A specialist energy consultancy

Improved Modelling of HV Rural Networks to Reduce Losses

Losses Discretionary Reward Tranche 1 Initiative 5

SP Energy Networks

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Executive Summary

We have successfully developed a modelling tool to identify HV feeders with high levels of phase imbalance and the associated higher levels of losses. Intervention on 232 rural HV feeders, subject to validation, could yield a maximum losses saving of 1.08GWh/yr.

In our Tranche 1 submission it was acknowledged, from several industry studies, that phase imbalance on long rural overhead 11kV circuits is a major contributor to 11kV network losses. Determination of the degree of imbalance on 11kV circuits has traditionally required expensive monitoring.

We have developed a modelling tool to estimate the extent and location of phase imbalance on rural 11kV networks. This modelling tool utilises readily available network metrics to identify feeders which are likely to exhibit high imbalance, these comprise total length of single-phase spur, total number of single-phase transformer and total number of customers supplied by single-phase transformer.

This has reduced the need for monitoring and informed our understanding of this source of losses. Models have been calibrated using data collected from 52 HV feeders across 8 Primary substations located across both of our licence areas.

This work has indicated a high level of imbalance on a total of 232 HV rural feeders across both licence areas. Upgrading single phase spurs to three-phase lines was found to be cost prohibitive. The low-cost solution of phase-phase line reconnections shows a payback period of between 7 to 14 years. The level of benefit does not warrant a dedicated programme, but intervention activity will form part of existing asset modernisation programmes. The maximum potential losses savings associated with all 232 feeders are circa 1.08GWh per annum.

Detailed unbalanced load flow modelling was undertaken on the Whitchurch Primary feeder, which was found to have the longest total length of single phase lines and the highest phase imbalance amongst all of the HV feeders. The annual losses were assessed for the base case and for two possible interventions. One intervention was to change the phase connections of the single phase lines to balance the currents by swapping the jumpers from one phase to another. The other intervention considered was to rebuild the single phase line with three phase lines. For the phase-phase line reconnection the annual loss reduction was found to be 4.64 MWh, and for the line re-built with 3-phase lines the annual loss reduction was found to be 8.24 MWh.

Further measurement should be undertaken on a set of HV circuits to validate model results. Following this, asset modernisation programmes should be amended accordingly and appropriate policies updated to reflect new learning.

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1 Introduction

TNEI is supporting SPEN in delivering a number of their LDR tranche 1 initiatives. This report summarises the activities and outcomes for Initiative 5 – Improved Modelling of HV Rural Networks to Reduce Losses.

1.1 Losses Obligations and Discretionary Reward Mechanism

Licence Condition 49 (Electricity Distribution Losses Management Obligation and Distribution Losses Strategy) imposes on DNOs a requirement to ensure that Distribution Losses from its Distribution System are as low as reasonably practicable. In addition to this obligation, in May 2016 Ofgem introduced a Losses Discretionary Reward (LDR) “to encourage and incentivise DNOs to undertake additional actions (over and above meeting their losses licence obligation) to better understand and manage electrical losses”.

The LDR is awarded over three financial periods, or tranches. SPENs Tranche 1 submission was designed to meet Ofgems’ expectations by driving innovation in our losses approach, improving our understanding of losses, increasing our engagement with stakeholders and developing our processes to manage losses.

Our program of work for Tranche 1 committed to conduct ten innovative initiatives to improve and share our understanding and management of losses. These initiatives cover a breadth of activities, including; examination of the application of smart meter data to reduce technical and non-technical losses, improving network modelling assessment tools, investigating voltage optimisation schemes and power factor assessments, reporting our revenue protection activities and improving distribution substation efficiency and metering.

This report details the outputs of initiative 5 “Improved Modelling of HV Rural Networks to Reduce Losses”. This initiative is based on development of improved tools for considering losses in the planning timeframe. This will enhance our ability to make losses related investment decisions.

Following the award of LDR Tranche 1, Ofgem issued guidelines for Tranche 2 stating: “the focus will shift from an assessment of processes... to one of specific actions undertaken and concurrent improvements in understanding”. Ofgem expect DNOs to be able to provide evidence of actions undertaken to improve their operations and to set out their vision for future in respect of managing losses.

This initiative report, and its peers, sets out the innovative activities undertaken by SPEN, over and above those mandated by Licence Condition 49, to better understand and manage electrical losses. The activities carried out to date will also form part of the supporting material for our Tranche 2 submission. SPENs Tranche 2 submission will be both forward and backward looking, to describe the actions already undertaken, and to present our ambitions for the future.

1.2 Background

SPEN’s network includes many long rural HV circuits, especially within the SP Distribution licence area. There may be high levels of load imbalance on parts of these circuits due to heavily-loaded single-phase spur lines. Recent findings from within the industry[1],[2] indicate the following:

- Rural HV networks form the majority of losses in supplying HV customers;

[1] Imperial College and Sohn Associates, “Management of electricity distribution network losses”, IFI, Feb 2014
[2] Western Power Distribution Losses Investigation, Apr 2017-Sept 2017, https://www.westernpower.co.uk/docs/Innovation/Current-projects/Losses-Investigation/6-MONTHLY-PPR-Losses-Investigation-September-2017.aspx

- The costs of imbalance losses rise steeply when imbalance exceeds a few percent; and
- The costs of imbalance losses increase in severity with circuit length.

One of the aims of this piece of work was to consider in more detail the losses due to imbalance on these long HV circuits within the SPEN networks, and to develop a parametric model to enable the circuits experiencing the most severe imbalance to be identified.

2 Project Activities and Methodology

2.1 Introduction

The completed activities for this project are given below:

- A parametric model was formulated based on readily available network data, in which weightings for each criterion were established to indicate the likelihood of phase imbalance.
- Pre-existing data (GIS and HV feeder imbalance results) collected during LCNF Tier 2 Flexible Networks[3] was used to find correlations between parameter metrics and phase imbalance. Based on this analysis, a parametric model was developed.
- The Whitchurch Primary feeder was identified for further detailed study. Possible interventions to alleviate phase imbalance were investigated, and two interventions were selected for analysis.
- The annual feeder losses were assessed for the base case (with existing levels of losses) and for the two interventions for Whitchurch and cost benefit analysis has been carried out to clarify the feasibility of these intervention actions.
- Additional feeders with potential high imbalance were identified for potential further study and measurement.

These steps are summarised in Figure 2-1 below.

[3] **SPEN .** Flexible Networks for a Low Carbon Future . *HV and LV Phase Imbalance* . [Online] September 2015. https://www.spenergynetworks.co.uk/userfiles/file/HVandLVPhaseImbalanceAssessment16.pdf

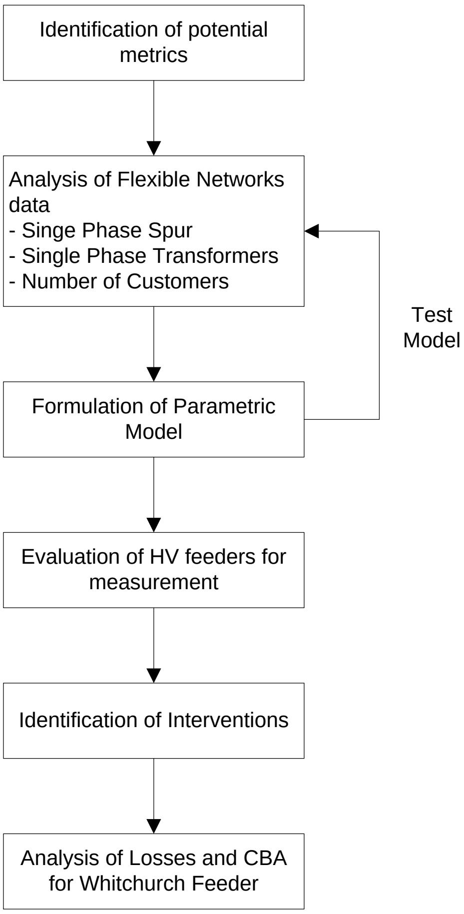


Figure 2-1 Summary of steps completed for Initiative 5

2.2 Parameter Metrics and Modelling

Possible parameter metrics for formulation of the parameter model included the following:

- number of customers supplied by each spur line;
- total number of transformers, number of single-phase transformers;
- km of single phase line;
- the ratio of single-phase line to three-phase line;
- km of non-backbone line divided by the number of non main-line fusing positions; and
- the numbers of reported incidences of nuisance tripping of three-phase equipment.

2.3 Correlation Coefficient Methodology

In order to efficiently identify single-phase HV feeders with potentially high imbalance, correlations were tested between the measured phase imbalance and a range of network parameter metrics as described in Section 2.2. These metrics relate to the characteristics of single phase circuits. A correlation coefficient was generated by using the CORREL function in Microsoft Excel.

The equation for the correlation coefficient is:

$$Correl(X_{NP}, Y_{PI}) = \frac{\sum(x_{NP} - \overline{x_{NP}})(y_{PI} - \overline{y_{PI}})}{\sqrt{\sum(x_{NP} - \overline{x_{NP}})^2 \sum(y_{PI} - \overline{y_{PI}})^2}}$$

Where,

X_{NP}: Array of network parameter metric

Y_{PI}: Array of phase imbalance metric

x_{NP}: Network parameter metric of individual feeder

y_{PI}: Phase imbalance metric of individual feeder

$\overline{x_{NP}}$: Average network parameter metric

$\overline{y_{PI}}$: Average phase imbalance metric

The calculated correlation coefficient is a value between -1 and +1, which indicates how strongly the phase imbalance and network parameter metrics are related to each other. Specifically:

- A correlation coefficient of +1 indicates a perfect positive correlation. As the network parameter metric increases, the phase imbalance metric increases. As the network parameter metric decreases, phase imbalance metric decreases;
- A correlation coefficient of -1 indicates a perfect negative correlation. As the network parameter metric increases, the phase imbalance metric decreases. As the network parameter metric decreases, the phase imbalance metric increases;
- A correlation coefficient near 0 indicates no correlation.

2.3.1 Phase Imbalance Measurement Processing

For this analysis, the following statistical relationships have been calculated:

- Maximum
- Mean
- 95th Percentile
- Mean of 100 highest loading points

The HV feeder phase imbalance was quantified based on the relationship between the 3-phase currents. Unlike voltages, there is no standard method to represent phase imbalance for 3-phase currents. For the SPEN Flexible Networks project, the HV phase imbalance was calculated as the difference in current (in amperes) between the most heavily loaded phase and the least heavily loaded phase, and the maximum HV phase imbalances were reported as the phase imbalance of the HV feeders.

Since the phase imbalance varies significantly with the changing demand, the maximum HV phase imbalance may not be the most accurate way to characterise the HV feeder phase imbalance. Therefore, in addition to the maximum HV phase imbalance, the mean, and 95th percentile values of the annual HV phase imbalance were also calculated based on the measurement data in 2014.

In addition, the mean value of the HV phase imbalance for the 100 highest phase loadings (ranked by the sum of 3-phase currents) was also calculated for each feeder. This value was used in the Flexible Networks project to investigate the LV feeders with persistent phase imbalance.

2.4 Losses due to Phase Imbalance

Phase imbalance has been identified one of the sources of loss on the network. Losses are greater for an unbalanced feeder as the losses on each phase are proportional to the square of the current. The losses in a three phase system are given by the equation below:

$$\text{Losses} = (I_A^2 \times R_A) + (I_B^2 \times R_B) + (I_c^2 \times R_C)$$

By way of an example, for a balanced system with a total current of 300 A the losses would be:

$$\text{Losses} = (100^2 \times R_A) + (100^2 \times R_B) + (100^2 \times R_C)$$

$$\text{Losses} = 10\,000\text{ R} + 10\,000\text{ R} + 10\,000\text{ R}$$

$$\text{Losses} = 30\,000\text{ R}$$

However, for an unbalanced system with one of the feeders having four times the load of the other two feeders, the losses would be given as follows:

$$\text{Losses} = (200^2 \times R_A) + (50^2 \times R_B) + (50^2 \times R_C)$$

$$\text{Losses} = 40\,000\text{ R} + 2\,500\text{ R} + 2\,500\text{ R}$$

$$\text{Losses} = 45\,000\text{ R}$$

In this case, it can therefore be seen that the losses in the unbalanced feeder are 1.5 times those in the balanced feeder.

Phase imbalance is not constant but will vary during daily, weekly and seasonal timeframes. This is illustrated in Figure 2-2, which shows the measurements for three phases are over a 24 hour period.

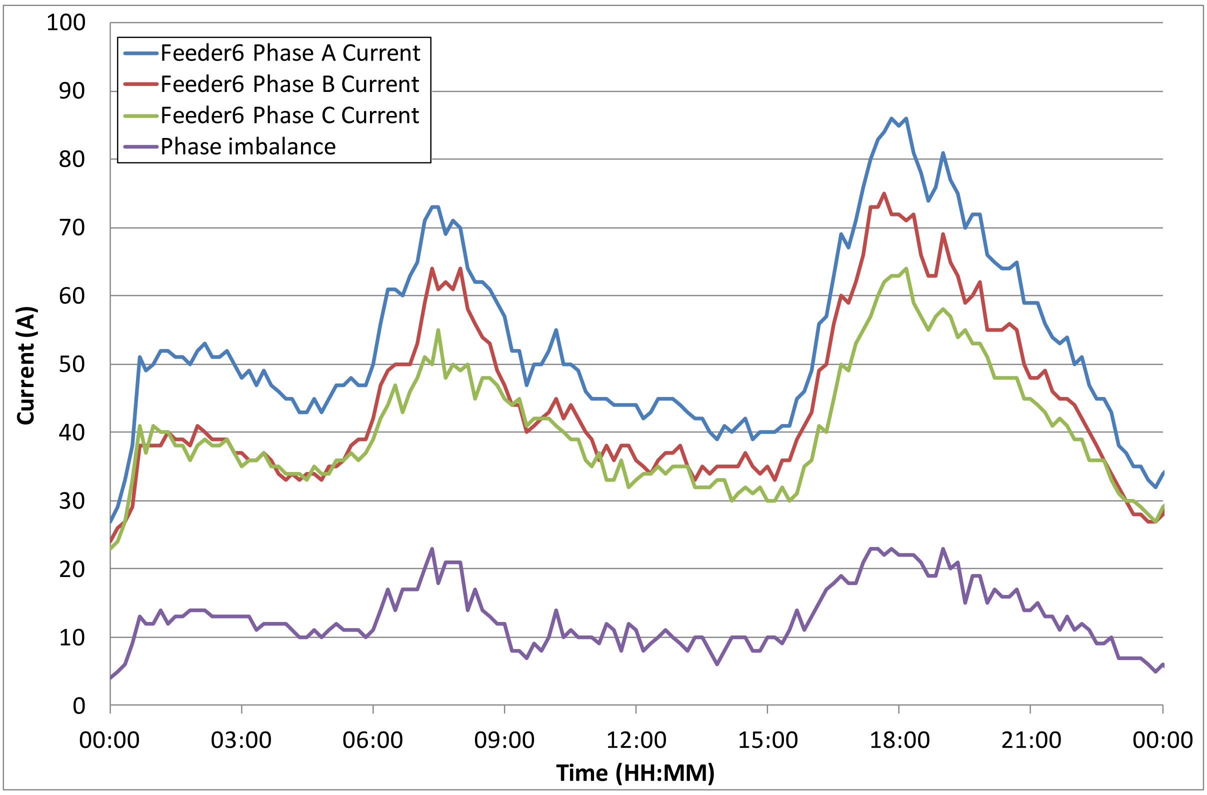


Figure 2-2 Example of Three Phase Loading over a 24 hour Period – Whitchurch Primary Feeder 6

2.5 LCNF Flexible Networks

LCNF funded project, "Flexible Networks for a Low Carbon Future", was carried out between 2012 and 2015. Part of this project looked into interventions that would allow for 20% of capacity headroom to be released. One of these interventions was to measure the extent of phase imbalance on three separate locations on the SPD and SPM, these areas being St Andrews, Whitchurch and

Ruabon. These were chosen to cover various network topologies and customer demographics and are shown in Figure 2-3 below.

Figure 2-3 LCNF Test Networks

Historically there has been little monitoring of the voltage and current on the 11 kV and LV network with a 'fit and forget' approach being taken. However, as part of the LCNF project, three phase voltage and current measurements were available for 89 Secondary substations with 233 LV feeders from 2013 to 2015 (mainly ground mounted substations for the three trial networks). The results are presented in a report compiled by TNEI and Strathclyde University[4].

Monitoring equipment was installed on all the feeders at a total of 7 primary substations and the data collected over a three year period. This data allowed for the extent of the phase imbalance on each network to be measured and analysed.

The LCNF project showed that the installation and management of monitoring equipment at primary substations took significant effort in terms of time and resources. This LDR initiative aims to match the measurement data with other network data to find correlations that would suggest possible locations for phase imbalance. Once identified these locations could be fitted with monitoring equipment to ascertain the level of imbalance and suggest suitable interventions.

2.6 Report Structure

The remainder of this report is structured as follows:

- Section 3 describes the modelling carried out to process the Flexible Networks GIS data;
- Section 4 describes the modelling carried out to process and correlate the Flexible Networks measurement data;
- Section 5 provides the formulation of the parametric model;
- Section 6 identifies the proposed measurement locations and the outputs from the measured data; and

[4] **Higgins, Charlotte, Ian, Elders and Sarah, Weatherhead.** *HV and LV Phase Imbalance Assessment.* Glasgow : SP Energy Networks, 2015.

- Section 7 provides the cost benefit analysis for intervention actions.

3 Use of GIS Data

The Geographic Information System (GIS) provided the source to the data used for correlation with the phase imbalance data from the Flexible Networks project. Each individual asset (circuit or transformer) is identified on using X (Easting) and Y (Northing) which gives its physical location. The three sections below describe how the GIS data was processed to find the parameters used in the model.

3.1 Three Phase and Single Phase line

The GIS data providing overhead lines and underground cables was used to calculate the relationship in each HV feeder in terms of three phase and single phase lines. The data enabled the length of each line to be identified, its feeder ID and whether it was three phase or single phase. This is shown in Appendix B. The X and Y co-ordinates of the line start and end terminals also allowed these values to be plotted on a graph. Figure 3-1 and Figure 3-2 show the proportion of single phase lines in each area. The results of this calculation are presented in Appendix C.

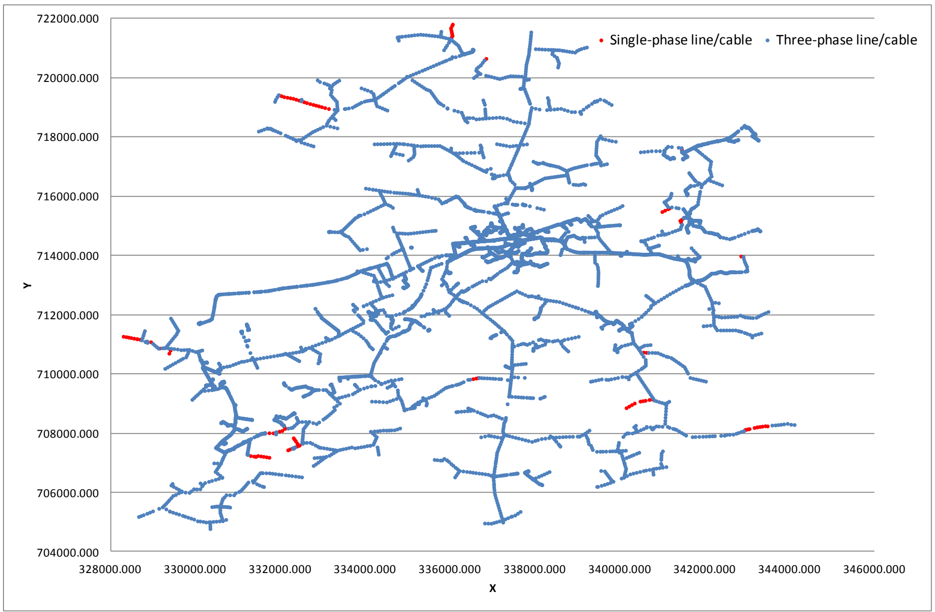


Figure 3-1 Cupar 11 kV network from the St Andrews test Site

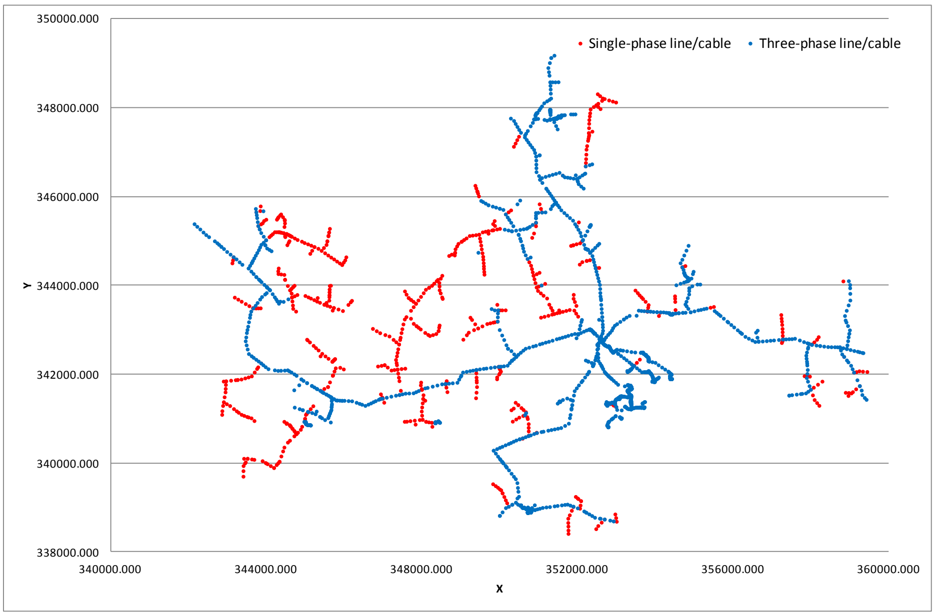


Figure 3-2 Whitchurch 11 kV Network

3.2 Number of Transformers

Specific transformer phase information is not readily available (requires a site visit to confirm). However, it could be estimated based on industrial practices and the coordinate information from the GIS data. Specifically, the ground mounted transformers are normally three-phase connected. For the pole mounted transformers, the transformers whose ratings are above 50kVA are normally three-phase connected, while those whose ratings are below 25kVA are normally single-phase connected. For the pole mounted transformers, whose ratings are between 25kVA and 50kVA, their phase connection has been estimated with the following GIS data:

- Feeder IDs and Coordinates of the transformers from the GM_TX and PM_TX data tabs, as shown in Figure 3-3;
- Feeder IDs and Coordinates of single-phase/three-phase lines, as shown in Figure 3-3.

	L	AJ	AM	AN
1	FEEDERID	SPNOOFCUST	X_1	Y_1
2	SP19113	97	354558.38300	702811.39200
3	SP19113	220	354883.24200	702507.69000
4	SP19123	171	357005.49100	703919.15900
5	SP19122	48	346993.85300	707706.03000
6	SP19113	6	350788.16600	700789.33200
7	SP19113	239	352628.93300	701800.65900
8	SP19122	1	352497.42600	703617.27900
9	SP19113	103	356097.02700	703353.09400

Figure 3-3 GM and PM GIS data used to estimate transformer phase and customer number information

Specifically, the distances *d* between a transformer and the start and end terminals of all the lines with the same feeder ID were calculated, using the equation below.

$$d = \sqrt{(x_{Tx} - x_{Line})^2 + (y_{Tx} - y_{Line})^2}$$

Where,

x_{Tx}: The x-coordinate of transformer

y_{Tx}: The y-coordinate of transformer

x_{Line}: The x-coordinate of the sending/receiving end of line section

y_{Line}: The y-coordinate of the sending/receiving end of line section

The transformer was assumed to be connected to the line which had a start or end terminal with the minimum distance to the transformer. The transformers connected to single-phase circuits were assumed to be single-phase transformers, while those connected to three-phase circuits were assumed to be three-phase transformers. This assumption was tested and found to be reasonable. The single-phase/three-phase transformer numbers of each HV feeder have been summarised and can be found in Appendix E.

3.3 Number of Customers

As shown in Figure 3-3, the number of customers supplied by each transformer could be found in the GIS using the GM_TX and PM_TX data tabs. The customers were assumed to be supplied by a single-phase circuit if the transformer was found to be a single-phase transformer, while the customers were assumed to be supplied by a three-phase circuit if the transformer was found to be a three-phase transformer. The customer numbers supplied by single-phase/three-phase circuits for each HV feeder were summarised in Appendix F.

3.4 Data Not Used

Additional data was initially proposed to be used in the development of this project. For the reasons stated below this data was not used.

3.4.1 NOJA Data

NOJAs are automated switches located on overhead lines. From a measurement point of view the location is useful as they tend to be situated midpoint on rural lines of the type this study is concerned with. However, the NOJA data was not of sufficient volume or quality to be of use. NOJAs do not record data at regular intervals but by exception when a measured value departs from a deadband. In addition, only data from the St Andrews test area was available. This would have only provided data on one network type which would not be sufficient to draw any conclusions.

3.4.2 Nuisance Tripping

This data was not available as part of the GIS data so was not included. Depending on the format of this data it may be possible to find a correlation between tripping and phase imbalance. However this would benefit from a larger data set of phase imbalance measurements. Using tripping data as a parameter will tend to favour sites that have high levels of short duration imbalance. These sites may have low levels of consistent imbalance, which would have more impact on the overall losses. The inclusion of tripping data in any measurement campaign would allow a clearer understanding of whether this would be a useful metric.

4 Analysis of Flexible Networks Measurement Data

4.1 Measurement Data

In the Flexible Networks project, eight primaries (and 52 HV feeders) were monitored between 2013 and 2015. The 3-phase currents of the HV feeders at these primaries were recorded at ten-minute intervals within this period. These measurements are point measurements in amperes, i.e. the recorded current represents a single RMS current measurement at the time shown. It should be noted that not all measurements were recorded from 2013 to 2015 due to issues such as communications dropout. The data availabilities of all these feeders is summarised in Table 4-1 below and provided in detail in Appendix B. For each year and each HV feeder, the time points with available current measurements were counted, and the percentages were calculated correspondingly, based on the expected annual measurement of 52560 (=365days x 24hours x 6measurement/hour). It was decided to focus on the measurement data for the year 2014 as the data for this year was found to have the best availability.

Table 4-1 Summary of HV Feeder Current Measurement Data Availability

Primary Name	Percentage of Available Data (for all HV feeders connected to each substation)		
	2013	2014	2015
Anstruther	45	80	63
Cupar	45	80	0*
Leuchars	0-34	0-81	0-73
St Andrews	47-48	56-61	9-35
Liverpool Rd	51	55	22
Whitchurch	28	37	57-60
Yockings Gate	45	95-96	9-11
Ruabon	0-15	0-78	0-72
Average	**38**	**67**	**34**

*please note that some HV feeders do not have any recorded data

4.2 HV Feeder Phase Imbalance Assessment

The HV feeder phase imbalance was quantified based on the relationship between the 3-phase currents. Unlike voltages, there is no standard method to represent phase imbalance for 3-phase currents. For the SPEN Flexible Networks Project, the HV phase imbalance was calculated as the difference in current (in amperes) between the most heavily loaded phase and the least heavily loaded phase, and the maximum HV phase imbalances were reported as the phase imbalance of HV feeders. Since the phase imbalance varies significantly with the changing demand, the maximum HV phase imbalance may not be the most accurate way to characterise the HV feeder phase imbalance. Therefore, in addition to the maximum HV phase imbalance, the mean and 95th percentile values of the annual HV phase imbalance were also calculated based on the measurement data of year 2014. In addition, the mean value of the HV phase imbalance at the 100 highest phases loading times (ranked by the sum of 3-phase currents) was also calculated for each feeder. This value was used in the Flexible Networks project to investigate the LV feeders with persistent phase imbalance.

The phase imbalance results based on the measurement data from 2014 are given in Appendix A. Some statistics of all the calculated HV feeder phase imbalance results are summarised in Table 4-2 below.

Table 4-2 Statistics of All the Calculated HV Feeder Phase Imbalance Results

Phase imbalance Metric	Current Imbalance (A)					
Phase imbalance index	Min	Max	Mean	5th Percentile	Median	95th Percentile
Maximum	4.00	49.00	15.73	7.00	14.00	29.65
Mean	0.66	11.39	3.73	1.29	3.37	7.85
95 Percentiles	2.00	19.00	6.92	3.00	6.50	13.30
Mean of 100 maximum load	1.75	23.43	6.04	2.10	5.02	13.83

4.3 Correlation Results

In this study, using the methodology described in the previous sections, the correlation coefficients were calculated for the data as outlined in Table 4-3. Each data was processed on its own and then as two different ratios of the full set of data.

Table 4-3 Data Sets Used for the Analysis

Main Data Set	Subset Processing
Cable Data	Total length of single phase spur
	Ratio of single phase spur line over all circuits
	Ratio of single phase spur over three phase line
Transformers	Number of single phase transformers
	Ratio of single phase transformers over all transformers
	Ratio of single phase transformers over three phase transformers
Customers	Number of customers supplied by single phase spur
	Ratio of number of customers supplied by single phase spur over total number of customers
	Ratio of number of customers supplied by single phase spur over number of customers supplied by three phase line

4.3.1 Single-phase spur

In the UK distribution networks, there are single-phase HV supplies taken from the 3-phase system. The single-phase HV supplies can be:

- A single-phase transformer connected to a single-phase spur, which is connected across two phases of the main 3-phase lines;
- A single-phase transformer connected directly to the main 3-phase lines.

The connection of a number of single-phase spurs, especially with long lengths, may lead to unbalanced loading on the three phases of the main HV feeders. Therefore, the correlation between the single-phase spur and phase current imbalance has been studied and the results are presented in the three tables below. The following observations have been made:

- Using the maximum value for phase imbalance provides a poor correlation when compared with the other calculated values.
- In general, it has been shown that the correlation is good as the value for “All HV Feeders” is high, indicating a strong positive correlation.
- The maximum, mean and 95th percentile points tend to be similar at the extreme positive and negative correlations. There is an exception for Liverpool Road and Cupar. For these the correlation for the 100th highest measurements is considerably lower than for the other two values. Overall, there is a strong correlation between areas with large amounts of single phase spurs such as Whitchurch and Ruabon. Areas with less single-phase lines show a reduced correlation. However this reduction in correlation is not directly proportional to the amount of single phase line.
- Feeders 22 and 23 at the Leuchers primary had no measurement data so were excluded from the correlation calculation.

Table 4-4 Total Length of Single Phase Spur

Primary substation	Maximum	Mean	95th percentile	Mean of 100 highest loading time points
Anstruther	0.05	-0.72	-0.94	-1.00
Cupar	0.26	0.58	0.57	0.41
Leuchars	-0.12	-0.12	-0.09	0.09
St Andrews	-0.29	-0.04	-0.09	0.23
Liverpool Road	-0.18	0.51	0.52	0.35
Whitchurch	0.92	0.89	0.93	0.97
Yockings Gate	0.34	0.89	0.93	0.88
Ruabon	0.59	0.91	0.90	0.92
All HV Feeders	**0.31**	**0.75**	**0.71**	**0.82**

Table 4-5 Ratio of Single Phase Spur to All Circuits

Primary substation	Maximum	Mean	95th percentile	Mean of 100 highest loading time points
Anstruther	-0.01	-0.76	-0.96	-0.99
Cupar	0.41	0.65	0.63	0.48
Leuchars	-0.12	-0.12	-0.09	0.09
St Andrews	-0.28	-0.05	-0.15	0.10
Liverpool Road	-0.19	0.50	0.51	0.34
Whitchurch	0.95	0.97	0.97	0.98
Yockings Gate	0.44	0.88	0.91	0.86
Ruabon	0.41	0.78	0.79	0.83
All HV Feeders	**0.25**	**0.73**	**0.66**	**0.78**

Table 4-6 Ratio of Single Phase Spur and Three Phase Spurs

Primary substation	Maximum	Mean	95th percentile	Mean of 100 highest loading time points
Anstruther	0.00	-0.75	-0.96	-0.99
Cupar	0.41	0.65	0.63	0.48
Leuchars	-0.12	-0.12	-0.09	0.09
St Andrews	-0.28	-0.05	-0.15	0.10
Liverpool Road	-0.19	0.51	0.52	0.35
Whitchurch	0.95	0.93	0.96	0.99
Yockings Gate	0.41	0.88	0.92	0.86
Ruabon	0.47	0.84	0.84	0.87
All HV Feeders	**0.28**	**0.74**	**0.69**	**0.81**

4.3.2 Single Phase Transformers

Single phase transformers will inherently cause an imbalance as they will be connected to either two phases of a three phase line or be connected to a single phase spur. The table below show the correlation between the number of single phase transformers (given as four statistical values) and the measured phase imbalance. From these tables the following observations were made:

- Similarly to the study with single phase spurs, using the maximum value provides a poor result.
- In general, it has been shown that the correlation is good as the value for “All HV Feeders” is high, indicating a strong positive correlation.
- Both Cupar and St Andrews have relatively low numbers of transformers and this is reflected in the low correlation figures seen in the number of single transformers.

- Liverpool Road has a HV feeder with a large proportion of single phase transformers but a low correlation was observed.
- The values for Whitchurch, Yockings Gate and Ruabon all have a large proportion of single phase transformers (especially Whitchurch) with all these three primaries showing strong correlations.

Table 4-7 Number of Single Phase Transformers

Primary substation	Maximum	Mean	95th percentile	Mean of 100 highest loading time points
Anstruther	-0.07	-0.80	-0.97	-0.99
Cupar	0.26	0.46	0.43	0.30
Leuchars	-0.77	-0.57	-0.33	-0.80
St Andrews	-0.09	0.13	0.08	0.40
Liverpool Road	0.07	0.49	0.49	0.37
Whitchurch	0.89	0.90	0.93	0.96
Yockings Gate	0.38	0.89	0.92	0.87
Ruabon	0.58	0.91	0.90	0.93
All HV Feeders	**0.45**	**0.75**	**0.71**	**0.79**

Table 4-8 Ratio of Single Phase Transformer to All Transformers

Primary substation	Maximum	Mean	95th percentile	Mean of 100 highest loading time points
Anstruther	-0.21	-0.87	-1.00	-0.98
Cupar	0.45	0.32	0.31	0.37
Leuchars	-0.77	-0.57	-0.33	-0.80
St Andrews	-0.07	0.16	0.14	0.34
Liverpool Road	0.07	0.49	0.49	0.37
Whitchurch	0.71	0.76	0.72	0.74
Yockings Gate	0.69	0.78	0.80	0.73
Ruabon	0.45	0.79	0.80	0.85
All HV Feeders	**0.37**	**0.64**	**0.56**	**0.66**

Table 4-9 Ratio of Single Phase Transformers and Three Phase Transformers

Primary substation	Maximum	Mean	95th percentile	Mean of 100 highest loading time points
Anstruther	-0.11	-0.82	-0.99	-0.99
Cupar	0.45	0.33	0.32	0.36
Leuchars	-0.77	-0.57	-0.33	-0.80
St Andrews	-0.10	0.13	0.10	0.34
Liverpool Road	0.07	0.49	0.49	0.37
Whitchurch	0.78	0.82	0.82	0.85
Yockings Gate	0.59	0.84	0.87	0.80
Ruabon	0.53	0.87	0.87	0.91
All HV Feeders	**0.34**	**0.69**	**0.60**	**0.73**

4.3.3 Number of Customers

One of the factors that was considered as a cause for phase imbalance was the number of customers supplied by a single phase transformer compared to those fed from a three phase transformer. Lightly loaded single spurs were put forward as one of the possible causes of unbalance. The number of customers was found from the GIS data and was used to calculate the correlation values in the tables below. From these tables the following observations were made:

- Using the maximum value gives inconsistent results.
- In general, it has been shown that the correlation is significant as the value for “All HV Feeders” is high, indicating a strong positive correlation.
- Liverpool Road shows a weak correlation despite having one feeder with a significant proportion of single phase customers.
- Whitchurch has a high correlation and has a significant proportion of single phase customers. However, both Yockings Gate and Ruabon show a high correlation but have relatively low numbers of single phase customers.

Table 4-10 Number of Customers

Primary substation	Maximum	Mean	95th percentile	Mean of 100 highest loading time points
Anstruther	-0.10	-0.82	-0.98	-0.99
Cupar	0.23	0.38	0.34	0.23
Leuchars	-0.77	-0.57	-0.33	-0.80
St Andrews	-0.04	0.17	0.12	0.43
Liverpool Road	0.07	0.49	0.49	0.37
Whitchurch	0.89	0.86	0.91	0.95
Yockings Gate	0.25	0.91	0.94	0.88
Ruabon	0.60	0.91	0.91	0.93

All HV Feeders	**0.44**	**0.76**	**0.72**	**0.82**

Table 4-11 Ratio of Number of Single phase Customers to Total Number of Customers

Primary substation	Maximum	Mean	95th percentile	Mean of 100 highest loading time points
Anstruther	0.27	-0.54	-0.84	-0.95
Cupar	0.08	0.35	0.25	0.05
Leuchars	-0.77	-0.57	-0.33	-0.80
St Andrews	-0.38	-0.15	-0.25	0.29
Liverpool Road	0.07	0.49	0.49	0.37
Whitchurch	0.60	0.68	0.65	0.67
Yockings Gate	0.26	0.91	0.94	0.87
Ruabon	0.61	0.92	0.91	0.93
All HV Feeders	**0.24**	**0.62**	**0.51**	**0.62**

Table 4-12 Ratio of Single Phase Customers to Total Number of Customers

Primary substation	Maximum	Mean	95th percentile	Mean of 100 highest loading time points
Anstruther	0.28	-0.53	-0.84	-0.95
Cupar	0.06	0.34	0.24	0.03
Leuchars	-0.77	-0.57	-0.33	-0.80
St Andrews	-0.39	-0.15	-0.26	0.29
Liverpool Road	0.07	0.49	0.49	0.37
Whitchurch	0.56	0.64	0.62	0.65
Yockings Gate	0.26	0.91	0.94	0.87
Ruabon	0.61	0.92	0.91	0.93
All HV Feeders	**0.22**	**0.58**	**0.48**	**0.60**

4.3.4 Further Investigation of the Correlation Study Results

Further studies based on the current measurement data were carried out to investigate the correlation study results.

As shown in the correlation results, the correlation coefficients calculated based on the maximum phase imbalance currents were inconsistent with those based on the other HV feeder phase imbalance metrics. One potential reason is that the maximum phase imbalance may not represent the HV feeder imbalance level accurately, since the maximum phase imbalance may be caused by some unusual loading condition, or simply by a measurement error. For instance, the maximum phase imbalance (49A) was observed for Liverpool Road Feeder 5. The sampled current profiles of this feeder are shown in Figure 4-1 below. It can be seen that for most of the time, the phase currents were well balanced, except at the time point around 18:00, when the maximum phase imbalance was observed.

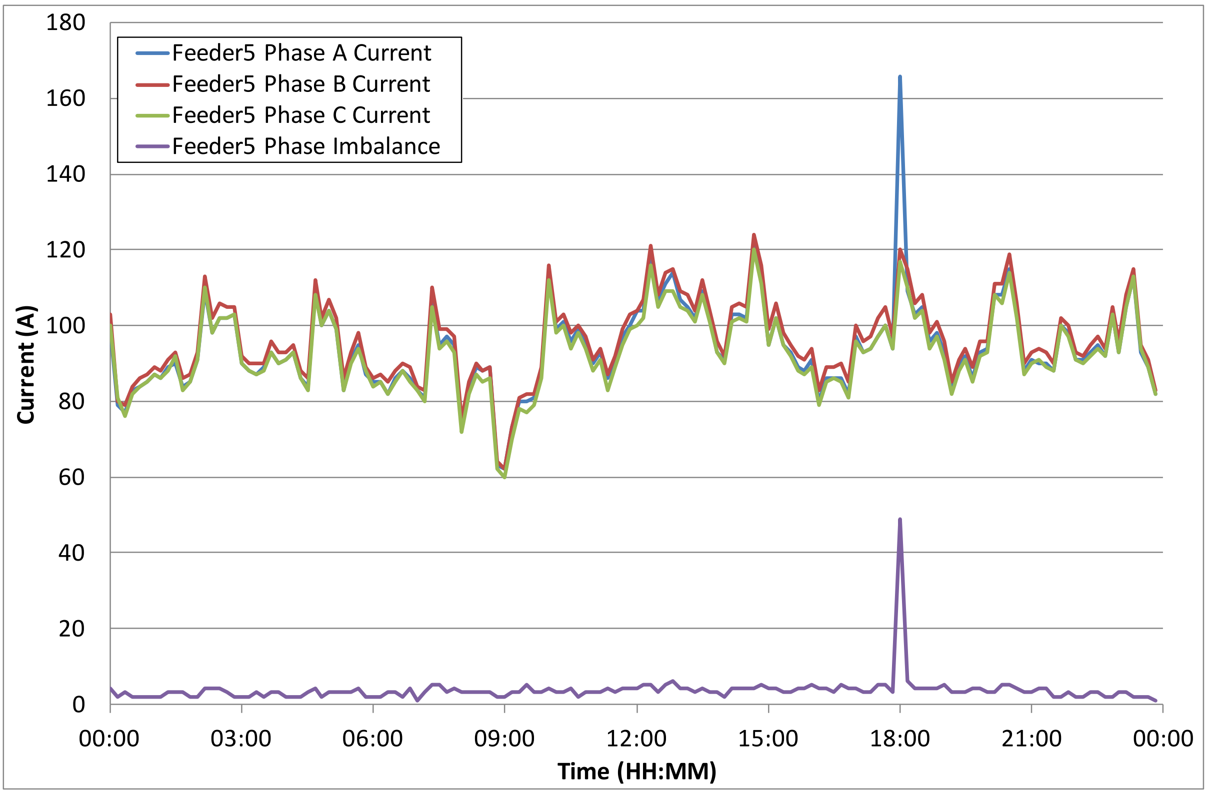


Figure 4-1 Current Profiles of Liverpool Road Feeder 5

In the correlation studies, it can be seen that although overall significant correlations could be observed, there are some exceptions, when weak correlation or even negative correlation was found. For example, negative correlation coefficients were observed for the Anstruther Primary at all times. For the Anstruther Primary, it could be seen from the phase imbalance calculation results that Feeder 23 had the largest phase imbalance, although it does not have any single phase spur or transformer. This is because most of the loads were single phase LV loads, supplied by three phase secondary transformers. If the imbalance in the LV networks is high, it can affect the imbalance at the HV feeder level. In contrast, Feeder 22 was reasonably well balanced although it has the longest single phase spur among all these four feeders. Although the single phase spur is long, the proportion of the single phase spur was still low (4.6%), which may not make any significant contribution to phase imbalance. In addition, Feeder 22 and 23 were both found to be relatively well balanced, as shown in Figure 4-2 and Figure 4-3.

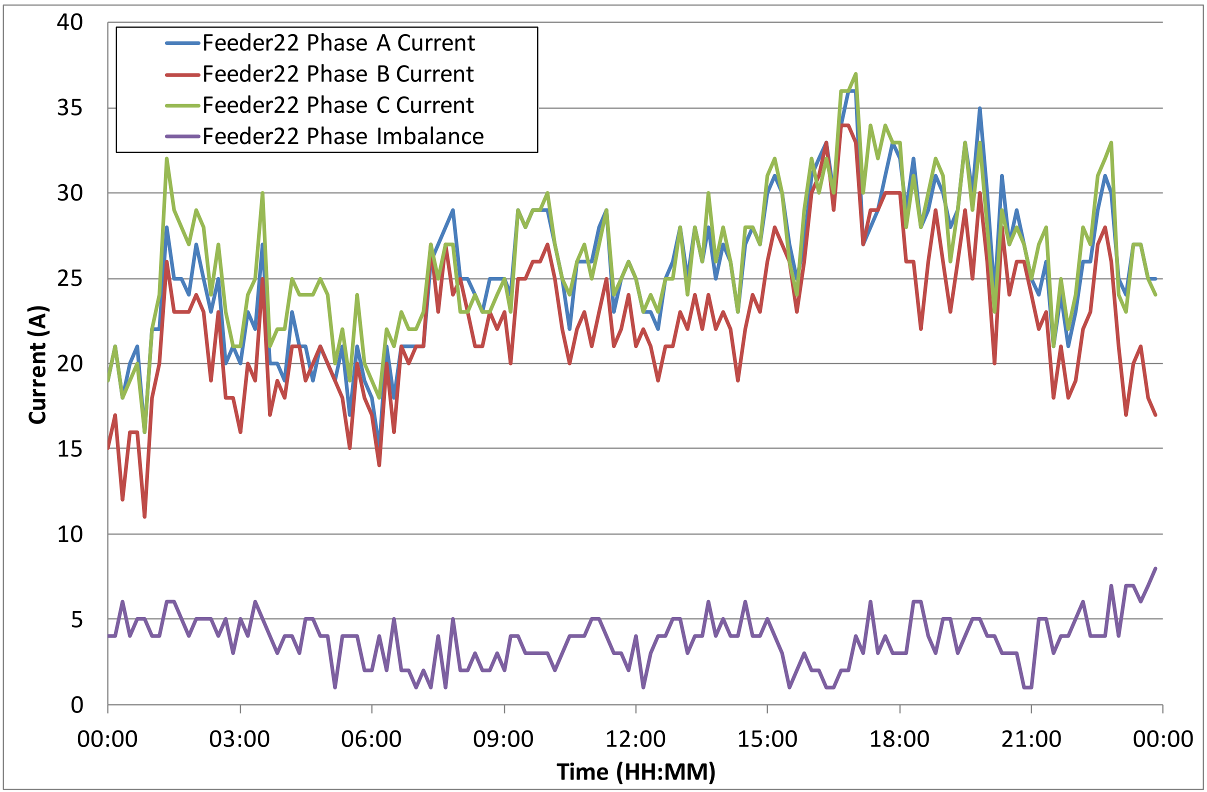


Figure 4-2 Current Profiles of Anstruther Primary Feeder 22

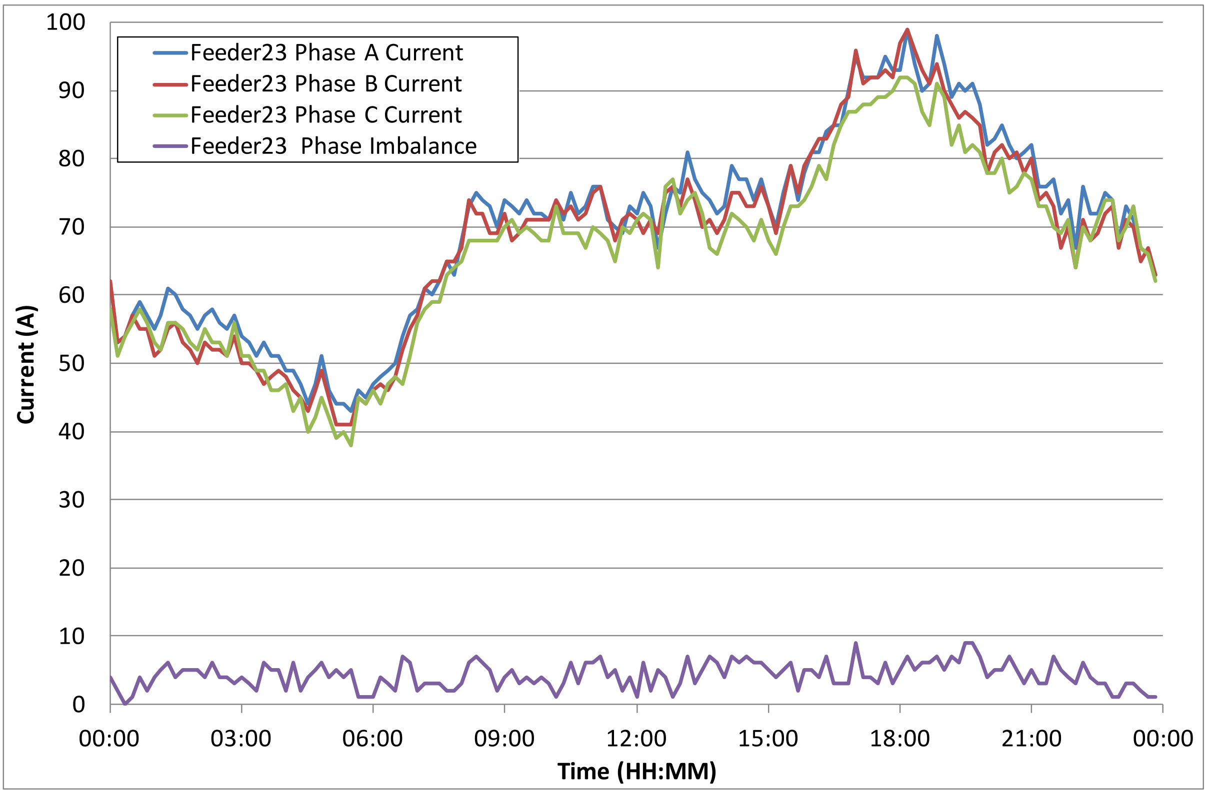


Figure 4-3 Current Profiles of Anstruther Primary Feeder 23

4.3.5 Summary of Results

The following observations were made, which were used to inform the development of the parametric model:

- Using the maximum current measurement does not provide an accurate way to represent imbalance or evaluate any results. Using the mean, 95th percentile or the mean of highest 100 loading time points will give similar correlation results.
- The single phase spur length is an indicator for phase imbalance especially where there is a large proportion of single phase spurs. This is shown by the high value for “All HV Feeders”. However this correlation is not linear, for example Cupar shows a correlation of around 0.6 whilst having relatively few single line lengths.

The number of single phase transformers and the customer numbers supplied by single phase transformers are also an indicator of phase imbalance as indicated by the correlation coefficients calculated for “All HV Feeders”.

The formulation of the parametric model was therefore based on three parameters:

- The single line length to three phase line length;
- The number of single phase transformers; and
- The number of customer supplied by single phase transformer.

5 Formulation of Parametric Model

A parametric model has been developed to predict the likelihood of HV feeders with high phase imbalance, based on the available network GIS data discussed previously.

5.1 Development of Parametric Model

As found in the correlation studies, correlations were observed between the current phase imbalance metrics (mean, 95th percentile value and mean of 100 highest loading points) and the following parameters for HV feeders:

- Total length of single-phase spur;
- Total number of single-phase transformer; and
- Total number of customers supplied by single-phase transformer.

A linear parametric model has been proposed based on the parameters above and is represented by the following equation:

$$\mathrm{I}_{\mathrm{PhaseImbalance}} = \alpha + \beta_1 \mathrm{L}_{1\mathrm{PhaseSpur}} + \beta_2 \mathrm{N}_{1\mathrm{PhaseTx}} + \beta_3 \mathrm{N}_{1\mathrm{PhaseTxCustomerNum}}$$

Where,

$I_{PhaseImbalance}$: Current Phase Imbalance Metric (A)

$L_{1PhaseSpur}$: Total length of single phase spur (m)

$N_{1PhaseTx}$: Number of single phase transformer

$N_{1PhaseTxCustomerNum}$: Customer number supplied by single phase transformer

α, β_1, β_2 and β_3: coefficients of the parametric model

Here, the coefficients were calculated for all the three current phase imbalance metrics. The mean and the 95th percentile values represent the level of phase imbalance, which is related to losses. The mean of 100 highest loading points provides an indication of phase imbalance level when the demand is high, which could be used to study the impact of phase imbalance on network capacity.

The data used for the correlation studies were used to calculate the coefficients in the parametric models, which can be found in Appendix H. The coefficients calculated by using the Regression function in Microsoft Excel are shown in Table 5-1.

Table 5-1 Coefficients of the Parametric Models

Phase imbalance Metric	α	β_1	β_2	β_3
Mean	3.0164	0.0005	0.0660	-0.0400
95th Percentile	5.8756	0.0005	0.0778	-0.0299
Mean of 100 highest loading points	4.7953	0.0008	0.0097	-0.0176

It can be seen in Table 5-1 that negative coefficient was determined for β_3. This is due to the feeder parameter multicollinearity, which is a phenomenon in which two or more predictor variables in a multiple regression model are highly correlated. The calculated correlation coefficients between the HV feeder parameters can be found in Table 5-2, which show a strong correlation between these three parameters. It should be noted that in this case, the coefficients in the parametric model should not be interpreted individually to predict the phase imbalance. It is possible to get rid of the negative coefficient by removing one or two parameters from the parametric model, or including more data to derive the parameter model. Since future measurement is expected, all these three parameters were retained.

Table 5-2 Correlation between HV Feeder Parameters

	Number of single phase transformer	Customer number supplied by single phase transformer
Total length of single phase spur	0.95	0.99
Number of single phase transformer	-	0.97

The developed model was applied to the existing data set, and the residuals were analysed. The residual *e* is calculated by the following equation:

$$e = y - \bar{y}$$

where y is the observed value and $\bar{y}$ is the predicted value.

Residual plots were also used to evaluate the parametric models. A residual plot is a graph that shows the residuals on the vertical axis and the independent variable on the horizontal axis. Since more than one independent variable is considered in the developed parametric models, the residuals are plotted against the HV feeder numbers, as shown in Appendix G. The residuals are expected to randomly disperse around the horizontal axis, which indicate that a linear regression model is appropriate. It can be seen from these plots that in general the residuals are dispersed randomly around the horizontal axis, which shows that the linear regression model could be used here.

The parametric models can also be evaluated using the R-squared function, which is a statistical measure showing how close the data are to the fitted regression line. It is the ratio between explained variation and total variation, and it is always between 0% and 100%:

- 0% indicates that the parametric model explains none of the variability of the response data around its mean.
- 100% indicates that the parametric model explains all the variability of the response data around its mean.

Normally, higher R-squared values indicate that the parametric model fits the data better. The R-squared values of the developed models have been calculated and can be found in Table 5-3. It can be seen that the R-squared values of the developed models are generally high. This indicates a good fit, i.e. that the parametric model explains much of the variability of the response data around its mean.

Table 5-3 R-squared Values of the Developed Parametric Models

Phase imbalance Metric used in the parametric model	R^2
Mean	61%
95th Percentile	54%
Mean of 100 highest loading points	69%

5.2 Limitation of the Parametric Models

The phase imbalance could be higher and more persistent if a significant amount of loads are connected unevenly. For example, the loads connected to the single-phase spurs are naturally unbalanced loads. In this case, the developed parametric models could be used to find the HV feeders with potential high phase imbalance. However, phase imbalance is also affected by many other factors, beside single phase spurs and single phase transformers. Potentially, a HV feeder may experience high phase imbalance, even if it does not have any single phase spur or transformer, since most of the loads are single phase loads and vary continuously. In this case, measurements may be required, instead of the parametric models, to identify a high imbalance.

6 Network Measurements

The developed parametric model has been applied to the GIS data of the HV networks of the whole SPEN license areas. The potential HV feeders to be measured have been proposed.

6.1 Input GIS Data

Based on studies from previous sections, the following data shown in Table 6-1 were requested and received from SPEN for the entire SPEN license areas.

Table 6-1 GIS Data Requested

Network Component	Tag in GIS data	Description
Overhead Line/Underground Cable	FEEDERID	HV feeder ID
	FEEDERID2	HV feeder ID 2
	OPERATINGV	Operating voltage
	SPNUMOFPHA	Phase number
	SHAPE_Leng	Feeder Length
	X1	Coordinate X of feeder terminal 1
	Y1	Coordinate Y of feeder terminal 1
	X2	Coordinate X of feeder terminal 2
	Y2	Coordinate Y of feeder terminal 2
Ground mounted /Pole mounted distribution transformer	FEEDERID	HV feeder ID
	FEEDERID2	HV feeder ID 2
	OPERATINGV	Operating voltage
	X	Coordinate X of transformer
	Y	Coordinate X of transformer
	SPNOOFCUST	Customer number
	SPTRANSRAT	Transformer rating

The received data records for each network component are summarised in Table 6-2.

Table 6-2 Number of GIS Data Records Received

Network Component	Number of Records
Overhead Line	111336
Underground Cable	272780
Ground mounted distribution transformer	27776
Pole mounted distribution transformer	58643

In addition, Primary INN values, which could be used to identify the HV feeder primary names, were also provided by SPEN.

6.2 Evaluation of HV Feeders with the Parametric Model

A Python script was developed to process and calculate the following parameters for the 5660 HV feeders in the entire SPEN license area:

- Total length of single-phase spur;
- Total number of single-phase transformer; and

- Total number of customers supplied by single-phase transformer.

Then the following phase imbalance metrics were predicted based on the parameters calculated above, and the parametric models developed in Section 5:

- Mean;
- 95th Percentile; and
- Mean of 100 highest loading points.

6.3 Potential HV Feeders to Be Measured

The HV feeders were selected based on the predicted phase imbalance metric values, and the 95th percentile values of each metric shown in Table 4-2. Specifically, for a HV feeder, if the predicted values of the three phase imbalance metrics are all above the corresponding 95th percentile values shown in Table 4-2, this HV feeder is considered to have potential for high imbalance, and could be measured in future.

With this approach, 232 HV feeders from 120 primary substations were selected. 112 HV feeders are in the SPD license area, while 120 HV feeders were in SPM license area. The details of these HV feeders and the predicted phase imbalance values can be found in Appendix I. Please note that it is envisaged that this methodology would be verified and refined over time as monitoring data becomes available for analysis.

14 HV feeders have been selected for more detailed analysis by considering the diversity of phase imbalance and license areas, as summarised in Table 6-3. These feeders were selected with the following considerations:

- The selected 232 HV feeders were grouped based on their estimated phase imbalances. In each group, two HV feeders were selected;
- Half of the 14 HV feeders were selected from the SPD license area, while the other half of the selected HV feeders were from the SPM license area.

The predicted phase imbalance index results for the Whitchurch feeders have also been provided in Table 6-3 by way of comparison. Generally, the imbalance metric for the Whitchurch feeders is somewhat lower than the predicted phase imbalance metric for the other selected feeders.

Table 6-3 HV Feeders Selected for Potential Measurement

License Area	Primary Name	FeederID	Mean Phase Imbalance Metric	95th Percentile
SPD	DOUGLAS WEST	SP83921	57.35	64.90
SPM	09/9585/002/E-LLANIDLOES	MW92303	24.08	31.69
SPM	09/1618/007/E-LLANFYLLIN	MW90604	45.80	55.08
SPD	CARGENBRIDGE	SP67422	45.50	54.91
SPM	09/1291/001/E-B R D	MW93705	11.162	15.73
SPD	CASTLE DOUGLAS	SP66523	34.01	42.04
SPD	PS-NX4164/001 NEWTON STEWART	SP68423	34.34	40.01
SPM	PS-SH4840/001 RHOSLAN	MW83004	27.52	36.28
SPM	09/1618/007/E-LLANFYLLIN	MW90603	25.71	34.51
SPD	ANNAN PRIMARY	SP66224	20.73	26.32
SPD	DALBEATTIE	SP66821	18.37	24.28
SPM	09/2107/009/E-RAVEN SQUARE	MW92003	14.41	20.06
SPM	PS-SH9465/001 LLANSANNAN	MW70204	13.92	18.96
SPD	CUMNOCK	SP73221	9.21	13.42
SPM	09/5242/001/E-WHITCHURCH	MW90408	3.02	5.88
SPM	09/5242/001/E-WHITCHURCH	MW90402	3.02	5.88
SPM	09/5242/001/E-WHITCHURCH	MW90403	5.00	8.92
SPM	09/5242/001/E-WHITCHURCH	MW90401	2.64	5.63
SPM	09/5242/001/E-WHITCHURCH	MW90406	11.95	19.93
SPM	09/5242/001/E-WHITCHURCH	MW90407	8.04	12.51
SPM	09/5242/001/E-WHITCHURCH	MW90404	3.13	5.99
SPM	09/5242/001/E-WHITCHURCH	MW90405	4.61	8.26

7 Cost Benefit Analysis

Cost benefit analyses have been carried out to evaluate the potential network interventions of correcting phase imbalance caused by single-phase lines.

7.1 Test Feeder Modelling

7.1.1 Based model

One of the HV feeders at Whitchurch Primary, Feeder MW90406, was selected here for the CBA analysis. This feeder has the longest total length of single phase lines, and also has the highest phase imbalance among all the HV feeders from the Flexible Networks. The balanced IPSA model of this HV feeder obtained from the Flexible Networks project has been converted to a three-phase unbalanced IPSA model. The developed unbalanced model of the selected HV feeder is shown in Figure 7-1.

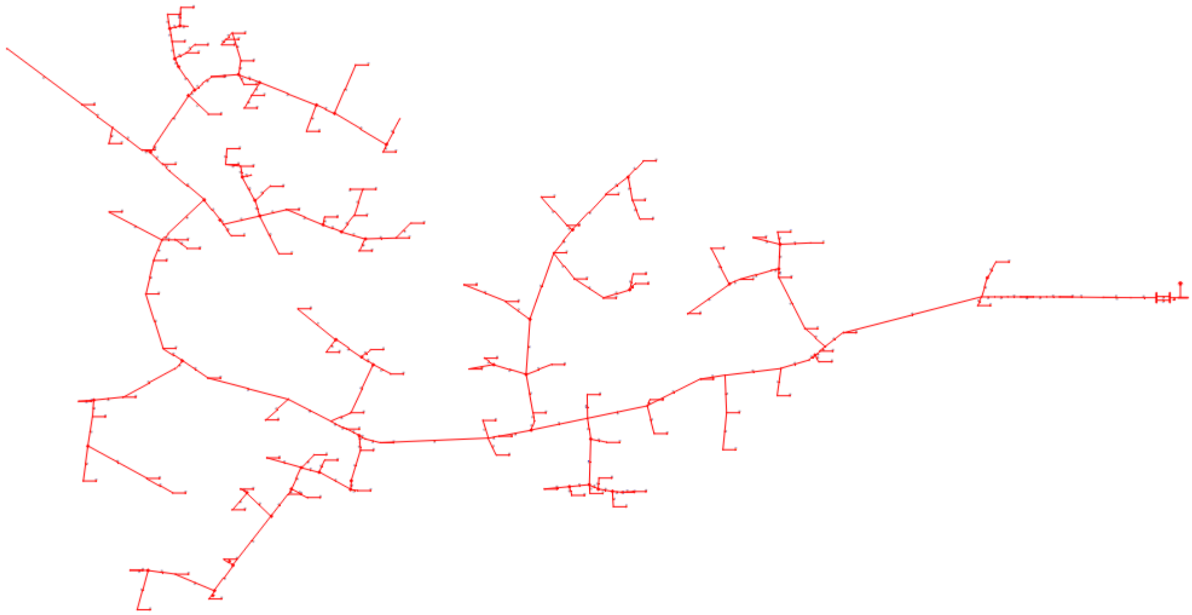


Figure 7-1 Three-phase IPSA Model of the Case Study HV Feeder

As shown in the previous sections of this report, although the number of phases of the HV line sections could be found from the GIS data, the exact phase information of these single-phase lines is not explicitly known. Therefore, the phase information of the single-phase lines was assumed based on the measurement data. Specifically, the single-phase lines have been grouped into 10 sections, as shown in Figure 7-2. Lines and loads in the same section have the same phase-phase connection, which could be AB, BC or CA. The phase information of these 10 single-phase line sections was determined by analysing the total loads on each line section and the maximum three-phase power from the measured data. Also, a trial and error approach was used to ensure the power flow on each phase matched with the measurement. The final phase information for each single-phase line section can be found in Table 7-1.

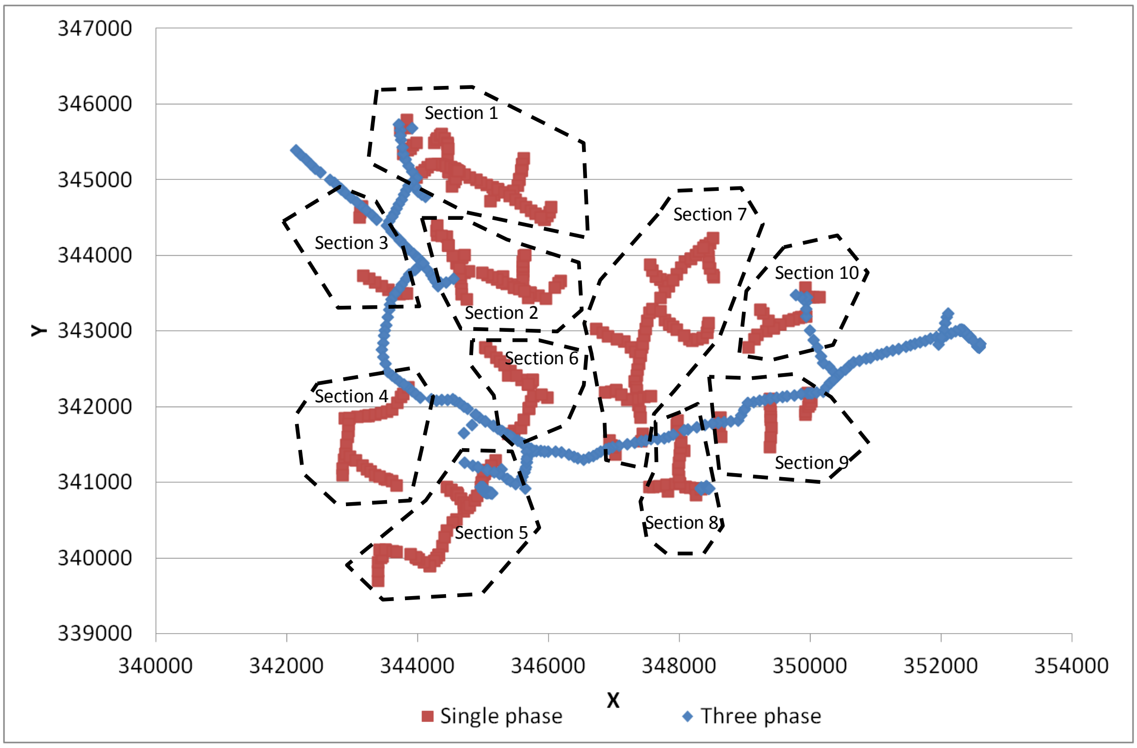


Figure 7-2 Single-phase Line Sections of Selected HV Feeder

Table 7-1 Phase Information of Single-phase Line Sections

Section Group	Phase-Phase Connection	Section Group	Phase-Phase Connection
Section 1	AB	Section 2	AB
Section 3	AB	Section 4	AB
Section 5	AB	Section 6	AC
Section 7	AC	Section 8	AC
Section 9	AC	Section 10	AC

7.1.2 Modelling of Interventions

A literature review[567] has been carried out to identify and study the potential imbalance correction interventions. The pros and cons of these interventions have been summarised in Table 7-2. The CBA was not performed for all of these interventions due to the following reasons:

- A conductor change was found to have only a marginal impact on the imbalanced currents;
- Dynamic phase balancing is not a mature technology yet, and there is limited knowledge of its mechanism;

[5] "Design and Analysis of Electrical Distribution Networks and Balancing Markets in the UK A New Framework with Applications", V. H. Pakka and R. M. Rylatt, De Montfort University, 2016
[6] "Reconfiguration of an Unbalanced Distribution System for Loss Reduction by Software Simulation", S. Saini, M. Mam and Deepika, IJERT, 2013
[7] "Loss reduction experiences in electric power distribution companies of Iran", A. Arefi, J. Olamaei, A. Yavartalab and H. Keshtkar, 2nd International Conference on Advances in Energy Engineering, ICAEE 2011

- Almost all the existing controllable devices in distribution networks are balanced three-phase, which means Active Network Management has limited control on phase imbalance.

Table 7-2 Review of the Phase Correction Interventions

Intervention	Pros	Cons	Included in CBA?
Phase-phase reconnection	Relatively low cost	Depending on the existing phase-phase connections	Yes
Re-built with three-phase lines	Increasing network capacity; possibility of future network extension or interconnection	High cost	Yes
Conductor change	Increasing network capacity; reducing losses for balanced loads	High cost and only marginal impact on imbalance currents	No
Dynamic phase balancing	Balancing loads in real time without changing the existing networks	Technology not well applied yet	No
Active Network Management	Capability of achieving other network control objectives e.g. constraint management	Most existing controllable devised are three-phase, hence ANM has limited control on phase imbalance	No

As shown in Table 7-2, two interventions have been modelled and evaluated, including phase-phase reconnection, and replacing all the single-phase lines with three-phase lines.

Phase-phase reconnection

The phase connections of single-phase lines were changed to balance the currents on the mainline, by swapping the jumpers from one phase to another one on the mainline. The phase-phase connections were rearranged based as shown in Table 7-3. It can be seen that phase-phase reconnections have been carried out for three sections, including section 4, section 5 and section 8.

Table 7-3 Phase Information of Single-phase Line Sections after Phase-Phase Reconnection

Section Group	Phase-Phase Connection	Section Group	Phase-Phase Connection
Section 1	AB	Section 2	AB
Section 3	AB	Section 4	BC
Section 5	BC	Section 6	AC
Section 7	AC	Section 8	BC
Section 9	AC	Section 10	AC

Re-built with three-phase lines

As informed by SPEN, when a single-phase line is completely re-built with three-phase lines, 100mm conductors are going to be used, despite the fact that most of the existing single-phase lines in the case study feeder are 25mm conductors. The parameters of the 100mm copper overhead line in the SPEN Windebut database (shown in Table 7-4) have been used in the simulation.

Table 7-4 Parameter of 100mm Copper Overhead Line

Material	Rating (A)	R (mOhms/m)	X (mOhms/m)
Cu	414	0.176	0.328

7.1.3 Three-phase annual demand data

Unbalanced load flow was conducted to calculate the total annual losses of the case study feeder. The three-phase power measurements with 10-minute interval from the Flexible Networks have been used to scale the loads in the IPSA model. It should be noted that the measurement was not always available, as show in Table 4-1. Therefore, the available measurement data between 2013 and 2015 was combined to create an annual demand data set, as specified in Table 7-5.

Table 7-5 Measurement Data Used for Simulation

Yea	Time Point From	Time Point To
2014	01/01 00:00	18/05 12:20
2015	18/05 12:30	27/09 23:50
2013	28/09 00:00	31/12 23:50

7.2 Cost Benefit Analysis

7.2.1 Annual losses

With the models and annual demand data, the HV feeder total annual losses of the base case and that with two interventions have been calculated and summarized in Table 7-6. It can be seen that both interventions could achieve considerable loss reductions.

Table 7-6 Annual Losses of Case Study Feeder

Test case	Annual Demand (MWh)	Total Annual Losses (MWh)	Total Annual Losses (%)	Loss Reduction (MWh)
Base Line	6263.74	106.85	1.71%	-
Phase-phase line reconnection	6261.13	102.21	1.63%	4.64
Re-built with 3phase lines	6256.02	98.61	1.58%	8.24

7.2.2 Cost Benefit Analysis

The cost benefit analysis of these two interventions was carried out for the case study HV feeder, using the Ofgem CBA template. The costs of the interventions were obtained from SPEN:

- The cost of phase-phase reconnection is in the order of £500-£1000 per spur;
- The cost of completely re-building the single-phase lines with three-phase lines is about £35k per mile. This cost does not include the costs for new wayleaves, planning consents, difficult terrain or having to replace overhead equipment, i.e. pole mounted transformer.

Phase-phase reconnection

Reconnecting some of the single-phase lines to different phases could balance the power flow and reduce losses on the mainline. For this case study feeder, the losses could be reduced by 4.64MWh per year, after reconnecting three single-phase spurs. The total cost of phase-phase reconnection in this case is in the range of £1500-£3000.

The benefits of loss reduction were calculated with the loss price £48.42m per MWh, which is the 2012/13 loss price as per Ofgem CBA template. The benefits achieved from loss reduction could outweigh the investment after 7-14 years respectively for a cost range of £1500-£3000. The 40 year Net Present Value (NPV) is £6.0-£7.5k, depending on the actual cost of phase-phase reconnection.

Re-built with three-phase lines

Completely rebuilding the single-phase lines with three-phase lines could reduce the losses. For this case study feeder, the losses could be reduced by 8.24MWh per year, after replacing all the single-phase lines with three-phase lines. However, the cost of rebuilding is significant. For this case study feeder, the total length of single-phase lines is 32.73km (20.34mile), and the total cost of rebuilding is £711.9k.

The benefits of loss reduction, quantified by the 40 year NPV (expected lifespan of overhead lines) of -£703k, does not justify the cost of reinforcement.

7.2.3 Conclusions

The following conclusions have been drawn from this work:

- A parametric model has been devised which can determine whether or not a feeder is unbalanced using three parameters, which appears to have a reasonable level of accuracy;
- A CBA for phase imbalance interventions has been performed, and it has been found that phase-phase reconnection could potentially achieve positive NPV values for HV feeders with high phase imbalance caused by single-phase lines;
- Although the payback period for this intervention and the sample feeder was found to be 7-14 years, the payback period for feeders with worse phase imbalance will be shorter and the NPV will be higher. In addition, when applied to the whole SPEN network, the potential benefits could become significant.
- If the level of loss reduction for phase-phase reconnection could be achieved for all 232 HV feeders identified as potentially having high phase imbalance then maximum potential losses savings are circa 1.08GWh per annum.

It is therefore recommended that further work is done in order to quantify the potential benefits of this approach more accurately as follows:

- It is suggested that measuring the phase imbalance on a number of selected feeders, as described in Section 6.3, would be a worthwhile next step. This would allow the parametric model to be refined and validated, and potentially enable phase-phase reconnection to be proposed on multiple feeders across SPEN's network.
- The CBA should then be expanded to take into account these measured feeders. If the parametric model is found to be accurate and potential benefits of intervention on these feeders more significant, then phase-phase reconnection may be identified as an intervention to reduce network losses due to phase imbalance.

Appendix A – Results of Phase Imbalance Processing

Primary substation	Feeder	Current Imbalance (A)			
		Max	Mean	95th Percentiles	Mean of 100 highest loading
Anstruther	Feeder12	14	3.05	7	4.8
	Feeder13	15	3.94	8	6.01
	Feeder22	17	3.20	6	2.62
	Feeder23	18	5.10	9	6.54
	Feeder Average	**16.00**	**3.82**	**7.50**	**4.99**
Cupar	Feeder12	29	4.16	9	7.69
	Feeder13	13	2.71	6	5.55
	Feeder14	17	3.60	8	6.23
	Feeder15	15	3.62	7	4.33
	Feeder22	11	0.87	3	3.34
	Feeder23	14	2.74	6	2.54
	Feeder24	16	3.57	7	4.76
	Feeder Average	**16.43**	**3.04**	**6.57**	**4.92**
Leuchars	Feeder12	8	1.62	3	3.36
	Feeder13	10	1.34	3	2.75
	Feeder14	14	5.92	9	6.1
	Feeder22	0	0.00	0	3.88
	Feeder23	0	0.00	0	2.07
	Feeder24	9	2.02	4	4.68
	Feeder25	7	1.26	3	5.12
	Feeder Average	**6.86**	**1.74**	**3.14**	**2.59**
St Andrews	Feeder12	14	3.71	8	4
	Feeder13	14	3.47	6	4.92
	Feeder14	15	4.34	9	9.29
	Feeder15	16	3.22	7	3.66
	Feeder16	20	6.20	11	7.17
	Feeder22	12	2.85	6	7.03

	Feeder23	11	2.99	6	8.08
	Feeder24	16	4.50	9	6.05
	Feeder25	20	5.76	11	11.53
	Feeder26	13	3.26	7	3.02
	Feeder Average	**15.10**	**4.03**	**8.00**	**6.00**
Liverpool road	Feeder1	30	5.94	11	8.96
	Feeder2	9	2.19	4	2.5
	Feeder3	17	5.42	10	6.67
	Feeder4	8	1.71	3	4.86
	Feeder5	49	3.14	5	2.12
	Feeder Average	**22.60**	**3.68**	**6.60**	**6.54**
Whitchurch	Feeder1	12	2.12	4	6.46
	Feeder2	6	1.35	2	3.61
	Feeder3	10	4.21	6	9.39
	Feeder4	10	2.60	5	23.43
	Feeder5	16	6.36	9	15.07
	Feeder6	29	11.39	19	2.25
	Feeder7	22	9.58	14	3.62
	Feeder Average	**15.00**	**5.37**	**8.43**	**9.28**
Yockings Gate	Feeder1	33	1.71	3	6.7
	Feeder2	12	1.36	3	11.49
	Feeder3	13	3.64	6	3.55
	Feeder4	23	6.68	12	7.41
	Feeder5	8	0.66	2	16.66
	Feeder Average	**17.80**	**2.81**	**5.20**	**5.52**
Ruabon	Feeder1	16	3.72	7	5.18
	Feeder3	22	8.48	14	1.75
	Feeder4	20	3.70	7	4.22
	Feeder5	10	1.35	3	4.8
	Feeder6	11	2.31	5	6.01
	Feeder Average	**15.80**	**3.91**	**7.20**	**7.04**

Appendix B – Results of GIS Feeder Data Analysis

	M	Y	AY	AZ	BA	BB	BC
1	FEEDERID	SPNUMOFPHA	SHAPE_LEN	X_Start	Y_Start	X_End	Y_End
2	SP19112	3	12.64408	355979.90100	707601.28200	355967.43770	707599.15150
3	SP19122	3	445.16774	349740.35580	707189.78720	350149.36300	707014.03900
4	SP19112	3	77.50012	356712.03800	707727.46500	356709.06300	707650.02200
5	SP19122	1	87.93075	353854.45920	707829.77800	353793.89300	707766.03200
6	SP19122	1	77.22232	353793.89300	707766.03200	353740.46600	707710.27500
7	SP19122	1	74.48636	353740.46600	707710.27500	353688.08900	707657.31400
8	SP19122	1	65.21821	353688.08900	707657.31400	353632.07900	707623.90300
9	SP19122	1	64.01296	353632.07900	707623.90300	353576.72700	707591.75000

Appendix C – Three Phase and Single Phase Spur

Primary substation name	Feeder ID	Total length(m)	Total length - 3phase(m)	Total length - 1phase(m)	Ratio of 1phase/3phase	Ratio of 1phase/total
Anstruther	SP19112	42965.38	42156.23	809.15	1.92%	1.88%
	SP19113	16375.48	16216.33	159.14	0.98%	0.97%
	SP19122	43800.81	41786.98	2013.83	4.82%	4.60%
	SP19123	3863.62	3863.62	0.00	0.00%	0.00%
Cupar	SP18512	35374.80	34608.69	766.11	2.21%	2.17%
	SP18513	7296.18	7296.18	0.00	0.00%	0.00%
	SP18514	60469.41	58489.32	1980.09	3.39%	3.27%
	SP18515	52904.95	51260.28	1644.67	3.21%	3.11%
	SP18516	8327.01	8327.01	0.00	0.00%	0.00%
	SP18522	21685.85	21559.74	126.11	0.58%	0.58%
	SP18523	4017.67	4017.67	0.00	0.00%	0.00%
	SP18524	29902.39	29214.84	687.55	2.35%	2.30%
	SP18525	46851.35	44679.86	2171.49	4.86%	4.63%
	SP18526	187.76	187.76	0.00	0.00%	0.00%
Leuchars	SP19312	2231.28	2231.28	0.00	0.00%	0.00%
	SP19313	4236.76	4236.76	0.00	0.00%	0.00%
	SP19314	565.79	565.79	0.00	0.00%	0.00%
	SP19322	575.56	575.56	0.00	0.00%	0.00%
	SP19323	1768.92	1768.92	0.00	0.00%	0.00%
	SP19324	5420.25	5398.54	21.71	0.40%	0.40%
	SP19325	9191.77	9191.77	0.00	0.00%	0.00%
St. Andrews	SP18612	2836.50	2836.50	0.00	0.00%	0.00%
	SP18613	1837.94	1813.12	24.82	1.37%	1.35%
	SP18614	31085.75	30639.47	446.28	1.46%	1.44%
	SP18615	5232.16	5232.16	0.00	0.00%	0.00%
	SP18616	4590.95	4578.46	12.49	0.27%	0.27%
	SP18622	6629.72	6610.22	19.51	0.30%	0.29%
	SP18623	51463.09	50347.43	1115.66	2.22%	2.17%
	SP18624	35721.50	34954.04	767.46	2.20%	2.15%
	SP18625	52608.17	52450.25	157.92	0.30%	0.30%
	SP18626	3570.89	3570.89	0.00	0.00%	0.00%
Liverpool	MW93801	3627.43	3627.43	0.00	0.00%	0.00%

Road	MW93802	2320.76	2320.76	0.00	0.00%	0.00%
	MW93803	18212.96	10192.06	8020.90	78.70%	44.04%
	MW93804	1546.48	1533.70	12.78	0.83%	0.83%
	MW90505	5165.50	5165.50	0.00	0.00%	0.00%
Whitchurch	MW90401	2668.59	2392.54	276.05	11.54%	10.34%
	MW90402	2474.91	2474.91	0.00	0.00%	0.00%
	MW90403	20645.28	15665.69	4979.59	31.79%	24.12%
	MW90404	5940.75	5728.17	212.58	3.71%	3.58%
	MW90405	16025.37	11566.96	4458.42	38.54%	27.82%
	MW90406	54215.62	21481.28	32734.35	152.39%	60.38%
	MW90407	29629.63	17500.56	12129.07	69.31%	40.94%
Yockings Gate	MW90501	5945.27	5745.64	199.62	3.47%	3.36%
	MW90502	1003.37	1003.37	0.00	0.00%	0.00%
	MW90503	1814.34	1814.34	0.00	0.00%	0.00%
	MW90504	48866.30	35893.63	12972.67	36.14%	26.55%
	MW90505	5165.50	5165.50	0.00	0.00%	0.00%
Ruabon	MW40801	5573.35	5226.51	346.84	6.64%	6.22%
	MW40802	3067.13	3067.13	0.00	0.00%	0.00%
	MW40803	23123.05	14280.60	8842.44	61.92%	38.24%
	MW40804	6883.35	6883.35	0.00	0.00%	0.00%
	MW40805	1473.66	1473.66	0.00	0.00%	0.00%
	MW40806	7905.25	6305.80	1599.44	25.36%	20.23%
	MW40807	3892.36	3892.36	0.00	0.00%	0.00%

Appendix D – Data Availability for HV Feeders – Flexible Networks

Primary name	Feeder	Number of Available Data			Percentage of Available Data		
		2013	2014	2015	2013	2014	2015
Anstruther	Feeder12	23580	41984	33327	44.86%	79.88%	63.41%
	Feeder13	23511	41994	33333	44.73%	79.90%	63.42%
	Feeder22	23579	41974	33078	44.86%	79.86%	62.93%
	Feeder23	23577	41989	33092	44.86%	79.89%	62.96%
Cupar	Feeder12	24687	42473	0	46.97%	80.81%	0.00%
	Feeder13	24688	42481	0	46.97%	80.82%	0.00%
	Feeder14	24688	42502	0	46.97%	80.86%	0.00%
	Feeder15	24688	42503	0	46.97%	80.87%	0.00%
	Feeder22	24684	42496	0	46.96%	80.85%	0.00%
	Feeder23	24684	42458	0	46.96%	80.78%	0.00%
	Feeder24	24684	42493	0	46.96%	80.85%	0.00%
Leuchars	Feeder12	17965	42555	38231	34.18%	80.96%	72.74%
	Feeder13	17966	42554	38228	34.18%	80.96%	72.73%
	Feeder14	17912	42554	38177	34.08%	80.96%	72.64%
	Feeder22	0	0	1	0.00%	0.00%	0.00%
	Feeder23	0	0	5394	0.00%	0.00%	10.26%
	Feeder24	17966	42454	38202	34.18%	80.77%	72.68%
	Feeder25	17965	42123	38230	34.18%	80.14%	72.74%
St Andrews	Feeder12	25109	31311	18351	47.77%	59.57%	34.91%
	Feeder13	25112	31311	18352	47.78%	59.57%	34.92%
	Feeder14	25111	31301	18353	47.78%	59.55%	34.92%
	Feeder15	25111	31311	18351	47.78%	59.57%	34.91%
	Feeder16	25111	31310	18347	47.78%	59.57%	34.91%
	Feeder22	24858	32116	4948	47.29%	61.10%	9.41%
	Feeder23	24859	29512	4741	47.30%	56.15%	9.02%
	Feeder24	24860	32117	4951	47.30%	61.11%	9.42%
	Feeder25	24858	32116	4953	47.29%	61.10%	9.42%
	Feeder26	24858	32115	4948	47.29%	61.10%	9.41%
Liverpool road	Feeder1	26832	28841	11424	51.05%	54.87%	21.74%
	Feeder2	26064	28842	11424	49.59%	54.87%	21.74%
	Feeder3	26834	28844	11426	51.05%	54.88%	21.74%

	Feeder4	26792	28841	11422	50.97%	54.87%	21.73%
	Feeder5	26829	28844	11425	51.04%	54.88%	21.74%
Whitchurch	Feeder1	14677	19702	30981	27.92%	37.48%	58.94%
	Feeder2	14678	19704	31485	27.93%	37.49%	59.90%
	Feeder3	14679	19702	31133	27.93%	37.48%	59.23%
	Feeder4	14645	19659	29719	27.86%	37.40%	56.54%
	Feeder5	14674	19697	31440	27.92%	37.48%	59.82%
	Feeder6	14678	19697	29774	27.93%	37.48%	56.65%
	Feeder7	14675	19702	31484	27.92%	37.48%	59.90%
Yockings Gate	Feeder1	23766	50269	5379	45.22%	95.64%	10.23%
	Feeder2	23762	50193	5912	45.21%	95.50%	11.25%
	Feeder3	23744	50289	5912	45.18%	95.68%	11.25%
	Feeder4	23761	50241	5379	45.21%	95.59%	10.23%
	Feeder5	23764	50190	4845	45.21%	95.49%	9.22%
Ruabon	Feeder1	7953	41126	37753	15.13%	78.25%	71.83%
	Feeder2	0	0	0	0.00%	0.00%	0.00%
	Feeder3	7955	41163	37694	15.14%	78.32%	71.72%
	Feeder4	7943	41163	37687	15.11%	78.32%	71.70%
	Feeder5	7955	41113	37725	15.14%	78.22%	71.78%
	Feeder6	7911	41165	37731	15.05%	78.32%	71.79%
	Feeder7	0	0	0	0.00%	0.00%	0.00%
Average		19966	34997	22441	37.99%	66.58%	42.70%

Appendix E – Three Phase and Single Phase Transformers

Substation	Feeder	Total Number of Transformers	Number of 1phase Transformer	Number of 3phase Transformer	Ratio of 1phase/3phase	Ratio of 1phase/total
Anstruther	SP19112	76	12	64	18.75%	15.79%
	SP19113	26	2	24	8.33%	7.69%
	SP19122	83	22	61	36.07%	26.51%
	SP19123	11	0	11	0.00%	0.00%
Cupar	SP18512	54	10	44	22.73%	18.52%
	SP18513	14	0	14	0.00%	0.00%
	SP18514	115	15	100	15.00%	13.04%
	SP18515	100	22	78	28.21%	22.00%
	SP18522	38	5	33	15.15%	13.16%
	SP18523	8	0	8	0.00%	0.00%
	SP18524	52	5	47	10.64%	9.62%
Leuchars	SP19312	5	0	5	0.00%	0.00%
	SP19313	7	0	7	0.00%	0.00%
	SP19314	0	0	0	0.00%	0.00%
	SP19324	8	0	8	0.00%	0.00%
	SP19325	12	2	10	20.00%	16.67%
St. Andrews	SP18612	5	0	5	0.00%	0.00%
	SP18613	5	0	5	0.00%	0.00%
	SP18614	52	5	47	10.64%	9.62%
	SP18615	13	0	13	0.00%	0.00%
	SP18616	11	0	11	0.00%	0.00%
	SP18622	8	0	8	0.00%	0.00%
	SP18623	94	19	75	25.33%	20.21%
	SP18624	72	9	63	14.29%	12.50%
	SP18625	91	11	80	13.75%	12.09%
	SP18626	7	0	7	0.00%	0.00%
Liverpool Road	MW93801	9	0	9	0.00%	0.00%
	MW93802	6	0	6	0.00%	0.00%
	MW93803	38	26	12	216.67%	68.42%
	MW93804	2	0	2	0.00%	0.00%
	MW90505	0	0	0	0.00%	0.00%
Whitchurch	MW90401	5	2	3	66.67%	40.00%

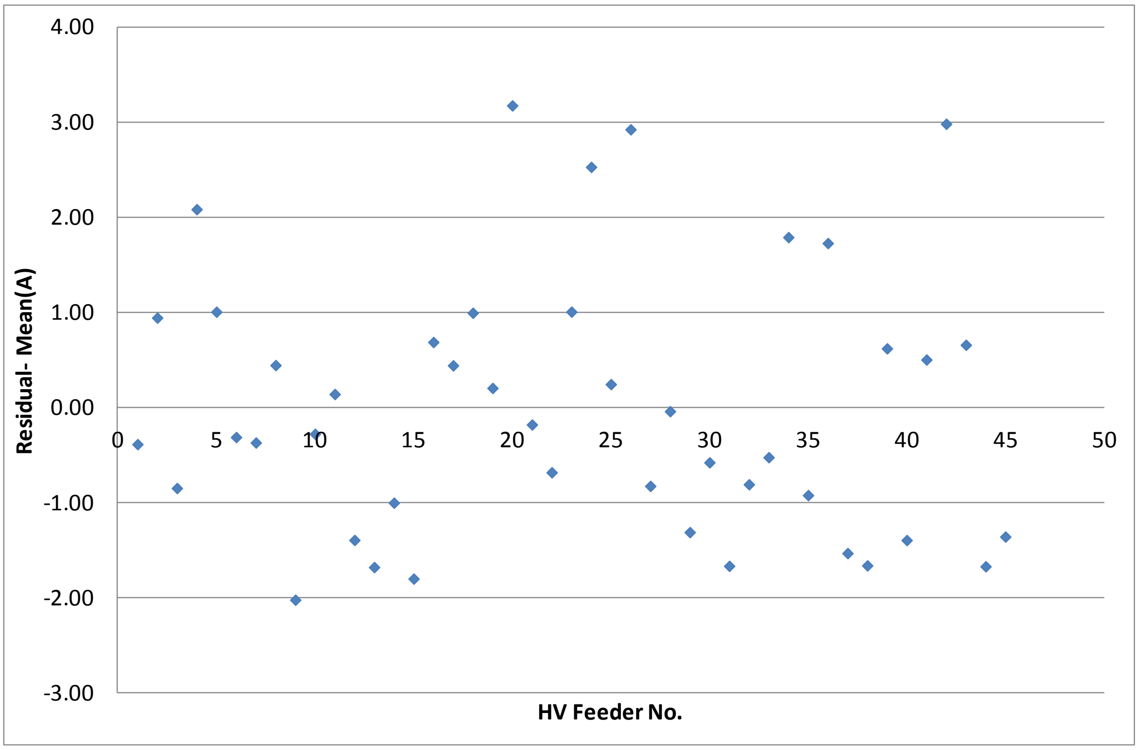
	MW90402	5	0	5	0.00%	0.00%
	MW90403	47	32	15	213.33%	68.09%
	MW90404	10	0	10	0.00%	0.00%
	MW90405	33	19	14	135.71%	57.58%
	MW90406	124	94	30	313.33%	75.81%
	MW90407	68	41	27	151.85%	60.29%
Yockings Gate	MW90501	14	3	11	27.27%	21.43%
	MW90502	2	0	2	0.00%	0.00%
	MW90503	7	0	7	0.00%	0.00%
	MW90504	112	53	59	89.83%	47.32%
	MW90505	1	0	1	0.00%	0.00%
Ruabon	MW40801	17	4	13	30.77%	23.53%
	MW40803	51	29	22	131.82%	56.86%
	MW40804	16	1	15	6.67%	6.25%
	MW40805	3	0	3	0.00%	0.00%
	MW40806	23	8	15	53.33%	34.78%

Appendix F – Customer Number Supplied by Three Phase and Single Phase Transformers

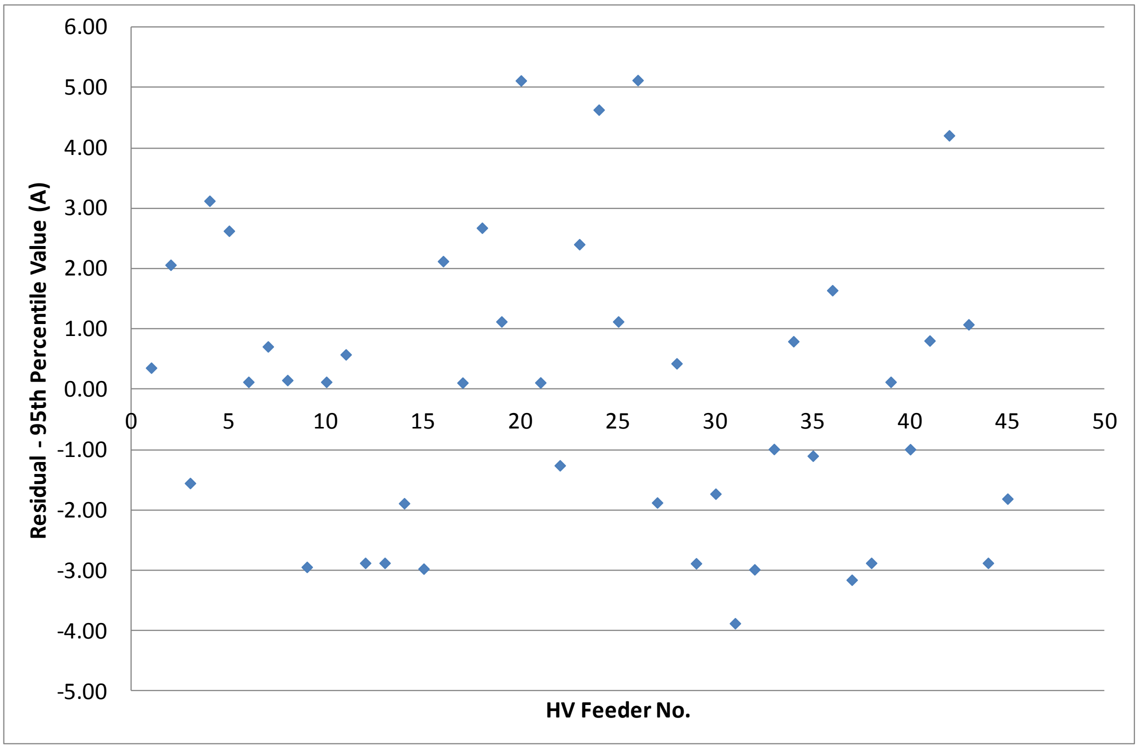
Substation	Feeder	Total Number of Customers	Number of 1phase Customers	Number of 3phase Customers	Ratio of 1phase/3phase	Ratio of 1phase/total
Anstruther	SP19112	1370	20	1350	1.48%	1.46%
	SP19113	2283	6	2277	0.26%	0.26%
	SP19122	346	37	309	11.97%	10.69%
	SP19123	1627	0	1627	0.00%	0.00%
Cupar	SP18512	1031	23	1008	2.28%	2.23%
	SP18513	1028	0	1028	0.00%	0.00%
	SP18514	1123	27	1096	2.46%	2.40%
	SP18515	548	54	494	10.93%	9.85%
	SP18522	1239	13	1226	1.06%	1.05%
	SP18523	1084	0	1084	0.00%	0.00%
	SP18524	789	7	782	0.90%	0.89%
Leuchars	SP19312	228	0	228	0.00%	0.00%
	SP19313	407	0	407	0.00%	0.00%
	SP19314	0	0	0	-	-
	SP19324	488	0	488	0.00%	0.00%
	SP19325	191	2	189	1.06%	1.05%
St. Andrews	SP18612	792	0	792	0.00%	0.00%
	SP18613	451	0	451	0.00%	0.00%
	SP18614	1394	6	1388	0.43%	0.43%
	SP18615	766	0	766	0.00%	0.00%
	SP18616	1455	0	1455	0.00%	0.00%
	SP18622	264	0	264	0.00%	0.00%
	SP18623	320	23	297	7.74%	7.19%
	SP18624	1331	13	1318	0.99%	0.98%
	SP18625	1396	15	1381	1.09%	1.07%
	SP18626	801	0	801	0.00%	0.00%
Liverpool Road	MW93801	1009	0	1009	0.00%	0.00%
	MW93802	1152	0	1152	0.00%	0.00%
	MW93803	220	87	133	65.41%	39.55%
	MW93804	309	0	309	0.00%	0.00%
	MW90505	0	0	0	-	-

Whitchurch	MW90401	132	15	117	12.82%	11.36%
	MW90402	111	0	111	0.00%	0.00%
	MW90403	124	68	56	121.43%	54.84%
	MW90404	734	0	734	0.00%	0.00%
	MW90405	110	51	59	86.44%	46.36%
	MW90406	613	352	261	134.87%	57.42%
	MW90407	415	106	309	34.30%	25.54%
Yockings Gate	MW90501	340	2	338	0.59%	0.59%
	MW90502	189	0	189	0.00%	0.00%
	MW90503	694	0	694	0.00%	0.00%
	MW90504	715	131	584	22.43%	18.32%
	MW90505	0	0	0	-	-
Ruabon	MW40801	1394	6	1388	0.43%	0.43%
	MW40803	655	102	553	18.44%	15.57%
	MW40804	1511	1	1510	0.07%	0.07%
	MW40805	294	0	294	0.00%	0.00%
	MW40806	851	18	833	2.16%	2.12%

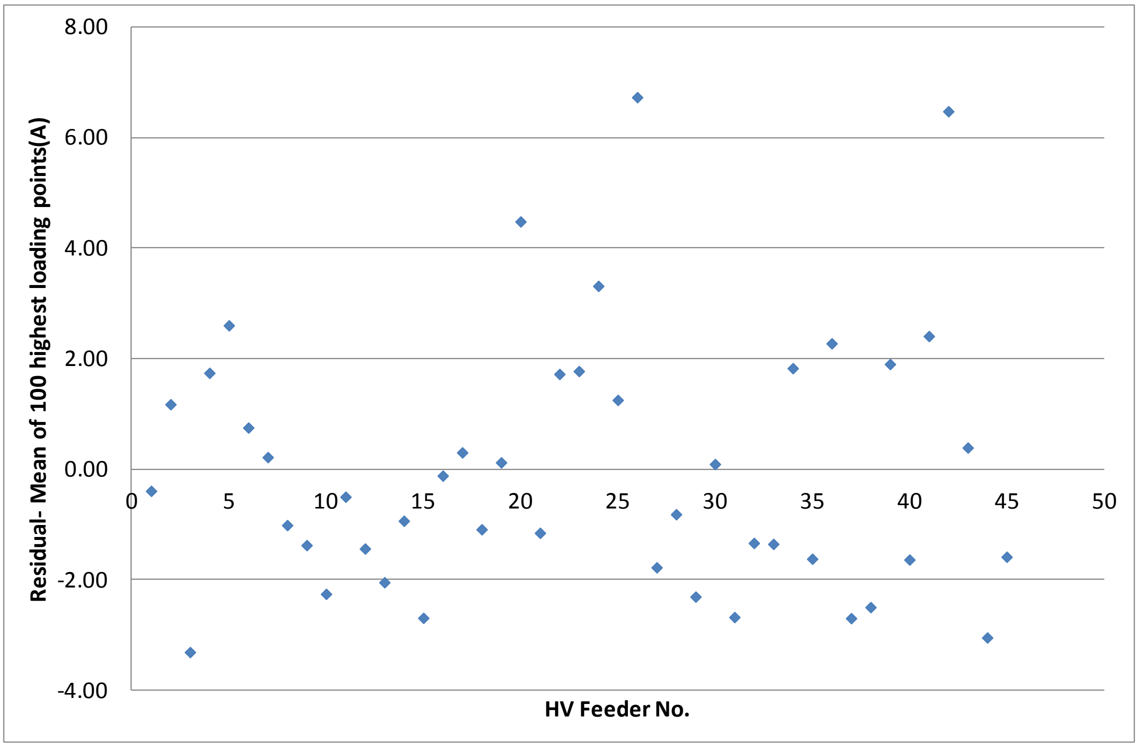
Appendix G – Residual Plots



Residual Plots – Mean



Residual Plots – 95th Percentile



Residual Plots – Mean of 100 highest loading points

Appendix H – Data Used for Regression Coefficients Calculation

Substation	Feeder	1 Phase spur	1 Phase Tx Number	1 Phase Tx Customer Number	Mean	95 Percentiles	Mean of 100 maximum load
ANSTRUTHER PRIMARY	Feeder12	809.15	12	20	3.05	7.00	4.80
ANSTRUTHER PRIMARY	Feeder13	159.14	2	6	3.94	8.00	6.01
ANSTRUTHER PRIMARY	Feeder22	2013.83	22	37	3.20	6.00	2.62
ANSTRUTHER PRIMARY	Feeder23	0.00	0	0	5.10	9.00	6.54
CUPAR PRIMARY	Feeder12	766.11	10	23	4.17	9.00	7.69
CUPAR PRIMARY	Feeder13	0.00	0	0	2.71	6.00	5.55
CUPAR PRIMARY	Feeder14	1980.09	15	27	3.60	8.00	6.23
CUPAR PRIMARY	Feeder15	1644.67	22	54	3.62	7.00	4.33
CUPAR PRIMARY	Feeder22	126.11	5	13	0.87	3.00	3.34
CUPAR PRIMARY	Feeder23	0.00	0	0	2.74	6.00	2.54
CUPAR PRIMARY	Feeder24	687.55	5	7	3.57	7.00	4.76
LEUCHARS PRIMARY	Feeder12	0.00	0	0	1.62	3.00	3.36
LEUCHARS PRIMARY	Feeder13	0.00	0	0	1.34	3.00	2.75
LEUCHARS PRIMARY	Feeder24	21.71	0	0	2.03	4.00	3.88
LEUCHARS PRIMARY	Feeder25	0.00	2	2	1.27	3.00	2.09
ST ANDREWS PRIMARY	Feeder12	0.00	0	0	3.71	8.00	4.68
ST ANDREWS PRIMARY	Feeder13	24.82	0	0	3.47	6.00	5.12
ST ANDREWS PRIMARY	Feeder14	446.28	5	6	4.34	9.00	4.00
ST ANDREWS PRIMARY	Feeder15	0.00	0	0	3.22	7.00	4.92
ST ANDREWS PRIMARY	Feeder16	12.49	0	0	6.20	11.00	9.29

ST ANDREWS PRIMARY	Feeder22	19.51	0	0	2.85	6.00	3.66
ST ANDREWS PRIMARY	Feeder23	1115.66	19	23	3.26	6.00	7.17
ST ANDREWS PRIMARY	Feeder24	767.46	9	13	4.50	9.00	7.03
ST ANDREWS PRIMARY	Feeder25	157.92	11	15	5.76	11.00	8.08
ST ANDREWS PRIMARY	Feeder26	0.00	0	0	3.26	7.00	6.05
LIVERPOOL ROAD PRIMARY	Feeder1	0.00	0	0	5.94	11.00	11.53
LIVERPOOL ROAD PRIMARY	Feeder2	0.00	0	0	2.19	4.00	3.02
LIVERPOOL ROAD PRIMARY	Feeder3	8020.90	26	87	5.42	10.00	8.96
LIVERPOOL ROAD PRIMARY	Feeder4	12.78	0	0	1.71	3.00	2.50
WHITCHURCH PRIMARY	Feeder1	276.05	2	15	2.12	4.00	4.86
WHITCHURCH PRIMARY	Feeder2	0.00	0	0	1.35	2.00	2.12
WHITCHURCH PRIMARY	Feeder3	4979.59	32	68	4.21	6.00	6.46
WHITCHURCH PRIMARY	Feeder4	212.58	0	0	2.61	5.00	3.61
WHITCHURCH PRIMARY	Feeder5	4458.42	19	51	6.36	9.00	9.39
WHITCHURCH PRIMARY	Feeder6	32734.35	94	352	11.39	19.00	23.43
WHITCHURCH PRIMARY	Feeder7	12129.07	41	106	9.58	14.00	15.07
YOCKINGS GATE PRIMARY	Feeder1	199.62	3	2	1.71	3.00	2.25
YOCKINGS GATE PRIMARY	Feeder2	0.00	0	0	1.36	3.00	2.30
YOCKINGS GATE PRIMARY	Feeder3	0.00	0	0	3.64	6.00	6.70
YOCKINGS GATE PRIMARY	Feeder4	12972.67	53	131	6.69	12.00	11.49
RUABON PRIMARY	Feeder1	346.84	4	6	3.73	7.00	7.41
RUABON PRIMARY	Feeder3	8842.44	29	102	8.48	14.00	16.66
RUABON PRIMARY	Feeder4	0.00	1	1	3.70	7.00	5.18
RUABON PRIMARY	Feeder5	0.00	0	0	1.35	3.00	1.75
RUABON PRIMARY	Feeder6	1599.44	8	18	2.31	5.00	4.22

Appendix I – Detailed Information of Potential HV Feeders to Be Measured

License Area	Primary Name	FeederID	Voltage Level(volt)	Length-single phase line(meter)	Number of single phase Tx	Number of customers supplied by single phase Tx	Mean	95th Percentile	Mean at top 100 load
SPD	DOUGLAS WEST	SP83921	11000	104083.8	132	225	57.35	64.90	83.34
SPM	09/9585/002/E-LLANIDLOES	MW92303	11000	92544.8	269	419	52.57	63.59	72.24
SPM	09/2128/005/E-LLANSILIN	MW90705	11000	94192.6	273	531	49.21	61.43	71.59
SPM	09/1106/005/E-LLANFAIR CAEREINION	MW91705	11000	84552.6	280	408	49.54	60.52	66.31
SPM	09/1618/007/E-LLANFYLLIN	MW90604	11000	79695	211	324	45.80	55.08	63.33
SPD	CARGENBRIDGE	SP67422	11000	88535.1	169	378	45.50	54.91	68.87
SPM	09/1106/005/E-LLANFAIR CAEREINION	MW91703	11000	76921	270	462	42.71	54.05	59.30
SPM	09/1291/001/E-B R D	MW93705	11000	73785.7	213	465	37.18	47.86	56.25
SPM	PS-SH8104/005 CEMMAES ROAD	MW01302	11000	72694.7	209	439	37.39	47.75	55.82
SPD	DALBEATTIE	SP66811	11000	76379	143	337	39.05	47.63	59.85
SPM	07/7956/001/E-BETWS-Y-COED	MW76504	11000	71409.3	227	476	36.42	47.35	54.34
SPD	PS-NX6080/002 GLENLEE HYDRO ST T	SP65521	11000	66219.9	134	269	35.85	43.55	53.03
SPD	CASTLE DOUGLAS	SP66523	11000	67463.3	123	313	34.01	42.04	53.12
SPM	PS-SH9465/001 LLANSANNAN	MW70202	11000	56489.4	164	280	32.28	40.37	45.54
SPD	PS-NX4164/001 NEWTON STEWART	SP68423	11000	59114.8	84	131	34.34	40.01	49.43
SPM	PS-SH8104/005 CEMMAES ROAD	MW01301	11000	51326.4	188	285	30.95	39.33	41.65

SPD	CARGENBRIDGE	SP67412	11000	61109.2	105	284	30.65	38.12	48.50
SPM	PS-SJ2406/005 WELSHPOOL	MW92106	11000	55505.7	169	359	28.93	37.87	43.43
SPD	CARRUTHERSTOWN	SP66411	11000	59833.4	120	328	29.21	37.29	46.87
SPM	08/6539/001/E-MAENTWROG	MW83302	11000	49378.5	134	188	30.25	37.00	41.32
SPM	04/2241/001/E-LLANGOLLEN	MW40402	11000	50985.9	157	293	28.41	36.50	40.94
SPM	PS-SH4840/001 RHOSLAN	MW83004	11000	54570.2	155	359	27.52	36.28	42.56
SPM	10/7281/001/E-RHYDLYDAN	MW01001	11000	48758.2	162	305	27.09	35.34	39.04
SPM	09/1618/007/E-LLANFYLLIN	MW90603	11000	49168.8	167	353	25.71	34.51	38.57
SPM	10/6075/001/E-LLANILAR	MW01101	11000	47650.8	149	291	26.21	34.16	38.30
SPM	09/0392/005/E-CAERSWS	MW92404	11000	45627.1	148	264	26.16	33.81	37.19
SPD	HEATHHALL PRIMARY	SP67712	11000	52382	81	225	26.85	33.37	42.49
SPD	PS-NT0437/001 BIGGAR PRIMARY NEW	SP82223	11000	51381.9	59	168	27.15	32.83	42.50
SPD	PS-NY3166/001 GRETNA	SP67311	11000	46563.8	92	180	26.32	32.47	38.85
SPM	09/1106/005/E-LLANFAIR CAEREINION	MW91704	11000	41179.7	147	240	24.72	32.08	34.13
SPM	10/6075/001/E-LLANILAR	MW01102	11000	41388	149	255	24.36	31.90	34.05
SPM	09/9585/002/E-LLANIDLOES	MW92305	11000	42258.2	145	267	24.08	31.69	34.48
SPM	PS-SH7317/004 DOLGELLAU	MW00205	11000	38323.3	165	261	23.57	31.33	31.70
SPD	PENPONT MONI	SP68513	11000	46431.8	75	173	25.41	31.29	38.71
SPM	PS-SH2631/002 BOTWNNOG	MW83604	11000	47388.3	180	481	20.51	30.74	35.05
SPD	PS-NS3152/001 KILBIRNIE	SP71622	11000	42485	113	229	23.60	30.46	35.01
SPM	PS-SH8840/001 TRYWERYN	MW40101	11000	40271.2	126	240	22.86	29.96	33.22
SPM	09/2128/005/E-LLANSILIN	MW90702	11000	39185.3	135	248	22.56	29.84	32.32

SPD	PS-NS3945/001 STEWARTON PRIMARY	SP72622	11000	39994	104	202	22.78	29.24	33.46
SPD	LOCKERBIE	SP67913	11000	43370.2	69	179	23.17	29.01	36.16
SPM	09/2299/001/E-FORDEN	MW92203	11000	40702.3	132	298	21.16	28.92	32.59
SPD	LOCKERBIE	SP67923	11000	41979.7	72	172	22.92	28.71	35.22
SPM	10/7500/003/E-MACHYNLLETH	MW00401	11000	38419.5	90	161	22.67	28.54	32.81
SPM	09/1106/005/E-LLANFAIR CAEREINION	MW91702	11000	37921.6	113	214	21.81	28.48	31.71
SPD	PS-NX6087/002 KENDOON HYDRO STA T	SP65813	11000	43210	34	114	23.38	28.15	36.84
SPD	DALBEATTIE	SP66813	11000	41209.1	75	195	21.79	27.84	34.25
SPD	PS-NX4145/001 SORBIE SORB	SP68622	11000	38389.1	79	157	22.09	27.79	32.75
SPD	AURS ROAD PRIMARY	SP40213	11000	37374.6	70	121	22.41	27.62	32.51
SPD	MOFFAT	SP68321	11000	37629.7	68	122	22.37	27.58	32.67
SPD	PS-NS7312/001 FAULDHEAD	SP67032	11000	38979.4	48	99	22.68	27.43	33.94
SPD	PS-NY3166/001 GRETNA	SP67321	11000	40138.1	68	177	21.48	27.27	33.66
SPM	PS-SJ1359/001 RUTHIN	MW71601	11000	39352.4	123	314	19.22	27.02	31.17
SPM	PS-SH9337/001 BALA	MW40203	11000	32947.2	108	169	20.67	26.78	28.58
SPD	PS-NX1957/001 GLENLUCE	SP67211	11000	38479	62	149	21.34	26.75	32.80
SPD	PENPONT MONI	SP68512	11000	36288.4	64	118	21.56	26.67	31.66
SPM	PS-SH7317/004 DOLGELLAU	MW00204	11000	32560.9	85	110	21.31	26.55	29.09
SPM	10/7500/003/E-MACHYNLLETH	MW00405	11000	34573.3	107	208	19.90	26.40	29.15
SPD	ANNAN PRIMARY	SP66224	11000	37809.2	66	162	20.73	26.32	32.09
SPM	09/0392/005/E-CAERSWS	MW92401	11000	32076.7	112	185	19.84	26.15	27.65
SPM	10/5980/016/E-PARC-Y-LLYN 33	MW01802	11000	32402.8	114	227	18.46	25.22	27.19

SPM	09/9585/002/E-LLANIDLOES	MW92301	11000	29593.8	105	162	18.99	24.97	26.05
SPD	TONGLAND DISTRIBUTION	SP69024	11000	34503.2	52	113	20.03	24.93	30.23
SPD	MAYBOLE	SP74212	11000	32242.8	76	136	19.51	24.91	28.30
SPD	HEATHHALL PRIMARY	SP67724	11000	37348.4	90	266	17.91	24.82	30.13
SPD	PS-NX4145/001 SORBIE SORB	SP68621	11000	33300.8	68	142	19.30	24.67	28.94
SPM	PS-SH3584/001 LLANDDEUSANT	MW80404	11000	33051.2	133	312	16.65	24.50	26.38
SPM	PS-SH9465/001 LLANSANNAN	MW70205	11000	29190.1	100	160	18.53	24.43	25.73
SPD	PS-NX4145/001 SORBIE SORB	SP68611	11000	33757.7	67	156	18.91	24.41	29.04
SPM	PS-SJ1157/002 LLANFWROG	MW72304	11000	30386.8	97	178	18.24	24.29	26.31
SPD	DALBEATTIE	SP66821	11000	34419.4	73	188	18.37	24.28	29.05
SPM	PS-SH9337/001 BALA	MW40206	11000	29639.4	96	165	18.30	24.20	25.95
SPM	PS-SH9465/001 LLANSANNAN	MW70201	11000	27460.1	92	117	18.82	24.17	25.06
SPM	PS-SJ0643/001 CORWEN	MW40301	11000	29555.8	123	242	16.96	23.95	24.79
SPD	DALBEATTIE	SP66812	11000	32675.7	60	134	18.76	23.95	28.52
SPD	STRANRAER NEW	SP68814	11000	30196.2	56	83	19.24	23.85	27.44
SPD	LANGHOLM	SP67612	11000	34592.6	69	197	17.84	23.79	28.99
SPM	PS-SH3939/001 FOUR CROSSES	MW82705	11000	31538.7	99	221	17.26	23.77	26.47
SPM	PS-SH8061/005 LLANRWST	MW76401	11000	31616.9	90	200	17.54	23.74	26.82
SPD	LOCKERBIE	SP67922	11000	33433.9	57	155	18.12	23.49	28.71
SPD	PS-NX0361/001 AUCHNEEL	SP68912	11000	29440.4	76	136	18.04	23.41	26.11
SPD	GATEHOUSE RIVER	SP67111	11000	31417.7	57	124	18.30	23.35	27.68
SPD	HEATHHALL PRIMARY	SP67723	11000	34367.8	76	228	16.94	23.28	28.33
SPD	DUNSCORE	SP66911	11000	31908.3	77	187	17.36	23.28	27.15
SPD	PS-NX4164/001 NEWTON STEWART	SP68414	11000	30160	55	105	18.27	23.09	27.02

SPD	BARRHILL	SP66313	11000	29354	67	126	17.80	22.97	26.13
SPM	PS-SH9337/001 BALA	MW40202	11000	27374.8	87	145	17.32	22.90	24.45
SPD	PENPONT MONI	SP68522	11000	31724.3	54	141	17.59	22.77	27.59
SPM	09/2817/001/E-LLANDRINIO	MW91804	11000	32071.7	112	304	15.07	22.58	25.55
SPM	09/1618/007/E-LLANFYLLIN	MW90602	11000	29507.4	106	253	15.37	22.28	24.39
SPD	PS-NY0990/001 KIRKBANK JOHNS	SP67511	11000	30532.5	47	124	17.18	22.10	26.89
SPM	PS-SJ1157/002 LLANFWROG	MW72301	11000	26364.7	72	132	16.32	21.58	23.74
SPD	PS-NS2000/001 GIRVAN	SP73517	11000	26976	43	69	17.25	21.54	25.05
SPM	09/1618/007/E-LLANFYLLIN	MW90601	11000	26856.2	91	193	15.39	21.49	23.24
SPM	09/3935/004/E-ELLESMERE	MW90303	11000	29611	94	255	14.55	21.34	24.32
SPM	09/0990/044/E-MOCHDRE	MW92904	11000	25933.2	108	226	14.71	21.34	22.10
SPM	PS-SH3584/001 LLANDDEUSANT	MW80401	11000	33453.7	107	358	13.31	21.32	25.63
SPD	SYMINGTON	SP86911	11000	29473.4	73	199	15.34	21.31	25.00
SPD	PS-NX0361/001 AUCHNEEL	SP68922	11000	27045.3	58	121	16.19	21.18	24.33
SPM	07/7767/003/E-DOLGARROG	MW76301	11000	28678.8	107	278	14.00	21.16	23.32
SPD	PS-NX4145/001 SORBIE SORB	SP68623	11000	27381.6	43	91	16.58	21.09	24.98
SPD	CARRUTHERSTOWN	SP66412	11000	32272	50	197	15.37	21.07	26.99
SPD	TONGLAND DISTRIBUTION	SP69011	11000	27415.4	67	160	15.42	20.91	24.02
SPD	STRANRAER NEW	SP68821	11000	26432.6	57	120	15.85	20.81	23.86
SPM	PS-SH4688/001 LLANDYFRYDOG	MW80603	11000	23857.8	104	198	14.48	20.76	20.93
SPD	LAUDER PRIMARY	SP13014	11000	27863.9	44	114	15.98	20.74	24.96
SPD	PINWHERRY 33/11KV	SP74822	11000	24975.4	46	68	16.44	20.73	23.53
SPD	PENPONT MONI	SP68521	11000	26226.3	72	166	14.89	20.49	23.04
SPM	PS-SH8104/005 CEMMAES ROAD	MW01303	11000	25515.8	76	164	14.86	20.48	22.56

SPD	STRATHAVEN	SP86812	11000	24882.4	51	89	15.88	20.44	23.14
SPM	04/0242/006/E-GLAN YR AFON	MW4A603	11000	24485.7	95	202	14.05	20.27	21.27
SPM	10/6385/001/E-BOW STREET	MW00601	11000	24444.7	79	162	14.57	20.20	21.78
SPM	09/2107/009/E-RAVEN SQUARE	MW92003	11000	23881.9	81	162	14.41	20.06	21.36
SPD	KINGSLAND PRIMARY	SP11523	11000	26156.1	27	66	15.88	19.95	24.31
SPM	09/5242/001/E-WHITCHURCH	MW90406	11000	32682	98	367	11.95	19.93	24.78
SPM	PS-SH3078/001 CAERGEILIOG	MW80701	11000	26752.4	89	239	13.36	19.91	22.32
SPD	PS-NT0437/001 BIGGAR PRIMARY NEW	SP82212	11000	23151.3	78	147	14.43	19.88	21.03
SPM	09/0392/005/E-CAERSWS	MW92403	11000	22584.9	78	138	14.49	19.85	20.75
SPD	SELKIRK PRIMARY	SP10523	11000	25657.6	56	136	14.73	19.84	22.96
SPD	SELKIRK PRIMARY	SP10522	11000	24273.6	52	104	15.02	19.75	22.41
SPD	PS-NT0437/001 BIGGAR PRIMARY NEW	SP82221	11000	26394.9	36	102	15.16	19.70	23.95
SPM	PS-SH9465/001 LLANSANNAN	MW70203	11000	21324	80	126	14.44	19.69	19.99
SPM	08/4674/008/E-LLANGEFNI IND ESTATE	MW84302	11000	26675.2	131	356	11.41	19.63	20.61
SPD	TONGLAND DISTRIBUTION	SP69022	11000	29052.2	62	220	13.55	19.60	24.19
SPD	LANGHOLM	SP67623	11000	23886.5	41	84	14.90	19.29	22.35
SPM	10/6385/001/E-BOW STREET	MW00604	11000	25215.6	79	207	13.18	19.27	21.59
SPM	PS-SH5877/001 BEAUMARIS	MW81101	11000	29893.2	126	413	10.49	19.25	22.07
SPD	PINWHERRY 33/11KV	SP74811	11000	24522.9	36	84	14.90	19.24	22.80
SPM	PS-SH9465/001 LLANSANNAN	MW70204	11000	20691.7	71	116	13.92	18.96	19.59
SPD	MAYBOLE	SP74213	11000	21774.3	45	70	14.61	18.89	20.99
SPM	09/3840/002/E-OVERTON	MW90202	11000	25062.4	90	249	12.14	18.78	20.84

SPM	07/7767/003/E-DOLGARROG	MW76303	11000	22012.2	72	159	12.96	18.45	19.87
SPD	PS-NX1957/001 GLENLUCE	SP67213	11000	22249.6	25	47	14.46	18.28	21.57
SPD	MOFFAT	SP68311	11000	21443.3	40	72	14.03	18.26	20.65
SPM	PS-SH5178/001 PENTRAETH	MW81002	11000	25046.3	96	286	11.05	18.13	20.23
SPM	04/0242/006/E-GLAN YR AFON	MW4A605	11000	18990.9	78	141	12.49	17.85	17.89
SPM	PS-SH7317/004 DOLGELLAU	MW00202	11000	18847.6	57	87	13.19	17.75	18.52
SPM	07/0465/003/E-BRYN STANLEY	MW72703	11000	21358	72	172	12.09	17.71	19.13
SPM	07/0465/003/E-BRYN STANLEY	MW72702	11000	20468	56	115	12.85	17.70	19.29
SPD	PS-NS2000/001 GIRVAN	SP73524	11000	20040.3	37	69	13.21	17.37	19.58
SPM	10/5900/002/E-TYWYN	MW00303	11000	18145.6	76	137	12.07	17.36	17.28
SPD	PS-NY2175/019 MIDDLEBIE PRIMARY	SP68212	11000	21602.1	35	93	12.94	17.33	20.35
SPD	PS-NY2175/019 MIDDLEBIE PRIMARY	SP68214	11000	19335.5	38	63	13.15	17.25	19.14
SPD	PS-NX0361/001 AUCHNEEL	SP68913	11000	19956.5	38	75	13.00	17.23	19.42
SPM	PS-SH2631/002 BOTWNNOG	MW83603	11000	22657.7	91	263	10.39	17.16	18.73
SPD	DUNSCORE	SP66912	11000	22433.9	43	135	12.22	17.14	20.34
SPM	08/4468/002/E-LLANGAFFO	MW81204	11000	22515.1	88	255	10.43	17.09	18.73
SPD	PS-NS3945/001 STEWARTON PRIMARY	SP72613	11000	18824.1	48	87	12.58	17.04	18.42
SPD	PS-NX4164/001 NEWTON STEWART	SP68422	11000	19985.9	33	69	12.92	17.03	19.50
SPD	PENPONT MONI	SP68511	11000	24590.3	52	203	11.23	16.95	20.91
SPD	PS-NS8448/001 BRAIDWOOD	SP82613	11000	19360.4	45	93	12.42	16.91	18.70
SPM	PS-SH4840/001 RHOSLAN	MW83002	11000	18401.1	78	162	11.34	16.90	17.06
SPM	08/5831/004/E-HARLECH	MW83703	11000	19030.5	48	96	12.33	16.88	18.42
SPD	PS-NS4338/001 GRASSYARDS	SP70723	11000	18038.3	46	77	12.44	16.77	17.96

SPD	PS-NX4164/001 NEWTON STEWART	SP68413	11000	19501.4	33	73	12.51	16.65	19.05
SPM	09/5029/005/E-WEM	MW91405	11000	18554.2	52	108	11.86	16.58	17.88
SPM	PS-SJ1165/001 LLANDYRNOG	MW71003	11000	20406.5	71	192	10.73	16.53	18.03
SPM	08/4675/010/E-LLANGEFNI	MW80904	11000	19822.6	76	195	10.63	16.52	17.57
SPD	PS-NX1957/001 GLENLUCE	SP67212	11000	19597.3	43	106	11.90	16.50	18.64
SPD	WOODEND PRIMARY	SP43813	11000	18467.9	19	25	12.96	16.45	18.95
SPD	HEATHHALL PRIMARY	SP67726	11000	20678.5	33	101	12.00	16.44	19.47
SPD	ANNAN PRIMARY	SP66212	11000	19176.4	30	70	12.26	16.34	18.82
SPM	PS-SJ2406/005 WELSHPOOL	MW92101	11000	18144.5	50	104	11.68	16.32	17.61
SPD	PS-NS4820/001 KILLOCH COLLIERY	SP73813	11000	18837.7	35	80	12.01	16.25	18.43
SPM	PS-SH4553/001 PENYGROES	MW82303	11000	19373.8	65	171	10.63	16.14	17.53
SPM	PS-SJ1165/001 LLANDYRNOG	MW71002	11000	19578.2	66	178	10.52	16.12	17.58
SPM	09/2299/001/E-FORDEN	MW92202	11000	17887.7	46	103	11.32	15.91	17.39
SPM	PS-SJ1157/002 LLANFWROG	MW72305	11000	15839.4	54	90	11.29	15.83	16.09
SPM	07/7956/001/E-BETWS-Y-COED	MW76502	11000	15745.6	59	102	11.09	15.81	15.86
SPM	PS-SN6081/002 ABERYSTWYTH	MW00803	11000	20648.1	83	252	9.24	15.79	17.27
SPD	PS-NS3670/001 KILMACOLM PRIMARY KCLM	SP42922	11000	17000	36	65	11.71	15.79	17.27
SPM	09/1291/001/E-B R D	MW93701	11000	15623.6	55	92	11.16	15.73	15.90
SPM	08/3692/001/E-CEMAES BAY	MW80301	11000	19761.6	72	217	9.45	15.51	17.09
SPD	PS-NX9875/001 DUMFRIES	SP65233	11000	20202.5	52	175	10.05	15.45	17.98
SPD	LETHANHILL	SP73922	11000	17598.7	44	108	10.83	15.45	17.05
SPM	07/0580/003/E-GRAIG FAWR	MW73002	11000	18758	69	194	9.65	15.43	16.68
SPM	PS-SH3845/001 RIVALS	MW82603	11000	14632.7	65	113	10.46	15.35	14.85

SPM	PS-SH3584/001 LLANDDEUSANT	MW80402	11000	18844.3	71	207	9.31	15.25	16.54
SPD	PS-NS8140/001 LESMAHAGOW	SP85321	11000	16044.1	44	90	10.74	15.16	16.16
SPM	PS-SH3473/001 LLANFAELOG	MW80801	11000	18292.4	61	177	9.56	15.07	16.54
SPM	PS-SH5178/001 PENTRAETH	MW81001	11000	16415.4	58	136	10.02	15.07	15.77
SPM	09/3426/001/E-WEST FELTON	MW92704	11000	17695.7	73	199	9.16	15.03	15.81
SPD	PS-NS7312/001 FAULDHEAD	SP67012	11000	16640.4	27	61	11.09	15.02	16.97
SPD	PS-NS5911/001 NEW CUMNOCK	SP74711	11000	14955.4	30	41	11.20	14.96	16.04
SPD	PS-NY3166/001 GRETNA	SP67312	11000	18476	29	103	10.50	14.90	17.68
SPD	SYMINGTON	SP86912	11000	15521.6	42	88	10.41	14.78	15.77
SPD	PS-NT0437/001 BIGGAR PRIMARY NEW	SP82213	11000	15811.8	31	65	10.76	14.77	16.29
SPM	PS-SH7043/001 MANOD	MW83502	11000	14690.5	52	100	10.16	14.76	15.00
SPM	04/0242/006/E-GLAN YR AFON	MW4A601	11000	15419.5	48	103	10.15	14.75	15.48
SPM	06/5748/001/E-WRENBURY FRITH	MW63902	11000	17072.2	48	135	9.74	14.67	16.20
SPM	09/1291/001/E-B R D	MW93702	11000	16899.5	58	162	9.23	14.55	15.69
SPM	09/2128/005/E-LLANSILIN	MW90704	11000	16790.7	71	196	8.67	14.48	15.13
SPD	LOCKERBIE	SP67912	11000	15630.7	30	70	10.40	14.45	16.05
SPD	TONGLAND DISTRIBUTION	SP69013	11000	15305.2	39	89	10.06	14.40	15.55
SPM	07/7956/001/E-BETWS-Y-COED	MW76503	11000	13723.2	56	105	9.71	14.40	14.20
SPD	ARDGOUR DR PRIMARY	SP40116	11000	15244.1	27	57	10.52	14.40	15.95
SPM	04/2958/001/E-CAERGWRLE	MW41104	11000	17175.2	72	209	8.42	14.38	15.21
SPD	AURS ROAD PRIMARY	SP40222	11000	14540.3	20	29	10.81	14.32	15.83
SPM	PS-SH8061/005 LLANRWST	MW76403	11000	15034.9	48	111	9.63	14.30	15.04
SPM	PS-SH8840/001 TRYWERYN	MW40102	11000	12731.2	48	70	10.06	14.30	13.96

SPM	08/6553/004/E-CWM DYLI	MW82404	11000	13693.2	74	156	8.84	14.26	13.45
SPD	GATEHOUSE RIVER	SP67121	11000	14003.1	32	54	10.32	14.21	15.08
SPD	ANNAN PRIMARY	SP66226	11000	16397.2	30	92	9.92	14.20	16.26
SPM	04/3148/004/E-BERSHAM COLLIERY	MW41404	11000	15392.1	46	116	9.49	14.19	15.21
SPD	STRATHAVEN	SP86822	11000	13049.8	48	80	9.83	14.17	14.04
SPM	PS-SJ2947/001 LEGACY	MW41205	11000	14761.7	41	93	9.75	14.15	15.07
SPM	PS-SH3584/001 LLANDDEUSANT	MW80405	11000	14694.5	47	109	9.47	14.10	14.80
SPD	STRATHAVEN	SP86811	11000	14295.6	33	66	10.06	14.09	15.11
SPM	07/7767/003/E-DOLGARROG	MW76304	11000	12370.8	49	74	9.78	14.07	13.62
SPD	ST BOSWELLS PRIMARY	SP12914	11000	15181.3	35	88	9.77	14.06	15.43
SPM	PS-SH2738/002 EDERN	MW82503	11000	14328.6	55	131	8.92	13.87	14.20
SPD	PS-NY2175/019 MIDDLEBIE PRIMARY	SP68213	11000	14441.7	33	77	9.69	13.84	15.03
SPM	04/2838/009/E-CADBURYS - KRONOSPAN	MW40503	11000	15194.6	57	153	8.63	13.83	14.51
SPM	10/5900/002/E-TYWYN	MW00302	11000	13195.7	46	90	9.37	13.79	13.95
SPD	MAYBOLE	SP74214	11000	14099.3	26	58	9.81	13.68	15.03
SPM	PS-SH3078/001 CAERGEILIOG	MW80705	11000	15993.2	76	223	7.50	13.64	14.08
SPD	PS-NS3559/001 LOCHWINNOCH PRIMARY	SP44323	11000	14227.7	21	49	9.91	13.63	15.24
SPD	PS-NS8841/001 CORRA LINN	SP83521	11000	12395.9	33	48	9.78	13.61	13.94
SPD	PS-NS7865/001 TOWERS ROAD	SP87022	11000	12869.1	27	41	9.91	13.61	14.38
SPM	PS-SH3845/001 RIVALS	MW82602	11000	13958.5	39	92	9.23	13.60	14.45
SPM	PS-SH8578/010 OLD MILL	MW76004	11000	12410.9	51	96	9.05	13.58	13.28
SPD	PS-NX4164/001 NEWTON STEWART	SP68424	11000	14429.5	20	52	9.83	13.57	15.33

SPD	INNERLEITHEN PRIMARY	SP12723	6600	15269.3	23	76	9.51	13.53	15.60
SPD	PS-NS7312/001 FAULDHEAD	SP67033	11000	13318.7	19	33	9.94	13.47	14.79
SPD	CUMNOCK	SP73221	11000	12445.6	41	76	9.21	13.42	13.57
SPM	09/5029/005/E-WEM	MW91406	11000	18525.7	75	273	6.76	13.41	15.17
SPD	PS-NX4859/001 CREETOWN	SP66712	11000	14039.3	39	100	8.96	13.40	14.37
SPM	PS-SN6081/002 ABERYSTWYTH	MW00804	11000	13075.4	61	140	8.30	13.40	13.12
SPM	10/6385/001/E-BOW STREET	MW00603	11000	13803.3	42	104	8.87	13.39	14.14
SPM	PS-SH3473/001 LLANFAELOG	MW80803	11000	13482.2	42	99	8.90	13.37	13.98
SPD	CASTLE DOUGLAS	SP66521	11000	14064.7	29	76	9.27	13.35	14.71
SPD	TONGLAND DISTRIBUTION	SP69012	11000	14728.3	31	94	9.03	13.33	14.93
SPM	09/2817/001/E-LLANDRINIO	MW91802	11000	14827.1	57	164	8.00	13.30	14.03