

Title: **Report for Deliverable 3.1 "Tool for translating data/reports from monitoring devices into OpenDSS"**

Synopsis: This document describes the procedure to translate the CSV daily reports from iHost (i.e., data from monitors in a given LV network) into OpenDSS so it can be used for load allocation purposes. The load allocation technique is also described in this document.

Document ID: UoM-ENWL_LVNS_Deliverable3.1v04

Date: 15th November 2012

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Executive Summary

The aim of the LV Network Solutions project is to provide ENWL with greater understanding of the characteristics, behaviour, and future needs of their low voltage networks. This will be based on the analysis of data gathered by appropriate monitoring schemes to be deployed on hundreds of LV feeders and substations, and the assessment of the corresponding computer-based network models in current and future scenarios.

In order to carry out impact analyses of low carbon technologies on the LV networks the networks themselves need to be modelled accordingly. For this, two sets of data are essential: network data and load profiles per customer/MPAN. The former is already being extracted and processed from ENWL's GIS-based files (as explained in Deliverables 1.3-1.4). The latter can either be produced from synthetic models or from monitored data. In this project, monitored data is, however, limited to one (LV busbar) or three (LV busbar, midpoint and endpoint) three-phase points in a given feeder. Consequently, a technique is required to 'disaggregate' monitored data for each moment in time (according to the sampling rate) in a way that MPANs are allocated loads that, as a whole, produce the same voltages and currents recorded by the monitors. This technique is called load allocation.

This document describes the procedure to translate the CSV daily reports from iHost (i.e., data from monitors in a given LV network) into OpenDSS so it can be used for load allocation purposes. The adopted load allocation procedure (embedded in OpenDSS) is also described in this document using test LV feeders.

Early results (limited to unrestricted domestic customers) show that profiles generated by the load allocation algorithm, enhanced by the use of Elexon-based data, produce:

- almost the exact aggregated load seen by monitors (error less than 0.5%); and,
- very similar single-phase voltages (errors of less than 2%).

Nonetheless, errors per individual customer/MPAN demand profile can be significant (compared to the pre-defined/synthetic load profiles). Consequently, it is important to highlight that MPAN profiles produced by the technique should not be considered individually but as a set of profiles that produce voltages and currents that match the corresponding monitoring points.

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1 Introduction

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

The aim of this project is to provide ENWL with greater understanding of the characteristics, behaviour, and future needs of their LV networks. This will be based on the analysis of data gathered by appropriate monitoring schemes to be deployed on hundreds of LV feeders and substations, and the assessment of the corresponding computer-based network models in current and future scenarios.

1.1 Deliverable 3.1

In order to carry out impact analyses of low carbon technologies on LV networks the networks themselves need to be modelled accordingly. For this, two sets of data are essential: network data and load profiles per customer/MPAN (Meter Point Administration Number). The former is already being extracted and processed from ENWL's GIS-based files (as explained in Deliverables 1.3-1.4). The latter can either be produced from synthetic models (such as the one from CREST [1]) or from monitored data. In this project, monitored data is, however, limited to one (LV busbar) or three (LV busbar, midpoint and endpoint) three-phase points in a given feeder. Consequently, a technique is required to 'disaggregate' monitored data for each moment in time (according to the sampling rate) in a way that MPANs are allocated loads that, as a whole, produce the same voltages and currents recorded by the monitors. This technique is called load allocation.

Deliverable 3.1 "Tool for translating data/reports from monitoring devices into OpenDSS" has been divided into two streams: translation of iHost reports and the adopted load allocation technique.

First, this document describes the procedure to translate the CSV daily reports from iHost (i.e., data from monitors in a given LV network) into OpenDSS [2] so it can be used for load allocation purposes. Although the format for the CSV reports have been previously agreed by Nortech and The University of Manchester, the data needs to be extracted in a systematic way so the load allocation technique can be carried out for each time step.

The load allocation technique, capable of estimating the unknown individual demands (kW and kVAr) of customers based on limited monitored points, is then described in the subsequent part of the report. This technique requires three sets of data: network data, currents at the head of the feeder (and other monitoring points if available), and approximate values of demand for each customer. While the latter can be any (sensible) value, such as the corresponding after diversity maximum demand, the closer to reality the better the final estimate. Here, these approximate demand values are obtained from Elexon's half-hourly demand profiles. Average consumptions per profile class are used on the same time and date as the monitored data.

2 Translation of Daily Reports from iHost into OpenDSS

The adopted load allocation technique (to be formally presented in the next section) requires from the monitored data the following information at a given moment in time for a given feeder:

- Three-phase currents from the monitor at the LV busbar; and,
- Three-phase currents and voltages from the monitors at the mid and end points.

The monitor at the LV busbar is called *EnergyMeter* within OpenDSS, whereas monitors downstream are called *Sensors*. The data required by these elements is contained in the daily reports produced by iHost. However, the data needs to be extracted in a systematic way so the load allocation technique can be carried out for each time step.

2.1 CSV Daily Reports

Monitored data for the LV Network Solutions project are compiled in CSV files that are created per LV substation on a daily basis. This is done automatically by the iHost server and in a format agreed previously by Nortech and the University. Data from all the devices installed at a give substation (including those downstream) are captured in a single CSV file for that substation only with each device providing a row of data for each timestamp.

In order to correlate each device with its location so it can be identified in the network models already in OpenDSS, the following data is used:

- Feature number for monitors at the LV busbar; and,
- Feature number and XY coordinates for monitors at the mid and end points.

The feature number is a unique code that represents the LV feeder that the monitors are connected to. The XY coordinates for the monitors downstream the busbar make it possible to pinpoint their exact (or as accurate as possible) location. Note that by the time of writing of this report, the final process to collect the XY coordinates has not yet been agreed. Nonetheless, the methodology presented here considers that information.

In addition to the feature number and the XY coordinates, a sequence number also exist that allows identifying the monitor at the busbar (number 0), midpoint (number 50), and endpoint (number 100).

Data is recorded using the following two types of files:

- PRN_YYYYMMDD_MinMaxMean.CSV; and,
- PRN_YYYYMMDD_MeanOnly.CSV.

Where PRN is the plant reference number (ENWL's ID of the substation), YYYY is year, MM is month, and DD is day. MinMaxMean files provide minimum, maximum and mean values of voltage, current and power per phases for the adopted sampling rate. MeanOnly files, on the other hand, only provide the mean values.

2.2 Creation of Individual Files per Feeder

The load allocation technique will be performed for each adopted time step (e.g., every minute, every 5 minutes, etc). This means that the information contained in a daily report for a given LV network needs to be split accordingly and per monitored feeder.

The new (TXT) files will be produced from the daily reports that include only mean values as the minimum and maximum information are for other purposes (i.e., characterisation of LV networks). The new files will be named as EM_FID_YYMMDDHHMM.TXT, where FID is the feature number (i.e., feeder ID) and YYMMDDHHMM corresponds to date and time (year, month, day, hour and minute).

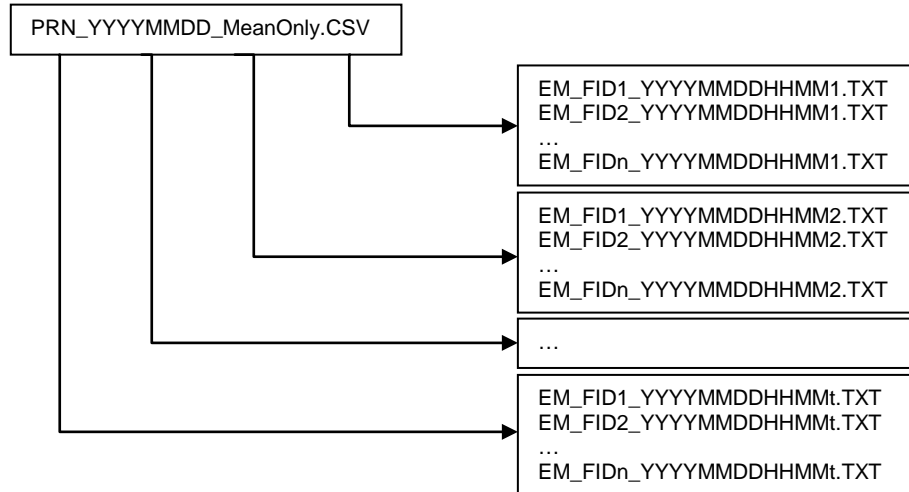


Figure 1. Data reorganisation from CSV daily reports

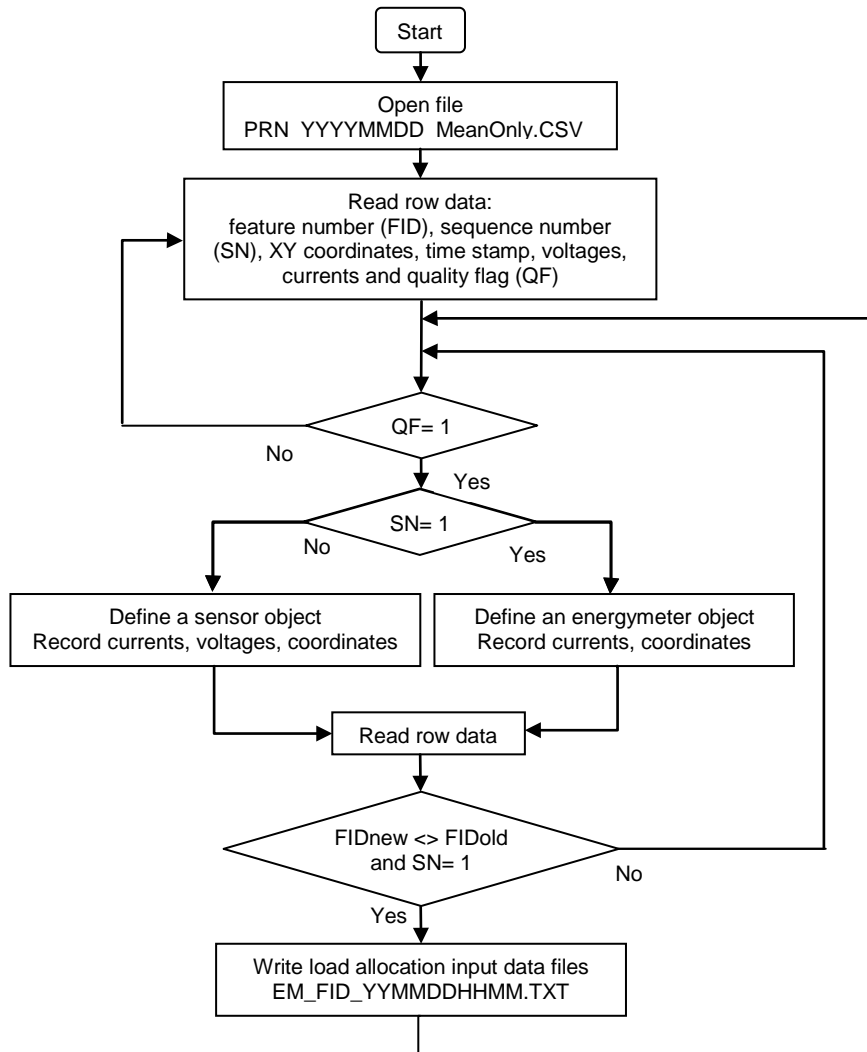


Figure 2. Creation of individual files for load allocation purposes

The files produced for each monitored LV feeder per time step will be stored in a single folder identified by the substation's code and corresponding date. The total number of files will depend on the number of monitored feeders and adopted sampling rate, as illustrated in Figure 1. For example, a single feeder with monitors adopting a sampling rate of 5 minutes will result in 288 new files for a given day.

As mentioned previously, for a given monitored period OpenDSS requires the (average) currents for the *EnergyMeter* (representing the monitor at the busbar) and the (average) currents and voltages for the *Sensors* (downstream monitors). Each of the new files has to be structured in a way to provide this information without further processing. This means a procedure has to be in place to extract the data from the CSV daily reports.

Figure 2 presents a flow chart with the logic to extract the key information from the daily reports. First, a daily report is opened. Data including feature number, sequence number, XY coordinates, time stamp, voltage and current values per phases, quality flag are read per row in turn. If the quality flag is "0" (i.e., there is a problem with data) then that row is not considered and the following row is read.

The next step is to define whether the row corresponds to an *EnergyMeter* or to a *Sensor*. The sequence number is used for this: "1" corresponds to the *EnergyMeter* (monitor at the busbar), "50" to a midpoint *Sensor* (midpoint monitor), and "100" to an endpoint *Sensor*. Once identified, the corresponding data is recorded accordingly for the new file.

The final step is to produce the file for the corresponding feeder and time interval. For this, it is checked whether the subsequent row of data has the same feature number as the previous one, i.e., if it is part of the same feeder. If it is different, then no more monitors are related to the same feeder (for the same time interval). Hence, the corresponding file is created (using the FID and time stamp).

To use the new files for load allocation purposes the mid and endpoint monitors need to be adequately placed and modelled in the OpenDSS network files. This is done manually by using the corresponding XY coordinates and by either attaching the monitors to existing nodes or creating new ones.

The outcome of the load allocation procedure will be daily load profiles for each MPAN in the corresponding feeder. The granularity of these load profiles will depend on the sampling rate used for the CSV daily report.

3 Load Allocation

By using a load allocation technique it is possible to 'disaggregate' monitored data for each moment in time (according to the sampling rate) in a way that customers (i.e., MPANs) are allocated loads that, as a whole, produce the same voltages and currents recorded by the monitors.

The proposed load allocation technique is capable of estimating the unknown individual demands (kW and kVAr) of customers based on limited monitored points. This technique requires three sets of data: network data, currents at the head of the feeder (and other monitoring points if available), and approximate values of demand for each customer. While the latter can be any (sensible) value, such as the corresponding after diversity maximum demand, the closer to reality the better the final estimate [3], [4]. Here, these approximate demand values will be obtained from Elexon's half-hourly demand profiles. Average consumptions per profile class will be used on the same time and date (albeit from a previous year) as the monitored data.

The following subsections will present how the load allocation works in a simple LV feeder, the improvements to be considered in the OpenDSS implementation, and a more elaborated example using a generic LV network.

3.1 Simple LV Feeder

Consider the simple three-phase LV feeder shown in Figure 3, with three-phase balanced loads at buses 4, 5 and 6. If the loads are known, then the L-N voltages and single-phase currents can be calculated by solving a power flow (as shown in Figure 4).

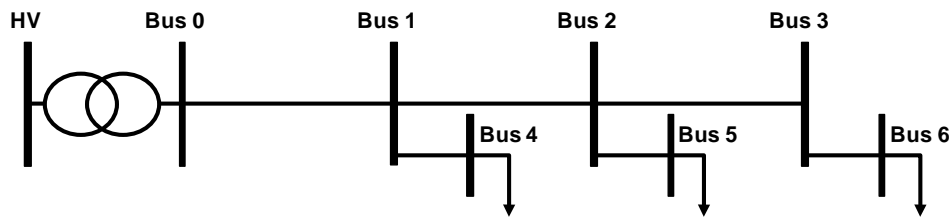


Figure 3. Simple LV Feeder

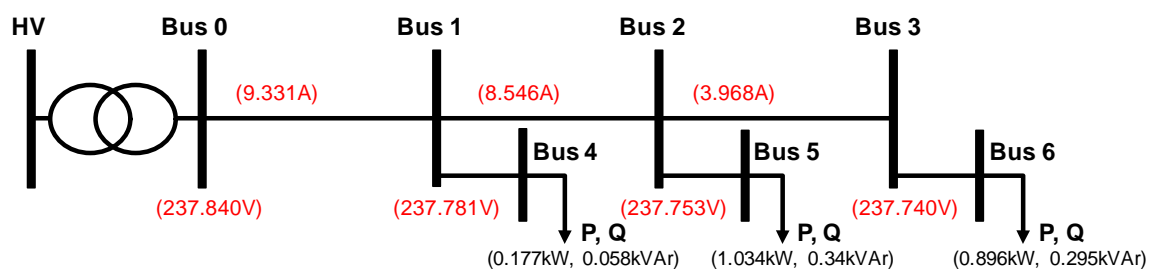


Figure 4. Simple LV feeder with known loads (single-phase values)

However, when the loads are unknown, as it is the case of (most of) those connected to LV networks, they have to be estimated in order to make it possible to compute voltages and currents throughout the feeder. The proposed load allocation technique (embedded in OpenDSS) allows such estimation provided that currents at the head of the feeder are known and that initial approximate values of load can be given.

Considering that the current through bus 0 and 1 (i.e., 9.331A per phase) is known (e.g., data from monitors – represented as *EM*) and assuming a flat 0.6 kW initial approximate value for all the three-phase loads then it is possible to apply the load allocation procedure. Figure 5 shows the estimated

loads (in red) considering a fixed power factor of 0.95 inductive. It can be seen that, for this particular feeder, the algorithm split evenly the total load among buses 4, 5 and 6. This even allocation is mainly due to the almost negligible voltage drop of the feeder (very short lines) and the fact that the initial approximate values of loads were the same for the three loads.

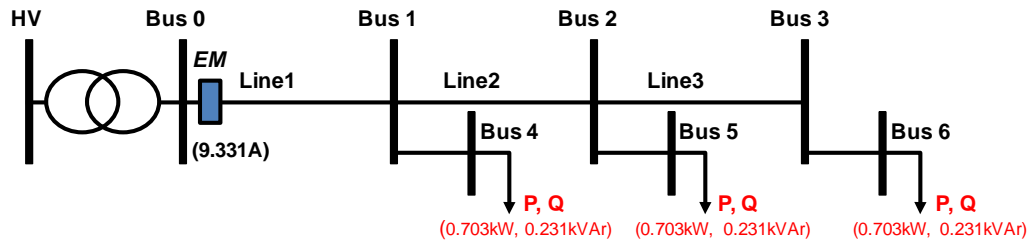


Figure 5. Results from the load allocation algorithm

Although this simple LV feeder is not realistic, it highlights the fact that the load allocation algorithm has limitations given the restricted amount of information. The use of extra monitors (downstream the feeder) will certainly improve its accuracy as it will allow matching currents and voltages at monitored points. Individual initial approximate values of load can also contribute to results closer to the actual values. However, this is unlikely to be adopted as the corresponding information is not available (based on energy consumption per customer/MPAN).

For illustration purposes, the above process of producing 'monitored' currents at the head of the feeder based on pre-defined loads to then run the load allocation algorithm was carried out for different load levels throughout a day (every 30 minutes). A comparison between the pre-defined loads and the allocated ones for buses 4 and 5 is shown in Figure 6 (the case above is at 9.00am).

Clearly, the algorithm continues to evenly allocate the total load which results in many cases with significant differences between pre-defined and allocated values. This is because a single initial approximate value of load was given to the three of them. However, what is important –and will be discussed later with the generic LV network– is how voltages after the load allocation compare to those values recorded by the monitors.

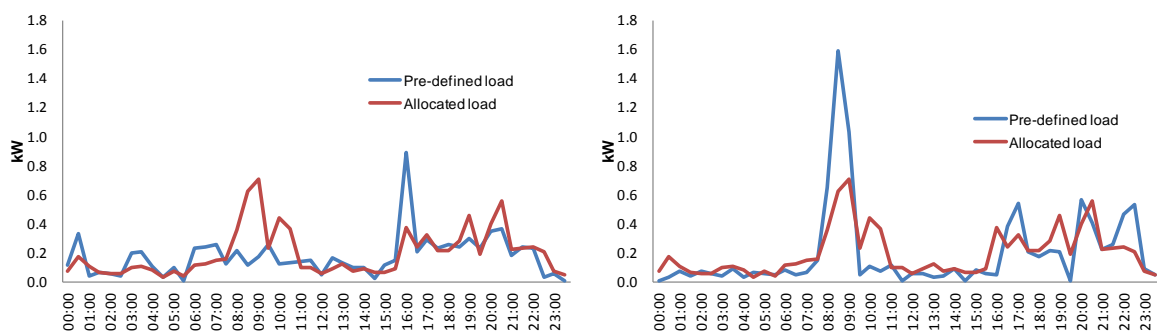


Figure 6. Pre-defined and allocated single-phase loads in a day: Bus 4 (left) and Bus 5 (right)

3.2 OpenDSS Implementation

The full implementation of the load allocation procedure in OpenDSS with real-life networks involves the use of monitors downstream the LV busbar. In addition, to improve the accuracy of the results, the initial approximate values of load will be based on Elexon's half-hourly demand profiles. Average consumptions per profile class will be used on the same time and date (albeit from a previous year) as the monitored data.

Once the LV network is modelled in OpenDSS (see Deliverable 1.2 for details), the load allocation procedure requires the following main steps:

1. Definition of initial approximate values of loads
2. Definition of *EnergyMeter* and *Sensors*
3. Execution of the load allocation algorithm

3.2.1 Definition of initial approximate values of loads

As mentioned previously, the better these initial approximate values are the more accurate the results. While it is possible to adopt a flat value for all consumers based on their average hourly power consumption in a month or a year (e.g., 0.4 kW for domestic unrestricted), this will be in many cases throughout the day far from reality.

DNOs are given by Elexon half-hourly profiles of the aggregated consumption (MWh) of their customers per profile class for the last financial year. With this it is possible to calculate the corresponding half-hourly average demand, as shown in Figure 7. In addition, each MPAN connected to the studied LV networks will also be identified according to its profile class. Consequently, half-hourly average demands for a given day (albeit a previous year) and time (constant during periods smaller than 30 minutes).

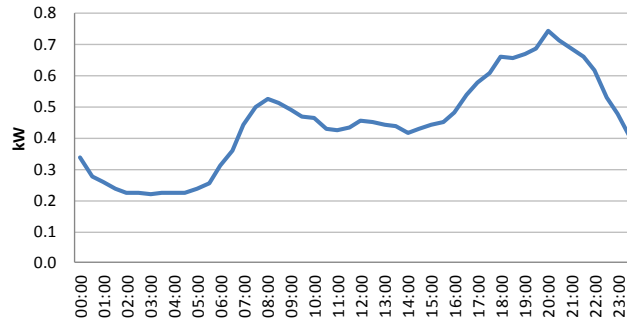


Figure 7. Half-hourly diversified (average) domestic unrestricted demand profile (1st April 2010)

It is important to highlight that OpenDSS does not formally require the initial approximate values for the loads. It requires either the energy consumption (including number of days) or the capacity of the substation. These values are accompanied with factors that are used to tune the load allocation algorithm. However, ultimately, OpenDSS internally translates this information into initial approximate values for the loads.

In order to incorporate the average half-hourly demand per profile class, energy consumption (defined in OpenDSS as *kWh*), number of days (*kWhdays*) and corresponding factor (*Cfactor*) are given in a way that actually provide the averages from Elexon data. OpenDSS calculates the initial approximate values for the loads (*kW*) for period *t* as follows:

$$kW(t) = Cfactor(t) * kWh / (kWhdays * 24)$$

Consequently, to 'force' OpenDSS to adopt an initial approximate value equal to the average from Elexon data (P_{ELEXON}) for a given profile class and period *t*, the *Cfactor* has to be calculated as:

$$Cfactor(t) = P_{ELEXON}(t) * kWhdays * 24 / kWh$$

where the values of energy (*kWh*) and number of days (*kWhdays*) become irrelevant, i.e., 'dummy' values (e.g., equal to 1).

With the above process it is possible to ensure that the initial approximate values of loads are much more realistic than a flat value for all periods. In terms of the reactive power, this will typically be calculated based on a given (fixed) power factor (e.g., 0.98 inductive).

3.2.2 Definition of *EnergyMeter* and *Sensors*

The adopted load allocation technique estimates loads based on the data from the *EnergyMeter* and *Sensors*. The former provides the single-phase currents at the head of the feeder, and the latter currents and voltages downstream. In the LV Network Solutions project, the *EnergyMeter* corresponds to the monitor installed at the LV busbar whereas *Sensors* correspond to those monitors installed at mid and endpoints. An example of the code required to model the *EnergyMeter* and *Sensors* in OpenDSS, including the corresponding input data, is shown in Figure 8.

```

EM_SyntheticNetwork_1800.txt - Notepad
File Edit Format View Help
New Energymeter.Energymeter1 Element=Line.LINE1 Terminal=1
Energymeter.Energymeter1.peakcurrent = [219.552 203.356 249.482 ]

New Sensor.Sensor2 Element=Line.LINE2 Terminal=1 kvBase=0.412
Sensor.Sensor2.Clear=Yes Currents= [21.4748 29.1105 23.688]
kvs=[0.235716 0.236089 0.235316]
New Sensor.Sensor232 Element=Line.LINE232 Terminal=1 kvBase=0.412
Sensor.Sensor232.Clear=Yes Currents= [1.46E-11 2.46E-11 1.93E-11]
kvs=[0.229899 0.232926 0.229582]
Ln 1, Col 1
    
```

Figure 8. Example of OpenDSS code for *EnergyMeter* and *Sensors*

Once the CSV daily reports per LV network have been decomposed into files per feeder and per time stamp, and the *EnergyMeter* and *Sensors* per feeder have been modelled accordingly (considering XY coordinates), an automatic process takes place to run the load allocation algorithm. This process is carried out per time step and will ultimately result in daily load profiles per MPAN connected to the analysed feeder.

3.3 Generic LV Feeder

Let us consider the generic LV feeder shown in Figure 9. It was created adopting ENWL's Code of Practice for LV Network Design [5]. This network has a total length of 710m with a total of 150 customers (single-phase, domestic unrestricted). Phase connections are randomly chosen. Voltage at the busbar is considered to be fixed at 412 V L-L.

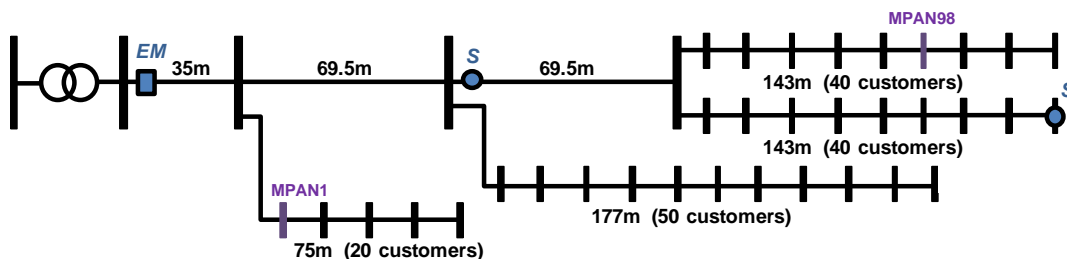


Figure 9. Generic LV Network

First, minute-by-minute domestic unrestricted profiles (a weekday in April) produced by the CREST tool are randomly allocated to the customers in order to create 'monitored' data (similarly to the simple LV feeder presented previously, section 3.1). The corresponding power flow analysis (minute-by-minute) is carried out.

Then, three locations in the feeder are considered to have monitors: the LV busbar (*EnergyMeter*), the midpoint (*Sensor*) and the endpoint (*Sensor*) – as shown in Figure 9. The corresponding single-phase currents and voltages obtained through the power flow analysis are 'given' to these monitors as data.

In addition to the monitored data, the load allocation algorithm requires the initial approximate values of loads. For this, half-hourly average demand (in kW) based on the Elexon profile for 1st of April 2010 (Figure 7) was used.

For simplicity, the load allocation algorithm was carried only for those points at the hour and half hour. A comparison between pre-defined and allocated loads for two of the customers (or MPANs) is shown in Figure 10. The relative positions of MPAN1 and MPAN98 can be seen in Figure 9.

The total allocated load (sum of all single-phase MPANs) matches almost exactly the total pre-defined load (max error of 0.4%, min error of -0.14%). However, when it comes to individual allocations the errors can increase significantly. On the other hand, while the results are strongly influenced by the fact that one initial approximate value is given to all MPANs (from the Elexon profile), it is clear that these are tuned accordingly so –as a whole– they match the values 'recorded' by the monitors (*EnergyMeter* and *Sensors*). This is the main reason why the MPAN profiles to be created in the LV Network Solutions project should not be considered individually but as a set of profiles that produce voltages and currents that match the corresponding monitoring points.

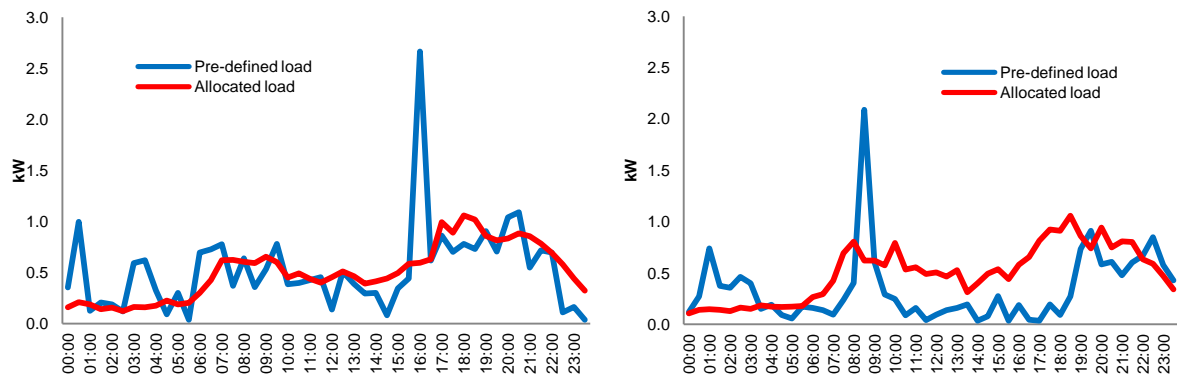
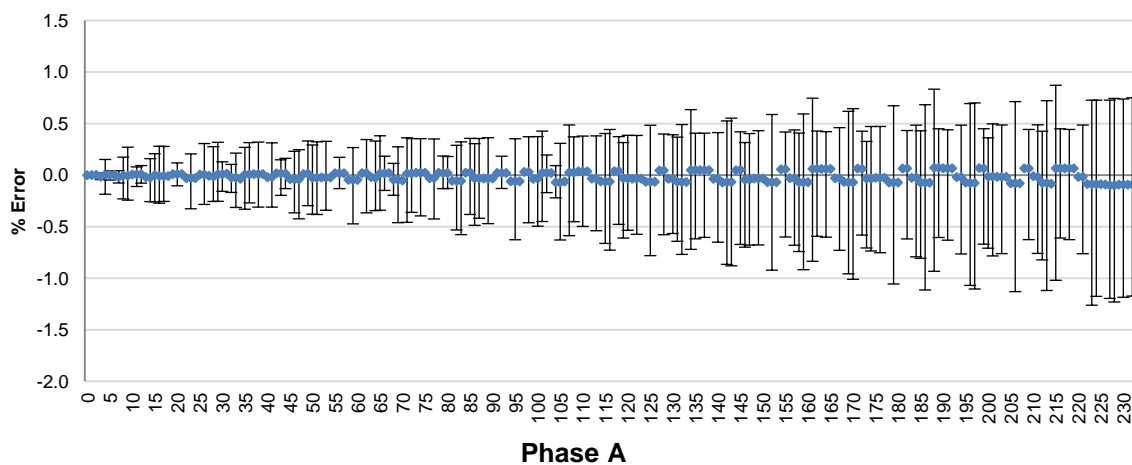


Figure 10. Pre-defined and allocated loads in a day: MPAN1 (left) and MPAN98 (right)

The single-phase voltage error bands (in percentage) for all the MPANs are presented Figure 11. These error bands have been produced by considering the errors for each hour and half hour from values calculated with the pre-defined loads. It can be seen that most of the errors are not bigger than +/- 1%.

The (electrical) distance from the sensors also matters. Indeed, the larger errors seen in Figure 11 occur for those MPANs located further from the monitors (i.e., *EnergyMeter* and the *Sensors*). For this generic LV feeder this mainly applies to the laterals. Nonetheless, the largest error found is around -1.6% for only a few nodes connected to phase b.



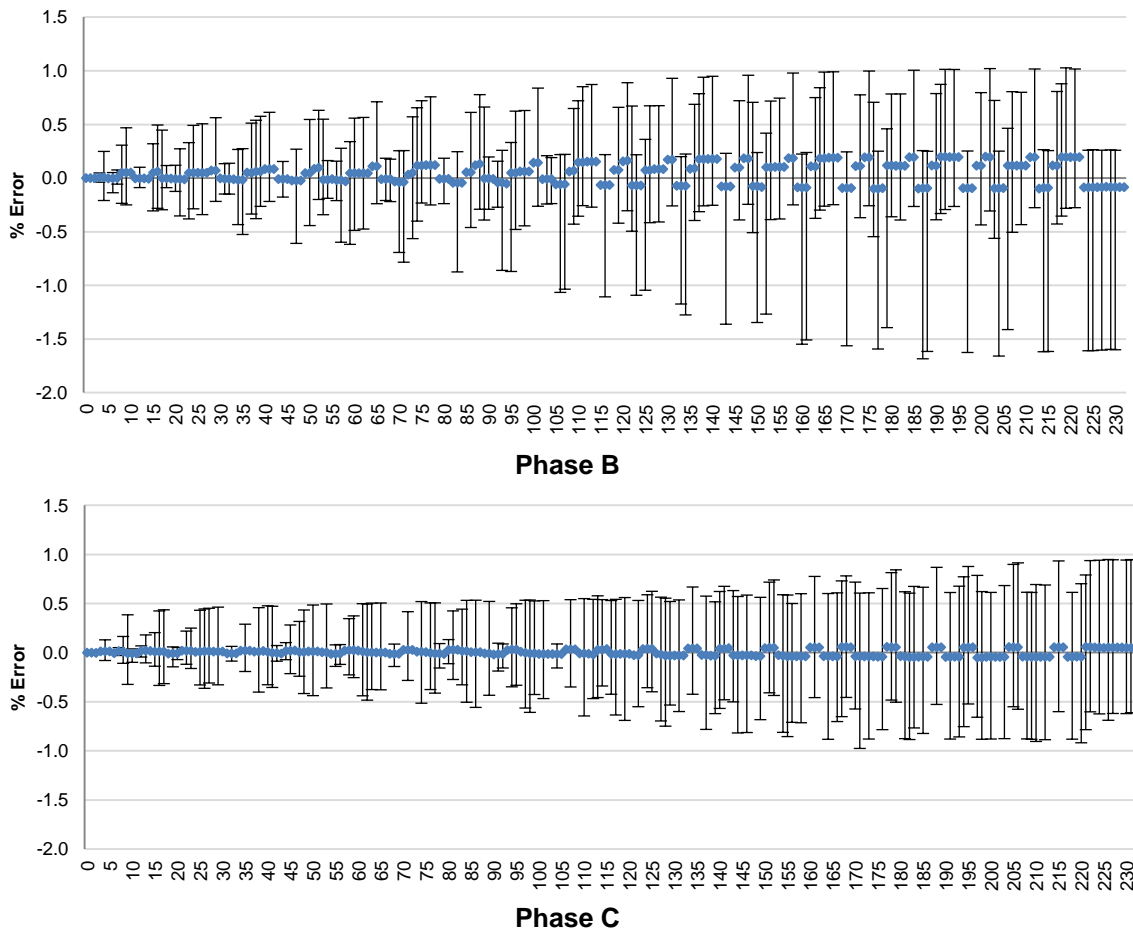


Figure 11. Voltage error bands for MPANs: Phases A, B, and C

4 Conclusions

In this document, two key elements required to create individual customer/MPAN load profiles have been described.

First, the procedure to translate the CSV daily reports from iHost (i.e., data from monitors in a given LV network) into OpenDSS has been presented. This requires splitting the daily reports in a way that the load allocation procedure can take place for each time step (e.g., every minute) for each feeder.

Then, the load allocation procedure embedded in OpenDSS was described and example using test LV feeders were presented. Early results (limited to unrestricted domestic customers) show that profiles generated by the corresponding algorithm, enhanced by the use of Elexon-based data, produce:

- almost the exact aggregated load seen by monitors (error less than 0.5%); and,
- very similar single-phase voltages (errors of less than 2%).

Nonetheless, errors per individual customer/MPAN demand profile can be significant (compared to the pre-defined/synthetic load profiles). Consequently, it is important to highlight that MPAN profiles produced by the technique should not be considered individually but as a set of profiles that produce voltages and currents that match the corresponding monitoring points.

5 References

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