Deliverable 3.2 "Production of validated networks"

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Title: **Deliverable 3.2 “Production of Validated Networks”**

Synopsis: This document describes the methodology used to validate the LV feeders studied throughout the LV Network Solutions project including feeders with PV systems. The validated feeders presented here are 16 corresponding to three different networks.

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Executive Summary

This report corresponds to Deliverable 3.2 "Production of Validated Networks" part of the Low Carbon Network Fund Tier 1 project "LV Network Solutions" run by Electricity North West Limited (ENWL).

The aim of the LV Network Solutions project is to provide ENWL with greater understanding of the characteristics, behaviour, and future needs of their low voltage networks. This 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 particular, this report explains the methodology used to validate the LV feeders studied throughout the LV Network Solutions project. This is necessary in order to verify whether the topology adopted in the models is the actual topology of the corresponding feeder. The methodology compares monitoring data at the head of each feeder with power flow results that adopt models based on ENWL's profiles. This was also extended to cater for feeders with photovoltaic systems by adopting sun irradiance monitoring data from The University of Manchester.

This report presents the results for 16 feeders corresponding to three different LV networks: Ruskin Avenue, Cutler Close and Dunton Green. From these, 11 feeders have successfully validated considering the proposed metrics. However, the results for 5 of them were outside the metrics and action will be taken so ENWL could provide further information. The methodology will be extended to all our LV feeder models.

It is important to highlight the proposed methodology is highly sensitive to the number of customers. From the extensive analysis, best results are found with feeders with more than 50 customers. Lower values of customers place too much bias towards the models used per profile class.

The University of Manchester

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1 Introduction – Overview of the Validation Process

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

The objective of this project is to provide ENWL with greater understanding of the characteristics, behaviour, and future needs of their LV networks. This 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.

As part of the LV Network Solutions project, approximately 1000 feeders in 200 LV networks will be monitored (head of the feeder and in some cases mid and end points). In addition, the corresponding computer-based models of the feeders are being implemented in the distribution system analysis software package OpenDSS. However, to ensure that the network characteristics are modelled as accurately as possible, it is crucial to validate them with the corresponding monitoring data.

Given that the models adopted for the conductors have followed ENWL Code of Practices, the proposed network validation focuses on verifying whether the topology adopted in the models is the actual one from which parameters are being monitored. For this, realistic load models have to be adopted in order to mimic the behaviour of customers. This is a very challenging task due to the uncertainties involving customer demand behaviour that in turn depends on weather conditions (e.g., sun radiation, summer/winter) and the corresponding phase connection.

The proposed methodology uses diversified ENWL load profiles (based on Elexon profiles) for each of the customers modelled in a given feeder. In particular Profile Class 1 (PC1), PC2, PC3 and PC4 were used also taking into consideration the date that is linked to that of the monitoring data. For those feeders with residential photovoltaic systems data from the Whitworth Meteorological Observatory at The University of Manchester was used. Once all these load and generation models are defined, a power flow analysis is carried out.

The validation method ultimately compares the total energy consumed (errors for both throughout the day, $E_{3Ø\ (all\ day)}$, and during peak demand, $E_{3Ø\ (5\text{-}8pm)}$) of the simulated feeder and that derived from the corresponding monitoring data. Four criteria are used to finally decide whether a feeder has passed or not the validation.

1. Energy metrics are equal or smaller than 20%, then the model is valid.
   $$E_{3Ø\ (all\ day)}\ \&\ E_{3Ø\ (5\text{-}8pm)} \leq 20\% \rightarrow \text{valid feeder}$$

2. One energy metric is equal or bigger than 70%, then the mode is not valid.
   $$E_{3Ø\ (all\ day)}\ |\ E_{3Ø\ (5\text{-}8pm)} \geq 70\% \rightarrow \text{feeder not valid}$$

3. Energy metrics are between 20% and 70%, the feeder has up to 30 customers (MPANs), and the current and active power metrics have similar levels of error, then the feeder is valid.
   $$E_{3Ø\ (all\ day)}\ \&\ E_{3Ø\ (5\text{-}8pm)} \geq 20\%\ \&\ \#MPAN<30\ \&\ I_{a,b,c} \approx P_{3Ø} \rightarrow \text{valid feeder}$$

4. Energy metrics are between 20% and 70%, the feeder has more than 30 customers, and the current and power metrics have different levels of error, then feeder is not valid.
   $$E_{3Ø\ (all\ day)}\ \&\ E_{3Ø\ (5\text{-}8pm)} \geq 20\%\ \&\ (\#MPAN>30\ |\ I_{a,b,c} \approx P_{3Ø}) \rightarrow \text{feeder not valid}$$

This report presents the results for 16 feeders corresponding to three different LV networks: Ruskin Avenue, Cutler Close and Dunton Green. The results are presented in Table 1.From these, 11 feeders have successfully validated considering the proposed metrics. However, the results for 5 of them were outside the metrics and action will be taken so ENWL could provide further information. The methodology will be extended to all our LV feeder models.

It is important to highlight the proposed methodology is highly sensitive to the number of customers. Best results are found with feeders with more than 50 customers. Lower values of customers place too much bias towards the models used per profile class.

Table 1 Valid and Non-Valid Feeders

Plant Ref	Site Name	Feature ID	# MPAN	% PV	Valid?
458720	Ruskin Avenue	44061978	49	0%	Yes
458720	Ruskin Avenue	44061983	21	0%	Yes
458720	Ruskin Avenue	44061991	28	4%	Yes
458720	Ruskin Avenue	44061995	22	0%	Yes
458720	Ruskin Avenue	44062000	42	0%	No
458720	Ruskin Avenue	44062003	34	0%	Yes
458720	Ruskin Avenue	44062007	51	0%	Yes
458720	Ruskin Avenue	44062010	23	0%	No
458720	Ruskin Avenue	44062023	56	0%	Yes
452064	Cutler Close	118038349	13	31%	No
452064	Cutler Close	118038359	18	28%	Yes
452064	Cutler Close	118038372	11	0%	No
330127	Dunton Green	260055770	70	40%	Yes
330127	Dunton Green	260055773	31	13%	No
330127	Dunton Green	260055780	26	15%	Yes
330127	Dunton Green	260055783	53	77%	Yes

The Appendix includes detailed analysis (including the proposed metrics) for each of the 16 feeders analysed.

2 Network and Feeder Characteristics

The network validation methodology proposed here is applied to three LV networks with a total of 16 feeders. Two of these LV networks, Cutler Close and Ruskin Avenue, have been evaluated with monitoring data for 1st April 2013. The third one, Dunton Green, adopted 1st October 2012. The corresponding feeders for these three networks and dates have been selected based on their availability of adequate data.

It is important to highlight that the monitoring data used for Ruskin Avenue, although of good quality, did not specify the corresponding feeder codes (feature ID number). To solve this, the same sequence used by iHost reports from 29th April was adopted. Consequently, it might be the case (not confirmed yet) that the monitoring data does not correspond to the feeders as adopted here.

Each of the selected LV networks present different characteristics. Ruskin Avenue has only one PV system, the largest volume of customers (MPANs), and the longest network (addition of the lengths of the corresponding feeders). Dunton Green has the largest number of PV installations. Cutler Close has the least number of MPANs. A summary of the network characteristics, such as substation capacity, number of feeders, total length, number of MPANs and number of PV installations and total capacity, are given in Table 2.

Table 2 General Network Characteristics

Plant Ref	Site Name	Cap. kVA	# Feeders	Length (m)	# MPAN	# PV	PV Inst. kW
458720	Ruskin Avenue	750	9	9339	326	1	3
452064	Cutler Close	800	3	1608	42	9	33.72
330127	Dunton Green	750	4	5373	180	77	160.4

The customer and PV composition (in percentage) of each network is presented in Table 3. Most of the MPANs for all networks are domestic unrestricted customers (PC1), then domestic economy 7 (PC2) ranging from 1% to 10%, and non-domestic unrestricted customers (PC3) ranging from 0.5% to 2.4%. Ruskin Avenue has only one non-domestic economy 7 customer (PC4). In Dunton Green, the penetration of PV is 43% (in terms of number of customers). This figure is 21% for Cutler Close.

Table 3 Substation MPAN specifications

Plant Ref	Site Name	# MPAN	% PV	% PC1	% PC2	% PC3	% PC4
458720	Ruskin Ave	326	0.31%	98.16%	0.92%	0.61%	0.31%
452064	Cutler Close	42	21.43%	88.10%	9.52%	2.38%	0.00%
330127	Dunton Green	180	42.78%	96.67%	2.78%	0.56%	0.00%

The next sections will present each LV network focusing on the individual characteristics of their feeders and MPANs.

2.1 Ruskin Avenue Substation (458720)

Figure 1 shows the topology of Ruskin Avenue network. The MPANs are depicted as small turquoise lines and the corresponding substation as yellow dot.

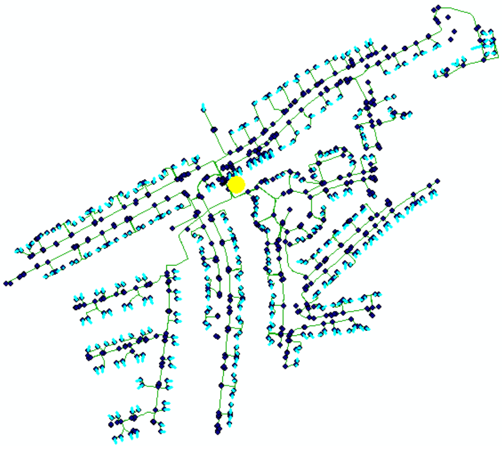


Figure 1 Ruskin Avenue

The feeder characteristics of Ruskin Avenue are shown in Table 4. Feeders 44061995, 44062000 and 44062003 have only PC1 customers. Feeder 44062010 has one PC4 customer. Feeders 44061978 and 44061983 have one PC3 customer. Feeder Only feeder 118038372 has one PV installation with a capacity of 3kW.

Table 4 Ruskin Avenue's Feeder Specifications

Plant Ref	Site Name	Feature ID	Length(m)	# PV	PV Inst. kW	# MPAN	# PC1	# PC2	# PC3	# PC4
458720	Ruskin Avenue	44061978	1410	0	0	49	47	1	1	0
458720	Ruskin Avenue	44061983	700	0	0	21	20	0	1	0
458720	Ruskin Avenue	44061991	733	1	3	28	27	1	0	0
458720	Ruskin Avenue	44061995	597	0	0	22	22	0	0	0
458720	Ruskin Avenue	44062000	1101	0	0	42	42	0	0	0
458720	Ruskin Avenue	44062003	968	0	0	34	34	0	0	0
458720	Ruskin Avenue	44062007	1396	0	0	51	51	0	0	0
458720	Ruskin Avenue	44062010	842	0	0	23	22	0	0	1
458720	Ruskin Avenue	44062023	1592	0	0	56	55	1	0	0

2.2 Cutler Close Substation (452064)

Figure 2 shows the topology of Cutler Close network. The MPANs are depicted as small turquoise lines and the corresponding substation as yellow dot.

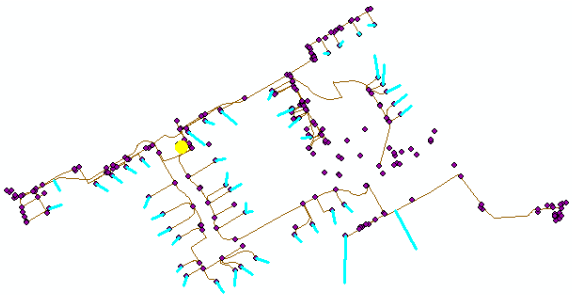


Figure 2 Cutler Close

The feeder characteristics of Cutler Close are shown in Table 5. Only feeder 118038372 has one PC3 customer and no PV installations. Feeder 118038359 has four PC2 customers and five PV installations with a total capacity of 18.36 kW. Feeder 118038349 has only PC1 customers with four PV installations.

Table 5 Cutler Close's Feeder Specifications

Plant Ref	Site Name	Feature ID	Length(m)	# PV	PV Inst. kW	# MPAN	# PC1	# PC2	# PC3
452064	Cutler Close	118038349	516	4	15.36	13	13	0	0
452064	Cutler Close	118038359	616	5	18.36	18	14	4	0
452064	Cutler Close	118038372	477	0	0	11	10	0	1

2.3 Dunton Green Substation (330127)

Figure 3 shows the topology of Cutler Close network. The MPANs are depicted as small turquoise lines and the corresponding substation as yellow dot.

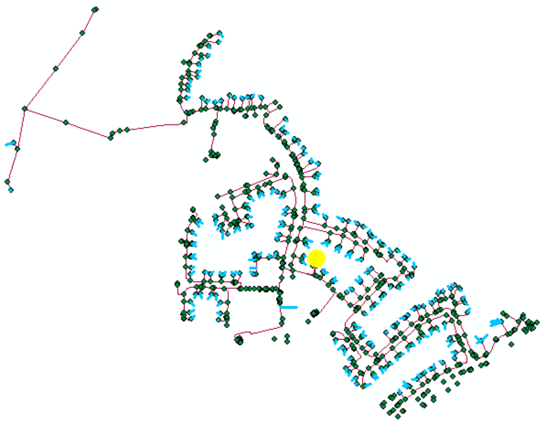


Figure 3 Dunton Green

The feeder characteristics of Dunton Green are shown in Table 6. Feeders 260055773 and 260055780 have four PV installations. Feeder 260055783 has the most PV installations with a total capacity of 82.88kW. Feeder 260055770 has the most customers with 59 PC1 customers and one PC2 customer.

Table 6 Dunton Green's Feeder Specifications

Plant Ref	Site Name	Feature ID	Length(m)	# PV	PV Inst. kW	# MPAN	# PC1	# PC2	# PC3
330127	Dunton Green	260055770	2292	28	59.12	70	69	1	0
330127	Dunton Green	260055773	869	4	8.14	31	28	3	0
330127	Dunton Green	260055780	921	4	10.26	26	25	0	1
330127	Dunton Green	260055783	1291	41	82.88	53	52	1	0

3 Network Validation: Methodology

To ensure that the network characteristics are modelled as accurately as possible, it is crucial to validate them with the corresponding monitoring data. The proposed network validation focuses on verifying whether the topology adopted in the models is the actual one from which parameters are being monitored. For this, realistic load models have to be adopted in order to mimic the behaviour of customers. This is a very challenging task due to the uncertainties involving customer demand behaviour that in turn depends on weather conditions (e.g., sun radiation, summer/winter) and the corresponding phase connection.

The proposed methodology uses diversified ENWL load profiles (based on Elexon profiles) for each of the customers modelled in a given feeder. In particular Profile Class 1 (PC1), PC2, PC3 and PC4 were used also taking into consideration the date that is linked to that of the monitoring data. For those feeders with residential photovoltaic systems data from the Whitworth Meteorological Observatory at The University of Manchester was used. Once all these load and generation models are defined, a power flow analysis is carried out and the energy-based comparisons are made against the monitoring data at the head of the feeders.

In this section, the proposed methodology will be presented for two types of LV feeders: those without PV installations and those with. For the former, the methodology solely considers load models. For the latter, PV profiles are incorporated.

For illustration purposes, two feeders part of Ruskin Avenue (one with PV installations, 44062023, and one without, 44061991) will be used in the following sections.

3.1 LV feeders without PV installations

3.1.1 Load Models

MPAN specifications for the feeder 44062023 of Ruskin Avenue are shown in Table 7. It has, according to the GIS data, 16, 18 and 22 MPANs at phases A, B and C, respectively. Most MPANs are PC1 with the exception of one PC2 at phase C.

Table 7 MPAN Specifications: Ruskin Avenue, Feeder 44062023

Plant Ref	Site Name	Feature ID	Phase	# MPAN	# PC1	# PC2
458720	Ruskin Avenue	44062023	A	16	16	0
458720	Ruskin Avenue	44062023	B	18	18	0
458720	Ruskin Avenue	44062023	C	22	21	1

For this feeder only PC1 and PC2 load profiles are of importance. Consequently, considering the date selected for the monitoring data (to be used for the validation), i.e., 1st April 2013, the corresponding profiles can be selected from the ENWL load profiles database but adapted to the available year (in this case, 1st April 2011). These profiles are shown in Figure 4.

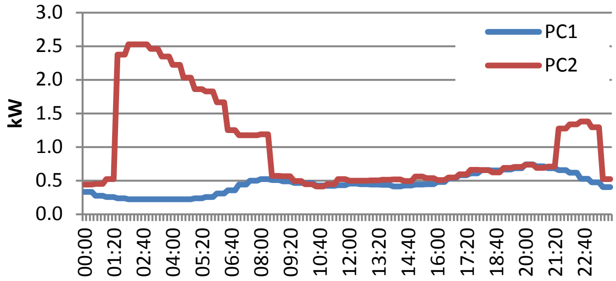


Figure 4 PC1 and PC2 MPAN profiles on 1st April 2011

The above profiles can then be used via OpenDSS to produce the corresponding power flow analysis. A voltage (at the busbar) of 240V was adopted throughout the day as well as a power factor of 0.98 (inductive).

3.1.2 Initial Comparisons: Simulation vs. Monitoring Data

The results from the 10-minute resolution power flow analysis (i.e., simulation) at the head of the feeder 44062023 are shown in Figure 5 (for the whole day). Voltages, currents and active powers for phases A, B and C are presented. Voltages remain close to 240V all day long. Phase C, with the largest number of MPANs, reaches during peak demand currents of 70A and active power of 16kW.

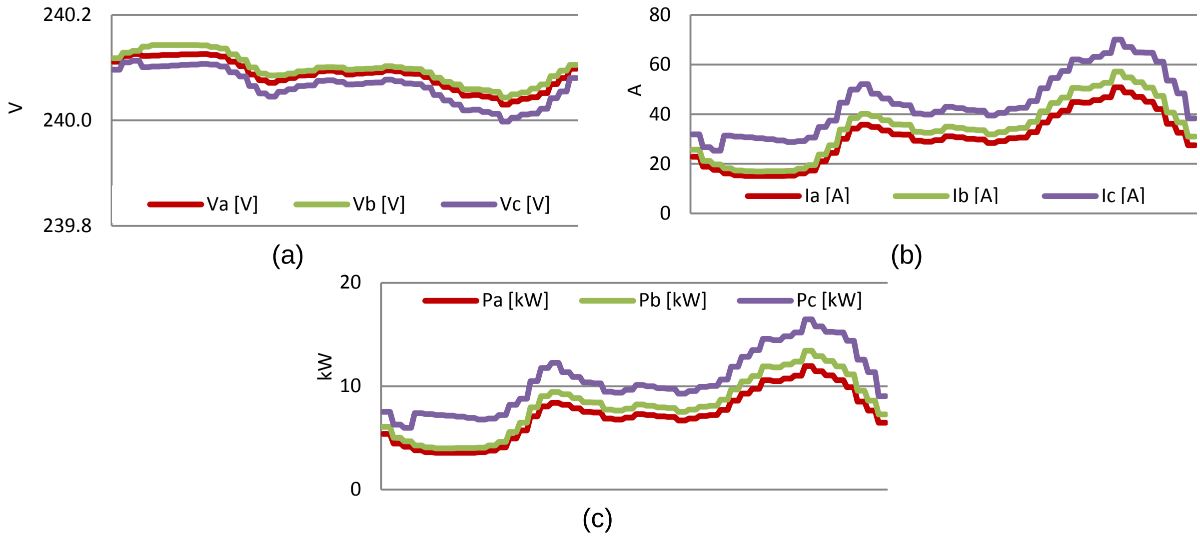
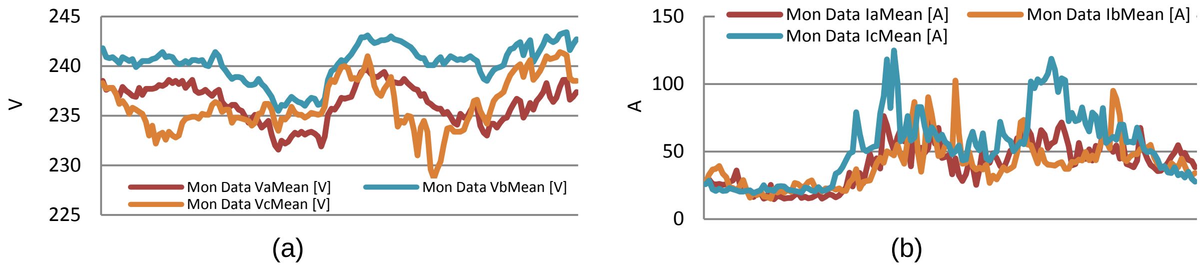
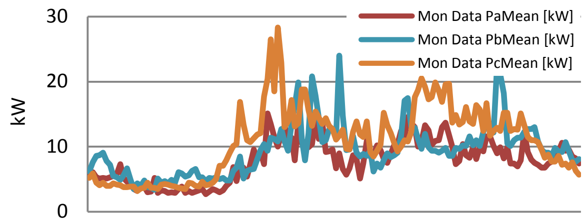


Figure 5 Power flow results for feeder 44062023

From the monitoring data (1st April 2013), voltages, currents and active powers for phases A, B and C are presented in Figure 6. Throughout the day, voltages change between 240V and 229V. Phase C reaches during peak demand currents of 125A and active power of 28kW.

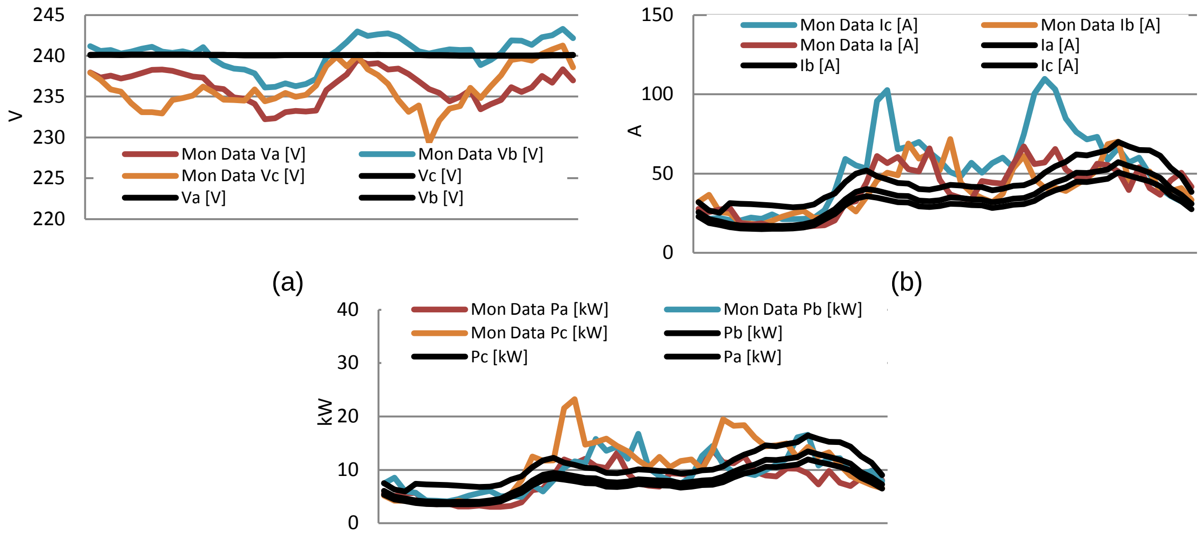




(c)

Figure 6 Monitoring data for feeder 44062023, 1st April 2013

In order to compare the simulation results and monitoring data, first it is needed to decrease the granularity of the latter. For this, the 10-minute averages for currents, voltages and power are calculated. Figure 7 shows the corresponding values throughout the day for both the simulation and the monitoring data. Apart from voltages (simulated as fixed), the patterns of current and active power show an overall good match. However, for validation purposes, it is crucial to quantify this match.



(c)

Figure 7 Simulation vs. Monitoring Data, feeder 44062023

To have a closer look at the active power per phase, the corresponding comparison figures are shown in Figure 8. In terms of power consumption throughout the day, it is clear that the load models adopted fail to closely match what happens in reality (under or overestimating the values). However, in terms of energy (i.e., the area produced by each curve), it can be seen that –perhaps– a closer match exist.

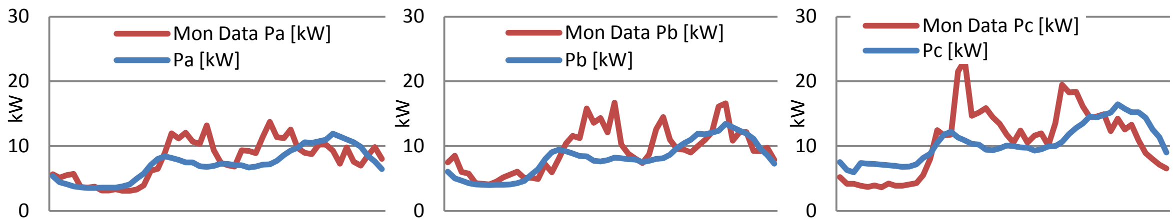


Figure 8 Comparison of active power per phase

3.1.3 Network Validation Metrics and Criteria

The validation method ultimately compares the total energy consumed (errors for both throughout the day, $E_{3\varnothing\text{ (all day)}}$, and during peak demand, $E_{3\varnothing\text{ (5-8pm)}}$) of the simulated feeder and that derived from the corresponding monitoring data. It also considers mean percentage errors of phase voltages and currents ($V_{a,b,c}$, $I_{a,b,c}$) as well as the percentage error of three-phase active power ($P_{3\varnothing}$).

Four criteria are used to finally decide whether a feeder has passed or not the validation.

1. Energy metrics are equal or smaller than 20%, then the model is valid.
   $E_{3Ø\,(all\,day)}$ & $E_{3Ø\,(5\text{-}8pm)} \leq 20\%$ → valid feeder

2. One energy metric is equal or bigger than 70%, then the mode is not valid.
   $E_{3Ø\,(all\,day)}$ | $E_{3Ø\,(5\text{-}8pm)} \geq 70\%$ → feeder not valid

3. Energy metrics are between 20% and 70%, the feeder has up to 30 customers (MPANs), and the current and active power metrics have similar levels of error, then the feeder is valid.
   $E_{3Ø\,(all\,day)}$ & $E_{3Ø\,(5\text{-}8pm)} \geq 20\%$ & #MPAN<30 & $I_{a,b,c} \approx P_{3Ø}$ → valid feeder

4. Energy metrics are between 20% and 70%, the feeder has more than 30 customers, and the current and power metrics have different levels of error, then feeder is not valid.
   $E_{3Ø\,(all\,day)}$ & $E_{3Ø\,(5\text{-}8pm)} \geq 20\%$ & (#MPAN>30 | $I_{a,b,c} \approx P_{3Ø}$) → feeder not valid

The network validation metrics of feeder 44062023 are given in Table 8. According to the above criteria; both energy metrics are smaller than 20%. Therefore, the model of feeder 44062023 is valid.

Table 8 Network validation metrics for feeder 44062023

	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3Ø}$ (mean)	$E_{3Ø}$ (mean)
% Error (all day)	1%	25%	19%	8%
% Error (5-8pm)	2%	16%	6%	0%

3.2 LV feeders with PV installations

3.2.1 Load Models

MPAN specifications for the feeder 44062023 of Ruskin Avenue are shown in Table 9. It has, according to the GIS data, 10, 8 and 10 MPANs at phases A, B and C, respectively. Most MPANs are PC1 with the exception of one PC2 at phase C.

Table 9 MPAN Specifications: Ruskin Avenue, Feeder 44061991

Plant Ref	Site Name	Feature ID	Phase	# MPAN	# PC1	# PC2
458720	Ruskin Avenue	44061991	A	10	10	0
458720	Ruskin Avenue	44061991	B	8	8	0
458720	Ruskin Avenue	44061991	C	10	9	1

For this feeder only PC1 and PC2 load profiles are of importance. Consequently, considering the date selected for the monitoring data (to be used for the validation), i.e., 1st April 2013, the corresponding profiles can be selected from the ENWL load profiles database but adapted to the available year (in this case, 1st April 2011). These profiles are shown in Figure 9.

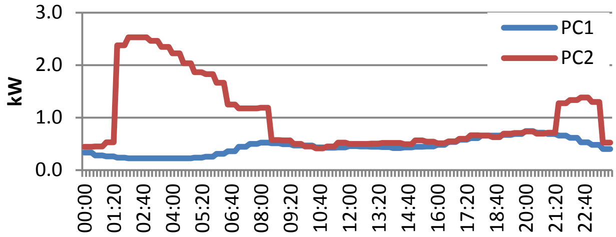


Figure 9 PC1 and PC2 MPAN profiles on 1st April 2011

The above profiles can then be used via OpenDSS to produce the corresponding power flow analysis. A voltage (at the busbar) of 240V was adopted throughout the day as well as a power factor of 0.98 (inductive).

3.2.2 PV Profiles

The project members have access to two databases containing real sun radiation data. One is from the Whitworth Meteorological Observatory at The University of Manchester which has one weather station on top of Sackville Street Building, Manchester. The other database aggregates measurements from 10 weather stations located at 10 ENWL substations (all also monitored by the LV Network Solutions project). For the creation of the most suitable PV profiles, the closest weather station to the feeder should be considered.

Due to availability, data from The University of Manchester was used in this report.

The feeder chosen to show the proposed methodology is 44061991, part of Ruskin Avenue. This feeder only has one PV installation (3kW of capacity) related to an MPAN connected to phase B.

The PV generation profile is determined considering sun radiation data and parameters related to efficiency. The PV output at time *t* is calculated (approximately) by equation (1).

$$PV(t) = SunRad(t) * PkW * 7 * 0.1 * 0.95 \quad (1)$$

where SunRad(*t*) is the real sun radiation data (kW/m^2) at *t* time, PkW is the installed capacity (kW), 7 corresponds to the area for a 1kW PV installation (m^2/kW), 0.1 is the adopted PV efficiency, and 0.95 is the adopted inverter efficiency.

The resulting PV generation profile using data from The University of Manchester and considering 1st April 2013 as well as equation (1), is shown in Figure 10.

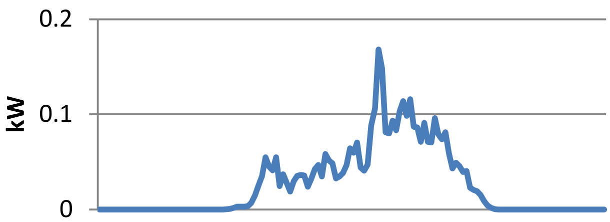


Figure 10 PV Profile for 1st April 2013

Hereafter PV generation can be defined as for OpenDSS with its generation value and other information such as; connection, phase, nominal voltage (240V) and power factor (1) for each time step. Finally, computer based model of LV feeder with loads regarding their load profiles and PV generation definitions are ready to run power flow analysis.

The above profile can then be used via OpenDSS (along with load models) to produce the corresponding power flow analysis. Unity power factor was adopted for all PV installations.

3.2.3 Initial Comparisons: Simulation vs. Monitoring Data

Figure 11 shows the corresponding values throughout the day for both the simulation and the monitoring data. Apart from voltages (simulated as fixed), the patterns of current and active power show an overall match. However, for validation purposes, it is crucial to quantify this match.

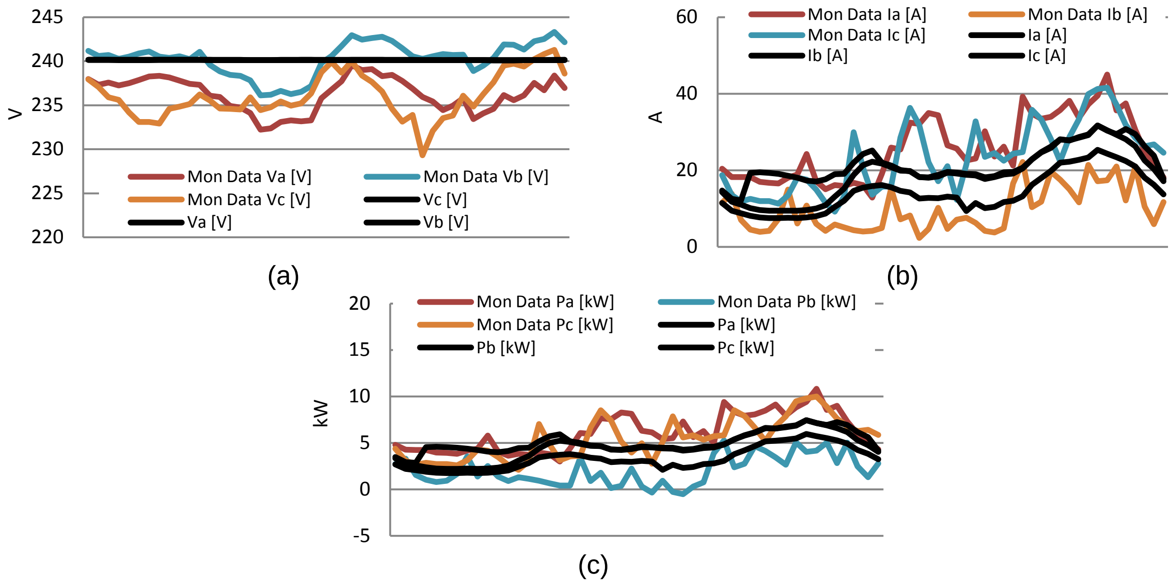


Figure 11 Simulation vs. Monitoring Data, feeder 44061991

To have a closer look at the active power per phase, the corresponding comparison figures are shown in Figure 12.. In terms of power consumption throughout the day, it is clear that the load models adopted fail to closely match what happens in reality (under or overestimating the values). However, in terms of energy (i.e., the area produced by each curve), it can be seen that –perhaps– a closer match exist.

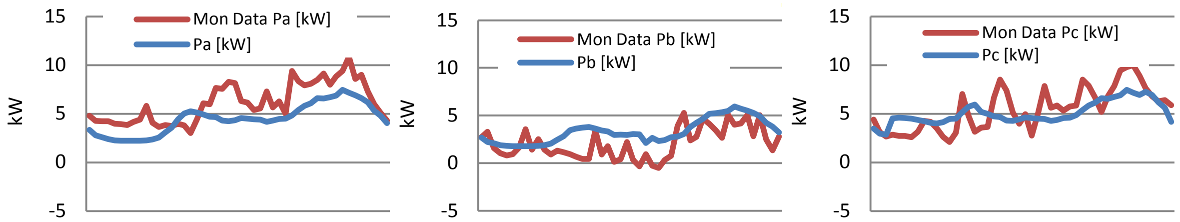


Figure 12 Comparison of active power per phase

3.2.4 Network Validation Metrics and Criteria

The network validation metrics of feeder 44061991 are given in Table 10. According to the network validation criteria as mentioned previous section; both energy metrics are smaller than 20% then the computer based model of feeder 44061991 is valid.

Table 10 Network validation metrics for feeder 44061991

	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3\phi}$ (mean)	$E_{3\phi}$ (mean)
% Error (all day)	1%	51%	20%	5%
% Error (5-8pm)	2%	27%	9%	8%

3.3 Conclusions

This report presented the methodology used to validate the LV feeders studied throughout the LV Network Solutions project. This is necessary in order to verify whether the topology adopted in the models is the actual topology of the corresponding feeder. The methodology compares monitoring data at the head of each feeder with power flow results that adopt models based on ENWL's profiles. This was also extended to cater for feeders with photovoltaic systems by adopting sun irradiance monitoring data from The University of Manchester.

The validation method ultimately compares the total energy consumed (errors for both throughout the day, $E_{3Ø\text{ (all day)}}$, and during peak demand, $E_{3Ø\text{ (5-8pm)}}$) of the simulated feeder and that derived from the corresponding monitoring data. Four criteria are used to finally decide whether a feeder has passed or not the validation.

1. Energy metrics are equal or smaller than 20%, then the model is valid.
2. One energy metric is equal or bigger than 70%, then the mode is not valid.
3. Energy metrics are between 20% and 70%, the feeder has up to 30 customers (MPANs), and the current and active power metrics have similar levels of error, then the feeder is valid.
4. Energy metrics are between 20% and 70%, the feeder has more than 30 customers, and the current and power metrics have different levels of error, then feeder is not valid.

The methodology was applied to 16 feeders corresponding to three different LV networks: Ruskin Avenue, Cutler Close and Dunton Green. From these feeders, 11 were successfully validated considering the proposed metrics. However, the results for 5 of them were outside the metrics and action will be taken so ENWL could provide further information. The results are presented in Table 11. The methodology will be extended to all our LV feeder models.

It is important to highlight the proposed methodology is highly sensitive to the number of customers. From the extensive analysis, best results are found with feeders with more than 50 customers. Lower values of customers place too much bias towards the models used per profile class.

Table 11 Valid and Non-Valid Feeders

Plant Ref	Site Name	Feature ID	# MPAN	% PV	Valid?
458720	Ruskin Avenue	44061978	49	0%	Yes
458720	Ruskin Avenue	44061983	21	0%	Yes
458720	Ruskin Avenue	44061991	28	4%	Yes
458720	Ruskin Avenue	44061995	22	0%	Yes
458720	Ruskin Avenue	44062000	42	0%	No
458720	Ruskin Avenue	44062003	34	0%	Yes
458720	Ruskin Avenue	44062007	51	0%	Yes
458720	Ruskin Avenue	44062010	23	0%	No
458720	Ruskin Avenue	44062023	56	0%	Yes
452064	Cutler Close	118038349	13	31%	No
452064	Cutler Close	118038359	18	28%	Yes
452064	Cutler Close	118038372	11	0%	No
330127	Dunton Green	260055770	70	40%	Yes
330127	Dunton Green	260055773	31	13%	No
330127	Dunton Green	260055780	26	15%	Yes
330127	Dunton Green	260055783	53	77%	Yes

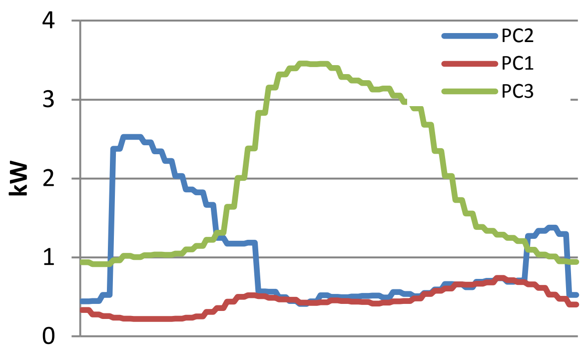
4 Appendix

The 16 feeders of three LV networks are examined in detail to provide a better understanding of the network validation methodology.

4.1 Ruskin Avenue Substation (458720)

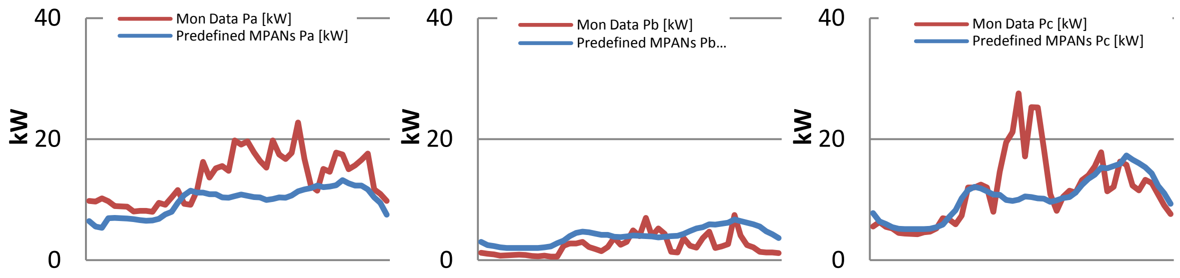
4.1.1 Feeder 44061978

ENWL Load Profiles



Plant Ref	Site Name	Feature ID	Phase	# PV	# MPAN	# PC1	# PC2	# PC3
458720	Ruskin Avenue	44061978	A	0	17	15	1	1
458720	Ruskin Avenue	44061978	B	0	9	9	0	0
458720	Ruskin Avenue	44061978	C	0	23	23	0	0

Active power per phase at the head of feeder

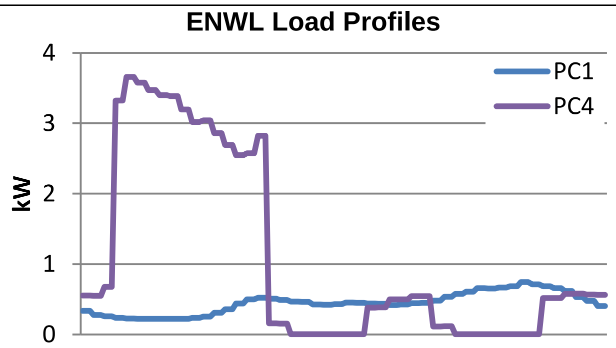


	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3\emptyset}$ (mean)	$E_{3\emptyset}$ (mean)
% Error (all day)	1%	52%	15%	12%
% Error (5-8pm)	2%	44%	8%	0%

Comments

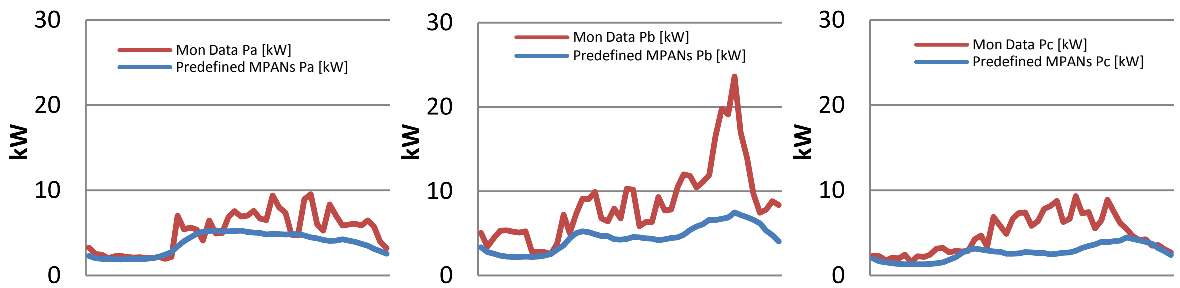
- Based on the first criteria, this feeder is valid.
- The largest differences in power consumption appear around noon.

4.1.2 Feeder 44061983



Plant Ref	Site Name	Feature ID	Phase	# PV	# MPAN	# PC1	# PC2	# PC3
458720	Ruskin Avenue	44061983	A	0	5	4	0	1
458720	Ruskin Avenue	44061983	B	0	10	10	0	0
458720	Ruskin Avenue	44061983	C	0	6	6	0	0

Active power per phase at the head of feeder

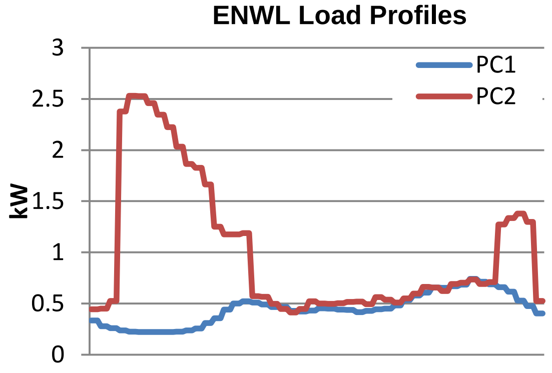


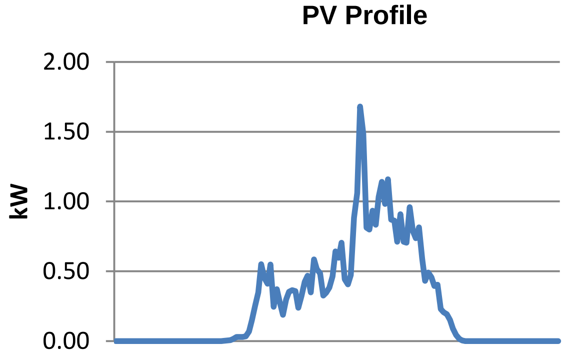
	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3\phi}$ (mean)	$E_{3\phi}$ (mean)
% Error (all day)	1%	35%	38%	41%
% Error (5-8pm)	2%	45%	50%	51%

<u>Comments</u>

- Based on the third criteria, this feeder is valid.
- The differences in power consumption appear throughout the day except early morning with less than 30 customers.

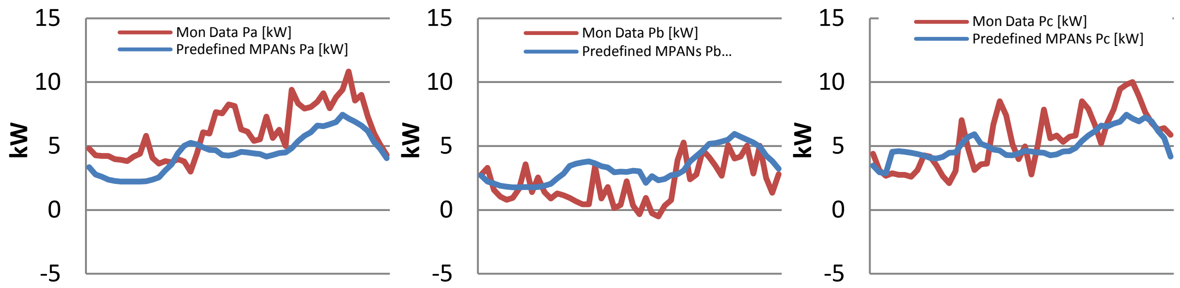
4.1.3 Feeder 44061991





Plant Ref	Site Name	Feature ID	Phase	# PV	PV Inst. kW	# MPAN	# PC1	# PC2
458720	Ruskin Avenue	44061991	A	0	0	10	10	0
458720	Ruskin Avenue	44061991	B	1	3	8	8	0
458720	Ruskin Avenue	44061991	C	0	0	10	9	1

The active power at the head of feeder



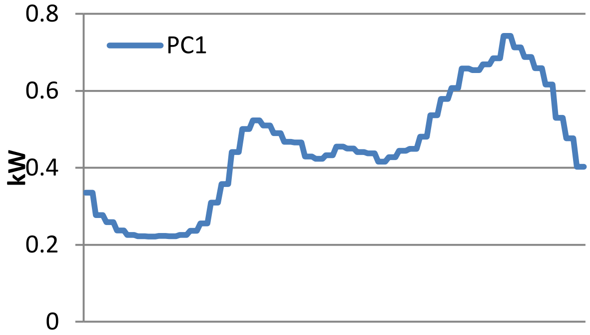
	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3ø}$ (mean)	$E_{3ø}$ (mean)
% Error (all day)	1%	51%	20%	5%
% Error (5-8pm)	2%	27%	9%	8%

Comments

- Based on the first criteria, this feeder is valid.
- The patterns of power closely match.

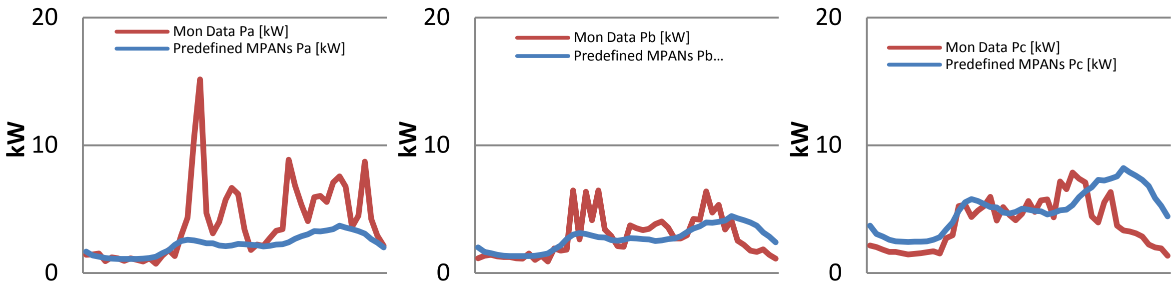
4.1.4 Feeder 44061995

ENWL Load Profiles



Plant Ref	Site Name	Feature ID	Phase	# PV	# MPAN	# PC1
458720	Ruskin Avenue	44061995	A	0	5	5
458720	Ruskin Avenue	44061995	B	0	6	6
458720	Ruskin Avenue	44061995	C	0	11	11

Active power per phase at the head of feeder

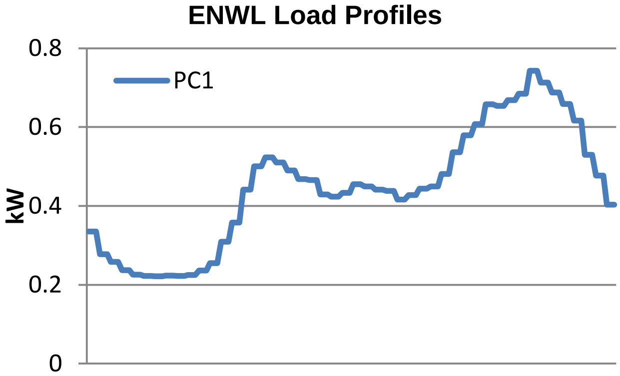


	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3\varnothing}$ (mean)	$E_{3\varnothing}$ (mean)
% Error (all day)	1%	40%	29%	7%
% Error (5-8pm)	2%	41%	12%	6%

Comments

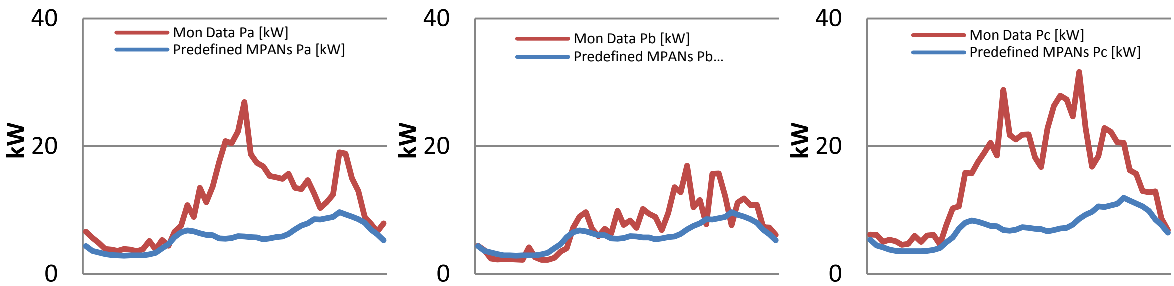
- Based on the first criteria, this feeder is valid.
- The largest differences in power consumption appear at phase A.

4.1.5 Feeder 44062000



Plant Ref	Site Name	Feature ID	Phase	# PV	# MPAN	# PC1
458720	Ruskin Avenue	44062000	A	0	13	13
458720	Ruskin Avenue	44062000	B	0	13	13
458720	Ruskin Avenue	44062000	C	0	16	16

Active power per phase at the head of feeder



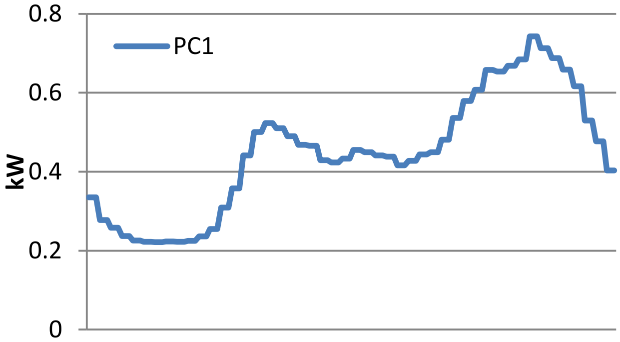
	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3ø}$ (mean)	$E_{3ø}$ (mean)
% Error (all day)	1%	37%	37%	45%
% Error (5-8pm)	2%	37%	39%	39%

Comments

- Based on the forth criteria, this feeder is not valid.
- The monitored power consumptions are more significant for phases A and C.
- MPAN/PV information and network configuration need to be checked with ENWL.

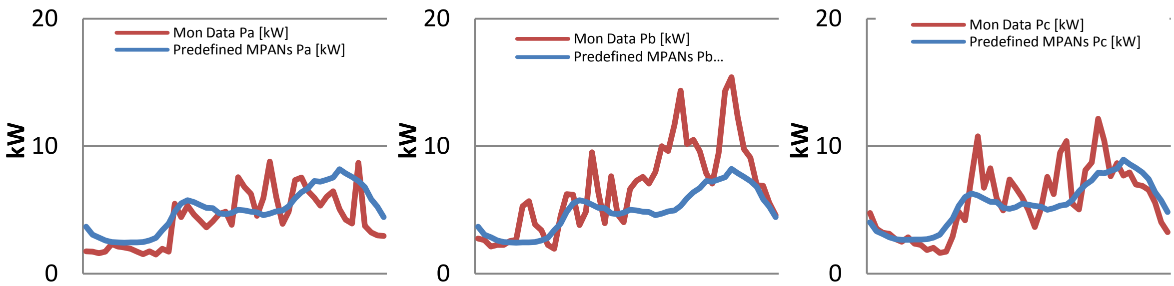
4.1.6 Feeder 44062003

ENWL Load Profiles



Plant Ref	Site Name	Feature ID	Phase	# PV	# MPAN	# PC1
458720	Ruskin Avenue	44062003	A	0	11	11
458720	Ruskin Avenue	44062003	B	0	11	11
458720	Ruskin Avenue	44062003	C	0	12	12

Active power per phase at the head of feeder

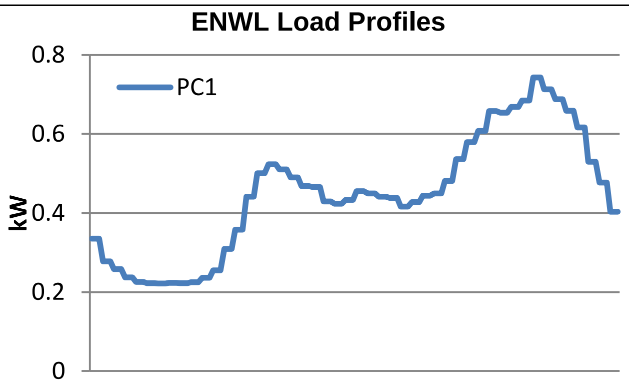


	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3ø}$ (mean)	$E_{3ø}$ (mean)
% Error (all day)	1%	30%	20%	9%
% Error (5-8pm)	2%	23%	13%	13%

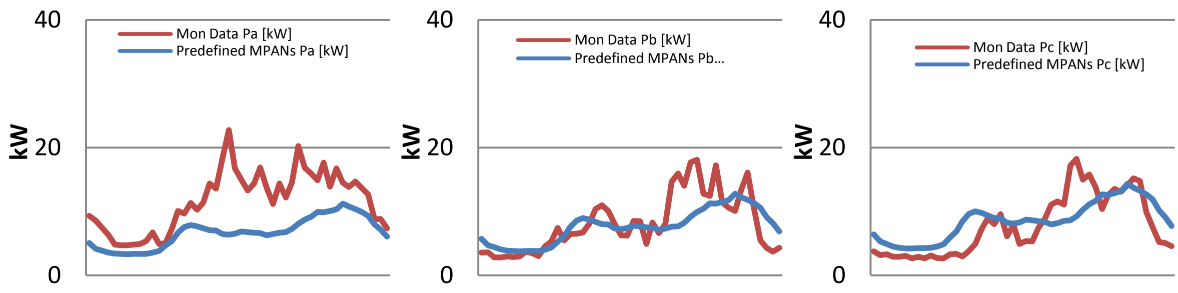
Comments

- Based on the first criteria, this feeder is valid.
- The patterns of power generally match overall at phase A and C.

4.1.7 Feeder 44062007



Plant Ref	Site Name	Feature ID	Phase	# PV	# MPAN	# PC1
458720	Ruskin Avenue	44062007	A	0	15	15
458720	Ruskin Avenue	44062007	B	0	17	17
458720	Ruskin Avenue	44062007	C	0	19	19



	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3ø}$ (mean)	$E_{3ø}$ (mean)
% Error (all day)	1%	38%	20%	17%
% Error (5-8pm)	2%	22%	19%	20%

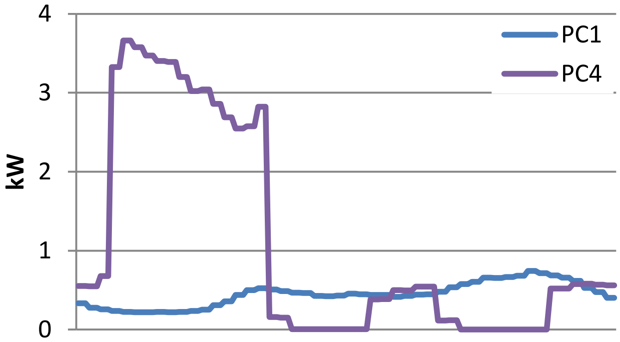
Comments

- Based on the first criteria, this feeder is valid.
- The largest differences in power consumption appear at phase A.

The University of Manchester

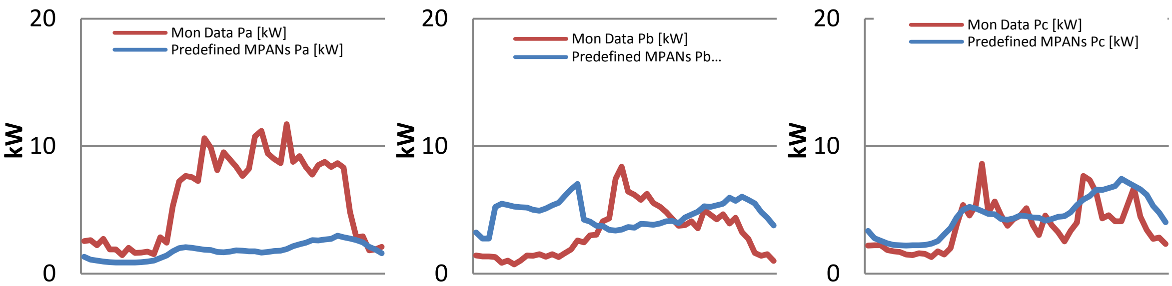
4.1.8 Feeder 44062010

ENWL Load Profiles



Plant Ref	Site Name	Feature ID	Phase	# PV	# MPAN	# PC1	# PC2	# PC3	# PC4
458720	Ruskin Avenue	44062010	A	0	4	4	0	0	0
458720	Ruskin Avenue	44062010	B	0	9	8	0	0	1
458720	Ruskin Avenue	44062010	C	0	10	10	0	0	0

Active power per phase at the head of feeder



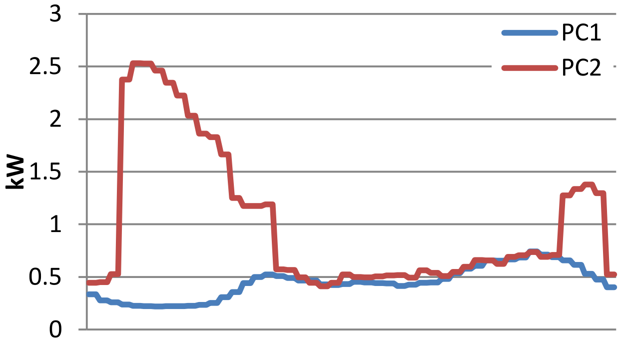
	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3ø}$ (mean)	$E_{3ø}$ (mean)
% Error (all day)	1%	72%	47%	16%
% Error (5-8pm)	2%	44%	20%	21%

Comments

- Based on the third criteria, this feeder is not valid.
- In terms of power consumption, the real profile of the PC4 customer at phase B doesn't match the ENWL load profile.
- The load models adopted fail to match with the largest differences in power consumption.
- MPAN/PV information and network configuration need to be checked with ENWL.

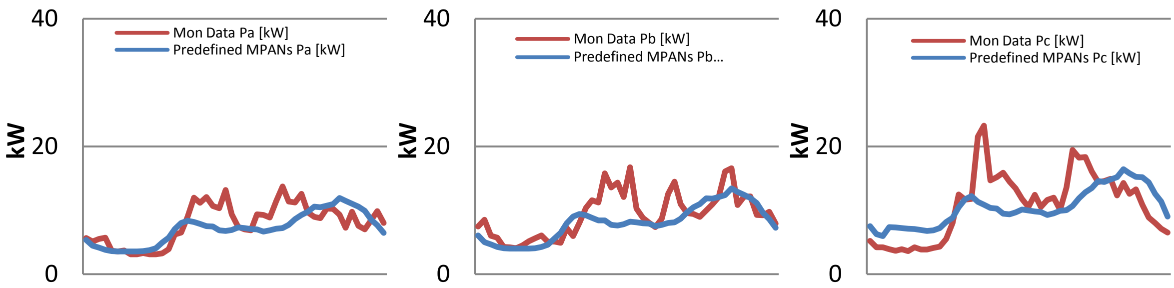
4.1.9 Feeder 44062023

ENWL Load Profiles



Plant Ref	Site Name	Feature ID	Phase	# PV	# MPAN	# PC1	# PC2
458720	Ruskin Avenue	44062023	A	0	16	16	0
458720	Ruskin Avenue	44062023	B	0	18	18	0
458720	Ruskin Avenue	44062023	C	0	22	21	1

Active power per phase at the head of feeder



	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3\phi}$ (mean)	$E_{3\phi}$ (mean)
% Error (all day)	1%	25%	19%	8%
% Error (5-8pm)	2%	16%	6%	0%

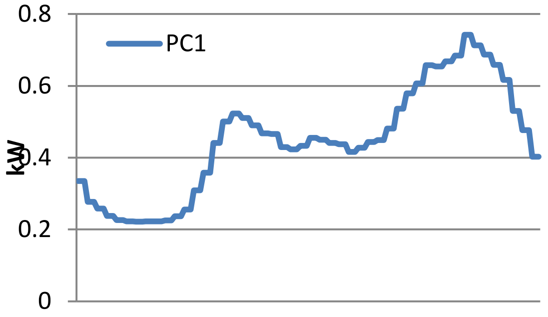
Comments

- Based on the first criteria, this feeder is valid.
- The patterns of power closely match.

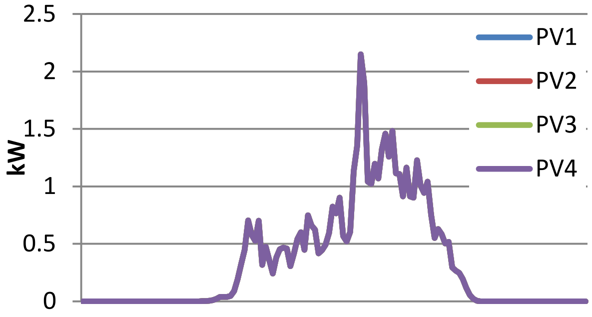
4.2 Cutler Close Substation (452064)

4.2.1 Feeder 118038349

ENWL Load Profiles

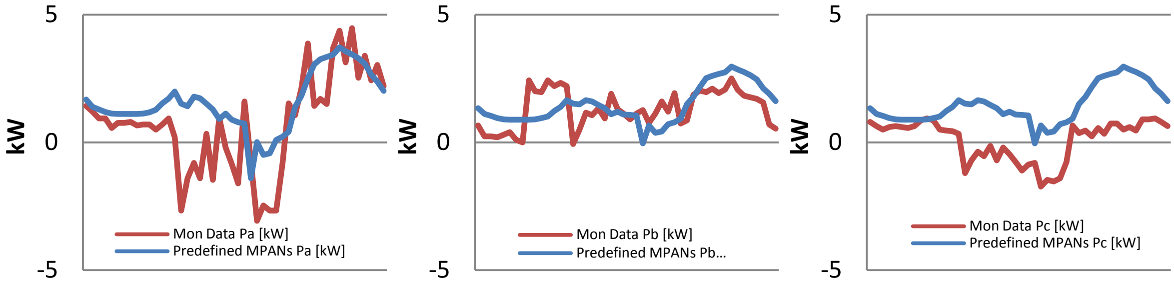


PV Profiles



Plant Ref	Site Name	Feature ID	Phase	# PV	PV Inst. kW	# MPAN	# PC1
452064	Cutler Close	118038349	A	2	7.68	5	5
452064	Cutler Close	118038349	B	1	3.84	4	4
452064	Cutler Close	118038349	C	1	3.84	4	4

Active power per phase at the head of feeder

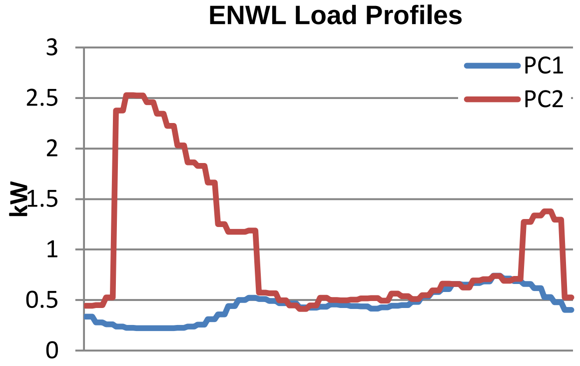


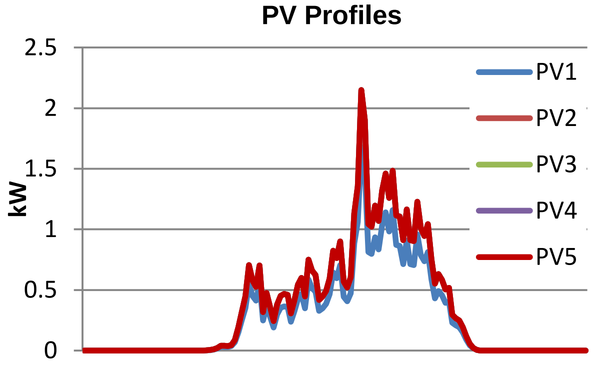
	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3ø}$ (mean)	$E_{3ø}$ (mean)
% Error (all day)	3%	79%	135%	110%
% Error (5-8pm)	3%	131%	60%	53%

Comments

- Based on the second criteria, this feeder is not valid.
- The feeder has 31% of PV penetration (in terms of number of customer).
- Largest differences in power consumption and generation appear throughout the day.
- MPAN/PV information and network configuration need to be checked with ENWL.

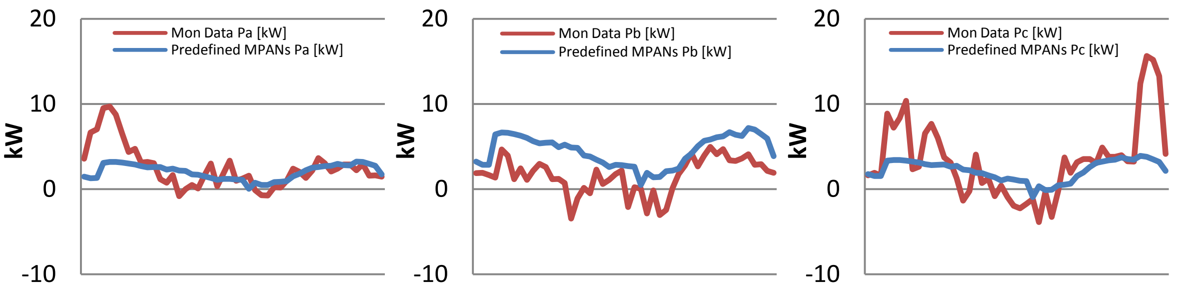
4.2.2 Feeder 118038359





Plant Ref	Site Name	Feature ID	Phase	# PV	PV Inst. kW	# MPAN	# PC1	# PC2
452064	Cutler Close	118038359	A	1	3.84	4	3	1
452064	Cutler Close	118038359	B	2	7.68	9	7	2
452064	Cutler Close	118038359	C	2	6.84	5	4	1

Active power per phase at the head of feeder



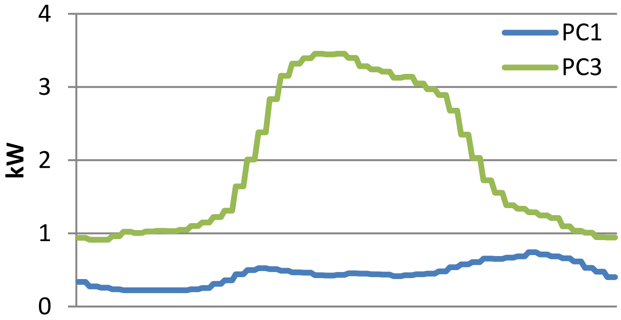
	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3\phi}$ (mean)	$E_{3\phi}$ (mean)
% Error (all day)	3%	70%	175%	15%
% Error (5-8pm)	3%	31%	22%	10%

Comments

- Based on the first criteria, this feeder is valid.
- This feeder has 28% of PV penetration (in terms of number of customers).
- The pattern of power closely matches during peak demand.

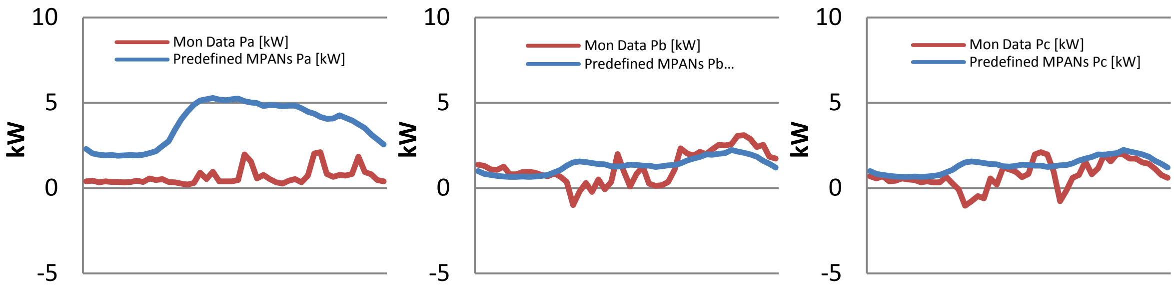
4.2.3 Feeder 118038372

ENWL Load Profiles



Plant Ref	Site Name	Feature ID	Phase	# PV	PV Inst. kW	# MPAN	# PC1	# PC2	# PC3
452064	Cutler Close	118038372	A	0	0	5	4	0	1
452064	Cutler Close	118038372	B	0	0	3	3	0	0
452064	Cutler Close	118038372	C	0	0	3	3	0	0

Active power per phase at the head of feeder



	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3ø}$ (mean)	$E_{3ø}$ (mean)
% Error (all day)	3%	201%	789%	145%
% Error (5-8pm)	3%	151%	73%	68%

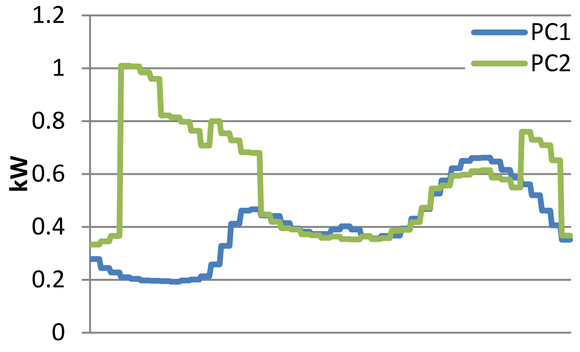
Comments

- Based on the second criteria, this feeder is not valid.
- Reverse power at phases B and C indicate generation in the feeder. However, there is no PV installation according to the information given by ENWL.
- MPAN/PV information and network configuration need to be checked with ENWL.

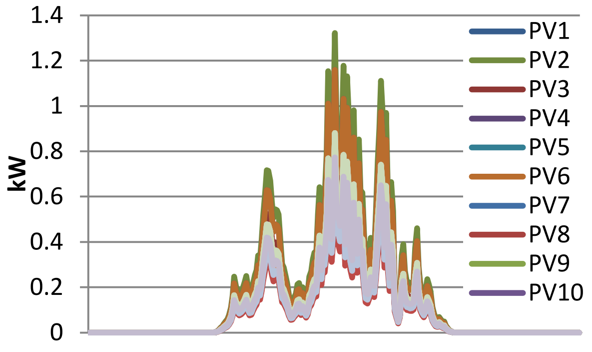
4.2.4 Dunton Green Substation (330127)

4.2.5 Feeder 260055770

ENWL Load Profiles

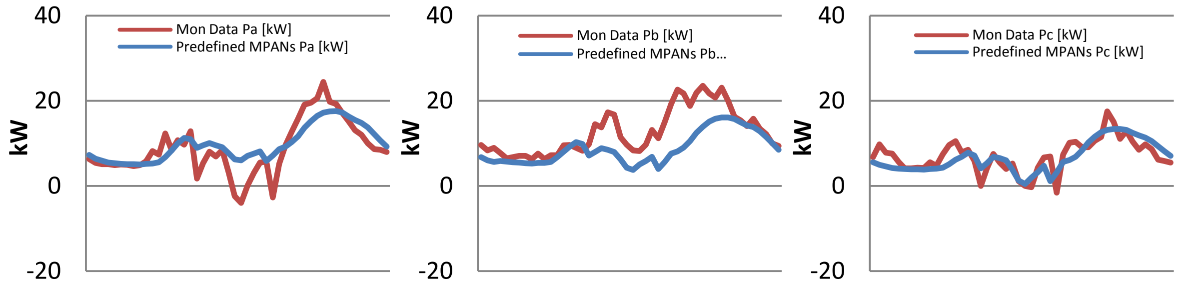


PV Profiles



Plant Ref	Site Name	Feature ID	Phase	# PV	PV Inst. kW	# MPAN	# PC1	# PC2	# PC3
330127	Dunton Green	260055770	A	7	14.58	26	26	0	0
330127	Dunton Green	260055770	B	9	19.15	24	23	1	0
330127	Dunton Green	260055770	C	12	25.39	20	20	0	0

Active power per phase at the head of feeder

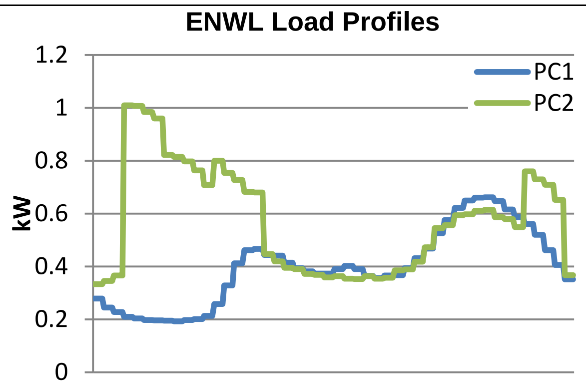


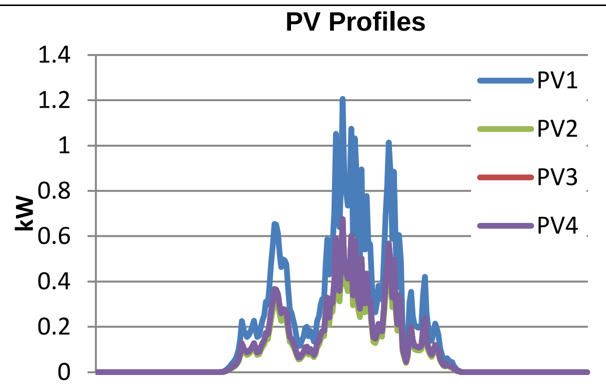
	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3\emptyset}$ (mean)	$E_{3\emptyset}$ (mean)
% Error (all day)	1%	27%	24%	12%
% Error (5-8pm)	0%	19%	17%	18%

Comments

- Based on the first criteria, this feeder is valid.
- This feeder has 40% of PV penetration (in terms of number of customers).
- The pattern of power shows an overall good match.

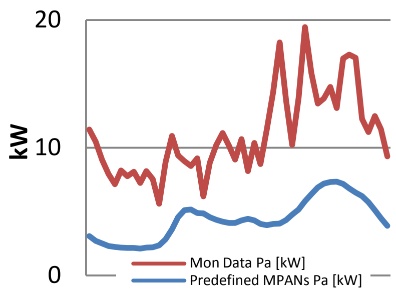
4.2.6 Feeder 260055773

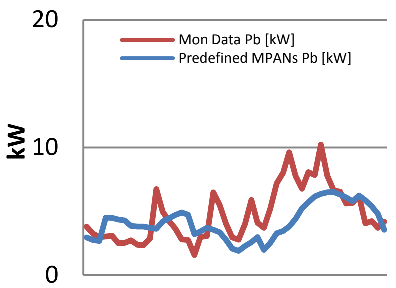


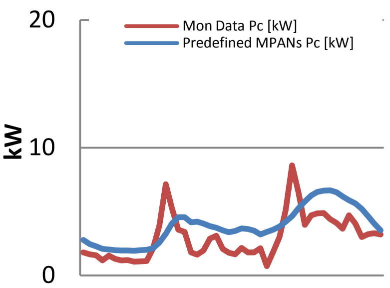


Plant Ref	Site Name	Feature ID	Phase	# PV	PV Inst. kW	# MPAN	# PC1	# PC2
330127	Dunton Green	260055773	A	0	0	11	11	0
330127	Dunton Green	260055773	B	3	6.62	10	7	3
330127	Dunton Green	260055773	C	1	1.52	10	10	0

Active power per phase at the head of feeder





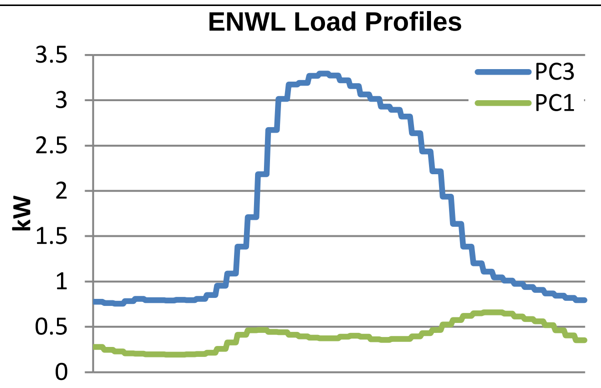


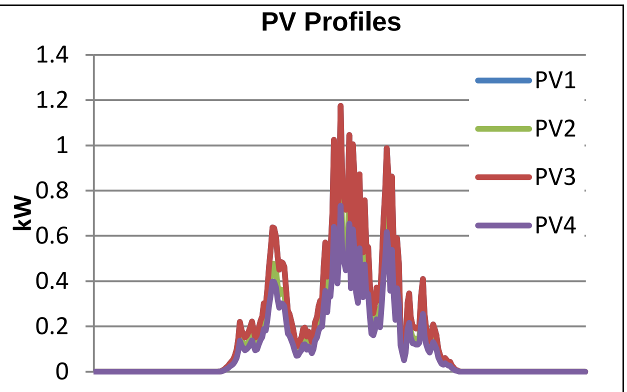
	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3ø}$ (mean)	$E_{3ø}$ (mean)
% Error (all day)	1%	47%	32%	34%
% Error (5-8pm)	0%	36%	30%	31%

Comments

- Based on the forth criteria, this feeder is not valid.
- The patterns of power at phases B and C closely match. However, the differences at phase A are significant.
- MPAN/PV information and network configuration need to be checked with ENWL.

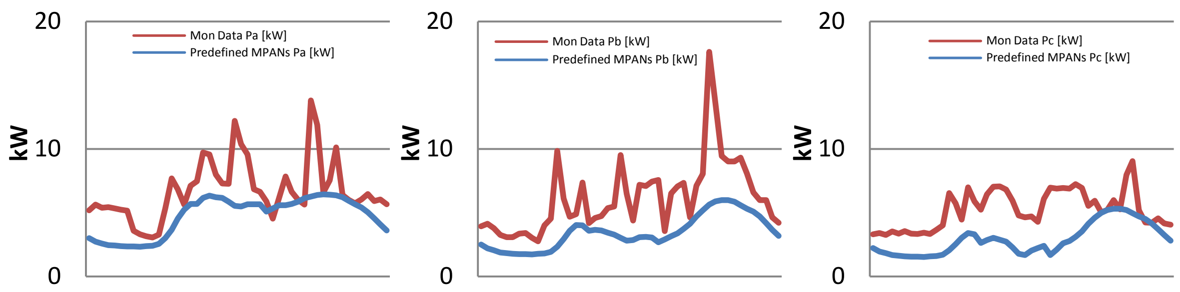
4.2.7 Feeder 260055780





Plant Ref	Site Name	Feature ID	Phase	# PV	PV Inst. kW	# MPAN	# PC1	# PC2	# PC3
330127	Dunton Green	260055780	A	1	3.04	9	8	0	1
330127	Dunton Green	260055780	B	1	2.28	9	9	0	0
330127	Dunton Green	260055780	C	2	4.94	8	8	0	0

Active power per phase at the head of feeder

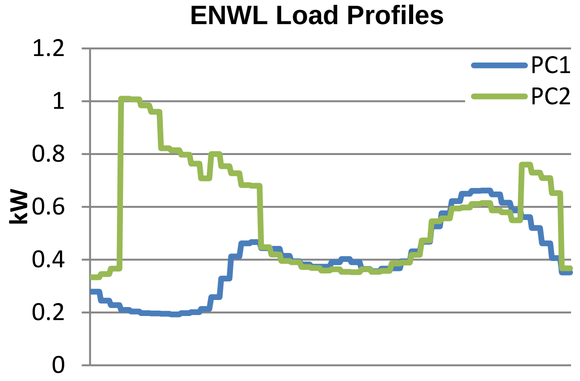


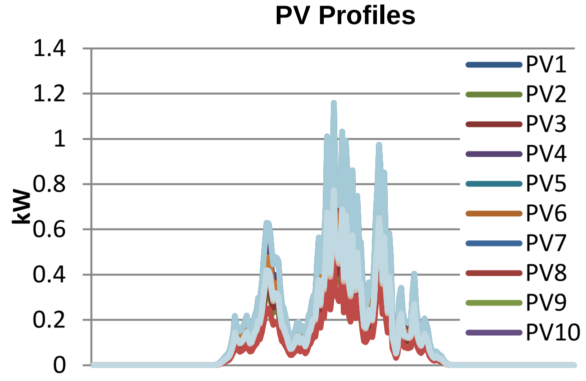
	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3ø}$ (mean)	$E_{3ø}$ (mean)
% Error (all day)	1%	27%	24%	12%
% Error (5-8pm)	0%	19%	17%	18%

Comments

- Based on the first criteria, this feeder is valid.
- In terms of power consumption, there are under and overestimated values. However, in terms of energy, a close match exists.

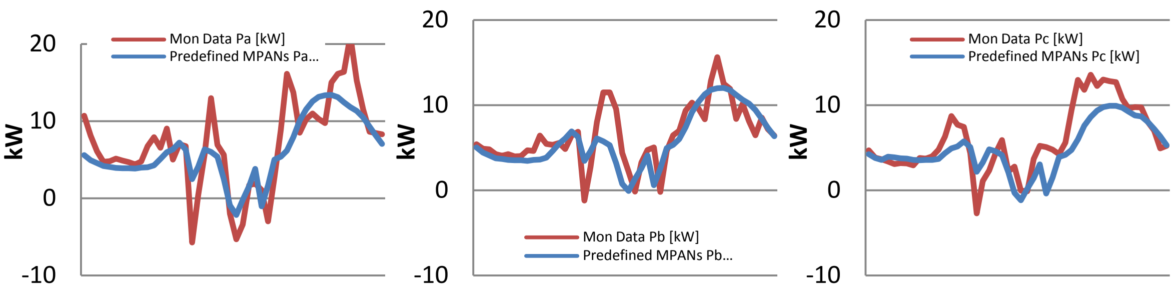
4.2.8 Feeder 260055783





Plant Ref	Site Name	Feature ID	Phase	# PV	PV Inst. kW	# MPAN	# PC1	# PC2
330127	Dunton Green	260055783	A	17	34.32	20	20	0
330127	Dunton Green	260055783	B	12	24.46	18	18	0
330127	Dunton Green	260055783	C	12	24.1	15	14	1

Active power per phase at the head of feeder



	$V_{a,b,c}$ (mean)	$I_{a,b,c}$ (mean)	$P_{3ø}$ (mean)	$E_{3ø}$ (mean)
% Error (all day)	1%	26%	35%	13%
% Error (5-8pm)	0%	19%	9%	7%

Comments

- Based on the first criteria, this feeder is valid.
- This feeder has 77% of PV penetration (in terms of number of customers).
- The pattern of power shows an overall good match.