incentives to customers to modify the customer demand during peak hours. Demand response contracts are established with industrial and commercial customers to learn to what extent different demand response initiatives can influence customers to minimise periods of peak demands.

The “Coventry and Birmingham Low Emission Demonstrators” (CABLED) and “Switch EV” trials also aimed to investigate how EVs are used by customers [33], [34]. Data on vehicle performance, infrastructure usage patterns, impacts and requirements with a minimum of 12 months of seasonal conditions were collected so that a successful production launch of ultra-low-carbon vehicles could be conducted and the associated infrastructure could be developed.

The “Smart Move EV” trial aimed to quantify the effect of range anxiety on vehicle usage pattern [35]. It was shown from the drive data that range anxiety effects were significant throughout the trial with 93% of journeys commencing with over 50% battery SOC. Users modify their driving style when battery SOC reduces below 50%.
The aforementioned trials aimed to investigate the EV usage patterns. They also examine how these usage patterns impact the electricity grid. Nonetheless, none of them explored the impact that both the actual use of the EVs and the control techniques to manage technical issues on the network can have on customers. Increasing customer’s satisfaction could potentially improve EVs uptake levels. Hence, when managing the EV charging, it is critically important to evaluate customers’ satisfaction. Indeed, this factor represents an important and significant different of the MEA project over other trials.
6 Updated EV Impact Analysis on LV Feeders

6.1 Introduction

The impact analyses on the created computer-based models are part of future Work Activities, more specifically WA3. Nonetheless, this section updates the results of the impact analysis presented in the Work Activity 1 “Evaluation of the initial trial” - Report for Deliverables 1.1, 1.2, and 1.3. This is done to update the potential impacts of different EV penetration levels on these non-validated networks.

This update considers more accurate load modelling and more effective impact metrics. In particular, PC2 customers are also modelled. The CREST tool has also been updated (version 1.0B [4]) to cater for more realistic PC1 customers. In addition, voltage compliance with the British Standard BS EN50160 is also considered in the impact analysis.

6.1.1 Load Profiles

The load behaviour of customers in the monitored LV networks is not available. Therefore, the time-series behaviour of the domestic loads are created using the CREST tool [4] for a winter weekday (worst case).

6.1.2 Electric Vehicle Profiles

The time-series behaviour of the EVs are obtained using the statistical analysis reported by an Irish trial [17]. The main information used for the creation of EV profiles is presented in Figure 39. The first one – Figure 39(a) – presents the probability distribution function (PDF) of connection times, i.e., when the EVs are connected to the charging point. The second one – Figure 39(b) – shows the PDF of energy required for each vehicle during each connection period.

The original probabilities of the connection times are shifted here three hours earlier to create a higher coincidence with the peak demand in the UK (~7pm) [36]. This allows investigating further stresses on the LV networks during peak hours. Furthermore, the energy demanded during a connection is used to determine the duration of the EV connected to the LV network. This takes into account the charging capacity (a normal single-phase connection is limited by 16 A). Indeed, the EV used in the simulations is based on a real EV: the Nissan Leaf used in the MEA project, with a battery of 3kW and 24 kWh.

![Figure 39: PDFs of (a) EV connection times and (b) daily EV energy requirement](image)

The EV battery charging process is assumed to be continuous, i.e., once it starts, it will stop until the battery stops withdrawing power (e.g., user disconnects the vehicle or battery is fully charged). It is assumed that there is a maximum of one EV per household despite the number of residents. Thus, taking into account the EV chosen and the two probability distributions it is possible to create EV profiles to be used in the impact assessment. Some examples are presented in Figure 40. These
profiles show different lengths and starting points due to the different energy requirements and connection times of each car.

Figure 40: Example of individual EV profiles

6.2 Impact Assessment on an LV Feeder – Cleadon Manor LV Feeder

The Cleadon Manor LV feeder that is monitored in the MEA project was illustrated in Figure 31. This feeder is used in this section to present the electrical variables (current and voltages) for the base case. It is also used to illustrate the impact assessment of the worst case (all customers with a car). The granularity used in the simulations is one minute.

It must be mentioned that the cable type of this feeder, which feeds 54 customers, is a 300 Wavecon, which means that the cable capacity is approximately 360 A. The results presented below consider a line-to-line voltage of 416 V at the secondary of the distribution transformer (which is aligned with UK practice).

It is also worth mentioning that the voltage range tolerance is +10%/-6% [37]. Furthermore, the European standard EN50160 [38] is used here to define if customer has a voltage problem.

Figure 41 shows the current at the head of the feeder and the voltages at both the head and remote end of the feeder for the base case, i.e., without EVs. As it can be noticed, the feeder operates without any technical problem. It can also be observed that the available headroom is significant, and hence, this particular feeder is expected to withstand a large number of EVs, e.g., a 100% penetration level.

Indeed, it can be observed in Figure 42 that even for a 100% EV penetration level, the current at the head of the feeder is still lower than the cable capacity (360 A). Furthermore, it can also be noted that significant voltage drops may not be obtained even for the customer connected at the far end of the feeder.

Even though this particular feeder does not present technical problems (neither low voltages nor overloads), even for a 100% penetration level, it is important to note that the voltage at the remote end of the feeder and the current at the head of the feeder are significantly affected by large EV penetration levels. This means that for similar high penetrations other monitored LV feeders could be negatively impacted, increasing thus the likelihood of low voltages and congestion problems. This is further discussed in the next section.

6.3 Multi-Feeder Analysis

The impact assessment previously implemented is useful for understanding the behaviour of one particular feeder under different penetration levels of EVs. Nonetheless, the lessons obtained from one feeder cannot be necessarily extrapolated to a different one. Two feeders can present different technical problems at different EV penetration levels. For this purpose, all the feeders from the 4 LV
networks that belong to NP are analysed in this section to assess the impacts from EVs. This corresponds to a total of 17 feeders out of which 4 are actually monitored as part of the MEA project.

The number of feeders that presents voltage and/or thermal problems for each EV penetration level is illustrated in Figure 43. As it can be observed, overloads (thermal problems) may occur for penetration levels larger than 30%.

This does not necessarily mean that the monitored feeders are the ones with problems. More importantly, Figure 43 shows that three feeders are likely to face voltage problems for high penetration levels. Figure 44 finally shows the occurrence of the first problem for each penetration level. As it can be observed, voltage issues may occur first for a considerable number (40%) of feeders.

Figure 41: Electrical variables for the Cleadon Manor LV feeder for 0% penetration

6.4 Transformer Analysis

The penetration of EV in LV networks could also affect the HV/LV substation. Thermal problems can be faced at the transformer level. Therefore, the power flows for each of the simulations among the feeders that belong to the same substation are aggregated, i.e., each feeder has the same EV penetration. Then, the corresponding maximum hourly power flow is compared with the rating (nominal rating) of each of the 4 substations under analysis. Figure 45 indicates the number of substations overloaded for each EV penetration level. It can be seen that thermal problems may occur for penetration levels larger than 40% in one substation (Valley Lane East).
Figure 42: Electrical variables for the Cleadon Manor LV feeder for 100% penetration

Figure 43: Feeders with technical problems per penetration level (out of 17)
It is important to highlight that the use of cyclic ratings could provide more headroom for the transformer. Nonetheless, given that this and similar ratings consider specific demand profile characteristics, further analyses are needed to ensure their applicability.

Figure 44: Occurrence of the first problem

Figure 45: Transformers with thermal problems per penetration level
7 Conclusions

This report corresponds to Deliverables 2.1, 2.2 and 2.3 “Low Voltage networks” part of the GB Ofgem’s Low Carbon Network Fund Tier 2 project “My Electric Avenue” (MEA) run by EA Technology Ltd.

The aim of the MEA project is to implement and evaluate the performance of an innovative, cost-effective operational approach to control the charging points at which electric vehicles (EVs) are connected to: the low voltage (LV) distribution networks. This will allow more EVs to be connected to LV networks without the need of traditional reinforcements, thus deferring investment.

The following Deliverables are discussed within this report:

**Deliverable 2.1 “Translation of network data from Northern Powergrid (NP) and Scottish and Scottish and Southern Energy (SSE) into OpenDSS”**
- The CSV files corresponding to the four NP LV feeders that are involved in the MEA project have been successfully translated into OpenDSS. The remaining feeders connected to each of the four substations have also been translated into OpenDSS.
- The GIS files corresponding to the five SSE LV feeders that are involved in the MEA project have been processed. Although some issues with the network data have been found, initial LV feeder models have been successfully created in OpenDSS. Feedback from SSE will be used to adopt adequate assumptions to improve the network data.

**Deliverable 2.2 “Creation of non-validated computer-based models of monitored LV networks ready to be used for planning studies”**
- Computer-based models have been created for the LV networks that belong to NP. These models can now be used for planning studies.
- Computer-based models, considering the available data, have also been created for the LV feeders that belong to SSE. These models will be improved with feedback from SSE.

**Deliverable 2.3 “Review of available data and techniques to model EV loads including an initial assessment for load shifting”**
- A thorough review has been carried out to examine the approaches that have been investigated in the literature for EV modelling. This review also shows the different EV projects that have taken place worldwide. It was found that complex optimization techniques have been used but primarily in medium voltage networks. In addition, none of them have actually studied the effects that the proposed control strategies have in customers.

In addition to the previously described Deliverables (2.1, 2.2, 2.3), this report has been extended with updated time-series simulations that aimed to assess the potential impacts (thermal or voltage problems) of different EV penetration levels on the available (non-validated) LV networks that are involved in the MEA project (part of Work Activity 3).

- These simulations highlighted that the four monitored feeders of NP may not present technical problems for high penetration levels. Nonetheless, the other feeders within the same LV networks could present both thermal and voltage problems for penetration levels higher than 30% (30% of the customers with an EV). Finally, it was also found that three transformers are likely to be overloaded due to high EV penetration levels. These results will be further discussed in following reports.
8 References


