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Title: **Dissemination Document “Low Voltage Networks Models and Low Carbon Technology Profiles”**

Synopsis: This is a companion document to the low voltage network models and the low carbon technology profiles available on www.enwl.co.uk/lvns. These have been developed as part of the Low Carbon Network Fund Tier 1 project “LV Network Solutions” run by Electricity North West Limited (ENWL) and The University of Manchester from 2012 to 2014.

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1 Introduction

This report is a companion document to the low voltage network models and the low carbon technology profiles available on www.enwl.co.uk/lvns. These network models and profiles have been developed as part of the Low Carbon Network Fund Tier 1 project “LV Network Solutions” run by Electricity North West Limited (ENWL) and The University of Manchester from 2012 to 2014.

The main objective of the LV Network Solutions project was to provide ENWL with greater understanding of the characteristics, behaviour, and future needs of their low voltage distributions networks, analysing the capabilities of ENWL networks to host new low carbon technologies, studying the penetration levels (% of houses with a particular technology) that trigger power quality problems (mainly voltage and asset overloading) and analysing new strategies, technologies and policies to increase the penetration level of low carbon technologies minimising the impacts on LV networks.

To achieve the above objective, the utilization of realistic LV networks and LCT profiles was crucial. However, such models were not available at the beginning of this project to implement the corresponding assessment. Particularly, Distribution Network Operators (DNOs) do not, in general produce these models at this voltage level mainly because of the historic passive nature of LV circuits and the assumption that demand (size and behaviour) does not change dramatically over the time. In respect of the LCTs, these technologies are starting to be adopted by residential customers and therefore no much information is yet available. Nonetheless, it is expected that in the short and medium terms a better understanding would be achieved thanks to the different efforts for acquiring real data in real condition for LCTs.

In this context, to assess the impacts of LCTs in LV networks, realistic profiles and feeder models were developed during this project. Through this document, ENWL and The University of Manchester are making available to the research and engineering communities 25 real LV networks and some examples of the LCT profiles studied within the project, including photovoltaic systems (PVs), electric vehicles (EVs), electric heat pumps (EHPs) and micro combined heat and power (μ CHPs).

This companion document is structured as follows: The second chapter presents a summary about the procedure implemented to create the network models and the LCT profiles. Chapter three shows the details about the information released via www.enwl.co.uk/lvns such as data structure and examples. Finally, chapter four indicates a collection of publications that so far have used totally or partially models developed within this project.

It is recommended that the following journal paper (recently accepted) is used as a summary document to understand in detail the impacts of LCTs on LV networks:

- A. Navarro, L.F. Ochoa, “Probabilistic Impact Assessment of Low Carbon Technologies in LV Distribution Systems”, *IEEE Transactions on Power Systems*, In Press, Accepted in Jun. 2015

2 Network and Profile Creation

2.1 Creation of Networks

Due to the ‘fit and forget’ design approach traditionally adopted for low voltage distribution networks, DNOs do not need to carry out further analyses, i.e., no need for power flow studies. As a consequence, most DNOs do not have readily available electrical models of their LV networks. In most of the cases, available data is limited to Geographic Information Systems (GIS) for asset management purposes. The lack of real electric models for LV networks makes fundamental the conversion of GIS data into a suitable format so power flow-based studies can be carried out. However, GIS data of such extensive networks are prone to issues. One of the main problems is the network connectivity, i.e., two feeder segments that seem and should be connected in the GIS data visualization are separated by a small distance (from mm to a couple of cm), which can lead to a model unsuitable for power flow analysis.

Consequently, during this project a systematic methodology to achieve the full reconnection of LV feeders in cases where no other connectivity data is available was implemented, allowing the creation of computer based model for these circuits. In this document only a summary of the methodology is presented and more details could be found in “Deliverable 1.2: Tool for Translating Network Data from ENWL to OpenDSS” [1].

2.1.1 Creation of Line Segments

GIS manages a large amount of information by using the concept of polyline to store the data. This representation does not allow having direct access to all information about each segment in the polyline. Basically, the polyline is a continuous line comprised by one or more line segments. The polyline is treated as a single object within the GIS file and, therefore, there is no direct visualisation of the coordinates associated with one polyline. For example, the polyline in Figure 1 is represented just by one row in the attributes table (Table 1) 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.

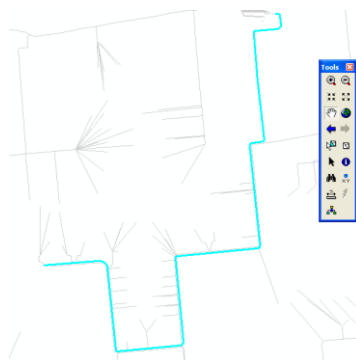


Figure 1: Polyline example from one feeder

Attributes of pavilion way_polylines								
FID	Shape	WALL_TER_0	SUBSTATI_1	NAME_PLA_0	NAME	TRANSFOR_1	VARIABLE_0	TRANS
5357	Polyline							
5358	Polyline							
5359	Polyline							
5360	Polyline							
5361	Polyline							
5362	Polyline							
5363	Polyline							
5364	Polyline							
5365	Polyline							
5366	Polyline							
5367	Polyline							
5368	Polyline							

Table 1: Polyline information associated with the polyline example

In order to have access to all the segments of the polyline it is necessary to implement a procedure in GIS software (e.g., ARCGIS 9.2). This procedure uses the following functions:

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 segments has the same “feature A”.
2. Split segments to vertices: This function indicates the vertices of each segment.
3. Add XY coordinates to each vertex: This function includes the coordinates of each vertex for each segment of the polyline.

Figure 2 exemplifies the application of the previous procedure over one low voltage feeder. The points indicate the position of the vertices in the feeder.



Figure 2: Vertices of each segment of the polyline

2.1.2 Topology Reconnection

The GIS Data Base for this project presents many connections that seem connected but in reality are separated by a small distance (from mm to a couple of cm). The easy way to identify the connectivity issues is through the determination of the connected components. A connected component of a graph is a sub-graph in which any vertices are connected to each other by paths (by definition one connected component is not connected to another connected component). The methodology implemented to calculate the connected components was the Breath First Search Algorithm [2].

The Breath First Search is a graph search algorithm that begins at the root node and explores all the neighbouring nodes. Then, for each of the latter nodes, it explores their (unexplored) neighbouring nodes, and so on, until it finds every node connected. This algorithm was implemented in MATLAB and applied to the GIS-based information. As an example, Figure 3 shows the connected components in one feeder, each colour represents one connected component. There are fifteen connected components; therefore, there are fourteen groups of segments without connection with the main LV feeder (blue line in the figure below).

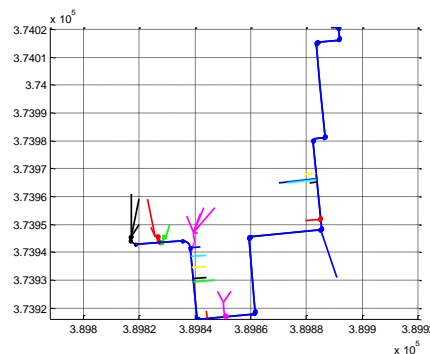


Figure 3: Connected components in one feeder

As a result, no power flow can be run in these disconnected networks. Thus, Figure 4 presents the flow chart to achieve the reconnection of the feeders from the GIS data.

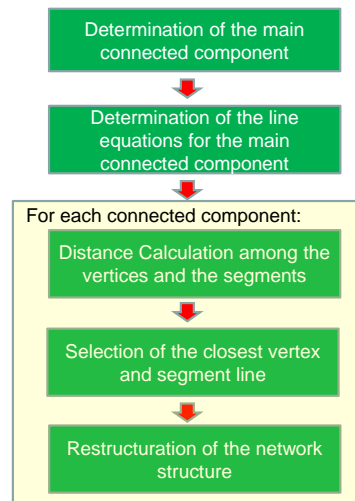


Figure 4: Flow chart of the reconnection process

The algorithm is described in the next paragraphs by using a network example as a base case. This example has three connected components and is depicted in Figure 5.

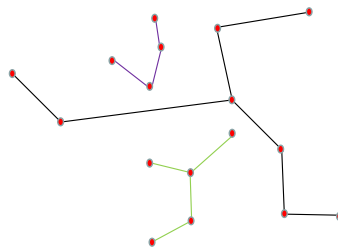


Figure 5: Network example with 3 connected components

1. Determination of the main connected component: The total length of each connected component is calculated, thus, the main connected component (the longest one) is determined (black line in Figure 5).
2. Determination of the line equations for each segment of the main connected component: The problem to solve is the distance between one point (vertex of the connected component) and one line (segment line of the main connected component). Therefore, it is necessary to calculate the line equation for each segment of the main connected component. Figure 6 indicates the lines (red dotted lines) for each segment of the main feeder.

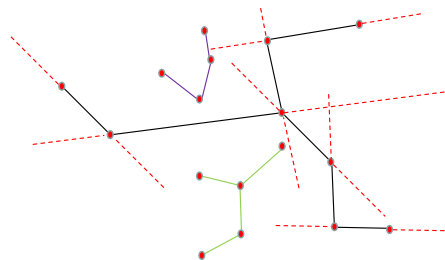


Figure 6: Equations determination for the main feeder

3. Determination of the distance between each vertex of the connected component and each segment line of the main connected component. This is shown in Figure 7 (blue dotted lines).

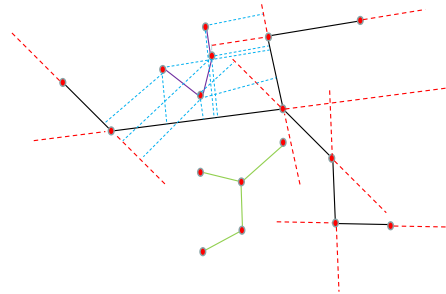


Figure 7: Distance determination

4. Selection of the closest vertex among the feasible vertices:
 - a. Determination of the new vertex on each segment line: The new vertex is the intersection point between the segment line of the feeder and the perpendicular line to the segment which passes through the closest point (connected component vertex).
 - b. Feasible new vertices and connection: The distance is calculated between one point and one line equation, in this way it is possible that the intersection between the perpendicular line and the line equation is not inside of the segment line. For that reason, the feasible new vertices will be those vertices located along the segment line.
 - c. Determination of the connection: The final connection will be the shortest connection among the feasible solutions (Figure 8).

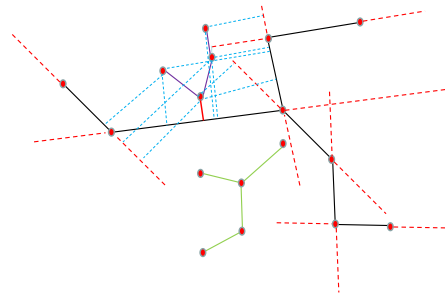


Figure 8: Example of feasible new vertices

Since the distance is too small (lower than 1 cm), instead of using a new connection line between the two vertices, the position of the closest vertex is changed to the position of the new vertex on the segment line. In this way, the two vertices are merged in one vertex on the segment line (Figure 9).

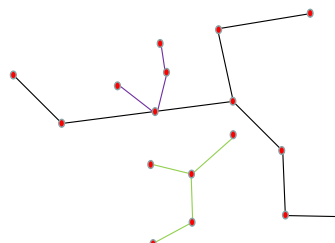


Figure 9: Example of feasible new vertices

5. Updating the network structure: The incorporation of new vertices and new connections requires the elimination of old connections that are not available anymore from the database and the creation of the new connections.

It is important to highlight that the proposed methodology has been successfully applied to all the feeders released with this document.

2.1.3 Computer-Based Models

Once the feeder topology is fully connected, the next step to be able to run power flow simulations is to translate the processed information into a computer-based network model. In this work the chosen format is OpenDSS [3]. This is an open and free software package to solve power flows in unbalanced distribution networks; the most important characteristics are the abilities to represent the time dimension (particularly relevant for the analysis of distributed generation) and to be controlled by other software environment (e.g., VBA, Matlab, etc.).

The flow chart for the complete process to translate GIS data into the OpenDSS format is shown in Figure 10. It is possible to observe that the conductor, topology and MPAN (Meter Point Administration Number, i.e., customer information) is obtained from the GIS files. The load profiles are inputs in the model. Finally, the database can relate the MPANs to specific profile classes (e.g., domestic unrestricted, economy 7, etc.). Thus, using the information available it is possible to create all of the files required (lines, loads, transformers, load profiles, generation profiles, monitors, sensors, etc.) to represent the data in the OpenDSS format.

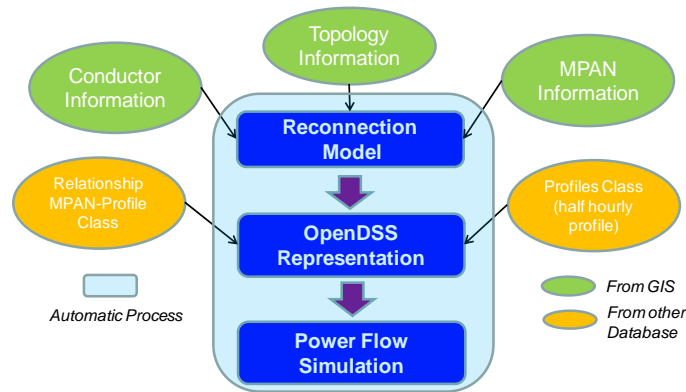


Figure 10: Automatic Translation to OpenDSS

2.2 Creation of Load and LCT Profiles

To understand the impacts of LCTs on LV networks throughout a day, the adoption of time-series profiles is required. The profiles developed during this project correspond to residential loads, photovoltaic systems (PVs), micro-combined heat and power units (μ CHPs), electric heat pumps (EHPs) and electric vehicles (EVs). These daily profiles have a resolution of 5 minutes. It is worth mentioning that while the loads are assumed to have inductive power factor equals to 0.98, all the LCTs are assumed to operate at unity power factor.

Additionally, it is important to highlight that only a summary of the methodologies and/or tools used to create the profiles is presented in this document. Additional details could be found in Deliverable 1.5 [4] and Deliverable 3.5 [5] associated with this project.

2.2.1 Load Profiles

The load profiles used were obtained from the computational model developed by CREST (Centre for Renewable Energy Systems Technology) at Loughborough University. This model creates computational profiles for residential loads based on the domestic behaviour of British costumers [6]; it takes into account the number of people at home, the type of day, the month, and the uses of the appliances.

To mimic the stochastic behaviour of the load consumption per household, a pool of different load profiles was created by using the tool. The proportion of profiles with certain number of people is

based on UK statistics [7]. Hence, the proportion of houses with one person, two people, three people and four or more is 29%, 35%, 16% and 20%, respectively.

2.2.2 Photovoltaic profiles

The data used for the PV profile creation was obtained from the Whitworth Meteorological Observatory, located at The University of Manchester. This data has a granularity of one minute for Global and diffuse radiation (W/m²). As an example, the daily profiles for the period July 2012 and December 2012 are presented in Figure 11. 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 till 2012 [8]. The distribution of PV panels with installed capacity lower or equal to 4 kW using the Feed-In-Tariff scheme is shown in Figure 12. As a result, it is possible to have for each sun profile the complete spectrum of PV profiles for each PV panel in a feeder by following the UK installed capacity distribution.

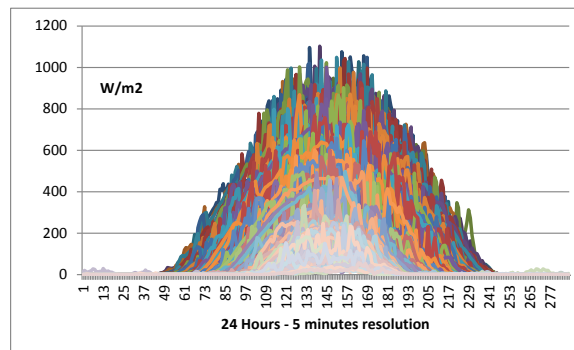


Figure 11: Daily sun radiation profiles

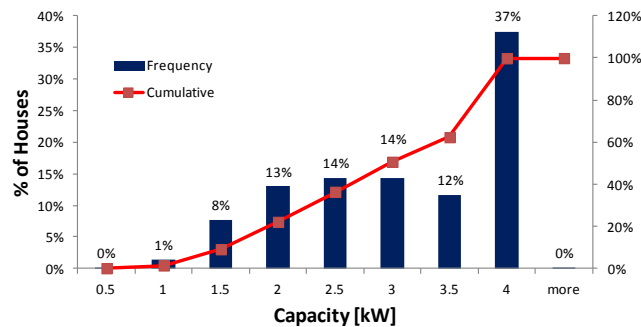


Figure 12: Distribution of residential PV panels in UK

2.2.3 Micro-combined heat and power

Real data corresponding to the operation of μ CHP units from a field trial in the UK [9] has been considered for the creation of these profiles. This data provides the electricity generation for different μ CHP units and the corresponding electricity consumption of the houses where these units are installed; all this data has a granularity of 5 minutes. A pool of μ CHPs is created by randomly shifting the real profiles available (16 houses for the North West of England) from 5 to 30 minutes [10]. Two μ CHP profiles are presented in Figure 13, here is possible to observe the cycling operation of this technology (heating periods) and the maximum generation produced, about 1.0 kW in each unit.

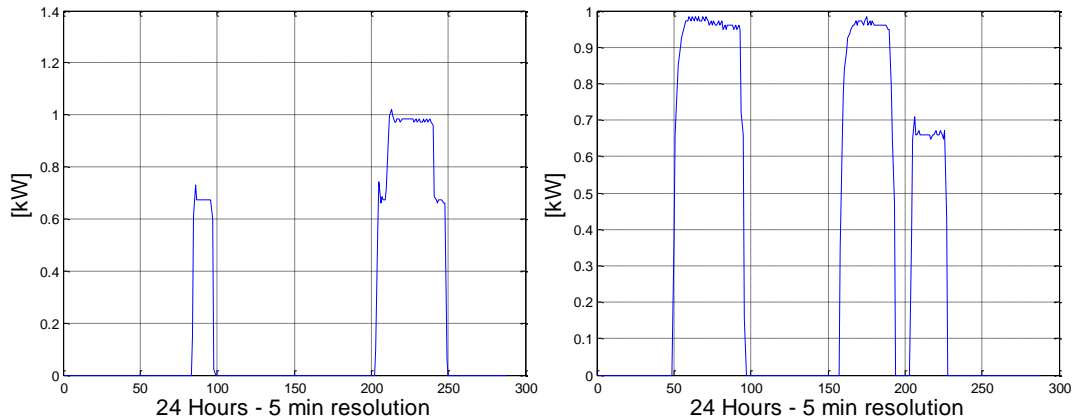


Figure 13: Example of μ CHP profiles

2.2.4 Electric heat pump profiles

The household thermal demand delivered by the μ CHP in [9] is used for the creation of EHP profiles according to the methodology proposed in [10]. There, an input-output black box model approach is used to “transform” the household thermal demand into EHP electrical demand. More specifically, the heat capacity and the relevant electricity consumption curves are taken from manufacturers’ catalogues, i.e. [11] and [12], and fitted through models to represent their dependence on the air outdoor temperature and of the delivery temperature (typically air or water at different temperatures, depending on the house distribution system). An auxiliary heater is assumed to be available with the EHP in order to increase the thermal capacity under harsh conditions. In this project, the EHP has been designed to cover 80% of the peak thermal load on the coldest day, as indicated by manufacturer’s recommendations [12]. The remaining capacity for space heating and domestic hot water (DHW) is covered by the auxiliary heater if this is needed.

The traditional operation of EHP is an on-off process, where the length of each period depends on the heat requirements and the temperature conditions (outside and inside). Thus, the on-off operation is simulated in this project by introducing different cycling period according to different heat requirements. In fact, the total amount of heat is determined for each heating period (dotted black line in Figure 14). Starting with a minimum EHP cycling period of 10 minutes per hour, the EHP heat production and consumption is determined. If the heat production is lower than the energy requirement in the heating period the EHP cycling period is increasing by 5 minutes. This process is repeated until the EHP production is matched with the heat requirement. Hence, the cycling period will be shorter for lower heat requirements and longer for higher heat requirements (Figure 14).

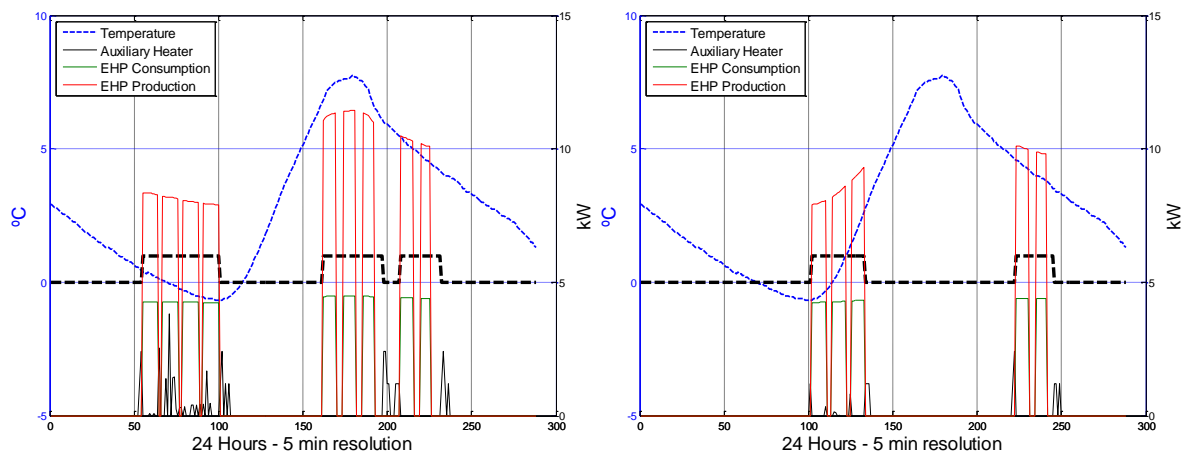


Figure 14: Example of EHP and auxiliary heater profiles for two different houses

The variation on the heat production output levels in Figure 14 is determined by the dependence of the heat output on the ambient temperature as from manufacturers' performance maps. Thus, it is possible to see how the EHP production increases as the temperature increases.

This approach can be considered only as a first approximation of EHP modelling for network studies. In fact, more advance and therefore accurate models have been developed since the elaboration of this project. Hence, those models, such as [13] and [14], are recommended for future research and detailed analysis of electro thermal technologies.

2.2.5 Electrical Vehicles profiles

In this project, the information available in [15] for a one year field trial of EV in Dublin is used to create EV profiles. The main results used for the creation of profiles are presented in Figure 15. The distribution in the left side indicates the connection times, this is when the EVs are connected to the charging point and the one in the right side indicates the energy required for each vehicle during each connection period.

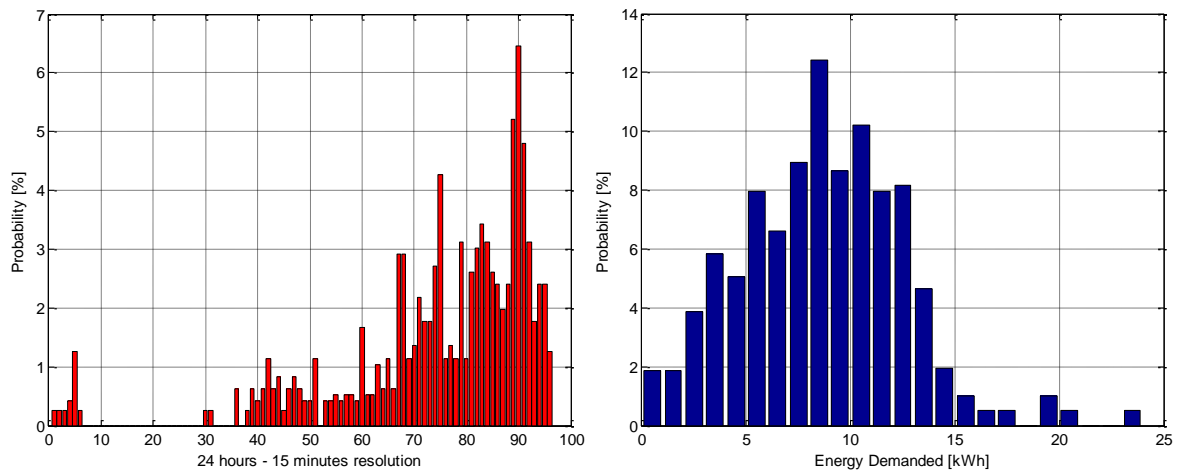


Figure 15: Probability distribution function of EV connection times and EV energy requirement

From the previous probability distributions, it is possible to know when an EV is connected to the network and how much energy is required. Hence, the following process was implemented to create a pool of EV profiles:

1. Random selection of the connection time and the amount of energy required by following the distributions presented in Figure 15.
2. The energy required is divided by the battery capacity (3kW/24kWh, e.g. Nissan Leaf) to calculate the number of periods required.
3. The charging time is the period between the connection time and the total time required (connection time + the periods required)

3 Released Information

The main characteristics of the information released via www.enwl.co.uk/lvns are explained in this chapter. Two sets of information, each of them in one of the folders associated with this companion document, are presented. The first set corresponds to models for 25 LV distribution networks and it is located in the folder “LV Networks Models”. The second one corresponds to a pool of one hundred profiles for each LCT analysed in this project and it is located in the folder “LCT Profiles”.

3.1 Low Voltage Networks

The input information to build these networks comes from GIS files with the network topology and the cable characteristics (type of cable, phase connection, etc.). The procedure to transform that data into networks models was described in Section 2.1.

As a result, 25 LV networks are shared with this document. This implies 131 low voltage distribution feeders, 5952 customers and about 172 kilometres of LV cables (including all the services cables) and 19 MVA of installed capacity. The visualization of all the networks is shown in Figure 16, Figure 17, Figure 18 and Figure 19.

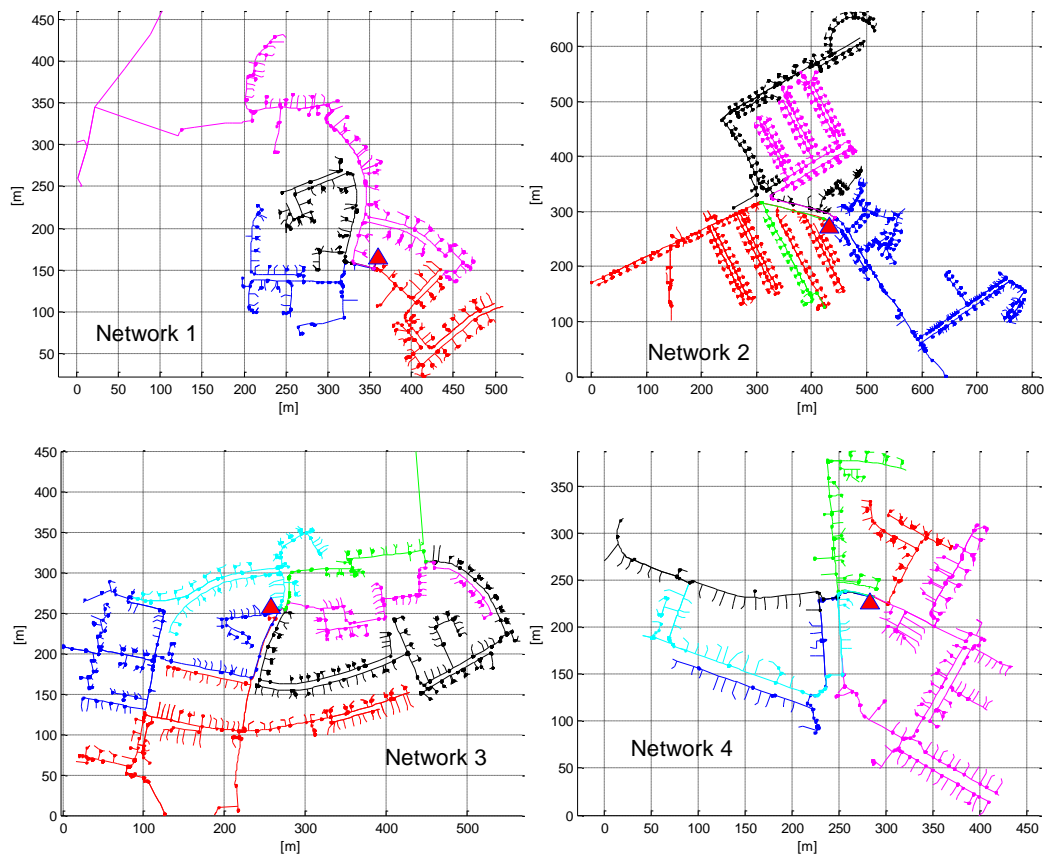


Figure 16: Networks 1-4

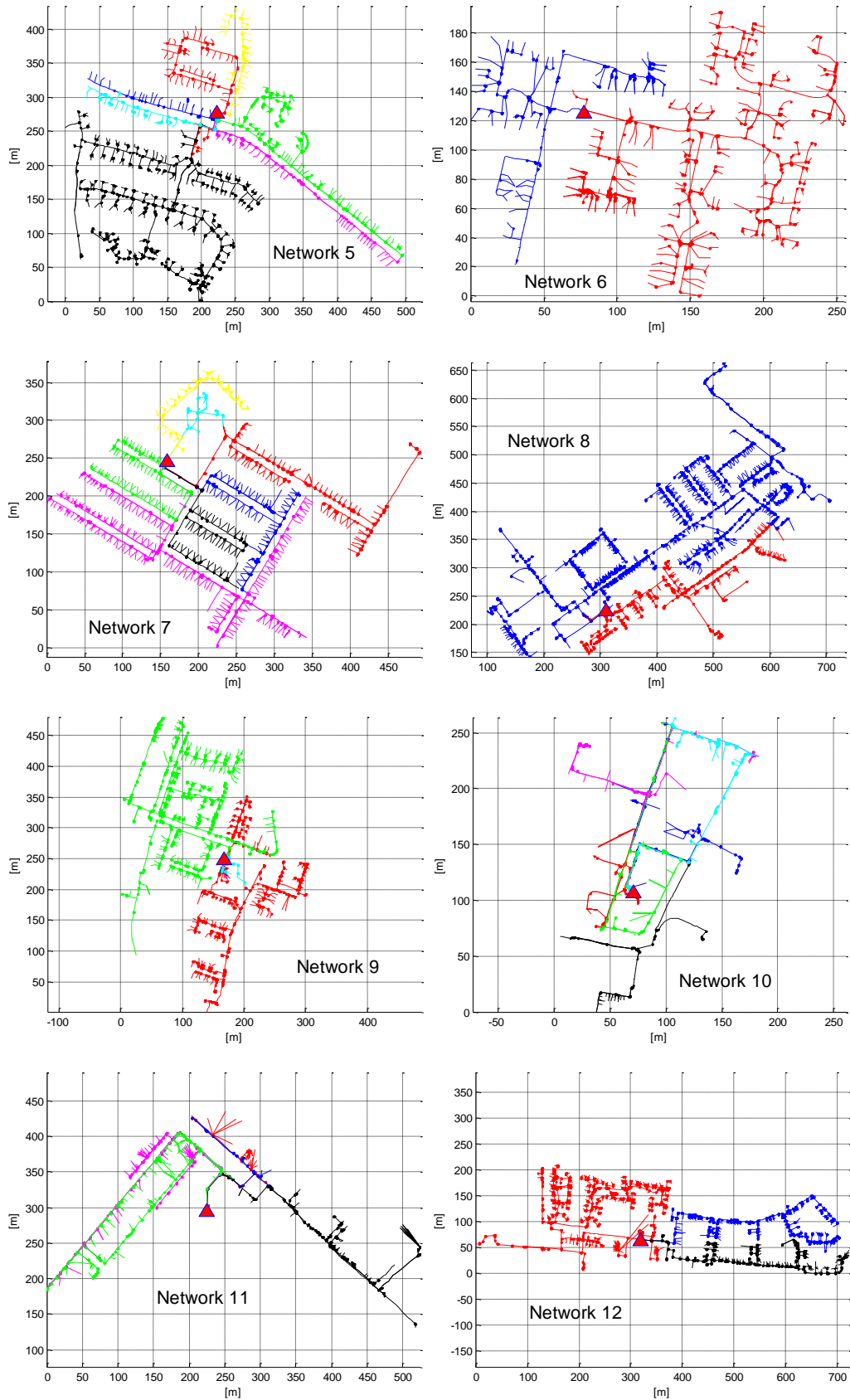


Figure 17: Networks 5-12

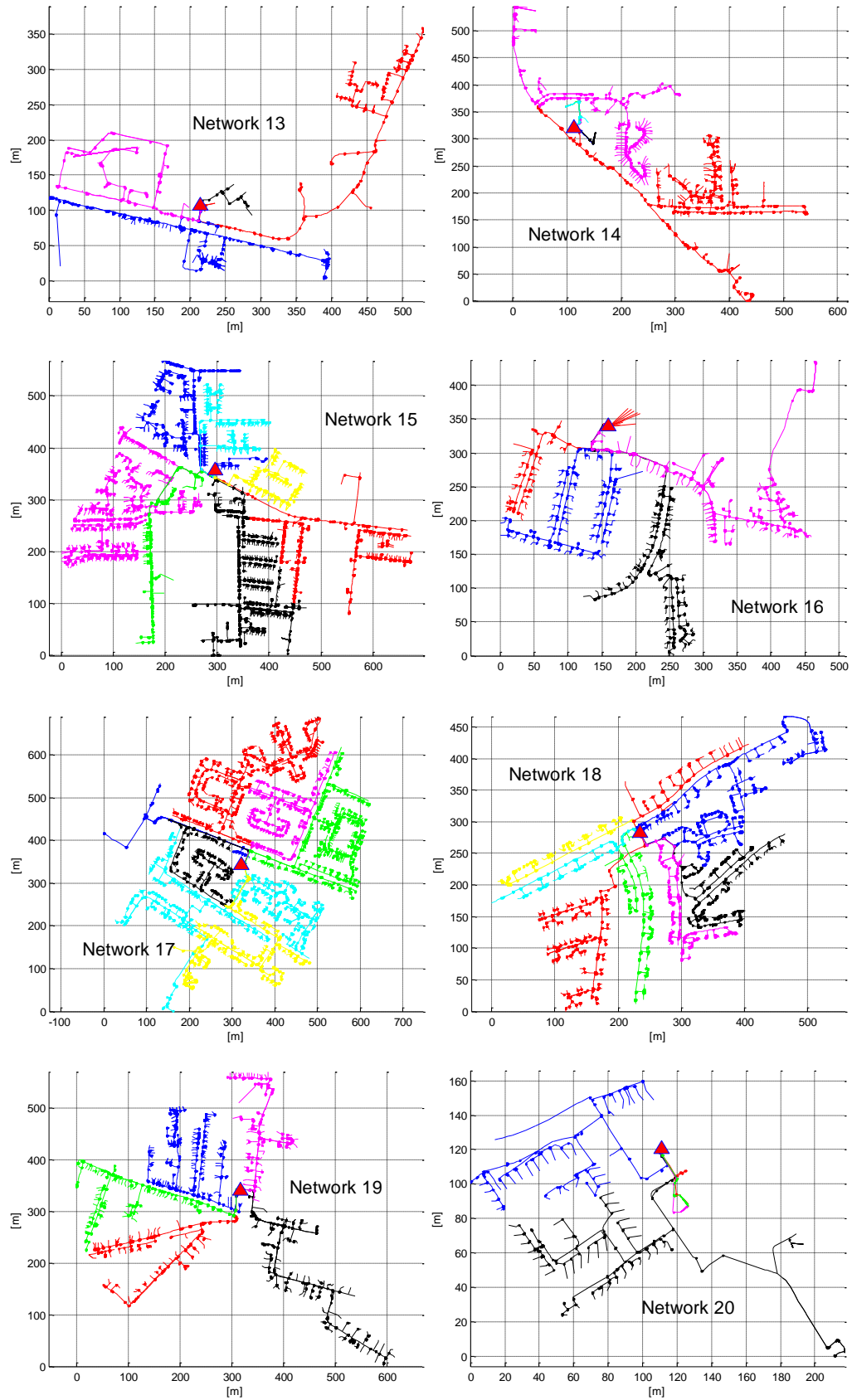


Figure 18: Networks 13-20

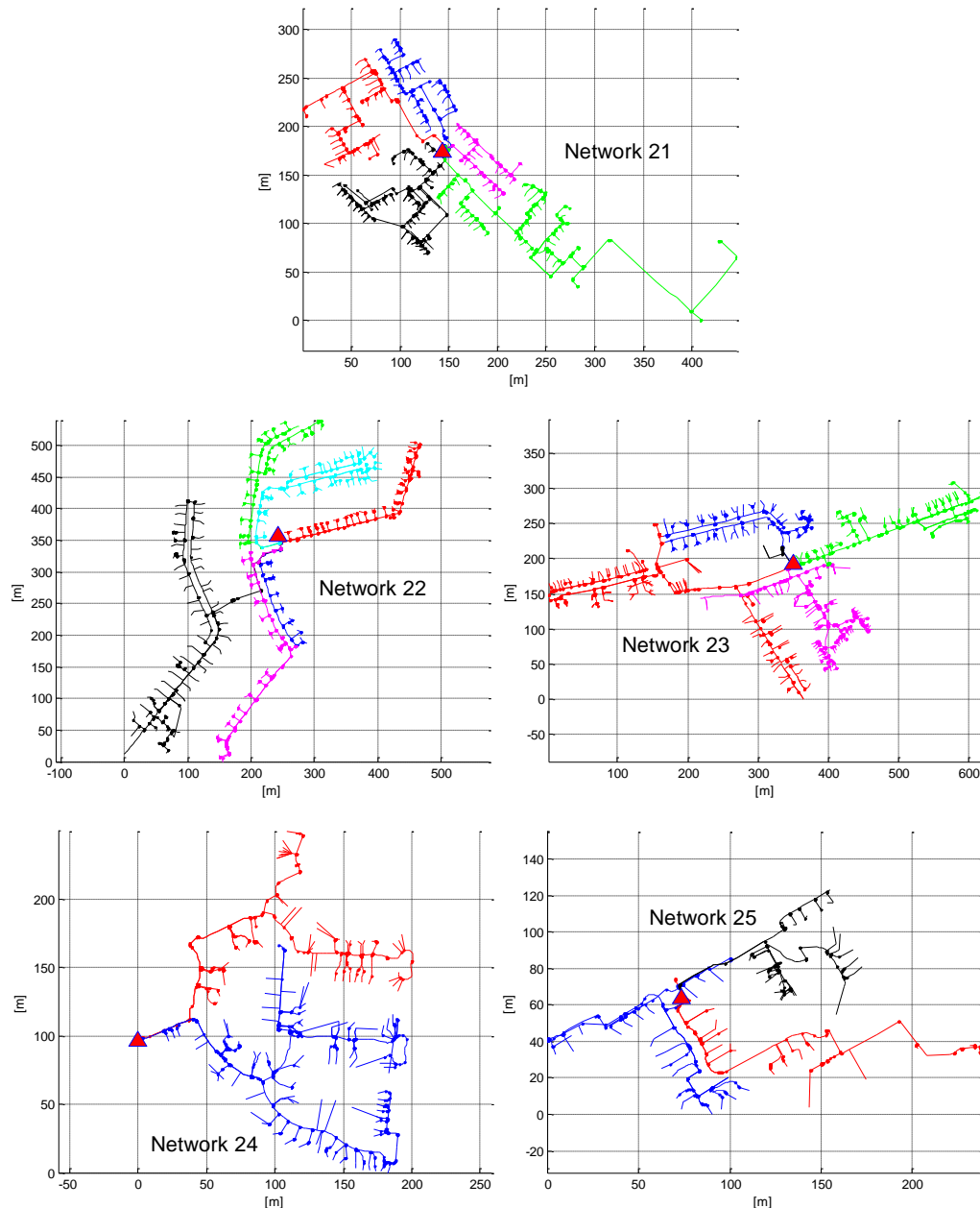


Figure 19: Networks 21-25

3.1.1 Data Structure

The information related to each network is located in the folder “LV Network Models”. This main folder contains 25 sub-folders, one for each of the networks. These sub-folders are named from Network 1 to Network 25; each of them is further subdivided with folders for each of the feeders (named from 1 to N) that belong to the corresponding network.

The feeder folders contain the information (files) about the computer-based model representation. Two families of files are incorporated, the txt files correspond to the OpenDSS representation of the LV feeders and the MS Excel files correspond to exactly the same information but can be used to create these models in different platforms. This could be useful for those not familiar with OpenDSS¹ but capable users of other power flow engines.

¹ An OpenDSS tutorial can be found in: <https://sites.google.com/site/luisfochoa/research/opendss-training>

The txt files are:

1. Master: This file controls the execution of OpenDSS, reading the data and giving the instruction for the software execution.
2. Lines: This file contains each line segment of the feeder, source and end nodes, the distance between the two vertices and the type of cable.
3. Loads: This file indicates in which bus the loads are connected, the type of load (single phase or three phases), the nominal load voltage and the load power factor. Additionally, this file incorporates an important part to run time-series analyses, which is the load shape (load profile) associated with each load. In this file, only the load shape names are incorporated, their characteristics are indicated in a different file.
4. LoadShapes: this file provides the electrical behaviour of one load along one determined period (power production and/or consumption). This file includes the path where the profile (shape) is located. Each profile is located in one excel file.
5. LineCode: This file incorporates the network parameters. The name of these conductors is the same name used in the "Lines" file.
6. Transformers: this file has the technical transformer parameters.
7. Monitors: 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.

The MS Excel files are:

1. Feeder_Data: This file has the information about each line of the network and it can be used to create the feeder representation in any power flow simulator. In this file each row represents a line segment, and it has the following information in each of its columns:
 - a. Node A: it represents the source node for the corresponding line segment.
 - b. Node B: it represents the end node for the corresponding line segment.
 - c. D: this shows the distance in meters for the corresponding line segment.
 - d. Phase: it indicates the phases connected in the corresponding line segment. The number 4 represents a three phase line, number from 1 to 3 represent single phase connections. For instance, 1 represents a single phase line connected to phase 1.
 - e. Load: this column indicates if there is a load connected at the end of the line segment. Hence, 0 represents that there is not any load connected in the end node. 1 represents that there is one load (house) connected in the end node.
 - f. Cable= this column shows the type of cable for the corresponding line segment.
2. XY_Position: This file shows the X and Y coordinates for each node in the network. In this file each row represents a node, and it has the following information in each of its columns:
 - a. Node: it has the ID (feeder identification) of the node. This ID is unique for each node and it is useful to relate this file with the Feeder_Data file. In fact, the source and end nodes use this ID.
 - b. X: this column indicates the X coordinates for the corresponding node.
 - c. Y= this column indicates the X coordinates for the corresponding node.
3. Connectivity_matrix: this file delivers the information about the phase connection for each load. In this file each row represents a node with a load connected, and it has the following information in each of its columns:
 - a. Bus: it indicates the bus where the corresponding load is connected.
 - b. Phase: it indicates the phase where the corresponding load is connected.

It is important to highlight that among the 131 feeders, there are 7 feeders that appears with an unexpected level of imbalance. It is therefore up the users to incorporate them into the analysis or rebalance them by allocating to different phases the loads. These particular feeders are: Feeder 6 in Network 5, Feeder 4 in Network 13, Feeder 3 in Network 14, Feeder 2 in Network 17, Feeder 2 in Network 18, Feeder 4 in Network 19 and Feeder 3 in Network 20.

3.2 Load and LCT Profiles

Applying the tools and methodologies presented in section 2.2, a pool of 2000 profiles were created for each of the technologies during this project. Particularly, with this report, 100 profiles for each of them are shared and incorporated in the folder “LCT Profiles”. It is worth mentioning that these profiles were randomly selected from the corresponding pool and therefore they can be used only as an example to have a general understanding about the impacts of these new technologies, however, if more specific cases are studied, new profiles should be developed.

All the released profiles correspond to daily individual residential profiles for a week day with a resolution of 5 minutes. Specifically, these profiles correspond to:

- Winter load profiles (located in “Winter_Load_Profiles.xlsx”).
- Summer load profiles (located in “Summer_Load_Profiles.xlsx”).
- Winter EHP profiles (located in “Winter_EHP_Profiles.xlsx”).
- Winter μ CHP profiles (located in “Winter_uCHP_Profiles.xlsx”).
- Winter EV profiles (located in “Winter_EV_Profiles.xlsx”).
- Summer PV profiles (located in “Summer_PV_Profiles.xlsx”).

Most of the profiles are created for the winter case because is the period when distribution networks in the UK are under the largest stress, i.e., peak load. Only the PV case and the corresponding loads are presented for summer in order to understand the corresponding impacts when the PV generation is the highest. For this particular technology, all the 100 profiles are assumed to face the same sun irradiance (no significant sun irradiance differences are expected in such small area, i.e., LV feeder supplied zone). Furthermore, the sun irradiance used is one of the highest sun irradiances during 2012 in Manchester.

3.2.1 Data Structure

The six pool-samples are presented in the associated folder “LCT Profiles”, each of the samples is located in a MS Excel file. This file has the same structure for all the technologies, which is a matrix with 288 rows and 100 columns. There is one column representing each individual profile and each row represents a time-step (288 periods due to the 5 minutes resolution) from 00:00 to 24:00.

To visualise these profiles, this section presents a couple of individual profiles and the average aggregated profile for each of the sample-pool released with this report. For instance, Figure 20 (left-side) shows an example of three individual profiles from the file “Winter_Load_Profiles.xlsx”, these profiles behaves different along the day but in aggregate way (right-side of the same figure) they behaves as expected for a LV network. This aggregated profile represents the average profile among all the profiles presented in the corresponding MS Excel file. Figure 21 points out the same information but for the summer. It can be observed that the average peak (about 0.85 kW) is lower than in winter (about 1.0 kW) and that the evening peak hours are less. In fact, only after 20:00 (period 250), the average peak in summer is higher than 0.7 kW, whereas in winter is higher after 17:00 (period 205).

The operation of EHP (file “Winter_EHP_Profiles.xlsx”) is shown in Figure 22, on the left hand side is possible to appreciate the operation of three different unites, for which all of them present the base consumption (EHP operation) and the auxiliary heater operation (spikes in Figure 22). The right hand side presents the average among the 100 EHP profiles, producing for this particular case, an average peak demand of 2.0 kW.

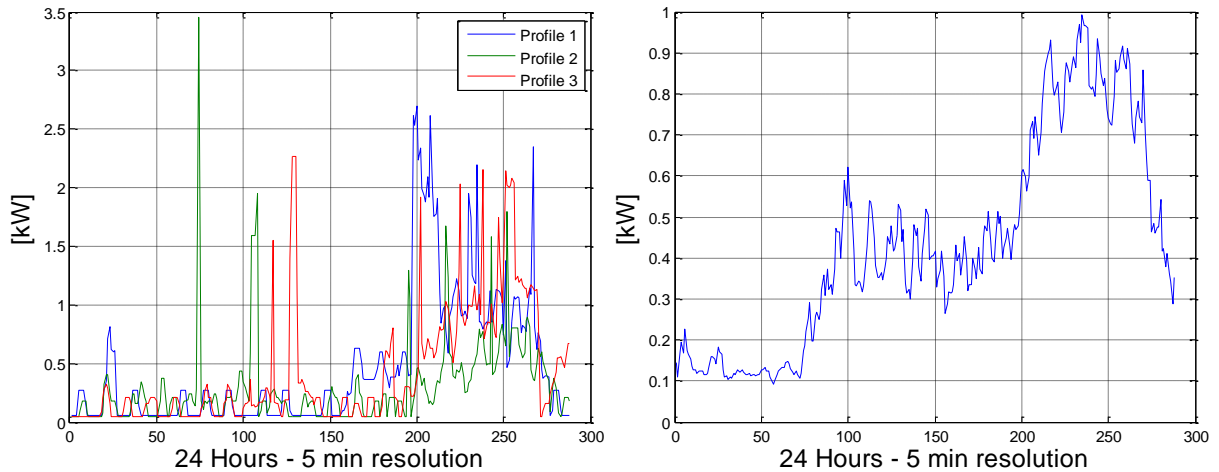


Figure 20: Winter Loads– individual profiles (left-side) and aggregated profile (right-side)

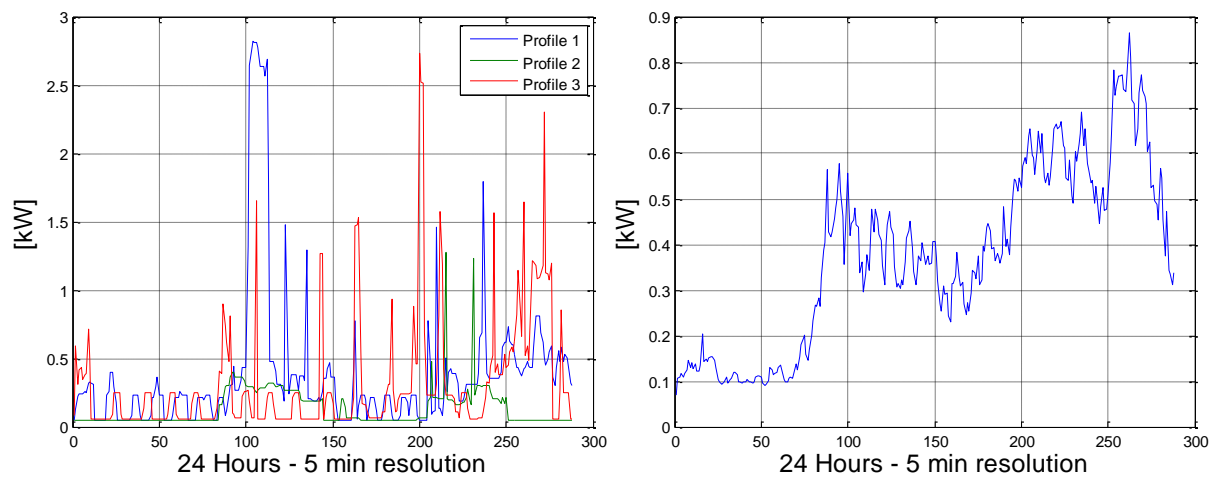


Figure 21: Summer Loads – individual profiles (left-side) and aggregated profile (right-side)

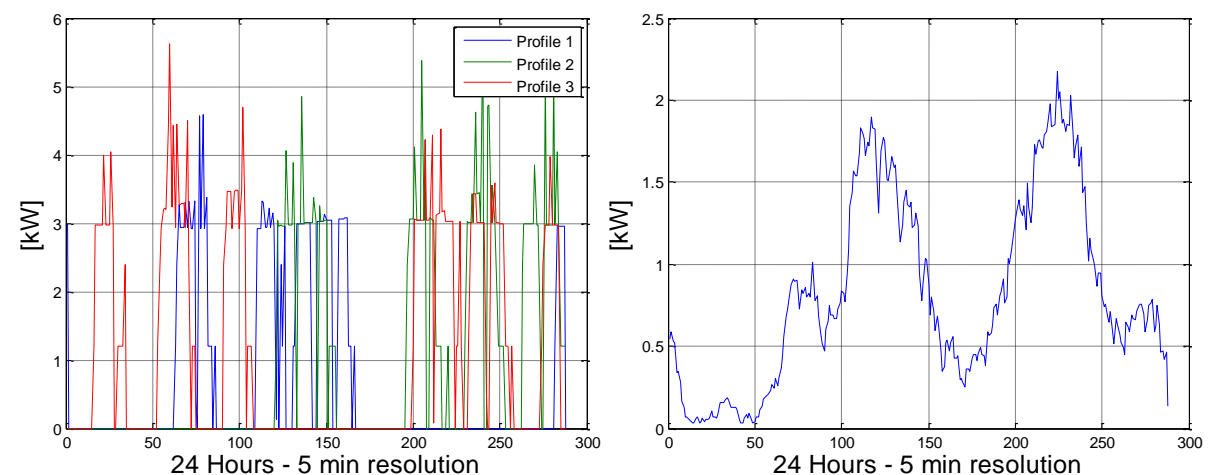


Figure 22: Winter EHPs – individual profiles (left-side) and aggregated profile (right-side)

Three examples of μ CHP operation from the file “Winter_ μ CHP_Profiles.xlsx” are presented in Figure 23 (left-side). These profiles represent electricity production and therefore depending on the load consumption they can imply power injections at residential level. The average generation (Figure 23, right-side) for this technology is 0.5 kW.

The charging power for three electric vehicles obtained from the file “Winter_EV_Profiles.xlsx” is depicted in Figure 24, there the 3.0 kW charging capacity can be observed. For this particular case and with the input data obtained in [15], the average peak is about 1.2 kW and it occurs around 23:00.

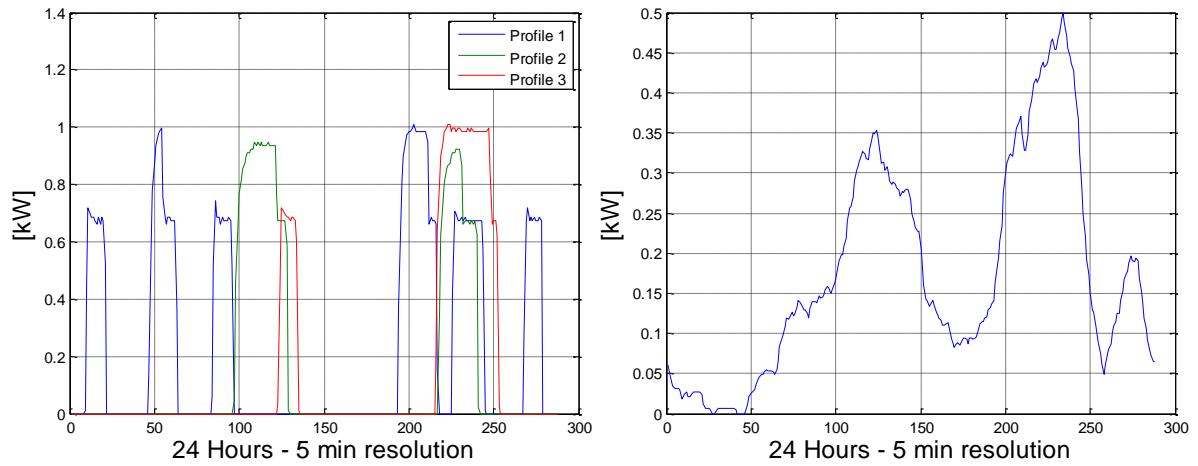


Figure 23: Winter μ CHPs – individual profiles (left-side) and aggregated profile (right-side)

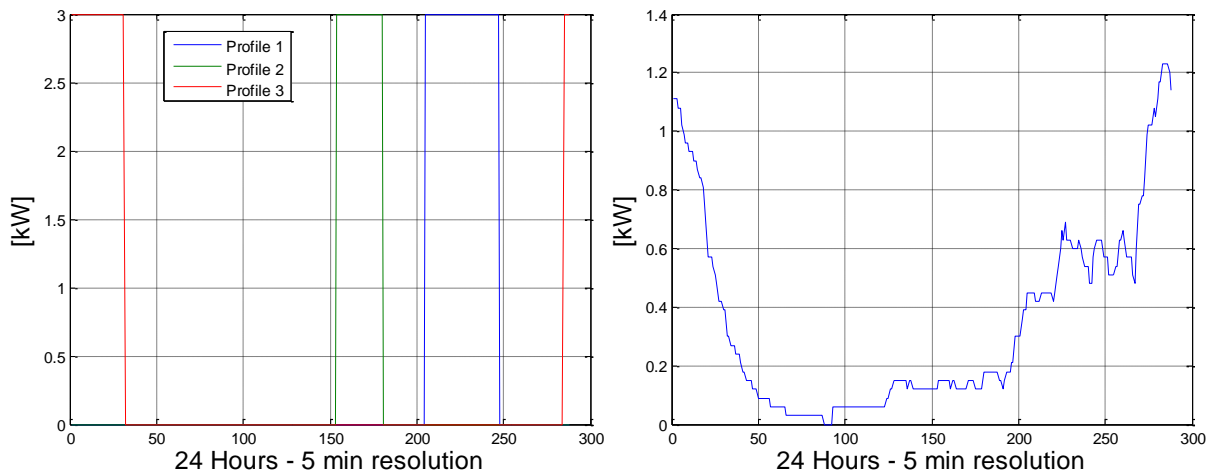


Figure 24: Winter EVs – individual profiles (left-side) and aggregated profile (right-side)

The information related to the PV profiles is located in the file called “Summer_PV_Profiles.xlsx”. As was mentioned before, these profiles are created for different size of PV units (summary of the methodology in Section 2.2) but for the same sun irradiance, therefore they are affected at the same time for exactly the same cloud passing effect. The sun irradiance used for the creation of these PV profiles is presented in Figure 25. Hence, the same pattern is observed in all the released PV profiles. For instance, the three different profiles shown in Figure 26 have the same shape but different amplitude since the different size of the PV panels used. The maximum average power production for these profiles is 3.0 kW (Figure 26, right hand side).

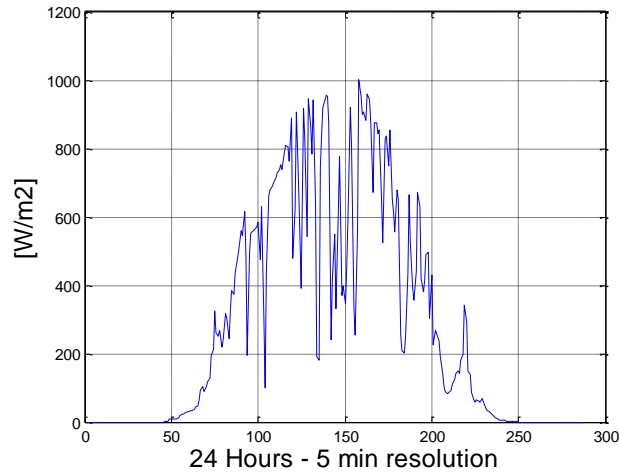


Figure 25: Sun irradiance for the creation of PV profiles in this document

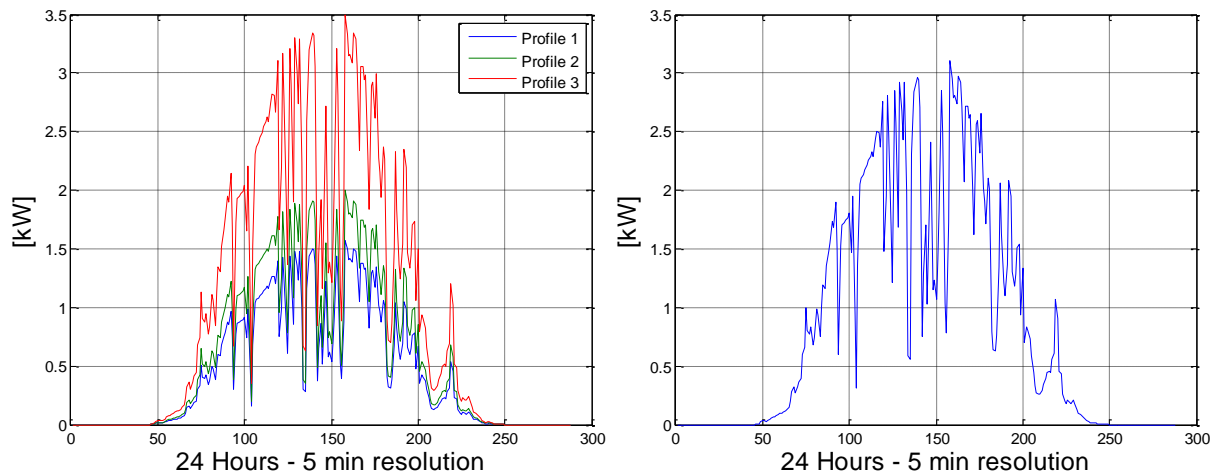


Figure 26: Summer PVs – individual profiles (left) and aggregated profile (right)

3.3 Application Example: Impacts of LCTs on a LV Feeder

To show the potential applications of the networks and the example profiles released with this report, this section analyses the impacts of the LCTs considering one LV feeder. Particularly, the feeder under analysis corresponds to feeder 1 in Network 1 located in the folder “LV Network Models”. This feeder supplies 55 loads through 1431 m of cables (including service cables). The voltage at the secondary of the transformer (reference voltage for this simulation) is 416 V phase to phase. The visualization of this feeder is presented in Figure 27, where the red triangle represents the MV/LV transformer (beginning of the feeder).

To observe the potential effects of these technologies, six deterministic cases are implemented:

1. Winter load profiles without any LCT.
2. Winter load profiles and every house with EV.
3. Winter load profiles and every house with EHP.
4. Winter load profiles and every house with μ CHP.
5. Summer load profiles without any LCT.
6. Summer load profiles and every house with PV.

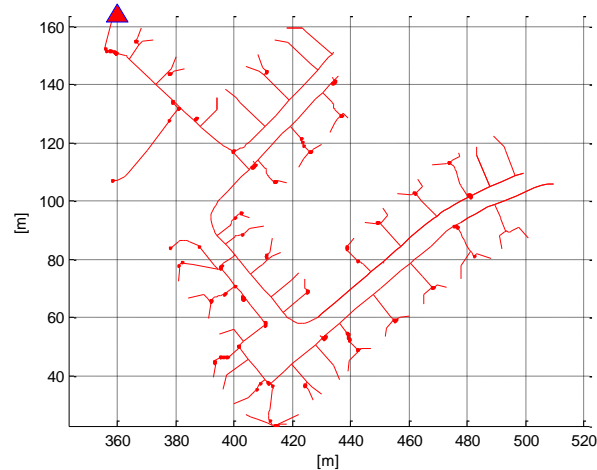


Figure 27: Example Feeder - Feeder 1 in Network 1

In order to populate the feeder for each of these cases, the profiles described in the previous section and located in the folder “LCT Profiles” are used. To facilitate the reproduction of the results is important to mention that the profiles are allocated in the following way: the load profile allocated to “load i” is the one indicated in the “column i” in the corresponding excel file with the profile. For instance, in the case of the PV analysis, the load 10 will take the load profile located in the column 10 in the file Summer_Load_Profile.xlsx and the generation profile located in the column 10 in the file Summer_PV_Profiles.xlsx. The same applied for the rest of the technologies.

Once the profiles are allocated, a power flow is executed in OpenDSS for each of the cases implemented. To exemplify the impacts, two graphs are depicted for each case, these are: the daily magnitude of the current at the head of the feeder and the daily voltage profile in the last customer of the feeder, i.e., load 55 in this example feeder.

Figure 28 presents the winter case without any LCT; there the typical profile for residential load can be observed for the current at the head of the feeder (one morning peak, one valley and one evening peak). For this case, the voltage at the last customer has a minimum value of 230V during the evening peak.

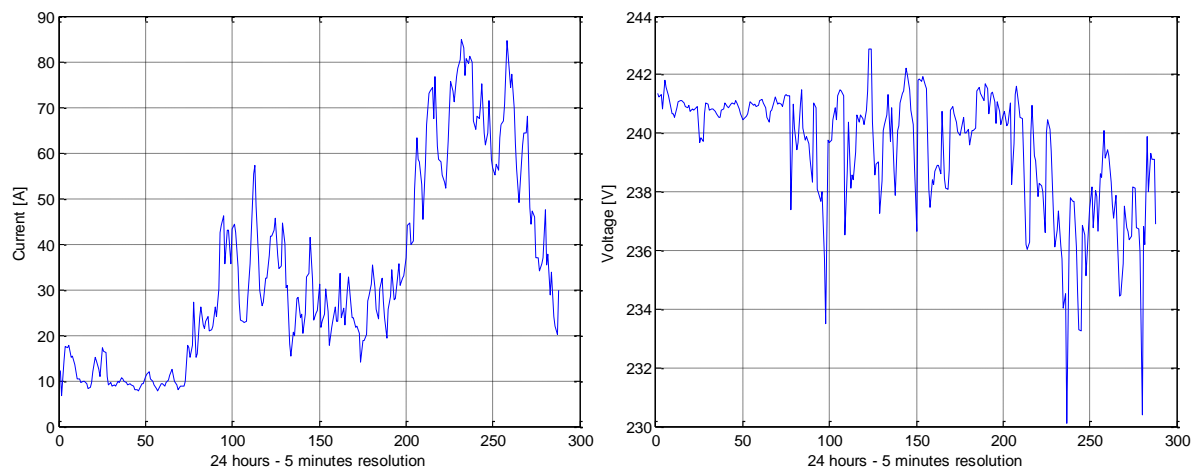


Figure 28: Current and voltage outputs for the Winter Load Profiles

Figure 29 and Figure 30 show the effects of the 100% EV and 100% EHP penetration, respectively, on the winter profiles. Interestingly, the current is increasing in both cases but with a considerable higher current injection for the EHP case. In fact this current is almost 3 times higher in the EHP case than in the base winter case. The voltage profile is consistent with this reaching almost 220V in the EHP case.

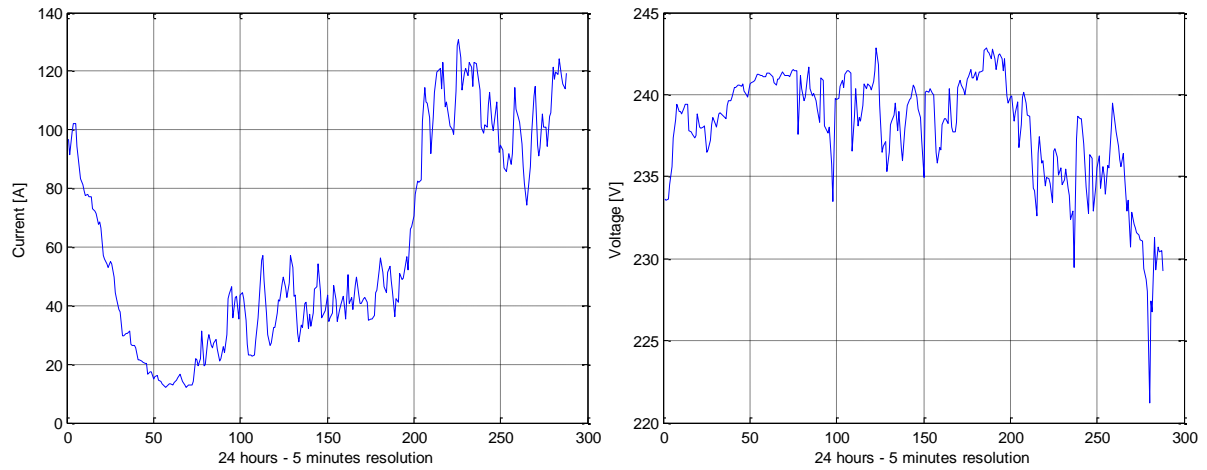


Figure 29: Current and voltage outputs for the Winter Load Profiles and EVs

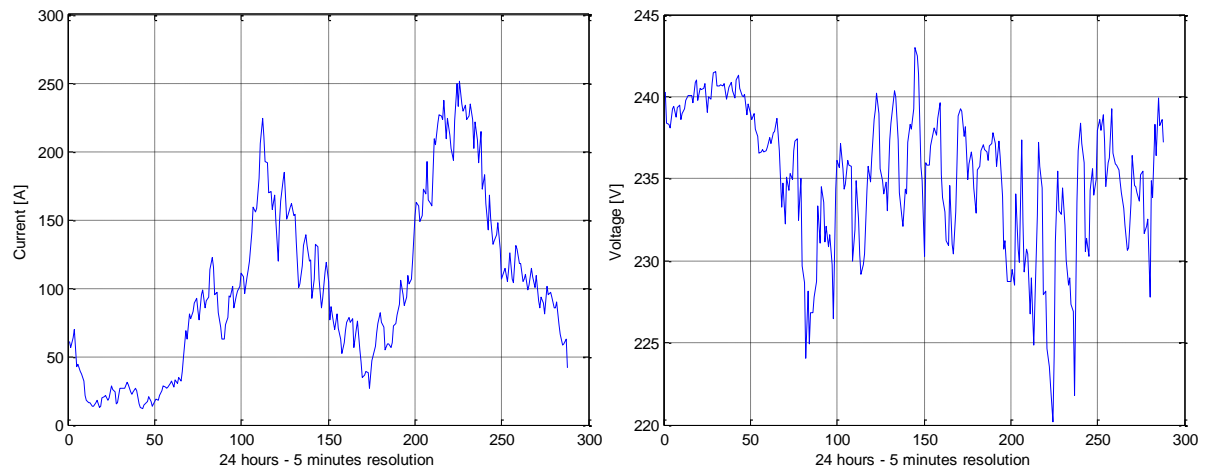


Figure 30: Current and voltage outputs for the Winter Load Profiles and EHPs

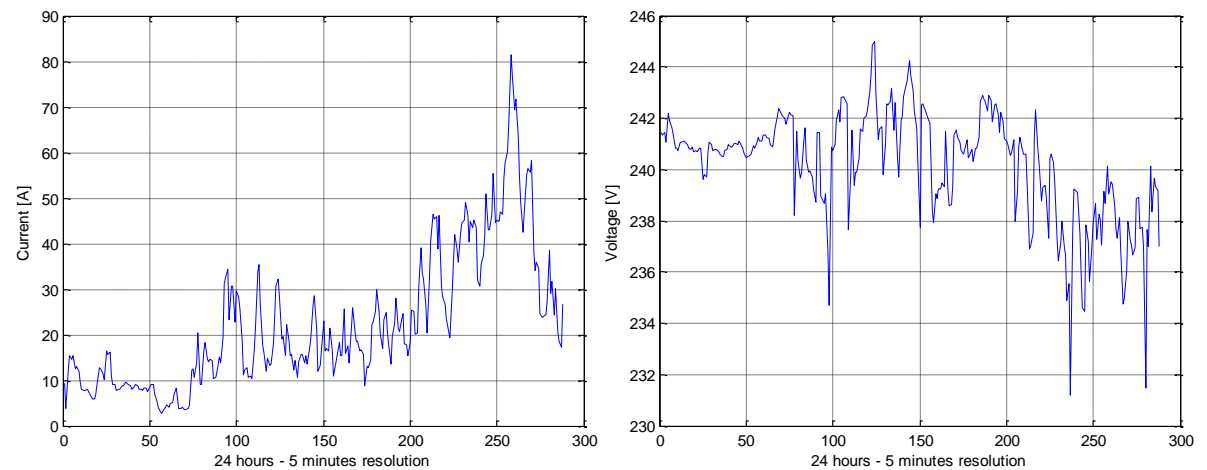


Figure 31: Current and voltage outputs for the Winter Load Profiles and μ CHPs

The positive effect of the local generation from the μ CHP can be observed in Figure 31, this figure shows that even if the peak current remains the same as the winter base case, the total current injection decreases along the day (due to the local generation). This also produces an improvement in the voltage profile, showing a minimum voltage just below 232V.

The current and voltage for the summer base case are presented in Figure 32, indicating a current profile lower than the winter base case and therefore producing a voltage profile with a higher minimum value (i.e., 234 V). Including 100% of PV to these summer profiles produces the results exemplified in Figure 33; there the increase in voltage during the sun time period is evident. This is result of the massive reverse power flow (the local generation is much larger than the local consumption) as can be observed in the current profile (current magnitude) for this case where the current is at least two times higher than the summer base case during the sunlight period.

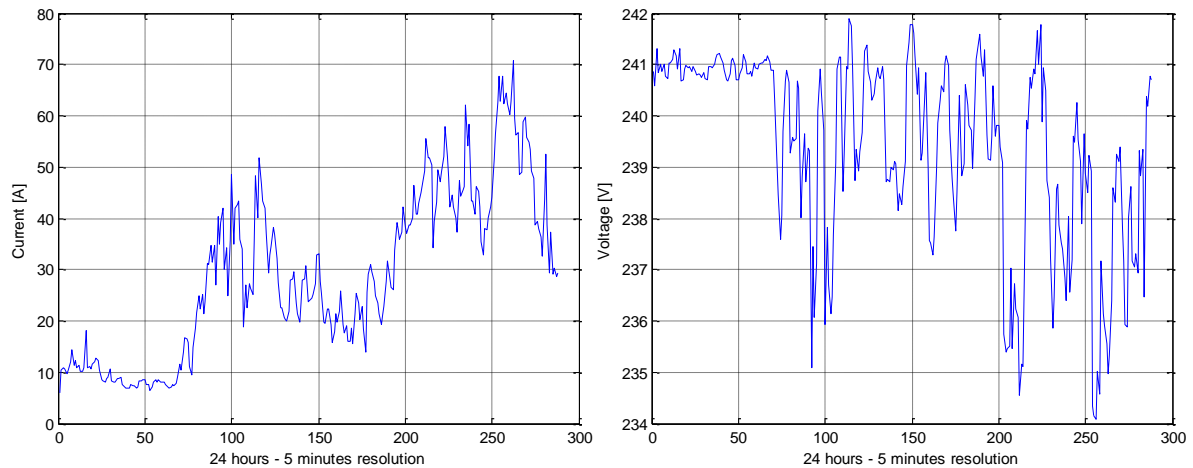


Figure 32: Current and voltage outputs for the Summer Load Profiles

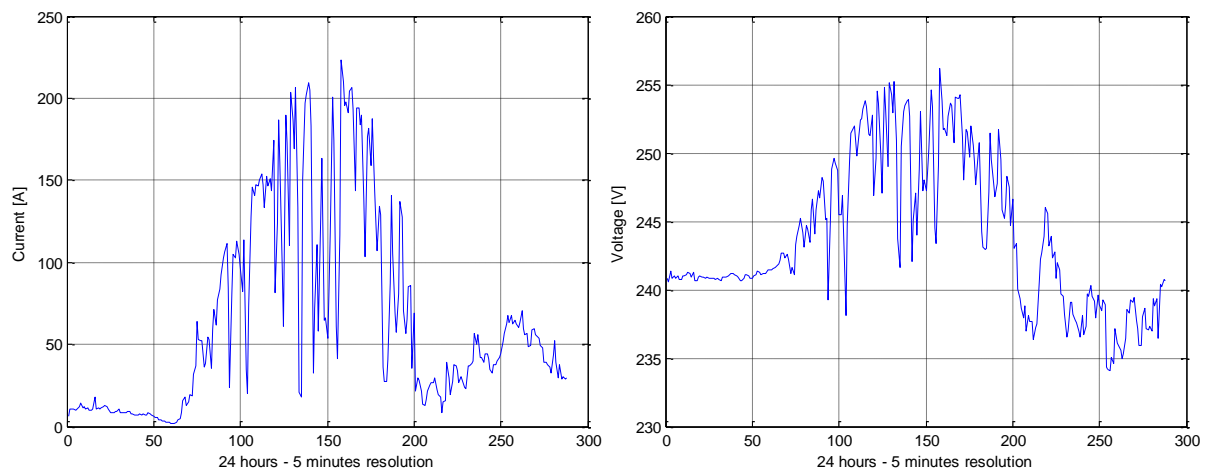


Figure 33: Current and voltage outputs for the Summer Load Profiles and PVs

As a summary, Figure 34 and Figure 35 contain the comparison of currents and voltage profiles for the winter and summer cases, respectively. This figures show that the largest impacts in this particular feeder are produced by the incorporation of EHP.

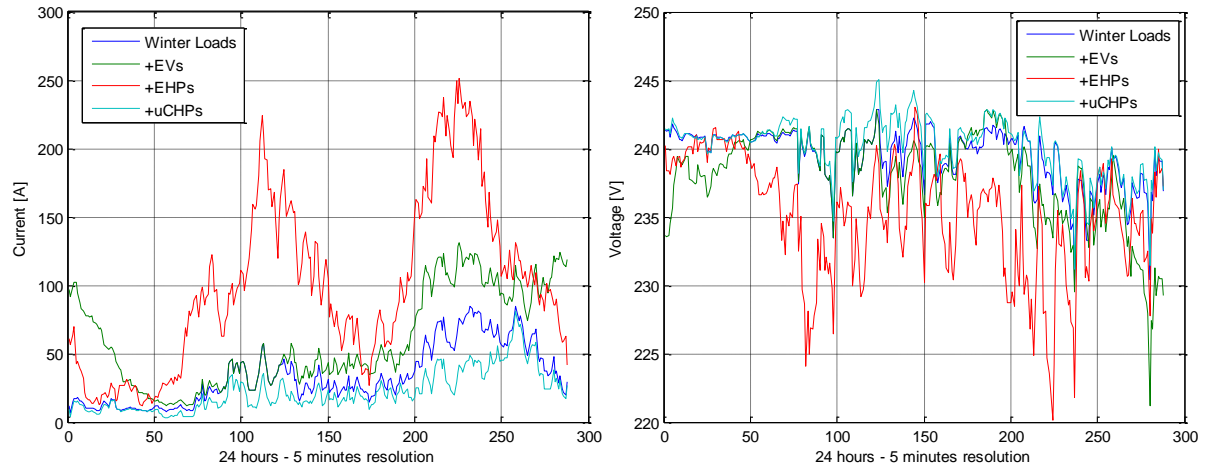


Figure 34: Current and voltage comparison for all the winter cases

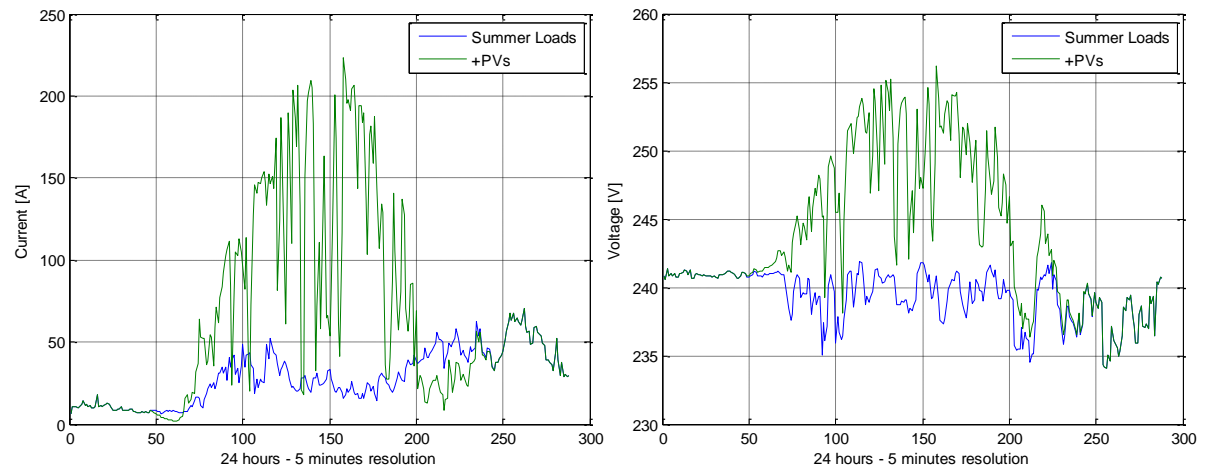


Figure 35: Current and voltage comparison for all the summer cases

4 Publications Based on the Models

The networks and profiles created during the development of the LV Network Solution Project have enabled an important amount of research about the impacts of low carbon technologies on LV distribution networks and also the analysis and investigation of several potential actions to minimise those impacts. Many of these studies have been published or recently accepted to peer-reviewed international journals and top international conferences.

ENWL and The University of Manchester are making available the presented network models and LCT profiles to encourage further research in this area of key importance worldwide.

4.1 Published/Accepted Papers

1. A. Navarro, L.F. Ochoa, "Probabilistic Impact Assessment of Low Carbon Technologies in LV Distribution Systems", IEEE Transactions on Power Systems, In Press, Accepted in Jun. 2015.
DOI Link: <http://dx.doi.org/10.1109/TPWRS.2015.2403252>
2. V. Rigoni, L.F. Ochoa, G. Chicco, A. Navarro-Espinosa, T. Gozel, "Representative Residential LV Feeders: A case study for the North West of England", IEEE Transactions on Power Systems, In Press, Accepted in Jan. 2015.
DOI Link: <http://dx.doi.org/10.1109/TPWRS.2015.2403252>
3. A. Navarro Espinosa and L. Ochoa, "On the Cascading Effects of Residential-Scale PV Disconnection Due to Voltage Rise", in Proc. of IEEE Power and Energy Society General Meeting, Jul. 2014.
DOI Link: <http://dx.doi.org/10.1109/PESGM.2014.6939428>
4. A. Navarro Espinosa and P. Mancarella, "Probabilistic modelling and assessment of the impact of electric heat pumps on low voltage distribution networks" Applied Energy, vol. 127, pp. 249-266, Aug. 2014.
DOI Link: <http://dx.doi.org/10.1016/j.apenergy.2014.04.026>
5. Y. Zhou, A. Navarro Espinosa and J. Mutale, "Security of Supply: Implication of Residential Photovoltaic Panels in Low Voltage Network", in Proc. of IEEE PES International Conference on Power System Technology (POWERCON2014), Oct. 2014.
DOI Link: <http://dx.doi.org/10.1109/POWERCON.2014.6993985>
6. A. Procopiou, C. Long, and L. Ochoa, "Voltage Control in LV Networks: An initial Investigation," in Proc. of IEEE PES Innovative Smart Grid Technologies Conference (ISGT-Europe), Oct. 2014.
DOI Link: <http://dx.doi.org/10.1109/ISGTEurope.2014.7028971>
7. A. Navarro Espinosa, L. F. Ochoa, and D. Randles, "Assessing the Benefits of Meshed Operation of LV Feeders with Low Carbon Technologies," in Proc. of IEEE PES Innovative Smart Grid Technologies Conference (ISGT), Feb. 2014.
DOI Link: <http://dx.doi.org/10.1109/ISGT.2014.6816494>
8. A. Ballanti, A. Navarro Espinosa, L. F. Ochoa, and F. Pilo, "Assessing the Benefits of PV VAR Absorption on the Hosting Capacity of LV Feeders," Innovative Smart Grid Technologies Europe (ISGT EUROPE), Copenhagen 2013 IEEE/PES, pp.1-5, 6-9 Oct. 2013.
DOI Link: <http://dx.doi.org/10.1109/ISGTEurope.2013.6695423>
9. A. Navarro Espinosa, L. F. Ochoa, P. Mancarella, and D. Randles, "Impacts of Photovoltaics on Low voltage Networks: A Case Study for the North West of England," in Proc. of 22th International Conference on electricity Distribution (CIRED 2013), Jun. 2013.
DOI Link: <http://dx.doi.org/10.1049/cp.2013.1229>

10. A. Navarro Espinosa, L. F. Ochoa, and D. Randles, "Monte Carlo-Based Assessment of PV Impacts on Real UK Low Voltage Networks," in Proc. of IEEE Power and Energy Society General Meeting, Jul. 2013.
DOI Link: <http://dx.doi.org/10.1109/PESMG.2013.6672620>
11. A. Navarro Espinosa, L. F. Ochoa, and P. Mancarella, "Learning from Residential Load Data: Impacts on LV Network Planning and Operation," in Proc. of 6th IEEE PES Transmission and Distribution: Latin America Conference and Exposition, Aug. 2012.
DOI Link: <http://dx.doi.org/10.1109/TDC-LA.2012.6319101>
12. K Petrou, J. Quirós-Tortós, and L.F. Ochoa, "Controlling EV charging points for congestion management of UK LV networks," in Proc. of IEEE PES Innovative Smart Grid Technologies Conference (ISGT-America), Feb. 2015.
13. A. Navarro Espinosa and L. Ochoa, "Increasing the PV Hosting Capacity of LV Networks: OLTC-Fitted Transformers vs. Reinforcements" in Proc. of IEEE PES Innovative Smart Grid Technologies Conference (ISGT-America), Feb. 2015.
14. A. Procopiou, C. Long, and L. Ochoa, "On the Effects of Monitoring and Control Settings on Voltage Control in PV-Rich LV Networks," in Proc. of IEEE PES Power and Energy Society General Meeting (PES), Jul. 2015.
15. A. Ballanti, L.F. Ochoa, V. Turnham, "Monte Carlo assessment of customer voltage constraints in the context of CVR schemes", 23rd International Conference on Electricity Distribution (CIRED 2015), *Accepted*.
16. A. Navarro Espinosa, R. Shaw, D. Randles and L. Ochoa, "Reconstruction of Low Voltage Networks: From GIS Data to Power Flow Models", 23rd International Conference on Electricity Distribution (CIRED 2015), *Accepted*.
17. A. Navarro Espinosa, T. Gozel, R. Shaw, D. Randles and L. Ochoa, "Data Analysis of LV Networks: Determination of key parameters from one year of monitoring over hundreds of UK LV feeders", 23rd International Conference on Electricity Distribution (CIRED 2015), *Accepted*.
18. M. Aydin, A. Navarro Espinosa and L. Ochoa, "Investigating the Benefits of Meshing Real UK LV Networks", 23rd International Conference on Electricity Distribution (CIRED 2015), *Accepted*.
19. J. Quiroz-Tortos, A. Navarro Espinosa, L. Ochoa, M. Gillie and R. Hartshorn, "Probabilistic Impact Assessment of EV Charging on Residential UK LV Networks", 23rd International Conference on Electricity Distribution (CIRED 2015), *Accepted*.
20. C. Long, L.F. Ochoa, G. Bryson and D. Randles, "Adoption of capacitors to mitigate voltage issues in low voltage networks with photovoltaic systems", to 23rd International Conference on Electricity Distribution (CIRED 2015), *Accepted*.
21. A. Navarro Espinosa, L. Zhang, N. Good, P. Mancarella and L. Ochoa, "EHP in Low Voltage Networks: Understanding the Effects of Heat Emitters and Room Temperatures", IEEE PES PowerTech 2015, *Accepted*.

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